REGION 1 FISH PASSAGE EVALUATION CRITERIA

Determining the effect of drainage structures on fish migration is a difficult and complex process and the tools and information to assess fish passage are constantly evolving. Passage success is dependent on the swimming capability of the fish and lifestage of concern, stream discharge, and the relationship of fish movement with stream discharge. The decisions we make regarding how passage success is defined are not simple and could have an effect on fish growth, predator/prey interactions, vulnerability to environmental events, recruitment, spawning success, etc. Additionally, considering the high cost of culvert replacements and retrofits, Region 1 has put significant effort into developing evaluation criteria to best assess fish passage throughout the region. The assumptions used in the R1 evaluation criteria are based on the best available information and are conservative.

While some culverts may be complete barriers to all fish species and lifestages, many culverts may restrict only the movement of a particular lifestage at certain flows. The mere presence/absence of fish upstream of a culvert is a poor indicator of the ability of that structure to efficiently pass fish. The structure may pass only the strongest swimmers, both within or between age classes and species and restricted to very limited time periods related to high or low flows or resident fish upstream of a structure may represent an established isolated population. The best evaluation of fish passage would be actual field assessments of fish swimming performance at the site during all flow conditions when fish want to move. However, this is not cost-effective or logical at every crossing structure. Considering that there are thousands of fish bearing stream crossings in Region 1, it is necessary to develop a more efficient way of evaluating whether or not **existing** stream crossing structures provide for effective fish passage.

The USFS Region 1 fish passage evaluation criteria screening process is used to quickly classify existing crossings as either meeting, needing refined hydraulic analysis, or failing to meet fish passage criteria for a chosen fish species, lifestage, and flow in a standardized and consistent manner. By utilizing passage evaluation criteria, the number of crossings that require an in-depth passage evaluation will be reduced. Two flowcharts, similar to one used by the California Department of Fish and Game (2001), were constructed for juvenile and adult Cutthroat and Bull trout for Region 1 and would essentially categorize crossings for all salmonids found in Region 1. Passage screens for fish species most applicable to the Dakota Prairie and a portion of the Custer NF are currently in development and will be utilized for those fish streams where salmonids do not occur. **These salmonid flowcharts do not represent design standards and should not be utilized when designing new fish stream crossings.** These flowcharts attempt to define whether passage is achieved through existing structures at the time of survey. The USFS Northern Region encourages use of the stream simulation technique when designing new fish bearing stream-crossing structures.

The regional passage evaluation criteria flowcharts first determine whether the crossing meets natural channel simulation criteria. It is important to remember that these evaluation criteria are not as rigorous as stream simulation DESIGN criteria. Criteria for evaluating for natural channel simulation include:

- Streambed substrate is continuous in character and profile throughout the entire length of structure (Representative bed material must be arranged in a stable manner that provide for flow diversity, energy dissipation, and continuity of bedload transport throughout the structure)
- Crossing is set at or below stream grade – no outlet perch (No perch is assumed if streambed substrate is continuous throughout the structure)
- Structure width is equal to or greater than the average bankfull width of the channel out of the influence of the crossing – no constriction of the active channel exists

- No steep drops occur immediately upstream of structure – channel slope between the crossing inlet and the first upstream holding habitat is similar to overall channel gradient (This must be verified for all crossings initially considered passable from the screen)

If the site inventory data verifies the above natural channel simulation criteria, the crossing is considered adequate for passage of all salmonids, including the weakest swimming lifestage. If not, one proceeds through the flowcharts to further evaluate the site until a passage status is determined. The following categories will be used to classify crossings for juvenile and adult cutthroat and Bull trout for Region 1:

CHANNEL SIMULATION:	Conditions assumed to be passable for all species/lifestages.
GREEN:	Conditions assumed adequate for passage of the analysis species lifestage.
GREY:	Conditions may not be adequate for the analysis species lifestage presumed present. Additional analysis is required to determine the extent of barrier. It is here where we would denote possible flow barriers using hydraulic analysis.
RED:	Conditions do not meet passage criteria at all desired flows for the analysis species lifestage. Assumed to be a barrier for that lifestage

It is important to note that fish may be able to pass through a number of the culverts identified in the RED and GREY categories during portions of the year, i.e. the culvert may actually be only a partial (flow) barrier. This may be only for a short window of time, however. We are primarily concerned that passage may not be possible for a particular lifestage during the more extreme flow periods and most important migration times of the year such as during spring runoff and low base flows. To best prioritize sites for remediation work, hydraulic analysis is suggested to determine the true extent of the barrier.

The passage evaluation criteria flowcharts do not cover all possible scenarios, thus the inventory data will need to be thoroughly reviewed for any unique passage problems that may exist at crossings initially categorized as CHANNEL SIMULATION or GREEN. For example, a crossing may meet all flowchart criteria for passage but may still have a significant debris or sediment blockage either within or at the inlet, drop inlet, or a break within the structure itself. Further manual data review will catch and redefine these crossings appropriately.

The following evaluation criteria are used in the flowcharts to define passability at crossing sites that fail to meet natural channel simulation:

- Residual Inlet Depth – backwatering
- Channel constriction – based on bankfull channel width
- Outlet drop –perch
- Structure gradient

Figures 1 and 2 on the following pages display the Regional fish passage evaluation criteria flowcharts, followed by the rationale for the thresholds chosen for the flowcharts.

Juvenile salmonid fish passage evaluation criteria at flows less than bankfull flows for Region 1

(NOT INTENDED TO BE USED FOR DESIGNING NEW STRUCTURES)

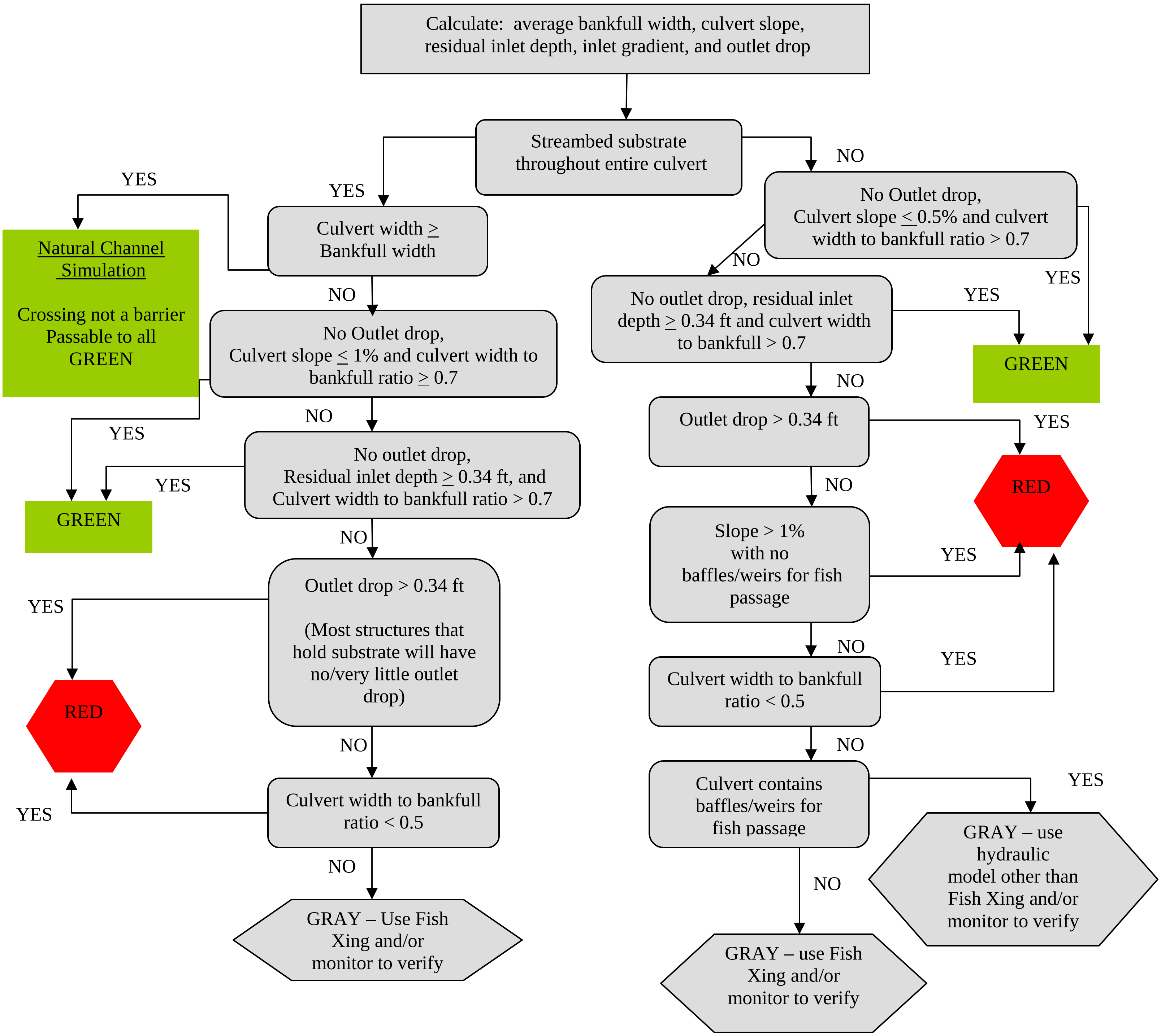


Figure 1. Fish passage evaluation criteria for Region 1 juvenile salmonids.

Adult salmonid fish passage evaluation criteria for Region 1

(NOT INTENDED TO BE USED IN DESIGNING NEW STRUCTURES)

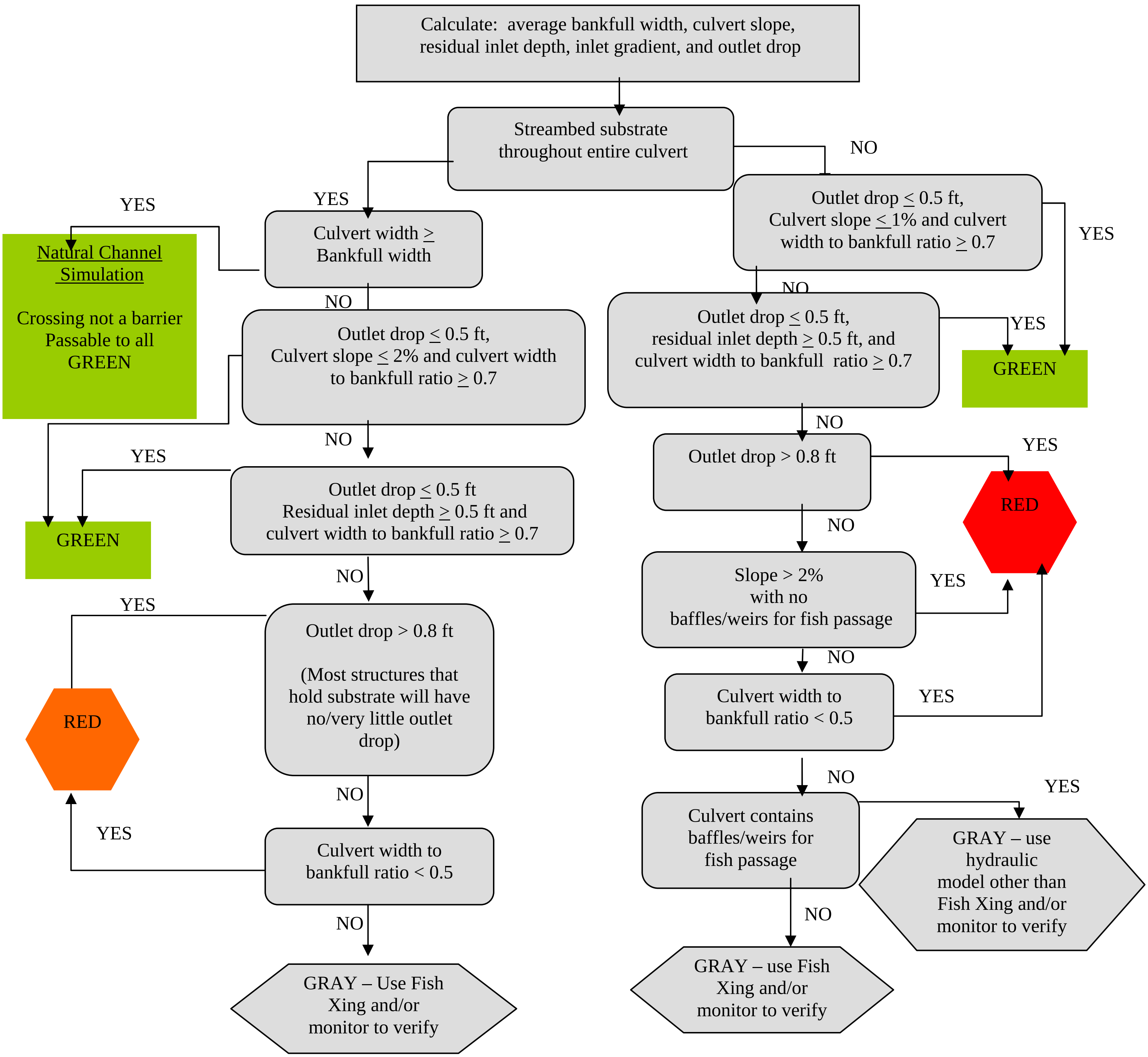
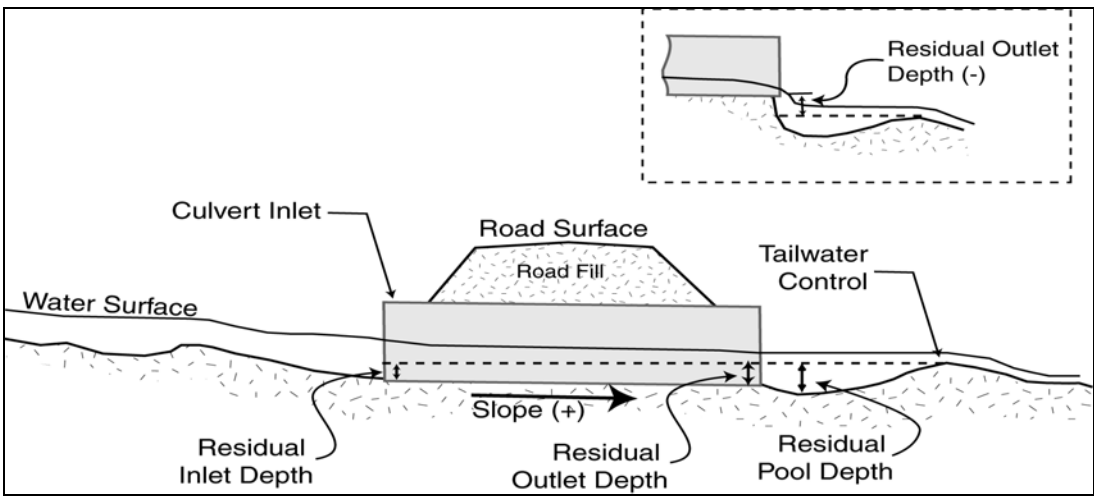


Figure 2. Fish passage evaluation criteria for Region 1 adult salmonids.

THRESHOLD VALUES USED IN EVALUATION FLOWCHARTS

RESIDUAL INLET DEPTH

Residual inlet depth is the depth of water at the inlet of the structure under no flow (or very low flow) conditions. When the outlet tailwater control elevation is higher than that of the inlet invert, the residual inlet depth will be a positive number and the structure will be backwatered at all flows (Figure 3). This positive depth, i.e. backwatering, is generally conducive to passage of most species and lifestages since it lowers velocities within the structure. It is important to note that springfed streams may never experience very low flows and have ample water depth throughout the structure but may not maintain a positive residual inlet depth. The main reasons for setting a minimum residual inlet depth are to acknowledge that passage may be possible in culverts with slightly higher gradients than would otherwise allow passage if not backwatered enough to lower velocities throughout the entire structure and also to ensure that depth is adequate to allow passage at low flow conditions.



Residual Pool Depth = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Pool Bottom}})$
Outlet Drop = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Outlet Invert}})$ *(No outlet drop if Outlet Depth $\geq$ 0)*
Residual Inlet Depth = $(\text{Elev}_{\text{Tailwater Control}} - \text{Elev}_{\text{Culvert Inlet}})$

Figure 3. Measurements used in evaluation criteria (from Taylor and Love, 2001).

The minimum depth necessary for successful passage depends on fish size, as larger fish require more water for passage. Based on a literature review of research findings and stream crossing design guidelines, the minimum water depths that allow most adult and juvenile trout to pass through a culvert range from 0.25 foot (3 inches) to 1 foot (12 inches). For adult steelhead and salmon the minimum water depth required for passage varies from 0.59 foot to 1 foot. Belford and Gould (1989) found that 0.26 foot (3.12 inches) was sufficient depth to pass adult trout through the six Montana highway culverts evaluated in their study. The Idaho Department of Lands fish passage manual (1998) sets minimum depth criteria of 0.25 foot (3 inches) during migration. California Department of Fish and Game (1998) has a minimum of 1 foot for adult Chinook and steelhead and 0.5 ft for juvenile salmon and all trout.

The Washington Department of Fish and Wildlife (2000) has a design standard minimum depth criterion of 0.8 foot for adult trout and 1 foot for adult Chinook and steelhead. Thompson (1972) found that for successful upstream migration of adult salmon and trout through non-embedded culverts, a minimum of water depth of 0.59 foot (7.1 inches) for steelhead and 0.79 foot (9.5 inches) for Chinook is required. The NMFS SW Region (2001) requires a minimum water depth of 1 foot (12 inches) for adult steelhead and salmon and 0.5 foot (6 inches) for juvenile salmon when designing non-embedded culverts. Burton (1998) suggests having a minimum water depth of 0.49 foot (5.9 inches) for adult trout and 0.984 foot (11.8 inches) for adult salmon for the Boise River basin. Virginia's trout can maneuver a minimum depth of flow of 0.29 foot (3.5 inches) (Warren and Pardew 1998).

Based on these findings, a minimum residual depth of 0.34 foot (4 inches) is recommended for passage of juvenile cutthroat and Bull trout and 0.5 foot (6 inches) for passage of adult cutthroat and Bull trout for Region 1. However, if the culvert gradient is low enough (< 0.5 % for juveniles and 1% for adults) and meets outlet drop criteria (no drop for juveniles and < 0.5 foot for adults), it is still considered GREEN even without meeting a minimum residual inlet depth criteria.

OUTLET LEAP or PERCH

Perching of a culvert above the water surface of the exit pool is a common obstacle to fish passage. The water level present in the culvert at the time of the survey is not a true measurement of perch height because it is flow dependent. Region 1 used a conservative assessment of perch by comparing the outlet invert elevation to the tailwater control elevation (Figure 3). This is a flow independent measurement. Ideally, the perch height should be evaluated at various discharges up to the high flow design discharge. However, this would be too time consuming for this comprehensive assessment of all culverts in the region.

Through biological monitoring, fish have been observed jumping considerable vertical and horizontal distances to clear obstacles. However, few studies of the ability of fish to jump have actually been conducted, especially for young and small fish. Lab studies have determined that ideal jumping conditions of fish occur when the ratio of the jump height to the depth of the pool below the jump is 1:1.25 (Robison et al 1999). NMFS SW Region (2001) states that culvert perch needs to be evaluated for both high design flow and low design flow and should not exceed 1 foot for adult fish and 6 inches for juveniles with a jump pool of at least 2 feet. Burton (1998) states in his protocol for assessing fish passage at culverts in the Boise River Basin that the standard maximum jumpable height for adult trout is 0.984 foot (11.8 inches) and 1.968 foot (23.6 inches) for adult salmon. The Idaho Dept of Lands (1998) guidelines for new stream crossing installation permits a maximum drop of 1 foot from the culvert outlet when a holding pool is provided. The USFS R10 and R6 fish passage assessment screening criteria requires leap to be less than 4 inches to even consider that juvenile Coho salmon might be successful in upstream passage, although the crossing is only considered passable (GREEN) when the structure is not perched.

Based on this literature review and consultation with fisheries biologists, a maximum perch height of 0.34 foot (4 inches) is recommended for juvenile cutthroat and Bull trout and 0.8 foot (9.6 inches) for adult trout. Still, for a crossing to be considered passable (GREEN), there must be no perch for juveniles and less than or equal to 0.5 foot (6 inches) perch for adults only when backwatered at least 0.5 foot. All crossings with a perch up to and including 0.34 ft for juveniles and between 0.5 foot and 0.8 foot for adults will be considered GRAY and hydraulic analysis must be conducted to make a passage determination. If the perch height is between 0 and 0.34 foot for juveniles or between 0 and 0.8 foot for adults, then the residual outlet pool depth must 1.25 times greater than the perch height or the crossing will be considered impassable (RED).

VELOCITY and CULVERT GRADIENT

Velocity within the culvert is determined primarily by culvert length, width, and resulting gradient and roughness elements within the culvert. If a culvert is installed at too steep a gradient, or the culvert width is narrower than the streambed width, the water velocity will be increased within the culvert. Even very slight changes in the slope of the culvert (0.5% to 1.0%, for example) and substrate roughness within the structure may significantly change the culvert velocity.

According to an Idaho Dept of Lands (1998) unless backwatered properly, bare culverts greater than 50 ft long will cause fish passage problems for adult spring migrating trout (6-12 inches) if installed at over a 0.5% gradient and over 0% for juvenile and weak swimming fish. If adequately backwatered, the culvert could be up to 4% gradient for adults and 3% for juveniles and still allow upstream passage. The Idaho guidelines state that culverts without streambed substrate that are less than 50 ft long can be installed up to 1% gradient for adult passage and 0.5% for juvenile passage. NMFS SW Region (2001) new installation guidelines require the slope of a non-embedded culvert to be less than 0.5% for salmon and steelhead. In the USFS Region 6 and 10 passage assessment matrices for juvenile Coho salmon, culvert grade for bare culverts must be less than 0.5% to be considered passable (GREEN). Bare culvert crossings with gradients between 0.5% and 1% would be considered GRAY for juvenile passage and would require hydraulic analysis to determine passability. Pipe arches with less than 100% substrate coverage can have a gradient of up to 2% (GRAY) before being considered non-passable (RED). If the culvert contained 100% substrate coverage of adequate depth (20% of culvert rise), then culvert gradient could be up to 2% in circular culverts with 2x6 corrugations and still be passable (GREEN) and go as high as 4% in that same situation before being considered non-passable (RED). The California Dept of Fish and Game (2001) assessment flowchart determines that culverts with slopes greater than 2% and not adequately backwatered and/or with a perch are considered non-passable (RED) for adult and juvenile anadromous salmonids. Culverts at with less than 2% gradient and not adequately backwatered and/or with a perch are considered GRAY, thus requiring hydraulic analysis.

Based on this literature review, a maximum culvert gradient of 1% is recommended for juvenile trout and 2% for adult trout when backwatering does not meet minimum residual depth criteria and/or an outlet perch exists before being categorized as non-passable (RED). To be considered GREEN for juvenile passage, an embedded culvert may have a slope of up to 1% (unless residual inlet depth is 0.34 foot or greater), but must have no outlet drop and a culvert width to bankfull width ratio of at least 0.7 if embedded. If not embedded, the culvert slope must be no more than 0.5% (unless residual inlet depth is 0.34 foot or greater) and have no outlet perch and have a culvert width to bankfull width ratio of at least 0.7 to be considered GREEN for juvenile passage. For an embedded culvert to be considered GREEN for adults, the slope may be 2% or less (unless residual inlet depth is 0.34 foot or greater) and have an outlet drop of no more than 0.5 foot and a culvert width to bankfull width ratio of at least 0.7. If the culvert is not embedded, the culvert slope must be no more than 1% (unless residual inlet depth is 0.5 foot or greater), have an outlet drop of no more than 0.5 foot and a culvert width to bankfull width ratio of at least 0.7. In the cases where the residual inlet depth meets the minimum depth criteria and backwatering exists and there is no outlet perch (or up to 0.5 foot perch for adults), then culvert gradient is automatically allowed to be higher to some degree. Any culverts that have no or insufficient backwatering and/or any perch for juveniles (between 0.5 and 0.8 foot perch for adults) with gradients less than 1% for juveniles and 2% for adults will be considered GRAY and will require hydraulic analysis to determine passability.

CHANNEL CONSTRICTION

Constriction is addressed in two manners within the flowchart. The first manner is addressed is found within the natural channel simulation criteria – the culvert width must be equal to or greater than the average bankfull width and have substrate retained throughout the structure. If the crossing meets these criteria, it is not constricting the channel and considered GREEN. Secondly, in all other structures (embedded or non-embedded), the culvert width must be at least equal to 70% (ratio of 0.7) of the bankfull channel width as well as meeting requirements for outlet drop and slope to be categorized as GREEN. If the culvert width is less than 50% (ratio of 0.5) of the average bankfull channel width, it is considered RED for all lifestages. In most cases, if a culvert overly constricts the channel, the tailwater control becomes scoured and incised by the higher velocity, backwatering is significantly reduced or eliminated and a perch may or may not form. In other words, if the structure overly constricts the channel, most likely there is an outlet perch as well. Constriction thresholds are based on initial culvert inventory data review and hydraulic analysis for a number of sites in R1.

Be aware that at all natural channel simulation and GREEN categorized crossings, it will still be necessary to review the inlet gradient and identify sites that have a steep drop in the channel profile directly in front of the culvert inlet providing evidence that the crossing does indeed constrict the channel (Evidenced by hourglass shapes that suggest velocities within the structure are higher than that of the stream channel). This steep slope can be a migration barrier to both adult and juvenile fish because it creates supercritical flow just inside the inlet. Therefore, if the inlet gradient is excessive compared to channel gradient upstream of the crossing, the site will be designated as GRAY until hydraulic analysis can be completed for the site.

FISH SWIMMING PERFORMANCE

The speed at which fish swim is dependent on factors such as species, age, length, mode, water temperature, etc. Swim speeds for each fish species or lifestage must be entered into the FishXing software and compared to the predicted culvert hydraulic values to analyze passage conditions at a road crossing. A separate passage analysis must be conducted for all of the concerned fish species and lifestages presumed present. In assessing or designing for passage through culverts, two aspects of swimming speeds are of concern, prolonged and burst speeds. Those are defined as follows:

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

2) Burst (darting) speed is the speed a fish can maintain for a very short period, generally 5 to 10 seconds, without gross variation in performance. Burst speed is employed for feeding, escape, and negotiating difficult hydraulic situations, and represents maximum swimming speed. Metabolic activity in this mode is strictly anaerobic and utilizes all of the white muscle tissues.

Below are the recommended swimming capabilities for several salmonid species and lifestages common to Region 1 (original field data sources noted). For other species of interest, refer to the scientific literature. For adult trout, a length value of 150 mm was chosen as a representative size of the adults occurring in streams where most culverts have been installed, realizing that there are likely larger adults that occupy the stream as well. For juveniles, the 60 mm size was chosen because this is the typical size of cutthroat trout by the following spring prior to the first high streamflow and also the size of Bull trout close to the end of their first season of growth and likely when they are looking for habitat with more discharge (to avoid dewatered sections) or to find substrate suitable for concealment as stream temperatures drop.

Species	Length	Prolonged speed	Swim Duration	Burst speed	Swim Duration	Source
Adult Rainbow trout	150 mm	2.5 ft/s	30 minutes	5 ft/s	5 seconds	Hunter and Mayor, 1986
Juvenile Rainbow trout	60 mm	1.8 ft/s	30 minutes	2.4 ft/s	5 seconds	Hunter and Mayor, 1986
Adult Cutthroat trout	150 mm	2.5 ft/s	30 minutes	5 ft/s	5 seconds	Hunter and Mayor, 1986
Juvenile Cutthroat trout	60 mm	1.7 ft/s	30 minutes	2.2 ft/s	5 seconds	*
Adult Bull Trout	150 mm	2.13 ft/s	30 minutes	5 ft/s *	5 seconds	Jones, unpublished thesis
Juvenile Bull Trout	60 mm	1.7 ft/s	30 minutes	2.2 ft/s	5 seconds	*
Adult Brook trout	150 mm	2 ft/s	30 minutes	4.1	5 seconds	Bell, 1986; Beamish 1978
Juvenile Brook trout	60 mm	1 ft/s	30 minutes	1.63	5 seconds	Hunter and Mayor, 1986/Beamish 1978
Adult Chinook and Steelhead		6 ft/s	30 minutes	10 ft/s with max leap speed of 12 ft/sec	5 seconds	Hunter and Mayor, 1986
Juvenile Steelhead	60 mm	2 ft/s	30 min	3 ft/s	5 seconds	Hunter and Mayor, 1986

***** Swim speeds for juvenile Cutthroat and Bull trout are based on juvenile rainbow trout because of the absence of other data in the research literature. Adult Bull trout burst speed is based on cutthroat trout because of absence of other data in the research literature.

LITERATURE CITED

Beamish, F. W. H. 1978. Swimming capacity. In *Fish Physiology* (Edited by Hoar W. H. and Randall D.J.), pp. 101-187. Academic Press, New York.

Belford, D. A., and W. R. Gould. 1989. *An evaluation of trout passage through six highway culverts in Montana.* North American Journal of Fish Management 9(4): 437-445.

Bell, Milo C. 1986. *Fisheries handbook of engineering requirements and biological criteria*. Portland, Oregon, Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, North Pacific Division. 290 pp.

Bell, Milo C. 1973 *Fisheries handbook of engineering requirements and biological criteria*. Portland, Oregon, Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, North Pacific Division.

Burton, T. 1998. *Protocol for Assessing Fish Passage at Culverts for the Boise National Forest.* Boise NF, unpublished manuscript, 6 pp.

California Department of Fish and Game. 1998. *California Salmonid Stream Habitat Restoration Manual, 3rd Edition, Part X Fish Passage Evaluation At Road Crossings.*

Hunter, Larry A., and Lesley Mayor, 1986. *Analysis of Fish Swimming Performance Data: Volume I.* North/South Consultants Inc., Winnipeg, Manitoba. 33 pp.

Idaho Department of Lands Forester Forum, July 1998. *Fish Passage Guidelines When Installing Stream Crossings.* Forest Practices No 12, Boise, ID, 8 pp.

Jones, Darrin 2003 "Susceptibility of bull trout, *Salvelinus confluentus*, to *Renibacterium salmoninarum*, causative agent of bacterial kidney disease". Unpublished thesis. University of Idaho.

National Marine Fisheries Service, Southwest Region September 2001. *Guidelines for Salmonid Passage at Stream Crossings.* Santa Rosa, CA, 14 pp.

Robison, G.E., A. Mirati, and M. Allen. 1999. *Oregon Road/Stream Crossing Restoration Guide: Spring 1999, Advanced Fish Passage Training Version.* http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/orfishps.htm

Taylor, Ross N. and Michael Love. 2001. *Fish Passage Evaluation at Stream Crossings*. Prepared for California Department of Fish and Game.

Thompson, K. 1972. *Determining stream flows for fish life. Pages 31-50 in Proceedings, instream flow requirements workshop.* Pacific Northwest River Basins Commission, Vancouver, Washington.

USDA Forest Service Region 6. 2001. *Fish Passage through Road Crossings Assessment, with Explanations and Instructions.*

USDA Forest Service Region 10. 2002. *Tongass National Forest Monitoring and Evaluation Report for Fiscal Year 2001*. R10-MB-458.

Warren, M.L., and M.G. Pardew. 1998. *Road Crossings as Barriers to Small Stream Fish Movement* Trans Am Fisheries Soc 127:637-644.

Washington State Department of Fish and Wildlife Habitat Program, SSHEAR section. August 2000. *Fish Passage Barrier and surface water Diversion Screening Assessment and Prioritization Manual.* http://www.wa.gov/wdfw/hab/engineer/fishbarr.htm