Standard Operating Procedure for Critical Riffle Analysis for Fish Passage in California

DFG-IFP-001

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California Department of Fish and Game
Instream Flow Program
Sacramento, California

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Table of Contents

List of Figures

List of Tables

Acknowledgements

This standard operating procedure (SOP) represents the protocols for critical riffle analysis (CRA) of the California Department of Fish and Game (Department) Water Branch Instream Flow Program (IFP). The process in this SOP draws from current methods used by the Oregon Department of Fish and Wildlife (ODFW). Modifications are made to ODFW methods in both procedural scope and in the application of regional information relevant to California. The overall concept of the procedure in this SOP is based on information in *Determining Stream Flows for Fish Life* presented by Ken Thompson at the *Instream Flow Requirements Workshop* on March 15-16, 1972 (Thompson 1972). This SOP was developed by Melinda Woodard of the Marine Pollution Studies Laboratory Quality Assurance (QA) Team, with Microsoft Excel® spreadsheet technical assistance provided by Candice Heinz of the Department IFP. Technical review of this document was provided by IFP staff, and members of the ODFW Water Quality and Quantity Program. This document has been reviewed by the Department Office of the General Counsel.

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Abbreviations and Acronyms

CRA	Critical Riffle Analysis
Department	California Department of Fish and Game
IFP	Instream Flow Program
ODFW	Oregon Department of Fish and Wildlife
SOP	Standard Operating Procedure
USGS	United States Geological Survey

Introduction

This document serves as the SOP for CRA studies for the Department's IFP. It may be used in conjunction with other IFP SOPs to support procedures involved in CRA. Instructions are provided for:

- Project planning considerations:
  - Project timing
  - Site selection
  - Fish passage criteria
- Field methods:
  - Transect preparation
  - Data collection
- Data analysis:
  - Tabular data entry
  - Fish passage criteria
  - Graphing of results
  - Comparison of results against fish passage criteria

Scope of Application

This SOP provides procedural reference for Department staff conducting CRA, when site conditions and research objectives indicate that CRA is an appropriate methodology. It is also intended as an informational resource for staff from other state and federal agencies, nongovernmental organizations, private contractors, and other organizations throughout California. Fish passage criteria cited in this document are specific to California and should not be extrapolated beyond the state borders.

This SOP applies only to wadeable streams having low gradient riffles with less than 4% gradient and substrates dominated by gravel and cobble. This procedure is used to identify flows that support physical movement of salmonids through critical riffle sites. Other factors that may be important to evaluate overall migratory success include length of riffle, availability of rest areas, condition of fish, water temperature, and others.

This SOP is not applicable to high gradient riffles greater than 4% gradient and boulder dominated substrates (Flosi et al. 1998). It does not apply to river or stream channels that do *not have riffles, such as those dominated by silt and sand substrates with particle sizes less than 0.1 inches. Finally, this procedure is not applicable to culverts, weirs, bedrock ledges, or anticlines with associated drops.*

Note: Safety should always be a primary concern when conducting CRA. Do not conduct sampling when field conditions are unsafe.

What is Critical Riffle Analysis?

The CRA methodology is used to identify protective stream flow rates (also known as passage flows) necessary for the passage of salmon and trout through critical riffles. Riffles are habitat units in streams and rivers with relatively shallow depth and swiftly flowing turbulent water. They serve multiple functions in the ecological processes of coldwater streams and rivers, and are an integral link in the life histories of salmon and trout. Many species of aquatic macroinvertebrates develop and grow in riffles, which provide a food source for salmonids. Riffles also provide salmonids with well mixed, oxygenated water, and escape shelter from predators.

Critical riffles are shallow riffles that are particularly sensitive to changes in stream flow due to diminished water depth. Changes in stream flow and associated water depth may limit the hydrologic connectivity of river habitats and impede critical life history tactics of salmon and trout. In such cases, the critical riffle may become a potential barrier to upstream and downstream passage for salmon and trout. This may prevent adults from moving to and from spawning areas, prevent smolts from migrating downstream to staging areas in brackish waters of lagoons and estuaries before the ocean, and prevent rearing juvenile salmonids (e.g., steelhead) from being able to move between adequate summer freshwater rearing habitats.

Method Overview

Salmon and trout passage flows are determined by locating a critical riffle, identifying a transect along the riffle's shallowest course from bank to bank, and measuring water depth at multiple locations across the transect. Adequate water depths of sufficient width are necessary to identify passage flows and promote passage of adult and juvenile salmonids at critical riffle sites. Field data are compared to species- and lifestage-specific water depth criteria meeting the percent total and percent contiguous proportion (see *Section 3* for more information) of the critical riffle width available for fish passage. After a minimum of three to six field events have been completed over a wide range of discharges, stream discharge rates and percent of transect meeting the minimum depth criteria for the species and lifestages are plotted to determine flow rates necessary for passable flows. Both the criteria (percent total and the percent contiguous) must be met and then the higher flow rate among the two criteria that are found to meet the minimum depth for the target species and lifestage may be used to identify the passage flows for the target salmon and trout at the critical riffle site. Water velocities may also be measured across the passage transect, including the thalweg, to evaluate suitability of velocities that support passage of the target species and lifestage.

Section 1: Considerations for Project Planning

Before collecting data for CRA, it is important to identify the appropriate timing of the sampling series and choose the appropriate site. The timing of the sampling series may be linked to the target species and its biology, so it is important to clearly identify the target species, life stages, and when the target species occurs in the river.

CRA is conducted by collecting depth measurements across the critical riffle transect. This SOP uses only depth criteria of target species passage to determine passability in critical riffles. In a few special cases, the project manager may decide to collect stream velocity measurements across the critical riffle and assess results in relation to a target species' maximum velocity tolerances. Please consult the Department IFP for more information about these procedures before planning such a project.

Crew safety is of paramount importance; ensure that the river can be safely sampled by crews during the highest flow point. Contact the Department IFP for project planning assistance, as needed.

1.1 Project Timing

Data for CRA are collected as a three- to six-part field sampling series, typically collected on the receding limb of the hydrograph. The three to six sampling events should be timed to capture the full range of discharges necessary to adequately bracket and identify passage flows for the target species and life stages. Ideally, the first data collection event would be at the highest wadeable flow of the targeted flows, with subsequent collections taken as flow decreases.

Development of a flow exceedence probability chart based upon unimpaired flow conditions for the period of record may be useful to identify target flows for sampling. The exceedence probability chart will indicate the percentage of time that stream flow is likely to equal or exceed a value of interest. A good project planning starting point is to identify the 20%, 50%, and 80% exceedence flows for sampling. Additional sampling will also be needed to develop a robust relationship between salmon and trout passable criteria and flows – most likely at flows between the 20% to 80% exceedence probability range, depending on site specific conditions such as channel morphology, substrate, and flow relationships.

It may be useful to create a lifestage periodicity table indicating when target species occur in the river of interest. This table may be used to determine the timing of sampling so that sampling occurs during the range of when the target species are dependent on bypass flows for passage. It is important to consider the timing of target species life stages when determining the range of sampling events. Contact the Department IFP for assistance developing a flow exceedence probability chart or lifestage periodicity table, as needed. The Department IFP has an SOP on how to develop flow exceedence probability charts (*CDFW-IFP-005*), which is available on the Department's IFP web site.

1.2 Site Selection: Locating the Critical Riffle

The identification of sampling sites for CRA should be made collaboratively by Department staff familiar with the study area. In some cases, it may be difficult to identify or agree collaboratively on the most critical riffle (i.e., most water depth-sensitive riffle) in a stream reach by visual observation alone. In these instances, it may be necessary to collect depth measurements at multiple critical riffle sites, including maximum thalweg depths, in order to identify the most depth-sensitive critical riffles and their respective salmon and trout passage flows.

Section 2: Field Procedures

Once a riffle has been identified for CRA, the transect is established, marked, and photographed before collecting data. During the initial CRA sampling event, the critical riffle transect is located and marked with head and tail pins and flagged with site information. The riffle is then photographed before depth is measured across the CRA transect. CRA also requires a discharge measurement, which may be obtained either from a nearby USGS gage, or by collecting discharge across a nearby transect as outlined in the IFP discharge SOP (*DFG-IFP SOP 002*).

The field data sheet can be found online at the Department IFP documents page: http://www.dfg.ca.gov/water/instream_flow_docs.html.

2.1 Equipment List

Before beginning the field day, crews should pack the following equipment:

- Stadia rod (engineering grade rod capable of measuring 1/10 ft and 1/100 ft)
- Fiberglass measuring tape (100-300 ft)
- Staff gage
- 0.5 in x 2.5 - 4 ft rebar (2-10 pieces depending on site)
- Small hammer or mallet
- GPS unit
- Field data sheets (available at http://www.dfg.ca.gov/water/instream_flow_docs.html)
- Pencils
- Flagging and permanent marker
- Camera
- Calculator
- Small carabiners or spring clamps (5-10)

Note: If discharge will be calculated on a nearby discharge transect, crews should also pack equipment as listed in DFG IFP SOP 002.

2.2 Establishing the Transect

Establish a transect running along the shallowest course of the riffle from bank to bank using a measuring tape. This transect will rarely be linear, but should instead follow the contours of the riffle along its shallowest course from bank to bank (*Figure 1*). The critical riffle transect is established during the first sampling event, and is then used repeatedly for each subsequent sampling event. Once the transect is identified, the headpin and tailpin are set during the initial site visit before continuing with data collection. During subsequent field measurements at other flows, the course of the shallowest contour across the riffle will need to be identified and verified with depth measurements to confirm transect location.

Step 1: Set the headpin for the transect on the left bank of the river looking upstream. The headpin serves as the starting point for each critical riffle measurement, starting from zero feet.

Step 2: Attach a flag to the headpin. This flag is marked with project and site identification information.

Step 3: Set the tailpin adjacent to the edge of the critical riffle on the right bank of the river when facing upstream.

Step 4: Attach a wind-up, light weight measuring tape to the base of the headpin. The tape should be of sufficient length for the site (e.g., 100-ft, 200-ft, 300-ft). The tape should display 1/10-ft measurements.

Step 5: Work across the riffle, following the contour of shallowest course. Secure the measuring tape in place with rebar and small carabiners or spring clamps to hold the tape in place along the riffle contour as you work (*Figure 1*).

Step 6: Work across the riffle until the tailpin is reached. Attach the other end of the measuring tape to the base of the tailpin.

2.3 Data Collection

Once the transect has been set up, field data are collected. The CRA field data sheet may be found online at http://www.dfg.ca.gov/water/instream_flow_docs.html.

Step 1: If not already in place, set up the measuring tape along the contour of the riffle's shallowest course, as described in *Section 2.2*.

Step 2: During each sampling event, document the transect with one or more photographs taken while facing upstream. Record the photograph file name(s) on the field data sheet.

Step 3: Populate the CRA field data sheet with the following:

- Location (e.g., Candice River, Lower Reach)
- Site name (e.g., Unit 222)
- Riffle name (e.g., Riffle B)
- Site description (e.g., wide riffle near #34 diversion pump)
- GPS coordinates (e.g., N38.53.331, W121.17.092)
- CRA sample event number and targeted flow value (e.g., Sample event 1 - 10 cfs targeted flow)
- Sampling date
- Staff initials (i.e., the staff conducting the CRA)
- Start time (i.e., the times when sampling starts)
- Start staff gage stage height (i.e., the stage heights from a nearby staff gage when sampling starts) Staff gage may be a temporary gage that is installed just for purposes of doing the CRA or it may be from a nearby permanent gage if one exists. The staff gage stage height is used to assess whether fluctuations in flow occurred during the sample event.
- Left bank wetted edge (LBWE) (i.e., the distance on the tape measure where the wetted edge exists on the left bank)
- Right bank wetted edge (RBWE) (i.e., the distance on the tape measure where the wetted edge exists on the right bank)
- Total length of the transect from headpin to tailpin (i.e., total length of the transect following the shallowest course from bank to bank)

Figure 1. Example of a critical riffle transect that follows the shallowest course from bank to bank

Step 4: Determine the interval size at which to measure depth along the transect by considering the total transect width. Depth should be measured at a minimum of 20 intervals along the transect at small enough increments to accurately represent changes in bed profile elevation. A minimum sampling interval of one foot is recommended for CRA sites with critical riffles of greater than 20 ft from bank to bank. The sampling interval for CRA sites that are less than 20 ft from bank to bank should be adjusted so as to meet the 20 minimum depth measurements. Consultation with ODFW staff indicate more robust depth to flow relationships being achieved with approximately 50 depth measurements on the critical riffle (Tim Hardin, personal communication, July 2, 2012).

Step 5: Using a stadia rod (with scale to 1/100 ft), measure depth along the transect in interval distances as determined in Step 4 (*Figures 2* and *3*). Record distance and depths at stations in feet on the CRA field data sheet.

Note: Careful attention should be taken to record water depths at individual locations as the fish would encounter and use them. For example, the stadia rod should not be placed between two rocks to measure depth unless it appears that a fish could swim between them freely. Using the same example, if the stadia rod fits between two rocks (without being on top of the rocks), but the upstream passage is blocked by other rocks immediately upstream or downstream within the measurement cell of the longitudinal profile of the critical riffle, then the measurement should be taken on top of, instead of between the rocks. In these cases the shallowest points (on top) of the wetted substrate should be selected if the fish could not use the depths between rocks due to passage obstructions either immediately upstream or downstream of the transect. Add any such notes to the comments section on the CRA field data sheet.

Step 6: Populate closing data fields on the CRA field data sheet: end time and staff gage end depth.

Step 7: Remove the measuring tape from headpin and tailpin, and clean up other equipment as necessary.

Step 8: Obtain and record discharge data on the CRA field data sheet either from a nearby United States Geological Survey (USGS) gage, or by conducting a site specific discharge measurement on a nearby discharge transect suitable for such measurements as defined by *DFG-IF SOP 002*.

Step 9: Ensure that all data fields have been populated on the CRA field data sheet before leaving the site.

Figure 2. Example using stadia rod to measure depth along a critical riffle transect

Figure 3. Detail: Using the stadia rod to measure depth along a critical riffle transect

Section 3: Data Entry and Analysis

After each sampling event, data are transferred from the CRA field sheet to the field event-specific CRA Microsoft Excel® worksheet. After data have been collected from each sampling event, data may be compared with the current criteria for fish passage, as established by IFP. This section discusses the criteria for fish passage and how to assess if the critical riffle meets these criteria.

3.1 Data Entry

After each sampling event, transfer data from the field sheet to the corresponding *CRA for Fish Passage* Microsoft Excel® worksheet (available online at the Department IFP documents page: http://www.dfg.ca.gov/water/instream_flow.html). The *CRA for Fish Passage* sampling event worksheet calculates the number of cells that meet the criteria for fish passage (as outlined in *Section 3.2*) for each sampling event. See below for specific data entry instructions for entering field data into the Microsoft Excel® spreadsheet.

There are six tabs in the online Microsoft Excel® spreadsheet (*DFG IFP CRA for Fish Passage data online*) named for each of six sample events (e.g., “CRA 1-6” for sample event one of six; “CRA 2-6” for sample event two of six). The online Microsoft Excel® spreadsheet also contains:

1. The “Example Passage Form”, which is a filled-out example data form
2. The “CRA Cumulative Calculations” tab, which includes cumulative calculation data tables for the percent contiguous passable widths and percent total passable widths data; these are used for summarizing the results from each sample event and subsequent data analysis
3. The “Passage Criteria and Codes” tab, which includes salmon and trout species codes and their minimum depth criteria

When filling out the Microsoft Excel® spreadsheet, be sure to enter all relevant information for the sampling conducted (e.g., location, site description, date). The next step is to identify the target species and lifestage for the CRA and enter the respective criteria into the field data form. The target species and lifestage criteria are selected from the “Passage Criteria and Codes” tab in the Microsoft Excel® spreadsheet. For example, enter “St” in the species code and “0.7” ft depth in the target species depth criteria of the field sheet if interested in assessing passable flows for adult steelhead.

Using the “CRA Passage Form” tab, enter the field data into the “Distance” and “Depth” categories. The “Distance” entry is typically the position of the tape measure where the depth data were recorded. The “Width” column will be populated by the spreadsheet based upon the distance or locations of depth measurements taken. The spreadsheet will calculate the percent contiguous passable flows and percent total passable flows for each sample event based upon the site-specific distance and depth field data, and the target species depth criteria. In order for the “Percent Contiguous” calculation to be correctly summarized, the user will have to “Sum” the longest range of contiguous cells meeting the depth criteria and enter this value in the highlighted contiguous width cell on the bottom of the spreadsheet (highlighted in red).

It is also important to note that the maximum transect length must be entered in each of the (three to six) sample event data sheets for the percent contiguous and percent total calculations to be accurate. The maximum transect width should be the same value for each site, and for each of the three to six flows sampled. Further, the maximum transect width will be the largest length of the transect (shallowest course from bank to bank) of all the measured sample events for the site. Maximum transect widths should not typically exceed beyond the toe of bank – the point where the streambed and one bank join. The streambed is defined as that part of the channel usually not occupied by perennial terrestrial plants, but including gravel bars, and lying between the toe of each bank.

After all of the sampling events have been conducted, and data entered for all events in their individual event tabs, select the “CRA Cumulative Calculations” tab. Manually enter the flows of each sampling event along with the number of cells meeting passage criteria for the target species as outlined above.

3.2 Criteria for Fish Passage

The IFP has established two criteria for development of passage flows for salmon and trout:

1. At least 10% of the entire length of the transect must be contiguous for the minimum depth established for the target fish; *and*
2. A total of at least 25% of the entire transect must be at least the minimum depth established for passage of the target fish.

The minimum water depth needed for adequate adult and juvenile salmonid passage through a critical riffle is established in *Table 1*. Depth passage criteria for adults (*Table 1*) are based upon a literature review conducted by R2 Resources (2008) and are intended to provide protective conditions for passage. Ideally, there should be sufficient clearance underneath the fish so that contact with the streambed and abrasion are minimized, which R2 Resources (2008) considered to be 0.1 ft. When selecting the appropriate criteria, use the minimum depth for the adult fish if both adult and juvenile fish are known to be in the system at the same time. The Department may update the minimum depths in *Table 1* as new information is developed.

Table 1: Minimum depth criteria for adult and juvenile salmonid passage to be used in critical riffle analysis

Species	Minimum Depth (ft)
Steelhead (adult)	0.7
Coho Salmon (adult)	0.7
Chinook Salmon (adult)	0.9
Trout (adult, including 1-2+ juvenile steelhead)	0.4
Salmonid (young of year juvenile)	0.3

3.3 Example of Comparing Data Analysis Results to Fish Passage Criteria

A riffle measuring 100 ft from bank to bank along its shallowest course is being analyzed for passage of adult steelhead (minimum depth = 0.7 ft). To meet IFP criteria for successful passage, this riffle would need to have:

- A *contiguous* portion of at least 10 ft in length measuring at least 0.7 ft deep; *and*
- A *total* of at least 25 ft in length with a depth of at least 0.7 ft.

After data are collected for all time series, two minimum discharge rates are calculated by creating two graphs using the summary data entered on the “CRA Cumulative Calculations” tab of the Microsoft Excel® spreadsheet:

1. River discharge rates versus percent contiguous passable width; and
2. River discharge rates versus percent total passable width required for fish passage.

Working with one graph at a time, plot the relevant variables using Microsoft Excel®, then generate a best fit line on the graph. To find the discharge required for target fish passage through the critical riffle, find the point on the Y-axis that meets each criterion for the passage of the target fish, and use Microsoft Excel® to find where this point hits the line of best fit and its corresponding point on the X-axis. This point on the X-axis is the discharge required for fish passage through this critical riffle.

Note: If there is more than one target species (as listed in Table 1) involved in the study, generate one set of graphs per target species.

Below is an example of the results from the six sampling events at a critical riffle site for both the percent contiguous passable width and percent total passable width. In this example, the flow rate (75 cfs) associated with Criterion 1 (Percent Contiguous; *Figure 3*) is the same as Criterion 2 (Percent Total; *Figure 4*), and is therefore identified as the minimum flow rate required for the passage flow at the critical riffle site. *If the flow rates differ between the two criteria, the higher of the two flow rates shall be identified as the minimum passage flow for the critical riffle.*

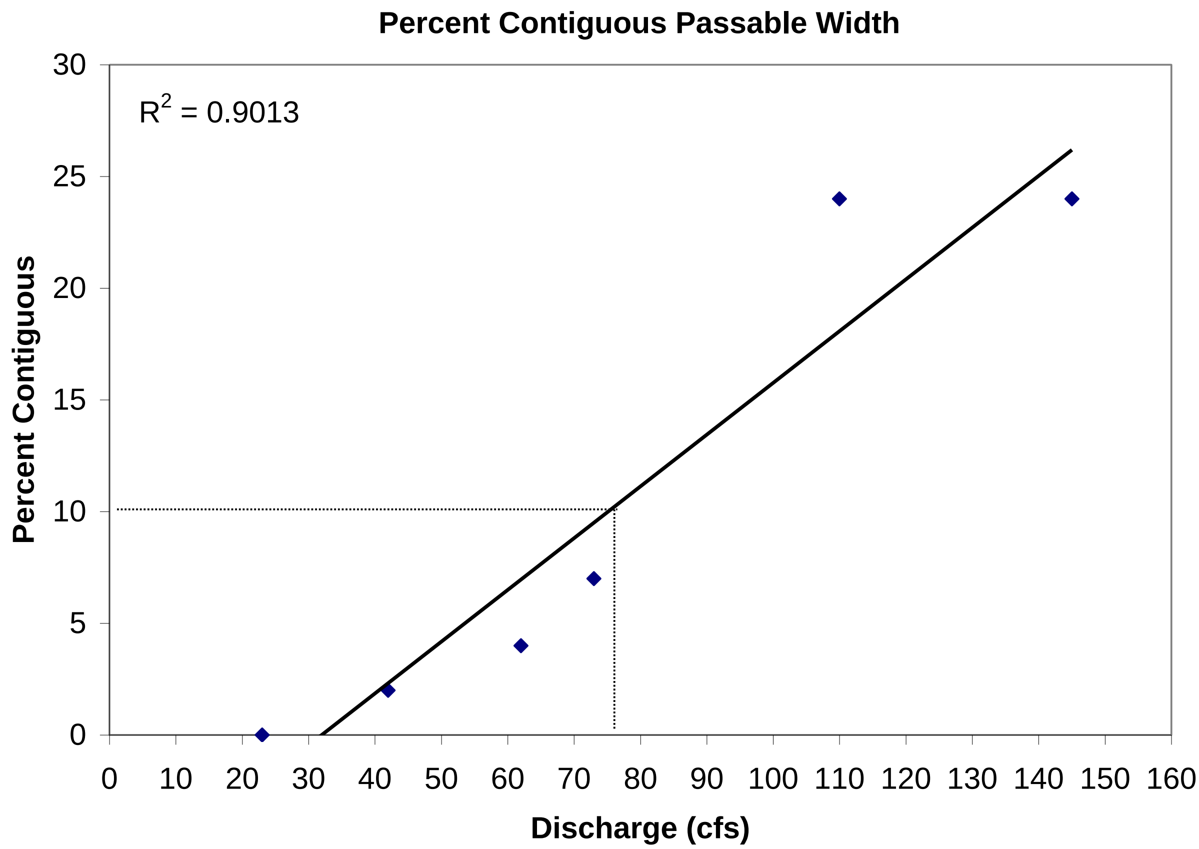

Figure 4. An example of the relationship between river discharge (cfs) and percent contiguous passable width required for adult steelhead passage

In *Figure 4*, a flow of 75 cfs is required for fish passage through this critical riffle. The dashed line represents the criteria for minimum acceptable flow for passage.

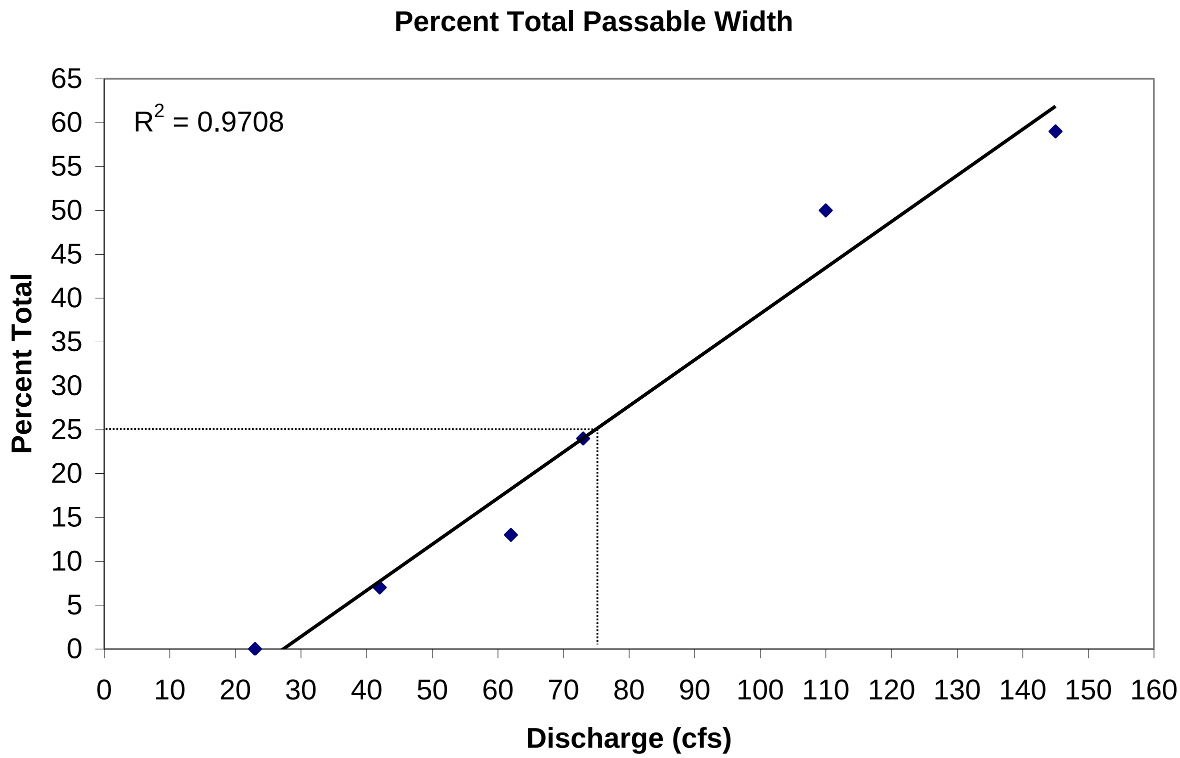

Figure 5. An example of the relationship between river discharge (cfs) and percent total passable width required for adult steelhead passage

In *Figure 5*, a flow of 75 cfs is required for fish passage through this critical riffle. The dashed line represents the criteria for minimum acceptable flow for passage.

3.4: Consideration for Application of Passage Flow Rates

Several important factors should be taken into consideration during the development and application of passage flows for salmon and trout. Consider the target species and their life history tactics, with careful attention to approximate time frames for migration.

Adult salmonids are dependent upon their ability to migrate to spawning habitats at appropriate times that coincide with their life history traits. If adult salmonids are unable to, or delayed in, reaching spawning habitats, the spawning population could be impacted, leading to reduced egg and fry production. Juvenile salmon are dependent upon their ability to migrate from freshwater riverine habitats (including lagoon habitats) to the ocean. Juvenile salmonids that may rear in freshwater riverine and lagoon habitats (i.e., steelhead) for 1 – 3 years are dependent upon their ability to access successful rearing habitats in the low-flow summer months. This rearing habitat must have adequate flow (depth and velocity), food, water quality (temperature), and escape cover from predators.

Glossary

Critical Riffle	Critical riffles are those riffle habitats that may be particularly sensitive to changes in stream flow due to shallow water depth, and as such may prevent adult salmon and steelhead fish passage to and from spawning areas and/or may prevent movement of rearing juvenile salmonids between adequate summer rearing habitats.
Discharge	The volume rate of water flow transported through a given cross-sectional area. The units that are typically used to express discharge include m^3/s (cubic meters per second), and ft^3/s (cubic feet per second).
Exceedence Probability	Exceedence probability is the probability that a certain flow value is going to be exceeded.
Passage Flow	The amount of flow identified to be maintained in the river channel for support of salmon and trout passage.

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