Standard Operating Procedure for the Habitat Retention Method in California

CDFW-IFP-006

Version 2

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

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Habitat Retention Method in California

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Abbreviations and Acronyms

Term	Definition
BMI	Benthic macroinvertebrate
cfs	Cubic feet per second
cm	Centimeter
Department	California Department of Fish and Wildlife
ft	Feet/foot
ft/s	Feet per second
GPS	Global positioning system
HP	Headpin
HRM	Habitat retention method
IFP	Instream Flow Program
in.	Inch
LBWE	Left bank wetted edge
m	Meter
PHABSIM	Physical habitat simulation
QA	Quality assurance
QC	Quality control
RBWE	Right bank wetted edge
s	Second
SOP	Standard operating procedure
TP	Tailpin
USGS	U.S. Geological Survey
VBM	Vertical benchmark
WSEL	Water surface elevation

Conversions

1 cfs ≈ 2.83×10^{-2} m^3/s
1 in. = 2.54 cm
1 ft = 0.3048 m

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Introduction

This standard operating procedure (SOP) represents the protocol for habitat retention method (HRM) studies conducted by the Department IFP. It is intended to replace the original 2016 SOP. It may be used in conjunction with other IFP SOPs. The overall concept of this SOP is based on information found in *Hydraulic Simulation in Instream Flow Studies: Theory and Techniques* (Bovee and Milhous 1978) and *Evaluation of Instream Flow Methods and Determination of Water Quantity Needs for Streams in the State of Colorado* (Nehring 1979). Instructions are provided for:

- Preparation and considerations for field work
  - HRM limitations and constraints
  - Method application
  - Site selection
- Data collection
  - Equipment list
  - Field procedures
- Data Analysis
  - Habitat retention rating curve development
  - Rating curve results interpretation

Scope of Application

This SOP provides the procedural reference for Department staff conducting the HRM, when site conditions and research objectives indicate that the HRM is an appropriate method. For example, the HRM is used to evaluate habitat maintenance flows at riffle sites that contain hydraulic bed controls. This SOP is intended as an informational resource for other state and federal agencies, nongovernmental organizations, private contractors, and other organizations throughout California.

The HRM method is used to identify habitat maintenance flows that maintain hydraulic criteria for average depth, average velocity, and wetted perimeter, at the hydraulic control of a riffle. These three parameters are good indicators of flow-related stream habitat quality. The HRM quantifies the minimum flow sufficient to provide a basic survival level for fish during times of the year when streamflow is at its lowest (Annear et al. 2004). Use of the HRM for fish and wildlife includes the following considerations:

- Transect locations must be at hydraulic control points of riffles.
- The method is only useful for identifying threshold flows for hydraulic parameters (i.e., depth, velocity, and wetted perimeter).
- The method is limited to streams with a bankfull width of 100 ft or less.
- The method is not suitable for complex channels.
- There is a limited ability to identify trade-offs between different flow levels and habitat suitability for various aquatic organisms.
- Other methods and/or models are needed to assess flow requirements for other riverine elements such as channel geomorphology, riparian vegetation, or water quality.

There are two main approaches to conducting hydraulic control based habitat methods such as the HRM. Both approaches require data to be collected along the hydraulic control of a representative alluvial riffle. The field-based approach requires a minimum of 10 site visits at prescribed flow events to generate hydraulic habitat relationships. The modelling approach uses a surveyed bed profile, paired with a flow measurement, and a computer program based on Manning's equation to develop hydraulic habitat relationships.

This SOP focuses on describing HRM data collection and analysis using the modeling approach. It provides an overview of rating curve development but does not describe hydraulic modelling in depth to account for user discretion in selecting a computer program based on Manning's equation. The Department encourages SOP users to contact the IFP with any questions or for assistance with project planning. The Department is not responsible for inappropriate application or inaccurate interpretation of the HRM SOP. The Department highly recommends that an experienced instream flow practitioner conduct all field work and data analysis.

Note: Safety is a primary concern when conducting instream flow studies. Conduct sampling only when field conditions are safe.

What is the Habitat Retention Method?

The HRM is a site-specific method used in riffle habitats to identify habitat maintenance flows that allow for the movement and long-term persistence of aquatic biota. Riffles are characterized by shallow habitats with relatively fast velocities compared to pools or glides. As such, riffles tend to generate high concentrations of dissolved oxygen, and consist of substrates (i.e., gravel and cobble) that are well-suited for the production of benthic macroinvertebrates (BMI) and spawning of many species of salmonids. Additionally, smaller fish may seek refuge in riffles to avoid larger predatory fish that inhabit deeper habitats (e.g., pools). As a result of their shallow depths, riffles (and their hydraulic parameters) are more sensitive to changes in stream flow than other habitat types (e.g., pools, runs, and glides). Diminishing flow at riffles can in turn limit fish passage, including anadromous salmonid ocean outmigration or upstream spawning migration. Dewatering of riffles decreases BMI productivity during the summer and may also limit pool-to-pool movements of juvenile fishes.

For the purposes of this SOP, habitat maintenance flows are defined as the amount of continuous flow in cubic feet per second (cfs) required to maintain hydraulic criteria for average depth, average velocity, and percent wetted perimeter (described in Table 1) at the hydraulic control of riffles (depicted in Figure 1). These hydraulic criteria vary depending on the species and life stage of fish that frequent or reside in the stream, as well as the stream width. The criteria for average depth increases proportionally to stream width, considered the bankfull width, due to the assumption that larger streams support larger fish, which require greater passage depths (R.B. Nehring, pers. comm., October 1, 2018).

Table 1. Key flow parameters used to determine flow criteria, using the habitat retention method in riffle habitats. Percent wetted perimeter is relative to bankfull conditions.[1]

Bankfull width (ft)	Average depth (ft)	Average velocity (ft/s)	Wetted perimeter (%)
1−20	0.2	1	50
21−40	0.2−0.4	1	50
41−60	0.4−0.6	1	50−60
61−100	0.6−1.0	1	70

[1] Table and values are adopted from Nehring (1979).

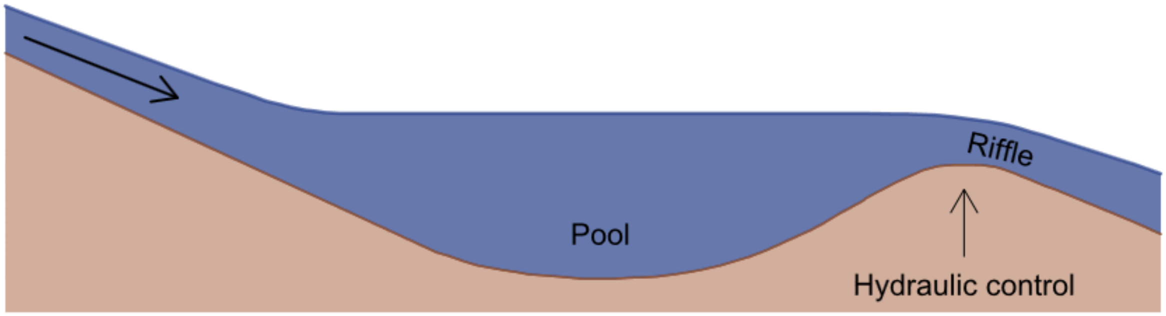

Figure 1. Conceptualized longitudinal profile of a pool-riffle sequence showing the location of the hydraulic control.

A key assumption of the HRM is that if hydraulic criteria are maintained in riffle habitats, adequate flow conditions will also be maintained for other habitat types, such as pools and runs, located in the same stream reach (Nehring 1979). Though each criterion is important, the depth criterion must always be met in addition to at least one of the other criteria. The average depth criterion for streams up to 20 ft in width is 0.2 ft (Table 1). For streams that are wider than 20 ft, bankfull width is multiplied by 0.01 to determine the average depth criterion. For example, if a stream is 28 ft wide, the average depth criterion is 0.28 ft.

Additionally, the minimum depth criteria presented in Table 2 are recommended to determine habitat maintenance flows protective of salmonid species and life stages in California. These criteria were based on Thompson (1972) and a literature review conducted by R2 Resource Consultants (2008), which was adopted by the California State Water Resources Control Board (2014). When using the criterion from Table 2, values should be equal to or greater than values represented in Table 1 or the largest fish (based on body depth) for species and life stages that would occur in the stream system during the period of concern. The minimum depth criteria are based on fish body size, specifically average body height (or depth). The water must be deep enough for a salmonid to adequately navigate over a critical riffle with sufficient clearance underneath it, so that contact with the streambed and abrasion are minimized (R2 Resource Consultants 2008). For example, while assessing the maintenance flow for young-of-year salmonids, the depth criterion would be 0.3 ft for streams narrower than 30 ft, and 0.01 times the bankfull width for streams greater than 30 ft.

Table 2. Depth criteria for adult and juvenile salmonid passage to be used with the habitat retention method.

Species	Minimum depth (ft)
Steelhead (adult)	0.7
Coho salmon (adult)	0.7
Chinook salmon (adult)	0.9
Trout (adult, including age 1-2+ juvenile steelhead)	0.4
All salmonids (young-of-year juvenile)	0.3

The bankfull elevation is used to identify bankfull width, and bankfull discharge. It is also used to calculate percent wetted perimeter. The bankfull elevation determination is an integral component in the development of habitat maintenance flows. IFP follows bankfull identification processes outlined by Leopold et al. (1964), Rosgen (1994), and the Colorado Water Conservation Board (CWCB; 2006). For the purposes of this SOP, bankfull elevation is determined using the following indicators:

1. Top of point bars
2. Change in the lower limit of perennial vegetation
3. Change in slope from slope to vertical or vice versa
4. Change in substrate particle size
5. Bank undercuts; and/or
6. Stain lines (Harrelson et al. 1994)

All indicators need not be present and not necessarily identified in this order. The bankfull elevation, as depicted in Figure 2, can be recognized by physical indicators along the stream bank. Elevation is generally located below sedges and other plants that may survive submerged under high flows (CWCB 2006). Special considerations may be necessary when working in intermittent and ephemeral streams where bankfull stage indicators may be less defined (USACE 2012).

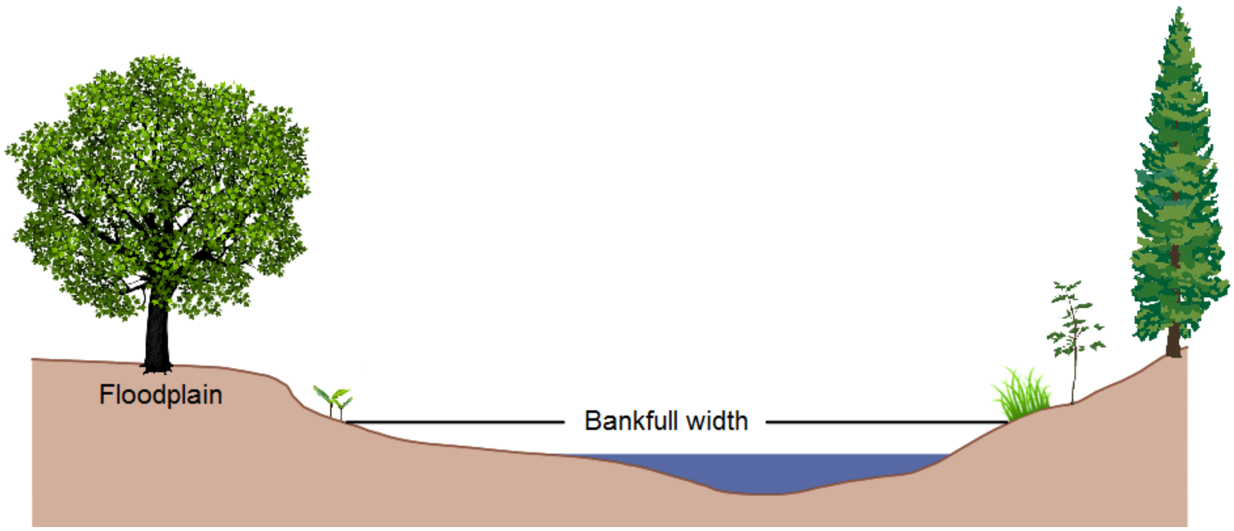

Figure 2. Conceptualized cross-section of a stream channel highlighting the bankfull width for use with the habitat retention method. Note: Bankfull conditions commonly occur at elevations where there are visible changes in channel slope, vegetation, and/or substrate.

Method Overview

Cross-sectional transects are established at the hydraulic control point of riffles. It is essential that the transect be placed on the apex of the controlling bed element. It is not appropriate to simply place the transect anywhere in a shallow riffle as the hydraulic criteria generated at those points will differ from the precise control feature. The bankfull width of the stream (which is necessary for determining the percent of wetted perimeter) is measured along the transect at the bankfull elevation using a fiberglass measuring tape.

Bed elevation readings are obtained along the stream channel cross-section using an engineering level, such as an auto level (see the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c)). Hydraulic slope is also estimated by measuring the riffle length and taking water surface elevations (WSELs) at the upstream and downstream extent of each riffle mesohabitat unit. A discharge measurement must be recorded for each HRM transect. A single discharge may be used for all transects that are located in the same reach if it is free of physical obstructions, tributaries, or diversions between each HRM transect, and discharge remains consistent across sites. Discharge is measured in the reach and near the site using a flow meter and top-setting wading rod (see the *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California*

(CDFW 2013a)). Discharge may also be obtained from a nearby representative stream gage. An applicable stream gage must have no physical obstructions, tributaries, or diversions between the gage location and the HRM transect(s) in the reach.

Bed elevation and WSEL data are used to calculate the flow area (*A*), wetted perimeter, and hydraulic radius (*R*) each transect. Based on the 'constant shear stress at the boundary' assumption (Khiadani et al. 2005), hydraulic radius is defined as the ratio of the channel's cross-sectional area of the flow to its wetted perimeter (i.e. the portion of the cross-section's perimeter that is "wet"). WSEL and riffle length are used to estimate hydraulic slope (*S*); and velocity and cross-sectional area data are used to estimate discharge (*Q*). These values are then used to calculate Manning's roughness coefficient (*n*) using the Manning's equation for open channel flow (Gupta 2008):

$$Equation\ 1: \qquad n = \left(\frac{1.486}{Q}\right) A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \textit{(English units)}$$

The calculated values for discharge, hydraulic slope, and Manning's roughness coefficient, along with the bed elevation data collected in the field, are used as inputs to create rating curves between discharge and average hydraulic depth, average flow velocity, and wetted perimeter. When HRM criteria (Table 1) for depth and at least one other parameter are met, flows are deemed to be suitable for aquatic macroinvertebrate survival and the long-term persistence of aquatic biota. Furthermore, when species and life stage-specific HRM criteria (Table 2) for depth and at least one other parameter are met, flows are deemed to be suitable for movement of the selected salmonid species and life stage.

Hydraulic parameters are modeled over a range of flows based on a single field flow measurement and the estimated Manning's roughness coefficient. It is recommended that when using hydraulic models, two or more additional site visits at different discharges are taken to compare field observations with model outputs (Annear et el. 2004). The Department IFP employs a computer program based on Manning's equation to model hydraulic parameters, though other programs are available. Depending on the computer program selected for analysis, data collection requirements may differ. Review the data input requirements of the selected model before beginning field data collection.

Section 1: Field Work Preparation and Considerations

HRM surveys should be conducted by at least two practitioners who have experience with standard surveying equipment for collecting streambed and WSEL data as well as discharge measurements. The Department SOPs on streambed and WSEL data collection (CDFW 2013c) and discharge measurements (CDFW 2013a) are available on the Department's IFP website. Contact Department IFP staff for project planning and method assistance.

For calculating habitat maintenance flows using Manning's equation, it is important for an experienced practitioner to survey sites when flow is near the anticipated maintenance flow (see Section 1.2: *Method Application*). The Manning's equation best predicts the target hydraulic parameters when the channel section is surveyed close to the target flow stage (i.e., near the anticipated maintenance flow). Determining the approximate maintenance flow at the time of survey may be difficult. Flow duration analysis may be used to help guide the timing of field surveys (see the *Standard Operating Procedure for Flow Duration Analysis in California* (CDFW 2013b)). In some cases, it may take multiple surveys to capture field data at the approximate maintenance flow. If field surveys are taken at the same HRM transect at multiple flows, each survey event will require collection of corresponding slope measurements.

Crew safety is of paramount importance; only perform fieldwork when crews can safely survey.

1.1 Method Limitations and Constraints

The HRM is used to identify flows required to maintain hydraulic habitat conditions suitable for maintenance of aquatic biota at different life stages. According to Annear et al. (2004), the method's main limitations are: by assuming hydraulic habitat as a surrogate for addressing the biology of a stream, other ecological components are not considered; site selection and transect placement must be performed by an experienced practitioner in order to yield appropriate flow prescriptions; and analysis results in a single flow prescription per site thereby omitting flow needs for intra- and inter-annual variability.

1.2 Method Application

For maximum viability of the results, collect HRM data when instream flow is near the anticipated maintenance flow. In alluvial channels, the Manning's roughness coefficient is particularly sensitive to changes in WSEL and is generally much higher during low-flow conditions when compared to high flow conditions (Limerinos 1970; George and Schneider 1989). As such, the streambed should be watered at the toe of each bank to avoid transects containing dry portions of streambed. Additionally, flows close to the maintenance flow will limit the likelihood of obtaining erroneous estimates of hydraulic parameters for model simulations using the Manning's equation. The IFP recommends that the simulated flow range is between 0.4 and 2.5 times the survey flow, which is generally consistent with the recommended flow range for physical habitat simulation (PHABSIM) models (Milhous et al. 1984).

1.3 Site Selection

Within a river reach, target a minimum of three representative riffles with roughly rectangular beds (as opposed to V-shaped channels) for the HRM. A sample size of at least three is required to calculate a statistically significant variance and allows for channel morphology comparability. Select riffle sites that are representative of the overall geomorphic structure and shape of the river reach. For each riffle surveyed, the transect must be located at the hydraulic control, which is typically located at the riffle crest (see Figures 1 and 3). Streamflow should be uniform across the transect to maximize the reliability of Manning's equation (Grant et el. 1992). The transect location should have natural banks or grasslines, not eroding or undercut banks, and be free from braiding (CWCB 2006).

Note: While selecting riffles, beware of redds (e.g., salmonid, lamprey) that may be present. Avoid and place transects away from redds.

Figure 3. Example of a transect across the hydraulic control at the top of a riffle. Photo taken facing upstream.

Section 2: Field Procedures

Establish transect locations as specified by this SOP. At each transect, install a headpin (HP) and tailpin (TP) on the left bank and right bank, respectively. Install the HP and TP as high up on the bank as possible. The left and right banks are designated while facing upstream. Measure the bankfull width (see *Method Overview*) and wetted width (distance between left bank and right bank wetted edges). Install a vertical benchmark (VBM). Bed and WSEL data are surveyed using a stadia rod at multiple stations located along the measuring tape that is stretched from HP to TP. Stations are selected to include representation of streambed features, including the deepest point and each location with a distinct change in channel topography.

HRM transects within the river reach must be accompanied by a representative discharge measurement to develop discharge rating curves. If an operational stream gage is located near enough to the transect to negate stream gains and losses, discharge may be obtained from the stream gage as opposed to measuring discharge directly. Practitioners must understand and identify the limitations and accuracy of the stream gage selected for use with the HRM. For example, U.S. Geological Survey (USGS) operates stream gages that are accurate to the nearest 0.01 ft or 0.2 percent of stage, whichever is greater (Olson and Norris 2007).

If measuring discharge in the field, collect the discharge data from a nearby site suitable for measuring discharge (see the *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (CDFW 2013a). Depths are measured to the nearest 0.05 ft. Distances between measurements should be set so that less than 5% of the entire flow measured, and no more than 10% (Turnipseed and Sauer 2010), passes between any two adjoining measurement locations along the transect. Generally, at least 20 velocity and depth measurements are needed along each transect. A single good quality discharge site can be used for multiple HRM transects if there are no inputs or diversions between transect locations and the flow measurement is representative of each HRM transect flow.

2.1 Equipment List [2]

Auto level

Bucket for flow meter calibration

Camera

Clipboard

Flagging tape

Flow meter

Gloves

GPS unit

Hammer

Hearing protection

Lag bolt (for VBM)

Loppers (if needed to remove vegetation)

Pencils

Permanent marker

Rebar (two per transect) and safety caps

Rite-in-the Rain field data sheets or notebook

Stadia rod (engineering grade rod capable of measuring 1/10 ft and 1/100 ft)

Staff gage

Two fiberglass measuring tapes

Tripod

USGS top-setting wading rod

2.2 Data Collection

Step 1: Insert the staff gage into the substrate near the stream's edge, near the transect, and out of the foot traffic path (see Figure 4). Record gage height to the nearest 0.01 in. immediately before and after data collection to account for any fluctuations in water surface height that may occur during data collection. If the gage height changes more than 0.02 in. during data collection, the measurements need to be retaken when water levels stabilize (see the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c)).

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[2] Calibrate the flow meter and auto level according to manufacturer's instructions prior to use.

Step 2: During the field survey, establish each transect identified during the site selection process (outlined in Section 1.3: *Site Selection*):

- Establish the transect HP and TP on the stream banks so that the measuring tape is level and is located across the apex of the riffle's hydraulic control. Install the HP and TP by hammering in rebar on the left and the right banks, respectively. The HP and TP must be installed above bankfull to ensure that the left and right bankfull locations can be identified and recorded along the transect tape.
- Install the VBM, in this case a lag bolt, on a permanent, unmovable point (see the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c)).
- Mark GPS waypoints at the HP, TP, and VBM, and record the corresponding waypoints.

Step 3: String the fiberglass measuring tape across the transect from HP to TP creating a taut, level, and straight line with the measuring tape. Starting at 0 ft, record the total distance from HP to TP. Record the distances on the measuring tape to the nearest 0.1 ft where the left bank wetted edge (LBWE) and right bank wetted edge (RBWE) occur. Additionally, record the distances on the measuring tape where bankfull conditions occur on the left bank and right bank to the nearest 0.1 ft. Take photos, notes, and sketches to identify changes in slope, substrate, and vegetation to support the identification of the bankfull elevation in the field.

Step 4: Photograph the transect facing upstream and downstream and ensure that the left bank and right bank are visible in each photo. Take additional photos of the left and right bank capturing the indicators (see *What is the Habitat Retention Method*?). Photos taken in the field can be used to help determine bankfull locations prior to data analysis. Ensure that the photos are clear and record photo identification numbers.

Step 5: Set up the auto level in a location where the entire transect is within the line of sight of the instrument, if possible. Otherwise, a turning point must be established to collect streambed elevation data for the entire transect. Ensure that there is a clear line of sight between the auto level and the VBM and HP locations. After recording the VBM elevation, collect and record streambed elevation data at 1-ft increments from HP to TP, with additional measurements taken at the lowest point at the thalweg and at any changes in slope, as needed. Take additional elevation points along the transect to identify marked changes in slope, substrate, and vegetation to support the identification of the bankfull elevation. Smaller or larger increments may be allowed to accurately capture higher levels of bed complexity and to adhere to the goal of representing all topographical change[3]. For detailed guidance on collecting streambed elevation data, see the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c).

Step 6: At the transect, measure and record representative WSELs near the LBWE, RBWE, and at the midchannel. At the downstream extent of the riffle, preceding changes in hydraulic slope, measure and record representative WSELs at the midchannel and near the LBWE, RBWE as needed. Measure and record the riffle length from the transect (i.e., upstream extent) to the downstream extent where the WSELs were measured. These measurements will be used to calculate hydraulic slope.[4] Once all bed and WSEL data are collected, resurvey the VBM using the auto level and stadia rod. Resurveying the VBM is a necessary check to ensure that the auto level was stationary for the survey duration. For detailed guidance on collecting WSEL data, see the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c).

Note: The upstream extent is located at the hydraulic control (i.e., on the transect) and the downstream extent occurs at the bottom of the riffle mesohabitat unit, just upstream of the next habitat unit and preceding changes in hydraulic slope.

Step 7: If measuring discharge in the field, find a suitable location to measure discharge in the reach and near the HRM transect and establish a discharge transect. For detailed guidance on measuring discharge, see the *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (CDFW 2013a).

Step 8: After data collection is complete and data sheets are checked for completeness, remove all survey equipment.

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[3] Increments greater than 1 ft may be appropriate in engineered channels, such as concrete-lined channels, with a relatively uniform cross-section.

[4] An experienced practitioner may use professional judgment to determine the level of detail needed to accurately measure the change in hydraulic slope. For example, if the transect is located on a river bend and it is determined that WSELs on the left bank are more representative than measurements on the right bank, it may be acceptable to only take measurements in the representative areas.

Figure 4. Example of staff gage used to assess changes in WSEL during surveys.

Section 3: Data Analysis

3.1 Developing the Habitat Retention Rating Curve

Data may be entered and stored in a spreadsheet program such as Microsoft Excel in preparation for analysis. Once all field data are entered and checked according to procedures identified in the project study plan, development of rating curves and data analysis can commence. Department IFP QA documents, including a study plan template, are available at https://www.wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/SOP. Please contact the Department IFP for assistance.

The Department IFP uses the commercially available software NHC Hydraulic Calculator (HydroCalc; Molls 2010), a computer program based on Manning's equation, to model hydraulic parameters and the stage-discharge relationship for cross-sectional transects. However, several programs based on Manning's equation are available and any can be used. For more guidance on hydraulic modelling, please contact the Department IFP.

HydroCalc requires the survey discharge, hydraulic slope, and Manning's *n* roughness coefficient to develop the rating curve for each HRM transect site. Next, compare the hydraulic parameters calculated from survey field data to the model output for validation. The following steps can be used as general guidance for generating a rating curve using HRM survey data. These steps are associated with HydoCalc. Steps may need to be altered if using a different software program.

Step 1: Calculate the discharge measurement associated with the HRM transect following the *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (CDFW 2013a). A practitioner may choose to use discharge data from an operational stream gage in place of a field discharge measurement (see Section 2: *Field Procedures*). The gage data must be representative of conditions during the time of the HRM survey. The downloaded gage data would be paired with the bed profile and WSEL survey data and used in place of a field discharge measurement in HydroCalc for the transect HRM analysis. Gage data that would be selected for pairing based off time and date of survey data of interest. Although it is acceptable to use a gage discharge HRM analysis, the IFP recommends that a field discharge measurement be taken, if feasible, to increase confidence in the modeled relationship between the surveyed WSELs and flow.

Step 2: Surveyed streambed and WSEL data, collected in accordance with the *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013c), convert from foresight measurements to elevations. This is done by subtracting the foresight height from the height of the instrument. For purposes of HRM data collection, the height of the instrument or instrument height is the VBM elevation, assumed to be 100 ft, plus the VBM foresight height measured in the field.

Step 3: The hydraulic slope of the HRM riffle mesohabitat unit is calculated as the average WSEL elevation measured at the hydraulic control minus the average WSEL elevation measured at the downstream extent of the mesohabitat unit, divided by the average length of the mesohabitat unit. Measure WSELs and unit lengths at representative points.

Step 4: Manning's *n* is calculated using Equation 1 (see *Method Overview*). Area is calculated as the wetted area of the HRM transect, using the bed elevation data. Hydraulic radius is calculated as the area divided by wetted perimeter.

Step 5: Discharge, Manning's *n*, slope, and the associated bed elevations for the HRM transect are uploaded into HydroCalc (Figure 5). HydroCalc is then used to compute the HRM transect parameters. To validate the rating curve, we recommend comparing the HydroCalc parameters of area, wetted perimeter, hydraulic radius, and average WSEL to those calculated from the transect survey data and used in the Manning's *n* computation. The closer the predicted transect parameters are to the field surveyed data, the stronger the relationship is between the HydroCalc rating curve and the surveyed data. If the HydroCalc-predicted parameters differ greatly from the values calculated with the surveyed data, the practitioner may want to use transect data at a different flow or may need to omit a site from further analysis.

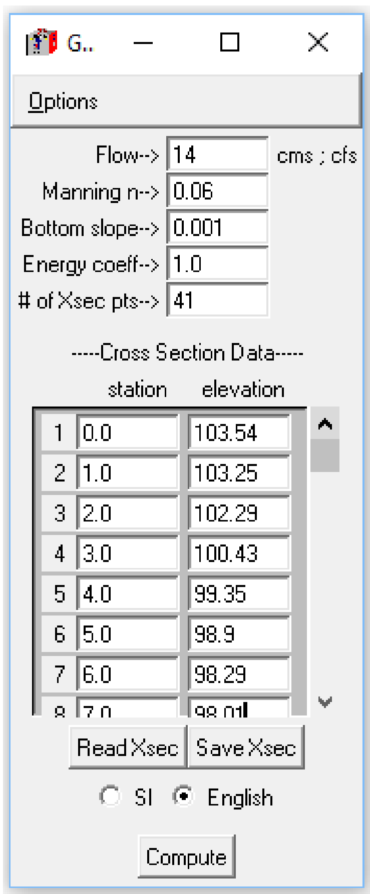

Figure 5. Example HRM transect data uploaded into HydroCalc (Molls 2010) for rating curve generation.

Step 6: Plot the validated HydroCalc cross-section parameters (Figure 6). The plot can be used to determine the bankfull LBWE and RBWE identified in the field. Manually adjust the flow value in HydroCalc until the water surface (blue line) is positioned where bankfull conditions are met.

The HydroCalc bankfull LBWE and RBWE locations (ft) along the transect should be recorded and used to determine the bankfull width in ft. The bankfull width and associated flow are used later in the HRM analysis.

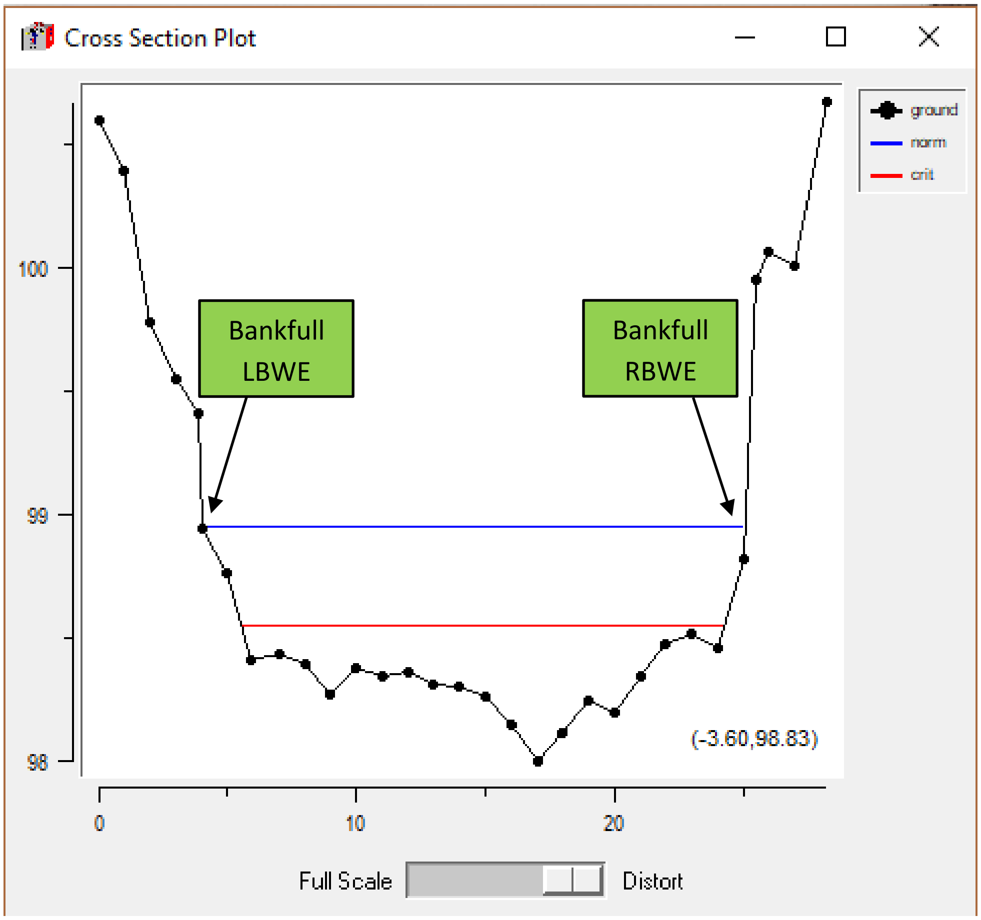

Figure 6. Example HRM transect HydroCalc (Molls 2010) cross-section plot and bankfull wetted edge location identification.

Step 7: The rating curve is generated in HydroCalc by changing the flow back to the measured discharge associated with the HRM transect, and by selecting *Rating Curve*. The flow range is entered and must include the previously identified bankfull flow. The practitioner should take into consideration that flow range entered doesn't exceed the 0.4 and 2.5 thresholds for PHABSIM models (Milhous et al. 1984). The number of data points selected by the practitioner will determine the interval at which HydroCalc will model the transect's stage-discharge relationship (Figure 7). In the example, the transect's rating curve will be generated at 1-cfs intervals from 1 to 50 cfs. When the practitioner saves the results of the rating curve, hydraulic parameters will be predicted at each cfs interval.

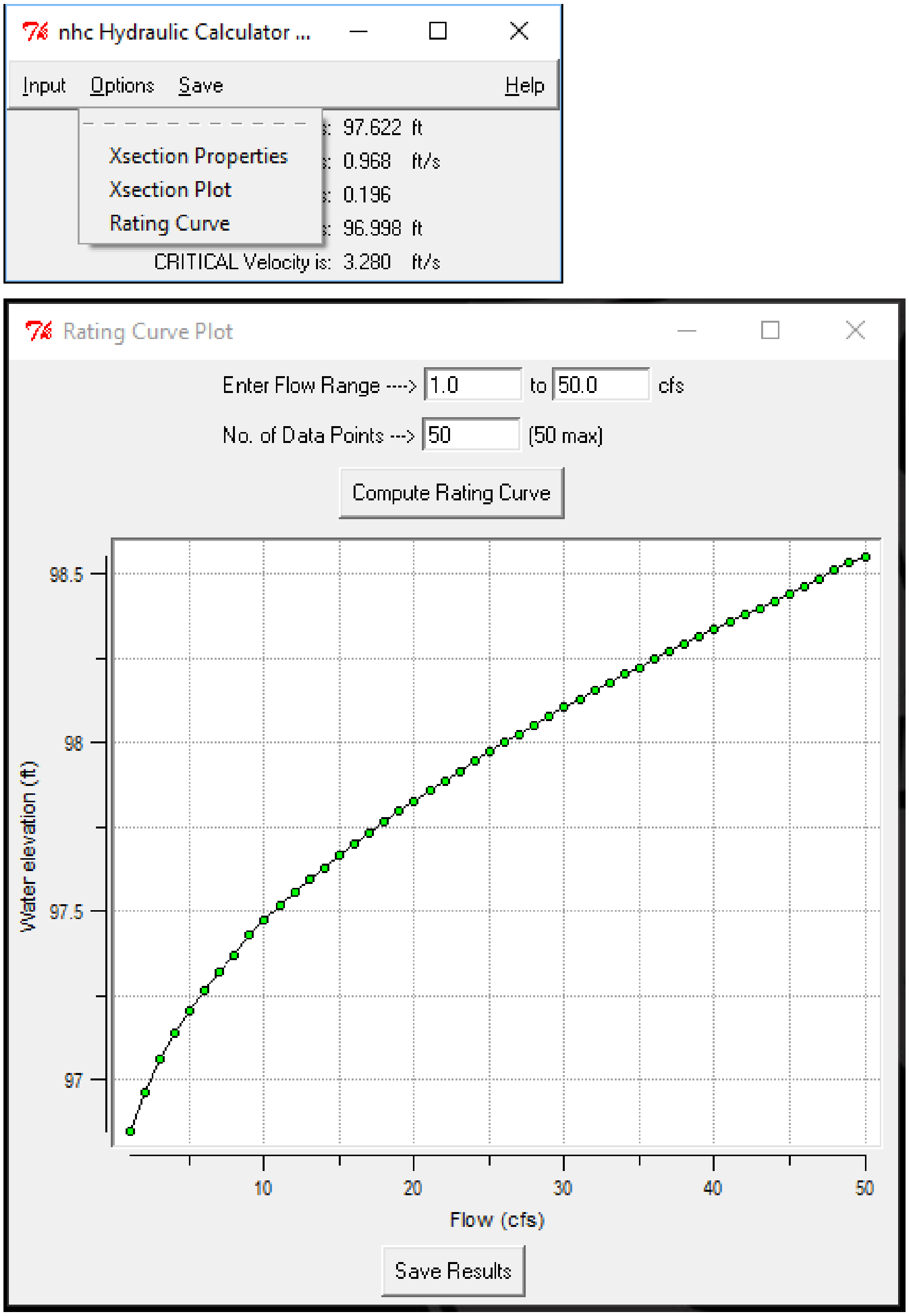

Figure 7. Example rating curve computation using HydroCalc (Molls 2010).

3.2 Interpreting the Results

Record the HydroCalc rating curve hydraulic parameters in a spreadsheet program or notebook. List average depth, average velocity, and percent wetted perimeter at each flow increment. Percent wetted perimeter is calculated for each flow increment by dividing the predicted incremental wetted perimeter by the wetted perimeter determined at bankfull flow.

The following three scenarios provide guidance on how to apply the HRM criteria. In each scenario, the maintenance flow occurs when depth and at least one other hydraulic parameter are met (Table 1). Table 3 represents rating curve hydraulic parameters for a hypothetical stream with a 20-ft bankfull width. Table 4 represents rating curve hydraulic parameters for a hypothetical stream with a 70-ft bankfull width.

Scenario 1: The surveyed stream has a bankfull width of 20 ft, and no salmonids are present. When determining the habitat maintenance flow, reference the key flow parameters in Table 1. The maintenance flow must provide at least 0.2 ft of depth, in addition to 1 ft/s velocity and/or 50% wetted perimeter. For scenario 1, the habitat maintenance flow is identified as 1 cfs, which meets the depth and wetted perimeter criteria (Table 3).

Scenario 2: The surveyed stream has a bankfull width of 20 ft. Age 1-2+ steelhead represent the largest size class of fish in the stream during the period of concern. For this scenario, the maintenance flow is identified by using the depth criterion for a specific species and life stage of interest, found in Table 2. The depth criterion for age 1-2+ steelhead is 0.4 ft. Therefore, the maintenance flow must provide at least 0.4 ft of depth, in addition to 1 ft/s velocity and/or 50% wetted perimeter. For scenario 2, the habitat maintenance flow is identified as 4 cfs, which meets the depth and wetted perimeter criteria (Table 3).

Table 3. Example HRM transect habitat maintenance flows and hydraulic parameters for scenarios 1-2. Scenarios represent habitat maintenance flows meeting example criteria.

Flow (cfs)	Average depth (ft)	Average velocity (ft/s)	Wetted perimeter (%)
1	0.212	0.212	67.222
2	0.277	0.253	84.973
3	0.353	0.297	86.655
4	0.415	0.331	88.067
5	0.467	0.358	89.272
6	0.516	0.383	90.936
7	0.562	0.405	92.618
8	0.603	0.424	94.222
9	0.642	0.442	95.845
10	0.677	0.458	97.374

Scenario 1

Scenario 2

Scenario 3: The surveyed stream has a bankfull width of 70 ft. Age 1-2+ steelhead represent the largest size class of fish in the stream during the period of concern. Using the criteria from Table 1, the maintenance flow must provide at least 0.7 ft of depth, in addition to 1 ft/s velocity and/or 70% wetted perimeter. For scenario 3, the habitat maintenance flow is identified as 36 cfs, which meets the depth and wetted perimeter criteria (Table 4).

Table 4. Example HRM transect habitat maintenance flows and hydraulic parameters for scenario 3. Scenario represents habitat maintenance flows meeting example criteria.

Flow (cfs)	Average depth (ft)	Average velocity (ft/s)	Wetted perimeter (%)	
1	0.116	0.199	64.995	
2	0.157	0.243	82.308	
3	0.193	0.279	89.104	
4	0.222	0.307	92.715	
5	0.252	0.333	93.746	
…	…	…	…	
31	0.646	0.623	123.189	
32	0.657	0.630	123.720	
33	0.668	0.637	124.240	
34	0.679	0.643	124.703	
35	0.689	0.650	125.056	← Scenario 3
36	0.705	0.660	125.275	

Glossary

Term	Definition
Bankfull	The observed and identifiable location on each bank where change in slope, change in substrate, and/or lower limit of perennial vegetation occurs. Additional indicators include the top of point bars, bank undercuts, and stain lines. Elevation is generally located below sedges and other plants that may survive submerged under high flows.
Discharge	The volume of water passing through a given cross-sectional area per unit time, typically expressed in cfs.
Habitat maintenance flows	The amount of continuous flow required to maintain hydraulic criteria for average depth, average velocity, and percent wetted perimeter at the hydraulic control of riffles.
Habitat retention method	Method for evaluating and identifying habitat maintenance flows that allow for the movement and long-term persistence of aquatic biota. Criteria for hydraulic parameters are based on Nehring (1979). Species- and life-stage-specific depth criteria are based on body depth requirements from Thompson (1972) and R2 Resource Consultants (2008), which were adopted by the California State Water Resources Control Board (2014).
Hydraulic control	A horizontal or vertical constriction in the channel, such as the crest of a riffle (Annear et al. 2004).
Toe of bank	The break in slope at the foot of a streambank where the bank meets the streambed.

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