Standard Operating Procedure for the Wetted Perimeter Method in California

CDFW-IFP-004

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California Department of Fish and Wildlife
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Table of Contents

List of Figures

Acknowledgements

This standard operating procedure (SOP) represents the protocol for the wetted perimeter method (WPM) of the California Department of Fish and Wildlife (CDFW) Water Branch Instream Flow Program (IFP). The processes in this SOP draw from methods used by the California Department of Fish and Wildlife and as described by the Instream Flow Council (Annear et al. 2004). This SOP was developed by Candice Heinz with the CDFW IFP, and Melinda Woodard with the Quality Assurance Research Group at Moss Landing Marine Laboratories.

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Abbreviations and Acronyms

CDFW	California Department of Fish and Wildlife
IFP	Instream Flow Program
LBWE	Left Bank Wetted Edge
RBWE	Right Bank Wetted Edge
SOP	Standard Operating Procedure
WPM	Wetted Perimeter Method

Introduction

This document serves as the wetted perimeter method (WPM) standard operating procedure (SOP) for the California Department of Fish and Wildlife (CDFW) Instream Flow Program (IFP). This document may be used in conjunction with other IFP SOPs as relevant to support procedures involved in WPM. Instructions are provided for:

- Preparing for Field Work
    - WPM Limitations and Constraints
    - Method Application
    - Site Selection
- Data Collection:
    - Equipment List
    - Field Procedures
- Developing the Wetted Perimeter - Discharge Curve
    - Data Entry
    - Graph Development
- Wetted Perimeter - Discharge Curve Results Interpretation
    - Summary of Results
    - Determining Instream Flow Needs

Scope of Application

This SOP provides procedural reference for CDFW staff conducting WPM, when site conditions and research objectives indicate WPM 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.

The CDFW Instream Flow Program encourages staff and contractors to contact us with any questions or for assistance with project planning. For more information, contact Diane Haas of the CDFW IFP at: Diane.Haas@Wildlife.ca.gov or (916) 445-8575.

This SOP describes the field procedure for determining wetted perimeter, and should only be applied when data yield a curve as described in the “What is the Wetted Perimeter Method?” section. This field WPM may be used to examine the low flow component of the hydrologic regime for ecological function and benthic macroinvertebrate production in systems that meet requirements as described in this document.

Depending on project objectives and field constraints, it may be preferable to use hydraulic modeling to model flows, determine wetted perimeter, and more thoroughly describe the flow regime of the target stream. Procedures for collecting streambed elevations to develop hydraulic models may be found in SOP number CDFW-IFP-003.

What is the Wetted Perimeter Method?

Streams and rivers are characterized by five primary riverine components and the complex interactions among those components. As noted in Annear et al. (2004) these include the river's hydrology, biology, geomorphology, water quality and connectivity. When the hydrology is changed, each of the other components is influenced to varying degrees. As water resources are developed for out-of-stream uses there are corresponding changes in other riverine components that may alter the form and function of a stream and associated ecological processes that are critical for supporting fish populations and their habitat. To address the full spectrum of those changes associated with flow modification, studies are typically needed to address each of these five components. The WPM may be used to address one of these components, as outlined below.

The term *wetted perimeter* refers to the perimeter of a cross sectional area of a streambed from wetted edge to wetted edge, where water depth is measurable to at least 0.01 ft (Figure 1). WPM is used to determine flow needs for maintaining productive riffle habitats, typically during the summer and/or fall months (Annear et al. 2004). This method is not applicable for use in determining salmonid rearing flows or identifying trade-offs between flow levels and specific biological functions, water quality, or geomorphic processes. The method application assumes that the flow represented by the incipient asymptote will protect the food producing riffle habitats at a level sufficient to maintain the existing fish population at some acceptable level of sustained production. The method further assumes that the stream channel is stable and unchanging over time (Annear et al. 2004). Wetted perimeter transect lengths, transect water depths, and discharge data are collected at a site over different flow conditions to generate the wetted perimeter - discharge curve (wetted perimeter vs discharge; Figure 2). The WPM is applicable to identifying flows for productive riffle habitats, and is to be used in conjunction with other methods and methodologies when more detailed information is needed to address specific questions of species and lifestage specific flow needs, river form, function or ecological processes.

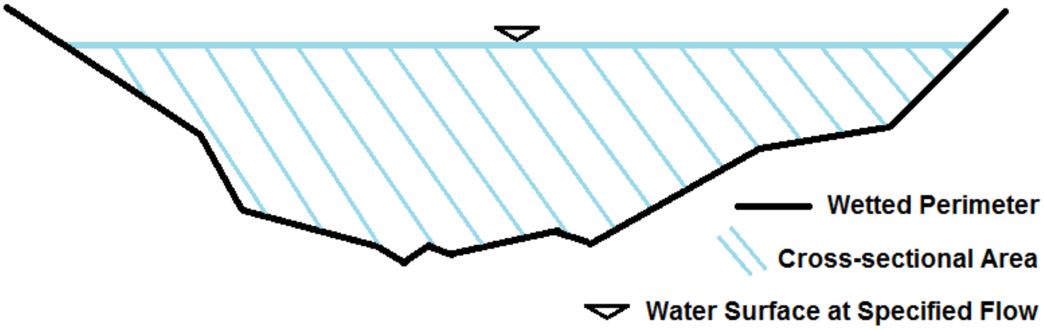


Figure 1. Visual representation of wetted perimeter

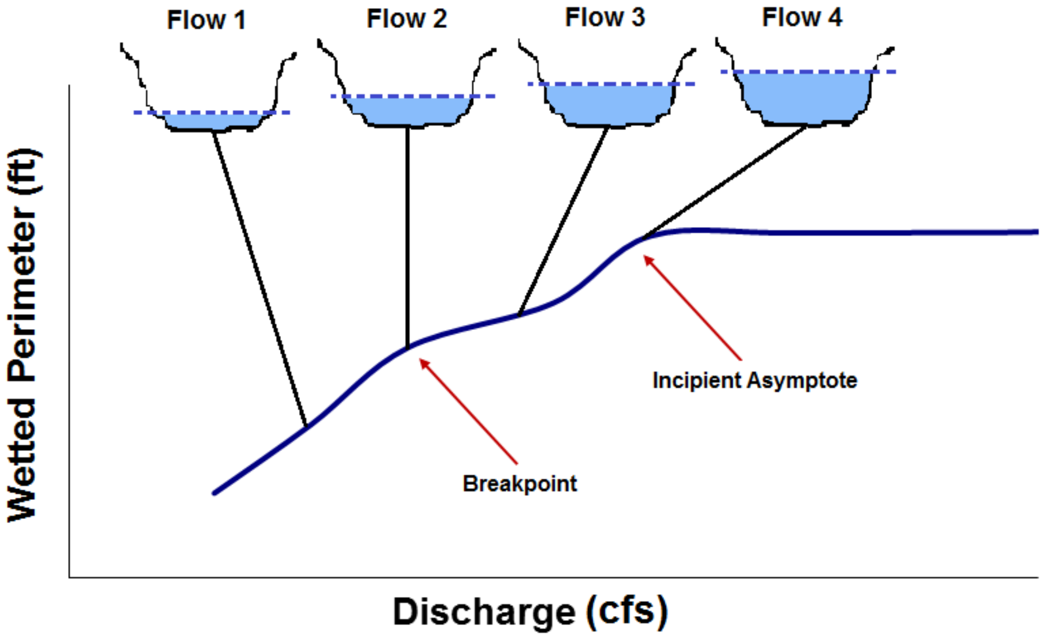


Figure 2. Typical wetted perimeter – discharge curve displaying breakpoint, incipient asymptote, and a visual representation of streambed cross sections at various flows

The wetted perimeter - discharge curve can then be used to identify a *breakpoint*, which defines the threshold below which aquatic habitat conditions for benthic invertebrates rapidly decline. The breakpoint is found at the curve's point of maximum curvature. The breakpoint represents the lower threshold for critically important food production. In theory, the breakpoint represents the transition from rapidly declining to critically important food production (Figure 3). Identification of a second inflection point—the incipient asymptote—is recommended to identify the upper threshold for riffle food production (Figure 3). Flows at the incipient asymptote are assumed to provide at or near optimum food production for riffle habitats (Leathe and Nelson 1989).

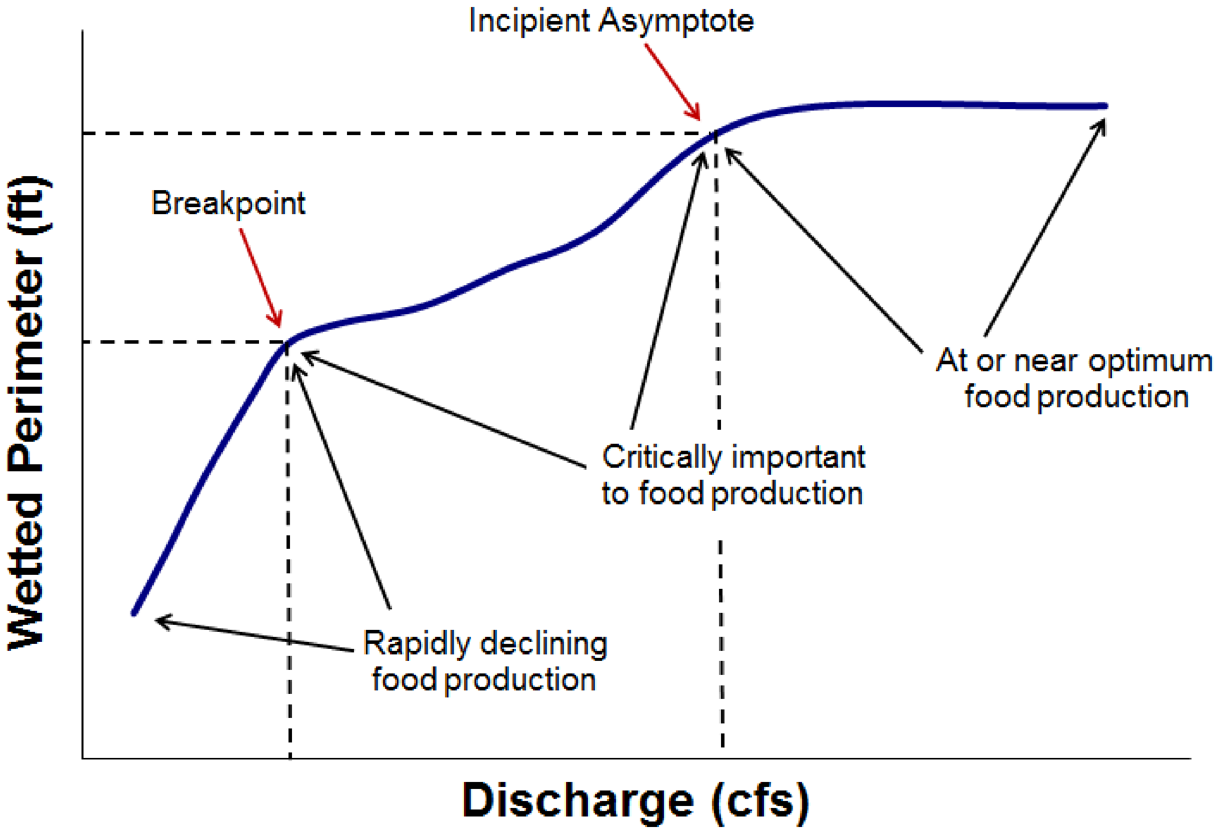


Figure 3. An example wetted perimeter - discharge curve showing relationship between breakpoints and fish food production

Method Overview

The Wetted Perimeter Method (WPM) is limited to use in riffles with rectangular streambed profiles. Riffle sites are selected because they are typically shallow, depth-sensitive areas of a stream that are most impacted by changes in flow, and they are critical habitats for benthic macroinvertebrates that fish eat. Additionally, data from shallow riffle habitats display a more distinct breakpoint once a wetted perimeter - discharge curve is developed (Kozlowski 1988). The IFP suggests that three to five representative riffles be surveyed per a stream reach, with one transect per riffle located at the hydraulic control of the riffle.

The transects are initially established with a head pin and a tail pin at each transect. The transect length is measured from head pin to tail pin, then the length from wetted edge to wetted edge is measured to obtain the wetted width. Beginning at the left wetted edge near the head pin, the water depth is measured at 1-ft intervals, or smaller intervals as needed, across the transect to the right bank wetted edge. A flow measurement must be recorded for each WPM transect measurement. Flow can be measured by taking discharge measurements near the site using a flow meter and top setting rod (see CDFW Discharge SOP number CDFW-IFP-002 for procedures) or by pairing nearby gage flow data with the days and times the streambed was surveyed. The riffle transect must be measured multiple times over a range of flows to develop the wetted perimeter - discharge relationship.

Once wetted perimeters and associated flows for the streambed cross sections are obtained for the range of important flows (see CDFW Flow Duration Analysis SOP number CDFW-IFP-005 for procedures and information about determining target flow ranges), a wetted perimeter-discharge curve is developed by plotting wetted perimeter against discharge. The breakpoint and incipient asymptote, as thresholds of desired habitat conditions, are then identified to determine instream flow needs necessary for maintaining riffle production of benthic macroinvertebrates. This recommendation can be used in conjunction with other flow analysis methods to develop a more holistic instream flow regime for environmental purposes.

Section 1: Preparing for Field Work: Site Selection

Before collecting WPM data, it is important to select a site with characteristics that support accurate WPM measurements, as outlined in Section 1.1. Flow Duration Analysis may be used to determine flow measurement parameters (see CDFW SOP number CDFW-IFP-005). The WPM data may be collected at any time of year, depending on site characteristics and flow levels, as long as the guidelines outlined below are met. The flow recommendation from WPM applies at all times of the year except when recommendations from other methods show that higher flows are needed for other riverine purposes.

Crew safety is of paramount importance; ensure that the river can be safely surveyed by crews. Contact the CDFW IFP for project planning assistance, as needed.

1.1 Method Limitations and Constraints

As outlined by the Instream Flow Council (Annear et al. 2004):

The Wetted Perimeter method uses measurements of hydraulic habitat to derive recommendations and assumes a relation between habitat and biology. Use of this method should be restricted to streams or stream segments where the stage at the chosen transect area is flow-sensitive (such as the riffle hydraulic control) and represents the geomorphic structure and shape of the river channel throughout the targeted river segment. Such areas are often, though not always, associated with bedrock-controlled high gradient streams with well-defined, rectangular-shaped riffles and no significant floodplains. If used in other streams, it should be considered as only one component of a recommendation that uses additional analyses. The method typically does not provide the necessary regime of flows that are critical to riverine ecology, but it may be a component.

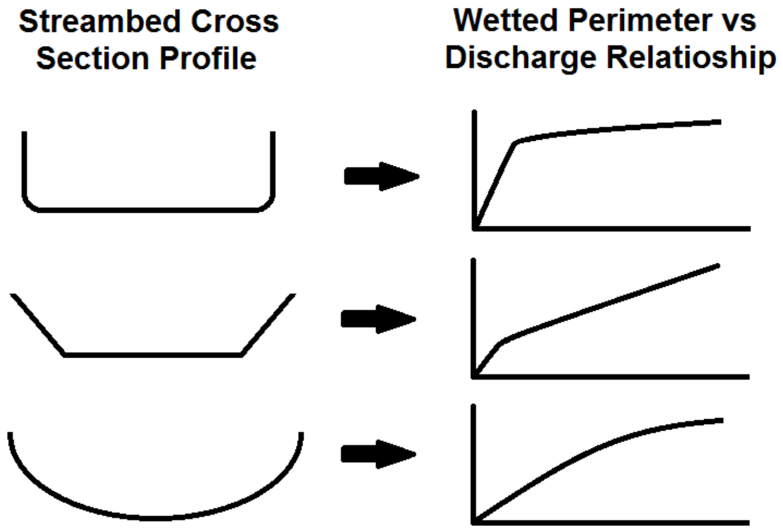


Figure 4. Streambed cross-sectional bed profiles and the corresponding wetted perimeter - discharge relationships

1.2 Method Application

Data should be collected for WPM using flows from the roughly 20-80% exceedance flow range, depending on physical site conditions, to develop a robust wetted perimeter – discharge relationship. Annear et al. (2004) recommends sampling at a minimum of 10 different discharge levels that encompass flows to at least bankfull for developing empirical wetted perimeter – discharge relationships using WPM.

1.3 Site Selection

Within the river segment of interest, target 3-5 representative riffles with rectangular beds for WPM. Each riffle should have one targeted transect located at the hydraulic control. The riffle sites should be representative of the overall geomorphic structure and shape of the river segment of interest. The hydraulic control of the riffle is typically located at the crest of the riffle.

Section 2: Field Procedures

During the initial data collection, establish the locations of transects as specified by the project manager. At each transect, install a head pin and tail pin, labeled with site name and transect number (see the Discharge SOP CDFW-IFP-002 for details on installation of the head pin and tail pin). Leave all pins installed for the duration of the study. At each transect, total transect length is measured, along with the transect distance at the right bank wetted edge (RBWE) and left bank wetted edge (LBWE). Water depths are measured using a stadia rod at 1-ft intervals, or smaller intervals as needed, across the channel from wetted edge to wetted edge.

Each WPM transect must be accompanied by a representative discharge measurement in order to develop a wetted perimeter - discharge curve. The discharge data can be obtained from a nearby stream flow gage on the stream in question or by collecting discharge measurements near the WPM site as specified in CDFW SOP number CDFW-IFP-002. If using gage data, ensure that the gage is measuring the same discharge as is occurring at the transect location. That is, there are no physical obstructions, tributaries, or diversions between the gage location and the transect. If there is no representative gage, discharge must be collected for WPM from a nearby site suitable for discharge measurements as described in CDFW-IFP-002.

Each WPM transect must be measured at a minimum of 10 flows that encompass flows at different levels up to bankfull height. Depths are measured to 0.01 ft and distances are measured to the nearest 0.1 ft.

2.1 Equipment List

Survey measuring tapes
Rebar (two per transect) and safety caps
Hammer
Stadia rod

Loppers (if needed to remove vegetation)
Field data sheets, as found at: http://www.dfg.ca.gov/water/instream_flow.html
Pencils

If collecting discharge measurements in the field, see Equipment List for Discharge Measurements, CDFW SOP number CDFW-IFP-002.

2.2 Data Collection

Step 1: During the first field data collection event:

- Install the transect pins at each transect location.
- Establish head pin and tail pin at each transect by hammering in rebar on the left and the right banks of the selected cross-section. Place the rebar far enough up the bank to accommodate for higher flows.
- Label each head pin with site name and transect number.
- Keep the rebar installed for the duration of the study to ensure that the same exact locations are surveyed. (Use of rebar safety caps is recommended)

Step 2: String the survey measuring tape across the transect from head pin to tail pin creating a taut, straight line. Record the full transect length to 0.1ft on the field data sheet next to “HP to TP.” This measurement is necessary to ensure that subsequent measurements are made on the same transect.

Step 3: Measure and record the transect distance at the left bank wetted edge (LBWE) and the right bank wetted edge (RBWE) to 0.1 ft.

Step 4: Starting from the left bank (head pin), measure and record the water depth at 1-ft intervals, or smaller intervals as needed, along the transect with a stadia rod to 0.01 ft. Dry measurements (e.g., rocks or other substrate out of water) within the wetted area should be indicated with a zero depth. For distances outside the wetted perimeter, depth cells should be left blank.

Step 5: Retrieve discharge data from a nearby gage OR by collecting discharge data near the WPM site according to the CDFW Discharge SOP, number CDFW-IFP-002.

Step 6: Repeat Steps 2-5 for each transect at each flow event.

Step 7: Repeat Steps 2-6 for each field event until all data have been collected for analysis.

Section 3: Data Entry and Analysis

After all data have been collected from the 10+ flow events, data may be entered into Excel or a similar program in preparation for data analysis. The project manager may alternatively decide to enter data after each field event.

One tab is created for each transect at each flow event. This tab should contain all transect data from the flow event, including water depths and wetted perimeter distances.

A summary table is then created to group wetted perimeter data for all transects. Each table lists information from all transects in the riffle, including flow value for the field event, wetted perimeter of the transect in the riffle, and the wetted perimeter of the riffle's transect at each flow event.

Enter field data for the riffle at each flow event

Step 1: Create a tab for each transect at each flow event. Label the tab with riffle number and discharge value for that flow event (e.g, Site 18 (3 cfs)).

Step 2: In each tab, create two columns: "Distance (ft)" and "Depth (ft)". Distance is the transect distance at 1-ft increments, or smaller increments as needed, where water depths were measured (Figure 5). Enter both distance and depth data for the transect at the flow event.

Step 3: In each tab next to the distance and depth data, create a table that will assist in calculating wetted perimeter. Label the three columns as follows: "Wetted Width (ft)", "Average Depth (ft)", and "Wetted Perimeter (ft)" (Figure 5).

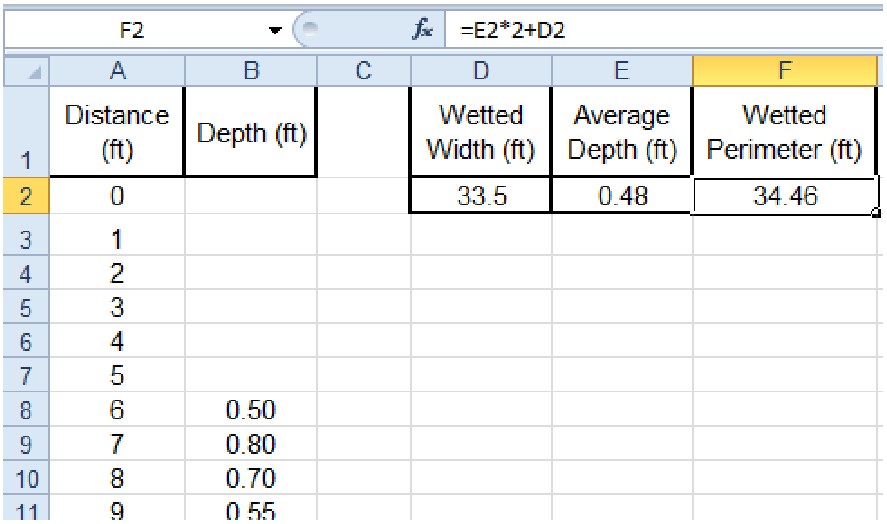
Step 4: Enter the wetted width (RBWE minus LBWE) from the field data into the wetted perimeter calculation table under the "Wetted Width (ft)" column (Figure 5).

<u>Step 5:</u> Calculate the average depth in the wetted perimeter calculation table by averaging together all water depths from across the transect during the flow event. Do not include distances outside of the wetted area, but do include areas that are out of water within the wetted transect area. In Excel, type “=AVERAGE(“ and highlight all transect depths, then close parenthesis and hit enter.

<u>Step 6:</u> Calculate wetted perimeter in the wetted perimeter calculation table by using the following formula:

Wetted Perimeter = (Average Depth x 2) + Wetted Width

*Example of Excel formula formatting: =E2*2+D2*



F2 | fx | =E2*2+D2

	A	B	C	D	E	F
1	Distance (ft)	Depth (ft)		Wetted Width (ft)	Average Depth (ft)	Wetted Perimeter (ft)
2	0			33.5	0.48	34.46
3	1					
4	2					
5	3					
6	4					
7	5					
8	6	0.50				
9	7	0.80				
10	8	0.70				
11	9	0.55				

Figure 5. An example of appropriate data organization and wetted perimeter calculation in Excel

<u>Step 7:</u> Repeat Steps 1-6 for each transect at each flow event until all data have been entered for analysis.

Section 4: Data Analysis: Developing the Wetted Perimeter - Discharge Curve

Before flow recommendations for riffle productivity may be made, the wetted perimeter - discharge curve must be produced for each riffle site on the river of interest. The wetted perimeter - discharge curve is created by plotting discharge values versus wetted perimeter values for the riffle at each flow event. One curve is made for each riffle site included in the study.

Step 1: Create a graph in Excel for the riffle site that plots wetted perimeter values on the y-axis and discharge values on the x-axis (Figure 6). The graph can be placed in the same tab as the summarized riffle data in Section 3, or a new tab can be created to hold each wetted perimeter - discharge curve.

- Under the “Insert” tab, select the graph type “scatter-plot with smooth lines and markers”.
- Right click the blank graph and select “Select Data”.
- Insert flow values into the x-axis box and average wetted perimeters into the y-axis box.

Step 2: Title the graph and label the axes (Figure 6). The title should include:

- the method used (Wetted Perimeter)
- the river of study
- the reach
- the riffle site name or number
- date range of sampling

Step 3: Adjust the axes numbers as desired to reflect scale and/or add minor tick marks under the “format axis” options (right click the axis). The graph should look similar to Figure 6 (below).

Step 4: Repeat Steps 1-3 for each riffle in the study to generate a curve for each riffle.

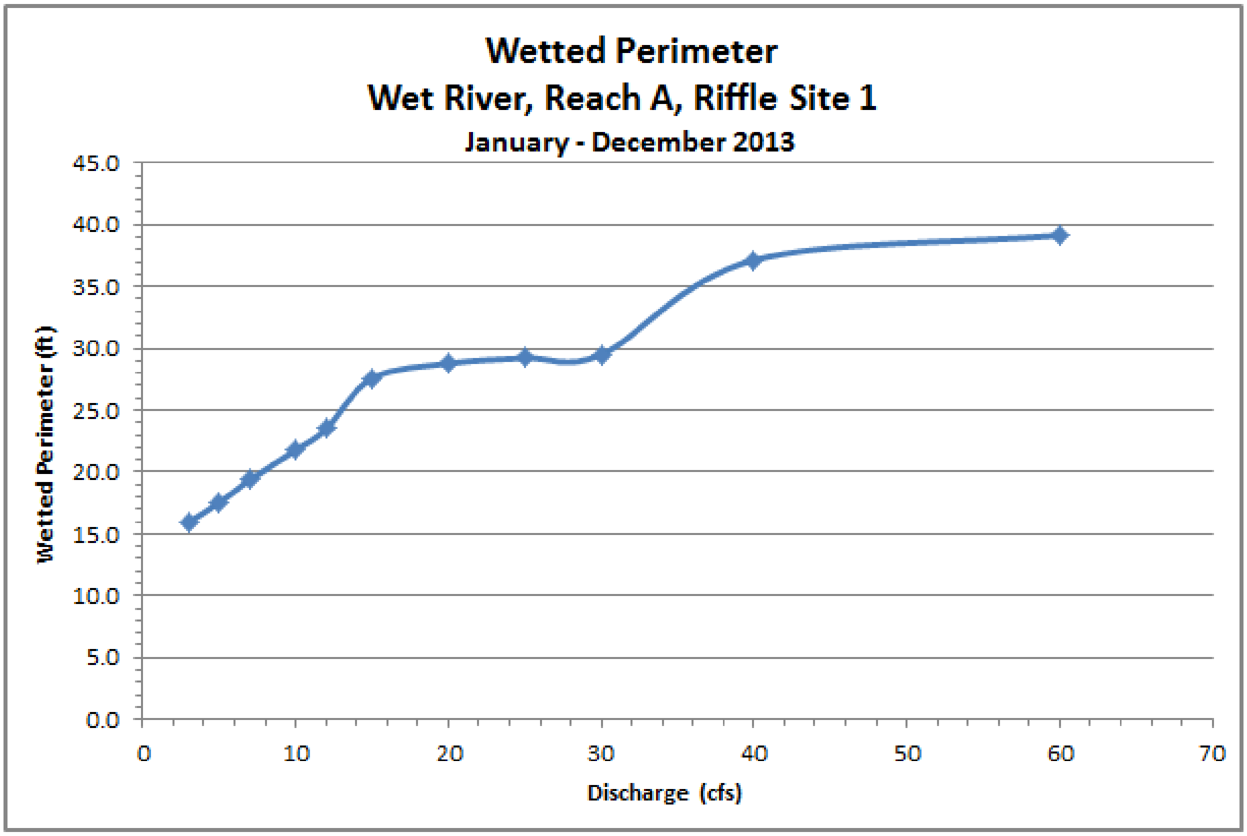


Figure 6. An example of a wetted perimeter - discharge curve for a riffle

Section 5: Interpreting the Curve and Identifying the Breakpoints

The breakpoint and the incipient asymptote must be identified for each wetted perimeter - discharge curve. The breakpoint is found at the curve's first point of maximum curvature while the incipient asymptote is found at the second point of maximum curvature. These points are commonly identified by visual observation or by determining the point where the tangent to the curve is 45° (Gippel and Stewardson 1998), then drawing a vertical line from that point to the x-axis to identify flow rate associated with that point. If the channel is not rectangular in shape, breakpoints and/or incipient asymptote points may not be identifiable. **If the wetted perimeter – discharge curve does not have an identifiable breakpoint and incipient asymptote, this method may not be used to calculate wetted perimeter for this riffle site.**

Figure 7 shows an example of a wetted perimeter - discharge curve with the breakpoint and incipient asymptote identified. The breakpoint is estimated at 14 cfs, which suggests that flows less than 14 cfs would result in unfavorable conditions and rapidly declining riffle food production. The incipient asymptote flow is estimated to be 38 cfs, which suggests that flows between 14 cfs and 38 cfs are critically important to food production. Flows above 38 cfs are more likely to maintain aquatic macroinvertebrate production levels at natural levels up to a point. (Figure 7).

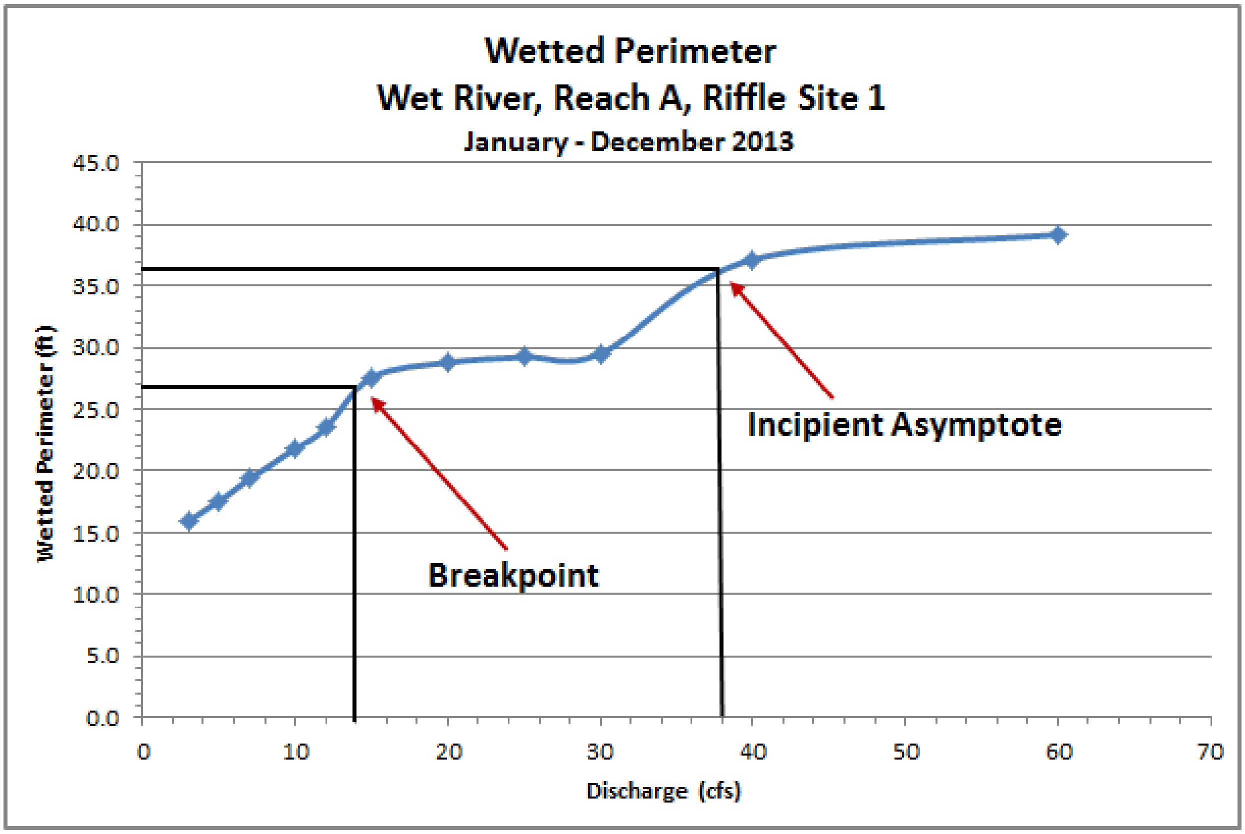


Figure 7. An example wetted perimeter - discharge curve for a riffle site displaying breakpoint (14 cfs) and incipient asymptote (38 cfs)

Section 6: Considerations for Determining Flow Recommendations

Once the breakpoint and incipient asymptote flows have been identified for all riffles within a reach, compile the data into a summary table. The method typically does not provide the necessary regime of flows that are critical to riverine ecology, but it may be a component.

Flow at the incipient asymptote is assumed to provide optimally productive riffle habitats. The CDFW recommends using the WPM mean incipient asymptote flow as a component of an overall instream flow regime needs assessment for maintaining riffle productivity.

Glossary

Wetted Perimeter – Discharge Curve	A wetted perimeter – discharge curve is developed by plotting wetted perimeter values of a cross section of a stream (y-axis) against associated discharge values (x-axis). The curve reflects the amount of wetted streambed at various flows with the assumption that flow levels influence food productivity in riffles. If the surveyed channel is rectangular in shape, the curve should display two distinct points of maximum curvature: the breakpoint and the incipient asymptote. The wetted perimeter – discharge curve is useful for determining flows for riffle productivity, and can be used as a component of a larger instream flow needs assessment.
Breakpoint	The breakpoint of a wetted perimeter – discharge curve defines the lower threshold below which aquatic riffle habitat conditions for benthic invertebrates rapidly decline. The breakpoint represents the transition from “critically important food production” and “rapidly declining food production.” The breakpoint is identified at the curve’s first (lower) point of maximum curvature.
Incipient Asymptote	The incipient asymptote of a wetted perimeter – discharge curve defines the upper threshold at or above which aquatic riffle habitat conditions are at optimum food production. The incipient asymptote represents the transition between “critically important food production” and “optimum food production.” The incipient asymptote is identified at the curve’s second (upper) point of maximum curvature.

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