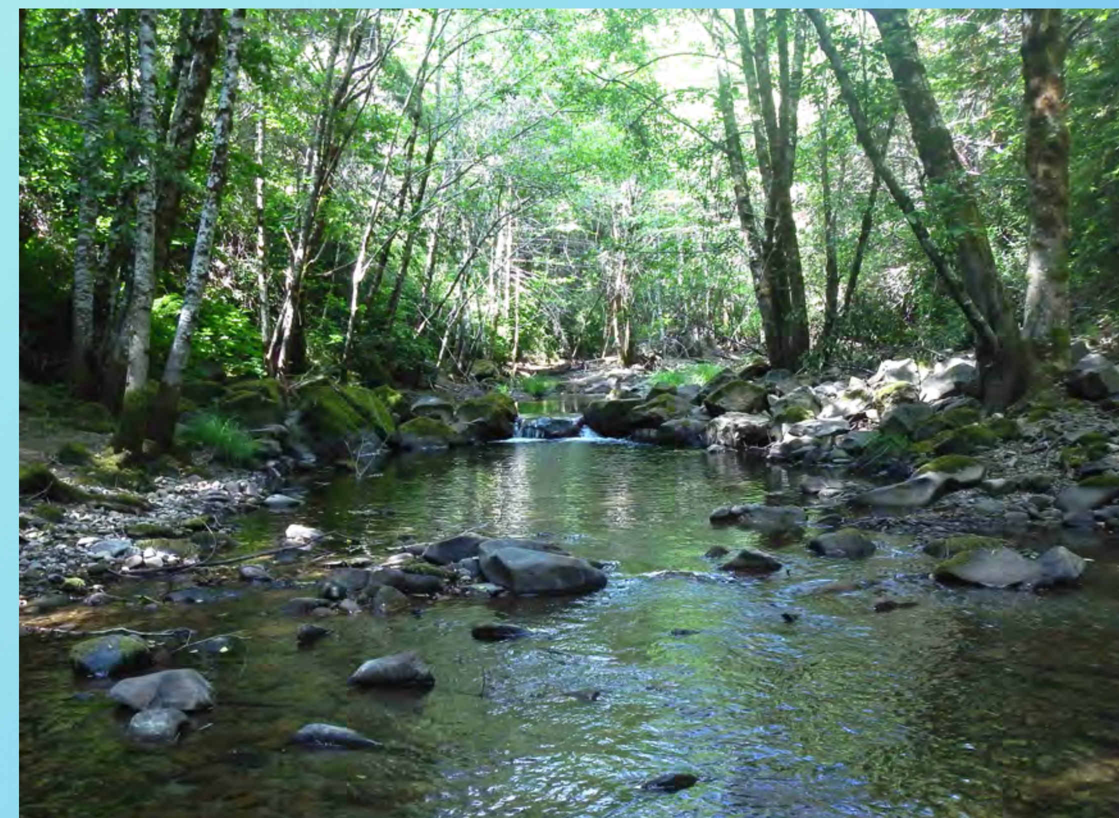
DRAFT TECHNICAL REPORT MAY 2016

A Regional Strategy for Protecting Instream Flows in North Coast California Watersheds



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A Regional Strategy for Protecting Instream Flows in North Coast California Watersheds

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TABLE OF CONTENTS

1. INTRODUCTION

The challenges of managing water in California's coastal watersheds are complex. Throughout the region, mounting authorized and unauthorized riparian and appropriative water diversions, as well as a changing climate, alter the magnitude, duration, and timing of streamflows, inhibiting the life history opportunities of juvenile salmonids. In the last decade, management of instream flows has become a priority in recovering state and federally listed salmonid populations integral to the ecology and economy of the California's North Coast (SWRCB 2010a, CDFG 2004, NMFS 2014, 2015).

Traditional site-specific instream flow studies, while an important management tool in certain applications, have significant limitations in managing streamflows in most of the hundreds of small salmon-bearing tributaries throughout the north coast (CalTrout et al. 2014). Site-specific instream flow studies are expensive and have long implementation timelines, and typically focus only on hydraulic habitat (flow depth and velocity). One alternative that has been proposed for prescribing instream flow criteria is a percent of flow diversion approach (AEIC 2011, Richter et al. 2012), but this approach has limitations when applied in coastal watersheds. The objective of this report is to describe a modified percent of flow method for identifying instream flow needs and recommending water diversion allocations for salmon-bearing streams in the North Coast region of California. We propose this strategy to prescribe protective instream flow criteria and calculate a maximum level of cumulative daily diversion, which can then be allocated among multiple users in a watershed. Our method can be applied across a range of watersheds throughout the region without the need for site-specific studies or localized gage data. This report discusses the biological validity of our approach, and offers two watersheds within the South Fork Eel River Basin as case-studies.

2. OVERVIEW OF INSTREAM FLOW NEEDS AND WATER ALLOCATION PROTOCOLS

Surface water diversions in regulated streams can be placed into two general categories: *bypass flow* strategies and *diversion rate* strategies. Under a bypass flow strategy, the diverter agrees to 'bypass' a specified volume or rate of streamflow downstream of the intake/dam for the right to divert (and often impound) the rest. Traditionally, this bypass streamflow is intended to provide the minimum streamflow necessary to maintain some level of ecological function. The bypass flow strategy provides a minimum level of protection, and does not adequately protect natural variability in the hydrograph across seasons. In a *diversion rate* strategy, the diverter or diverters are allowed a cumulative maximum diversion rate, for example a percentage of the ambient streamflow. There is no minimum bypass streamflow. Application of a diversion rate strategy does not guarantee full protection, but does have strong mechanisms built-in to prioritize and protect a full range of instream flow needs. In a bypass strategy, the bypass flow is based on a streamflow threshold. In a diversion rate strategy, the cumulative maximum diversion rate is the threshold.

Within each strategy there are various approaches to determining the appropriate threshold. In the following paragraphs, we discuss common approaches to calculating these thresholds. We then describe our proposed new approach to setting thresholds under the diversion rate strategy, which we call the modified percent of flow approach.

The Bypass Flow Strategy

The conventional approach for determining bypass flows is a site-specific instream flow study (Annear et al. 2004). These studies usually follow the Instream Flow Incremental Methodology (IFIM) approach and identify streamflow thresholds assumed protective of priority life history needs of salmonid species. The bypass flow approach was designed primarily to meet flow release requirements below storage reservoirs and hydropower dams, where operational releases target microhabitat and water temperature conditions for long stretches of river downstream. Bypass thresholds are poorly suited for unregulated coastal streams, where multiple independent water diversions are scattered along headwater and mainstem reaches. The problem of managing multiple independent surface diversions is not new (SWRCB 2014, Deitch et al. 2009, 2014), but has become compounded recently with the proliferation of vineyard and marijuana agriculture, both well-suited to the coastal Mediterranean climate.

Percent of Flow Diversion Rate Strategy

In diversion rate strategies, maximum rates of diversion are typically expressed as a percentage of natural streamflow. To protect natural flow variability, water managers from a growing number of states and foreign countries have adopted a "percent of flow" (POF) diversion rate approach, including Oregon, Florida, Maine, and Virginia, several Canadian Provinces, and members of the European Union. The natural flow regime is critical to freshwater ecosystems, sustaining physical habitat, food webs, water quality, and biological interactions (Nehlsen et al. 1991, Poff et al. 1997; Trush et al. 2000; Bunn and Arthington 2002; Arthington et al. 2006; Acreman and Ferguson 2010; Poff et al. 2010; SWRCB 2010; Richter et al. 2012). A POF strategy allows diversion and storage of a specified maximum percentage of the daily ambient streamflow, while maintaining natural flow variability. Instream flow criteria within California that have adopted POF diversion strategies include those from the upper mainstem Eel River (NMFS 2002) and Lee Vining Creek, tributary to Mono Lake (McBain and Trush 2010). The SWRCB's 2014 *Policy for Maintaining Instream Flows in Northern California Coastal Streams* ("North Coast Policy") offers a hybrid diversion rate strategy, combining a minimum bypass flow (MBF) with a maximum cumulative diversion rate. The Alberta Environment Information Center (AEIC 2011) proposes a POF strategy, prescribing 15% diversion of ambient flow to fully protect the riverine environment. Richter et al.'s 'presumptive standard' (2012) suggests a maximum cumulative diversion rate of 10% of the unimpaired flow to provide a "high level" of ecological protection and 20% of the unimpaired flow to provide a "moderate level" of ecological protection.

The POF diversion strategy is ecologically superior to a bypass flow strategy because it protects natural flow variability, but has several inherent problems when applied to California's coastal watersheds. First, allowing a variable volume of water appropriation based on the water supply available across different water year types can allow demand (appropriations) to become dependent on the abundant water supplies available in wetter years, creating water deficits during drier water years. Another problem with a POF approach applied directly to the ambient streamflow is that the streamflow available from which to divert water cannot easily be predicted in advance, so providing reasonable certainty that remaining instream flows meet protective flow criteria post-diversion becomes challenging. Additionally, relying on real-time gaging to measure flow and then compute a diversion rate is impractical for most riparian and small appropriative water right holders to implement at a point of diversion (POD). Stream gaging is costly, and quality control by state agencies is difficult to maintain. Finally, even if streamflow is known, the same diversion rate applied in different channel types may produce different hydraulic habitat effects.

A Proposed Modified Percent of Flow Strategy- Overview

To maintain the ecological advantages of a diversion rate strategy but overcome the challenges of implementing a POF approach, we are proposing a modified Percent Of Flow (mPOF) strategy. As with the POF strategy, the mPOF strategy protects seasonal flow variability. However, while a POF strategy diverts a predefined percentage of the daily ambient streamflow, a mPOF strategy prescribes a cumulative daily maximum diversion *volume* from a calculated streamflow baseline (the daily 90% exceedance flow), resulting in a variable diversion *rate* across time, and thereby ensuring (1) greater protection of inter-annual flow variability, and (2) predictable water volumes for diversion for water users. The mPOF strategy proposed here can be applied regionally at any location on any ungaged stream, avoiding the need for expensive site-specific instream flow studies. Our strategy can be calibrated for coastal watersheds from the Klamath River south to Santa Cruz, roughly corresponding to the historic distribution of SONCC and CCC Coho Salmon.

The framework for this method is summarized here and described in detail in Section 3. In brief, the mPOF strategy establishes a *streamflow baseline* for a given POD by computing the daily 90% exceedance streamflow either from available streamflow records or through regional flow exceedance relationships. A regional streamflow baseline can be computed for a given POD without gaging records, using only a regionalized flow exceedance curve and a computed or modeled mean annual streamflow (described below). We then apply a percent diversion rate to the streamflow baseline to compute a cumulative daily maximum allowable diversion volume for each day of the water year. For a given POD, the daily allowable diversion *volume* does not change from year to year, regardless of the water year type (i.e., wet, normal, dry). However, the daily maximum diversion *rate* as a percent of the ambient flow decreases in wetter water years. This method thus provides a fixed maximum allowable volume of water for each day of the water year for appropriation at a safe, cumulative maximum diversion rate. Risk associated with water over-allocation in watersheds should be minimized using this approach. The water volume available for appropriation depends on the percentage of the streamflow baseline allocated, and can provide a reliable water supply adequate to meet water demand in most coastal watersheds. This is demonstrated in two case studies described in Section 5.

We derive a protective maximum cumulative diversion rate, to be diverted from the streamflow baseline, based on a percentage change in stream stage height (water elevation) rather than an arbitrary percentage of flow. We believe this is more protective than basing allowable diversion on a simple percentage of streamflow, given the sparse evidence in the literature for the protectiveness of the latter. We apply a rule allowing no greater than a 5% decrease in stage as a result of cumulative diversions. In the analysis below, using a regional relationship between riffle crest thalweg (RCT) depth and streamflow, we show that a 10% reduction in streamflow produces approximately a 5% change in riffle crest depth over a wide range of streams and channel types. Five percent is assumed to be *de minimus* with regard to environmental impacts, therefore, our provisional prescription is to allow appropriation of up to 10% of the streamflow baseline in coastal watersheds in northern California. This prescription could be modified where a site specific study is warranted, similar to the approach taken in the North Coast Policy (SWRCB 2014).

The feature of a fixed daily and annual water volume available at each POD for appropriation is important. It means water certainty for each day, season, and water year. In addition, implementation is highly simplified, as each water user is assigned a fixed daily volume that fits within the cumulative maximum diversion rate available for allocation. Water users need not know the ambient streamflow; they can reliably divert their allocated daily volume and never risk over-consumption, lack of water availability, or impairment to the stream from which they are diverting.

3. A MODIFIED PERCENT OF FLOW PROTOCOL

In this section, we describe each step in developing a modified percent of flow (mPOF) strategy. The four steps are: (1) estimate daily average flow (Qavg) at the point of diversion (POD); (2) construct a regional (dimensionless) and POD flow duration curve; (3) construct a regional and POD streamflow baseline; and (4) apply a diversion rate as a fixed percent of the streamflow baseline.

Step #1: Select reference stream gages and estimate daily average flow at POD

Several steps rely on data from reference USGS stream gages, although the protocol could also be completed with unimpaired hydrology models. Reference streams should be selected based on the following criteria: a long period of record, a range of drainage areas, variability in watershed aspect, and limited effects from consumptive water use. For the South Fork Eel River Basin (Figure 1), we selected three reference streams (Table 1). Elder Creek and Bull Creek are almost entirely public land and are minimally affected by human water diversions with only a few riparian diversions in each basin. The South Fork Eel River near Leggett is larger than the other two watersheds and includes a mix of public land, private industrial timberland, rural residential development including marijuana cultivation, the town of Laytonville, and irrigated pastures/vineyards. Summer streamflows at the Leggett gage have declined significantly in recent decades, but the declines can largely be explained by decreasing annual precipitation and the magnitude of declines is less than other portions of the Eel River Basin (Asarian 2015).

Mean annual streamflow (**Q_{avg}**) is a common hydrologic statistic, and is required to apply our regional approach at an ungaged POD. There are several methods available to estimate Q_{avg}. Our approach currently employs the formula used in the North Coast Policy:

$$\mathbf{Qavg_{POD} = Qavg_{Gage} * (DA_{POD} / DA_{Gage}) * (P_{POD} / P_{Gage})}$$

where $Qavg_{POD}$ = mean annual unimpaired flow rate estimated at the POD, in cubic-feet per second (cfs); $Qavg_{Gage}$ = unimpaired mean annual flow rate recorded at the reference gage, in cfs; DA_{POD} = drainage area at the POI, in square miles; DA_{Gage} = drainage area at the reference gage, in square miles (mi^2); P_{POD} = average annual precipitation of the POI, in inches (in); and P_{Gage} = average annual precipitation of the gage, in inches (in).

A convenient data source for P and DA for the POD's catchment area is the U.S. EPA's WATERS Google Earth interface (https://www.epa.gov/waterdata/viewing-waters-data-using-google-earth) which delineates watersheds from NHD-plus (McKay et al. 2015, http://www.horizon-systems.com/nhdplus) and provides statistics including 1971-2000 P_{avg} from the PRISM Climate Group (Daly et al. 2008, http://www.prism.oregonstate.edu/).

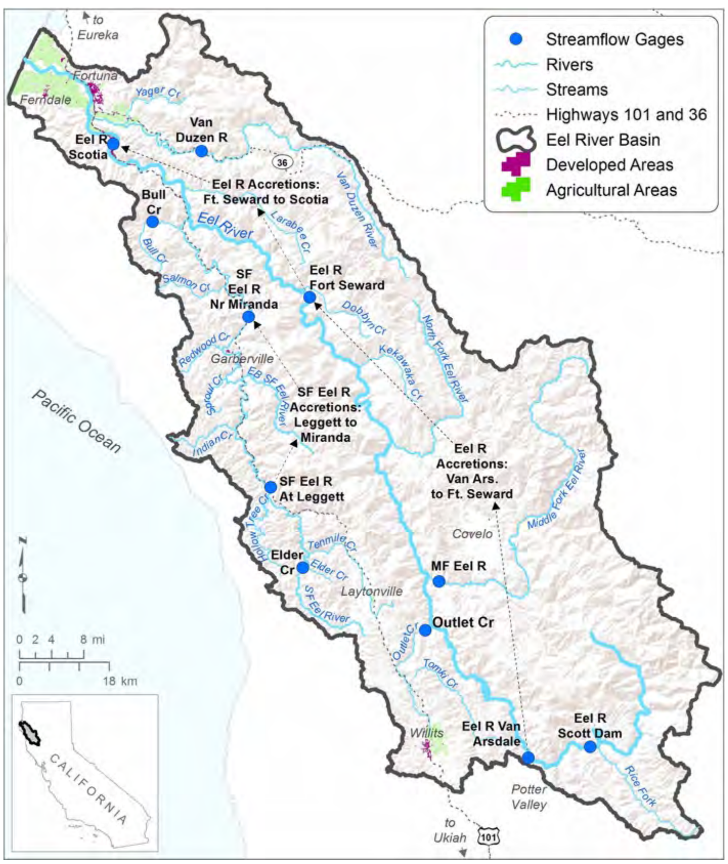

Figure 1. Location of the North Coast of California, the South Fork Eel River Basin, and long-term reference streamflow gages within the basin.

Table 1. Streamflow gages in the South Fork Eel River Basin with streamflows that are relatively unimpaired by water diversions, including some common gage metrics. * P_{avg} is mean annual precipitation for 1971-2001 from PRISM, accessed through WATERS/NHD-plus interface.** Missing data for water years 1995-1999 and 2005-2007.

Location	Drainage Area (mi^2)	Period of Record	Q_{avg} (cfs)	P_{avg} (in)*
Elder Creek USGS gage #11475560	6.5	10/1/1967 – 9/22/2014	25	99.7
Bull Creek USGS gage #11476600	28.1	10/1/1960 – 9/22/2014	115	64.9
South Fork Eel near Leggett USGS gage #11475800	248	10/1/1965 – 10/29/2013**	804	81.4

Step #2: Construct a regional dimensionless flow duration curve and POD flow duration curve

A flow-duration curve is a simple means of expressing the time distribution of discharge – it shows the percentage of time, for a given period, that any specified discharge is equaled or exceeded. It thus provides a useful device for analyzing the availability and variability of streamflow. To construct 'dimensionless' annual flow duration curves:

- Sort mean daily flow values by magnitude (across entire period of record), assign rank numbers, then calculate the exceedance probability (0 to 100%, the percent of time over the period of record that flow was equaled or exceeded on that day) for each flow.
- Divide each daily flow (Q_x) by Qavg to obtain a Q_x/Qavg ratio, then plot against exceedance probability to create dimensionless (unit-less) flow duration curves (Figure 2).

The South Fork Eel River at Leggett gage is recommended as a 'representative' daily average flow duration curve for SF Eel River streams. In this case, we feel the use of one gage is justified because the variation between the reference gages results in relatively small differences in diversion volumes.

To construct a daily average flow duration curve for any POD, the Y-axis of the regional dimensionless flow duration curve (Figure 2) is multiplied by the Qavg for the POD.

Step #3: Construct a regional streamflow baseline and POD streamflow baseline

For each reference gage (Table 1), plot annual hydrographs for the period of record as 'exceedance probability vs. date' charts (e.g., Figure 3). Then compute the 'daily 90% exceedance' for each date (i.e., an exceedance curve computed independently for each day of the water year, where 90% of the historical records for that date exceed the plotted point).

In the case of the South Fork Eel River at Leggett, regression trendlines were fit to the 90% exceedance for each date, using separate curves for the spring recession and the fall ascension so the curves provided a smoothed fit spanning the entire water year and resulting in a *regional exceedance baseline* (Figure 4). As shown in Figure 4, the curves for the three reference gages in the SF Eel are nearly identical. Testing on nine other gaged streams in the North Coast region found a similar congruency in the relationship between exceedance and date. Exceedance probabilities follow a similar seasonal pattern at all sites across the region, with lowest exceedances (i.e., streamflows are highest) in March and highest exceedances (i.e., streamflows are lowest) in August and September.

Finally, to produce the *streamflow baseline* for the POD, replace the exceedance (Y-axis) of the regional exceedance baseline with the predicted streamflows from the POD's daily average flow duration curve (the result of Step #2). The result is a POD's streamflow baseline (Figure 5). An MS Excel spreadsheet is developed for these computations.

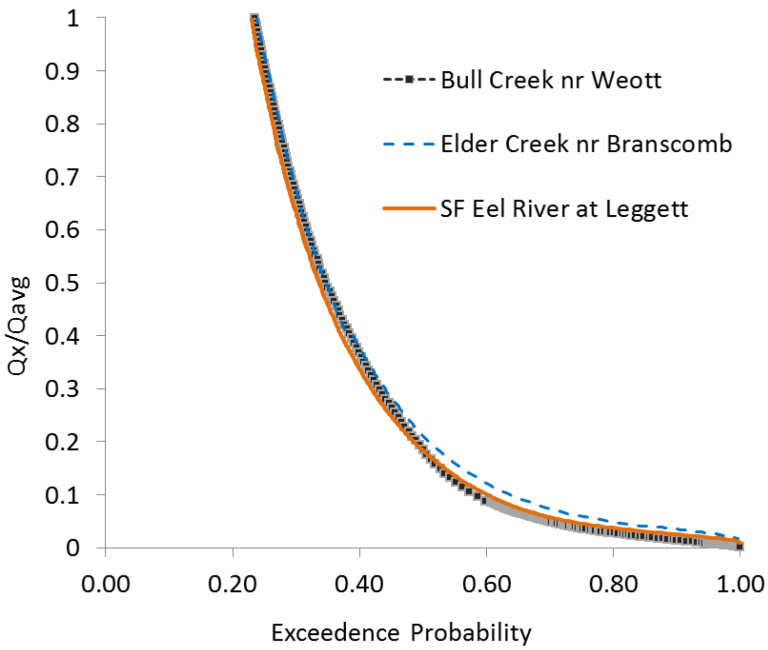

Figure 2. Dimensionless daily average flow duration curves for three stream gages within the South Fork Eel River Basin relatively unimpaired by diversions. Some variation is evident, but overall the curves are remarkably similar. The flow duration curve for South Fork Eel River at Leggett gage, selected as a reference, is highlighted in bold.

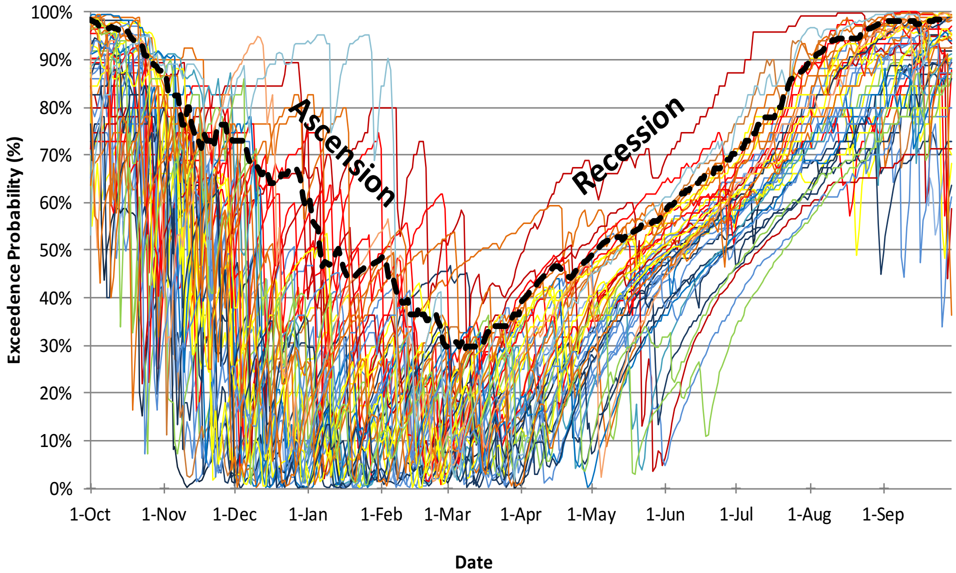

Figure 3. Illustration of the 90% exceedance baseline plotted with date-exceedance hydrographs for an example stream gage (USGS 11-475560 Elder Creek near Branscomb, CA). This chart is developed by replacing daily average flow values for each annual hydrograph with the exceedance value, then computing and plotting the 90% exceedance value for each day of the water year. Trendlines can then be fit to the 90% daily exceedance data (shown in Figure 4).

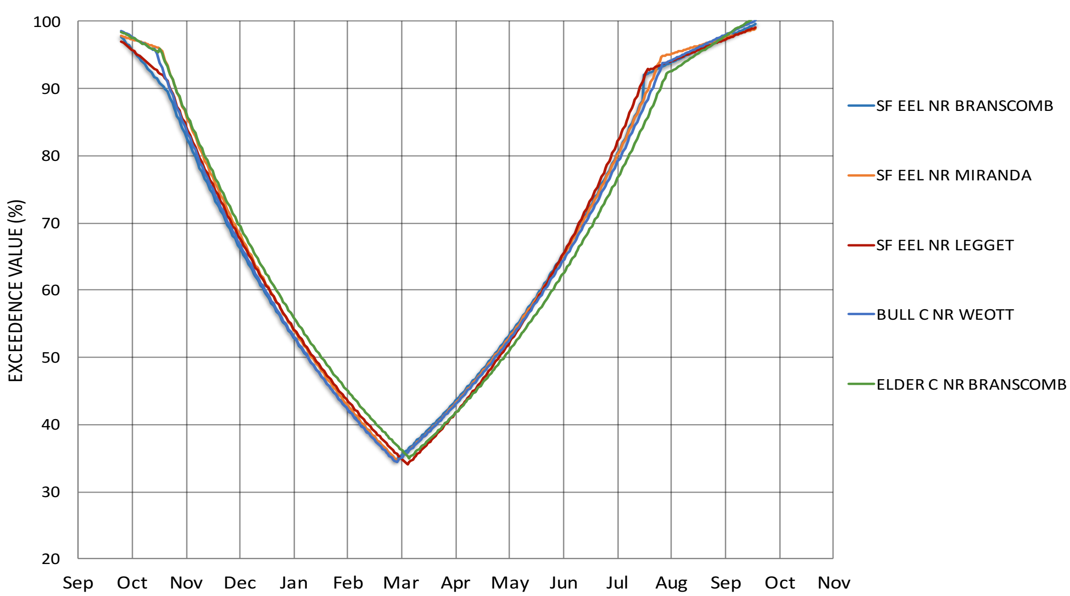

Figure 4. Regression curves fit to the 90% exceedance baselines for several long-term stream gages in the South Fork Eel River Basin with streamflows that are relatively unimpaired by diversions. These curves exhibit remarkably similar slopes in ascension and recession curves, allowing a regionally representative curve to be used.

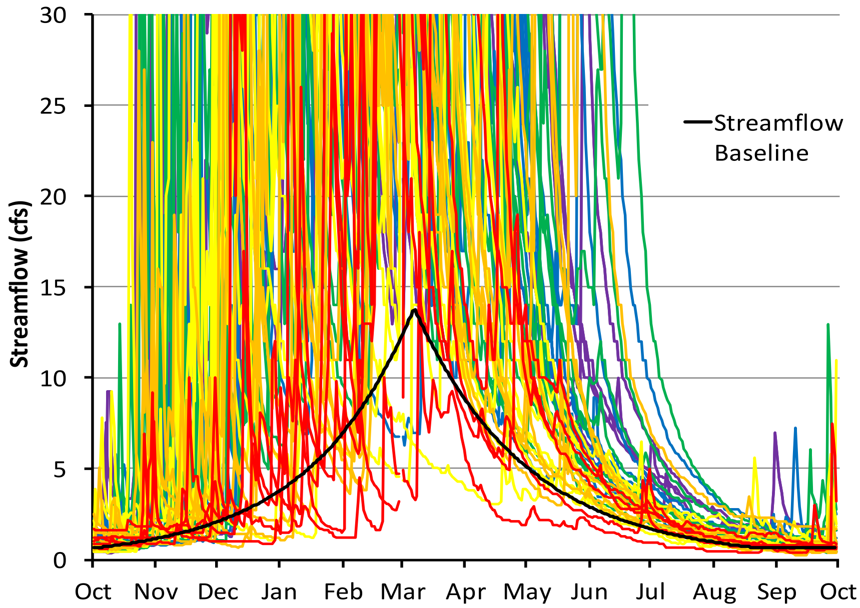

Figure 5. The streamflow baseline for Elder Creek is produced by replacing exceedance value in the trendline curve (from Figure 4) with streamflow. The streamflow baseline is shown plotted with Elder Creek annual hydrographs, "enveloping" the bottom range of daily average flows.

Step #4: Apply a variable diversion rate as a fixed percent of the streamflow baseline

In the final and critical step in the mPOF protocol, allocate a fixed percentage of the streamflow baseline for diversion.. The recommended diversion rate is a fixed or constant percentage of the streamflow baseline, while the diversion rate is variable relative to the unimpaired streamflow which constantly changes.

The following section describes our approach linking a percentage diversion of the streamflow baseline to hydraulically-dependent instream flow needs of coastal stream channels, a step currently not integrated into most POF strategies.

4. A MODIFIED PERCENT OF FLOW DIVERSION RULE

The ecological basis for our maximum allowable diversion rate is summarized as follows: (1) the riffle-pool unit is the basic salmonid habitat unit of gravel-bed streams in California's coastal watersheds; (2) most streamflow-habitat relationships within the riffle-pool unit are a function of channel morphology (particularly bed roughness, channel slope, and width-to-depth ratios); (3) during low streamflow conditions, the riffle crest acts as a weir, controlling hydraulic habitat in the riffle-pool unit; (4) hydraulic relationships between riffle crest depth and streamflow are sensitive to channel morphology and thus can relate streamflow to salmonid habitat in an ecologically meaningful way; and (5) therefore, a diversion rate based on a percentage change in RCT depth provides a measurable ecological nexus between salmonid habitat and the rate of diversion. We propose that for a regional, programmatic instream flow criterion, **the maximum allowable cumulative diversion rate on any given day should not decrease the median RCT depth more than 5%.** The ecological justification for this diversion rate rule is explained in more detail in the following sections.

The Riffle-Pool Unit

The vast majority of coastal watersheds that support anadromous salmonid populations exhibit relatively similar geomorphic and hydrological characteristics: a riffle-pool channel morphology typified by lowgradient (<5%), moderately confined channels, with sporadic bedrock and large wood influence. The underlying structure to a riffle-pool morphology (Figure 6) is the bar unit (Dietrich 1987) or the alternate bar morphology described by Leopold et al. (1964).

A single riffle-pool sequence, which we refer to as a hydraulic unit, is thus a basic morphological unit ubiquitous of streams in our coastal watersheds (Langbein and Leopold 1968; Lisle 1979, 1982, 1987; Richards 1982; Trush et al. 2000). As described by Lisle (1982) "riffle-pool sequences are often created by bars extending over the full channel width. …At low to moderate flows, the submerged bar crest forms the control section for the pool upstream and often forms the downstream riffle crest." The pool represents a topographic depression, while the riffle is a protuberance on the channel bed, or a topographic high.

Streamflow and habitat within the riffle-pool unit

Research in numerous instream flow assessments (the Trinity River, Mono Lake tributaries, Upper Tuolumne River, Shasta River, Mattole River, Napa River, Alameda Creek, Indian Creek (Navarro), and Mill Creek (Navarro)) supports the concept that hydraulic units manifest characteristic hydraulic patterns (water depths and velocities), which in turn create and sustain salmonid micro-habitats. Other research has also demonstrated that the riffle-pool sequence is a primary determinant of meso-scale hydraulic patterns (Bovee et al. 1982, Carling at al. 1994, Trush et al. 2000, Emery et al. 2003; Mossop and Bradford 2006). Riffles provide abundant and productive benthic-invertebrate habitat; the pool-head is a productive juvenile salmonid rearing area resulting from the velocity 'tongue' extending into the pool delivering food resources; deep pools offer juvenile refugia and adult holding area; and pool tails provide sorted gravels and water velocities favored for spawning.

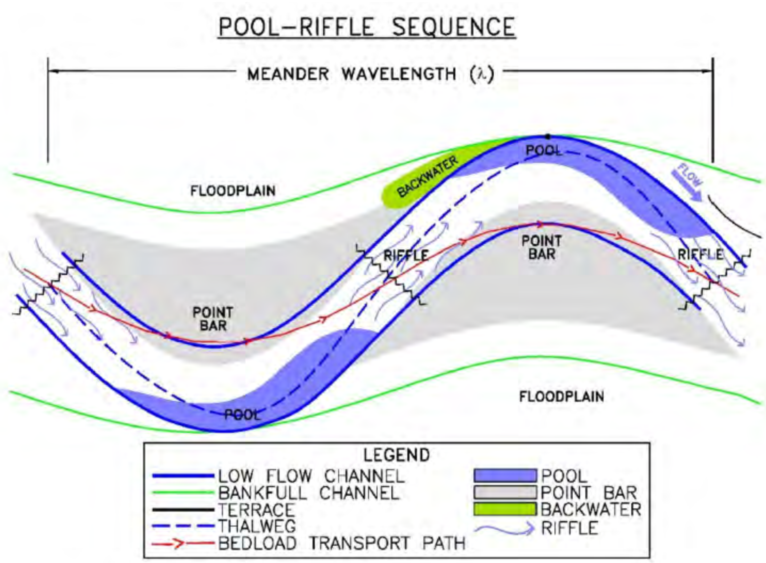

Figure 6. Plan-view diagram of two pool-riffle sequences (or 'hydraulic units') comprising a single alternate bar unit, showing the migration of the thalweg through the pool and crossing over at the riffle. Figure adapted from Dietrich (1987).

Hydraulic units are thus a basic template linking streamflow hydraulics to salmonid micro-habitat utilized by individual fish (Trush et al. 2000). In addition, variability between hydraulic units is a key concept addressed in stream ecology and instream flow management. Flow-habitat relationships within the riffle-pool unit are strongly affected by channel morphology (Bovee 1978).

The riffle crest as hydraulic control

In the moderate and low-flow range, the stability of the hydraulic characteristics within a pool-riffle sequence stems from the hydraulic 'control' exerted at the riffle crest (Clifford et al. 2002). The riffle crest controls the upstream pool or run water surface elevation, depth and velocity in pools, and indicates the boundary of the downstream riffle (Figure 7). The active channel cross section at the riffle crest hydraulically controls the magnitude and shape of hydraulic curves used in many instream flow investigations (e.g., see CDFW 2013a, 2013b). As streamflow recedes to zero, hydraulic connectivity is lost between consecutive pools, exposing the channelbed between them (the riffle). At the 'stage of zero flow' the residual pool water surface elevation is the same as the zero riffle crest thalweg elevation (Lisle 1987; Madej 1999). The downstream extent of each residual pool terminates at the riffle crest.

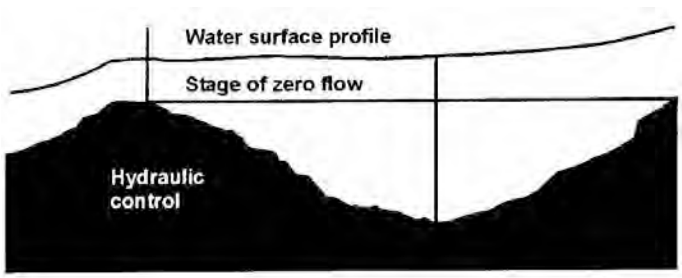

Figure 7. Figure 4-27 from Bovee et al. (1988), illustrating the typical channel bedform exhibited by a riffle-pool morphology, the hydraulic control exerted by the riffle crest, and the stage of zero streamflow corresponding to the thalweg of the riffle crest.

Hydraulic relationships between Q and RCT depth are computed by measuring RCT depth over a range of flows and plotting the rating curve. A set of 10 RCT-Q rating curves (i.e., one curve for each primary riffle crest) from Elder Creek (Figure 8) illustrates the range in RCT-Q ratings.

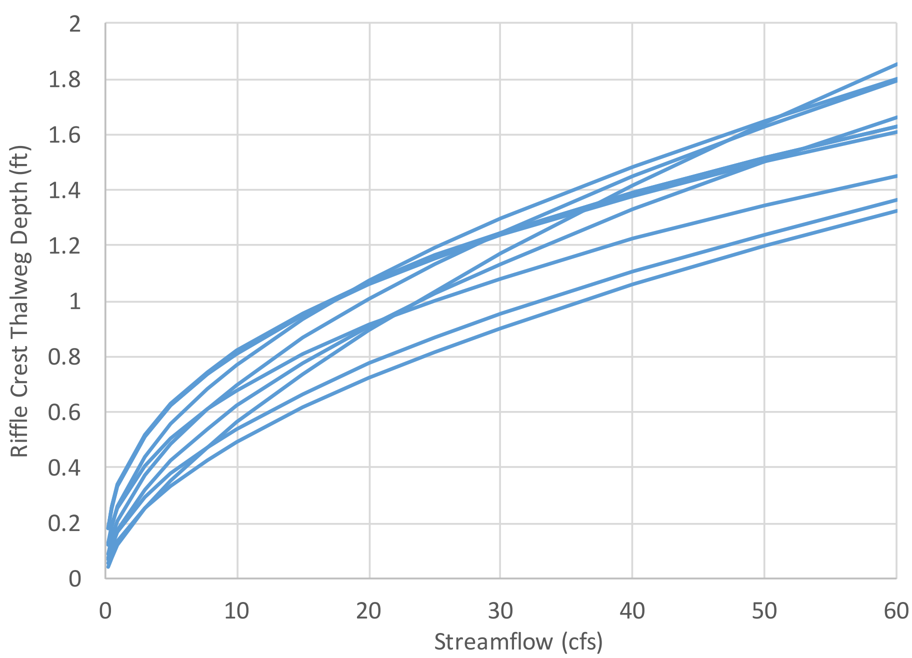

Figure 8. Elder Creek family of 10 riffle crest thalweg rating curves.

The proposed RCT rule for computing maximum allowable diversion rate

To link stream hydraulic performance over a range of flows to ecological functions those variable flows sustain, we propose a simple rule for computing a maximum allowable diversion rate.

> **RCT 5% Rule: To protect instream flow needs from excessive cumulative diversions, a maximum cumulative diversion rate applied to the streamflow baseline on any given day should not decrease median RCT depth more than 5%.**

RCT-Q rating curves generated from USGS gaging stations in Coastal California share a similar pattern to that of the South Fork Eel River rating curves. Comparison of the percent reduction in RCT depth resulting from varying streamflow diversion rates shows that limiting streamflow diversion to 10% limits RCT depth reduction to approximately 5% change (Figure 9).Within the South Fork Eel River basin and across several California coastal streams, preliminary research and fieldwork indicate that a 10% diversion rate from the streamflow baseline could become a regional guideline in California's coastal watersheds.

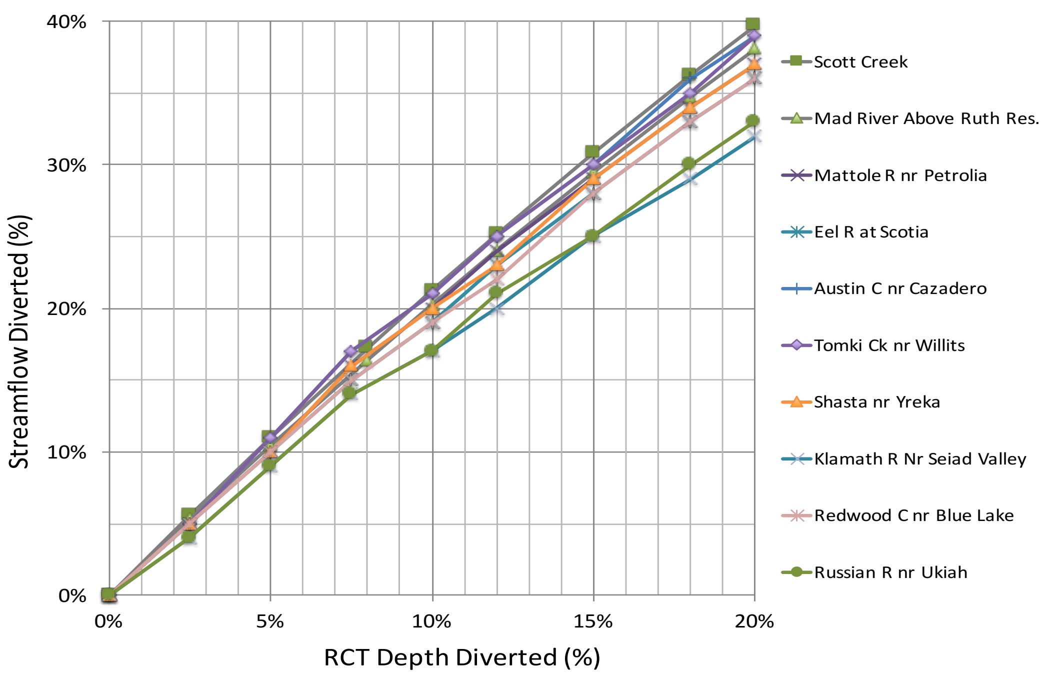

Figure 9. The percentage decrease in streamflow producing a percentage change in RCT depth from USGS gaging station RCT-Q rating curves on selected California coastal streams and rivers.

The streamflow baseline offers an ideal baseline from which to prescribe variable diversion rates expressed as a percentage of the unimpaired streamflow. If each date's streamflow along a POD's streamflow baseline is diverted at a maximum of 10%, the decrease in RCT depths for the median RCT-Q rating curve is unlikely to exceed 5% in any water year type, even dry years. If the absolute magnitude of the diversion rate is applied to streamflows greater than those comprising the streamflow baseline, the decrease in RCT depth will be less than 5%.

5. CASE STUDIES: THE MPOF STRATEGY APPLIED TO SF EEL RIVER WATERSHEDS

The following sections provide two example case studies applying the mPOF framework to specific points of diversion, using Elder Creek and Sproul Creek in the South Fork Eel River (Figure 1) as example watersheds.

Elder Creek: A POD where long-term unimpaired streamflow data are available

For most PODs, a long-term record of measured daily unimpaired streamflows and an empirical RCT-Q curve will not be available. However, the availability of such data greatly simplifies the calculation of the streamflow baseline and helps illustrate its application in formulating maximum allowable diversion rates.

Here we present a simplified case study in which a hypothetical POD is located at one of our reference streamflow gages, Elder Creek. We follow the four steps outlined above.

Step #1: Select reference stream gages and estimate daily average flow at a POD

This step is greatly simplified by the availability of daily average streamflow data at the POD. The USGS *Elder Creek nr Branscomb CA* gage has a 48 year record, from which Qavg is computed as 25.1 cfs.

Step #2: Construct a regional dimensionless flow duration curve and POD flow duration curve

This step is also greatly simplified by the availability of streamflow gaging records. A regional dimensionless flow duration curve is not needed. Instead the Elder Creek gage data are used to construct an annual flow duration curve for the POD (shown in Figure 2).

Step #3: Construct POD streamflow baseline from the regional streamflow baseline

The streamflow baseline for the Elder Creek POD is developed by calculating the 90% exceedance for each date and then fitting a regression curve to the 90% exceedance (shown in Figure 5 for Elder Creek). Only two water years in Elder Creek's 48 year period of record consistently fall below the streamflow baseline for lengthy portions of the water year.

Step #4: Apply a variable diversion rate rule as a fixed percentage of Elder Creek's streamflow baseline

A variable diversion rate rule is then applied based on the relationship between RCT depth and streamflow. As explained above, for Elder Creek, and most other streams within the region, a 10% diversion rate will prevent the median RCT depth from decreasing more than approximately 5%. For our case study, if all the water available for appropriation were diverted, the natural hydrograph's streamflow variability would be protected (Figure 10); the water supply available for appropriation would total approximately 283 acre-feet annually. The daily allowable diversion is computed as 10% of each day's streamflow baseline. The cumulative maximum allowable diversion thus allows a fixed number of residential or other water users on each date, dependent on their daily water consumption needs (Figure 11).

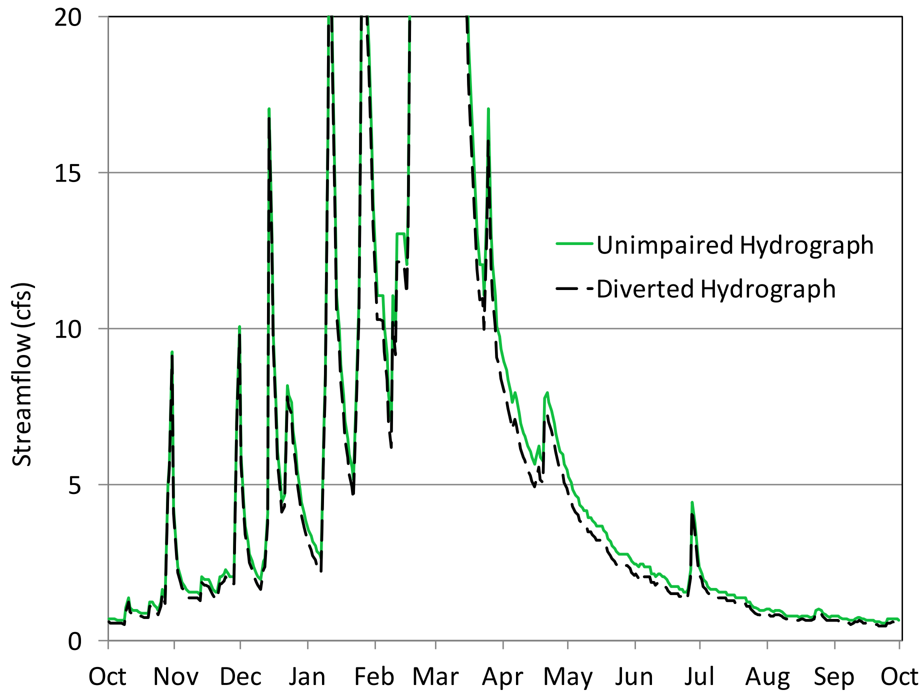

Figure 10. Annual hydrograph (WY 2001) for the 6.5 mi^2 Elder Creek POD. The daily diversion allocation subtracted from an example annual hydrograph shows little effect on the natural hydrograph, but a 10% diversion rate of the streamflow baseline in Step #4 yields 283 acre-feet annually, with a minimum daily water supply of 29,000 gallons per day.

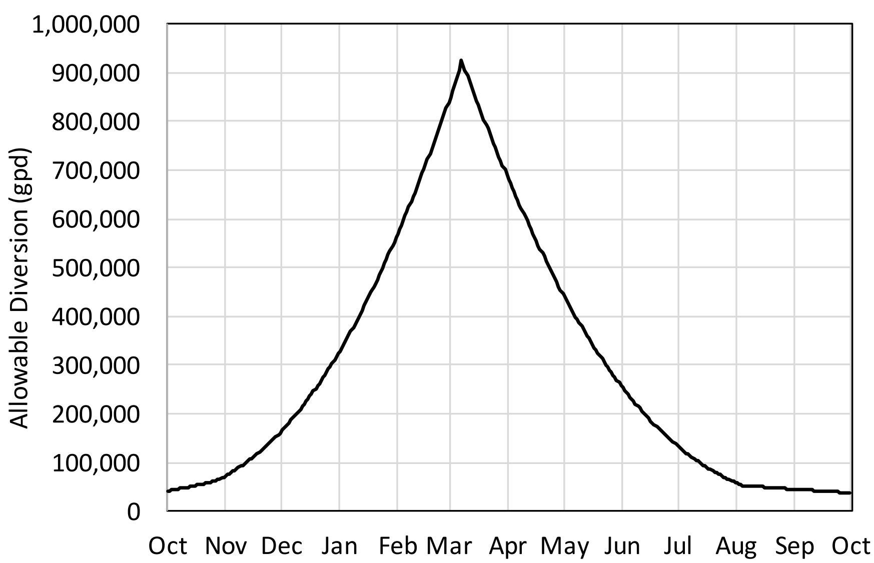

Figure 11. Maximum allowable diversion rate (in gallons per day) for a hypothetical Elder Creek POD or group of PODs. The annual volume of water available for appropriation at this POD is 337 ac-ft; the minimum daily allowable diversion is 38,169 gpd.

Sproul Creek: A POD where long-term unimpaired flow data are not available.

The second, more complex POD case study examines a POD on a small third order stream in Sproul Creek, a 24.0 mi tributary to the SF Eel River. The simulated POD is located on the South Fork Sproul Creek below the confluence of Cox Creek, with a drainage area of 4.99 mi^2. There are no gaging records or anecdotal streamflow measurements at this site, nor any RCT-Q data. To employ our regional methodology and compute a variable diversion rate with a percent diversion from a streamflow baseline (as demonstrated for Elder Creek), the methodology requires a regional dimensionless exceedance baseline (Figure 2).

Step #1: Select reference stream gages and estimate daily average flow at POD

Our adopted protocol for calculating mean annual unimpaired flow (Qavg) follows the North Coast Policy (SWRCB 2014), employing the following unit runoff equation for estimating Qavg at an ungaged POD:

$$\mathbf{Qavg_{POD} = Qavg_{GAGE} * (DA_{POD}/ DA_{GAGE}) * (P_{POD}/ P_{GAGE}),}$$

where $Qavg_{POD}$ = mean annual unimpaired streamflow at the POD in cubic-feet per second (cfs); $Qavg_{GAGE}$ = unimpaired mean annual streamflow at the reference gage; DA_{POD} = drainage area at the POD, in square miles; DA_{GAGE} = drainage area at the reference gage, in square miles; P_{POD} = average annual precipitation of the POD, in inches; and P_{GAGE} = average annual precipitation of the gage's watershed, in inches. The North Coast Policy's unit runoff equation requires a reference gage ($Qavg_{GAGE}$) (Table 1). The nearest long-term, currently-operating stream gage to the Sproul Creek POD is the USGS 'Bull Creek nr Weott' gage (11-476600; DA = 28.1 mi^2) approximately 28 miles downstream of Sproul Creek. Its 54 year period of record has a Qavg of 115 cfs, or a unit runoff at Qavg =114 cfs/28.1 mi^2 = 4.09 cfs/mi^2. The North Coast Policy's unit runoff equation also requires an estimate of long-term annual precipitation for the POD (P_{POD}) and for the reference gage (P_{GAGE}). The U.S. EPA's WATERS Google Earth interface (http://www2.epa.gov/waterdata/viewing-waters-data-using-google-earth) delineates watershed drainage areas from NHD-plus (McKay et al. 2015, http://www.horizon-systems.com/nhdplus) and estimates long-term annual average precipitation from the PRISM Climate Group (Daly et al. 2008, http://www.prism.oregonstate.edu/).

Applying the North Coast Policy equation, and using PRISM to estimate mean annual precipitation, gives estimates of $Qavg_{POD}$ for the Sproul Creek POD of:

$$\mathbf{Qavg_{POD} = 115\ cfs * (4.99\ mi^2/ 28.1\ mi^2) * (67\ in/ 96\ in) = 14.3\ cfs}$$

Step #2: Construct regional dimensionless exceedance curve and a POD exceedance curve

The method for developing a regional dimensionless exceedance curve is discussed in Section 3 Step #2 above. For this case study, we selected the USGS 'SF near Leggett' gage as our regional exceedance curve. Then, using the mean annual discharge at our POD calculated in Step #1, we produce a daily average flow duration curve for the Sproul Creek POD by multiplying the Y-axis of the regional dimensionless flow duration curve (Figure 2) by the Qavg for the POD. The resultant flow duration curve is shown in Figure 12.

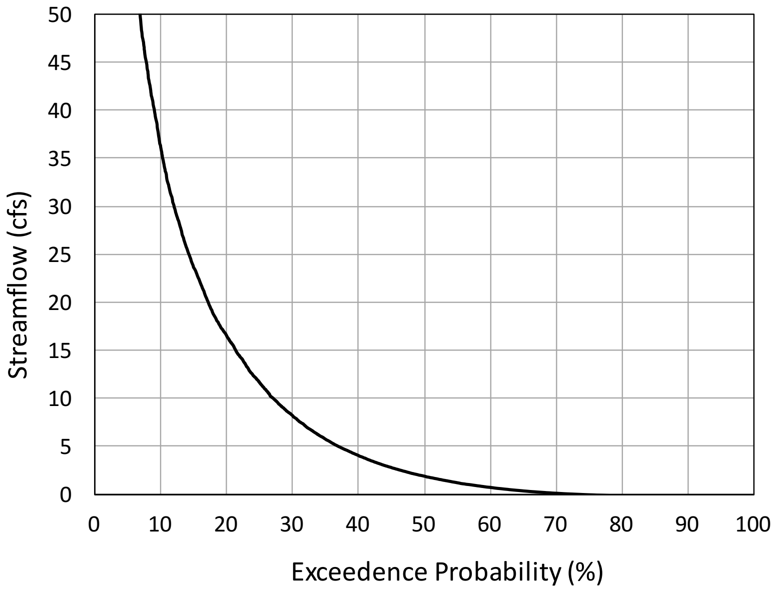

Figure 12. South Fork Sproul Creek POD (DA = 4.99 mi2) daily average flow duration curve constructed from the regional dimensionless flow duration curve.

Step #3: Construct regional streamflow baseline and a POD streamflow baseline

The ungaged South Fork Sproul POD does not have the prerequisite gaging data to construct a streamflow baseline. As with the daily average flow duration curve, a dimensionless streamflow baseline was created from the USGS South Fork Eel River gaging stations (Figure 4). Then, the exceedance curve developed in Step #2 was used to replace exceedance values in Figure 4 with streamflow values, resulting in a streamflow baseline for the Sproul Creek POD (Figure 13).

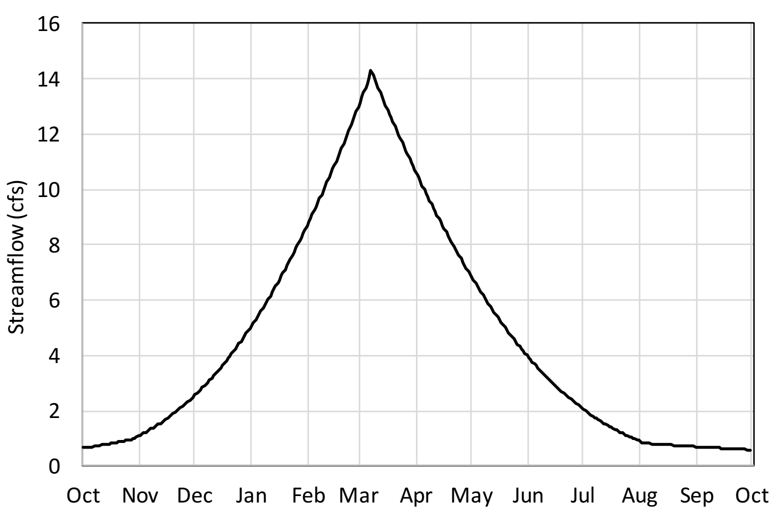

Figure 13. Streamflow baseline for a 4.99 a South Fork Sproul Creek POD constructed from the dimensionless daily average flow duration curve from the South Fork Eel River at Leggett gage (in Figure 2) and the regional exceedance baseline (in Figure 4).

Step #4: Apply a variable diversion rate as a fixed percentage of the streamflow baseline

With a streamflow baseline estimated for the Sproul Creek POD, the final step is to apply the regional variable diversion rate of 10% to the streamflow baseline, to produce a daily maximum allowable diversion rate for each day of the water year (Figure 14).

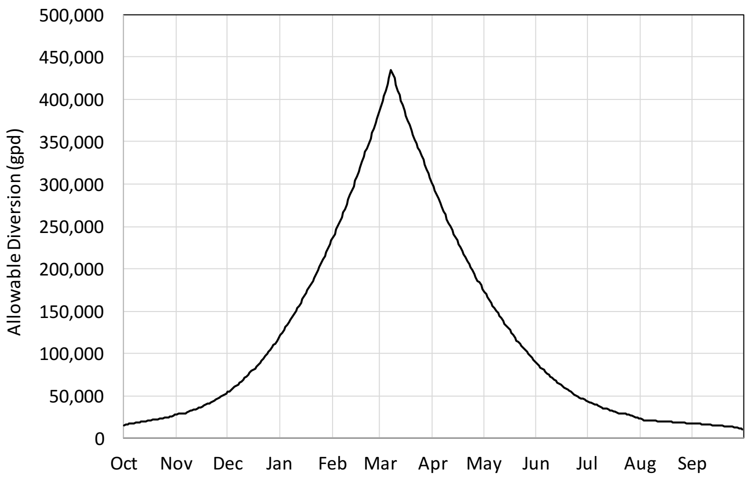

Figure 14. Maximum allowable diversion rate (in gallons per day) computed using the regional methodology for the South Fork Sproul Creek POD. The annual volume of water available for appropriation at this POD is 138 ac-ft; the minimum daily allowable diversion is 11,029 gpd.

In summary, application of a mPOF strategy to unregulated streams in Northern California would allow a fixed daily water allocation for appropriation, and would thus protect flow variability, avoid cumulative impacts of multiple independent water diversions, and maintain water quality and salmonid habitat beneficial uses. Because the method depends on a percentage of the streamflow baseline allocated for appropriation, this method can provide a reliable water supply adequate to meet water demand in most coastal watersheds. Risk associated with new water over-allocation is minimized, and water security is ensured. In addition, implementation is highly simplified, as new water users are assigned a fixed daily volume that fits within the cumulative maximum diversion rate available for allocation at any point of diversion. In this way, senior water right allocations can be met first from the available daily volume, and then new allocations can be made with the remaining available volume. Finally, this strategy is comparatively simple to implement – water users need not have access to gaging and know the ambient streamflow and do not need to conduct site specific studies.

6. NEXT STEPS: METHOD REFINEMENT AND VALIDATION

This paper has outlined a *modified Percent of Flow* strategy to protect instream flows while providing reasonable water diversion allocations in North Coast streams. To support this strategy there are several areas in which additional research or analysis may be needed. Two studies are currently underway to examine empirical relationships between fish habitat, fish behavior and change in RCT stage: the Sproul Creek Flow Study, and an Upper South Fork Eel food web, hydraulics and fish response study.

Sproul creek site-specific study to validate the 5% Riffle Crest Thalweg rule

The Sproul Creek instream flow study will be conducted in spring through fall of 2016 to test our hypothesis that the proposed variable diversion rule protects anadromous salmonid habitat and the stream ecosystem. Our study will measure riffle crest thalweg depths over a range of streamflows, as well as standard instream flow methods (PHABSIM, wetted perimeter, critical riffle analysis, and other empirical methods). Functional relationships will be developed between hydraulic controls and key ecological processes including: upstream fish passage and migration, spawning habitat availability and quality, productive BMI habitat, quality and abundance of juvenile salmonid rearing habitat, and late-summer disconnectivity. Initially seven habitat criteria will be relied upon as ecological performance measures by which to quantitatively evaluate the variable diversion rate rule.

In addition to the Sproul Creek instream flow study, additional corollary data collection will take place to (1) assess regional variation (within the SF Eel) in Q-RCT rating curves, (2) conduct a sensitivity analysis of alternative methods for obtaining an estimate of mean annual unimpaired flow, and (3) further assess the regional variability in the dimensionless flow duration curves.

Upper SF Eel River studies to investigate food web structure in response to hydraulic performance

Additional studies will be conducted in the upper mainstem SF Eel River at the UC Berkeley Angelo Reserve in spring and summer 2016. This research will evaluate how the duration and spatial extent of suitable mainstem summer-rearing habitat changes for juvenile salmonids in response to food web dynamics (current and previous winter antecedent) and hydraulic habitat metrics. Specifically, the study will investigate how seasonal changes in stream hydraulics including RCT depth and in food web structure affect salmonid density, population structure, behavior, and diet (the dependent variables). Data from this research will be synthesized descriptively, statistically, and in a bioenergetics model to address the primary research question.

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