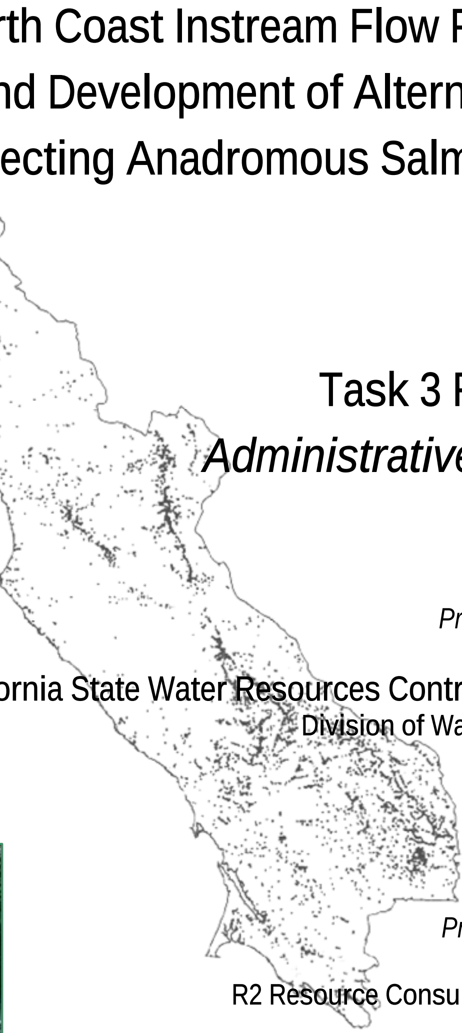
North Coast Instream Flow Policy:
Scientific Basis and Development of Alternatives Protecting Anadromous Salmonids



Task 3 Report
Administrative Draft

Prepared for:

California State Water Resources Control Board
Division of Water Rights

Prepared by:

R2 Resource Consultants, Inc.

Stetson Engineers, Inc.

August 6, 2007
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LIST OF ACRONYMS AND ABBREVIATIONS

BMI	Benthic Macro Invertebrate
CDF	California Department of Forestry
CDV	Cumulative Diversion Volume
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CFII	Cumulative Flow Impairment Index
DA	Drainage Area
DFG	California Department of Fish and Game
Division	Division of Water Rights
DP	On-Stream Dam Permitting
DS	Diversion Season
DWR	California Department of Water Resources
EIR	Environmental Impact Report
ESA	Endangered Species Acts
ESU	Evolutionarily Significant Unit
EUR	Estimated Unimpaired Runoff
FP	Fish Passage and Protection
HSPF	Hydrologic Simulation Program – Fortran
HSI	Habitat Suitability Index
MBF	Minimum Bypass Flow
MCD	Maximum Cumulative Diversion
MOC	Monitoring Oversight Committee
NCRCD	Napa County Resource Conservation District
NMFS	National Marine Fisheries Service
NPS	National Park Service
PHABSIM	Physical Habitat Simulation
POD	Point of Diversion
POI	Point of Interest
Policy	North Coast Instream Flow Policy
QA/QC	Quality Assurance/Quality Control
Q	Flow
Q_m	Unimpaired Mean Annual Flow
Q_{MBF}	Minimum Bypass Flow
R2	R2 Resource Consultants
SEC	Sonoma Ecology Center
SED	Substitute Environmental Document
State Water Board	State Water Resources Control Board
Stetson	Stetson Engineers
USGS	US Geological Survey
WUA	Weighted Usable Area

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EXECUTIVE SUMMARY

Background

The State Water Resources Control Board (State Water Board) is responsible for administering water rights in the State of California. Assembly Bill 2121 (Stats. 2004, ch. 943, §1-3) added Sections 1259.2 and 1259.4 to the California Water Code. Water Code §1259.4 (as amended in July 2005) requires the State Water Board to adopt by January 1, 2008, a policy for maintaining instream flows in coastal streams from the Mattole River to San Francisco, and in coastal streams entering northern San Pablo Bay. The policy, termed the North Coast Instream Flow Policy, (hereinafter "Policy") will be prepared and adopted in accordance with state policy for water quality control for the purposes of water right administration. In addition, the State Policy for Water Quality Control requires preparation of a Substitute Environmental Document (SED) that analyzes the potential significant adverse environmental impacts, including cumulative impacts, of the Policy.

In developing the Policy, Water Code section 1259.4 authorized the State Water Board to consider the draft "Guidelines for Maintaining Instream Flows to Protect Fisheries Resources Downstream of Water Diversions in Mid-California Coastal Streams," which were developed by the California Department of Fish and Game (DFG) and National Marine Fisheries Service (NMFS) (DFG-NMFS 2002). The DFG-NMFS (2002) Draft Guidelines were specifically developed pursuant to respective agency mandates and missions to protect and restore endangered and threatened anadromous salmonids and their habitats. The DFG-NMFS (2002) Draft Guidelines contained three elements governing restrictions on flow, and an element governing restrictions on instream barriers. The DFG-NMFS (2002) Draft Guidelines also allow, under some circumstances, for site specific studies to be conducted as a means to evaluate whether additional water diversion, the presence of an on-stream dam, and/or a reduction in protective measures can be allowed without adversely affecting anadromous salmonids and their habitat. These same four elements and the option for site-specific studies have been carried through into the development of the Policy. The Division of Water Rights (Division) currently considers the DFG-NMFS (2002) Draft Guidelines when evaluating water right applications, but the Division has not adopted them as formal State Water Board policy.

This report presents the results of an evaluation of the technical basis and rationale behind the DFG-NMFS (2002) Draft Guidelines, and assesses the regional protectiveness of Policy element alternative criteria for anadromous salmonids in the Policy area. The technical evaluation included identification and analysis of possible alternative criteria and/or refinements to the DFG-NMFS (2002) Draft Guidelines that might afford a higher level of protectiveness to anadromous salmonids at the regional level, in terms of biologically desirable instream flows and permissible diversion rates.

The alternative criteria were developed considering comments received during the California Environmental Quality Act (CEQA) scoping process and from earlier reviews of the DFG-NMFS (2002) Draft Guidelines. The alternative criteria furthermore address many of the substantive comments and recommendations made in 2000 by the State Water Board's Peer Review Panel (Moyle et al. 2000) and by Trout Unlimited (prepared by McBain-Trush; MTTU 2000) concerning the protectiveness of proposed State Water Board instream flow management guidelines that preceded the DFG-NMFS (2002) Draft Guidelines. The comments and recommendations included, notably: addressing effects of channel size on anadromous salmonid passage and spawning instream flow needs in smaller streams; basing instream flow standards on clearly defined objectives; using biological and hydrological criteria that can be expressed as testable hypotheses; developing a monitoring program that tests the hypotheses; avoiding cumulative diversion rates that adversely affect habitat downstream in the watershed; restricting on-stream impoundments only to cases where they do not affect anadromous salmonids either locally or downstream; generally operating on-stream dams to allow passage, prevent losses of fish to diversion, avoid causing cumulative effects on habitat downstream, and control exotic species; and considering the potential for future recolonization of habitat lost due to development.

Report Outline

There are ten main chapters in this report, followed by references and appendices containing more detailed supporting technical information and data.

- Chapter 1 provides background information on the Policy, its general applicability, and the target resources that are being protected.

- Chapter 2 identifies general features of protectiveness relative to instream flow needs of anadromous salmonids. Important habitat and biological needs potentially affected by the Policy are identified, and their dependence on various instream flow attributes discussed. Important flow requirements are summarized and protective metrics are identified for assessing each habitat need.

- Chapter 3 describes the four potential elements of the Policy for which protective alternatives were developed.

  Three policy elements place restrictions on the timing and amount of flow diverted:

  - Diversion Season – The period during which new diversions could be permitted without adversely affecting anadromous salmonids and their habitat.

- Minimum Bypass Flow (MBF) – The minimum instream flow rate that is protective of anadromous salmonid spawning and passage. It is the flow rate of water that must be moving past the point of diversion before water may be diverted under a permit.

- Maximum Cumulative Diversion (MCD) –The maximum amount of water, either by flow rate or volume, that may be withdrawn from a watershed by multiple diverters before new diversions begin to negatively impact the natural instream flow variability needed for maintaining adequate channel structure that protects anadromous salmonid habitat.

The last policy element places restrictions on instream barriers:

- Permitting of On-Stream Dams – Measures recommended for protection of instream flows and anadromous salmonid habitat in situations where existing unauthorized dams occur or new on-stream dams are proposed.

- Chapter 4 describes the data collection and analytical approach used to evaluate the protectiveness of the three Policy elements restricting flow.

The next four chapters describe the protectiveness of each of the four elements and include:

- Chapter 5, which describes the Policy element alternative criteria restricting diversion season, and evaluates their protectiveness.

- Chapter 6, which describes the Policy element alternative criteria restricting minimum bypass flow, and evaluates their protectiveness.

- Chapter 7, which describes the Policy element alternative criteria restricting maximum cumulative diversion rates, and evaluates their protectiveness.

- Chapter 8, which describes the Policy element alternative criteria related to the permitting of on-stream dams, and evaluates their protectiveness.

The last two chapters present further issues for protectiveness related to implementation of the Policy:

- Chapter 9 describes general fish passage and screening protection needs at diversion and dam facilities.

- Chapter 10 presents attributes and recommendations for an effectiveness monitoring program designed to assess the protectiveness of the Policy. The data gathered in the effectiveness monitoring program could be used to provide the supporting basis for future revisions to the Policy.

The information and results detailed in these chapters are summarized below. The information in this report will ultimately be integrated into the SED, where the various Policy elements will be evaluated for effects on non-target aquatic resources and other environmental resources.

Definition of Protectiveness

Because anadromous salmonid species listed under the federal and California Endangered Species Acts (ESA) inhabit the Policy area, the protectiveness of the Policy elements should be conservative (i.e., risk averse) and have broad applicability over the range of streams and channels directly or indirectly used by these species. At the same time, the Policy needs to be relatively simple to understand and apply. Attributes of instream flow and diversions that are associated with protectiveness for anadromous salmonids and that were considered in this evaluation include:

- Having flows that support important biological functions (e.g., spawning) available during the seasons they are needed.
- Providing a minimum bypass flow (below diversions) that creates suitable upstream passage, spawning, incubation, emergence, and rearing conditions.
- Allowing within- and across-year, natural flow variability to maintain suitable channel morphology, riparian habitat, and upstream/downstream passage conditions.
- Maintaining connectivity of habitats, by providing unobstructed upstream and downstream passage at dams and diversions.
- Providing protective screens to prevent loss of fish into diversion canals.
- Limiting the amount of water that can be cumulatively withdrawn from a system (both above and within the range of anadromous salmonids) to avoid or minimize impacts to downstream habitats.
- Maintaining the natural upstream to downstream transport of energy and materials (e.g., sediment, wood, food) that are important for the sustainability of anadromous salmonids and their habitats.

Methods for Analyzing the Protectiveness of Policy Element Alternative Criteria

Policy element alternative criteria were assessed for protectiveness by identifying their effects on important anadromous salmonid habitat components, including: upstream passage, spawning and incubation, juvenile winter rearing, smolt outmigration, channel and riparian maintenance, and estuarine habitat and connectivity to the Pacific Ocean. A particular flow-related alternative was considered protective if its effects on habitat components were either undetectable, meaning it caused no effect relative to unimpaired flow conditions; or minimal, meaning it would cause non-biologically significant effects relative to unimpaired flow conditions. Because the elements related to instream barriers were all directed toward protecting anadromous salmonids, the assessment of these elements was focused on the sufficiency of their protection of salmonids and their habitat.

In addition to reviewing existing literature and data related to the flow needs of anadromous salmonids and their habitat, physical and hydraulic cross-sectional data were collected from 13 streams within the Policy area in late summer of 2006. These data were used to specifically assess the effects of the flow-related elements on anadromous salmonid upstream passage and spawning habitat availability, as these two fishery attributes could be most directly related to the effects of diversion using numerical habitat-flow criteria. Impaired flow time series (i.e., with diversion) were compared with estimated unimpaired flow conditions (i.e., without diversion). This provided an estimate of the extent to which each flow-related element could affect primarily anadromous salmonid passage and spawning habitat availability, but also other habitat needs as well.

Overview of Policy Element Alternative Criteria

As described above, the proposed Policy consists of four elements intended to protect fishery resources, specifically targeting anadromous salmonids. Alternatives proposed for the three Policy elements restricting flow diversions (diversion season, minimum bypass flow, and maximum cumulative diversion) are summarized in Table 1. Alternatives proposed for the element restricting instream barriers are summarized in Table 2. Tables 3, 4, 5, and 6 summarize the relative protectiveness of each of the alternatives on a policy element-specific basis.

Table 1. Policy Element Alternatives Proposed to Restrict Diversions.

Diversion Season (DS)	Minimum Bypass Flow (MBF)	Maximum Cumulative Diversion (MCD)
DS1. 12/15 – 3/31 **DS2.** Year Round **DS3.** 10/1 – 3/31	**MBF1.** February median daily flow **MBF2.** 10% Exceedance Flow **MBF3.** Drainage Area (DA) < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$ Q_m = unimpaired mean annual flow (cfs); For streams above anadromous habitat, DA is determined at the upper limit of anadromy **MBF4.** Drainage Area < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ Drainage Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$ For streams above anadromous habitat, DA is determined at the upper limit of anadromy	**MCD1.** MCD Rate = 15% of 20% Winter (12/15-3/31) exceedance flow **MCD2.** MCD Rate = 5% of 1.5 yr flood peak flow **MCD3.** MCD Volume = 10% estimated unimpaired flow (no restriction on diversion rate) **MCD4.** MCD Rate = diversion rate which results in a maximum reduction of the time flow is above the MBF to ½ day during a 1.5 yr flood event

Table 2. Policy Element Alternative Criteria Proposed to Restrict Instream Barriers.

Stream Class	Permitting of On-stream Dams (DP)
Class I	**DP1.1** On-stream dams may not be issued water right permits. **DP1.2** New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. Fish passage and screening is provided; 2. A passive bypass system is provided to bypass the minimum instream flow requirements; 3. An exotic species eradication plan is implemented; 4. A gravel and wood augmentation plan or bypass system is implemented; and 5. Disturbed riparian habitat will be mitigated
Class II	**DP2.1** On-stream dams may not be issued water right permits. **DP2.2** New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. A passive bypass system is provided to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.

Table 2. Policy Element Alternative Criteria Proposed to Restrict Instream Barriers.

Class II (cont)	**DP2.3** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.
Class III	**DP3.1** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. The on-stream dam will not dewater a Class II stream; and 2. The on-stream dam will cause less than 10% cumulative instantaneous flow impairment at locations where fish are seasonally present. **DP3.2** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; and 3. A gravel and wood augmentation plan or bypass system is implemented. **DP3.3** A water right permit may be considered for an on-stream dam.

Diversion Season

A summary of the regional protectiveness of the diversion season Policy element alternative criteria is presented in Table 3. The protectiveness analysis indicated that water temperatures may become critical before October 1 and after March 31 and could be adversely affected by new diversions. Maintaining protective minimum bypass flow and maximum cumulative diversion criteria would preclude any adverse effects of flow diversion to anadromous salmonid habitat between October 1 and December 15.

Table 3. Summary of Protectiveness of Diversion Season (DS) Alternatives.

Policy Element: Diversion Season		
Alternative	**Regionally Protective?**	**Basis**
DS1: 12/15 – 3/31	Yes	Start date is protective of water temperatures that are suitable for summer habitat and fall upstream migration. End date avoids adverse water temperature effects on steelhead incubation and smolt outmigration.
DS2: Year Round	No	New diversions cannot be permitted during the late spring, summer, and early fall because instream flows during these periods generally limit anadromous salmonid rearing habitat quantity and quality in the Policy area.
DS3: 10/1 – 3/31	Yes	Start date is protective of water temperatures that are suitable for summer habitat and fall upstream migration. End date avoids adverse water temperature effects on steelhead incubation and smolt outmigration.
Biological Recommendation:	**Apply Alternative DS3**	

Minimum Bypass Flow

A summary of the regional protectiveness of the minimum bypass flow (MBF) Policy element alternative criteria is presented in Table 4. The protectiveness analysis indicated that the MBF provides the first level of protection for upstream passage and spawning habitat during the diversion season, whereas the maximum cumulative diversion rate provides a second order (i.e., lower) level of protection. Two of the four alternative criteria were previously identified: DFG-NMFS (2002; MBF1) and MTTU (2000; MBF2). The other two alternative criteria, MBF3 and MBF4, were developed based on a review of regional data describing upstream passage and spawning habitat-flow needs, and were considered to define upper and lower bounds of instream flow needs, respectively.

Table 4. Summary of Protectiveness of Minimum Bypass Flow (MBF) Alternatives.

Policy Element: Minimum Bypass Flow

Alternative	**Regionally Protective?**	**Basis**
MBF1: February Median Daily Flow	Partially	Protective of upstream passage and spawning habitat flow needs in streams draining more than about 5 mi^2. Under-protective in smaller streams.
MBF2: 10% Exceedance Flow	Partially	Protective of upstream passage and spawning habitat flow needs in streams draining more than about 4 mi^2. Under-protective in smaller streams.
MBF3: Drainage Area (DA[1]) < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$ Q_m = unimpaired mean annual flow (cfs); For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	Yes	Generally protective of upstream passage and spawning habitat flow needs across a wide variety of stream sizes in the region. Protects winter rearing habitat as well. Does not affect outmigration, channel and riparian maintenance, and estuarine habitat flow needs.
MBF4: Drainage Area < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ Drainage Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$ For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	No	Protective of upstream passage and spawning habitat flow needs in some streams, but a majority of streams in the region are under-protected with respect to upstream passage and spawning habitat flow needs for steelhead and coho. Appears to under-protect Chinook upstream passage and spawning habitat flow needs in nearly all streams. In all cases, the MBF is sufficiently low that adverse effects could occur to upstream passage and spawning opportunities even with small diversion rates.
Biological Recommendation:	**Apply Alternative MBF3**	

[1] Drainage area (DA) is evaluated in square miles.

Maximum Cumulative Diversion Rate

A summary of the regional protectiveness of the maximum cumulative diversion (MCD) Policy element alternative criteria is presented in Table 5. The analysis of protectiveness suggested that the MCD element has the greatest effect on channel and riparian maintenance conditions. The analysis indicated, however, that there is no clear guidance for specifying a protective flow threshold level of MCD with respect to avoiding changes to channel morphology that would adversely impact salmonid habitat. The change in channel morphologic response was predicted to occur roughly proportionally to the change in the bankfull flow rate resulting from the MCD (approximated by the change in the 1.5 year peak flow event). However, the level of change in channel morphologic response that would adversely affect salmonid habitat and production potential could not be determined with certainty. Therefore, in the absence of a clearly defined protective flow threshold level for channel and riparian maintenance, no additional alternative MCD criteria were developed. Instead, the MCD criteria proposed by DFG-NMFS (2002) and MTTU (2000) were assessed for protectiveness. Assessment of protectiveness was based on the relative changes to channel morphology and effects on upstream passage and spawning habitat.

Restrictions on Permitting of On-Stream Dams

The DFG-NMFS (2002) Draft Guidelines recommended against permitting on-stream dams on streams that are classified as Class I or II pursuant to the California Department of Forestry (CDF) stream classification system. In general, the analysis completed as part of this study indicated that on-stream dams are not protective of anadromous salmonids unless they are constructed in such a way that they do not: (1) impede upstream or downstream passage where appropriate, (2) interrupt the downstream transport of bedload or larger pieces of wood during high flows, (3) provide habitat for non-native, exotic aquatic species that compete with or prey on juvenile salmonids, and (4) cause increased water temperatures downstream. The DFG-NMFS (2002) Draft Guidelines and selected variations thereof were considered for their protectiveness (Table 6).

Fish Passage and Protection Measures

The analysis of protectiveness concurred with general conclusions of the DFG-NMFS (2002) Draft Guidelines regarding the importance and protectiveness of requiring fish passage and screening requirements as part of diversions.

Table 5. Summary of Protectiveness of Maximum Cumulative Diversion (MCD) Alternatives.

Policy Element: Maximum Cumulative Diversion		
Alternative	**Regionally Protective?**	**Basis**
MCD1 (Rate): MCD Rate = 15% of 20% Winter (12/15-3/31) Exceedance Flow	Yes	Generally allows the lowest instantaneous rate of diversion. Likely results in negligible channel change over the long term.
MCD2 (Rate): MCD Rate = 5% of 1.5 yr flood peak flow (annualized series)	Yes	Allows a higher instantaneous rate of cumulative diversion than MCD1 and MCD4. This alternative will likely result in long term adjustment and reduction in channel size, but the potential change is thought to be minor in terms of bankfull width, depth, and surface grain size distribution. Basing a MCD rate on the 1.5 year flood peak flow rate more directly accounts for the relation between channel size and instream flow need.
MCD3 (Volume): MCD Volume = No restriction on diversion rate, stop diversion after the ratio of total cumulative diverted volume to unimpaired runoff volume = 10%	Partially	May not be protective of coho and Chinook upstream passage and spawning habitat flow needs during the first month of the diversion season (for DS1 or DS3) in dry and average years. May not be protective of channel maintenance flow needs. Protectiveness is related more defensibly to flow rate rather than volume.
MCD4 (Rate): MCD Rate = Diversion rate that corresponds to a half-day reduction in the duration of time that flow is above the MBF during a 1.5 year flood event	Yes, but impractical to apply	Provides a comparable level of instantaneous diversion rate to MCD1 (15% of 20% winter exceedance flow). Likely results in negligible channel change over the long term. Impractical because its implementation requires detailed hourly hydrograph information for each stream.
Biological Recommendation:	**Apply Alternative MCD2.** There is uncertainty in defining the maximum amount of change in channel maintenance flows that could occur that would still be protective of anadromous salmonid habitat. Regardless of which MCD alternative is chosen for the Policy, effectiveness monitoring data collected over a period of 10 to 20 years would be needed to assess whether the Policy could be reopened in the future to include a less restrictive MCD that would still be protective of channel maintenance flows while offering the opportunity for higher diversion rates.	

Table 6. Summary of Protectiveness of the On-Stream Dam Permitting Restrictions (DP) Alternatives.

Policy Element: Restriction of On-Stream Dams/Reservoirs			
Stream Class	**Alternative**	**Regionally Protective?**	**Basis**
Class I	**DP1.1**		
	On-stream dams may not be issued water right permits.	Yes	DFG-NMFS (2002) Guidelines
	DP1.2		
	New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. Fish passage and screening is provided; 2. A passive bypass system is provided to bypass the minimum instream flow requirements; 3. An exotic species eradication plan is implemented; 4. A gravel and wood augmentation plan or bypass system is implemented; and 5. Disturbed riparian habitat will be mitigated.	Partially – dependent on success of mitigation measures	Although this alternative allows some existing on-stream dams on Class I streams to receive water right permits, it contains criteria to mitigate existing adverse impacts to anadromous salmonids and protect and/or restore important ecosystem functions to those streams.
Class II	**DP2.1**		
	On-stream dams may not be issued water right permits.	Yes	DFG-NMFS (2002) Guidelines
	DP2.2		
	New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. A passive bypass system is provided to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.	Yes	Although this alternative allows some existing on-stream dams on Class II streams to receive water right permits, it contains criteria design to protect and/or restore important ecosystem functions to those streams and still afford a high level of protectiveness.

Table 6. Summary of Protectiveness of the On-Stream Dam Permitting Restrictions (DP) Alternatives.

Class II (cont)	**DP2.3** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.	Partially	Multiple on-stream dams on Class II streams have potential to cause adverse cumulative effects on downstream spawning and rearing habitat quantity and quality in Class I streams.
Class III	**DP3.1** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. The on-stream dam will not dewater a Class II stream; and 2. The on-stream dam will cause less than 10% cumulative instantaneous flow impairment at locations where fish are seasonally present.	Partially	DFG-NMFS (2002) Guidelines Protectiveness could be increased via inclusion of additional fish protection measures as provided in DP 3.2.
	DP3.2 A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; and 3. A gravel and wood augmentation plan or bypass system is implemented.	Yes	This alternative contains criteria that must be met before on-stream dams would be allowed on Class III streams. The criteria are designed to protect and/or restore important ecosystem functions, and provide an additional level of protectiveness not provided by the DFG-NMFS (2002) Guidelines.
	DP3.3 A water right permit may be considered for an on-stream dam.	Partially	With no restrictions imposed, cases would likely occur where protectiveness would not be assured. Multiple on-stream dams built without restrictions on Class III streams are likely to cause adverse cumulative effects on downstream spawning and rearing habitat quantity and quality in Class I and II streams.
Biological Recommendation:		**Apply DP1.1, DP2.2 and DP3.2**	

Site-Specific Studies

Site-specific studies provide the most detailed and accurate information regarding instream flow needs for a particular stream. Such studies can be conducted by applicants seeking to adjust/reduce specific restrictions of diversion that are imposed by various Policy elements. Site-specific studies should be designed in consultation with and approved by applicable state and federal resource agencies including the California Department of Fish and Game, and the National Marine Fisheries Service. The results of such studies could then be evaluated by respective resource agencies to determine whether and to what extent adjustments could be made to the Policy elements in question.

Effectiveness Monitoring Recommendations

The protectiveness analyses suggested certain levels or attributes of each Policy element that are protective of anadromous salmonids and their habitat. Once the Policy is implemented, the next step would be to initiate a monitoring program to evaluate the effectiveness of the Policy for protecting anadromous salmonids. The effectiveness monitoring program described in this report is designed to assess the effectiveness of the Policy elements that are aimed at maintaining minimum bypass flows, protecting natural flow variability, and avoiding cumulative impacts. Nine steps are recommended and described for establishment of the effectiveness monitoring program, and a study design outline is provided as a guide to the approximate level of effort that may be required for its implementation. The final design of the effectiveness monitoring program will reflect technical input from a Monitoring Oversight Committee and the availability of funds.

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1. INTRODUCTION

1.1 BACKGROUND AND PURPOSE

The State Water Resources Control Board (State Water Board) is responsible for administering water rights in the State of California. The State Water Board's mission is to preserve, enhance and restore the quality of the State's waters, and ensure their proper allocation and efficient use for present and future generations. In administering the water right process, the State Water Board's Division of Water Rights (Division) must consider the effects of its actions on the public trust, the public interest, and the environment, including adverse impacts on threatened and endangered species (SWRCB 2005).

Assembly Bill 2121 (Stats. 2004, ch. 943, §1-3) added sections 1259.2 and 1259.4 to the California Water Code. Water Code section 1259.4 (as amended in July 2005) requires the State Water Board to adopt by January 1, 2008, a policy for maintaining instream flows in coastal streams from the Mattole River to San Francisco, and in coastal streams entering northern San Pablo Bay. The policy, termed the North Coast Instream Flow Policy, (hereinafter "Policy") will be prepared and adopted in accordance with state policy for water quality control for the purposes of water right administration.

The State Water Board consequently contracted in May 2006 with a team led by Stetson Engineers (Stetson), and including R2 Resource Consultants (R2) to help develop the Policy and supporting technical and environmental documents. The Stetson Team is in the process of assisting the State Water Board in preparing the Policy, in accordance with Water Code section 1259.4. The State Policy for Water Quality Control requires preparation of a Substitute Environmental Document (SED) that analyzes the potential significant adverse environmental impacts, including cumulative impacts, of the Policy. The SED replaces an Environmental Impact Report (EIR), pursuant to Public Resources Code section 21080.5. The SED must include, at a minimum, a Policy description, Policy alternatives, and mitigation measures to avoid or reduce the Policy's effects on the environment (SWRCB 2005).

In developing the Policy, Water Code section 1259.4 authorizes the State Water Board to consider the draft "Guidelines for Maintaining Instream Flows to Protect Fisheries Resources Downstream of Water Diversions in Mid-California Coastal Streams," which were developed by the California Department of Fish and Game (DFG) and National Marine Fisheries Service (NMFS) in 2002, referred to from here forward as the "DFG-NMFS (2002) Draft Guidelines." The DFG and NMFS recommended that permitting agencies (including the State Water Board), planning agencies, and water resource development interests use the DFG-NMFS (2002) Draft Guidelines when evaluating proposals to divert and use water from northern California coastal streams. The DFG-NMFS (2002) Draft Guidelines were specifically developed pursuant to respective agency mandates and missions to protect and restore endangered and threatened anadromous salmonids and their habitats (DFG-NMFS 2002). The Division currently considers the DFG-NMFS (2002) Draft Guidelines when evaluating water right applications, but they have not been adopted as formal State Water Board policy (SWRCB 2005).

As part of the overall Policy review process, the Division requested that Stetson and R2 evaluate the technical basis and rationale behind the DFG-NMFS (2002) Draft Guidelines and assess its overall protectiveness to anadromous salmonids (i.e., steelhead trout [*Oncorhynchus mykiss*], coho salmon [*O. kisutch*], and Chinook salmon [*O. tshawytscha*]), which are the target aquatic resources for which the DFG-NMFS (2002) Draft Guidelines were developed. In addition, the State Water Board requested that Stetson-R2 evaluate the technical basis and level of resource protectiveness provided by other alternative criteria, and document the science forming the basis. The evaluation included identification and analysis of possible alternative criteria and/or refinements to the DFG-NMFS (2002) Draft Guidelines that might afford a broader, regional level of protectiveness and restoration potential to the target resources in more streams, in terms of biologically desirable instream flows and permissible diversion rates. Alternative criteria were developed based on comments received during the California Environmental Quality Act (CEQA) scoping process and from earlier reviews of the DFG-NMFS (2002) Draft Guidelines.

Given the focus by DFG and NMFS on anadromous salmonids as the target resource based on requirements of the Endangered Species Act (ESA), the emphasis of this report is on the technical evaluation of the levels of protectiveness offered these species by various Policy elements alternatives. The elements, described in Section 1.4, provide a clearly defined framework for evaluating the benefits of implementing the Policy on anadromous salmonids. Use of the elements as a framework for evaluation is consistent with the history of the development of the DFG-NMFS (2002) Draft Guidelines, which is summarized in Appendix A.

This report is organized as follows:

- Chapter 1 provides important background information on the Policy purpose and applicability.
- Chapter 2 summarizes the important flow needs for anadromous salmonids and their habitat, and identifies specific quantitative criteria or other indirect measures used in assessing protectiveness.
- Chapter 3 identifies specific elements of the Policy, alternative criteria considered for each element, and how they were formulated.

- Chapter 4 describes the analytic methods and results of the evaluation of protectiveness of Policy elements restricting flow diversion.
- Chapter 5 discusses the protectiveness of alternative criteria identified for the Policy diversion season element.
- Chapter 6 discusses the protectiveness of alternative criteria identified for the Policy minimum bypass flow element.
- Chapter 7 discusses the protectiveness of alternative criteria identified for the Policy maximum cumulative diversion element.
- Chapter 8 discusses the protectiveness of alternatives identified for the Policy on-stream dam permitting element.
- Chapter 9 discusses the protectiveness of providing for fish passage and screening.
- Chapter 10 describes an effectiveness monitoring program designed to assess the protectiveness of the Policy.
- Chapter 11 is the list of references used in the report and appendices.
- Eleven appendices describe technical details and supporting references relied on in the main report.

The information in this report will ultimately be integrated into the SED, where the various Policy elements will be evaluated for effects on other non-target aquatic resources.

1.2 SPATIAL APPLICABILITY OF THE POLICY

The Policy area encompasses coastal and inland channels located in Marin, Sonoma, and portions of Napa, Mendocino, and Humboldt counties (Figure 1-1). The Mattole River constitutes the northern-most coastal basin under consideration, and the Napa River the eastern-most basin draining into San Pablo Bay. Major coastal salmon and steelhead stream basins from north to south include the Mattole, Ten Mile, Noyo, Big, Navarro, Garcia, Gualala, Russian, Walker, and Lagunitas drainages. Major salmon and steelhead stream basins draining to San Pablo Bay include Sonoma Creek and the Napa River. There are also numerous smaller basins draining directly into the Pacific Ocean and San Pablo Bay that either currently or historically supported anadromous salmonids. Policy area streams range widely in size as well as geologic, geomorphic, hydraulic, hydrologic, and biologic characteristics. Such characteristics manifest themselves in streams that differ in channel size, channel slope, valley

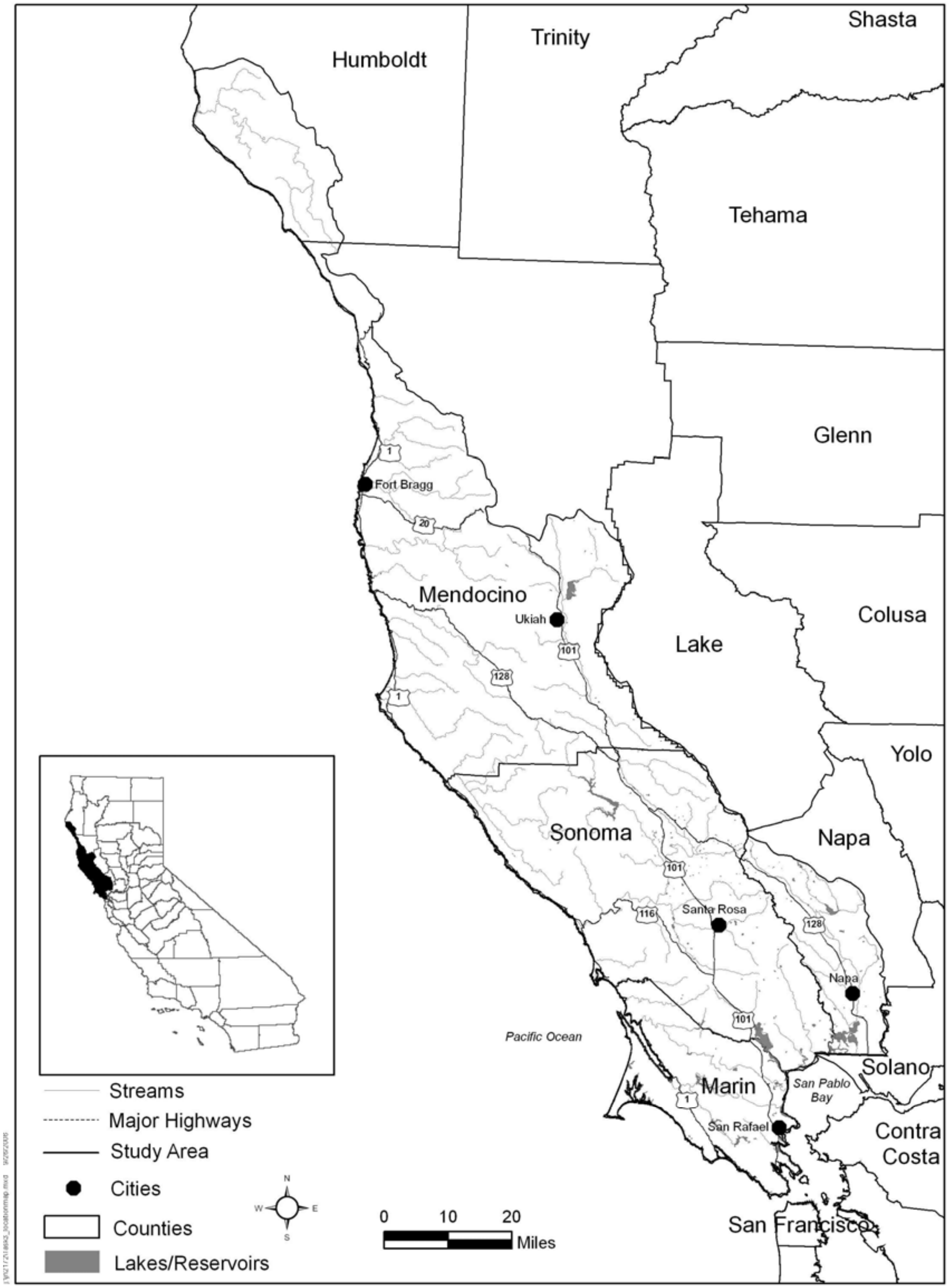

Figure 1-1. Policy area, pursuant to Water Code §1259.4, as required by Assembly Bill 2121.

confinement, channel incision, topographic relief, soil type, hillslope and riparian vegetation, annual precipitation, and other abiotic and biotic features. As such, they present a variety of channel conditions that may be utilized by anadromous salmonids over a range of temporal and spatial scales that render coincident flow responses highly variable. Specific physical features of the Policy area influencing stream flow and fish habitat are described in greater detail in Appendix B.

The Policy likely will set restrictions on diversions in the Policy area that are conservatively protective for anadromous salmonids and their habitat. These restrictions may be superseded on a case-by-case basis if a site-specific study can demonstrate, for example, that higher water usage or a watershed-based approach used to coordinate usage amongst diverters to maximize water usage would still be protective of anadromous salmonids and their habitat.

There is no distinction made in the analysis of the protectiveness of the Policy concerning the value of different streams containing historical habitat for anadromous salmonids. The NMFS follows a similar principle when establishing critical habitat ranges. Critical habitat is defined under Section 3 of the ESA as (1) specific areas within the geographical area occupied by the species at the time of listing, on which are found those physical or biological features that are essential to the conservation of the listed species and that may require special management considerations or protection, and (2) specific areas outside the geographical area occupied by the species at the time of listing that are essential for the conservation of a listed species (70 FR 52488). Establishing equal importance to critical habitat in different streams recognizes (1) the species' use of diverse habitats and underscores the need to account for all of the habitat types supporting the species' freshwater and estuarine life stages, from small headwater streams to migration corridors and estuarine rearing areas, and (2) the importance of natural variability in habitat use (e.g., some streams may have fish present only in years with abundant rainfall, whereas other streams may have better spawning habitat conditions during dry years) (65 FR 7764). Federal regulations further provide that unoccupied areas be designated when the present range would be inadequate to ensure the conservation of the species (50 CFR 424.12(e)). Similar fundamental principles apply to permitting of water right applications in a protective manner under the Policy. In view of the multitude of impacts to anadromous salmonids listed under the ESA and the degraded condition of populations that warrant listing, as broad an area should be protected as possible (as logically conditioned by historical range limits) to buffer against or offset temporary reductions in stock size that may occur locally. This need in part reflects uncertainty in the precise amount of habitat needed to sustain anadromous salmonid species in the Policy area, and uncertainty in the complex relations between minimum viable population size, habitat conditions and carrying capacity, and instream flows (e.g., Castleberry et al. 1996; IFC 2002). It also reflects the need to maintain diversity of habitat and flows for sustaining healthy aquatic ecosystems (Poff et al. 1997).

1.2.1 Applicability Upstream of Passage Barriers

Questions were raised during the CEQA scoping process regarding whether restrictions on diversion and on-stream dams need to be applied to streams above existing upstream passage barriers caused by human actions. For example, comments dated September 15, 2006, by Wagner & Bonsignore Consulting Civil Engineers, James C. Hanson Consulting Civil Engineer, and the law firm Ellison, Schneider & Harris L.L.P. (Consulting Engineers), included a recommendation to limit restrictions on diversions to streams only where anadromous fish and habitat are currently sustainable.

There are numerous artificial barriers that have influenced historical distribution. Figure 1-2 depicts potential structural barriers identified by CalFish in their Passage Assessment Database [http://www.calfish.org]. These potential barriers include points of diversions which are usually assigned an unknown barrier status. Lifting Policy limitations above structural barriers would not be protective of the anadromous salmonid resource if the possibility exists that historically accessible habitat will be re-opened by correction of passage barriers. This has proven to be an effective, high-return method for restoring anadromous salmonid populations elsewhere (e.g., Roni et al. 2002).

Efforts have been made, and will likely continue, to inventory and characterize passage barriers throughout the Policy area, with the eventual goal of restoring runs upstream. For example, fish passage barrier surveys conducted by the Sonoma Ecology Center (SEC) in the Sonoma Creek watershed identified over 100 potential man-made barriers, including 23 full barriers and 48 partial (flow-dependent) obstacles to passage. Habitat was estimated to have been lost in approximately 170 miles of stream length due to barriers, amounting to approximately 25% of stream length in the freshwater portion of the Sonoma Creek watershed. It was hypothesized that the potential maximum fish population supported by available habitat may be reduced to a similar degree (SEC et al. 2004). Elsewhere, Taylor et al. (2003) visited 545 stream crossing sites and surveyed 183 of them for their potential as passage barriers in the Russian River watershed. They created a ranked list of 125 crossings for use by DFG in prioritizing the order in which specific barriers should be corrected. RTA (2003) similarly visited and assessed passage conditions at 90 sites in Marin County.

In summary, current trends in fisheries management within the Policy area are to identify and correct passage barriers caused by human actions. Once barrier problems are corrected, it is likely that efforts will be undertaken to subsequently improve habitat conditions above the former barrier location (e.g., DFG 1996; Flosi et al. 1998; DFG 2002; Roni et al. 2002; DFG 2004). Hence, the Policy should also apply above existing barriers to stream reaches potentially supporting anadromous salmonids, or that influence flow and habitat in such downstream reaches, in anticipation of restored runs in the future.

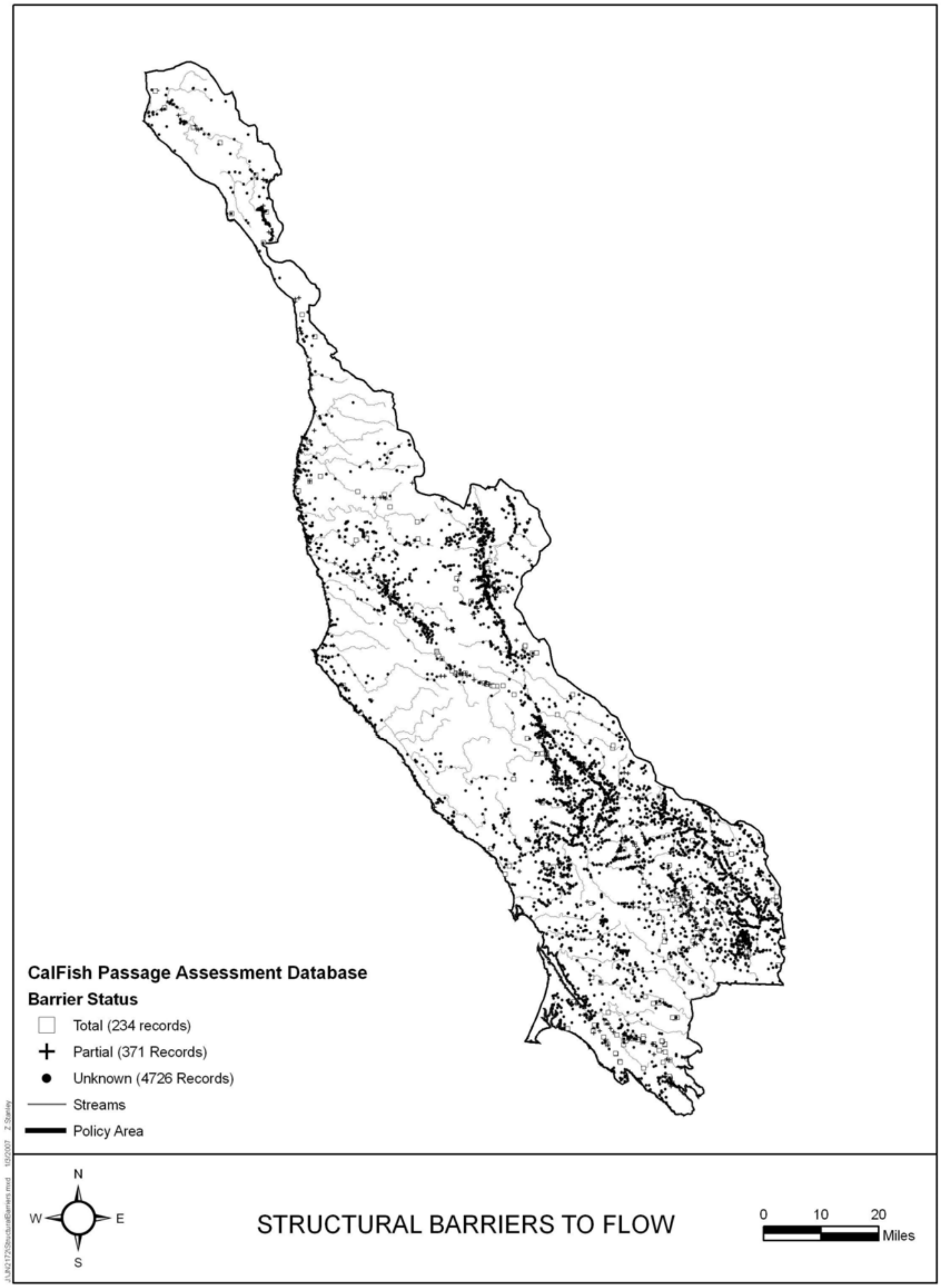

Figure 1-2. Potential fish passage barriers identified in CALFISH for the Policy Area.

1.2.2 Applicability to Ephemeral Streams

A similar question was raised in the scoping comments regarding the protection of winter flows in ephemeral streams. Studies have shown that even relatively small, ephemeral streams (i.e., streams that flow seasonally or in response to storm events, but that typically become dewatered or dry during a portion of the year) have been used for spawning and rearing by anadromous salmonids. In these instances, adult fish move into and spawn within the streams when they contain flow, and assuming flows remain sufficient throughout egg incubation and fry emergence, then, as flows recede, newly emerged fry move downstream to larger systems where flow conditions are more suitable for rearing. For example, steelhead trout are capable of spawning in tributaries in the Policy area that dry up in summer, where fry emigrate downstream soon after hatching (Moyle 2002). Juveniles may also move up into tributaries to overwinter and then emigrate in the spring before the stream dries up. Coho salmon juveniles for example have been observed to use ephemeral tributaries for over-winter rearing (e.g., Ebersole et al. 2006). For these reasons, and because of potential cumulative effects of upstream diversion on downstream flows and gravels, ephemeral streams also require flow protection.

1.2.3 Stream Classification for Defining Spatial Applicability of Policy Elements

The spatial applicability of specific Policy elements will depend in part on the type of stream channel potentially affected by granting an application for water right. There are correspondingly two important implementation issues for the Policy related to the type of stream concerned: (1) Which streams the Policy should be applied to in order to be protective toward anadromous salmonids, and (2) whether different stream types (or classes) require different levels of protection depending on location in the channel network and biological characteristics. These types of issues have been and can be addressed by the use of a stream classification system. Such a system can be identified here for purposes of implementing the Policy and protecting anadromous salmonids. The DFG-NMFS (2002) Draft Guidelines referenced an existing system developed by the California Department of Forestry (CDF; Cal. Code Regs., tit. 14, section 916.5, Table 1) which defines three stream type classes. Appendix D includes a review of issues related to stream classification in the context of setting protective instream flow standards, in which it was concluded that the CDF classification system can be used with the addition of clarifying language including distinguishing between anadromous and non-anadromous fish species. The corresponding stream classification definitions given in Section 916.5, Table 1 are as follows:

- Class I – Fish always or seasonally present onsite, includes habitat to sustain fish migration and spawning;

- Class II – Fish always or seasonally present offsite within 1,000 feet downstream and/or aquatic habitat for non-fish aquatic species; excludes Class III waters that are tributary to Class I waters;
- Class III – No aquatic life present, water course showing evidence of being capable of sediment transport downstream to Class I or Class II waters under normal high water flow conditions.

1.3 ANADROMOUS SALMONID SPECIES OF CONCERN

There are three anadromous species of concern found in the Policy area: steelhead trout, coho salmon, and Chinook salmon. Of these, steelhead trout have the broadest, and Chinook salmon the narrowest historical distribution. Current distributions are much reduced over historical extents because of habitat degradation, habitat loss, and other factors caused by human settlement and development. For purposes of the Policy, it was assumed that historically available habitat could become useable again through appropriate habitat restoration, and implementation of improved land and water management practices. It is because of the currently low population numbers that NMFS and DFG have listed various Evolutionarily Significant Units (ESUs) of each species as threatened, endangered, and/or species of concern within the Policy area, as defined under the federal Endangered Species Act (ESA), and/or the California Endangered Species Act (CESA). Critical habitat designations by NMFS indicate the likely range that could support salmonid populations. Actions adversely affecting critical habitat cause "take" as defined under the ESA.

The important general features of the three species' life histories and distributions that may be affected by implementation of the Policy are summarized in Appendix C.

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2. PROTECTING ANADROMOUS SALMONID HABITAT FLOW NEEDS

The State Water Board has continuing authority to protect public trust uses and to prevent the waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water in the state, regardless of basis of right. Accordingly, the State Water Board must carefully consider and decide on the appropriate level of resource protectiveness that must be achieved (to meet its public trust responsibilities) via Policy adoption and implementation. In the case of anadromous salmonids, this is a difficult proposition and requires an understanding of important life history functions and flow dependence. A review of the literature on this is provided in Appendix D which includes an overview of the issues and problems related to defining and quantifying protective instream flow levels. Specific flow-related criteria are reviewed and selected for analysis in Appendix G. This chapter summarizes instream flow requirements and criteria of anadromous salmonids for each important life history stage potentially influenced by winter diversions under the Policy. It has previously been shown that new diversions cannot be permitted during the late spring, summer, and early fall because instream flows during this period are generally limiting anadromous salmonid rearing habitat quantity and quality in the Policy area (e.g., SEC et al. 2004).

2.1 UPSTREAM PASSAGE FLOW NEEDS

Adult salmonids returning to streams to spawn must do so at the proper time and with sufficient energy to complete their life cycle (Bjornn and Reiser 1991). Delays in migration may impact at least a portion of the spawning population and lead to reduced egg and fry production. Upstream migration appears generally to coincide with the decline in flow following a runoff event, and thus it is the occurrence of a flow pulse that appears to be most important, not necessarily its magnitude. Furthermore, the requisite magnitude of attraction flow to the mouth of a stream may be larger than the minimum passage flow, but its magnitude is uncertain (SWRCB 1995).

In general, the degree to which stream flow conditions may become problematic to upstream migrating adults relates directly to their migration period. Thus, stocks that migrate during the late fall and winter under high stream flow conditions (e.g., winter steelhead) would be less likely to encounter flow related impediments, than stocks that migrate in late summer or early fall, such as Chinook salmon. The approximate dates of upstream passage for anadromous salmonid species in the Policy area, coinciding with the proposed range of Policy diversion season element alternative criteria defining the winter diversion season, are (see Chapter 3 and Appendices C and G):

Steelhead:	11/1 – 3/31
Coho:	10/1 – 2/28
Chinook:	10/1 – 1/31

The level of flow necessary for upstream passage through shallow water constrictions depends on the ability of fish to negotiate specific water depths. This ability reflects predominantly body size, with larger bodied Chinook requiring deeper water than smaller bodied coho salmon. Criteria for critical depths needed for successful upstream passage are discussed in detail in Appendix G. Table 2-1 presents summary upstream passage criteria considered applicable to evaluating protectiveness of the Policy for the three anadromous species of concern.

Table 2-1. Minimum Upstream Passage Depth Criteria for Analyzing the Protectiveness of the Policy for Upstream Passage Needs (see Appendix G for sources).

Species	**Minimum Passage Depth Criterion (ft)**
Steelhead	0.7
Coho	0.6
Chinook	0.9

In addition to riffle constrictions, physical barriers such as waterfalls, debris jams, and diversion structures can delay or prevent upstream migration of adults. Low stream flow can directly influence the passage conditions at potential barriers, but the flow needed for upstream passage is highly specific to site geometry, more so than riffle passage. It is generally not feasible to develop a regional policy protecting passage over such obstructions without collecting extensive data, and thus it must be assumed that a Policy protecting riffle passage at the regional scale will also protect upstream passage over select channel obstructions.

Other anadromous salmonid habitat needs influenced by instream flow include cover, water temperature, dissolved oxygen, and turbidity. These needs are discussed in Appendix D. They are generally assumed to be associated with secondary effects of flow diversion during the winter compared with flows needed for sufficient passage depth.

2.2 SPAWNING AND INCUBATION HABITAT FLOW NEEDS

Flow is an important influence on the reproductive capacity of anadromous salmonid populations. The conditions that exist during the period in which eggs are deposited in the gravels, embryos incubate and hatch, and fry subsequently emerge can be primary determinants of year-class-strength and the ultimate numbers of fish that may be recruited into the population. Spawning and egg incubation success is dependent on both the quantity and quality of spawning habitat, both of which are modified by the amount of stream flow.

Stream flow influences the amount of spawning habitat available within a stream by determining the extent to which spawning gravels are wetted with suitable combinations of water depth and velocity. Embryos in redds constructed closer to the channel thalweg may under certain circumstances be more vulnerable to effects of scour and fine sediment deposition than embryos in redds constructed higher up on the cross-section. Large decreases in stream flow can result in redd dewatering. Low winter flows may also expose eggs to freezing temperatures. Adverse effects include reduced embryo growth and alevin size, accelerated or delayed hatching and emergence depending on temperature, and mortality.

Stream flow also plays an important role in providing and maintaining the quality of the spawning gravels. High flows mobilize and transport fine sediments from spawning gravels, which increased gravel permeability and facilitates transport of oxygen to, and metabolic wastes from the developing embryos.

In addition to incubation duration, the timing of spawning of salmon and trout in streams is also closely linked to water temperatures. In the streams within the mid-California coastal area, water temperatures are important determinants of when fish spawn, how long the eggs incubate (development is directly related to water temperature), and when fry emerge. Flow diversion can lead directly and indirectly to thermal alteration due to changes in flow and condition of the riparian zone. The approximate dates of peak spawning by anadromous salmonid species in the Policy area, coinciding with the proposed range of Policy diversion season element alternative criteria defining the winter diversion season, are (see Chapter 3 and Appendices C and G):

Steelhead: 12/1 – 3/31
Coho: 11/1 – 2/28
Chinook: 11/1 – 1/31

The level of flow necessary for spawning reflects the size of the fish and other factors that influence habitat selection including depth, velocity, and spatial distribution and quantity of suitably-sized spawning gravel. Depths and velocities must be suitable over areas with suitable gravel at the correct time. Depth is generally limiting only in terms of shallowness, whereas there are lower and upper limits to suitable velocities for spawning. The criteria vary with species. As for upstream passage, larger bodied Chinook require deeper water than smaller bodied coho salmon. Criteria for critical depths and velocities needed for successful spawning are discussed in detail in Appendix G. Table 2-2 presents summary depth and velocity criteria considered applicable to evaluating protectiveness of the Policy alternatives for the three anadromous species of concern.

Table 2-2. Minimum Depth, Favorable Velocity, and Substrate Spawning Criteria for Analyzing the Protectiveness of the Policy for Spawning Habitat Needs (see Appendix G for sources).

Species	Minimum Depth (ft)	Favorable Velocities (ft/s)	Useable Substrate D_{50} (mm)
Steelhead	0.8	1.0-3.0	12-46
Coho	0.8	1.0-2.6	5.4-35
Chinook	1.0	1.0-3.0	11-78

The general number of days for spawning and incubation in the Policy area are presented in Table 2-3. It can be seen in the table that embryos in redds constructed in late winter/early spring generally emerge sooner after fertilization than from redds constructed earlier in the winter. This is because of increasing water temperatures in the late winter/early spring. The data used to generate these criteria are discussed in Appendix G.

Table 2-3. Summary of General Lengths of Incubation Time and Maximum Intragravel Residence Time from Initiation of Spawning to Emergence for Anadromous Salmonids in the Policy Area. The Total Duration Numbers were Used in the Analysis (see Appendix G for sources).

Species	Approximate Time to Emergence From Fertilization (days)		Total Duration of Vulnerability to Dewatering (days)	
	Nov 1–Feb 28	Mar 1–April 30	Nov 1–Feb 28	Mar 1–April 30
Steelhead	60	47	65	52
Coho	75	62	80	67
Chinook	90	70	95	75

2.3 JUVENILE WINTER REARING HABITAT FLOW NEEDS

The habitats that constitute rearing areas are diverse and perhaps more complex than any other life history stage. For some stocks of salmon and trout, the upper drainages represent spawning and initial rearing areas, where fry and juveniles can grow in relatively protected areas that are generally free from large predators, and that contain excellent water quality characteristics. The conditions afforded to fry and juvenile anadromous salmonids in many instances establish the overall carrying capacity of the stream and therefore factor directly into defining numbers of returning adults. Stream flow is an important determinant of the capacity of a stream to support a certain number of juvenile salmonids, through the direct influence on the distribution and quantity of water depths and velocities utilized by fry and juvenile salmonids, particularly at lower base flows when physical living space becomes limiting.

Water depths used by rearing salmonids can be quite variable depending on the factors associated with such depths, e.g., substrates, cover, food, velocity, predator density. Newly hatched fry often utilize the extreme edge habitats of a stream where velocities are low and there are few predators. As salmonid juveniles grow they are capable of using deeper waters with limits of use generally related to some other interrelated parameter such as velocity. Shifts in velocity usage by fish have also been observed seasonally, presumably in response to increased water flows and decreases in water temperature. The shifts are generally from higher velocities in the summer feeding periods to lower velocities during the winter holding periods. During these periods, coho salmon have been observed moving into side channels, alcoves and beaver ponds containing large woody debris for cover and overwintering habitat. The availability of high flow can influence accessibility to such habitat.

High flows are also important for maintaining juvenile habitat quantity and quality, through channel maintenance and flushing flows. In addition to transporting sediments from pools and cobble areas used for rearing and over-wintering, and riffles serving as food production areas, high flows are necessary to create habitat-structure in the form of large wood and boulder deposits. High flows are also needed to inundate riparian and floodplain vegetation that serve to increase bank stability, provide shade and contribute allochthonous (out of stream) materials/nutrients to the stream.

Rearing habitat locations are more widely dispersed in a stream network than passage, and spawning habitat locations and instream flow needs for juvenile salmonids are correspondingly more difficult to quantify. Specific types of rearing habitats, such as side channels in larger rivers, tend to have the most specific flow requirements at which they become connected with the main channel and experience flow-through. Such habitat can be especially important in larger channels for all three species. However, this and other types of rearing habitat are also more difficult to analyze for suitable instream flows because of scale-related effects where fish size is much smaller than channel size, such that depth-averaged velocities may not be a reasonable approximation of what juveniles are selecting.

Experience with Physical Habitat Simulation (PHABSIM) and other flow assessment methods indicates that minimum instream flows for juvenile salmonids as defined by depth and velocity distributions tend to be lower than minimum instream flows for adults and spawning, irrespective of channel size (Vadas 2000; R2 2004). Hence, for this analysis, it was assumed that flows that meet spawning habitat criteria will also provide sufficient water to protect juvenile rearing habitats.

2.4 OUTMIGRATION FLOW NEEDS

There is evidence that salmon and steelhead smolts migrate downstream to the ocean in the spring in large numbers in response to a variety of factors including high flows. Some factors act through influencing the onset of smolting, and appear to include water temperature, lunar rhythms, photoperiodicity, and annual physiological rhythms. Some research results point to the potential importance of the timing and duration of short-term flow changes to stimulating downstream migration of juvenile salmonids. Elevated water temperatures in late spring, which may be exacerbated by low flows, can inhibit or reverse smoltification in late outmigrants, especially steelhead. This can lead to fish remaining in the stream an extra year, and increased mortality if summer low flows limit holding capacity and survival.

There is also evidence that Chinook salmon juvenile survival increases with flow variability in the spring and early summer outmigration period, as defined by the ratio of mean to median flow rate evaluated over the same period. In the Policy area, higher velocities commensurate with higher flows reduce the time it takes for anadromous species to reach the estuary, where increased growth rates can occur.

There are no specific criteria for defining a suitable flow regime to stimulate and/or facilitate downstream passage on a regional basis. Hence, protectiveness can be assessed by specifying the outmigration season and comparing its overlap with the diversion season. Information reviewed in Appendix C indicates that the primary dates of outmigration by anadromous salmonid species in the Policy area are from March through June. Juvenile Chinook begin outmigrating about a month earlier, reflecting their ocean type life history and earlier fall spawning dates. Outmigration behavior is also exhibited by steelhead juveniles in the November-February period, and may reflect searching for or redistribution across over-wintering habitat.

2.5 CHANNEL AND RIPARIAN MAINTENANCE FLOW NEEDS

It has been demonstrated that large flood events, which may impart short term impacts to a population, are key to the continuous renewal of high quality physical habitats and ecological functions that promote population viability and health. Channel and riparian conditions, and their influence on anadromous salmonid habitat quantity and quality, are strongly dependent on high flow variability. The overall weight of scientific evidence indicates that a range of flow levels, rather than just one, are needed to be protective of instream habitat and riparian conditions.

Channel maintenance flows influence both the quantity and quality of anadromous salmonid habitat. Channel maintenance is a long-term process whereby the basic habitat structure of a stream is formed and maintained by multiple, variable high flow events occurring on an annual basis. These flows effectively maintain channel structure and the riparian zone to the extent that the characteristic variability represented in anadromous salmonid habitat persists over time. Diversions during high flows will reduce flow magnitude. Evaluating morphologic responses to reductions in high flow magnitude is complicated because channels are generally free to adjust their width, depth, slope, and bed grain size distribution in response to changes in flow regime. These attributes may adjust in concert or individually depending on circumstance.

Establishment and maintenance of riparian vegetation can be particularly dependent on flow variation. Indeed, some species of riparian plants (e.g., cottonwoods) are especially dependent on flood events that serve to stimulate germination of seeds leading to new plant growth. The existence of a healthy riparian zone in part controls channel form, water quality, and other features and functions that comprise anadromous salmonid habitat. Removal of riparian vegetation can lead to increased summer water temperatures, changes in water quality and quantity, decreased habitat for aquatic-origin adult insects, decreased bank stability and increased sediment inputs, and decreased wood recruitment that provide instream habitat structure. Reducing peak flows by diverting water has the potential to affect riparian vegetation primarily through three mechanisms: (1) reduction in groundwater recharge through the stream banks, (2) reduction of scouring flows that create new surfaces for riparian vegetation, and (3) reduction in growth rates during the early spring. Thus, the degree of protectiveness of diversion restrictions reflects the amount of water that may be diverted without adversely affecting the health, diversity, and future potential of the riparian zone.

However, suitable criteria for both channel and riparian maintenance flows are less well defined than criteria for upstream passage, spawning/incubation, and rearing. The primary quantitative metrics for assessing protectiveness are the degrees of change in channel morphologic characteristics, expressed as changes in surface grain size distribution, and bankfull width and depth. As discussed in Appendix D in greater detail, minor to moderate changes in these channel values are approximately linear with changes in bankfull flow (as represented by the 1.5 year peak event magnitude) (Figure 2-1). Because the changes to channel values never reach a lower limit (i.e., bottom out) and the linkage between reduction in channel size and anadromous salmonid production cannot be identified with great accuracy and precision, there is no readily discernable flow reduction limit suggested for identifying a protective channel and riparian maintenance flow.

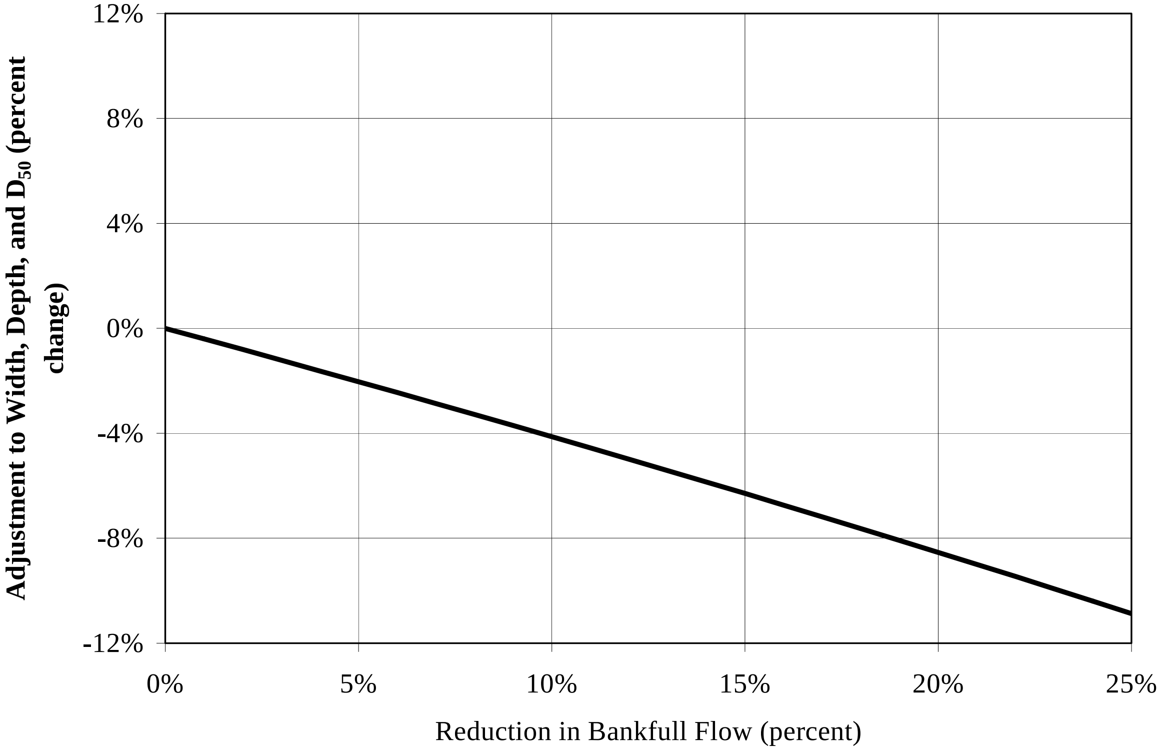

Figure 2-1. Predicted long-term potential changes in channel width, depth, and grain size distribution resulting from a reduction in bankfull flow due to diversion in Policy area streams potentially supporting anadromous salmonids.

2.6 ESTUARY HABITAT/OCEAN CONNECTIVITY FLOW NEEDS

Estuaries are an important interface between the freshwater and saltwater phases of the anadromous salmonid life cycle for both upstream and downstream migrants, although the importance can vary greatly from relatively little to a critical bottleneck depending on river and species. There are two flow-related influences on the suitability of estuaries for anadromous salmonids in the Policy area:

1. Reducing access to returning adult salmon and steelhead in the fall through sand bar closures across the mouth of the estuary, and

2. Providing suitable freshwater over-summer habitat conditions.

Sand bars at the entrance of some California coastal streams can create temporary upstream migration barriers to salmon and steelhead trout. The processes controlling the breaching of these sand bars are complicated and depend on the resource and basin in question. Estuaries in the Policy area tend to become blocked during the low flow summer months, typically some time during July, August, and/or September. Blocking has the potential to delay entry of returning adults, with greatest potential effects occurring in the Policy area to Chinook salmon that return the earliest of the three target species.

Estuaries in the policy area are used over the summer as rearing habitat by steelhead and Chinook. Although Chinook salmon downstream migration occurs earlier in the spring, juvenile fish at the end of the season may be trapped in the lagoon for the summer. Available data suggest that these lagoons may provide more productive rearing habitat for salmonids than open systems in the Policy area, allowing increased growth that improves ocean survival.

The primary flow needs related to estuary habitat implementation of the Policy therefore pertain to breaching in the fall months to facilitate the return of adults to freshwater. However, specific flow requirements for breaching vary with the basin, making it difficult to identify a regional flow-based criterion. Protectiveness of the element alternatives can be indirectly evaluated by comparing the general level of impaired base flows occurring during the diversion resulting from the element alternatives with flow characteristics required for sand bar breaching as reported in the literature (see Appendix D).

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3. INSTREAM FLOW POLICY ELEMENT ALTERNATIVE CRITERIA

Four fishery protection elements contained in the DFG-NMFS (2002) Draft Guidelines (see Appendix A) provided the framework for defining potential Policy elements. These followed two main themes: elements restricting flow diversion and an element restricting instream barriers. A number of alternative criteria have been identified for each of the elements restricting flow diversion. In the case of the element restricting instream barriers, alternative criteria were composed of the DFG-NMFS (2002) Draft Guidelines and modifications thereof that varied in restrictiveness. Each of the four fishery protection elements, as well as alternative criteria identified during the scoping process, are identified and described below in the context of how they would function to benefit anadromous salmonids.

3.1 POLICY ELEMENTS RESTRICTING FLOW DIVERSION

Three potential elements of the Policy involve restrictions on diversions to benefit anadromous salmonids: (1) diversion season, (2) requirements for a minimum bypass flow during the diversion season, and (3) the maximum permissible cumulative diversion rate or volume. Table 3-1 lists the various alternative criteria evaluated for each element.

Two sets of alternative criteria were provided that encompassed all three elements, the first in the DFG-NMFS (2002) Draft Guidelines (Alternatives DS1, MBF1, MCD1, MCD2, and MCD3 in Table 3-1) and the second in a proposal provided by Trout Unlimited (MTTU 2000; Alternatives DS2, MBF2, and MCD4). Background on the DFG-NMFS (2002) Draft Guidelines and the Trout Unlimited proposal is provided in Appendix A.

The DFG-NMFS (2002) Draft Guidelines recommended modifications to the State Water Board staff proposals for the administration of applications for water diversions (SWRCB 1997, 1998) that withdraw less than 3 cfs or 200 acre-ft/yr by implementing measures described below. Diversions that withdraw more than 3 cfs or 200 acre-ft/yr would require site-specific studies and monitoring. The measures specified for smaller diversions would apply to cases where site-specific studies were not conducted. However, the option to conduct site-specific studies would also be available for small diversions, the results of which could be used to justify different criteria for each element than were recommended by the DFG-NMFS (2002) Draft Guidelines.

The Trout Unlimited (MTTU 2000) proposal included the same elements as the DFG-NMFS (2002) Draft Guidelines, but differed with respect to the timing and levels of permissible extraction, and was to be applied to streams with drainage areas smaller than about 10 mi^2. In addition, the Trout Unlimited proposal made no distinction between (1) existing, legally permitted, and (2) new permit applications for diversion, and would apply to all diversions in perennial and ephemeral streams with or without anadromous salmonids.

Table 3-1. Policy Element Alternative Criteria Proposed to Restrict Diversions

Diversion Season	Minimum Bypass Flow	Maximum Cumulative Diversion
DS1. 12/15 – 3/31	**MBF1.** February median daily flow	**MCD1.** MCD Rate = 15% of 20% Winter (12/15-3/31) exceedance flow
DS2. Year Round	**MBF2.** 10% Exceedance Flow	**MCD2.** MCD Rate = 5% of 1.5 yr flood peak flow
DS3. 10/1 – 3/31	**MBF3.** Drainage Area (DA) < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$ Q_m = unimpaired mean annual flow (cfs); For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	**MCD3.** MCD Volume = 10% estimated unimpaired flow (no restriction on diversion rate)
	MBF4. Drainage Area < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ Drainage Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$ For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	**MCD4.** MCD Rate = diversion rate which results in a maximum reduction of the time flow is above the MBF to ½ day during a 1.5 yr flood event

Several other specific alternative criteria were identified for discrete elements restricting diversion and are described in Table 3-1 and in the following sections. In particular, the MBF3 and MBF4 alternatives summarized in Table 3-1 were both developed to account for variation in instream flow needs for different channel sizes, but respectively approximated the maximum/minimum amounts of water that might be left instream without substantially over-/under-protecting anadromous salmonids.

3.1.1 Diversion Season (DS) Element

The proposed Policy would restrict the season of operation of new diversions to the period of highest winter flows when water is most available and the impacts of water withdrawals on fishery resources would be minimized. New diversions would not be permitted during the summer, fall, or late spring months, which are periods when streamflows are especially important to limiting anadromous salmonid populations. The primary question concerning the protectiveness of this element of the Policy is to determine which dates bracketing the winter diversion season are the most biologically appropriate for the target species. Three alternative criteria were identified for the diversion season.

3.1.1.1 DFG-NMFS (2002) Draft Guidelines Diversion Season DS1

The DFG-NMFS (2002) Draft Guidelines proposed a December 15 – March 31 diversion season that reflected biological timing (i.e., periodicity) of various anadromous salmonid life stages, and the availability of water, the latter based on an analysis of five gages in the Russian River basin (SWRCB 1997).

3.1.1.2 Trout Unlimited (MTTU 2000) Diversion Season DS2

Trout Unlimited (MTTU 2000) proposed no limitation to the diversion season as long as instream flow restrictions were met (see sections below on minimum bypass flow and maximum cumulative diversion).

3.1.1.3 Consulting Engineers (2006) Diversion Season DS3

A set of comments and recommendations provided on September 15, 2006 during the CEQA scoping process by Wagner & Bonsignore Consulting Civil Engineers, James C. Hanson Consulting Civil Engineer, and the law firm Ellison, Schneider & Harris L.L.P. (Consulting Engineers) proposed that the diversion season begin on October 1 instead of December 15. The early date would allow on-stream reservoirs to fill and subsequently spill earlier in the fall depending on the magnitude of instream flows.

3.1.2 Minimum Bypass Flow (MBF) Element

The minimum bypass flow (MBF) element of the Policy would set a minimum instream flow that must be moving past a point of diversion before water may be diverted under a permit. The term, ‘bypass,’ refers to flow that is not impounded or diverted and hence remains in the stream. This element reflects the need to provide and maintain sufficient instream flows downstream of diversions and on-stream dams for anadromous salmonid habitat.

3.1.2.1 DFG-NMFS (2002) Minimum Bypass Flow Alternative Criterion MBF1

The DFG-NMFS (2002) Draft Guidelines recommended a MBF equal to the February median daily unimpaired flow. The month of February was chosen because analysis indicated it was generally the highest median flow during the winter period (based on hydrologic analysis of Russian River tributaries), and would thus be expected to protect spawning and egg incubation habitat of salmonids in other months. A median statistic was considered preferable to a mean because it better reflected flow duration, and was not influenced as strongly by infrequent, high flow events.

3.1.2.2 Trout Unlimited (MTTU 2000) Minimum Bypass Flow Alternative Criterion MBF2

Trout Unlimited (MTTU 2000) proposed a geomorphic measure, defined as the active channel stage height, for determining the magnitude of the MBF. The active channel was defined as corresponding to the lower limit of woody riparian vegetation, particularly white alder, and the concomitant edge of a defined gravel-sand bench in straight reaches. The bench and white alder roots were reported to contain lower flows, thereby keeping the active channel bed and any anadromous salmonid redds therein wetted during declining flows (MTTU 2000). However, in lieu of site-specific studies for determining the active channel stage height, Trout Unlimited recommended the annual 10% exceedance flow as an approximation of the flow resulting in the active channel water level. This metric would therefore allow diversions to occur approximately 36.5 days per year on average.

3.1.2.3 Minimum Bypass Flow Alternative Criterion MBF3

The MBF3 alternative criterion was developed based on comments from the 2000 State Water Board workshop peer review panel (Moyle et al. 2000) and those from MTTU (2000). The development of this criterion is presented in Appendix E. The alternative criterion incorporated basin size (drainage area) and hydrology (mean annual flow) into the development of the following criteria for MBF (Q_{MBF}) that are focused on protecting spawning habitat and upstream passage:

- Basin Area < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\,(DA)^{-0.48}$ (3.1)
- Basin Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$
- Locations Above Anadromous Habitat: $Q_{MBF} = 9.4\ Q_m\,(DA_2)^{-0.48}$

where Q_m and DA are the estimated mean annual flow and drainage area at the point of diversion (POD), respectively, and DA_2 is determined at the upper limit of anadromous habitat. These criteria are displayed in Figure 3-1.

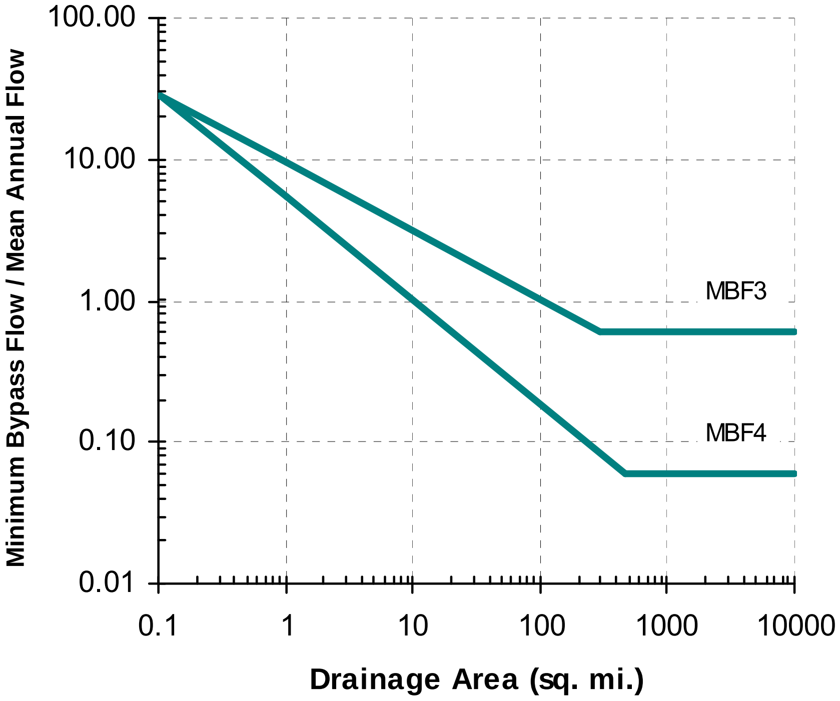

Figure 3-1. Comparison of the MBF3 and MBF4 alternative criteria for the Minimum Bypass Flow (MBF) element of the Policy, which account for variation in instream flow needs with stream size at different levels of protection.

The alternative's format is consistent with Moyle et al.'s (2000) comment that the DFG-NMFS (2002) Draft Guidelines should include a separate minimum passage depth criterion for smaller streams used by anadromous salmonids. The normalization of instream flow needs by mean annual flow was accordingly done to account for channel size effects on flow needs vs. stream flow.

This alternative criterion was developed to be protective of anadromous salmonid habitat in as many streams as possible based on measures of channel size expressed in terms of drainage area and mean annual flow. In cases where proposed diversions would cause flows to drop below stated criteria, site specific studies could be conducted in consultation with resource agencies to determine if lower MBFs could be allowed that would still be protective. Analysis of this alternative criterion (which is described in detail in Appendix E) suggested that while a more restrictive minimum bypass flow could be imposable on diversions, doing so would likely not provide significant additional, quantifiable benefits to the three anadromous salmonid species.

3.1.2.4 Minimum Bypass Flow Alternative Criterion MBF4

The MBF4 alternative criterion was developed in part from existing instream flow studies which provided a minimum negotiated level of protection for anadromous salmonids (see Appendix E). The alternative criterion would allow diverters to extract as much water as possible, while still providing MBFs that ostensibly would not imperil the sustainability of anadromous salmonids. This alternative criterion was developed to be protective of anadromous salmonid habitat based on a lower level of protection compared with the MBF3 alternative and was similarly based on measures of channel size expressed in terms of drainage area and mean annual flow.

The MBF4 criterion for MBF (Q_{MBF}) consists of the following criteria that are based on protecting spawning habitat and upstream passage:

- Basin Area (DA) < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ (3.2)
- Basin Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$
- Basin Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$
- Locations Above Anadromous Habitat: $Q_{MBF} = K\ Q_m\ (DA_2)^M$

where K and M depend on the drainage area as indicated above, and DA_2 is the drainage area determined at the upper limit of anadromous habitat. These criteria are plotted in Figure 3-1 for comparison with the MBF3 alternative criterion.

3.1.3 Maximum Cumulative Diversion (MCD) Element

This element of the Policy was focused on defining the magnitude of the maximum cumulative diversion (MCD) rate or total volume of diversions that could be allowed when stream flows exceed the MBF while still being protective of fishery resources. The overall intent of the MCD element is to allow for some flow diversion while still preserving natural flow variability downstream (see Appendices D and E for discussion of the ecological importance of flow variability). Detailed geomorphic analysis (see Appendix D) did not reveal a clearly defined, protective threshold MCD rate (or equivalent volume) for protecting channel and riparian maintenance flows. Four alternative criteria were thus identified based on existing recommendations: three formulated from the DFG-NMFS (2002) Draft Guidelines and one from MTTU (2002).

Comments received during scoping from the Consulting Engineers (2006) recommended that determination of water availability should involve estimating the actual seasonal depletion due to cumulative diversions in the watershed above the POD, rather than the cumulative amount appropriated. Water would be considered available for diversion as long as the actual average annual cumulative depletion remained below the estimated average annual stream flow in more than half the water years considered. However, there is no legal mechanism preventing all water rights holders from simultaneously diverting their full appropriated amounts of water from the stream, provided such flows are available at the time of diversion and regardless of past diversion practices. It follows then that evaluation of the MCD element requires a worst-case scenario in which it is assumed that all appropriated water is diverted, rather than an estimate of actual current use. Thus, this recommendation was not evaluated further.

3.1.3.1 DFG-NMFS (2002) Maximum Cumulative Diversion Alternative Criteria MCD1, MCD2, and MCD3

The DFG-NMFS (2002) Draft Guidelines contained two primary approaches for maintaining natural flow variability and avoiding significant cumulative effects due to diversion. Absent site-specific information and analyses demonstrating otherwise, the DFG-NMFS (2002) Draft Guidelines stated that the natural hydrograph should be protected by either:

a. Limiting the cumulative instantaneous rate of withdrawal (i.e., MCD rate) to 15% of the winter 20% exceedance flow during the period December 15-March 31, subject to a limiting cumulative rate of withdrawal that does not appreciably diminish (qualified as <5% of) the natural hydrograph flows needed for channel maintenance (considered to be approximated by the 1.5 year peak annual flood) and upstream fish passage;

OR

b. Limiting the total cumulative volume of water to be diverted, at historical limits of anadromous fish distributions, to 10% of the unimpaired runoff during the period December 15-March 31 during normal water years, using a Cumulative Flow Impairment Index (CFII). Hydrologic analysis is required for projects with CFIIs between 5%-10% to demonstrate that a diversion will not impair geomorphic processes and salmonid migration and spawning.

The procedure proposed for calculating the CFII was:

$$CFII = \frac{Cumulative\ Diverted\ Volume\ From\ 10/1-3/31}{Estimated\ Unimpaired\ Runoff\ \ From\ 12/15-3/31}$$

The CFII was recommended as a screening method of determining which water right applications can be permitted without further study and which points of interest (POI) require detailed evaluation of potential cumulative impacts. Technical considerations in the evaluation of the protectiveness of the CFII are discussed further in Appendix J.

The analysis in Appendix D indicated that the limiting condition identified in option (a) of the DFG-NMFS (2002) Draft Guidelines above, whereby a MCD rate should not exceed a level equaling 5% of the 1.5 year annual peak flood, could potentially be the least restrictive option identified relative to cumulative flow diversion while still protecting channel maintenance processes. A review of local gage data identified in Appendix F indicates this level is, on average, roughly five to seven times the 15% of 20% exceedance flow rate proposed under the first component of the DFG-NMFS alternative criterion.

These criteria were used to develop three MCD alternatives which were separately assessed for protectiveness:

1. Maximum cumulative diversion rate = 15% of the unimpaired Dec 15 - Mar 31 20% exceedance flow (MCD1)
2. Maximum cumulative diversion rate = 5% of the 1.5 year flood magnitude (MCD2); and
3. Maximum cumulative diversion volume (CDV) = 10% of the unimpaired Dec 15 – Mar 31 normal year volume (MCD3).

The MCD3 alternative was formulated to provide a worst-case evaluation of the 10% CFII threshold with respect to hydrograph impairment during the beginning of the diversion season. In applying this alternative, it was assumed that:

1. There is no maximum limit imposed on the instantaneous rate of diversion.
2. The diversion demand is set equal to 10% of the estimated unimpaired runoff volume from December 15 until March 31.
3. All flows above the MBF are diverted until the diversion demand is satisfied.

3.1.3.2 Trout Unlimited (MTTU 2000) Maximum Cumulative Diversion Alternative Criterion MCD4

Trout Unlimited recommended that the MCD be calculated based on changes in flow timing, with the goal of minimizing the reduction in total time available for spawning. Explicit guidance was not given regarding how much can be diverted when flows exceed the MBF, but examples given by MTTU (2000) implied that the diversion rate resulting in a shift of the descending limb of the event hydrograph of half a day at the time the MBF occurs is the MCD at any time during the event (Figure 3-2). Trout Unlimited proposed that the 1.1-year to 1.5 year event be used as the basis for determining the MCD (MTTU 2000). Given hydrograph recession characteristics, the corresponding time that the hydrograph is compressed at higher flows will typically be shorter.

From a practical standpoint, implementation of this proposal is problematic as it effectively requires hourly hydrograph data to evaluate pending water right applications, data that are not readily available in most Policy area streams. Its application is further complicated by the observation that each runoff event would, in principle, be associated with a different MCD aimed at resulting in no more than one-half day shortening of flow at the MBF level.

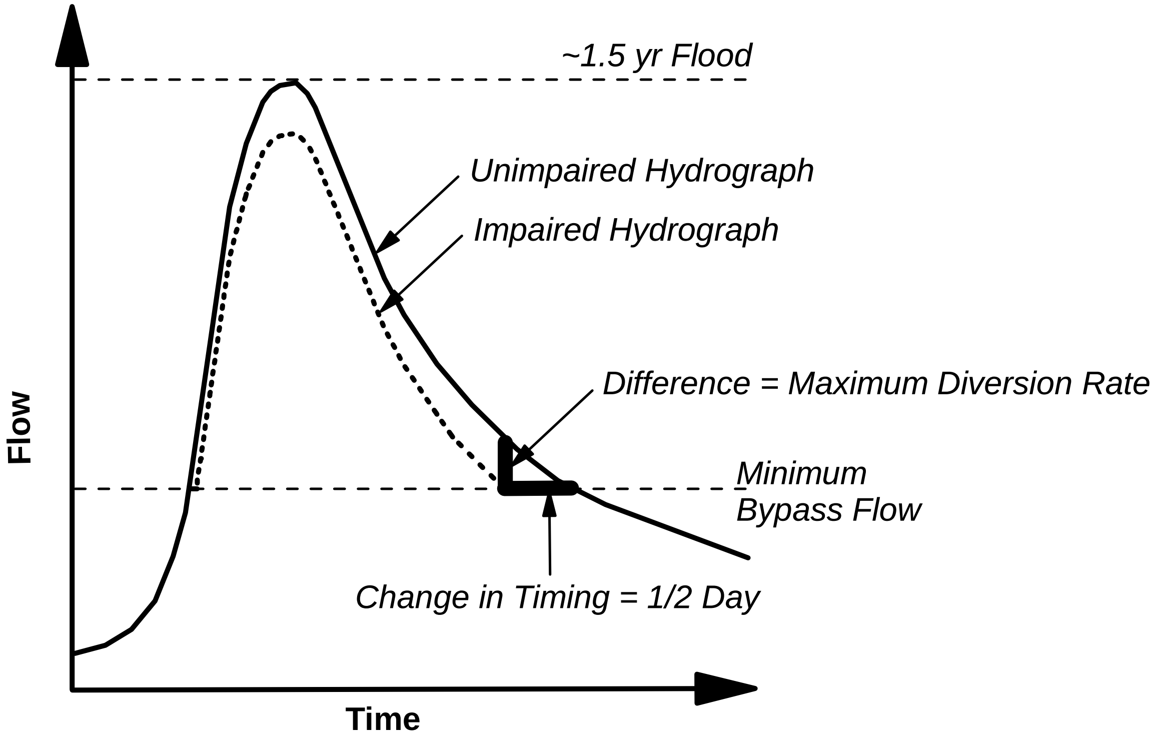

Figure 3-2. Conceptual determination of maximum cumulative diversion (MCD) rate following Trout Unlimited's proposal to base it on a maximum reduction in the time instream flows are at, or above the minimum bypass flow by one-half day.

3.2 POLICY ELEMENT RESTRICTING INSTREAM BARRIERS

There is one element of the Policy concerning instream barriers, and that is whether an on-stream dam could or should be permitted. This element involves measurable actions whose costs and benefits to water users and natural resources are more definitive and quantifiable than elements involving measures of flow quantity. The alternatives considered are shown in Table 3-2.

The alternatives range in degree of restrictiveness. For the protectiveness analysis, all alternatives were assumed to be applied in conjunction with the Policy elements restricting flow, including diversion season, MBF, and MCD. In some cases, exceptions to the imposed barrier restrictions may be possible, but only if site-specific studies conducted in cooperation with resource agencies demonstrate such.

3.2.1 Permitting of On-Stream Dams (DP) Policy Element

Construction of on-stream dams can result in a number of direct and indirect impacts to anadromous salmonids, including the local loss of free-flowing stream habitat and food production, loss of upstream fish production, providing habitat for non-native species, trapping of spawning gravels, and regulation of downstream flows. The objective of this Policy element is to avoid, reduce and/or mitigate for these impacts. Questions relevant to evaluating the effects of implementing this element concern how changes in methods of water diversion and storage practices may affect riparian resources and summer low flows, and if there are certain conditions where on-stream dams could still be allowed without impacting downstream resources.

The Consulting Engineers (2006) comments included a recommendation that dams and on-stream impoundments be permitted; (1) in channels, swales, or water courses that have surface runoff only during and immediately following precipitation events; (2) in water courses where there are existing downstream dams or other barriers; (3) in streams where there is no salmonid habitat or species at the POD and no significant impact to flows at the current upstream limit of anadromy; or (4) when the impoundment contains 10 acre-ft or less of water. The applicability of these recommended modifications to a given stream or channel would require site specific studies to be conducted, and therefore they were not considered as potential modifications to the DFG-NFMS (2002) alternative for regionally applied criteria.

Table 3-2. Policy Element Alternative Criteria Proposed to Restrict Instream Barriers.

Stream Class	Permitting of On-stream Dams (DP)
Class I	**DP1.1** On-stream dams may not be issued water right permits. **DP1.2** New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. Fish passage and screening is provided; 2. A passive bypass system is provided to bypass the minimum instream flow requirements; 3. An exotic species eradication plan is implemented; 4. A gravel and wood augmentation plan or bypass system is implemented; and 5. Disturbed riparian habitat will be mitigated
Class II	**DP2.1** On-stream dams may not be issued water right permits. **DP2.2** New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. A passive bypass system is provided to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.

Table 3-2. Policy Element Alternative Criteria Proposed to Restrict Instream Barriers.

Class II (cont)	**DP2.3** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.
Class III	**DP3.1** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. The on-stream dam will not dewater a Class II stream; and 2. The on-stream dam will cause less than 10% cumulative instantaneous flow impairment at locations where fish are seasonally present.
	DP3.2 A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; and 3. A gravel and wood augmentation plan or bypass system is implemented.
	DP3.3 A water right permit may be considered for an on-stream dam.

3.2.1.1 DFG-NMFS (2002) On-Stream Dam Permitting Alternatives (DP1.1, DP2.1, and DP3.1)

The DFG-NMFS (2002) proposed that the State Water Board avoid additional permitting of small on-stream dams beyond those already legally permitted. An exemption was provided in cases where the following conditions were met: (1) the proposed diversion was located in a stream where aquatic fauna were not historically present, per Class III designation under Cal. Code Regs., tit. 14, section 916.5, Table 1 (i.e., no aquatic life present, water course showing evidence of being capable of sediment transport downstream to fish-bearing waters under normal high water flow conditions); (2) the project would not lead to a cumulative diversion rate exceeding 10% of the natural instantaneous flow in any reach where fish are at least seasonally present ("cumulative" was defined to include all existing water rights); and (3) the project would not lead to dewatering of a fishless stream supporting other aquatic fauna.

3.2.1.2 Modifications to the DFG-NMFS (2002) Alternative (DP1.2, DP2.2, DP2.3, DP3.2, and DP3.3)

Trout Unlimited (MTTU 2000) proposed that new and existing on-stream dams must be individually approved by DFG following a quantitative analysis of; (1) cumulative effects on downstream anadromous salmonid habitat; (2) loss of upstream anadromous habitat; (3) effects on other fish resources as defined by DFG code; (4) effects on off-channel wetlands connected hydraulically to the channel via surface flow; and (5) channel maintenance flow needs. All downstream locations potentially impeding upstream migration of adult and juvenile salmonids must be identified. The analysis would need to consider all existing water rights upstream of potential barriers and the proposed water right application. An exemption would be allowed for on-stream dams on Class III streams where it could be demonstrated quantitatively that (1) the minimum bypass flow and maximum diversion rate guidelines could be met at the upstream limit of potential anadromy, (2) that downstream riparian vegetation and other fishery resources including seasonal wetlands may be sustained, and (3) minimum bypass flow guidelines are met in Class II and III channels and swales. New and existing on-stream dams that meet permitting criteria would need to have an operational plan approved by DFG for annually replacing an equivalent volume of coarse bed material into the downstream channel, so that the supply to salmonid spawning habitat downstream is not interrupted (MTTU 2000).

Alternatives to those proposed in the DFG-NMFS (2002) Guidelines were accordingly developed. The first alternative included protective modifications as suggested by Trout Unlimited and the State Water Board. The second included less restrictive criteria that those proposed by DFG-NMFS. All alternatives are shown in Table 3-2, distinguished by stream class.

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4. EVALUATION OF THE EFFECTS OF POLICY ELEMENT ALTERNATIVE CRITERIA RESTRICTING FLOW DIVERSION ON ANADROMOUS SALMONID HABITAT NEEDS

This chapter presents the methods and results for evaluating the effects of Policy elements restricting flow diversion on the various important anadromous salmonid habitat needs identified in Chapter 2. The assessment of anadromous salmonid habitat needs provided by each alternative criterion included both direct and relative comparisons of specific habitat metrics described in this chapter.

Quantitative analyses focused on the use of daily flow time series. Estimated unimpaired flow time series were compared with different impaired flow time series resulting from implementation of specific combinations of Policy element alternative criteria (diversion season, minimum bypass flow, and maximum cumulative diversion). Each impaired flow time series resulting from implementing a specific set of Policy element alternatives is called henceforth a “Flow Alternative Scenario.”

Whether or not a specific Policy element alternative criterion, or combination of alternative criteria (i.e., a Flow Alternative Scenario), could be considered protective depended on the extent to which each habitat need was adversely affected by the reduction in daily flows resulting from the allowed impairment. The relevant habitat metrics were derived from analyses of unimpaired and impaired flow data, using hydraulic and habitat data collected in the late summer of 2006 at a number of sites distributed over the Policy area (henceforth called “validation sites” in this report). Because the overall goal of the analysis was to determine protectiveness at the regional scale, an overall criterion used to evaluate the results for all validation sites was the extent to which Policy element alternative criteria resulted in some streams barely being protected and the rest being over-protected (see Appendix D for a discussion of the rationale). If more than one or two validation sites were adversely affected in some way, the outcome would then not be considered protective at a regional scale.

Of the six habitat needs identified in Chapter 2, upstream passage and spawning habitat metrics were assessed most directly using field data, in part because they were most readily quantifiable. Figure 4-1 depicts the general analysis steps followed for these two habitat needs. The steps are described further below and in greater detail in Appendices F and G. For some habitat needs, it was not possible to define a quantitative metric for establishing the degree of effect, such that a weight of evidence, literature-based approach was necessary instead; such cases are noted below.

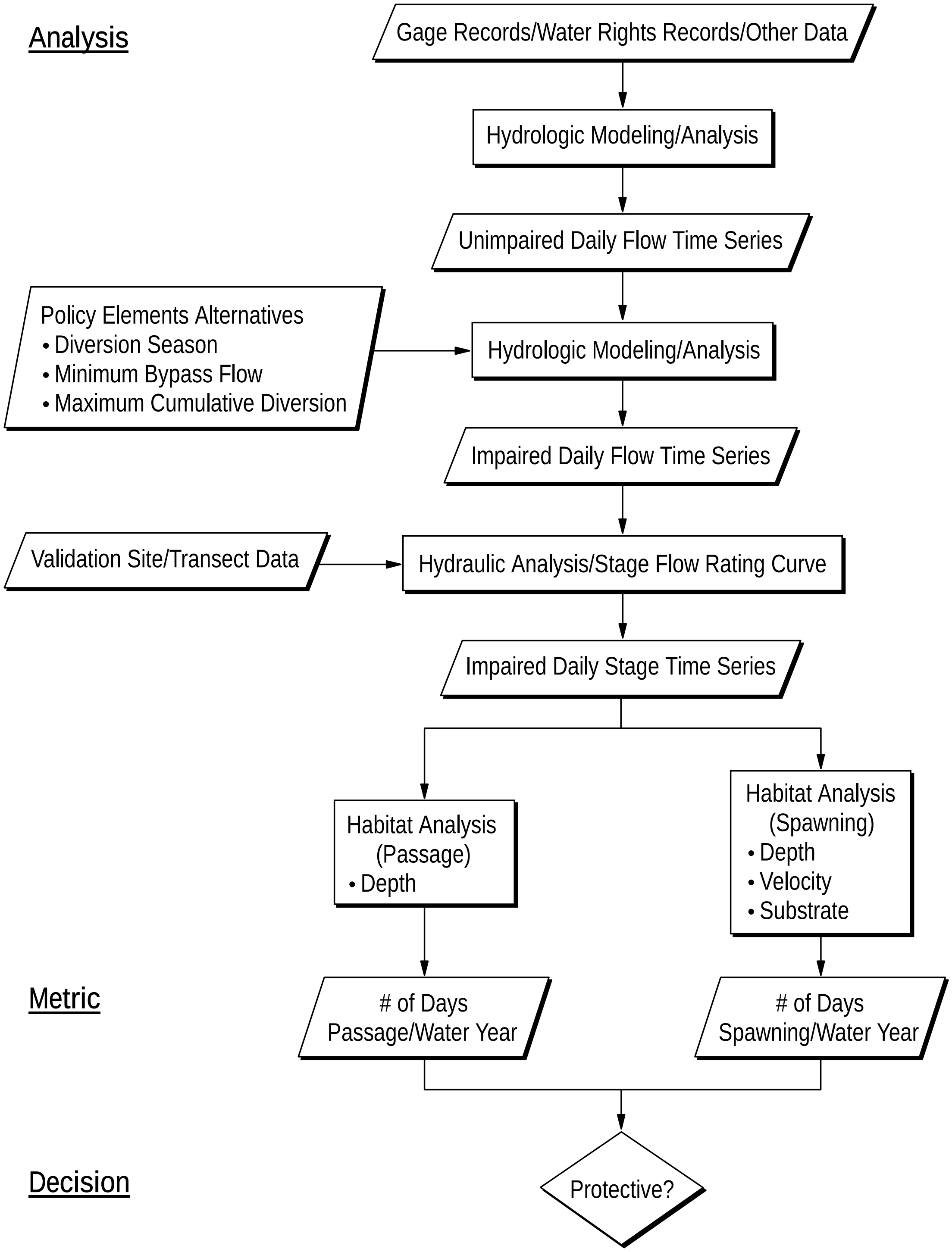


Figure 4-1. Outline of steps taken to analyze the protectiveness of Policy element alternative criteria restricting flow diversion with respect to anadromous salmonid upstream passage and spawning habitat needs.

The methods used to derive flow data for the validation sites are presented first, followed by the methods used to derive the habitat metrics. Results of the habitat analyses are then discussed (specific results are presented in Appendices H and I). The results serve as the basis for the analyses of protectiveness in subsequent chapters.

It should be noted that the analysis of anadromous salmonid habitat needs was restricted to assessing direct protective attributes of each Policy element described in Chapter 3, not indirect attributes or effects due to changes in diversion practices that result from implementation of the Policy. For example, in the case of riparian vegetation, which is an important element of salmonid habitat, the analysis considers how the MCD element may help maintain the level of high flow and how the level of high flow so-maintained could directly maintain and protect the riparian zone. The analysis in this chapter does not consider the indirect effects of shifting water extraction from surface water diversion to alternate sources, such as groundwater pumping and use of riparian water rights, which could lead to loss of the riparian zone by reducing the summer water table elevation. These types of indirect effects will be addressed in the effects analysis of the SED.

4.1 HYDROLOGY AT VALIDATION SITES

Thirteen validation sites were used to evaluate Policy element alternative criteria. Hydrologic data were collected and unimpaired daily flow time series were developed for each site. Policy elements restricting flow were then applied to time series of unimpaired flow in order to develop impaired time series. The hydrologic data and creation of time series at the validation sites is summarized below and is detailed in Appendix F.

4.1.1 Validation Site Locations

The thirteen validation sites were visited in the Policy area between August 28 and September 1, 2006 to collect spawning habitat and upstream passage data. As described in Appendix G, the sites were selected that (1) represented smaller sites (drainage area generally less than 15 mi^2) to supplement more readily available habitat-flow data for larger sites, and to address a critical data gap identified by MTTU (2000), (2) had a gage nearby from which an unimpaired winter daily flow time series could be reasonably estimated for at least two years, and preferably more, (3) would be well distributed across the Policy area, and (4) could be readily accessed to maximize field time efficiency. The major physical and hydrologic characteristics of the sites are summarized in Table 4-1, and their general locations depicted in Figure 4-2.

Table 4-1. Sites Where Transects Were Surveyed to Characterize Passage and Spawning Conditions Associated with Alternative Criteria for Policy Elements Regarding Restrictions on Flow. Streams are Ordered from Smallest to Largest Drainage Area.

Stream	**Date Visited**	**Drainage Area (mi^2)**	**Reach Slope (%)**	**Number of Transects**		**Water Years Analyzed**
				Passage	**Spawning**	
E. Fk. Russian River Trib	8/31/2006	0.25	2.50	1	0	1959-1961
Dry Creek Trib	8/30/2006	1.19	2.04	1	1	1968-1969
Dunn Creek	8/31/2006	1.88	1.58	2	2	1962-1964
Carneros Creek	8/29/2006	2.75	1.10	2	2	2002-2005
Huichica Creek	8/29/2006	4.92	0.79	1	1	2002-2005
Olema Creek	8/28/2006	6.47	0.91	2	2	1987-2003
Pine Gulch Creek	8/28/2006	7.83	1.14	2	2	1999-2003
Warm Springs Creek	8/30/2006	12.2	0.71	2	2	1974-1983
Santa Rosa Creek	9/1/2006	12.5	1.37	1	2	1960-1970
Albion River	8/31/2006	14.4	1.01	2	2	1962-1969
Salmon Creek	8/30/2006	15.7	0.69	2	2	1963-1975
Franz Creek	9/1/2006	15.7	0.29	2	2	1964-1968
Lagunitas Creek	8/28/2006	34.3	0.53	2	2	1956-1992

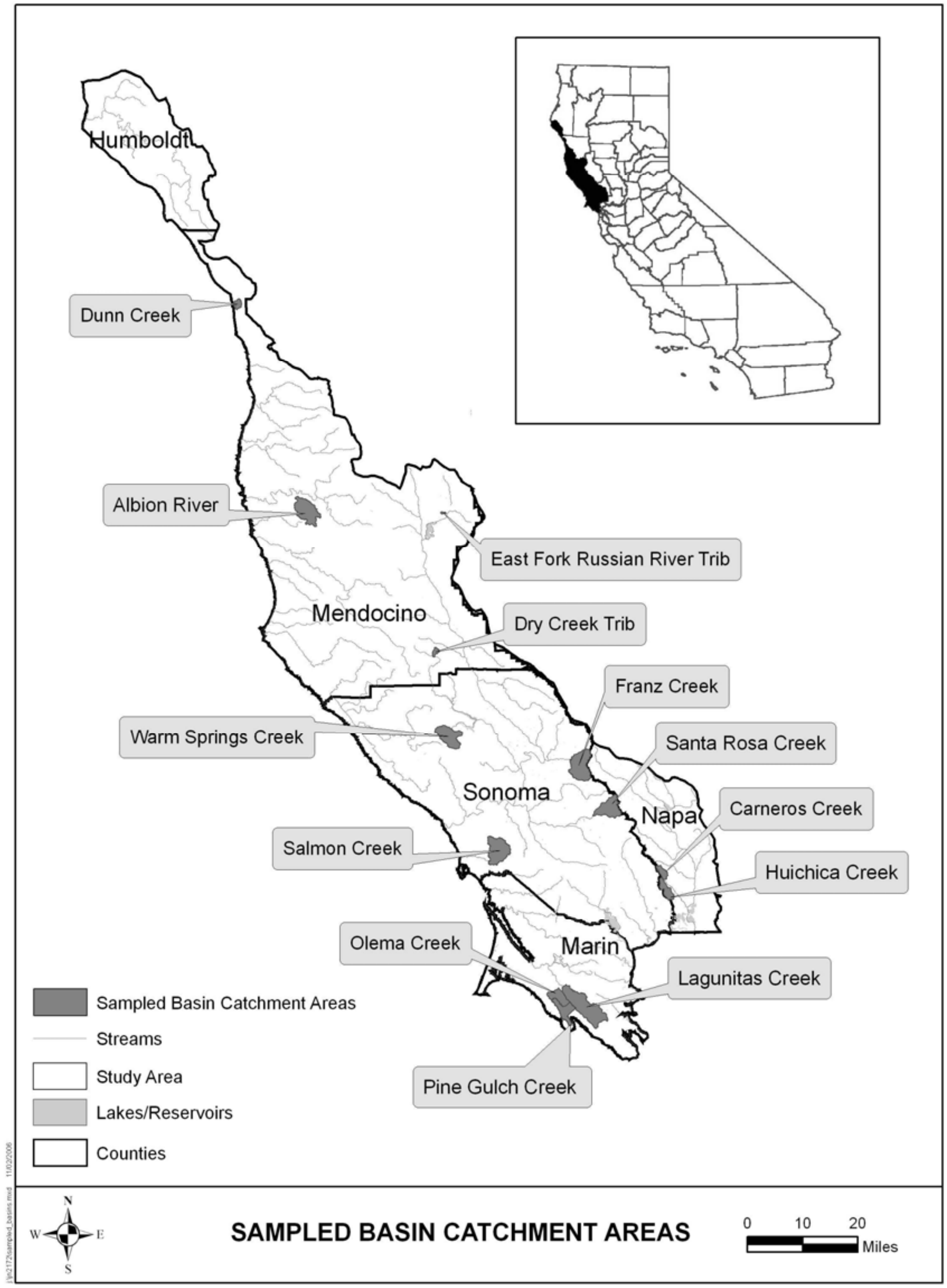


Figure 4-2. Locations of validation sites sampled for passage and spawning transects that were evaluated for protectiveness of Policy element alternative criteria involving restrictions on flow.

4.1.2 Estimation of Unimpaired Flow Time Series

Unimpaired flow is the natural flow in a stream without any human alterations to the hydrology; that is, the flow without any diversions or man-made storage. The unimpaired stream flow was needed particularly to analyze two of the Policy elements, MBF and MCD rate or volume. Accordingly, unimpaired flow time series were developed for each of the validation sites.

For all thirteen validation sites, gaged data were available from one of three sources: the US Geological Survey (USGS), Napa County Resource Conservation District (NCRCD), and the National Park Service (NPS). The gaged data were collected and compared to historical permitted diversions and storage to determine whether they represented unimpaired flows.

Historical permitted diversions and storage were estimated for the validation sites using data from the State Water Board's Water Rights Information Management System (WRIMS) database as of December 20, 2006. In cases where diversions and storage regulation during the gaged period of record were not significant, gaged flows were used as an estimate of unimpaired flow. This was the case for nine of the thirteen sites (Albion River, Dry Creek Trib, Dunn Creek, EF Russian River Trib, Olema Creek, Pine Creek, Salmon Creek, Santa Rosa Creek, and Warm Springs Creek).

For the remaining four validation sites, gaged data were not used to represent unimpaired flows because diversions and storage were determined to have potentially impacted measured daily flow rates significantly. Instead, calculated or modeled flows were used to represent unimpaired flows. For one validation site (Lagunitas Creek), unimpaired flows were obtained from the Marin Municipal Water District (MMWD) which has calculated such flows on a daily basis. For the other three streams with significant diversions and storage, a model (Hydrologic Simulation Program - Fortran, HSPF) was used to simulate unimpaired flows. Streamflow was modeled for the Carneros Creek, Franz Creek, and Huichica Creek validation sites. Details of the model inputs, calibration, and results are in Appendix F, Section F.2.4.

After the unimpaired time series for each validation site were created, hydrologic parameters such as mean annual flow, peak flood magnitude, and flow-duration (exceedance) values were computed. Development of these unimpaired flows and associated hydrologic parameters is described in detail in Appendix F, Section F.2.

4.1.3 Hydrology and Impaired Flow Time Series

Impaired daily flow time series were generated by applying, in concert, specific diversion season, MBF, and MCD rate or volume criteria to the estimated unimpaired flow daily time series. Details of the impairment calculations are given in Section F.3 in Appendix F.

Statistics and hydrologic parameters of the impaired time series were computed in order to assess changes to the hydrology resulting from the application of the Policy elements (see section F.3 in Appendix F). In addition, a sensitivity analysis was performed to specifically assess the effect of the MCD rate or volume criteria on the hydrology (Section F.4 in Appendix F). The sensitivity analysis was used in the assessment of protectiveness for the MCD Policy element. Results of the sensitivity analysis indicate that, in general, diversions occur less frequently but at much higher rates when the MCD volume method is employed. Maximum diversion rates are generally an order of magnitude higher when diversions are limited by the MCD volume method. Also, the MCD volume method reduces peak annual floods more significantly than the MCD rate methods.

As described in the next section, specific combinations of the three Policy elements restricting flow diversion were evaluated by first creating the appropriate impaired flow time series. Effects on anadromous salmonid habitat needs were then evaluated by relating various habitat-flow metrics to the impaired daily flows.

4.2 HABITAT ANALYSIS METHODS

The general approach of the habitat analysis involved evaluating the effects of impaired flows on the various important habitat needs of anadromous salmonids identified in Chapter 2. Negligible effects were interpreted as representing a protective condition in the context of the habitat attribute under consideration. Where possible, the unimpaired and impaired daily flow time series were related as directly as possible to effects on habitat quantity and quality. For habitat needs where a quantity or quality metric could not be identified and readily analyzed, the analysis of protectiveness relied on more general ecological and physical principles established in the literature.

It is important to note that the analyses of effects of flow diversions on habitat were complicated by the fact that the three elements restricting flow diversion must be applied in concert. As indicated in 4.1.3, each impaired daily flow time series is generated through hydrologic analysis, and the analysis requires that a set or combination of alternative criteria be specified for each of the three Policy elements, diversion season, MBF, and MCD. The diversion season controls the dates when instream flows are affected by impairment, and the MBF and MCD elements variously and simultaneously control the level of flow remaining in the stream. Hence, it is difficult to single out the effect of any one element alternative criterion without conducting a detailed sensitivity analysis where two elements are held constant at a given level of impact and the third element is varied. A habitat-flow sensitivity analysis was not feasible in the time frame and budget available.

Instead, a fixed number of impaired flow time series were generated and evaluated for passage, spawning, and channel maintenance habitat-flow needs. As described at the beginning of this chapter, the impaired flow time series corresponded to implementation of specific combinations of Policy element alternatives identified in Chapter 3; these specific combinations are referred to as Flow Alternative Scenarios and are described in Table 4-2. Flow Alternative Scenario 1 and 5 represent the two alternative expressions of the DFG-NMFS (2002) Draft Guidelines, one using a MCD rate (MCD1) and the other the CFII MCD volume (MCD5). Flow Alternative Scenario 2 represents the proposal by Trout Unlimited. Flow Alternative Scenario 3 (Upper Flow Scenario) represents a combination of the most restrictive Policy element alternatives; Flow Alternative Scenario 4 (Lower Flow Scenario) represents a combination of the least restrictive Policy element alternatives excluding those that were likely to not be protective. The number of Flow Alternative Scenarios compared was the minimum that could be analyzed to describe effects associated with the various Policy element alternatives. In the absence of a full sensitivity analysis, however, these five scenarios still described a range of impaired flow scenarios that appeared to have sufficient variation for inferring the relative protectiveness of alternatives for each distinct Policy element.

Of the Flow Alternative Scenarios listed in Table 4-2, Flow Alternative Scenarios 1, 2, 3, and 4 involve specifying a MCD rate as opposed to a volume (Flow Alternative Scenario 5). The corresponding flow rates estimated for MBF and MCD are presented in Table 4-3 (note there is no fixed MCD flow rate for Flow Alternative 5). An example of the effect of each Flow Alternative Scenario on the shape of the impaired hydrograph is depicted in Figure 4-3 for the October 1 – March 31 period of WY 1971 in a representative validation site, Salmon Creek. The MBF is visible as periods of steady flow below the natural, unimpaired hydrograph for the respective Flow Alternative Scenario time series. The point at which the CFII = 10% limit was reached under Flow Alternative Scenario 5 is also visible in the figure as the date when Flow Alternative 5 no longer results in flat-lining the hydrograph at the MBF level.

Table 4-2. Description of Flow Alternative Scenarios Evaluated in the Analysis of Protectiveness.

Flow Alternative Scenario	**Description, Policy Element Alternative Criteria Included**		
Unimpaired	Flow conditions using the estimated natural hydrology described in the previous section		
Flow Alternative Scenario 1	Flow conditions impaired with the maximum diversions allowed by the following Policy Element Alternatives:		
(DFG-NMFS 2002 Criteria, MCD Rate)	DS1 12/15-3/31	MBF1 February median daily flow	MCD1 Rate 15% of 20% winter exceedance flow
Flow Alternative Scenario 2 *(MTTU 2000 Criteria)*	DS2 Year round	MBF2 10% exceedance flow	MCD4 Rate Calculated for each site following the procedure depicted in Figure 3-2
Flow Alternative Scenario 3 *(Upper Flow Scenario)*	DS1 12/15-3/31	MBF3 Specified as a function of drainage area and mean annual flow	MCD1 Rate 15% of 20% winter exceedance flow
Flow Alternative Scenario 4 *(Lower Flow Scenario)*	DS3 10/1-3/31	MBF4 Specified as a function of drainage area and mean annual flow	MCD2 Rate 5% of 1.5 year flood magnitude
Flow Alternative Scenario 5 *(DFG-NMFS 2002 Criteria, MCD Volume)*	DS1 12/15-3/31	MBF1 February median daily flow	MCD3 Volume CFII = 10% estimated unimpaired runoff (EUR)

Table 4-3. Application of Protectiveness Criteria to the Thirteen Validation Sites, for Flow Alternative Scenarios where MCD is Specified as a Maximum Permissible Rate. Streams are Ordered from Smallest to Largest Drainage Area.

		Flow Alternative Scenario 1			Flow Alternative Scenario 2			Flow Alternative Scenario 3			Flow Alternative Scenario 4		
Stream	**Mean Annual Flow (cfs)**	**Diversion Season**	**Minimum Bypass Flow (cfs)**	**Maximum Diversion Rate (cfs)**	**Diversion Season**	**Minimum Bypass Flow (cfs)**	**Maximum Diversion Rate (cfs)**	**Diversion Season**	**Minimum Bypass Flow (cfs)**	**Maximum Diversion Rate (cfs)**	**Diversion Season**	**Minimum Bypass Flow (cfs)**	**Maximum Diversion Rate (cfs)**
E. Fk. Russian River Trib	0.13	12/15-3/31	0.3	0.1	1/1-12/31	0.3	0.1	12/15-3/31	2.4	0.1	10/1-3/31	1.9	1.3
Dry Creek Trib	2.2	12/15-3/31	6.8	1.5	1/1-12/31	5.6	3.2	12/15-3/31	19	1.5	10/1-3/31	10	5.5
Dunn Creek	2.5	12/15-3/31	4.3	0.8	1/1-12/31	5.5	0.1	12/15-3/31	17	0.8	10/1-3/31	8.5	4.7
Carneros Creek	3.8	12/15-3/31	2.7	1.5	1/1-12/31	6.6	9.0	12/15-3/31	22	1.5	10/1-3/31	9.8	13
Huichica Creek	7.4	12/15-3/31	6.1	3.0	1/1-12/31	14	1.8	12/15-3/31	32	3.0	10/1-3/31	12	11
Olema Creek	13	12/15-3/31	19	8.1	1/1-12/31	32	*na* [1]	12/15-3/31	50	8.1	10/1-3/31	18	*na* [1]
Pine Gulch Creek	12	12/15-3/31	16	6.2	1/1-12/31	25	1.1	12/15-3/31	42	6.2	10/1-3/31	14	37
Warm Springs Creek	35	12/15-3/31	39	20	1/1-12/31	92	11	12/15-3/31	99	20	10/1-3/31	30	43
Santa Rosa Creek	19	12/15-3/31	25	8.3	1/1-12/31	39	7.2	12/15-3/31	53	8.3	10/1-3/31	16	59
Albion River	20	12/15-3/31	21	11	1/1-12/31	51	10	12/15-3/31	52	11	10/1-3/31	15	37
Salmon Creek	25	12/15-3/31	21	12	1/1-12/31	50	13	12/15-3/31	63	12	10/1-3/31	18	69
Franz Creek	24	12/15-3/31	15	9.2	1/1-12/31	55	7.6	12/15-3/31	60	9.2	10/1-3/31	17	62
Lagunitas Creek	72	12/15-3/31	83	31	1/1-12/31	163	*na* [1]	12/15-3/31	124	31	10/1-3/31	29	*na* [1]

[1] - 1.5 year flood estimate not available from gage data

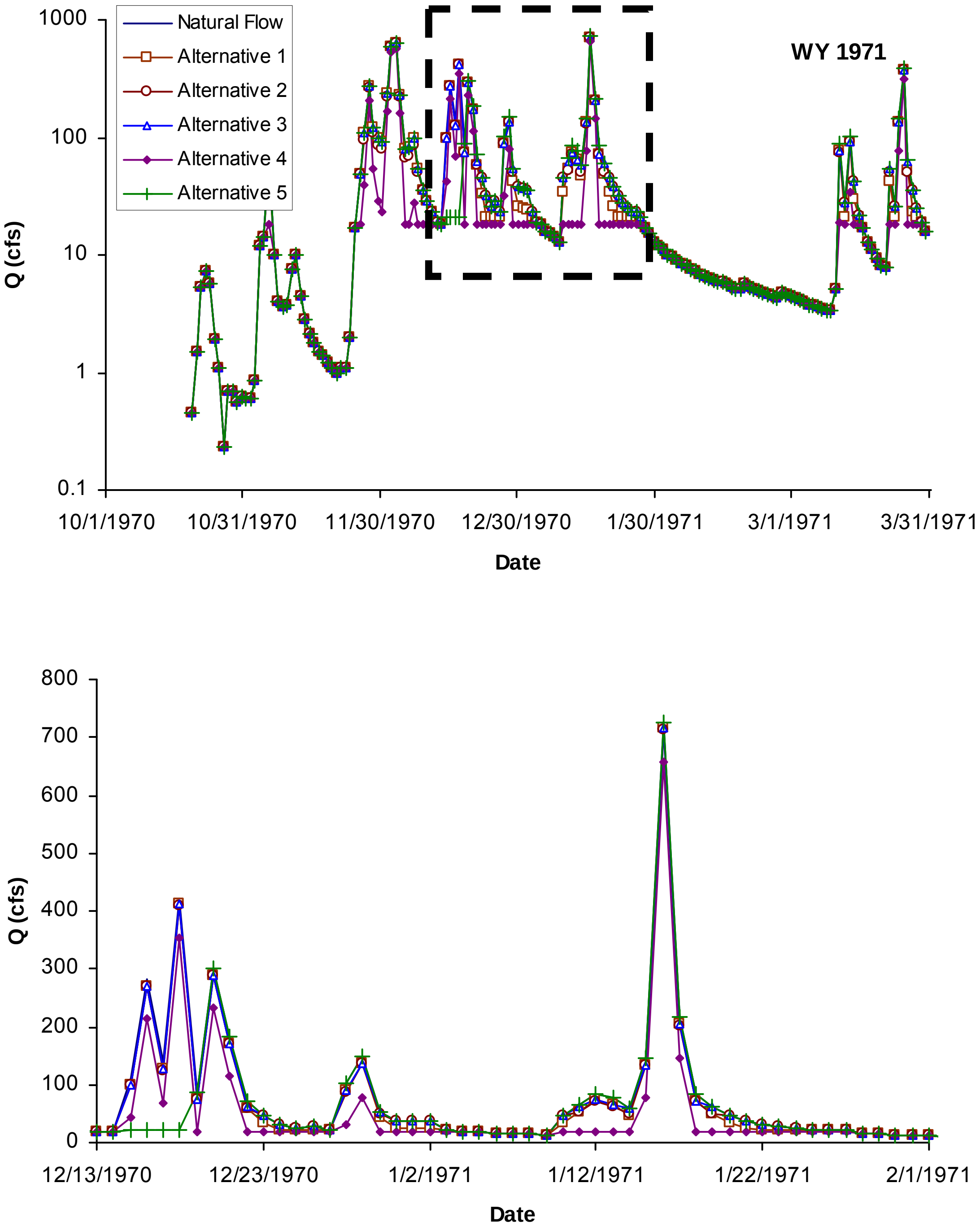


Figure 4-3. Example comparison of impaired hydrographs resulting from implementation of Flow Alternative Scenarios (listed in Table 4-2), for the October 1 – March 31 period of WY 1971 in the Salmon Creek validation site. Lower graph is an expansion of box indicated in upper graph.

4.2.1 Methods for Assessing Effects on Upstream Passage Needs

Methods used to analyze the effects (and conversely protectiveness) of Policy element alternative criteria to upstream passage are presented in detail in Appendix G. As shown in Figure 4-1, the habitat analysis for passage focused on quantifying the number of days that upstream passage was afforded in all 13 validation sites for each Flow Alternative Scenario. Protectiveness was inferred when the Flow Alternative Scenario (i.e., impaired flow time series) did not result in a substantial reduction in the number of days per water year that passage was afforded compared with unimpaired conditions. Two comparisons were made, in terms of (1) absolute and (2) percent difference in number of days from unimpaired flow conditions. A consistent, quantitative, biologically meaningful basis could not be identified for selecting a specific threshold, in terms of a number difference or a percent reduction, that distinguished between protective and non-protective flow conditions. For example, a 25 percent reduction in passage opportunities in a stream with few such occurrences each year could have greater biological significance to the indigenous anadromous salmonid stock than a comparable percent reduction in a stream with many days of passage afforded overall. It was thus necessary to invoke professional judgment when concluding whether a particular Flow Alternative Scenario (i.e., combination of Policy element alternatives) was protective or not.

In performing the analysis, one to two transects were sampled that best represented low flow passage barriers in the site after walking a length of stream and visually assessing low flow passage conditions. The number of transects depended on whether a single transect could be identified clearly as the low flow limiting condition for the length of site walked. Where uncertainty existed, two transects were placed at the two locations in the site that were perceived as being the most limiting to upstream passage at low flow.

The minimum flow providing passage was estimated for each passage transect sampled using a habitat-flow curve, where habitat was represented as a suitable width for passage (e.g., Figure 4-4). Where two transects were analyzed, the one requiring the highest minimum passage flow was used to represent limiting conditions in the site in comparisons between impaired and unimpaired flow conditions. Passage was considered feasible when a minimum 2 ft wide contiguous portion of the cross-section profile had a depth equaling or exceeding minimum depth criteria for each species. The upstream passage depth suitability criteria used in the analysis are presented in Table 2-1. The biological periods over which upstream passage was evaluated for the Flow Alternative Scenarios were, for each species:

a.	Steelhead:	From 11/1 through 3/31
b.	Coho:	From 10/1 through 2/28
c.	Chinook:	From 10/1 through 1/31

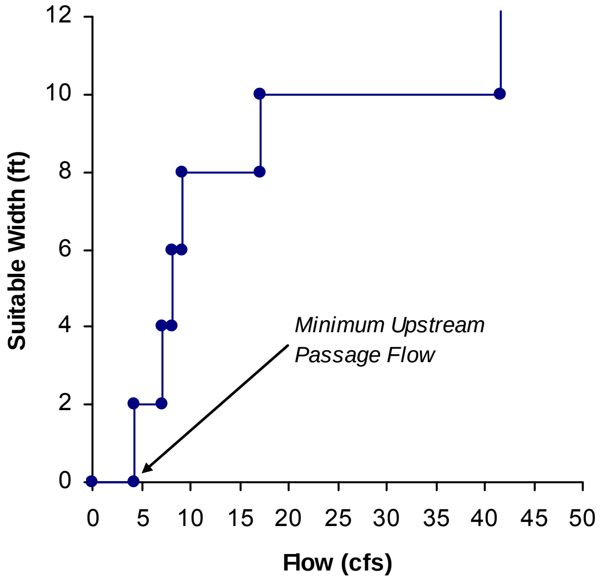


Figure 4-4. Identification of minimum upstream passage flow magnitude using a transect habitat-flow curve, as the lowest flow resulting in a 2 ft wide passage lane in the Dunn Creek validation site.

The protectiveness assessment included evaluating whether the daily flows associated with a Flow Alternative Scenario adversely affected upstream passage opportunities. Without a comprehensive habitat-flow sensitivity analysis for all thirteen sites (which was not possible for the given budget), it was not possible to completely partition out the effect of the MCD element on habitat availability from the effects of the MBF and diversion season elements. Professional judgment was therefore used to infer the protectiveness of the MBF and MCD element alternative criteria tested.

4.2.2 Methods for Assessing Effects on Spawning and Incubation Habitat Needs

Methods used to analyze effects (and conversely protectiveness) of Policy element alternative criteria to spawning and incubation habitat are presented in detail in Appendix G. As shown in Figure 4-1, the habitat analysis for spawning and incubation focused on quantifying the number of days that spawning was afforded across transects measured in 12 validation sites for each Flow Alternative Scenario (potential spawning habitat was not present in the accessible reach of one site). Spawnable substrates were only considered useable for successful reproduction if they remained wetted by 0.1 ft of water or more over the modeled duration of incubation (see Appendix G). Protectiveness was inferred when the impaired flow time series did not result in a substantial reduction in the number of days per water year that reproduction could occur successfully, compared with unimpaired conditions. Two comparisons were made, in terms of (1) absolute and (2) percent difference in number of days from unimpaired flow conditions. As for passage, a consistent, quantitative, biologically meaningful basis could not be identified for selecting a specific threshold in terms of a number difference or a percent reduction that distinguished protective and non-protective flow conditions. For example, a 25 percent reduction in the number of days spawning could occur successfully in a stream with few such occurrences each year could have greater biological significance to the indigenous anadromous salmonid stock than a comparable percent reduction in a stream with many days of spawning afforded overall. Professional judgment was therefore used when concluding whether a particular Flow Alternative Scenario (i.e., combination of Policy element alternatives) was protective or not.

In performing the analysis, one to two transects were sampled that best represented good quality spawning habitat in the site after walking a length of stream and visually assessing geomorphic and flow conditions. Transects were placed in channel locations where spawning was expected to occur based on professional experience. Typically, transects were placed preferentially over the pool edge/riffle crest interface, representing classic salmonid spawning habitat. The number of transects depended on the availability of spawning habitat within the length of site walked.

The minimum flow providing spawning was estimated for each transect based on depth, velocity, and substrate suitability criteria. Where two transects were analyzed, the one requiring the lowest minimum spawning flow was used to represent the site. The spawning habitat suitability criteria used in the analysis are presented in Table 2-2. The durations over which spawning habitat must remained wetted by at least 0.1 ft of water are presented in Table 2-3 for two general incubation periods, corresponding to before and after March 1. The lengths of incubation reflected general temperature trends recorded at USGS gages for the region. Species specific biological periods over which spawning activity was considered possible based on information summarized in Appendix C were:

a. Steelhead: from 12/1 through 3/31
b. Coho: from 11/1 through 2/28
c. Chinook: from 11/1 through 1/31

The protectiveness assessment included evaluating whether daily flows associated with each Flow Alternative Scenario adversely affected spawning habitat availability. As for the passage habitat analysis, it was not possible to completely partition out, or compare the effects of the MCD element on habitat availability from the effects of the MBF and diversion season elements. Professional judgment was therefore used to assess the protectiveness of the MBF and MCD element alternative criteria tested.

4.2.3 Methods for Assessing Effects on Juvenile Winter Rearing Habitat Needs

As discussed in Chapter 2 and Appendix D, juvenile anadromous salmonid winter rearing habitat was assumed to be protected if the flows provided by the MBF protected spawning and incubation habitat. High flow habitats and their accessibility could not be related directly to flow metrics given the high degree of site-specificity of the relationship. Such habitats were assumed to be protected if natural flow variability was preserved through the MCD element.

4.2.4 Methods for Assessing Effects on Outmigration Needs

Given the uncertainty discussed in Chapter 2 and Appendix D regarding clearly defining flow-based criteria protecting outmigration, it was not possible to identify a regional flow criterion that could be used to establish protectiveness. Instead, protectiveness was evaluated indirectly in terms of the effects of changing the end date of the diversion season relative to availability of pulse flows and seasonal increases in water temperature in the spring. The assessment relied primarily on existing literature.

4.2.5 Methods for Assessing Effects on Channel and Riparian Maintenance Needs

The analysis of protectiveness of channel and riparian maintenance flows involved estimating or hypothesizing changes in channel morphology and riparian condition that might occur from the different Policy element alternative criteria and the corresponding effects on anadromous salmonid habitat quantity and quality. The primary metric analyzed was the percent change in bankfull flow and the resulting changes in three fundamental morphologic attributes, bankfull depth, width, and surface grain size characteristics. This analysis was made based on a relationship derived from general gravel bed river data (Figure 2-1; details on derivation and rationale for using bankfull flow are given in Appendix D). However, the scatter of data used to generate the relations was large, resulting in uncertainty in the predictions of channel change. Increasing the level of confidence in such predictions would require extensive site-specific hydrograph and sediment transport analyses. Even then, additional uncertainty exists when attempting to relate morphologic changes to changes in anadromous salmonid habitat quantity and quality.

Therefore, protectiveness of channel and riparian maintenance flows was assumed to be provided by implementing a protective MBF and proposing a MCD that results in a relatively small level of channel morphology change. In the absence of clearly defined alternative criteria, the three cumulative diversion rate alternatives proposed by DFG-NMFS (15% of 20% winter daily exceedance flow; 5% of the 1.5 year flood) and MTTU (the diversion rate resulting in a half-day reduction in the duration of the MBF during the 1.5 year flood event), and the volume based CFII alternative proposed by DFG-NMFS, were evaluated for their effect on bankfull flow in terms of how they would change the 1.5 year flow magnitude in the validation sites. The assessment relied primarily on existing literature for determining direct effects on channel form and riparian condition and in turn anadromous salmonid habitat.

4.2.6 Methods For Assessing Estuary Habitat/Ocean Connectivity

As discussed in Chapter 2 and Appendix D, it was not possible to directly identify a regional flow criterion that could be used to protect estuarine habitat and provide ocean connectivity during the summer. Protectiveness was instead indirectly evaluated by comparing flow characteristics reported in the literature as being required for sand bar breaching, with the general level of base flows occurring during the diversion season associated with impaired Flow Alterative Scenarios.

4.3 HABITAT ANALYSIS RESULTS USED TO ASSESS PROTECTIVENESS

The results presented and discussed in this section were used as the basis for conclusions regarding the protectiveness of the three Policy elements restricting diversion on anadromous salmonid habitats.

4.3.1 Upstream Passage

Curves were developed that depicted the width of stream passable as a function of flow for each of the 13 validation sites (see Appendix H). In this case, habitat time series were derived by applying habitat-flow curves in Appendix H to flow time series for each site. An example of the resulting relationship is presented in Figure 4-5 for steelhead in Salmon Creek corresponding to the impaired flow time series depicted in Figure 4-3. The term ‘habitat’ refers to width of stream bed predicted to be passable that day. The data depicted in Figure 4-5 were used to determine the number of days that passage was possible, where for example any non-zero data point depicted in Figure 4-5 corresponded to a day with passage (the minimum passable width was set at 2 feet, where having wider passage lanes does not affect the ability to pass). The analysis focused on assessing changes in the total number of days that passage was predicted to be possible for each Flow Alternative Scenario (i.e., days with potentially successful passage opportunities).

The average number of days per year of potential upstream passage opportunities afforded by the unimpaired flow and each impaired Flow Alternative Scenario for all 13 validation sites are depicted by species in Figures 4-6 to 4-8 (based on data in Appendix I). Also presented in Appendix I are the results for the two water years with the fewest and most days of passage (these may not necessarily equate to wet and dry years, as the length and years of record vary among the gages).

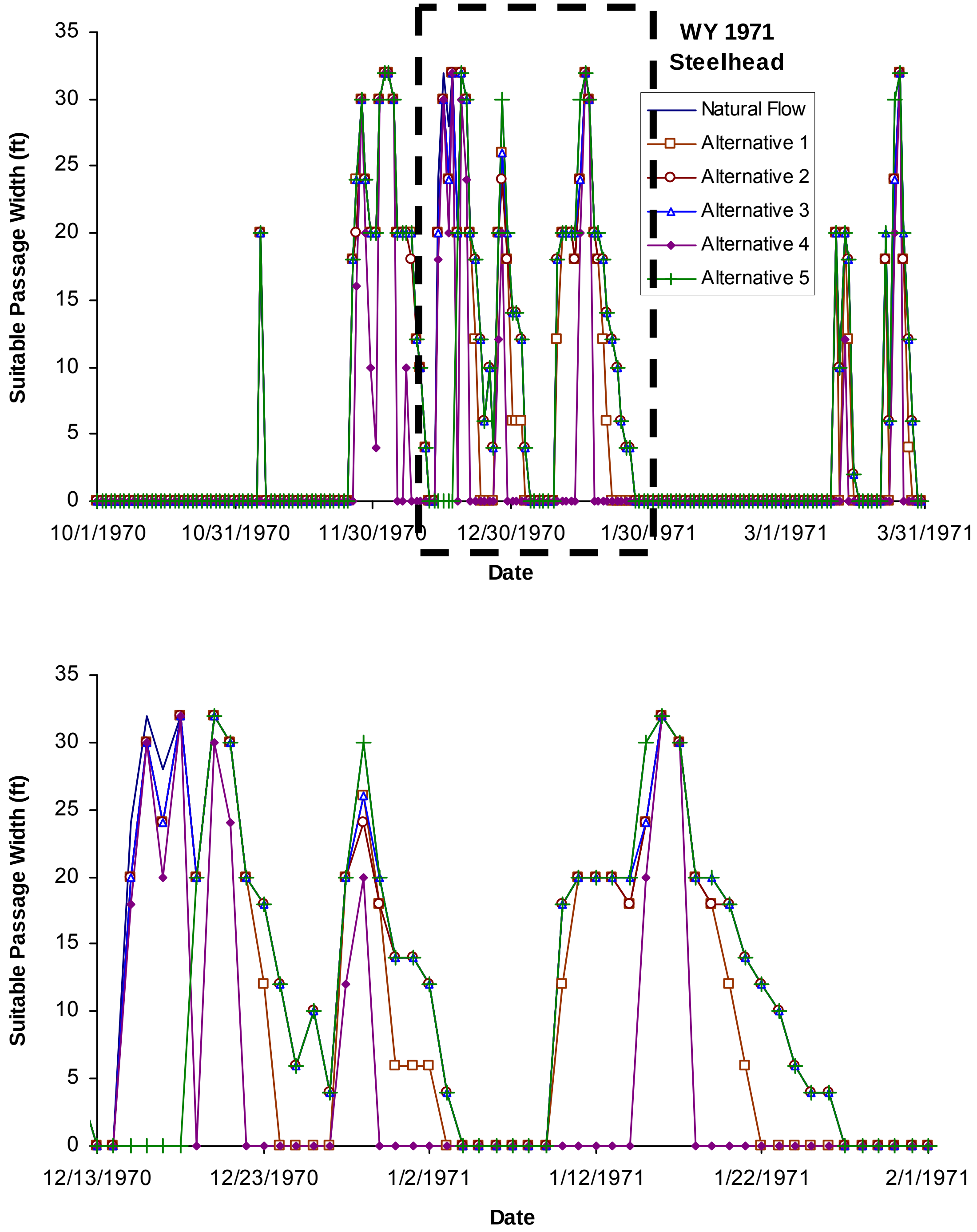


Figure 4-5. Comparisons of habitat time series for steelhead trout upstream passage resulting from implementation of Flow Alternative Scenarios (listed in Table 4-2), for the October 1 – March 31 period of WY 1971 in the Salmon Creek validation site. Lower graph is an expansion of box indicated in upper graph.

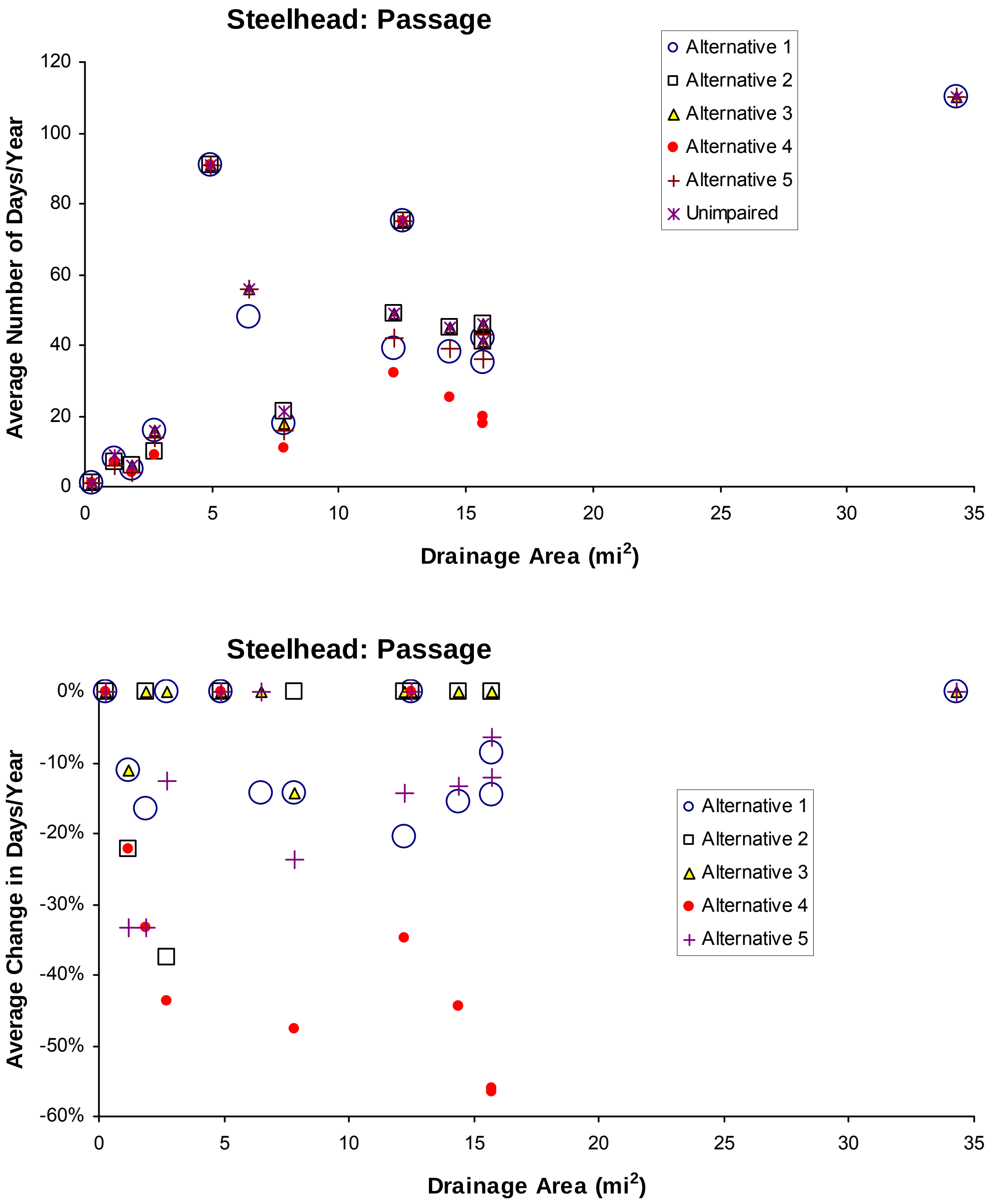
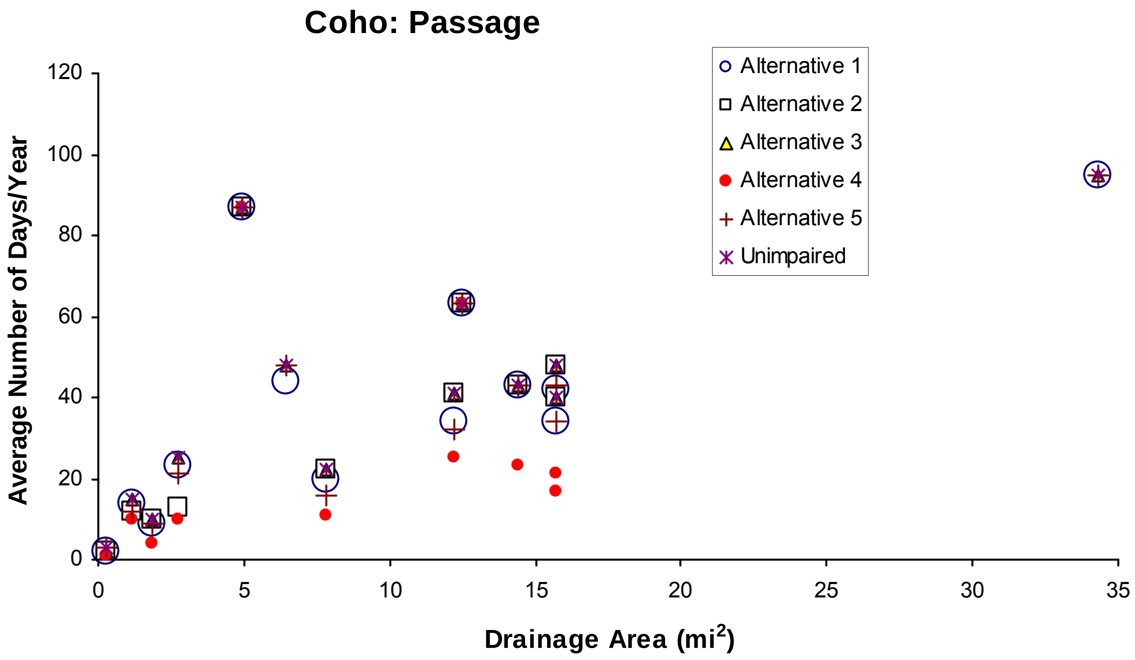


Figure 4-6. Predicted effects of the Flow Alternative Scenarios on upstream passage opportunities for steelhead trout in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom), as a function of drainage area.



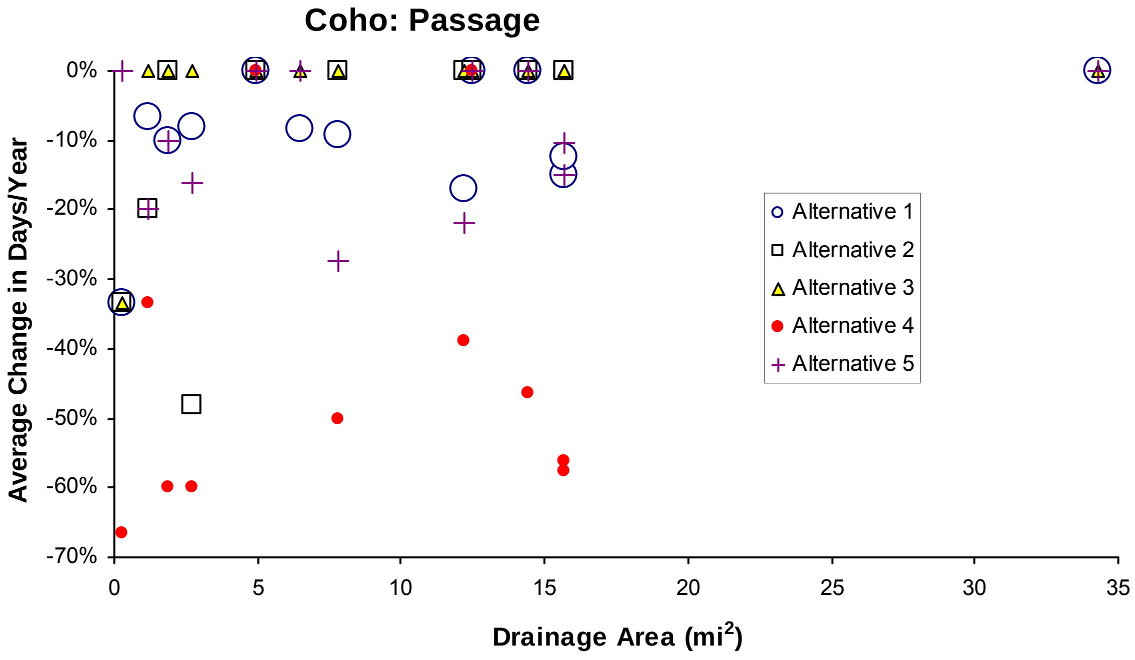
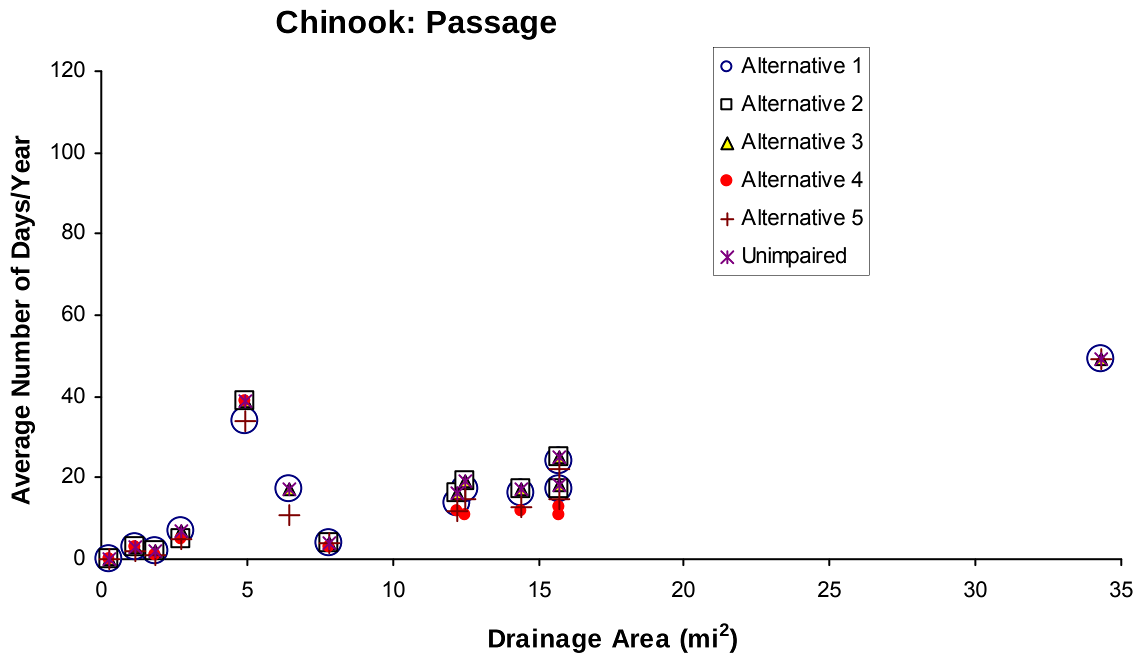


Figure 4-7. Predicted effects of the Flow Alternative Scenarios on upstream passage opportunities for coho salmon in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom), as a function of drainage area.



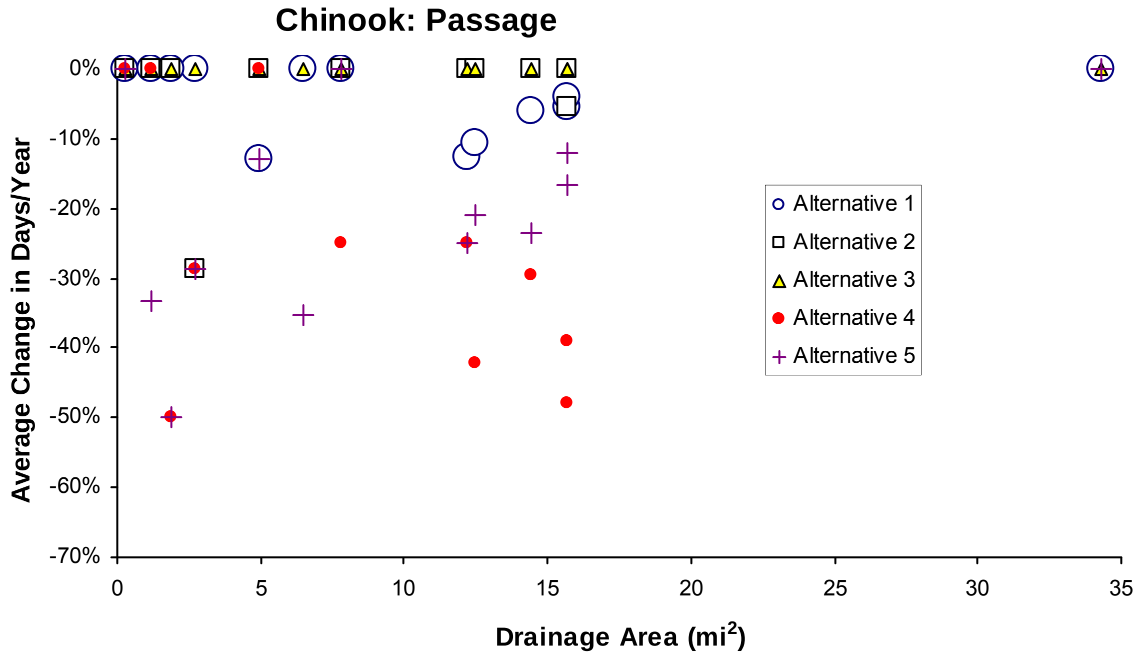
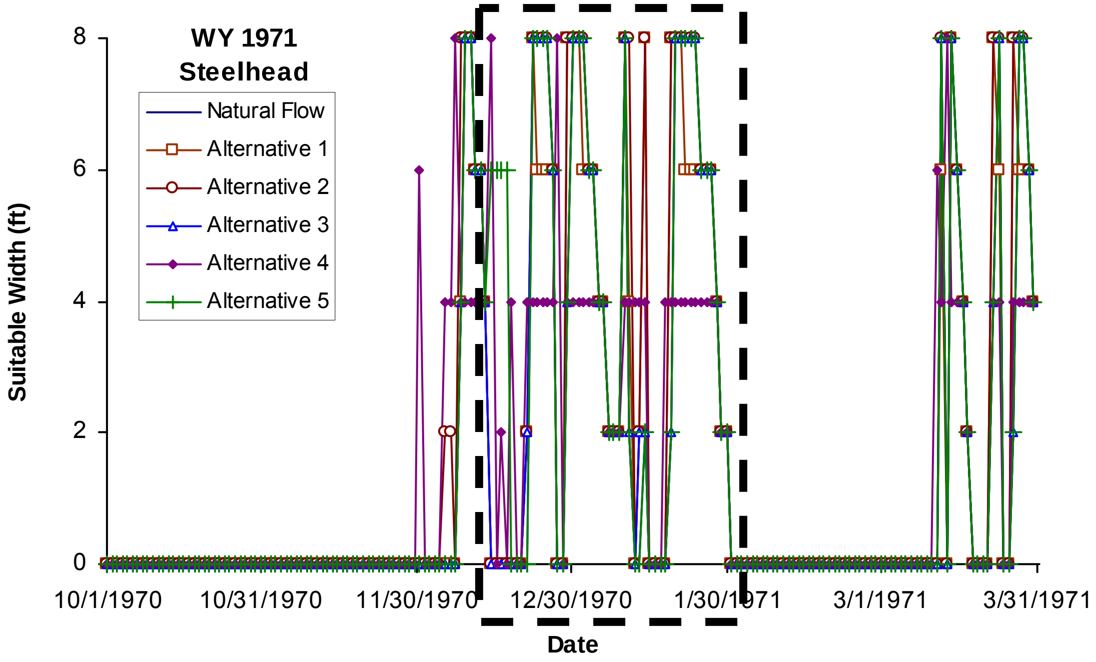


Figure 4-8. Predicted effects of the Flow Alternative Scenarios on upstream passage opportunities for Chinook salmon in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom), as a function of drainage area.

4.3.2 Spawning and Incubation

Curves were also developed of the relationships of the width of stream available for spawning as a function of flow for each of the 13 validation sites (see Appendix H). As for upstream passage, habitat time series were derived by applying spawning habitat-flow curves in Appendix H to flow time series for each site. Figure 4-9 depicts an example of the resulting relationship for steelhead in Salmon Creek corresponding to the impaired flow time series depicted in Figure 4-3. In this case, the term ‘habitat’ refers to the width of streambed with suitable depths, velocities and substrates available for a given day that stays wetted over the incubation season, thus providing for successful reproduction. The data depicted in Figure 4-9 can be used to assess effects in terms of the number of days that spawning habitat is provided, as well as relative changes in total habitat availability. For example, when unimpaired flows are relatively high, Flow Alternative Scenario 4 can be seen to result in a few days with more spawning habitat available than the other Flow Alternative Scenarios.

This analysis focused primarily on assessing changes in the total number of days that spawning habitat would be provided (i.e., days with potentially successful spawning opportunities; details on how spawning was determined to be successful are given in Appendices G and H), rather than an evaluation of the quantity of spawning habitat which would have required the placement and measurement of several more transects at each site. Accordingly, the total number of days was summed for each water year with complete unimpaired and impaired flow records, for each site. The average number of days per year with potential spawning opportunities afforded by the unimpaired flow and each impaired Flow Alternative Scenario for all 13 validation sites over all water years, are presented in Figures 4-10 to 4-12 (see Appendix I for details). Also presented in Appendix I are the results for the two water years with the fewest and most days with potentially successful spawning opportunities (these may not necessarily equate to wet and dry years, as the length and years of record vary among the gages).



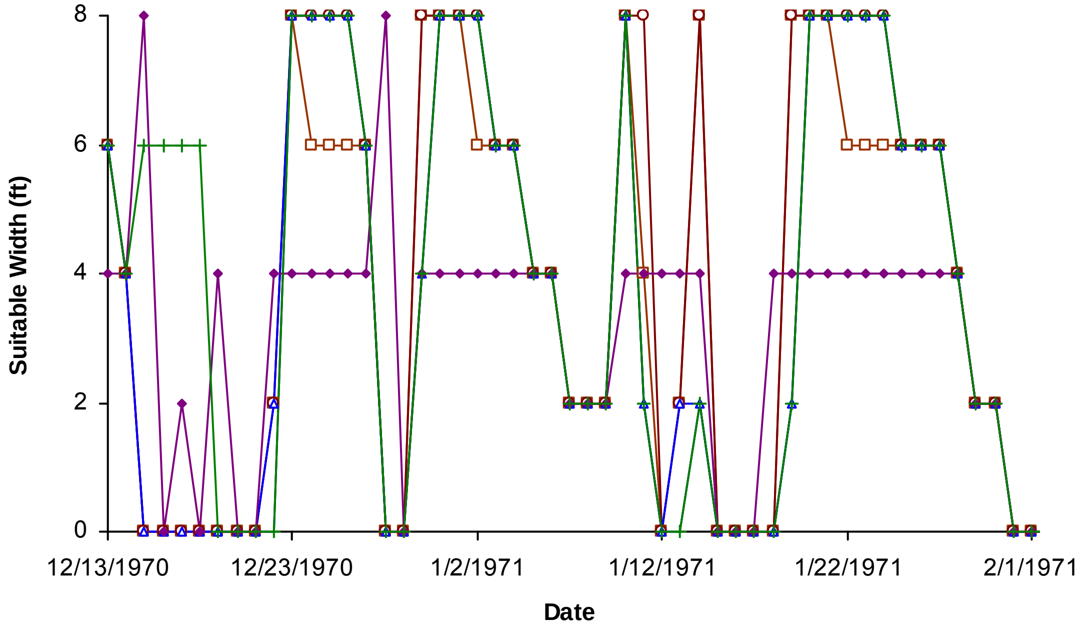
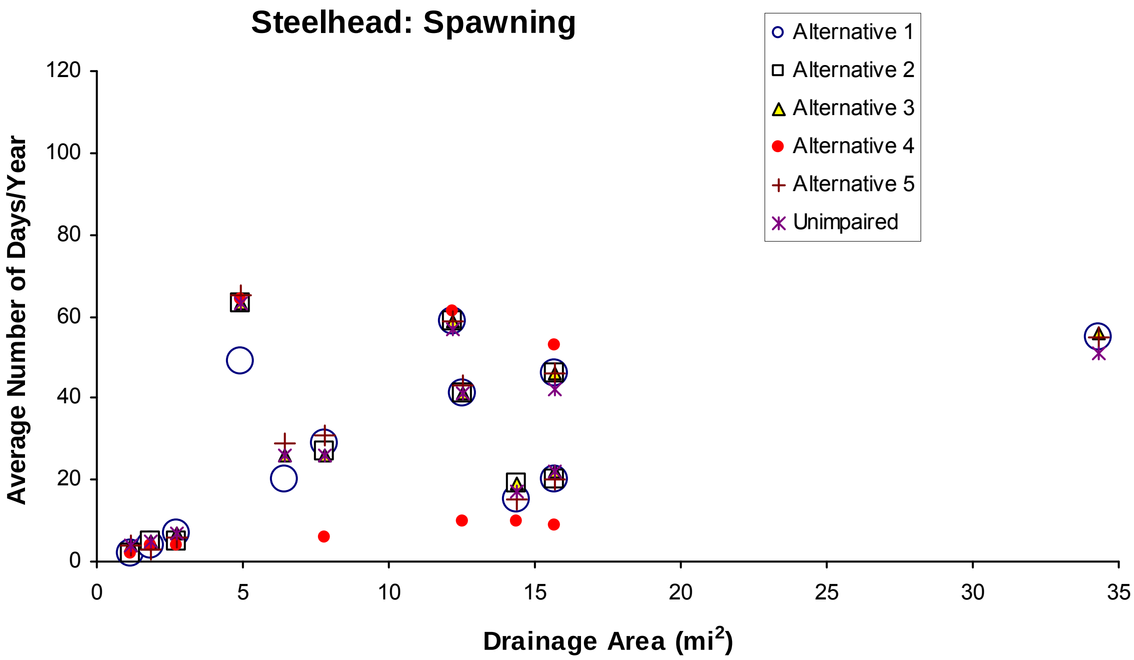


Figure 4-9. Comparisons of habitat time series for steelhead trout spawning and incubation resulting from implementation of Flow Alternative Scenarios involving a MCD rate criterion (listed in Table 4-3), for the October 1 – March 31 period of WY 1971 in the Salmon Creek validation site. Lower graph is an expansion of box indicated in upper graph.



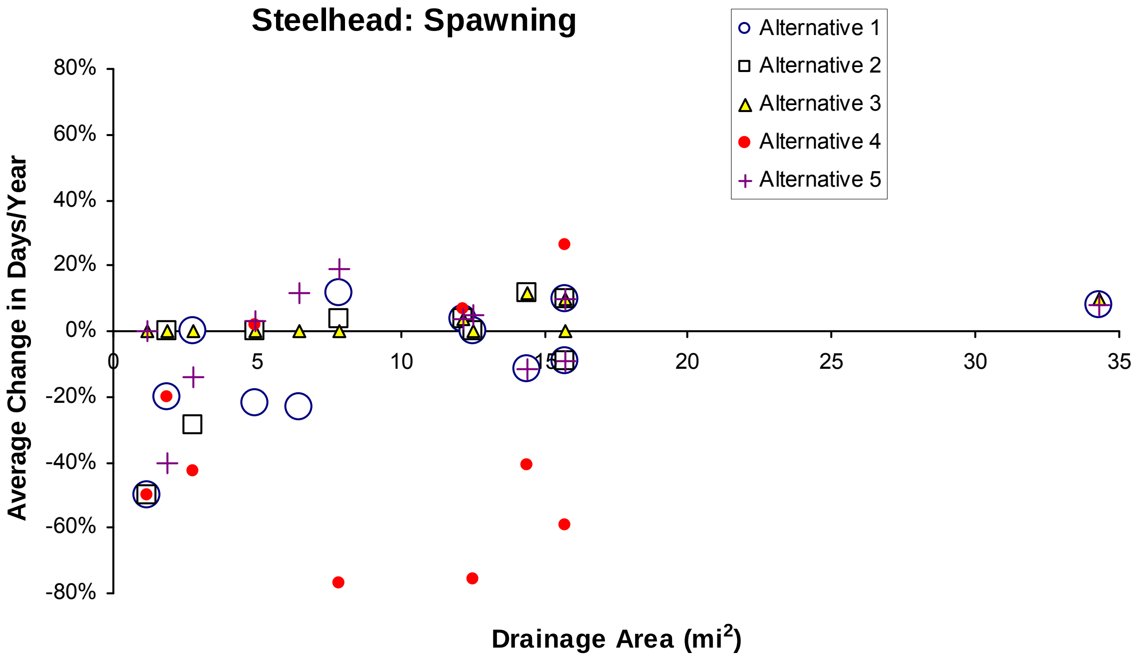


Figure 4-10. Predicted effects of the Flow Alternative Scenarios on spawning opportunities for steelhead trout in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom). Data are plotted against each site's drainage area and are summarized from information presented in Appendix I.

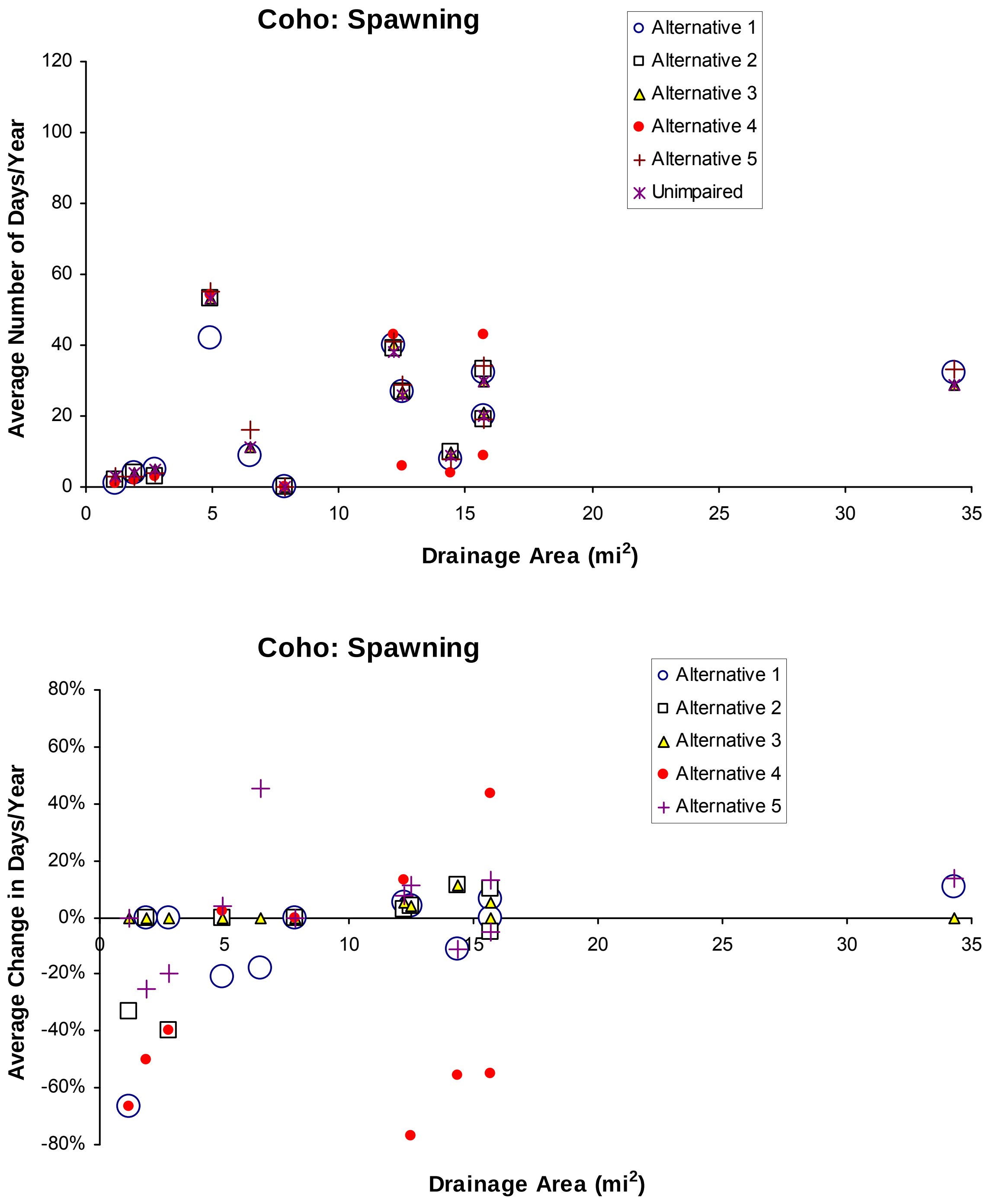
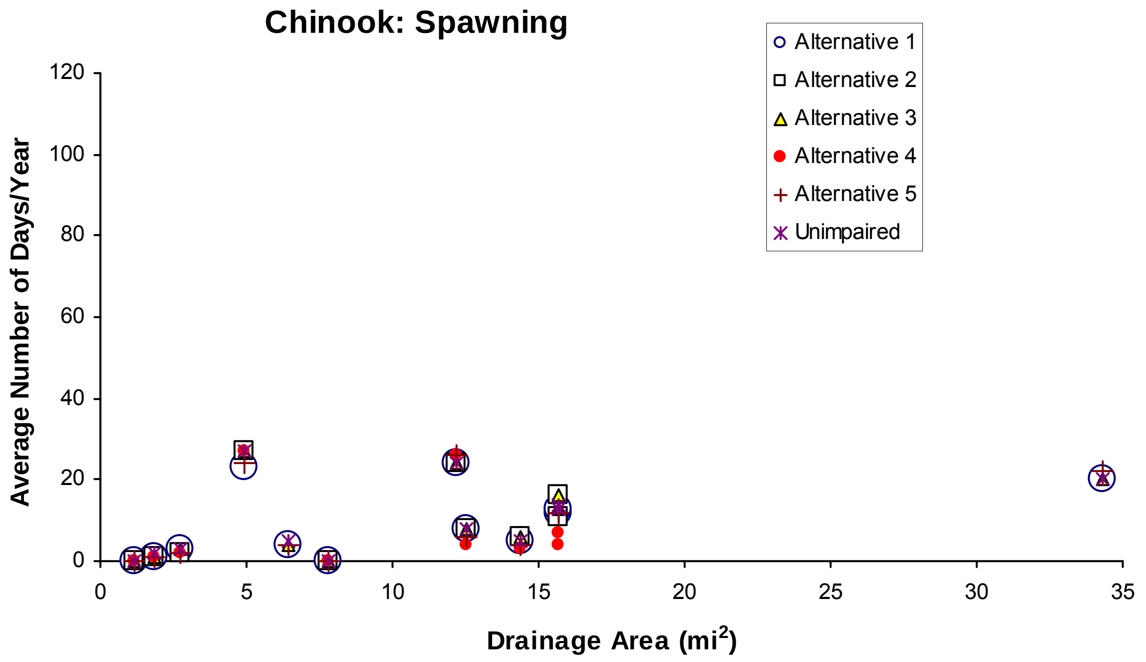


Figure 4-11. Predicted effects of the Flow Alternative Scenarios on spawning opportunities for coho salmon in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom). Data are plotted against each site's drainage area and are summarized from information presented in Appendix I.



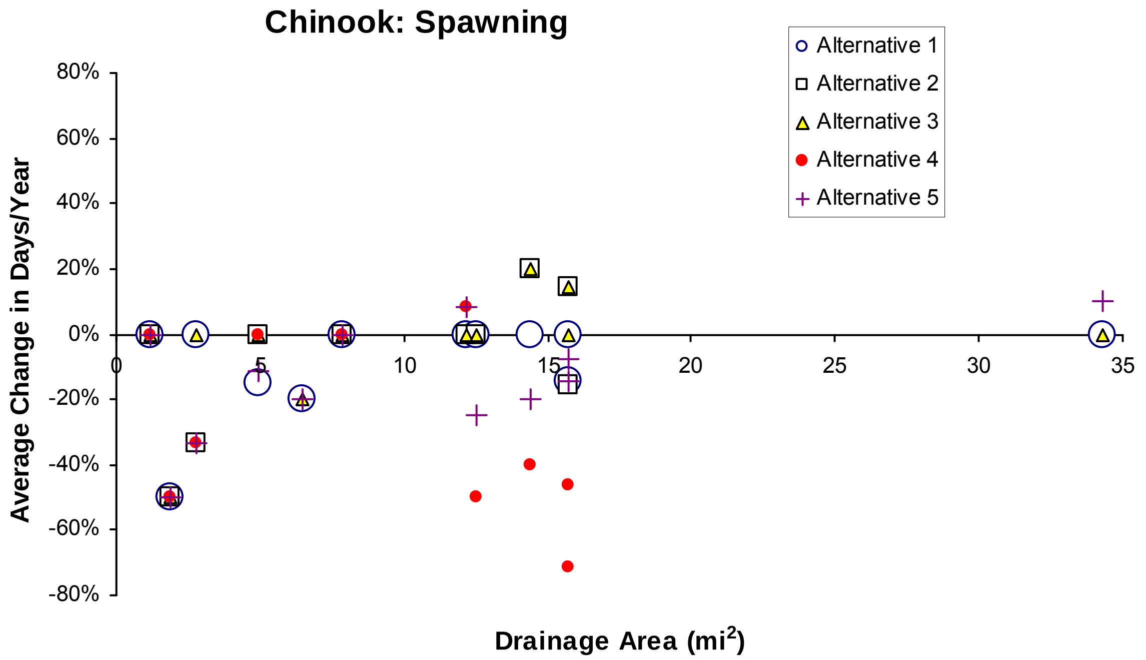


Figure 4-12. Predicted effects of the Flow Alternative Scenarios on spawning opportunities for Chinook salmon in the validation sites, expressed as average number of days per year (top) and percent change from estimated unimpaired flow conditions (bottom). Data are plotted against each site's drainage area and are summarized from information presented in Appendix I.

4.3.3 Juvenile Winter Rearing

There were no specific habitat-flow results for juvenile winter rearing habitat. As discussed in Chapter 2 and Appendix D, this habitat component was assumed protected by provision of spawning habitat through the MBF element and by maintaining natural flow variability through the MCD element.

4.3.4 Outmigration

The results of the literature review indicated that water velocity, temperature, level of smolt development, time of year and possibly turbidity can all influence the downstream migration of juvenile salmonids (Giorgi et al. 1985; Beeman and Rondorf 1992; Berggren and Filardo 1993; Achord et al. 1994; Buettner and Brimmer 1995; Skalski and Townsend 1999). Many of these factors are related to high flow and were considered when assessing protectiveness. There are primarily two ways described below in which diversion in the Policy area could adversely affect outmigration: through the effects of physical changes in flow rate on migration behavior, and through physiological effects of water temperature.

For example, the reduction in flow velocities caused by low to moderate rates of diversion in the Policy area has the potential to directly affect both (1) initiation of migration and (2) travel time of outmigrants as they head downstream to the ocean. The effect of reduced water velocity in the spring can be qualitatively evaluated by assuming that travel time is inversely proportional to water velocity. Average water velocities during spring runoff in Policy area streams may typically be between 3-10 ft/s (cf. Leopold et al. 1995), or 50-160 miles/day. Manning et al. (2005) tracked outmigrating steelhead smolts in the Russian River and observed travel speeds averaging around 9-12 miles/day. These speeds were similar to results from the previous year and for hatchery fish that exhibited speeds ranging from 3.7-12 miles/day, and appeared to be independent of differences in flow across years. Demko et al. (1998) observed travel speeds of Chinook smolts in the Central Valley ranging on the order of 5-7 miles/night. These speeds were generally less than average water particle speeds during high flow. However, Moser et al. (1991) noted faster, short-term travel speeds for coho of up to 36-64 miles/day, and longer duration speeds averaging 18 miles/day. Chinook migration rates have been observed in the Willamette River in Oregon to approximate 70 miles/day (Bradford et al. 1990). These rates are relatively fast, and most Policy area streams are comparatively short in length. Hence, the direct effects of flow reductions in Policy area streams during periods of smolt outmigration would not likely be biologically significant because they are unlikely to affect smolt swimming speeds and rates of downstream movement to an extent where delays in reaching the ocean would result in biologically meaningful consequences.

However, effects could still be indirectly manifest if flow reductions resulted in warming of water temperatures which can increase stress and incidence of disease. Temperatures of 15°C and

19ºC approximate the limit to optimal juvenile salmon growth, and the approximate onset of feeding inhibition and avoidance during migration, respectively (ODEQ 1995; McCullough 1999). These temperatures are generally reached in Policy area streams between March-May (15ºC) and April-July (19ºC), respectively, depending on the stream and location in the channel network (USGS water quality data). Temperature preference has been correlated with optimal growth temperature, and the general preference of juvenile salmonids appears to be for temperatures 15ºC and lower (McCullough 1999). Water temperatures around 15ºC and higher have been found to cause premature smolting and/or de-smoltification (failure to smolt), which may influence the numbers of fish reaching the estuary and successful transition to saltwater. This phenomenon has been observed for steelhead, Chinook and coho juveniles, with steelhead smolts appearing to undergo reverse smoltification more readily at elevated temperatures than salmon species (Wedemeyer et al. 1980). Elevated water temperatures could thus affect steelhead smolts more strongly than coho and Chinook smolts in Policy area streams, although all three species would likely be susceptible to adverse effects of elevated temperatures beginning in March.

4.3.5 Channel and Riparian Maintenance

As discussed in Appendix D, the literature indicates that the 1.5-year flood magnitude, as derived from an annual maximum flood series, is a hydrologic metric that can be used as an estimate of the bankfull flow or effective discharge magnitude. The bankfull flow metric can be applied throughout a drainage basin, and is a surrogate that effectively integrates the effects of magnitude, frequency and duration of high flows forming the channel and affecting riparian condition.

The clearest conclusion that could be inferred from the analysis of channel and riparian maintenance flow needs is that a greater rate of diversion is less protective than a smaller rate, but it was not possible to identify a clear threshold between protective and non-protective diversion rates or volumes in the context of anadromous habitat needs. The MCD Policy element has the most significant impact on channel and riparian maintenance flows.

Table 4-4 summarizes predicted percent reductions of the 1.5 year flood magnitude caused by implementing each MCD alternative criterion as part of the Flow Alternative Scenarios, as estimated for the four validation sites with the longest stream gage records (see section F.4 in Appendix F for details). The 15% of the winter 20% exceedance flow rate and the comparable magnitude diversion rate proposed by MTTU (2000) are predicted to result in negligible channel change based on a comparison of the percent reductions in Table 4-4 with Figure 2-1. The CFII = 10% alternative criterion proposed in the DFG-NMFS (2002) Draft Guidelines results in the greatest predicted change, at levels that according to Figure 2-1 could result in large changes in channel morphologic characteristics. Therefore, the CFII = 10% level does not appear to be regionally protective of channel maintenance flow needs. Based on professional judgment, the

5% of the 1.5 year flood magnitude appeared to have the potential to result in relatively small channel changes according to Figure 2-1 and be the closest of the MCD element alternative criteria to a protective regional channel maintenance threshold. Smaller diversion rates have a greater potential to be overly protective.

Hence, it was concluded in the analysis that specification of a protective maximum cumulative diversion limitation should involve an element of conservativeness, whereby a level is proposed that is considered by professional judgment to have a low risk of reducing channel size and surface grain size distribution over the long and short terms, respectively. Given the level of uncertainty in specifying a MCD that is protective of channel and riparian maintenance flow needs, it was concluded that effectiveness monitoring would be key to determining protectiveness in this context, particularly with respect to establishing whether additional water may be diverted.

Table 4-4. Estimated Reduction in the 1.5 Year Flood Peak Flow Rate Associated with Implementation of the Five Flow Alternative Scenarios, in Four Validation Sites with at Least Ten Years of Stream Flow Records.

		Percent Reduction in 1.5 Year Flood Magnitude by Flow Alternative Scenario				
Validation Site	**Unimpaired 1.5 Year Flood (cfs)**	**Flow Alternative Scenario 1** **(MCD1: 15% of 20% Winter Exceedance Flow)**	**Flow Alternative Scenario 2** **(MCD4: Reduce MBF Duration for 1.5 Year Event by ½ Day)**	**Flow Alternative Scenario 3** **(MCD1: 15% of 20% Winter Exceedance Flow)**	**Flow Alternative Scenario 4** **(MCD2: 5% of 1.5 Year Flood Flow Rate)**	**Flow Alternative Scenario 5** **(MCD3: CFII=10%)**
Albion R	1,020	1%	1%	1%	5%	31%
Salmon Cr	1,440	1%	1%	1%	5%	21%
Santa Rosa Cr	1,170	1%	1%	1%	5%	37%
Warm Springs Cr	690	3%	2%	1%	5%	13%

The estimated unimpaired 1.5 year floods reported in Table 4-4 (and in Table F-15 in Appendix F) may differ from those reported in Table F-13 in Appendix F. The unimpaired 1.5 year floods computed in Table 4-4 for comparison of the unimpaired and impaired scenarios were calculated only for the period of complete record of both unimpaired and impaired peak data to provide a meaningful comparison, as described in Section F.3.3 and also reported in Table F-15 in Appendix F. The unimpaired 1.5 year floods computed for each of the 11 validation sites for use in determining MCD2 and MCD4 were calculated from the full period of record of unimpaired instantaneous measurements to provide the most accurate estimate of the 1.5-year flood event, as described in Section F.2.6 and reported in Table F-13 in Appendix F.

4.3.6 Estuary Habitat/Ocean Connectivity

The literature review indicates that sand bar closing generally occurs during the summer months. The reduction of flows during the fall months could potentially delay sand bar breaching. Presently, sand bar breaching is artificially induced in some systems to meet various management goals and ensure impacts to aquatic fauna are minimized. In the case of the Russian River, management of flows into the estuary involves coordinated flow releases from Warm Springs and Coyote Valley dams during the summer months. Management actions can include mechanical breaching of the sandbar at the mouth to allow adult Chinook and coho access to the river during dry and critical water supply conditions. Artificial breaching has allowed some adult Chinook salmon to enter the Russian River as early as August, although the majority of upstream migration generally occurs in October or November when water temperatures are more favorable. The overall objective of a present multiagency estuary management proposal (Russian River Estuary Flow-Related Habitat Project; Cook 2004, Entrix 2004) is to improve adult passage and juvenile rearing habitat for listed salmonid species, while preventing flooding. Given the extent to which the Russian River and other affected estuaries are managed by artificial breaching, the Policy is unlikely to have direct biological effects in those systems.

In systems not managed by artificial breaching, the literature review indicated that the amount of flow required to breach the blocking sand bar tends to reflect a minimum flow level, not the peak magnitude of a pulse flow event during the fall. There does not appear to be one flow level associated with breaching because of various other physical factors involved. Findings in the literature and gage data suggest that the range of base flows occurring during the winter period typically exceeds the flow at which sand bar blockage occurs. For example, estimates of the flow needed in the Navarro River to keep the mouth open throughout the summer range from around 5 cfs (Cannata 1998) to 25 cfs (Fisk 1955). Mean monthly flow during the winter period at the Navarro River gage generally exceeds 30 cfs from October through June (USGS station 1146800). October flows in some years are less than 5 cfs, but on average the base flow exceeds the flow needed to breach the sand bar. As another example, the Mattole River sand bar was observed to close when flows were between 44-133 cfs at the Petrolia gage (USGS station 1146900; MRC 1995). Mean monthly flow during the winter period at this gage generally exceeds 200 cfs from October through June, although October flows in some years are less than 44 cfs. Specification of a minimum bypass flow that equals or exceeds winter base flow levels would ensure sand bar breaching dates would not differ from unimpaired flow conditions.

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5. PROTECTIVENESS OF DIVERSION SEASON ELEMENT ALTERNATIVE CRITERIA

This chapter analyzes the protectiveness of diversion season element alternative criteria for anadromous salmonids and their habitat in the Policy area. The analysis interprets results identified in Chapter 4, Appendix D, and in other relevant literature. The analysis focused particularly on differences in the five Flow Alternative Scenarios (Tables 4-2 and 5-1) with unimpaired flow conditions.

Table 5-1. Description of Diversion Season Element Alternative Criteria Evaluated in the Analysis of Protectiveness

Diversion Season Alternatives	Description	Impaired Flow Analysis
DS1 (DFG-NMFS 2002)	12/15-3/31	Flow Alternative Scenario 1, 3, & 5
DS2 (MTTU 2000)	Year Around	Flow Alternative Scenario 2
DS3 (Consulting Engineers 2006 Scoping Comments)	10/1-3/31	Flow Alternative Scenario 4

5.1 ANALYSIS OF PROTECTIVENESS

The times of year when new diversions can be permitted in the Policy area without adversely impacting anadromous salmonids are generally restricted to the winter high flow period, which generally corresponds to the months of December through March, although diversion may also be possible in the late fall months during storm events. During the diversion season, primary instream flow needs are protected by appropriate MBF and MCD element criteria. The winter diversion season specification also reflects the need to prevent permitting further diversion during the critical late spring, summer, and early fall months when low flows may substantially limit juvenile habitat quantity and quality in Policy area streams. Therefore, the protectiveness of the diversion season element hinges on specification of appropriate starting and ending dates that preclude the potential for adverse effects of winter diversion. The year-round alternative (DS2) is therefore not considered a feasible option.

5.1.1 Upstream Passage

Upstream passage needs have the potential to affect the beginning date of the diversion season. Upstream migration of anadromous salmonids in the Policy Area generally begins first with Chinook in September or October depending on the stream. Coho begin migrating upstream in substantial numbers in October, followed by steelhead in November (see Appendix C for details). The upstream migration of each species generally occurs opportunistically as flow conditions allow. Low flow years may be associated with infrequent upstream movement triggered by suboptimal flow increases, whereas wet years with numerous high flow events may allow a more even distribution of fish entry, upstream migration, and spawning (e.g., Tetzlaff et al. 2005). With protective MBF and MCD elements in place, the effect of the diversion season element should be minor on hydraulic conditions affecting upstream passage.

Water temperatures can influence upstream migration behavior during the October-December period when stream flows are increasing, and air and river temperatures are falling (NCRWQCB 2000). Adults generally do not migrate upstream until water temperatures are suitable, typically below 21ºC (McCullough 1999). Water temperatures in Policy area streams are generally near or above this level in September and below this level in October (USGS data). Thus, although stream flow reductions can increase periods of warmer water temperatures, diversions made after October 1 have a lower probability of interfering with upstream passage ability than diversions occurring earlier. As such, there does not appear to be a distinguishable difference in terms of protectiveness between the DS1 and DS3 alternative criterion start dates to the winter diversion season. Comparison of the results of the different Flow Alternative Scenarios in Appendix I indicates that the diversion season length has less influence on passage opportunities than the MBF and MCD. This suggests that the earlier diversion date (October 1) should be equally protective compared with the December 15 date, as long as protective MBF and MCD criteria are met. For example in Franz Creek (Figure I-12), it was predicted that the combined effect of lower MBF and higher MCD under Flow Alternative Scenario 4 would consist of substantial reductions in passage opportunities compared with Flow Alternative Scenario 2. At the same time, Flow Alternative Scenario 3, which involved the most protective combination of diversion season, MBF and MCD (see Table 3-1), does not substantially reduce passage opportunities compared with unimpaired flow conditions, in terms of number of days per year.

5.1.2 Spawning and Incubation Habitat

The major spawning activity in Policy area streams generally begins around October 1 and continues through the end of March (Chapter 4; Appendix C). Base flows are highest during the December-March period and provide the greatest opportunity for spawning.

With respect to the DS1 and DS3 alternative criteria diversion start dates (October 1, or December 15), redds that are created during early fall freshets in October and November could be constructed in any portion of the channel containing suitable depth, velocity and substrate characteristics, including channel margins as well as deeper channel segments (e.g., thalweg). Absent appropriate MCD and MDF criteria during these periods, redds constructed along the margins could be susceptible to dewatering if flows decrease after spawning is completed. Conversely, redds constructed near the thalweg could be more prone to scour during winter high flows (MTTU 2000). However, allowing a diversion start date of October 1 could benefit redds constructed near channel margins as well as deeper areas, provided appropriate MBF and MCD rate elements are met during this time. Indeed, comparison of results for the different Flow Alternative Scenarios (see Appendix I) indicated that diversion season length has less influence on spawning habitat availability for all three anadromous salmonid species than the MBF and MCD. For example in Franz Creek (Figure I-12), it was predicted that the combined effect of lower MBF and higher MCD under Flow Alternative Scenario 4 would consist of substantial reductions in spawning habitat availability compared with Flow Alternative Scenario 2. At the same time, Flow Alternative Scenario 3, which involves the most protective combination of diversion season, MBF and MCD, does not substantially reduce spawning opportunities compared with unimpaired flow conditions in terms of number of days per year. This suggests it should be possible to divert prior to December 15 as long as protective MBF and MCD criteria are met.

Chinook salmon are a special case and warrant a separate discussion. Because Chinook salmon migrate and spawn earlier than the other anadromous salmonid species, they would be most vulnerable to effects of diversion prior to December 15 due in part to their larger size and higher flow requirements. However, Chinook in the Policy area tend to spawn in larger channels, which require proportionally less water than smaller channels relative to mean annual flow. Therefore, maintaining base flows in upstream channels that are protective of steelhead spawning habitat needs after October 1 should also be moderately to fully protective of Chinook spawning needs downstream depending on the stream (see Appendix E). Also, because major spawning activity of Chinook and coho generally occurs in November and later, water temperatures should not be adversely affected by the earlier alternative criterion diversion start date.

5.1.3 Juvenile Winter Rearing Habitat

As long as an MBF element protective of spawning habitat is implemented, the start and end dates of the diversion season should not influence the protectiveness of juvenile rearing habitat. In general, upper water temperature thresholds for juvenile salmonid rearing tend to be higher than for adult upstream migration and smolt outmigration (cf. McCullough 1999). Hence, diversion season start and end dates that are protective of these habitat needs should also be protective of juvenile winter rearing habitat needs in terms of physical living space and water temperature.

5.1.4 Outmigration

Since the difference in diversion period between alternatives DS1 and DS3 only involves the start date, and most juvenile outmigration occurs in the spring, the effects of an earlier start date (October 1) should not reduce the overall protectiveness of the Policy relative to smolt outmigration. High flow events can still occur in April and later, thus it is necessary to assess the protectiveness of the March 31 end date proposed. The literature and available data indicated that March 31 is approximately the latest ending date of the diversion season that may be considered protective, as discussed below. Considerations other than physical habitat space influence protectiveness of the end date of the diversion period. Downstream water velocity and water quality are two important factors potentially influencing migration timing/rate and smolting processes, as described below.

Flows tend to drop off markedly in Policy area streams in April. Considerable numbers of salmon and steelhead smolts that depend on high flows complete their downstream migration through June. However, as indicated in Chapter 4, the effect of flow reduction on travel time is unlikely to be a critical determinant of outmigration success. Diversions during the post March 31 period may influence downstream migration success, by reducing the flow needed to stimulate and facilitate downstream migration.

The protectiveness of the Policy diversion season ending date is thus influenced predominantly by the relation between flow and water temperature. Increased water temperatures may interfere with smolting and fish health. Most coho salmon, steelhead, and Chinook salmon migrate downstream before highly stressful temperatures occur. Coho and steelhead tend to outmigrate as yearlings or older individuals in the Policy area, whereas Chinook emigrate primarily as young of year, including in the larger Russian River (Entrix 2004). Because older smolts tend to outmigrate first, high flows later in the outmigration season may be most important for later migrating, younger fish (Quinn 2005). Chase et al. (2003) noted downstream migration of Chinook smolts in the Russian River to peak through the first half of May and then slowly decline through June in 2002, and steelhead smolts to migrate primarily in mid-March through April. As discussed in Chapter 4, water temperatures have the potential to adversely affect smolt outmigration success in April and later, depending on the year and location. Late migrating steelhead and Chinook salmon can encounter stressful temperatures with adverse results, with later migrating Chinook being at greatest risk to decreases in spring flows (Entrix 2002). For all species, allowing additional diversion could lead to smolts being increasingly vulnerable to adverse water temperature conditions if new permits are approved for April or later.

The net conclusion based on the information reviewed is that extending the diversion past March 31 would not be protective of downstream migrant steelhead and salmon. Consequently, the year-round diversion season proposed by MTTU (2000) could also be considered as non-protective for outmigration in addition to summer rearing habitat.

5.1.5 Channel and Riparian Maintenance

The majority of channel and riparian maintenance flows occur after the first few fall storms, usually after October 1 and before March 31. As long as a protective MCD element is implemented, the start and end dates of the diversion season should not influence the protectiveness of the Policy towards ensuring suitable channel and riparian maintenance flows.

5.1.6 Estuary Habitat/Ocean Connectivity

Base flows after October 1 appear to be generally sufficient to promote sand bar breaching. Base flows in September may not be sufficient. Hence, an October 1 diversion season start date should be protective of freshwater entry by Chinook salmon, which is the earliest species to return to spawn. The end date of the Policy would need to extend into the summer before sand bar blockages would be promoted. Consequently, other factors than estuary habitat and ocean connectivity would be expected to control specification of a protective diversion season end date.

5.2 SUMMARY OF PROTECTIVENESS

Table 5-2 summarizes the protectiveness attributes of Policy diversion season element alternative criteria. Key habitat needs influencing the protectiveness assessment of the diversion season element are adult upstream passage, steelhead incubation during the late spring, and smolt outmigration, in terms of starting and ending dates of diversion.

A diversion season start date of October 1 would not be expected to be any less protective of upstream migration needs of anadromous salmonids than a December 15 start date, as long as protective MBF and MCD elements of the policy are also in place that protect upstream passage, spawning, winter rearing, and channel and riparian maintenance needs. Prior to October 1, water temperatures could be adversely affected by diversion leading to delay in upstream migration, and diversion may also potentially lead to delay in sand bar breaching dates. Permitting of new diversions should thus be avoided prior to about October 1. After March 31, water temperature increases may exacerbate adverse effects of diversion on incubation and smolting processes and survival, and thus permitting of new diversions should be avoided later in the spring.

Table 5-2. Summary of Protectiveness of Instream Flow Policy Diversion Season Element Alternative Criteria.

Policy Element: Diversion Season

Alternative	Regionally Protective?	Basis
DS1: 12/15 – 3/31	Yes	Start date does not contribute to adverse water quality conditions, and flows must be protected by appropriate MBF and MCD element alternative criteria. End date avoids adverse water temperature effects on steelhead incubation and smolt outmigration.
DS2: Year Round	No	New diversions cannot be permitted during the late spring, summer, and early fall because instream flows during this period are generally limiting anadromous salmonid rearing habitat quantity and quality in the Policy area.
DS3: 10/1 – 3/31	Yes	Start date does not contribute to adverse water quality conditions, and flows must be protected by appropriate MBF and MCD element alternative criteria. End date avoids adverse water temperature effects on steelhead incubation and smolt outmigration.

Biological Recommendation: **Apply the 10/1 – 3/31 DS3 alternative criterion**

6. PROTECTIVENESS OF MINIMUM BYPASS FLOW ELEMENT ALTERNATIVE CRITERIA

This chapter analyzes the protectiveness of the Minimum Bypass Flow (MBF) element alternative criteria identified in Chapter 3 for anadromous salmonids and their habitat in the Policy area. The analysis interprets results identified in Chapter 4, Appendix D, and in other relevant literature. The analysis focused particularly on differences between unimpaired flow conditions and impaired flow conditions under each of the five Flow Alternative Scenarios (Table 6-1). The analysis indicates that the MBF has the potential to impact primarily upstream migration, spawning success, and winter rearing habitat availability of anadromous salmonids.

Table 6-1. Description of Minimum Bypass Flow Element Alternative Criteria Evaluated in the Analysis of Protectiveness.

Minimum Bypass Flow Alternatives	Description	Impaired Flow Analysis
MBF1 (DFG-NMFS 2002)	February median daily flow	Flow Alternative Scenario 1, 5
MBF2 (MTTU 2000)	10% exceedance flow	Flow Alternative Scenario 2
MBF3 (Upper MBF)	Varies with drainage area and mean annual flow, protective of best spawning habitat conditions in all streams	Flow Alternative Scenario 3
MBF4 (Lower MBF)	Varies with drainage area and mean annual flow, lowest possible limit of protectiveness	Flow Alternative Scenario 4

6.1 ANALYSIS OF PROTECTIVENESS

The analysis below indicates that the MBF has the potential to impact primarily upstream migration, spawning success, and winter rearing habitat availability of anadromous salmonids.

6.1.1 Upstream Passage

Based on data described in Chapter 4 and Appendix E, the provision of spawning habitat appears to require more flow than passage on a regional basis, and therefore protection of the former should protect the latter. For example, steelhead and coho passage opportunities are generally provided more frequently in the validation sites than spawning opportunities (see graphs in Appendix I). Indeed, suitable passage conditions were afforded for steelhead on more days than suitable spawning habitat in ten out of twelve validation sites for unimpaired flow conditions (one site was not assessed for spawning habitat).

The data analysis also suggests that on a daily basis, suitable passage conditions in most Policy area streams are more limited for Chinook than for steelhead and coho (Figures 4-6 to

4-8 and Appendix I). The analysis indicates that passage conditions for Chinook are suboptimal under unimpaired flows in the validation sites, where passage depths are below the minimum depth criterion in Table 2-1 but still provide for limited passage under more stressful conditions (see range of alternate criteria in Appendix G). These results appear consistent with the existing distribution of Chinook in the Policy area, where the species is generally restricted to larger mainstem channels compared with the broader historical distributions of steelhead and coho.

As a related consideration, anadromous salmonids require holding habitat while they migrate upstream to spawn. Adult salmon and steelhead may enter spawning streams several weeks prior to spawning and seek out pools and cover to hold until flow conditions are suitable and/or they have matured sexually. For example, Bratovich and Kelley (1988) noted that most spawning in the Lagunitas Creek system occurred from 3 weeks to a month after adult fish had entered freshwater. Importantly, the provision of suitable passage conditions by the MBF element will allow access to important holding areas.

Comparisons of the reduction in average number of days per year with suitable passage conditions against those provided under unimpaired flow conditions suggest that Flow Alternative Scenarios 1 and 4 (described in Table 4-2) are least protective for upstream passage and that Flow Alternative Scenario 3 is most protective (Figures 4-6 to 4-8). Flow Alternative Scenario 4 typically resulted in an approximate 30-60% reduction in the number of suitable upstream passage days in most validation sites for all three species. Flow Alternative Scenario 2 appeared to be less protective than Flow Alternative Scenarios 1 and 3 in two of the smallest streams (i.e., drainage areas < about 4 mi^2).

Because results for the upstream passage analysis are based on Flow Alternative Scenarios that combine different Policy element alternatives to generate a flow time series (see Table 4-2), it is not possible to attribute the above results solely to the effects of the MBF. However, some inferences can be made from the results depicted in Figures 4-6 to 4-8 based on sites where the MCD levels of two Flow Alternative Scenarios are of comparable magnitude (see Table 4-3) but MBF levels are different. For example, Flow Alternative Scenarios 1 and 3 have the same MCD rate and diversion season for all sites, but different MBF levels, thereby allowing an evaluation of relative protectiveness of the MBFs with unimpaired flow conditions. In this case, the upper MBF in Flow Alternative Scenario 3 appears more protective as indicated by the greater number of sites afforded suitable passage conditions than in Flow Alternative Scenario 1 (Figures 4-6 to 4-8). As a second example based on site comparisons in Table 4-3, the Salmon Creek, Franz Creek, Albion River, and Santa Rosa Creek sites have similar MCD rates for Flow Alternative Scenarios 1 and 2, but the DFG-NMFS (2002) MBF in Flow Alternative Scenario 1 is about half that of the MTTU (2000) MFB in Flow Alternative Scenario 2 and is correspondingly less protective of upstream passage.

Flow Alternative Scenario 4, which includes the lower MBF4 alternative criterion for the MBF, resulted in substantial reductions in passage opportunities (Figures 4-6 to 4-8). While Flow Alternative Scenario 4 also includes a MCD rate that allows the greatest cumulative diversion of the four flow rate based element alternatives, it appears that the lower MBF4 level likely contributes to the overall reduction in suitable passage conditions. The MBF4 element alternative appears to result in suboptimal passage depth conditions for both Chinook and steelhead in most basins (see Appendix E, and the comparison of upstream passage requirements with criteria listed in Table G-3 in Appendix G).

The observations above suggest that the upper MBF (MBF3) alternative criterion contained in Flow Alternative Scenario 3 appears to be most protective of upstream passage needs in all size basins.

6.1.2 Spawning Habitat and Incubation

Protectiveness of the MBF for spawning and incubation habitat is, to a certain extent, facilitated by spawning behavior of anadromous salmonids. In general, steelhead and coho choose redd locations that are rarely exposed by falling stream levels in California coastal streams (Shapovalov and Taft 1954; Bratovich and Kelley 1988; Trush 1991). This phenomenon likely reflects fish waiting to begin spawning until the storm hydrograph is in recession. Water levels typically fall rapidly following the peak flow and then fall off more gradually as the source of water switches to groundwater storage within the basin (Linsley et al. 1982). Spawning activity seems to begin nearer the inflection point of the descending limb than the peak (Shapovalov and Taft 1954), and thus likely represents an adaptation to characteristics of groundwater input, rather than the more variable surface runoff. Spawners that use areas that are inundated and suitable at higher flows and become exposed at lower flows, would likely experience a selective pressure against that trait. Moreover, steelhead and coho spawning sites are frequently near riffle heads, in pool or run tails (Shapovalov and Taft 1954; Bratovich and Kelley 1988; Trush 1991). These sites are less prone to dewatering during flow reductions because the riffle crest downstream prevents the water level from decreasing to levels where redds become exposed (i.e., depth is greater than zero when there is no flow).

Higher MBFs, in addition to providing more suitable spawning habitat, should also be more protective against redd scour than lower flows. In general, under low flow conditions, redd construction may be concentrated closer to the channel thalweg and in deeper water areas closer to the upstream edge of a pool tail (i.e., closer to a pool). Redds constructed near the channel thalweg and near the upstream edge of the pool tail would likely be most susceptible to scour during high flows (Bratovich and Kelley 1988; MTTU 2000; DeVries 2000). Thus, if MBFs are too low during the spawning period, many redds may be constructed in the deepest regions of the channel where the stream bed may be more prone to scour (although not all thalweg locations are prone to deep scour depending on stream-wise position of the redd in the spawning bed; DeVries 2000). MTTU (2000) noted that a minimum bypass flow would be more protective if it allowed for some spawning to occur in locations other than the deepest spawning habitat available. A higher MBF would therefore be more protective from this perspective.

The validation site analysis suggested that Flow Alternative Scenarios 1, 2 and 3 provide comparable frequencies of spawning day opportunities for steelhead, coho, and Chinook in streams draining more than about 6-7 mi^2 (Figures 4-10 to 4-12). In most such cases, the three Flow Alternative Scenarios do not appreciably reduce the availability of days that spawning is possible compared with unimpaired flows. The greatest differences in spawning day opportunities were observed for Flow Alternative Scenario 4 over all sites. The analysis suggested that Flow Alternative Scenarios 1 and 2 had relatively large reductions in successful spawning opportunities compared with unimpaired flow conditions for drainage areas less than about 7 mi^2 and 4 mi^2, respectively.

The reductions in spawning opportunities observed above can be attributed in large part to the magnitude of the MBF calculated for the four MBF alternatives. The reason can be seen in Figure 6-1. This figure compares the four MBF alternatives against minimum spawning flow needs at the validation sites. The minimum spawning flow needs derived from field measurements are indicated by the diamonds. Predicted minimum bypass flows using MBF1 and MBF2 are shown by the squares and open circles, respectively. Predicted minimum bypass flows using MBF3 and MBF4 are indicated by the solid lines.

Figure 6-1 shows that MBF2, part of Flow Alternative Scenario 2, and MBF1, part of Flow Alternative Scenario 1, fall below minimum spawning flow needs for drainage areas less than about 4 mi^2 and 5 mi^2, respectively. Thus, these two hydrologic MBF metrics would not likely be protective of spawning habitat availability in streams with smaller drainage areas. They do appear to be protective in larger streams.

In contrast, the MBF3 alternative criterion (part of Flow Alternative Scenario 3) is associated with the smallest change in the number of spawning days compared with unimpaired flows, around +/- 10% (Figures 4-10 to 4-12), and also appears to protect most of the spawning habitat-flow needs determined for the validation sites (Figure 6-1). This demonstrates the overall protectiveness of the MBF3 criterion. In addition, Flow Alternative Scenarios 1 and 3 have the same MCD criteria, but Flow Alternative Scenario 1 was less effective in estimating minimum flow needs. This indicates that the MBF has a strong influence on spawning habitat availability, particularly in streams draining less than about 4-5 mi^2 (Figure 6-1).

Figure 6-1 shows the MBF4 criterion (part of Flow Alternative Scenario 4) can be protective of spawning conditions in some but not all streams. The habitat analysis indicated that in many of the larger streams, the MBF4 criterion is associated with a decreased frequency of predicted

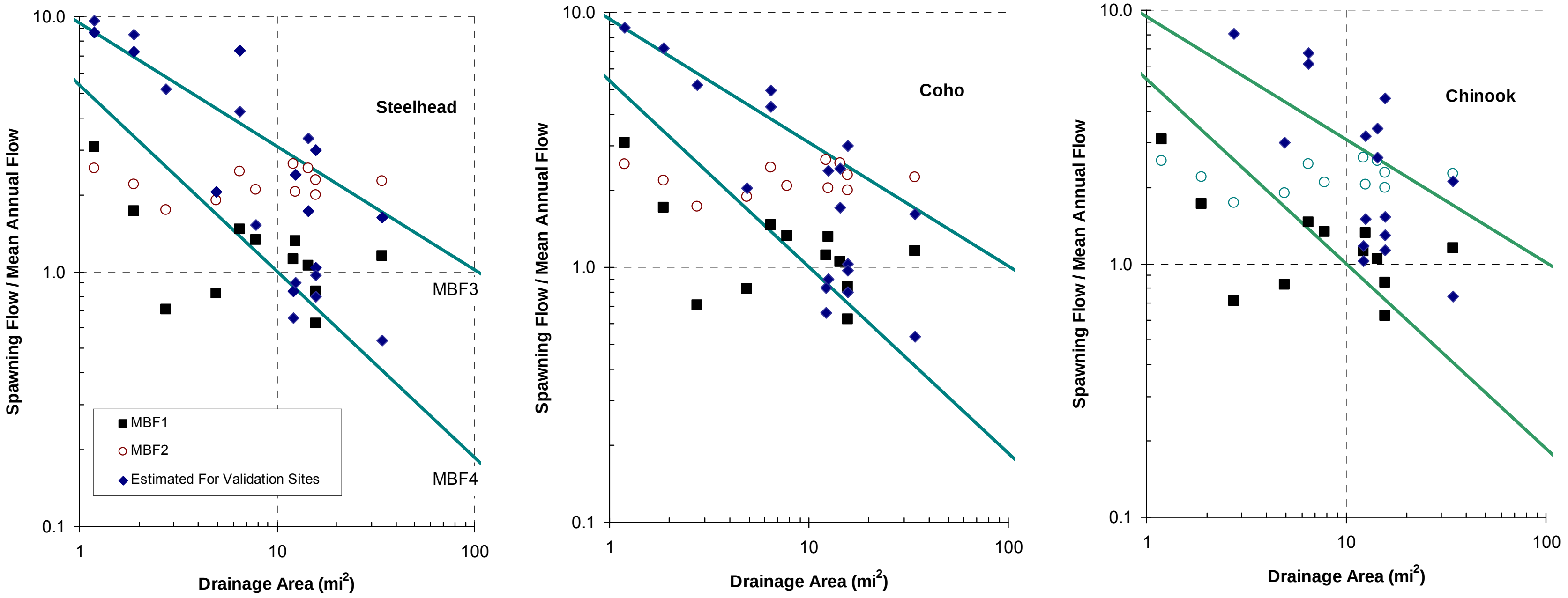

Figure 6-1. Comparisons of minimum bypass flow alternative criteria with protective spawning habitat-flow needs determined for the validation sites for steelhead, coho, and Chinook spawning, distinguished by drainage area. The spawning flow is scaled by the approximate unimpaired mean annual flow.

depths and velocities over steelhead and coho spawning substrates that meet suitability criteria (see Table 2-2), compared with other alternative criteria. Of the three species, the MBF4 criterion appears to be well below the flow needed for Chinook salmon spawning habitat (i.e., the diamonds) in more validation sites than for steelhead or coho (Figure 6-1).

6.1.3 Winter Rearing Habitat

As discussed in Chapter 4 and Appendix D, this habitat need is assumed to be protected by a MBF element that also protects spawning habitat.

6.1.4 Outmigration

The MBF element generally does not affect outmigration flow needs. As discussed in Chapter 5, the diversion season Policy element protects outmigrating smolts from the potential of adverse effects related to flow and water temperature during base flows resulting from Policy implementation. The need for pulse flows to stimulate and facilitate outmigration is affected by the MCD element.

6.1.5 Channel and Riparian Maintenance

The MBF element does not affect channel and riparian maintenance flow needs, which are affected by the MCD element.

6.1.6 Estuary Habitat/Ocean Connectivity

All of the MBF alternatives are generally protective of estuary habitat and ocean connectivity. As described in Chapter 4, the flow required to breach sand bars blocking river mouths is generally less than the winter base flow. All MBF alternatives appear to result in preserving winter base flows based on hydrologic analysis of the validation sites. Estuarine habitat conditions for juveniles generally do not become adverse until the summer. However, all of the MBF alternative criteria are protective of this anadromous salmonid habitat flow need if a protective winter diversion season alternative is used.

6.2 SUMMARY OF PROTECTIVENESS

Table 6-2 summarizes the protectiveness attributes of each MBF element alternative criterion considered. The results indicate that it is more protective on a regional basis to apply a conservative MBF threshold for administering water right permit applications under the Policy, and require site specific studies to determine if lower bypass flows might still be protective. Because a regionally protective Policy inherently results in over-protecting some streams (e.g., see Figure D-5 in Appendix D), application of the MBF3 alternative criterion would likely result in many cases where additional study could indicate that lower bypass flows might still be protective.

Table 6-2. Summary of Protectiveness of Minimum Bypass Flow (MBF) Alternatives.

	Policy Element: Minimum Bypass Flow	
Alternative	**Regionally Protective?**	**Basis**
MBF1: February Median Daily Flow	Partially	Protective of upstream passage and spawning habitat flow needs in streams draining more than about 5 mi^2. Under-protective in smaller streams.
MBF2: 10% Exceedance Flow	Partially	Protective of upstream passage and spawning habitat flow needs in streams draining more than about 4 mi^2. Under-protective in smaller streams.
MBF3: Drainage Area (DA[1]) < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$ Q_m = unimpaired mean annual flow (cfs); For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	Yes	Generally protective of upstream passage and spawning habitat flow needs across a wide variety of stream sizes in the region. Protects winter rearing habitat as well. Does not affect outmigration, channel and riparian maintenance, and estuarine habitat flow needs.
MBF4: Drainage Area < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ Drainage Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ Drainage Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$ For streams above anadromous habitat, DA is determined at the upstream limit of anadromy	No	Protective of upstream passage and spawning habitat flow needs in some streams, but a majority of streams in the region are under-protected with respect to upstream passage and spawning habitat flow needs for steelhead and coho. Appears to under-protect Chinook upstream passage and spawning habitat flow needs in nearly all streams. In all cases, the MBF is sufficiently low that adverse effects could occur to upstream passage and spawning opportunities even with small diversion rates.
Biological Recommendation:	**Apply Alternative MBF3**	

[1] Drainage area (DA) is evaluated in square miles.

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7. PROTECTIVENESS OF MAXIMUM CUMULATIVE DIVERSION ELEMENT ALTERNATIVE CRITERIA

This chapter analyzes the protectiveness of the maximum cumulative diversion (MCD) element alternative criteria identified in Chapter 3 for anadromous salmonids and their habitat in the Policy area. The analysis interprets results identified in Chapter 4, Appendix D, and in other relevant literature. The analysis focused particularly on differences between unimpaired flow conditions and impaired flow conditions under each of the five Flow Alternative Scenarios (Table 7-1).

Table 7-1. Description of Maximum Cumulative Diversion Element Alternative Criteria Evaluated in the Analysis of Protectiveness.

Maximum Cumulative Diversion Alternatives	Description	Impaired Flow Analysis
MCD1 (DFG-NMFS 2002)	MCD Rate = 15% of 20% winter (12/15-3/31) exceedance flow	Flow Alternative Scenario 1, 3
MCD2 (DFG-NMFS 2002)	MCD Rate = 5% of 1.5 year flood peak flow	Flow Alternative Scenario 4
MCD3 (DFG-NMFS 2002)	MCD Volume = CFII = 10% of estimated unimpaired runoff (no restriction on diversion rate)	Flow Alternative Scenario 5
MCD4 (MTTU 2000)	MCD Rate = calculated from site-specific hydrograph for a reduction in duration of MBF rate by ½ day during 1.5 year event	Flow Alternative Scenario 2

7.1 ANALYSIS OF PROTECTIVENESS

Depending on the timing and magnitude of the extraction relative to the instantaneous instream flow, individual diversions can have local effects on anadromous salmonids and their habitat in the downstream vicinity of the POD. The combined effect of multiple diversions upstream also influences the cumulative amount of water that flows at downstream locations, referred to in the DFG-NMFS (2002) Draft Guidelines as POI. Diversions can therefore have cumulative impacts on downstream resources as well as local impacts. The primary anadromous salmonid habitat needs potentially affected are addressed below. The analyses below and in Chapters 4 and 6 indicate that the MCD element has the potential to impact primarily channel and riparian maintenance flows, although upstream migration, spawning success, and winter rearing habitat availability of anadromous salmonids could be further adversely affected if an unprotective MBF element is applied.

7.1.1 Upstream Passage

Upstream passage of anadromous salmonids tend to be more restricted by low flows in smaller channels, where suitable passage depths are hydrologically less frequent, than in larger channels (MTTU 2000; R2 2004; Lang et al. 2004). The analysis in Chapter 6 and Appendix E indicates, however, that the MCD element should not appreciably affect upstream passage opportunities for steelhead and coho in most smaller channels when an MBF element is used that is protective of upstream passage flow needs based on the conservative depth criteria in Table 2-1. The validation site analysis results suggest that the primary way diversions could influence upstream passage under the Policy would be if the MCD element allows substantial reduction in peak flood magnitude earlier in the late fall/winter diversion season in some small streams if the MBF used is less than that truly needed for good passage conditions. In the extreme case, when flows greater than the MBF are completely diverted as is assumed for the worst case application under Flow Alternative Scenario 5, the impaired hydrograph would be essentially ‘flat-lined’ nearer the MBF level, akin to ‘lopping off the top.’ If this mode of diversion occurs for long enough (e.g., in dry and possibly average flow years), upstream passage opportunities of earlier migrating Chinook in particular could be reduced in frequency compared with unimpaired flow conditions.

The adverse effect of flat-lining the peak hydrograph, in the manner proposed for the worst case application of the CFII metric, can be seen in the validation site analysis results depicted in Figures 4-7 and 4-8 for Flow Alternative Scenarios 1 and 5. Flow Alternative Scenario 5 results in more reductions in coho and Chinook salmon passage opportunities compared with unimpaired and Flow Alternative Scenario 1 instream flows. It should be noted that the only difference between Flow Alternative Scenarios 1 and 5 is the use of different maximum cumulative diversion alternatives. They have the same MBFs and diversion seasons. Flow Alternative Scenario 1 applies a maximum diversion rate, whereas Flow Alternative Scenario 5 involves the worst case, unlimited diversion rate starting at the beginning of the diversion season until the CFII = 10% limit is reached. Since these two Flow Alternative Scenarios have a common diversion season start date of December 15, it is likely that applying an earlier start date (e.g., October 1) to Flow Alternative Scenario 5 could result in an even greater reduction in passage opportunities for coho and Chinook salmon because stream flows are generally higher for the month or so after December 15 than for the equivalent length period after October 1. A significant fraction of each species’ run migrates upstream between October 1 and December 15. Effects would be expected to be most pronounced in dry and average years when it can take up to 60 days or more after December 15 for the CFII to reach 10%. Hence, of the alternative criteria for the MCD element, the worst case, flat-lining method of diversion used when applying the CFII alternative criterion appears to have the greatest potential to reduce upstream passage opportunities for coho and Chinook in smaller stream channels, particularly when a regionally unprotective MBF element is implemented.

Other inferences can be made from the results depicted in Figures 4-6 to 4-8 based on sites where the MBF levels of two Flow Alternative Scenarios are comparable in magnitude in Table 4-3 and the MCD rates are different. For example, in the Dunn Creek and Dry Creek Tributary sites, the MBF levels for Flow Alternative Scenarios 1 and 2 are similar, but the MCD rate differs, where for Flow Alternative Scenario 1 it is higher in Dunn Creek and lower in Dry Creek than for Flow Alternative Scenario 2. In both cases, the higher MCD rate results in fewer passage opportunities in the respective streams for steelhead and coho (the streams are generally too small to support Chinook). In addition, the MCD rates in Pine Gulch Creek and Warm Springs Creek are generally higher for Flow Alternative Scenario 3 than Flow Alternative Scenario 1. Steelhead passage opportunities are fewer for Flow Alternative Scenario 3 in Pine Gulch Creek and comparable in Warm Springs Creek. Coho passage opportunities are comparable in both streams. These results suggest that upstream passage opportunities are less vulnerable to effects of diversions allowed by the MCD when the most protective MBF alternative criterion is applied (MBF3, part of Flow Alternative Scenario 3) than for the other MBF alternative criteria with which increased diversion rates are more likely to result in reduced passage opportunities.

7.1.2 Spawning and Incubation Habitat

The validation site analysis results for the MBF element in Chapter 6 indicated that diversion can adversely affect the availability of anadromous salmonid spawning habitat primarily when the MBF element is not protective. Use of a protective MBF criterion for spawning according to the conservative habitat suitability criteria in Table 2-2 should ensure that spawning habitat would remain available at some locations in a stream even at maximum cumulative diversions that are higher than the MCD1 alternative.

Figures 4-10 and 4-11 show that in a few cases, a less restrictive MCD which allows more diversion leads to lower peak flows that are predicted to provide more favorable conditions for steelhead and coho spawning. These cases are indicated by the points in the lower graphs of Figures 4-10 and 4-11 that plot as positive changes, where the number of days with spawning opportunities increase over unimpaired flow conditions. The result reflects additional time during the rising and descending limbs of event hydrographs in which the diversion of flow provides more spawning habitat (via provision of suitable depths and velocities over spawning gravels) than would otherwise exist.

7.1.3 Winter Rearing Habitat

As discussed in Chapter 4 and Appendix D, this habitat need is assumed to be protected by an MBF element that also protects spawning habitat.

7.1.4 Outmigration

The importance of flow for downstream passage was concluded in Chapters 4 and 5 and Appendix D to be minor for initiating and facilitating outmigration, as long as the diversion season ends before increasing water temperatures become an issue and, as well, there are still freshets. All of the MCD element alternative criteria result in the maintenance of flow pulses later in the diversion season and thus, would not be expected to adversely affect outmigration. By maintaining natural hydrograph variability and the associated stimulus for migration, flows that serve a channel maintenance function would also be generally sufficient for downstream passage at any point in the drainage network system. Prior to March 31, delays in migration and temperature effects do not appear to be significant, and thus downstream passage is not likely an important factor on which to base the MCD criterion. Consequently, all of the MCD alternative criteria can be considered to be protective of outmigration flow needs subject to the constraint of also having a protective diversion season element.

7.1.5 Channel and Riparian Maintenance

There are two approaches embodied in the MCD alternative criteria in which diversions may be managed to protect natural hydrograph functions, with varying effects on channel maintenance processes. In both approaches, water may be extracted when instream flows exceed the MBF. In the first approach, a fixed MCD rate may be permitted once instream flows exceed the threshold MBF (analyzed as Flow Alternative Scenarios 1-4). In the second approach, water may be extracted above the MBF threshold at any rate but total extractions are limited by the MCD volume (analyzed as Flow Alternative Scenario 5). As seen in Appendices F and J, the second approach allows more water to be diverted than the first, in terms of both volume and rate, and can thus have greater effects on channel processes and habitat availability. The second approach can result in a reduction of peak stream flows to the MBF, or “flat-lining,” which can adversely affect channel and riparian conditions. The first approach better preserves hydrograph variability in terms of frequency of channel modifying events, and thus would likely be more protective of anadromous salmonid habitat. However, what the levels of MCD rate and volume criteria should be to ensure protectiveness of channel and riparian maintenance flow needs are uncertain, as discussed in Appendix D.

7.1.5.1 Channel Maintenance Flows

Changes in Channel Size

The MCD element alternative criteria generally limit diversions in a manner such that bedload transporting flows still occur. However, the results described in Appendices D and F, and presented in Figure 2-1 and Table 4-4, suggest that specification of a relatively low magnitude MCD rate or volume will over the long term result in channel adjustments toward establishment of a smaller channel for a given basin size and available runoff volumes, and thus reduced habitat area. This long term outcome may not necessarily have negative impacts on anadromous salmonids. If the size adjustment is relatively small, then the change in channel size would not likely adversely affect production of anadromous salmonids. For example, if a 30 ft wide channel eventually becomes 5% narrower according to Figure 2-1, it may still provide all the habitat elements needed and used by anadromous salmonids. While the net effect may be reduced habitat area, there is no clear threshold defining when habitat loss related to channel size would impart a population level effect. Indeed, when coupled with MBFs based on current channel sizes, such channel narrowing may actually tend to increase the number of upstream passage and spawning opportunities as a function of increased water depths. If so, caution is needed to avoid a situation where additional diversions become considered subsequently feasible under the rationale of meeting MBF requirements reflecting a smaller channel. By setting a conservative diversion rate, effectiveness monitoring can later indicate if additional water is available for diversion without adversely affecting anadromous salmonid habitat (see Chapter 10).

Comparison of the flow magnitudes in Table 4-3 suggests that the 15% of 20% winter exceedance flow, and the MTTU (2000) alternative criteria for the MCD element (contained in Flow Alternative Scenarios 1 and 2, respectively) result in comparable maximum diversion rates. Table 4-4 shows that stream flows using these two alternatives correspond to roughly 1% of the 1.5 year flood peak flow rate for four validation sites. Based on Figure 2-1 and results in Appendix F, the two alternative criteria would therefore not be expected to result in significant channel change.

The analyses and literature reviewed in Appendix D and above suggest that a greater reduction in peak flow magnitudes associated with the MCD alternative criterion of the DFG-NMFS (2002) Draft Guidelines (i.e., 5% of the 1.5 year flood magnitude; contained in Flow Alternative Scenario 4) should still be protective; changes in channel size and spawning and rearing habitat should be relatively small. The 5% of the 1.5 year flood magnitude MCD alternative criterion has an advantage over the other MCD element alternative criteria in that it most directly accounts for the variation in channel maintenance needs throughout a channel network. This makes the criterion more attractive from the perspective of protecting against the effects of cumulative diversions upstream of a POI. As noted above, whether to allow an increase in diversion rates above this level should be assessed through monitoring and/or site specific studies.

The results in Table 4-4 indicate that the CFII=10% alternative (MCD3) criterion has the potential to adversely affect channel maintenance flow needs through relatively large reductions in channel size over the long term (greater than 10 years). The MCD3 criterion is thus likely not protective of channel maintenance flow needs at the regional level.

Changes in Grain Size Distribution

As suggested by the analysis in Appendix D, reductions in high flows are also expected to result in an increase in fine sediments ("fining") within the bed surface armor layer in Policy area streams, and possibly some loss in morphologic complexity associated with the substrate over the short term. Parker et al. (2003) conducted experiments of the effects of extracting various amounts of water when flows were around bankfull and lower. A variable flood hydrograph was found to be associated with reduced fine sedimentation the bed, and greater variation in bed elevation compared with conditions under a constant bankfull flow. The surface fines content progressively increased, and bed irregularity decreased, as the degree of diversion increased. Parker et al. (2003) inferred from the results that variable flows may be associated with a greater diversity in habitat than flows affected by diversion.

Fining of the streambed can fill-in the interstitial spaces of the substrate thereby reducing invertebrate production, and the quality of spawning gravels. However, changes in the subsurface layer composition primarily reflect changes in the prevailing sediment load (Dietrich et al. 1989) while changes in the armor layer more reflect changes in the hydrograph. Changes in sediment load should, in principle, not substantially change in response to small changes in bankfull flow regime. Given that salmonid embryos are generally buried well below the surface armor layer (Montgomery et al. 1996; DeVries 2000), it is unlikely that small reductions in channel maintenance flow magnitudes associated with the MCD alternatives would have large effects on intragravel survival of anadromous salmonid embryos.

7.1.5.2 Riparian Maintenance Flows

Implementation of the MCD under the Policy may affect riparian vegetation directly through reduction of winter peak flows. As described in Chapter 2 and Appendix D, riparian vegetation may be affected primarily through three mechanisms: (1) reduction in groundwater recharge through the stream banks, (2) reduction of scouring flows that create new surfaces that allow growth of riparian vegetation, and (3) reduction in growth rates during the early spring. The question for analyzing protectiveness concerns the amount of water that may be diverted without adversely affecting the health, diversity, and future potential of the riparian zone as affected by high flows in terms of each of these three factors.

Each factor is addressed below, although assessing the potential impacts of high-flow diversion on the riparian zone is complicated. Prediction of diversion impacts and mitigation needs must generally be based on site-specific information and analyses, reflecting a number of sources of variability not directly related to diversion rate (Risser and Harris 1989). Local geology, microclimate, and floodplain physiography determine the relative impact of diversion on scouring or availability of water to riparian plants. Lower gradient reaches with significant groundwater recharge primarily by streamflow may be associated with loss of riparian vegetation depending on the extent to which water is diverted relative to recharge rate. Steeper reaches may experience increased plant height or riparian encroachment due to reduction in frequency and severity of scouring flows, depending on the availability of adequate substrate. Species-specific adaptations can also influence the nature of effect of diversion on a riparian community (Risser and Harris 1989). Factors that may lead to shifts in dominant riparian forest species include frequency of disturbance, air temperature, root zone aeration, and depth to groundwater. For example, willow species prevail in high disturbance environments, cool growing seasons favor black cottonwood, and white alder can dominate when turbulent, well aerated water is close to the surface (Holstein 1984).

Stream Bank Groundwater Recharge

None of the instantaneous MCD rate alternative criteria would be expected to prevent or substantially reduce the frequency of large magnitude flows, and given the transient nature of streambank groundwater recharge, would not be expected to adversely affect the riparian zone in this manner. Additionally, given the relatively small changes in channel form expected in association with the largest magnitude MCD rate alternative criterion (i.e., the 5% of 1.5 year flood level), the riparian zone should be able to adjust to changes in the high flow regime. The unlimited diversion rate embodied in the CFII alternative criterion would not be expected to affect spring and summer streambank groundwater levels because in most years the CFII = 10% limit would be reached within the first month or two of the diversion season. Therefore, additional high flow events could still occur during the remainder of the winter. The CFII alternative criterion would be expected to have the greatest effects of all MCD alternative criteria in dry years.

Scouring Flows

Regional flood frequency regressions in DFG (2003a) indicate that a 5% reduction in the 2-year flood peak flow rate in the Policy area corresponds approximately to a 3% reduction in the 5-year flood peak flow rate. The highest MCD rate alternative criterion analyzed as part of Flow Alternative Scenario 3, i.e., a 5% reduction in the 1.5 year flood, would correspond to a smaller reduction in the magnitude of the 5 year flood and other recurrence interval events. Using the same regressions and plotting the results on log-probability paper suggests that the corresponding pre-diversion recurrence interval for the 3% reduction in the 5-year event flow rate is around 4.3 to 4.6 years for a range of drainage areas and precipitation values. Higher flood levels remain possible when the MCD element is based on an instantaneous rate, hence the highest MCD proposed as part of the Flow Alternative Scenario 4 is not predicted to result in a substantial reduction in the availability of scouring flows, especially in wet years when scouring activity is greatest under unimpaired flow conditions. Likewise, the CFII = 10% alternative criterion embodied in Flow Alternative Scenario 5, where all flow above the MBF is extracted until the 10% limit is reached, would not be expected to adversely affect scouring flows because the criterion would be reached relatively soon after the diversion season begins in wetter years.

Reduced Vegetation Growth

Riparian communities contain some of the most productive vegetation in the Policy area, largely because they receive the most water. Most of the growth of riparian vegetation occurs in the spring when water is still sufficiently available in the soil and temperatures are favorable. Red alder is frequently the dominant riparian tree in coastal forests within the Policy area. White alder forms gallery forests south and east of the range of red alder, but is much more restricted to channel margins and is thus a reliable indicator of permanent water table levels. Its roots need constant saturation by cool, well aerated water (Holstein 1984). Reduction in the streambank water table level by diversions in March could impact initial spring growth of these and other riparian species by reducing water availability to the roots. By restricting diversions to maintain natural variability in flood hydrographs, by not permitting additional diversion after March 31 during the peak of the growing season, and by specifying a relatively conservative MCD, all subject to site specific study if less restrictions are desired, the MCD element of the Policy should inherently protect riparian growth.

7.1.6 Estuary Habitat/Ocean Connectivity

The results and literature reviewed in Chapters 4 and 6 indicate that a protective MBF for spawning should also protect estuarine sand bar breaching processes. The MCD element is therefore generally protective for all Flow Alternative Scenarios that involve a MCD rate criterion. It is possible that the MCD alternative criterion of Flow Alternative Scenario 5 might not be protective in some cases if the diversion season started on October 1 instead of December 15, where higher flows would be prevented in the fall until the CFII = 10% limit is met. Depending on the stream, it is possible that Flow Alternative Scenario 5 could delay sand bar breaching in October or early November if flow increases up to the MBF level are attenuated downstream by channel storage, and base flows are still low. The uncertainty regarding the potential level of effect would need to be addressed through effectiveness monitoring and/or site specific study.

7.2 SUMMARY OF PROTECTIVENESS

Table 7-2 summarizes the protectiveness attributes of each MCD element alternative criterion considered. The analysis and literature indicate that overall, the 5% of the 1.5 year flood magnitude MCD alternative criterion would likely be as protective of anadromous salmonid habitat as the other alternative flow rate criteria, provided it is accompanied by a protective MBF criterion. For all MCD alternatives, effectiveness monitoring and site-specific studies would be needed to determine if additional water could be made available for use without decreasing protectiveness. Importantly, the CFII = 10% volume alternative criterion proposed in the DFG-NMFS (2002) Draft Guidelines does not appear to be protective of coho and Chinook upstream passage or spawning in many streams, and of channel maintenance flow needs in general. In addition, because the calculated magnitude of the CFII for a given date varies with specification of diversion season and MBF and the type of year, it would be difficult to establish a consistently protective volume.

Table 7-2. Summary of Protectiveness of Maximum Cumulative Diversion (MCD) Alternatives.

Policy Element: Maximum Cumulative Diversion

Alternative	**Regionally Protective?**	**Basis**
MCD1 (Rate): MCD Rate = 15% of 20% Winter (12/15-3/31) Exceedance Flow	Yes	Generally allows the lowest instantaneous rate of diversion. Likely results in negligible channel change over the long term.
MCD2 (Rate): MCD Rate = 5% of 1.5 yr flood peak flow (annualized series)	Yes	Allows a higher instantaneous rate of cumulative diversion than MCD1 and MCD4. This alternative will likely result in long term adjustment and reduction in channel size, but the potential change is thought to be minor in terms of bankfull width, depth, and surface grain size distribution. Basing a MCD rate on the 1.5 year flood peak flow rate more directly accounts for the relation between channel size and instream flow need.
MCD3 (Volume): MCD Volume = No restriction on diversion rate, stop diversion after the ratio of total cumulative diverted volume to unimpaired runoff volume = 10%	Partially	May not be protective of coho and Chinook upstream passage and spawning habitat flow needs during the first month of the diversion season (for DS1 or DS3) in dry and average years. May not be protective of channel maintenance flow needs. Protectiveness is related more defensibly to flow rate rather than volume.
MCD4 (Rate): MCD Rate = Diversion rate that corresponds to a half day reduction in the duration of time that flow is above the MBF during a 1.5 year flood event	Yes, but impractical to apply	Provides a comparable level of instantaneous diversion rate to MCD1 (15% of 20% winter exceedance flow). Likely results in negligible channel change over the long term. Impractical because its implementation requires detailed hourly hydrograph information for each stream.
Biological Recommendation:	**Apply Alternative MCD2.** There is uncertainty in defining the maximum amount of change in channel maintenance flows that could occur that would still be protective of anadromous salmonid habitat. Regardless of which MCD alternative is chosen for the Policy, effectiveness monitoring data collected over a period of 10 to 20 years would be needed to assess whether the Policy could be reopened in the future to include a less restrictive MCD that would still be protective of channel maintenance flows while offering the opportunity for higher diversion rates.	

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8. PROTECTIVENESS OF ON-STREAM DAM/RESERVOIR RESTRICTIONS

This chapter analyzes the protectiveness of the DFG-NMFS (2002) Draft Guidelines and alternatives (see Section 3.2.1) regarding the permitting of on-stream dams and water storage for streams within the Policy area (herein collectively, on-stream dams). The analysis interprets results identified in Chapter 4 and in other relevant literature, and focuses primarily on the periods of diversion.

8.1 ANALYSIS OF PROTECTIVENESS

The extent to which permitting an on-stream dam may adversely affect anadromous salmonids depends on, among other things, the size of the on-stream dam and area of stream inundated, whether upstream and downstream passage facilities are provided and the condition of such, the extent of anadromous salmonid habitat upstream and downstream from the on-stream dam, and whether flow releases from the on-stream dam are provided. In general, on-stream dams can directly impact salmonids if they: (1) prevent fish passage and block access to upstream spawning and rearing habitats; (2) intercept and retain spring and summer flows without providing continuous flow releases below the on-stream dam (i.e., bypass flows); (3) intercept and retain sediments/gravels that would otherwise replenish downstream spawning gravels; (4) intercept and retain large wood that would otherwise provide downstream habitat structure; and/or (5) create slow moving, lentic (lake-like) habitats that favor non-native species that may either prey on anadromous salmonids or compete for food and shelter.

8.1.1 Upstream Passage, Spawning, and Rearing Habitat

On-stream dams that are constructed without properly designed fishways can block upstream passage of adult and juvenile anadromous salmonids, thereby reducing the quantity of available habitat within the stream and its overall production potential (see Chapter 1). From the federal regulatory perspective, on-stream dams constructed in “critical habitat” remove stream habitat that is needed to ensure the conservation of anadromous salmonid species listed under the ESA (50 CFR 424.12(e)). In addition to preventing adult salmonids from reaching upstream spawning habitats, on-stream dams/reservoirs can prevent juveniles from moving upstream to find suitable rearing areas. In many stream systems within the Policy area, summer water temperatures exceed criteria for juvenile salmonids throughout most of the lower accessible reaches, and the only over-summering rearing habitat exists in isolated, stratified pools with groundwater input (e.g., Nielsen et al. 1994) or upstream in smaller, shaded channels.

Depending on their size and configuration, on-stream dams can retain most or all stream flow during certain times of the year. For example, many small dams with on-stream storage within the Policy area employ a “fill-and-spill” operational pattern in which the entire flow within the stream is retained by the dam until the reservoir is filled, before any downstream releases (“spill”) are provided. This pattern typically occurs during the late fall-early winter period when reservoir levels are low, and can result in lost spawning and rearing habitat for anadromous salmonids. Steiner (1996) noted that on-stream dams in tributaries within the Russian River basin have resulted in decreased habitat availability and increased water temperatures downstream.

On-stream dams that retain water year-round can create lentic habitats that are more suited to non-native, non-salmonid fish species such as bluegill and bass, as well as other exotic species such as the bullfrog. Impacts of non-native fish predation on anadromous salmonids in streams in the project area are well documented (e.g., Steiner 1996; Beach 1996), while the potential effects of other species introductions on salmonids are less understood. While bullfrogs have become a well established predator of sensitive amphibian species including red-legged frogs and salamanders (USFWS 2002), their impacts to salmonids are largely unknown.

8.1.2 Outmigration

On-stream dams that do not contain suitable fish bypass structures can delay the downstream migration of salmonid smolts and juveniles that seek to find a way past a structure (e.g., Manning et al. 2005). The potential impact of such delay becomes greatest during late spring when water temperature increases may lead to stress, disease, reverse smolting, and possibly death.

8.1.3 Channel and Riparian Maintenance

In addition to direct impacts related to fish passage and habitat loss, the regulation of flows by on-stream dams can disrupt sediment and wood transport processes that can impact the quality and quantity of downstream salmonid habitats. From a flow and sediment perspective, the filling of on-stream dams/reservoirs (particularly the fill-and-spill type) can reduce downstream peak flows (especially during dry years) resulting in an overall reduction in sediment transport and corresponding increase in sediment deposition. This can lead to sedimentation of spawning gravels or compaction of streambeds (Fisk 1955), and ultimately a reduction in egg and fry survival (Chapman 1988; Kondolf 2000). A second sediment related effect of on-stream dams relates to the trapping of bedload, which would otherwise be transported downstream (Benda et al. 2005). Trapping reduces the downstream supply of gravel, and may lead to a reduction in spawning habitat quality and quantity, streambed armoring, channel incision, and/or increased scour probability in spawning beds (Ligon et al. 1995; DeVries 2000). The degree of impact depends on the location of the on-stream dam and the balance between gravel supply and transport capacity within the spawning reaches (Montgomery and Buffington 1993, 1997; Montgomery et al. 1999; Kondolf et al. 1991; Moir et al. 2004).

On-stream dams can also intercept wood that would otherwise be transported downstream. Large woody debris represents an important habitat component in anadromous salmonid streams in the Policy area (Opperman 2002). Functionally, large woody debris provides velocity refuge and overhead cover for both adult and juvenile salmonids (e.g., Nickelson et al. 1992; Gregory et al. 2003; Opperman and Merenlender 2004). It also plays a role in shaping the morphology of a channel by contributing to pool formation, channel meandering, and channel stability. In general, the size of wood transported by water is dependent on the width of the channel. Pieces with lengths similar to or longer than the channel width are more likely to form habitat near where they entered the channel. Hence, on-stream dams located in Class III and possibly Class II streams are likely to trap mostly small pieces (on the order of 10 ft length or smaller) that would likely be flushed downstream eventually, or removed by the on-stream dam owner. In contrast, on-stream dams located in Class I channels are likely to trap larger pieces of wood, that may not become available to downstream reaches if they are not allowed to pass below the on-stream dam.

Depending on on-stream dam size and reservoir capacity, on-stream dams have the potential to regulate the quantity of water released downstream. In addition to directly affecting anadromous salmonid habitats, the regulation and reduction of flows can alter the vegetative communities (density, diversity, species composition) within the riparian zone, in some cases resulting in the complete collapse of native riparian plant communities (Rood et al. 1995; Scott et al. 1997). In general, the long term health of native riparian communities depends on flood flows to recharge alluvial aquifers, provide sites for seedling establishment, transport and deposit seeds on the floodplain, and replenish nutrients in floodplain soils. In addition, sufficient in-channel flows are needed for maintaining the alluvial aquifer within or near the rooting zone of riparian plants through the growing season.

8.2 SUMMARY OF PROTECTIVENESS

Table 8-1 summarizes the protectiveness of the alternatives that pertain to permitting of on-stream dams. The analysis indicates that the restrictions imposed by the DFG-NMFS (2002) Draft Guidelines (DP1.1, DP2.1, and DP3.1) would be protective of anadromous salmonids within the Policy area. The guidelines prohibit construction of on-stream dams/reservoirs on Class I and II streams, and conditionally allow such on Class III streams. The analysis also considered two sets of alternatives to the DFG-NMFS (2002) Draft Guidelines. One alternative (DP2.2) provides a mechanism from the State Water Board to address and evaluate situations where unauthorized on-stream dams exist on Class II streams, and a proposal from MTTU (2000) that includes more stringent criteria when considering on-stream dams for Class III streams. Other alternatives provide less stringent criteria than those proposed by DFG-NMFS. For example, alternatives DP2.3 and DP3.3 would increase the potential for adverse effects on downstream anadromous salmonid spawning and rearing habitat through the cumulative effect of permitting many dams.

Table 8-1. Summary of Protectiveness of the On-Stream Dam Permitting Restrictions (DP) Alternatives.

Policy Element: Restriction of On-Stream Dams/Reservoirs			
Stream Class	**Alternative**	**Regionally Protective?**	**Basis**
Class I	**DP1.1** On-stream dams may not be issued water right permits.	Yes	DFG-NMFS (2002) Guidelines
	DP1.2 New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. Fish passage and screening is provided; 2. A passive bypass system is provided to bypass the minimum instream flow requirements; 3. An exotic species eradication plan is implemented; 4. A gravel and wood augmentation plan or bypass system is implemented; and 5. Disturbed riparian habitat will be mitigated.	Partially – dependent on success of mitigation measures	Although this alternative allows some existing on-stream dams on Class I streams to receive water right permits, it contains criteria to mitigate existing adverse impacts to anadromous salmonids and protect and/or restore important ecosystem functions to those streams.
Class II	**DP2.1** On-stream dams may not be issued water right permits.	Yes	DFG-NMFS (2002) Guidelines
	DP2.2 New on-stream dams may not be issued water right permits. A water right permit may be considered for an existing, unauthorized on-stream dam that was built prior to 7/19/2006 if the following criteria are met: 1. A passive bypass system is provided to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.	Yes	Although this alternative allows some existing on-stream dams on Class II streams to receive water right permits, it contains criteria design to protect and/or restore important ecosystem functions to those streams and still afford a high level of protectiveness.

Table 8-1. Summary of Protectiveness of the On-Stream Dam Permitting Restrictions (DP) Alternatives.

Class II (cont)	**DP2.3** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; 3. A gravel and wood augmentation plan or bypass system is implemented; and 4. Disturbed riparian habitat will be mitigated.	Partially	Multiple on-stream dams on Class II streams have potential to cause adverse cumulative effects on downstream spawning and rearing habitat quantity and quality in Class I streams.
Class III	**DP3.1** A water right permit may be considered for an on-stream dam if the following criteria are met: 1. The on-stream dam will not dewater a Class II stream; and 2. The on-stream dam will cause less than 10% cumulative instantaneous flow impairment at locations where fish are seasonally present.	Partially	DFG-NMFS (2002) Guidelines Protectiveness could be increased via inclusion of additional fish protection measures as provided in DP 3.2.
	DP3.2 A water right permit may be considered for an on-stream dam if the following criteria are met: 1. A passive bypass system is used to bypass the minimum instream flow requirements; 2. An exotic species eradication plan is implemented; and 3. A gravel and wood augmentation plan or bypass system is implemented.	Yes	This alternative contains criteria that must be met before on-stream dams would be allowed on Class III streams. The criteria are designed to protect and/or restore important ecosystem functions, and provide an additional level of protectiveness not provided by the DFG-NMFS (2002) Guidelines.
	DP3.3 A water right permit may be considered for an on-stream dam.	Partially	With no restrictions imposed, cases would likely occur where protectiveness would not be assured. Multiple on-stream dams built without restrictions on Class III streams are likely to cause adverse cumulative effects on downstream spawning and rearing habitat quantity and quality in Class I and II streams.
Biological Recommendation:		**Apply DP1.1, DP2.2 and DP3.2**	

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9. IMPORTANCE OF FISH PASSAGE AND SCREENING MEASURES

This chapter reviews recommendations in the DFG-NMFS (2002) Draft Guidelines regarding following DFG and NMFS fish passage and screening requirements for on-stream dams and diversions in Policy area streams. Diversion structures may block or seasonally/periodically restrict upstream and downstream movements of adult and juvenile anadromous salmonids. Applicable Fish and Game Code sections concerning dams and diversions (Fish and Game Code section 5931) serve to protect anadromous salmonids from adverse effects, thereby potentially increasing production levels and survival. The DFG-NMFS (2002) Draft Guidelines are thus generally protective, although exemptions in the DFG code based on practicality for the dam or diversion owner could adversely affect anadromous salmonids depending on circumstance. To be fully protective, fish passage and screening should be required at any diversion located within the currently accessible range of anadromous salmonid habitat, as per the recommended passage (NMFS 2001; DFG 2003a) and screening (NMFS 1997) requirements. In addition, there should not be exemptions to passage or screening requirements for any diversion affecting Class I streams. Furthermore, fish passage and protection measures should be considered and evaluated in streams that are not currently accessible, but were used historically, if and when watershed restoration actions lead to correction of artificial barrier(s) downstream.

9.1 ASSESSING PROTECTIVENESS

Protectiveness may be assessed in the context of evaluating impacts in the absence of protective measures (i.e., what are the potential effects of on-stream dams and diversions that do not include fish passage and screening measures), and in terms of sufficiency for fully protecting anadromous salmonids within the Policy area.

9.1.1 Effects of On-Stream Dams and Diversions without Fish Passage and Screening Measures

On-stream dams and diversions constructed without properly designed fishways can block upstream passage of adult and juvenile anadromous salmonids, thereby reducing the quantity of available habitat within the stream. Inclusion of fishways into these structures may remedy the issue of upstream passage, but will not, in most cases, address the needs of downstream migrating juveniles and smolts. Protection and safe passage of smolts requires inclusion of properly designed bypass structures and/or diversion screens that will safely transport/guide downstream migrating fish below the on-stream dam, and prevent fish from entering diversion canals.

In addition to the effects associated with potential blockage and delay, structures associated with on-stream dams or diversions such as debris racks, intake screens, pumps, weir crests, bypass pipes, etc. may physically injure and/or kill (e.g., abrasion, impingement) fish moving near, over, or through such features. In addition, fish, especially juvenile salmonids, can become entrained into unscreened diversion canals where they would be more susceptible to predation and subjected to stress. Unless a fish return or bypass system is provided, any fish entering the canals would be lost from the population.

Minimizing or eliminating these impacts by requiring, in streams that support anadromous salmonids, measures that provide for unrestricted, volitional fish passage (upstream and downstream) at all diversions, and that prevent the loss of juvenile salmonids into diversions via screening would be protective of anadromous salmonids.

9.1.2 Protectiveness of Upstream Fish Passage Measures

The DFG-NMFS (2002) requirements regarding fish passage state that fish passage must be met for any diversion structure permitted where "anadromous salmonids have the likely potential to ascend the stream to the point of diversion." Both the DFG (2003a) and NMFS (2001) have published guidelines for salmonid passage at stream crossings with technical considerations that are also relevant to fishway design. In all cases involving anadromous salmonids, fishway designs must consider upstream passage of both adults and juveniles. Depth, velocity, energy dissipation, and other criteria comprising the passage guidelines have been based on extensive research into passage needs and ensure that no fish would be blocked or seriously delayed.

California Fish and Game Code sections 5930-5948 address the issue of on-stream dams and avoiding their adverse effects on fish passage in all rivers and streams naturally frequented by fish. DFG Code Section 5931 provides that the department shall cause plans to be furnished for a suitable fishway if it is determined by the Fish and Game Commission that there is not free passage over or around any on-stream dam. The DFG can consequently order the owner of the on-stream dam to provide a durable and efficient fishway. Upon construction, sections 5935 and 5936 require that the on-stream dam owner shall keep the fishway in repair and open and free from obstructions to the passage of fish at all times. In the case of a dam without a fishway, however, the owner should allow sufficient water to pass over, around, or through the dam to keep fish in good condition downstream of the dam. (section 5937). Therefore, in the context of providing protective fish passage facilities at dams, Policy language that refers to DFG requirements for passage would be protective of anadromous salmonids.

9.1.3 Protectiveness of Fish Screening Measures

The DFG-NMFS (2002) Draft Guidelines state that screening requirements must be met for any diversion structure permitted where "anadromous salmonids have the likely potential to ascend the stream to the point of diversion," and that screening must be done in accordance with NMFS and DFG's screening criteria. The DFG adopted NMFS (1997) screening criteria in 2000 as described in its screening policy (*www.dfg.ca.gov/nafwb/fishscreenpolicy.html*). The owner of the diversion must pay for construction, operation, or maintenance costs of any screen required pursuant to section 6100. The owner of the diversion is also required to supply sufficient water for a bypass to carry fish stopped by the screen or device back to the channel from which they were diverted. The magnitude of the bypass flow depends on the diversion amount, but is generally a small fraction as outlined in Section 6022 (generally less than 1 percent of the diversion flow rate).

Further, as part of its screening policy, the DFG shall make every effort to require the modernization of fish screens which do not meet present fish screening criteria. This effort shall include the Streambed Alteration process (Section 1600 et seq. of the Fish and Game Code). The DFG requires in its screening policy that variances from screening requirements shall be supported by a report, prepared by the diverter, which includes data from onsite monitoring and a review of historical entrainment and diversion data. The scope of the report and the sampling effort shall be approved by the Department of Fish and Game prior to the initiation of work.

When anadromous fish are not present in the stream, DFG has the responsibility per Section 6021 to determine the need for a screen and to install, operate, and maintain it. DFG’s screening policy includes making every effort to require the installation of fish screens on all unscreened diversions where other measures cannot reasonably prevent entrainment of fish.

Compliance with DFG and NMFS screening criteria as described above and specified in the DFG-NMFS (2002) Draft Guidelines should be protective of anadromous salmonids when screens are constructed, operated, and maintained properly.

9.2 SUMMARY OF PROTECTIVENESS

Compliance with DFG fish passage facility design requirements and fish screening facility design requirements of DFG or NMFS should be protective of anadromous salmonids in streams within the Policy area.

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10. EFFECTIVENESS MONITORING PROGRAM

The preceding chapters presented information and analyses evaluating the protectiveness of the proposed Policy element alternatives for the North Coast Instream Flow Policy. The assessment was based on existing information and data, supplemented by field data collected on 13 streams within the Policy area. These latter data were used for evaluating passage and spawning habitat flow needs in smaller basins. The analyses identified certain levels or attributes of each element that were deemed protective of anadromous salmonids and their habitats based on reasonable assumptions of biological criteria and channel response.

Implementation of a Policy that includes the recommended elements noted in Sections 5 through 8 (see Tables 5-2, 6-2, 7-2, and 8-1) should provide a sufficiently conservative level of protection of anadromous salmonids to meet both state mandated trust responsibilities as well as ESA objectives. However, questions remain as to (1) how implementation of the Policy would actually affect anadromous salmonids over longer time scales, say, in the range of 10 to 20 year time horizons that would correspond to 3 to 6 generations of anadromous salmonids, and (2) whether the currently proposed regionally protective criteria may be relaxed if they are indeed found to be overly conservative. The 10 to 20 year time frame should also be sufficiently long to allow detection of changes in channel morphology and composition of riparian vegetation. Such a determination requires development and implementation of a long-term monitoring program (herein, Monitoring Program). The framework for such a program is described in this chapter; detailed information pertaining to categories of monitoring, specific hypothesis to be tested, metrics to be used, and components of the program are provided in Appendix K.

10.1 MONITORING TYPES

In general, monitoring programs can be assigned into one of three types, depending on the objectives and questions to be addressed. These include: (1) compliance/implementation monitoring; (2) effectiveness monitoring; and (3) validation monitoring (see Appendix K for descriptions of each). Of these, effectiveness monitoring is the most appropriate for assessing the protectiveness of the Policy elements over the long term. Effectiveness monitoring can also provide insight on several aspects of the Policy including uncertainty and accountability. Uncertainty can include assumptions made or data gaps identified during policy development. Effectiveness monitoring also provides for accountability and ensures that potentially conflicting beneficial uses of a resource are balanced according to the values both explicit and implicit within policy goals.

In addition to effectiveness monitoring, certain aspects of the Policy would also be subject to compliance monitoring, which is used to determine if an intended action was implemented as planned. Installation of a stream gage below a diversion point to ensure required instream flow releases is an example of compliance monitoring. Compliance monitoring should be implemented under the enforcement program of the policy.

10.2 EFFECTIVENESS MONITORING PROGRAM GOALS AND OBJECTIVES

The primary goals of the Effectiveness Monitoring Program are to assess the effectiveness of the overall Policy to protect anadromous salmonid populations and their habitats in area streams and rivers. Specific objectives of the Monitoring Program would focus on evaluating individual Policy elements including those aimed at providing protective minimum bypass flows, protecting natural flow variability, avoiding cumulative impacts due to multiple diversions, and providing suitable fish passage and screens at diversions and on-stream reservoirs. Importantly, due to the wide range of geographical and temporal scales exhibited in the Policy area streams, the Monitoring Program is, of necessity, relatively general in nature and should be viewed as the starting point from which more detailed, site-specific monitoring plans can be derived. To be most effective, the Monitoring Program should be developed within an adaptive management framework (Lee 1993) as a means to provide a feedback loop linked to management actions. Thus, once the Policy is implemented, results of the Monitoring Program would be used to test whether goals and objectives are being met, and whether modifications to the Policy are warranted. Related to this, because the recommended level of protection afforded by the Policy is conservative to account for regional variation in instream flow needs across variable stream types and sizes, it is more likely that monitoring results would suggest some relaxation in the diversion restrictions could occur and still be protective of anadromous salmonids, rather than the need for more stringent restrictions.

10.3 EFFECTIVENESS MONITORING PROGRAM

There are a number of action items and components, some institutional and some technical that should be addressed and/or incorporated as part of the Monitoring Program (Figure 10-1). These are briefly described below, with more information, including an outline that describes selected metrics deemed suitable for evaluating specific Policy objectives, provided in Appendix K.

10.3.1 Establishment of Monitoring Oversight Committee

As a first step in the process of developing a coordinated Monitoring Program, it is recommended that the State Water Board form a nine member Monitoring Oversight Committee (MOC). A State Water Board senior staff member possessing a high level of experience in water resources management and a good understanding of hydrology, fluvial geomorphology, and salmonid biology should chair the MOC. Other members should include a second representative from the State Water Board, and one representative from each of the following agencies/academic institutions: DFG, NMFS, U.S. Fish and Wildlife Service, USGS, California Department of Water Resources (DWR), and two independent scientists from academic institutions. The MOC may also solicit input from other entities (e.g., US Forest Service, CDF, county water and flood

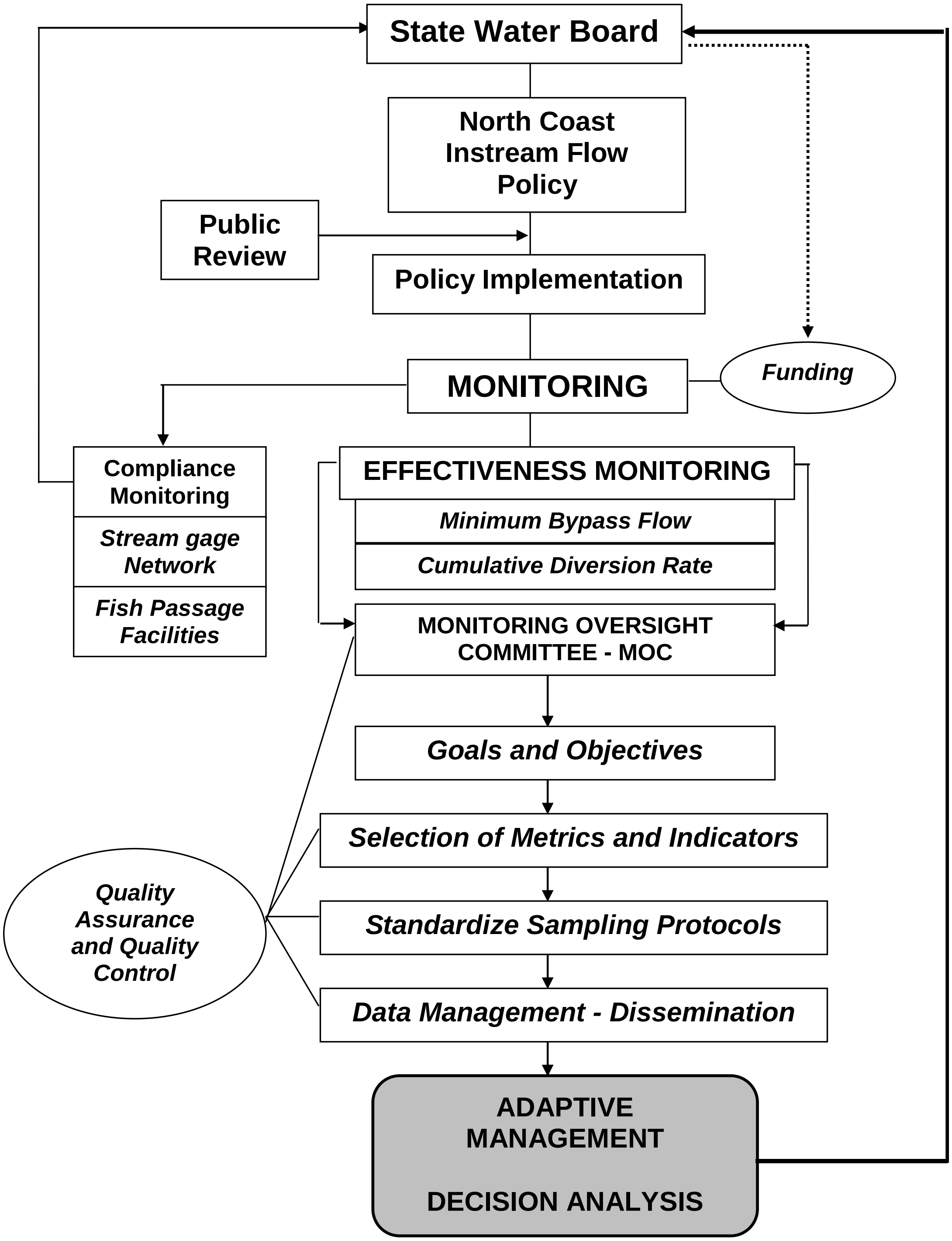

Figure 10-1. General components and actions associated with monitoring the protectiveness of North Coast Instream Flow Policy elements.

control districts and other water resource management agencies) and stakeholders involved in ongoing monitoring programs on certain streams and rivers, and who therefore possess stream-specific information. Also, the MOC may engage the services of certain technical specialists (e.g., statisticians; aquatic ecologists, geomorphologists, fish biologists, and others) to assist in preparing parts of the Monitoring Program. The MOC would be tasked with the overall preparation, implementation, and management of the Monitoring Program. An independent Science Review Panel appointed by the State Water Board would review key work products (including the Monitoring Program) developed by the MOC before being released to the public and prior to implementation. Specific activities of the MOC are described in Appendix K.

10.3.2 Selection of Appropriate Sampling Designs

As noted in Section 1.2 and Appendix B, the Policy area is large and contains over 3,400 classified stream segments of varying drainage area. Thus, the Monitoring Program should include sampling at a variety of spatial and temporal scales and, moreover, be founded on a strong, statistically derived sampling design (see Appendix K). This is important since regardless of whether the Monitoring Program evolves from existing programs or consists of an entirely new program, monitoring of all systems is simply not practical from a funding perspective.

10.3.3 Selecting and Monitoring Appropriate Indicators and Metrics

Choice of indicators and metrics to be measured will depend on specific Policy objectives. In terms of the Monitoring Program, two types of indicators will be important; (1) Effectiveness monitoring indicators that serve to detect potential changes in physical, geomorphological, and biological characteristics of streams attributable to Policy actions; and (2) compliance monitoring indicators, which address compliance activities associated with implementation of the Policy (can be done by the Division under the enforcement program established in the Policy).

10.3.3.1 Effectiveness Monitoring Indicators

There are three Policy elements for which effectiveness monitoring could be applied. These include the elements related to the diversion season, minimum bypass flows, and the maximum diversion rate. For each of these, there are a number of metrics/indicators that could be monitored, some of which are listed in Table 10-1, and discussed in more detail in Appendix K. It must be emphasized that there is no single set of metrics that will address all of the objectives and hypotheses raised regarding effects of Policy activities. Rather, there will likely be a suite of metrics, some standardized across geographic areas, and some that are scale-specific.

Table 10-1. Policy elements and potential effectiveness monitoring metrics useful for assessing protectiveness of the North Coast Instream Flow Policy on anadromous salmonids.

Policy Element	**Potential Monitoring Metrics**
Diversion Season	• Monitoring of this element captured in metrics specified under "minimum bypass flow" below.
Minimum Bypass Flow	• Derive spawning habitat vs. flow relationships from sites selected within a stratified subset of streams representative of Policy area streams; compare with Policy-imposed bypass flows. • Complete passage corridor analysis within the same subset of streams; compare with Policy-imposed bypass flows. • Spawning surveys within same subset of streams; monitoring for trends post-implementation of Policy; if possible – compare with trends in similar streams not subjected to Policy. • Redd marking and monitoring to evaluate "watering" duration from creation to projected fry emergence. • Biological monitoring (e.g., fry/smolt production – via outmigrant traps, screw traps, snorkeling, etc.) of anadromous salmonid populations within subset of streams; if possible – compare with trends in similar streams not subjected to Policy.
Maximum Cumulative Diversion	• Substrate quality monitoring – within subset of streams representative of Policy area streams; - Core sampling (bulk, grab, freeze-core) - Pebble counts - Ocular – embeddedness - Intragravel sediment monitoring • Cross-sectional profiles – subset of streams • Riparian corridor mapping/ vegetation species composition – subset of streams • Benthic macroinvertebrate (BMI) monitoring – subset of streams

10.3.3.2 Compliance Monitoring Indicators

With respect to the Policy, the major compliance factor relates to having an accurate and reliable means of monitoring and/or determining streamflows, both above and below diversions. Since existing stream gages are typically located in the lower reaches of streams, there is a risk that hydrologic models calibrated to distant downstream flow gages, or generalized relationships (e.g., to drainage area) may result in uncertain conclusions regarding the available unallocated surface flow in headwater streams. Therefore, consideration should be given to installation and monitoring of a stream gage network at selected watershed elevations, as a means to refine the discharge relationships, and also as a means to more accurately monitor/regulate the amount of surface flow being withdrawn by both unauthorized and authorized diversions.

10.3.4 Standardization of Sampling Protocols

Replication and repeatability are fundamental precepts in the design and conduct of statistically rigorous monitoring programs. Unless standards are implemented it will be more difficult to compare data sets collected at different times and places in the Policy area and draw appropriate conclusions. To the extent possible, the monitoring of all metrics should be completed using standardized sampling protocols and data analysis techniques. The MOC should ensure that detailed sampling protocols are drafted, reviewed and approved for each of the metrics selected for inclusion in the Monitoring Program (see Appendix K).

10.3.5 Quality Assurance/Quality Control Program

Since the data collected as part of the Monitoring Program would be used by the State Water Board in a decision-analysis framework, the validity of those data is critical. The MOC should therefore establish a rigorous Quality Assurance/Quality Control (QA/QC) Program designed to ensure that all data to be relied on have been collected and compiled in accordance with QA/QC protocols, and hence have been validated for use in the decision analysis process (see Appendix K).

10.3.6 Data Dissemination

It is envisioned that many agencies and entities would be involved in the implementation of various components of the Monitoring Program. It is also anticipated that the data so collected would be of interest to a wide range of personnel, including agency representatives, scientists, and the general public. The MOC should explore ways to facilitate the dissemination of these data, while at the same time preserving data integrity.

10.3.7 Funding Support

It is recommended that the State Water Board commit sufficient funding support to allow implementation and continuance of an approved Monitoring Program. When possible, the State Water Board should seek to retain existing and create new collaborative partnerships with other agencies and stakeholders as a means to increase monitoring efficiency while at the same time reducing costs.

10.3.8 Adaptive Management – Decision Analysis

The Monitoring Program described above was framed within an adaptive management construct that embodies decision analysis. Thus, it is recommended that the State Water Board develop a formal decision-analysis process to address questions related to which (if any) Policy elements warrant modification; what type of modification is needed (i.e., is the element over- or under-protective); and whether changes in the Monitoring Program are warranted. Monitoring describes what is biologically possible under a given set of Policy conditions. From this, scientists can estimate the probability of different biological conditions evolving, such as suitable spawning habitats, population increases etc. These estimates can prove useful in helping to formulate decisions regarding the extent to which the Policy elements should be modified. However, the degree of adjustment to be implemented is largely a policy decision that must be addressed specifically by the State Water Board.

10.4 MONITORING PROGRAM: PRELIMINARY STUDY DESIGN

This section provides suggestions relative to study design development and the selection of study sites and metrics for evaluation, and is intended to assist the State Water Board in planning the overall scope and budget for the Monitoring Program. It is anticipated that the implementation of the Monitoring Program as described above will occur in phases, with initial efforts focused on (1) establishing the MOC and (2) identifying the overall goals and objectives (Figure 10-1) that will form the basis for selecting study sites and the specific metrics to be monitored. To the extent possible, monitoring sites should be established that can be used to assess both the effectiveness of specific Policy elements, and from an enforcement standpoint, compliance with specified instream flows, diversion rates, and passage requirements. Clearly, efficiencies are gained and overall monitoring costs reduced when sites can be selected that serve more than one purpose.

The Monitoring Program study design should focus on answering the null hypotheses identified at the beginning of Appendix K. In addition to measurements of flow, a variety of other metrics may be monitored for each hypothesis, with the final list dependent on specific questions to be addressed. Of the four hypothesis noted in Appendix K Table K-2, the third, pertaining to the MCD, has the greatest uncertainty associated with it in terms of what maximum level of change equates with protectiveness. Monitoring will thus be a critical part of the Policy for establishing protectiveness of the MCD Policy element. In addition, data collection and analysis related to this hypothesis may be useful in the future if the State Water Board chooses to modify the requirements of the Policy by formally reopening it.

While there is no firm guide on the number of streams to sample and study sites to establish, the large geographic area encompassed by the Policy and the diversity of streams within it suggests the need to stratify the area based on drainage area classes and hydrologic sub-regions, and then selecting a subset of sites from each for detailed monitoring. This approach is intended to ensure some representative sampling within different basin size classes and hydrologic sub-regions, and thus, would lend itself to statistical analysis.

At a minimum, the list of streams should include the 13 evaluated in Chapter 4 (see Figure 4-2), which were used to assess protectiveness. The list would need to be expanded, however, as the 13 evaluated were selected, in part, because of their easy accessibility. Sites that were considered for the protectiveness analysis but not sampled because of access, time, and/or water availability limitations included: Redwood Creek near Muir Beach (National Park Service gage), San Geronimo Creek (Marin Municipal Water District gage), Morses Creek near Bolinas (USGS gage 11460160), Pudding Creek near Fort Bragg (Soda Creek near Boonville (USGS gage 11467850), Russian River near Redwood Valley (USGS gage 11460940), and Big Sulphur Creek (two sites near USGS gages 11463160 and 11463170). With suitable planning and discussion with biologists from various institutions, additional sites can likely be identified for sampling.

For purposes of statistical replication, it is necessary to sample a number of streams with similar characteristics forming a group often called a class or stratum. Similarity may be established any number of ways, ranging from the use of formal stream classification schemes that are different than the system used in the Policy (e.g., Montgomery and Buffington 1997), to statistical stratification and multivariate analyses (e.g., cluster analysis of various physical attributes of the stream). The number of streams necessary to represent each class will reflect in part, inherent variability within a class; that is, the greater the variability within a class, the greater the number of sites required for a specified level of statistical power. In addition, replication is necessary within a given stream. At least three samples of a given metric would be required per stream to be able to describe variability. A greater number of samples is desirable but may not be practicable depending on budget.

As an example of the above, assuming that: (1) the Policy area is stratified into six drainage area classes including <1 mi^2, 1-3 mi^2, 3-5 mi^2, 5-10 mi^2, 10-30 mi^2, and >30 mi^2; (2) the Policy area contains a minimum of three basic hydrologic sub-regions (coastal north, coastal south, and inland); and (3) a minimum of three sites are established per stream-hydrologic class combination, a total of 6 x 3 x 3 = 54 sites would be established for monitoring (Table K-2). This number would vary depending on the final number of drainage area and hydrologic classes selected. The actual number of sites would also need to be adjusted to account for existing stream gaging stations as well as other sites that may be part of other biological monitoring programs that are already collecting data relevant to assessing the Policy effectiveness. These latter sites could include those used by DFG or other agencies and stakeholders as part of long-term biological monitoring programs.

Given the importance of flow quantification to the Policy, most/all of the active and inactive stream gage sites should be considered for incorporation (either from an effectiveness or compliance standpoint) into the Monitoring Program. Given that there are currently 88 USGS stream gages within the Policy area, 31of which are active (Figure K-2), and assuming that the above 54 sites could be represented by a subset of the gaging stations, an additional 34 sites (represented by gage sites – i.e., 34 sites + 54 = 88) should be considered for inclusion into the Monitoring Program (Table K-2). However, the final number of sites and overall scope of the program will clearly need to be based on additional considerations including costs and funding support. It is in this matter that the MOC can be instrumental in achieving consensus on an acceptable Monitoring Program.

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APPENDIX A

Chronology and Technical Basis of the DFG-NMFS Draft Guidelines

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APPENDIX A

CHRONOLOGY AND TECHNICAL BASIS OF THE DFG-NMFS DRAFT GUIDELINES

This section describes the chronology and technical basis of the California Department of Fish and Game (DFG) and the National Marine Fisheries Service (NMFS) “Draft Guidelines for Maintaining Instream Flows to Protect Fisheries Resources Downstream of Water Diversions in Mid-California Coastal Streams” (DFG-NMFS (2002) Draft Guidelines). It is based largely on data and information provided by State Water Board staff, information obtained via internet searches, and information available in scientific publications. In addition, a meeting with State Water Board staff and representatives of NMFS and DFG was held on May 16, 2005 and provided supplemental information regarding the developmental history of the DFG-NMFS Draft Guidelines as well as the scientific basis for certain components of the guidelines.

The genesis for the DFG-NMFS Draft Guidelines began in 1994 when the State Water Board’s Division of Water Rights began an evaluation of the impacts on flows and the aquatic ecosystem of the Russian River basin that could be attributed to water demands from permitted and un-permitted diversions and instream structures. At the time, it was estimated there were 70 pending water right applications in the watershed, and 1404 permitted water rights. The Division held a series of public workshops in 1995 and 1996 to solicit comments and recommendations regarding possible courses of action that could be taken while protecting fishery and other resources, and initiated hydrologic modeling of the basin to predicted unimpaired and impaired flows.

An important workshop held on November 7, 1996 convened members from various agencies and groups to coordinate actions to protect anadromous fish in the Russian River basin. This was done, in part in response to the pending listings of a number of anadromous salmonids under the federal ESA. Attendees included NMFS, DFG, U.S. Army Corps of Engineers (USACE), Sonoma County Water Agency (SCWA), North Coast Regional Water Quality Control Board (RWQCB), California Coastal Conservancy (CCC), Sonoma County, Mendocino County, and others. Representatives from each organization presented a status report of ongoing studies, management plans, and watershed planning measures.

A.1 RUSSIAN RIVER STAFF REPORT (SWRCB 1997) RECOMMENDATIONS AND TECHNICAL BASIS

State Water Board staff reviewed the information generated by the workshops and studies, and subsequently developed a draft Russian River Staff Report (SWRCB 1997). The report summarized current major study and planning efforts, described a hydrologic model and its output, recommended a minimum winter bypass flow equal to 60% of the average annual unimpaired flow ($0.6Q_m$), identified a suitable diversion season for tributaries of the Russian

River extending from December 15 to March 31, and proposed various procedures for processing pending applications. The problem of maintaining instream flows for fish in the mainstem Russian River was left to the SCWA, which was subject to decision D-1610, which addressed provision of minimum instream flows for various seasons and water year types.

A.1.1 Diversion Season

The December 15 – March 31 diversion season stipulation reflected biological timing (or, periodicity) of various anadromous salmonid lifestages, and the availability of water based on an analysis of five gages in the Russian River basin (SWRCB 1997). The gage analysis indicated that the rainy season generally extended from November 15 to March 31. The December 15 date reflected the need to ensure that there was no reduction in pulse flows in the tributaries and mainstem of the Russian River in the early fall. Adult coho salmon and steelhead trout were noted in general to arrive at the mouth of the river in early fall and begin migrating upstream in November in response to storm pulses. An analysis of hydrologic flow and precipitation records indicated that more sustained winter flows generally did not occur until after mid-December. It was recommended that no diversions be permitted during the initial migration period when the availability of flows sufficient for upstream migration was less certain (SWRCB 1997). However, State Water Board staff concluded that pulse flows in the tributaries would not measurably affect flows in the mainstem Russian River.

The March 31 date was identified in consideration of late-incubating steelhead embryos and downstream migrating coho and steelhead juveniles. The steelhead incubation period was noted to extend into May, while the period for downstream migration of both species extended into June. Flows were considered unlikely to exceed the minimum bypass spawning flow in April in all years, and thus the cutoff-date for new diversions was set as March 31 (SWRCB 1997), analogous to the rationale used to identify the December 15 date.

A.1.2 Flow Magnitudes

The Russian River Staff Report (SWRCB 1997) proposed a minimum winter bypass flow equal to 60% of the mean annual unimpaired flow. This flow level was based on habitat needs of spawning steelhead, which were considered to require more flow than spawning coho. Steelhead spawning was reported to occur over the January-April period, and coho spawning in December and January. The period over which the 60% criterion applied was from November through April, inclusive, reflecting both upstream migration and spawning periodicities of steelhead.

The identification of the 60% criterion was based on a review of the results of instream flow studies conducted in two major tributaries to the Russian River, Big Sulphur Creek and Dry Creek, and in two nearby basins, Brush Creek and Lagunitas Creek, with drainage areas ranging between approximately 16-217 square miles (Table A-1). Most of the studies involved the use of the Physical Habitat Simulation (PHABSIM) system of the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM). The product of PHABSIM is a set of habitat-flow curves, with habitat represented by a habitat suitability-weighted measure of area termed Weighted Usable Area (WUA). The recommended steelhead spawning flows from the various studies analyzed ranged between approximately 70-110% of the mean annual flow in the four streams (Table A-1).

Table A-1. Summary of Optimum Steelhead Spawning Habitat Flows Derived from Previous Instream Flow Studies and Considered by State Water Board Staff (SWRCB 1997) in Development of Proposed Measures to Protect Anadromous Salmonids (data from Smith 1986; Snider 1985; SWRCB 1997).

Stream/Location	**Approximate Drainage Area (mi^2)**	**Average Annual Flow (Q$_m$; cfs)**	**Study Method/Basis**	**"Optimum" Spawning Flow as Percent of Q$_m$**
Big Sulphur Creek Near Mouth	~86	81	PHABSIM: Peak of WUA-Flow Curve	104%
Dry Creek Below Warm Springs Dam	~217	399	Correlation of Spawning Habitat Area With Flow	100%
Brush Creek Near Mouth	~16	44	PHABSIM: Peak of WUA-Flow Curve	114%
		44	DFG Recommendation	68%
Lagunitas Creek Taylor State Park	~38	69	PHABSIM: Peak of WUA-Flow Curve	72%

This range of flows was compared qualitatively with other various flow levels. A comparison was made to the Tennant (1976) method, where providing 60-100% of Q$_m$ reportedly would provide optimum habitat for fisheries. A general statement was attributed to M. Healey that the protectiveness of instream flows becomes more uncertain as flows drop below about 70% of natural levels.

Another comparison was made involving the case of Mono Lake tributaries on the east side of the Sierras, where flows during dry years were considered most critical to fish. It was assumed that maintaining flows representative of dry year conditions every year would not seriously harm anadromous fish populations. The State Water Board specified in Decision D-1631 that flows in Mono Lake tributaries should provide 80% of maximum WUA in dry years. Corresponding flows established for Lee Vining Creek in particular were roughly 55% of the average annual (presumably unimpaired) flow during the high flow period in dry years. The Russian River Staff

Report proposed following the dry year criteria established under D-1631 for Mono Lake tributaries, and noted from the PHABSIM results for spawning steelhead in Big Sulphur Creek that this likewise corresponded approximately to 0.6 Q_m (SWRCB 1997).

For other times of the year, the Russian River Staff Report (SWRCB 1997) proposed that a minimum flow equal to 30% of the average annual flow was needed to provide summer rearing habitat for steelhead and coho juveniles, which usually spend at least one year in freshwater before outmigrating to the ocean. The 30% criterion was based on similar reasoning as above for the winter flow criterion, to provide good rearing conditions during dry years. Since this flow level is typically greater than what is available during the May-October period in Russian River tributaries, the Russian River Staff Report recommended that no new diversions be allowed from tributaries during this period.

A.1.3 Other Flow-Related Considerations and General Application of Methodology

The Russian River Staff Report (SWRCB 1997) identified several other flow-related needs. Preservation of high pulse flows for gravel recruitment and transport was identified as important, but the report did not recommend a specific flow level or prescription method. It was recommended that specific permit terms be developed on a case-by-case basis. The need to facilitate salmon and steelhead migration was also identified. Accordingly, the Russian River Staff Report (SWRCB 1997) recommended that projects resulting in a migration barrier not be approved. On-stream projects located above existing permanent barriers, or on streams that do not provide habitat for coho or steelhead, could be approved on a case-by-case basis.

In summary, the Russian River Staff Report (SWRCB 1997) recommended that the proposed instream flow methodology apply primarily to relatively small projects on tributary streams, and that project-specific studies may be needed on larger projects. However, no guidance was given regarding specific size thresholds for stream channels and projects.

A.1.4 Extension of Russian River Staff Report (SWRCB 1997) Methodology to the Navarro River Basin

The State Water Board's Division of Water Rights expanded the area covered by the 1997 staff report to the Navarro River basin in 1998 when it published its draft decision on five pending water right applications for the Navarro River and several tributaries (SWRCB 1998b). The draft decision followed investigations of various complaints and publication of a staff report containing investigation findings and recommendations (SWRCB 1998a). The Navarro draft decision included the additional consideration of riparian rights, prohibiting additional diversion of water for use where riparian rights already existed (SWRCB 1998b).

A.2 EXTERNAL REVIEWS OF THE RUSSIAN RIVER STAFF REPORT (SWRCB 1997)

The Russian River Staff Report (SWRCB 1997) was sent out to approximately 800 parties for review and comment. Primary parties providing substantive comments pertaining to the biological, physical, and implementation bases of the methodology included McBain and Trush (1998; representing Trout Unlimited, TU) and NMFS. While they noted that the proposed approach represented steps in the right direction, McBain and Trush (1998) commented on points where their opinion or interpretation differed and raised several questions that remained unanswered. The NMFS provided comments in October 1998. State Water Board staff subsequently responded to comments and opened discussions with NMFS and TU. McBain and Trush (1999) provided additional comments and recommended an alternative approach. During the process, as described above, the area of concern was expanded to also include the Navarro River basin and other north coastal watersheds. The comments are summarized thematically below. Specific, proposed alternative approaches that arose during this process are described in Section A.3.

A.2.1 Seasonal Timing of Diversions

There was general concurrence regarding the selected diversion window. Limiting diversion to after the first winter storms and preserving late-spring flow variation was considered extremely important for upstream and downstream migration of anadromous salmonid adults and smolts. The consensus was that tributaries of the Russian River should be listed as fully appropriated for the period April 1 to December 14. It was noted, however, that the effects of existing water rights during that period were not covered by the guidelines. In addition, it was argued that providing flows strictly for spawning habitat between December 15 and March 31 would neglect upstream passage needs during that period.

A.2.2 Magnitude of Diversions and Instream Flows Relative to Water Availability

An important criticism of the proposed methodology was that it did not account for potential cumulative impacts of diversions in the tributaries or on the mainstem Russian River. An approach that focused only on the individual, incremental effect of a diversion and not the cumulative effect of multiple diversions posed a long-term risk to maintaining sufficient instream flows, analogous to “death by a thousand cuts.” In addition, the methodology proposed in the staff report did not provide the means for limiting future diversion in specific streams. It was recommended that as part of the requirements, pending and existing diversions be mapped onto each basin’s drainage network and quantified to assess total projected demand.

A.2.3 Basis of Recommended Instream Flow Magnitude

There were questions concerning the definition of what constituted an acceptable minimum instream flow. The definition in the Russian River Staff Report (SWRCB 1997) hinged on a methodology to define flow, and how that flow corresponded to low flow hydrologic measures. It was noted that the PHABSIM results evaluated in the staff report were for relatively large channels and could not be applied directly to smaller channels because of the influence of scale. It has been generally recognized that the ratio of PHABSIM-based flow recommendations to annual flow, decreases with increasing channel size (e.g., Hatfield and Bruce 2000). Hence, a flow resulting in maximum habitat area (or some percentage thereof), as represented for example by a metric such as PHABSIM's WUA, in one size stream generally will not represent the same percentage of average annual flow in another, larger or smaller stream. The assumption that there is a typical WUA-flow curve for all streams was questioned, as was setting the flow resulting in 80% of maximum spawning WUA as a suitable target. The concept and existence of an optimum flow was also questioned, reflecting absence of research showing this level leaves fish populations in good condition and the observation that areas with suitable habitat may shift location across the channel as discharge increases or decreases. It was noted that the instream flow studies reviewed indicated that optimal flows for salmonid spawning were generally much higher than the $0.6Q_m$ level.

Additional correspondence with results from the Tennant Method (Tennant 1976) was not considered to be a form of validation. The reason was given that the Tennant results represented more snowmelt dominated streams than project area streams characterized by greater hydrologic variability (i.e., more flashy). Similarly, the analogy to snowmelt-driven streams in the Mono Lake case was questioned.

The hypothesis that providing dry year flows in all years would be sufficient to sustain anadromous salmonid populations was also criticized on several bases. Imposing a dry year criterion was thought to potentially place threatened salmonid populations at considerable risk. Salmonid populations were thought to rely on average and wet years to allow them to rebound from dry year effects. Moreover, the fact that coho and steelhead populations were near the southern fringe of their latitudinal distributions was associated with an increased ecological risk, where environmental conditions were closer to adverse levels controlling distribution overall. Environmental perturbations were considered to have a greater relative effect on population sustainability of anadromous salmonids nearer their distribution margins than in areas within the central latitudes. In addition, specific examples comparing winter base flows in dry and other years indicated that allocating dry year flows to all years would reduce basin-wide distributions of fish and keep portions of the active channel unseasonably dry.

A.2.4 Effects of Instream Flows on Steelhead and Coho Migration and Spawning

McBain and Trush (1998, 1999) provided examples where the $0.6Q_m$ winter baseflow standard would reportedly result in sub-standard spawning habitat levels for steelhead populations in specific streams, that could lead to increased egg mortality in average and wet years by restricting redds created during the diversion period to the channel centerline, which would be at greater risk of scour during storm events. Redds created prior to December 15 were considered at risk of stranding once diversion began. Analyses of flow hydrographs for Russian River tributaries indicated that the standard would reduce naturally sustained winter flows thought to be needed for spawning by anadromous salmonids.

In addition, examples were given where the corresponding water level would result in water depths that would be too shallow to allow upstream migration of adult steelhead within smaller tributaries during base flow periods. The issue of scale was identified, where smaller channels were associated with a higher flow range for upstream passage than larger channels, sometimes in the more extreme flow range. The need to identify downstream passage barriers as part of the application process was noted.

A.2.5 Other Instream Flow Needs

It was noted that the proposed methodology did not include provisions for channel maintenance flows, which are important for mobilizing and transporting gravel and fine sediments, and for preventing riparian encroachment. These processes influence habitat quantity and quality for spawning and other steelhead lifestages. Other identified needs included ensuring groundwater recharge and side channel maintenance. Permitting of on-stream impoundments without suitable mitigation was noted to interrupt sediment transport, leading to downstream degradation of steelhead spawning habitat.

The Russian River Staff Report's (SWRCB 1997) methodology was criticized for not sufficiently considering biological needs during the winter diversion period. For example, there were no specific elements within the methodology to address the importance of juvenile over-wintering habitat, which has been proposed in the scientific literature to limit coho population size in particular. The methodology was also thought to be insufficient for preserving the range of important ecological processes occurring over different water years and watershed sizes. However, no specific recommendations were given that would link flow to these other processes.

A.2.6 Implementation, Monitoring, and Enforcement

The actual protectiveness of the Russian River Staff Report's (SWRCB 1997) methodology was considered dependent on the extent to which they were effectively implemented and followed. The proposed approach was criticized for the absence of relevant, specific measures for implementation and for not providing recommendations for effective monitoring and enforcement. Implementation issues were identified that could lead to non-compliance, including the need for better and more widespread stream gaging, the inability to forecast a water year in a coastal system compared with snowmelt basins, incomplete inventories of all cumulative existing water uses, and inability of existing flow models to permit real time flow allocation and enforcement. Relying on a proposed 2 cfs limit on pump capacity was likewise considered insufficient for controlling overall diversions. Another perceived critical implementation issue related to whether a stream was classified as fish-bearing or not, especially with respect to anadromous salmonids. Streams that were subject to human-caused blockages, through either diversion or presence of physical barriers including culverts in particular, could still provide habitat locally, or affect flows and habitats downstream.

A.3 PROPOSED ALTERNATIVES TO THE RUSSIAN RIVER STAFF REPORT (SWRCB 1997): JANUARY 31, 2000 WORKSHOP

During the review process, NMFS, DFG, and TU began developing alternative instream flow guidelines. In light of this, the State Water Board convened a peer review workshop held on January 31, 2000 to solicit further development and review of the suite of methodologies under consideration. A peer review panel, consisting of Dr.'s Peter Moyle (UC Davis), Matt Kondolf (UC Berkeley), and John Williams (private), was convened to host the workshop and write a report on its outcome. The primary proposals of DFG-NMFS and TU, and supporting details, are summarized below to identify the general collective thinking behind the development of instream flow guidelines for the study area, followed by a summary of the peer review panel's report and recommendations. The process was fluid in the sense that the various participants continued to modify their respective approaches through a series of discussions, including after the workshop. The sum of the information and recommendations were collectively considered in the development of the ultimate DFG-NMFS Draft Guidelines.

A.3.1 DFG-NMFS (2000) – Initial Draft Guidelines

The NMFS was supportive of the Russian River Staff Report's (SWRCB 1997) concept of a bypass flow policy identifying a minimum stream flow below which new withdrawals would be prohibited during winter months. However, NMFS considered a standard setting equal to $0.6Q_m$ to not be protective of steelhead trout, for similar reasons as summarized in Section A.2. In addition, NMFS considered it important to set guidelines for higher flows needed to manage fine sediment flushing and facilitate migratory movements of adult and juvenile anadromous fishes.

The NMFS (2000) noted that, given the potential variability of stream flow and habitat-flow relations in Russian River tributaries, any flow standard applied without site-specific information and used over a wide geographic area should be conservatively, yet reasonably (with respect to allowing diversion) biased toward salmon conservation. A bypass flow guideline was proposed for tributaries that equaled the February median flow. This level was thought to approximate flows needed to protect salmonid populations, and provide a conservative alternative to the 1997 staff report's $0.6Q_m$ recommendation, and still allow diversions to occur during the winter period.

The month of February was chosen because it was generally the month with the highest median flow in Russian River tributaries. The NMFS reasoned that maintenance of the February median flow should also protect spawning and egg incubation habitat of salmonids in other months, when flows were less.

A median statistic was considered preferable to a mean because it better reflected flow duration, and was not influenced as strongly by infrequent, high flow events. Review of 81 annual records of winter flows in five tributaries of the Russian River indicated that the February median flow led to more, sustained winter flows potentially useful to spawning salmonids than the $0.6Q_m$ level. A standard based on a median flow was also noted to provide for water diversions during the winter period.

Diversion only during high flows was thought to not significantly impact steelhead spawning and egg incubation, because such flows are not sustained. Furthermore, diversion of flow during these high flow periods was thought to reduce the incidence of redds being created nearer the channel margins during high flows, and thus reduce the potential for redd dewatering.

The NMFS (2000) recommended that site-specific studies be required for those seeking a minimum bypass flow lower than the February median; such studies would need to demonstrate that a lower bypass flow would have no significant adverse effect on aquatic resources.

The issue of cumulative effects was addressed indirectly. The NMFS (2000) recommended that the bypass flow be maintained at diversions in tributary headwaters even if salmonids and/or their habitat are not located in the channel immediately downstream of the diversion point. It was noted that headwater tributaries may be important areas for the production or transport of invertebrate foods that subsequently drift downstream to rearing juveniles. In addition, NMFS noted that headwater tributaries also contribute flow to downstream reaches that may support salmonids, and that cumulative downstream impacts could occur.

In recognition of the need to maintain some degree of natural flow variability and high stream flows for ecological and channel maintenance purposes, NMFS (2000) proposed limiting the instantaneous rate of diversion to less than 20% of the winter 20% exceedance flow, evaluated cumulatively for all diversions located at, and upstream of a diversion site. This flow would be maintained in conjunction with the February median bypass flow. A review of hydrographs for tributaries of the Russian River indicated that stream flow is especially high during about 20% of the time during the winter months. It was proposed that removal of a portion of this high flow would probably have no adverse effect on salmonids or stream ecosystem function. It was suggested that the proposed limit would (a) preserve natural high flow events needed for channel maintenance, (b) preserve days with intermediate flows, and (c) provide substantial quantities of water to irrigators and other water users.

In summary, NMFS (2000) and DFG-NMFS (2000) recommended that the State Water Board modify the water diversion approach proposed in the Russian River Staff Report (SWRCB 1997) by incorporating the following measures for coastal basins ranging from the Mattole River to the north, down the coast and into San Pablo Bay, up to and including the Napa River basin:

1. Diversions in streams with anadromous salmonid habitat that withdraw more than 3 cfs or 200 acre-ft/yr require assessments of: instream flow needs for fish habitat and channel maintenance; existing level of diversion-related impairment and limiting factors; and development of an effectiveness monitoring plan, all subject to agency review and approval;
2. For smaller diversions, use the February median flow as the minimum winter bypass flow guideline;
3. The natural hydrograph should be protected by limiting the cumulative instantaneous rate of withdrawal to 15% of the winter 20% exceedance flow during the period December 15-March 31, subject to a limiting cumulative rate of withdrawal that does not appreciably diminish (qualified as <5% of) the natural hydrograph flows needed for channel maintenance (e.g., around the 1.5- to 2-year flood events) and upstream fish passage; reduced from 20% of the 20% exceedance flow after discussions with State Water Board staff; (DFG-NMFS 2000; NMFS 2000);
4. Coordinate permitting so that cumulative withdrawals from upstream reaches do not exceed the maximum instantaneous withdrawal rate at any point on the stream;
5. Ensure that fish passage and screening requirements are met;
6. Avoid additional permitting of small on-stream reservoirs; and
7. Require the applicant to identify all other water rights and their basis in streams potentially affected by the proposed diversion, and provide evidence of compliance and effectiveness.

The flow levels specified above applied to cases where site-specific studies were not conducted. Studies that demonstrated another flow level as sufficient and not adversely affecting salmonids and their habitat could be used to justify a diversion rate otherwise not permitted under the guidelines above.

A further exemption was provided in cases where the following conditions were all met: (i) the proposed diversion was located in a stream where aquatic fauna were not historically present, per Class III designation under 14 CCR 916.5, Table 1 (i.e., no aquatic life present, water course showing evidence of being capable of sediment transport downstream to fish-bearing waters under normal high water flow conditions); (ii) the project would not lead to a cumulative diversion rate exceeding 10% of the natural instantaneous flow in any reach where fish are at least seasonally present ("cumulative" was defined to include riparian water rights), and (iii) the project would not lead to dewatering of a fishless stream supporting other aquatic fauna.

The DFG-NMFS (2000) identified the need to corroborate assumptions used in developing the guidelines through compliance and effectiveness monitoring. As part of this, it was considered essential that all existing diversions be quantified prior to the issuance of new permits to prevent over-allocation, and that stream gages be installed at key locations to monitor compliance. The State Water Board, DFG and NMFS were called to cooperatively develop and implement a plan to monitor the effectiveness of the proposed standards, and make refinements based on the information collected. In addition, the need for enforcement was identified, through stream gaging and random compliance inspections.

A.3.2 Trout Unlimited/McBain and Trush (2000) Proposal

The Trout Unlimited (TU) proposal was the product of a number of previous reviews related to the State Water Board (SWRCB 1997) Russian River basin staff report, the subsequent draft decision for the Navarro River basin (SWRCB 1998b), and the initial NMFS (2000) and DFG-NMFS (2000) draft guidelines for these and other coastal basins north of San Francisco and south of the Eel River. A set of initial recommendations was made (McBain and Trush 1999), followed by a revised, more comprehensive set (MTTU 2000). The newer recommendations reflected additional data analyses and various discussions with the agencies leading up to the January 31, 2000 peer review workshop, at which time the revised TU protocols were also presented.

Major initial recommendations (McBain and Trush 1999) were:

1. Protocol needs to include mechanisms to facilitate within-year (e.g., variable hydrographs) and interannual (e.g., wet vs. dry year protocols) flow variation, as opposed to what MTTU (2000) later called managing for a "typical" year;
2. More protective measures are needed for juvenile rearing habitat and channel maintenance; flow range should vary at a minimum between 10% exceedance base flow and 70% of the bankfull flow ($0.7Q_{BF}$) flow;
3. Proposed guidelines should be applied similarly for streams independent of the presence of anadromous fish; some streams could contain salmonids pending correction of artificial passage barriers, and other streams provide flows needed farther downstream;
4. Measures are needed to ensure that on-stream reservoirs pass unobstructed flows outside the diversion window, and new on-stream reservoirs should not be permitted;

5. Should ensure that cumulative diversion rates do not exceed the maximum permissible for the watershed;
6. Implementation and effectiveness monitoring are needed to assure fish habitats are not adversely impacted through application of specified criteria; and
7. Enforcement should be conducted at a minimum of on an annual, random basis.

McBain and Trush (1999) and MTTU (2000) stated that use of active channel discharge (Q_{AC}) could be defended on a geomorphic basis. It was stated that the Q_{AC}: (a) was the approximate threshold flow for sediment transport, (b) left a geomorphic signature in the channel consisting of a bench of coarse particles packed in a matrix of sand and fine gravel that originates at the active channel crest and extends approximately to the bankfull stage height, (c) limited woody riparian encroachment as indicated by the absence of white alder roots below this level, and (d) had important significance for adult salmonid access and juvenile rearing. The extent of white alder roots was stated as forming the active channel bench in northern California streams along straight reaches, preventing the channel from widening and concomitantly increasing the potential for redd stranding.

The value of the proposed Q_{AC} was reported to have an annual exceedance probability of ~10%. McBain and Trush (1999) noted that Caltrans used a higher fish passage flow standard for designing culverts than the annual 10% exceedance flow, and that an ongoing study found that the higher Caltrans high flow design standard for fish passage impeded upstream passage in small watersheds (presumed depth limitation, following final report conclusions; Lang et al. 2004).

McBain and Trush (1999) noted that the upper flow window value of $0.7Q_{BF}$ was approximated by the annual 1% exceedance flow. Its ecological significance was attributed to it being the flow that will not dewater most seasonally important habitat such as scour channels, side channels of abandoned meander bends, and alcoves. In addition, it was considered the lower flow threshold for initiating bedload transport and pool scour, and for preventing riparian encroachment of the channel.

The value of Q_{AC} was also noted to result in greater minimum passage depths (MPDs) in area streams, than the Russian River Staff Report (SWRCB 1997) and NMFS proposals, and more often met MPD criteria (MTTU 2000). Their analyses reflected work eventually reported by Lang et al. (2004). The behavior of steelhead was particularly noted where males may travel up and down several watersheds many days following the peak flow that initially stimulated their upstream migration. On-channel reservoirs in watersheds smaller than 10 mi^2 that did not pass peak flows were considered to prevent upstream migration of anadromous salmonids, because the affected streams required proportionally more water to provide passage and habitat conditions suitable for spawning.

The revised TU proposal (MTTU 2000), which was built on the previous recommendations and observations and on additional analyses, consisted of the following primary actions for diversion in streams with watershed areas less than about 10 mi^2:

1. No water should be diverted below the active channel stage height, as defined by Q_{AC} rather than a specified exceedance probability, although TU did recommend that a 10% exceedance probability be initially assigned as Q_{AC} for streams with watershed areas smaller than 10 mi^2 (and possibly a lower probability for streams with basin areas smaller than about 2 mi^2);
2. Diversions should be designed to reserve a fraction of higher flows exceeding the active channel stage height, whereby the maximum diversion rate would not alter the timing of the active channel flow by more than one-half day for each high flow event;
3. Existing on-stream reservoirs must be approved or removed, on all classes of streams (I, II, and III) pending a publicly available accounting of (i) potential cumulative downstream effects on anadromous salmonid habitat, (ii) potential use of upstream habitat, (iii) other fishery and aquatic resources as defined by the DFG code, (iv) off-channel habitat and wetlands, and (v) channel maintenance processes;
4. Application for a new on-stream reservoir could be approved only after it can be demonstrated that it does not impair the hydrograph at the upstream limit of potential anadromous habitat (including above currently impassable culverts and other anthropogenic barriers) and that it sustains downstream riparian, wetland and other aquatic resources;
5. The water right review process must identify all potential downstream barriers, and evaluate the cumulative effect of the proposed or existing diversion together with all existing upstream water rights;
6. All new and existing on-stream reservoirs that intercept coarse bedload must have an approved operational plan for annually replacing the lost bedload volume downstream of the structure;
7. The State Water Board should establish a protocol for required, consistent compliance monitoring and diversion design, with random compliance audits and assessment of penalties; and
8. The State Water Board should devise and implement an effectiveness monitoring program jointly with other resource agencies, as part of an ongoing adaptive management plan; the program should include development of regional channel size, active channel discharge, and hydraulic geometry relationships, plus an inventory of all

permitted, riparian, and other diversions so that downstream cumulative impacts can be properly assessed.

The proposed DFG-NMFS (2000) Draft Guidelines and State Water Board staff recommendations (1997, 1998b) were considered less protective than the criteria outlined in bullets 1 and 2 above. McBain and Trush (2000) compared the three sets of approaches with respect to total (or, cumulative) spawnable area, minimum passage depths, and availability of spawning habitat. They noted that, in some streams, even the DFG-NMFS (2000) proposed diversion rate criterion would result in substantial reductions in available spawning habitat.

A.3.3 Moyle et al. (2000) Proposal

Moyle et al. (2000) summarized the ideas and comments generated in the January 31, 2000 workshop. However, they did not recommend a definitive method for specifying allowable diversion rates and recommending instream flows. Instead, they provided a conceptual synthesis of actions that should be taken within the context of adaptive management, and that would lead to identifying a protective set of instream flow requirements. The primary recommendation was to defer approval of any new water rights until the various sources of uncertainty affecting the status of coho and steelhead populations were understood sufficiently, so that diversions could be conditioned to avoid unacceptable risk of harm to listed species and public trust resources. In the meantime, the State Water Board was urged to follow the tenets of adaptive management if any new diversions were indeed to be permitted. In this case, Moyle et al. (2000) suggested following the initial DFG-NMFS (2000) draft guidelines with the addition of a separate minimum passage depth criterion for smaller streams used by anadromous salmonids and consideration of the effects of diversions on the duration of high flows. Specific recommended actions for implementing the initial draft guidelines included:

1. Basing instream flow and bypass standards on clearly defined objectives;
2. Using biological and hydrological criteria that can be expressed as testable hypotheses;
3. Requiring a monitoring program that tests the hypotheses; and
4. Modifying the diversion conditions accordingly.

Other recommendations included not approving on-stream impoundments on perennial streams, and only approving such reservoirs on ephemeral streams in cases where only a fill and spill approach is considered acceptable and subject to the condition that they be emptied annually to control exotic species. Lastly, the State Water Board was urged to work with other resource agencies and academic institutions to promote biological and hydrological data collection, research, and monitoring, with effort most efficiently and effectively focused on a sub-sample of sites, and to improve flow estimation capabilities.

A.3.4 August 2000 SWRCB Workshop

In August 2000, the SWRCB held a workshop on the initial DFG-NMFS (2000) draft guidelines, comments and presentations from the January 2000 workshop, and Moyle et al.'s (2000) peer review report. During the workshop, Division staff reported that the higher February median bypass flow proposed by NMFS was about twice the magnitude of the 60%Q_m recommendation in the Russian River Staff Report (SWRCB 1997), but still allowed for diversion. Thus, Division staff recommended using the February median flow instead of 60%Q_m for the minimum bypass flow (SWRCB 2000).

A.4 REVISED DFG-NMFS (2002) DRAFT GUIDELINES

The revised DFG-NMFS guidelines published in 2002 (Draft Guidelines) contained many of the same elements presented in the initial DFG-NMFS (2000) draft guidelines. Minor modifications were made that reflected comments on the Russian River Staff Report (SWRCB 1997) and initial DFG-NMFS (2000) draft guidelines made by various participants in the process, including as part of the January 31, 2000 peer review workshop. The modifications also reflected discussions and comments shared between State Water Board staff (SWRCB 2001) and NMFS (Bybee 2001) concerning appropriate ways to assess cumulative impacts. The most substantive revisions concerned protection of the natural hydrograph and cumulative flow impacts. Item 3 in Section A.3.1 above was modified to be more conservative, as follows:

- Absent compelling site-specific information and analyses demonstrating otherwise, the natural hydrograph should be protected by either:

  a. Limiting the cumulative instantaneous rate of withdrawal to 15% of the winter 20% exceedance flow during the period December 15-March 31, subject to a limiting cumulative rate of withdrawal that does not appreciably diminish (qualified as <5% of) the natural hydrograph flows needed for channel maintenance and upstream fish passage; or
  b. Limiting the total cumulative volume of water to be diverted at historical limits of anadromous fish distributions to 10% of the unimpaired runoff during the period December 15-March 31 during normal water years, using a Cumulative Flow Impairment Index (CFII); hydrologic analysis is needed for projects with CFIIs between 5%-10% that demonstrates the diversion will not cause or exacerbate significant cumulative effects to salmonid migration and spawning flows.

An appendix was provided as part of the DFG-NMFS Draft Guidelines that detailed the procedure for calculating the CFII as:

$$CFII = \frac{Cumulative\ Diverted\ Volume\ From\ 10/1-3/31}{Estimated\ Unimpaired\ Runoff\ \ From\ 12/15-3/31}$$

The CFII was proposed to be evaluated at various points of interest (POIs) representing the point of diversion (POD) and the confluences of major intervening tributaries between the POD and the mainstem coastal rivers or estuary, depending on overall basin size. The locations of POIs were to be determined by NMFS and DFG staff. The Cumulative Diverted Volume (CDV) would be assessed for all existing water rights expected to be exercised during the period indicated in an average water year, including pre-1914 rights, riparian rights, small domestic and stock pond registrations, and other appropriative rights, plus the proposed diversion. The Estimated Unimpaired Runoff (EUR) would be similarly calculated for an average year, using standard hydrologic techniques. The specific technique applied would be left to the discretion of the applicant and could reflect available information as opposed to requiring collection of new data.

Cases where the calculated CFII exceeds 5% and there is an appreciable impairment on the hydrograph would require a site specific study addressing geomorphic effects (including channel maintenance, sedimentation, and estuarine disconnection from the ocean), anadromous salmonid spawning habitat flow needs (in including identifying minimum bypass flow and maximum instantaneous rate of withdrawal), and upstream salmonid migration ability below the diversion site(s).

A.4.1 Technical Basis of DFG-NMFS Draft Guidelines

Much of the underlying basis of the DFG-NMFS (2002) Draft Guidelines is described above, particularly with respect to setting of the diversion season and retaining flow variability in streams with diversions and impoundments. Primary sources of information detailing the technical basis of the guidelines included State Water Board (SWRCB 1997, 2001), DFG-NMFS (2000, 2000b, 2002), and personal communications with W. Hearn (NMFS), L. Hanson (DFG), and S. Herrera (SWRCB). The major concepts and data used in developing and providing the technical justification for the DFG-NMFS (2002) Draft Guidelines are summarized as follows:

1. The setting of instream flow standards in streams where a site-specific study has not been conducted has relied typically on hydrologic metrics that can be relatively easily estimated, including for ungaged basins. Hydrologic metrics to a certain extent inherently consider stream channel size and water availability. Deferral to the findings of a subsequent instream flow study allows for adjustment from potentially conservative guidelines. The standard setting approach used should be practicably implemented and yet be conservatively protective of aquatic resources in the absence of a more detailed, site-specific study.
2. The hydrologic-based New England Aquatic Base Flow Policy (ABF) served as an initial model for the development of the Russian River basin methodology. Appropriate metrics for use in the ABF were derived from an analysis of stream gages in unregulated

New England streams. The ABF method recommends the August median daily average flow as a minimum instantaneous summer low flow requirement, and seasonal releases equal to the median February and April/May flows in the fall/winter and spring periods, respectively, to protect fish spawning and incubation life stages (IFC 2002). The underlying assumptions of this method are that (i) hydrology could be used as a surrogate for habitat, and (ii) fish species and their various life history stages are adapted to median flow levels during the respective months of importance when each life stage's survival would be most vulnerable.

3. It was recognized that providing a single flow value cannot simultaneously meet the habitat requirements for all species and life stages of fish. Rather, a range of flows is needed to facilitate physical processes controlling form and function of stream channels and biological diversity within and adjacent to the stream ecosystem (IFC 2002). A basic principle for guideline development was therefore to preserve hydrograph variability as much as possible, with a lower limit instream flow set to protect habitat during baseline flow conditions.

4. The time of year that diversion could occur should reflect water availability for multiple uses. Summer flows are typically low, and early fall and spring flows are highly variable. Most water for uses other than instream needs is available during the winter-early spring months, and hence December 15-March 31 was defined as the permissible diversion period. The specified timing also reflected regional migration and spawning periodicities of coho salmon and steelhead trout.

5. A median flow statistic was considered reasonable and practical, because it could be estimated with less bias than other percentile and average values. February was selected as the corresponding month on which the median flow criterion should be based because a review of unregulated stream gage data in the region indicated flows were highest overall during that month. Selection of the February median flow would thus be more protective for fish than median flows of other months. In addition, the gage analysis indicated that flows in January and March were not substantially lower than in February, so that specification of a February median flow criterion would not severely restrict diversion during the rest of the permissible diversion season.

6. February was also the month of peak steelhead migration to spawning grounds in small tributaries within the project area, and thus represented a critical month for anadromous fishery protection. Flows needed to protect spawning and incubation tend to be higher than flows needed to protect other life stages, such as juvenile rearing and adult holding. Provision of flows that meet spawning and incubation needs should, therefore, be protective of other life history stages. Steelhead redds constructed nearer the median February flow level should be at less risk of dewatering and stranding than redds constructed at higher flow levels. Sustained flow over the redd is important given that typical intragravel residence times in the region range between roughly 40-60 days.

7. Sudden decreases in flows should be avoided, because they can result in trapping and stranding of over-wintering juvenile salmonids.

8. Hydrograph shape preservation could be better achieved through permitting a maximum instantaneous diversion rate, rather than specifying a total diversion volume with a minimum flow rate at which diversion could begin.
9. Reviews of unregulated stream gage data from the region indicated that a maximum instantaneous diversion equal to 20% of the 20% exceedance flow from the stream should not result in substantial changes in hydrograph shape or duration over the course of the winter period. Reducing the maximum diversion to 15% of the 20% exceedance flow would be more protective of the aquatic ecosystem.
10. Cumulative effects analyses should be conducted as screening tools, so that adverse effects can be avoided before they occur, particularly when site specific studies are not conducted.
11. Professional judgment of State Water Board staff of the results of hydrograph analyses suggested that cumulative diversions resulting in CFII values exceeding 10% would be detrimental to salmonids, and that risks of impact to salmonids also existed in some cases when the CFII value ranges between 5-10% (SWRCB 2001). Comparisons of hydrographs indicated that 15% of the winter 20% exceedance flow approximated 10% of the total unimpaired runoff during the winter diversion period, an amount that was considered to not appreciably change spawning flows and the overall hydrograph from natural conditions.
12. On-stream diversions were prohibited in streams that either currently support or historically supported anadromous salmonids. This was based on problems associated with fish passage, flow regulation, the trapping of bedload and large wood, and potential creation of non-native aquatic species habitats.

APPENDIX B

Physical Hydrological, and Ecological Conditions Influencing Anadromous Salmonid Habitat in Policy Area Streams

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APPENDIX B

PHYSICAL, HYDROLOGICAL, AND ECOLOGICAL CONDITIONS INFLUENCING ANADROMOUS SALMONID HABITAT IN POLICY AREA STREAMS

This appendix describes certain prominent physical, hydrological, and ecological characteristics associated with the Policy area that can influence anadromous salmonid habitats within adjoining streams and rivers.

B.1 PHYSICAL CHARACTERISTICS

The Policy area covers about 5,000 square miles and is generally mountainous, except for about 550 square miles of relatively flat area (slopes < 4%), 45 percent of which lies in the Russian River basin and the remainder in the lower part of basins draining into San Pablo Bay (Figure 1-1). The Policy area lies wholly within the northern California Coast Ranges physiographic section (Fenneman 1931). The mountain rocks consist of consolidated rock, mostly sandstone and shale, composing the Franciscan Formation. Volcanic rocks overlie the Franciscan rocks in some areas. The Franciscan rocks and, to a lesser degree, the younger volcanics, have been folded, faulted, and eroded to form northwest-trending ridges and valleys.

Some valleys in the Policy area are broad and flat and contain thick sedimentary deposits (USGS 1967). Some gradient valleys contain thick deposits of gravel derived from erosion of surrounding mountains, and others are steep and narrow, actively eroding, and contain relatively little alluvial gravel. Many channels are incised in response to tectonic and erosion processes, from land use practices resulting in the loss of a stabilizing riparian zone, and/or from increased peak flows in urbanized settings (Haltiner et al. 1996). Valleys generally follow zones of brecciated rock along folding and fault lines, where hummocky topography and landslides are prominent features of the landscape (Rantz and Thompson 1967; Kondolf et al. 2001).

B.2 HYDROLOGICAL CHARACTERISTICS

Streams in the Policy area have distinct seasonal runoff patterns, reflecting limited precipitation from June through September. The climate is characterized as Mediterranean, with mild wet winters and cool dry summers along the coast. Summer temperatures are considerably warmer in inland valleys than in coastal basins. Rantz and Thompson (1967) estimated that about 80 percent of the total precipitation in the Policy area falls during five months, from November through March. Mountains in the Policy area are of relatively low elevation resulting in little snowmelt runoff. Mean annual precipitation increases from south to north along the coast, and from inland to the coast for basins draining into San Pablo Bay, ranging from around 20 inches in the Napa Valley to around 110 inches on the mountain divide of the Mattole River basin. Mean annual precipitation is strongly influenced by altitude and steepness of the coastal mountain slopes. About 80 percent of the total annual runoff occurs during the four months of December through March. Rains during November generally contribute little runoff, and are absorbed by the ground. The bulk of precipitation typically falls during several storms each year. In general, flows during the summer and early fall are low compared with the winter, and many small streams may go dry. Some streams flow throughout the dry season during wet years, maintain isolated pools in average years, and have no water in them in dry years (Opperman 2002). There is little lag between rainfall and runoff once antecedent conditions become wetter in November, reflecting low soil and surface rock permeability and a limited capacity for sub-surface storage (Rantz and Thompson 1967). This results in streams with relatively ‘flashy’ storm runoff hydrographs. Rantz and Thompson (1967) noted a close relationship exists between flow-duration curves and low flow frequency curves derived for streams in the region. Both types of curves were found to be influenced by basin characteristics. The strength of the relationship was thought to reflect the regional consistency of the seasonal pattern of precipitation. Characteristics of the flow duration curve were correspondingly found to be related to discharge, and the magnitude of floods of any given frequency could be related to both the size of the drainage area and mean annual basin-wide precipitation.

Because of the low infiltration capacity and permeability of the Franciscan and volcanic rocks, baseflows in streams are poorly maintained. Along the mountain drainages, baseflow that does occur is maintained by groundwater discharge emerging from fractures through springs and seeps. As a result, some streams may be composed of discontinuous wet reaches with pools sustained over summer by groundwater discharge. Some higher elevation streams may run dry from summer to late fall. In the valleys, groundwater occurs in the alluvial deposits. There, baseflow is maintained by groundwater discharge along reaches where the water table is higher than the adjacent stream. In the larger valley drainages, such as the Napa River, Sonoma Creek, Petaluma River, Russian River, Lagunitas Creek, groundwater discharge is large enough to sustain perennial flow.

Due to the low water yield of the Franciscan and volcanic rocks, groundwater development in the mountainous areas is limited. Well yields are low, typically on the order of a few gallons per minute, but in some locations sufficient for domestic, stock pond, or small-scale irrigation purposes. The vast majority of groundwater development occurs in the larger valley drainages, particularly the Napa and Russian Rivers, where urban water purveyors operate extensive wellfields. Some wells in these areas yield as much as 3,000 gallons per minute (DWR 1975). Pumping of groundwater can deplete stream flow by intercepting tributary groundwater that would otherwise discharge to a stream, or by direct withdrawal from the surface flow.

Streams in some regions of the Policy area have less demand for water placed on them for out-of-channel use than other streams. Most coastal rivers and streams north of the Russian River have been impacted more by timber harvest activities than by water use. In general, there is a gradual shift in impacts from timber harvest towards water diversion and grazing in a southerly direction. As such, the Navarro River, and to a lesser extent the Garcia River represent transition basins in that they have experienced varying levels of timber harvest, water use, and grazing impacts. Impacts in other northern coastal basins resulting from implementation of the Policy are expected to be less significant than elsewhere, as projected water demands are unlikely to exceed the diversion limitations placed by the Policy.

Following the stream ordering system of Strahler (1957), where a first order stream is the highest channel in the network, a second order stream extends downstream of the junction of two first order streams and so forth, most streams in the Policy area are of third order or smaller, as designated in the 1:100,NHD Plus geospatial data sets from Horizon Systems Corporation developed for the Environmental Protection Agency using the USGS National Hydrography Dataset (NHD) as base data, Horizon Systems (2006). There are 2,594 first order, 616 second order, 161 third order, and 31 fourth order streams delineated in the Policy area. Most first order streams have a drainage area less than 3 mi^2 and most second order streams have a drainage area less than 10 mi^2 (Figure B-1). This indicates that the Policy must be applicable to a wide range of stream sizes, including small first and second order streams.

B.3 ECOLOGICAL CHARACTERISTICS

Riparian communities in the coastal basins north of the Russian River tend to include an overstory consisting of mixed conifer and hardwood big leaf species, and various willows, vines, epiphytes, herbaceous, and other woody plants forming an understory. Willows are typical pioneers in disturbed areas. In redwood forests, the redwoods form the primary overstory species, with other tree species forming part of the understory. Most riparian systems in the region have been altered by timber harvest or fire. Many systems have gone through succession to relatively diverse second growth forests (Ray et al. 1984).

Riparian communities in the eastern and northern portions of the Policy area have been described as one of three broad types, headwater areas, mid-level areas, and broad valley floodplains (Roberts 1984). In headwaters areas, stream channels are often actively eroding close to or at bedrock. Riparian vegetation composition and density reflects in large part the ability of plants to find a foothold and nourishment in thin alluvial soils. The stream flow regime in most cases provides adequate year-round water if not diverted. In mid-level areas, most streams contain gravel bars and sand flats supporting riparian vegetation, often in narrow strips between the stream and bedrock hillslopes. The vegetation is relatively susceptible to scouring during floods, with recolonization depending on seed source proximity to the channel and dispersal mechanisms. Riparian groves are found in wider valleys with terraces. In the third community type, broad-valley floodplain areas, deposition of a thick sediment layer near abundant water is associated with riparian gallery forests. Colonization processes occur rapidly, although this community is influenced heavily by land use practices including clearing and grading (Roberts 1984).

The area and diversity of the riparian zone in the Russian River watershed has been reduced considerably from historic levels by a variety of land uses. Many of the areas which historically supported floodplain wetlands and riparian forests in a mature stage have been converted to agricultural lands. The construction of large dams on the East Fork of the Russian River and Dry Creek have influenced characteristic flow and sediment transport regimes, which in turn have likely influenced the extent and characteristics of the riparian zone as well. Most of the riparian community in the basin is dominated by hardwood species such as California bay laurel, white alder, and various oak and willow species. However, several invasive species including particularly giant reed are changing the riparian zone community structure at isolated locations in the basin (Florsheim et al. 1997; Opperman 2002; Opperman and Merenlender 2003).

Riparian zones in the Policy area serve a variety of functions for creating and maintaining anadromous salmonid habitat, including providing habitat structure and cover through input of large woody debris (LWD) and bank stability, water temperature control through shading, input of organic material for secondary production, and by insect drop as a juvenile food source. Of these, only the benefits and importance of LWD as a habitat element for anadromous salmonids in Policy area streams remain equivocal. LWD can be an important mechanism for creating spawning and rearing habitat for anadromous salmonids, especially in conifer forested streams on the North Coast and in the Pacific Northwest (e.g., Gregory et al. 2003). However, streams with hardwood dominated riparian zones can have a very low loading and geomorphic influence of LWD on channel form and fish habitat, although streams with relatively high hardwood LWD loading values can have some fish habitat associated with LWD-jams, but not individual pieces. This is because individual pieces of hardwood LWD are considerably smaller than LWD provided by mature conifers and can break down faster, and thus have less influence on channel form. In general, streams on private land may have significantly less LWD than streams in protected watersheds (Opperman 2002).

Anadromous salmonid habitat requirements during the winter diversion season include primarily passage, spawning, incubation, and winter rearing. In general, spawning habitats in Policy area streams tend to be more evenly distributed in lower gradient channels, while in higher gradient channels, spawning areas are sporadic and often limited to distinct patches or pockets, a result of gravel supply, transport, and deposition patterns. The ability of anadromous salmonids to use these spawning habitats and negotiate passage barriers in the Policy area is strongly dependent on flow magnitude and duration, gradient, and channel shape and size (Rantz 1964; MTTU 2000). In the smallest streams, passage may occur only during high water events. Spawning occurs in areas with suitable gravel quality and quantity, during freshets and/or base flows. Winter rearing generally requires deeper water and cover that can be provided in the form of large substrate, overhanging vegetation, or undercut banks. In Policy area streams, availability of rearing habitat is generally controlled by base flow. A more detailed description of anadromous salmonid habitat requirements, specifically as they are related to certain Policy elements is provided in Appendix D.

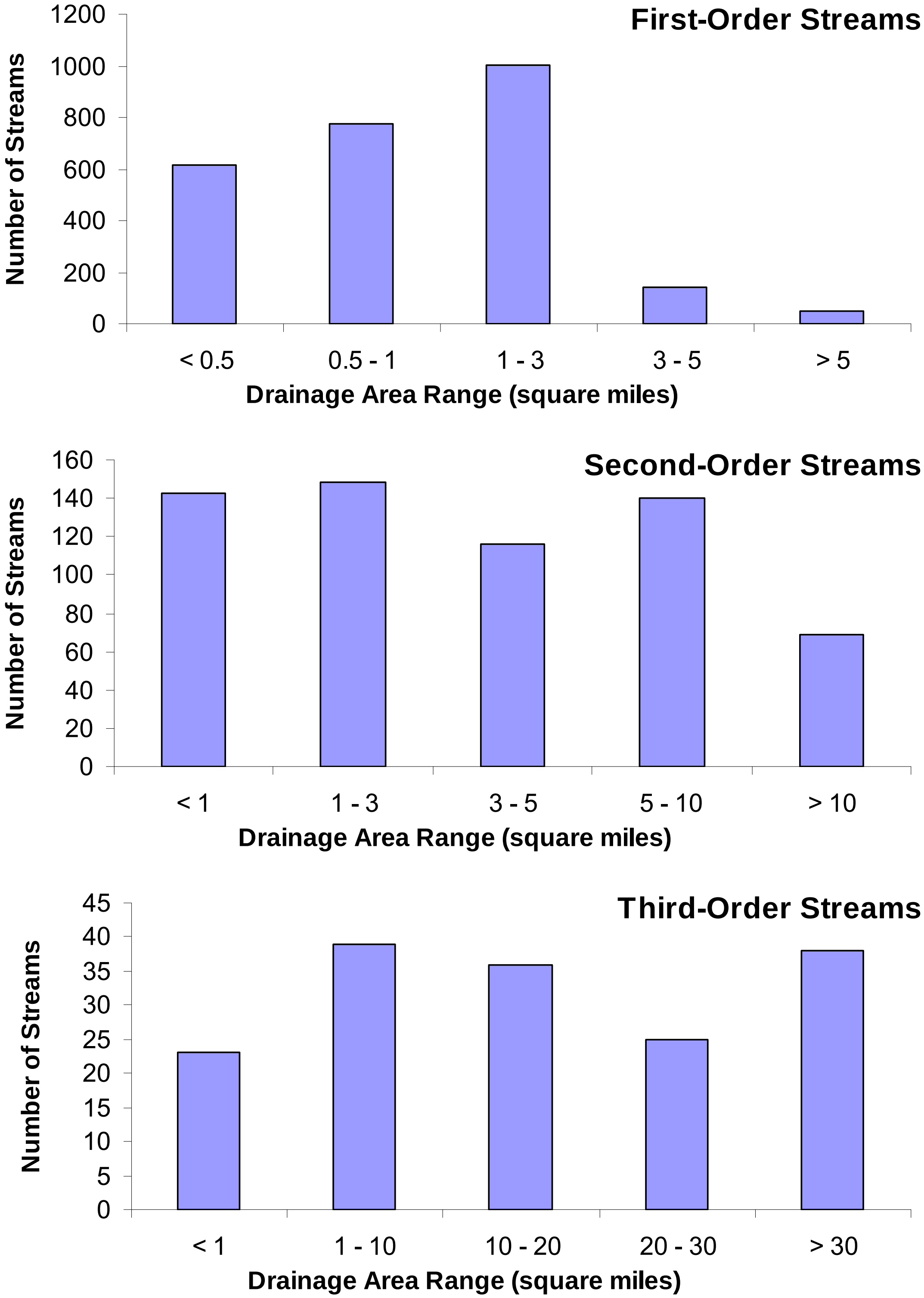

Figure B-1. Relative frequency of drainage basin areas, by Strahler stream order across the Policy area.

APPENDIX C

Summary of Important Biological Characteristics of Target Anadromous Salmonid Species

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APPENDIX C

SUMMARY OF IMPORTANT BIOLOGICAL CHARACTERISTICS OF TARGET ANADROMOUS SALMONID SPECIES

C.1 STEELHEAD TROUT

NMFS has identified two steelhead ESUs in the Policy area: the Northern California ESU and the Central California Coastal ESU. Figure C-1 depicts the range of critical habitat designated by NMFS in 2005 for both ESUs (70 FR 52488). The Northern California ESU was federally-listed as a threatened species on June 7, 2000 (65 FR 36074); its threatened status was reaffirmed on January 5, 2006 (71 FR 834; DFG 2006). The ESU includes populations in coastal river basins from Redwood Creek in Humboldt County southward to the Gualala River. The Central California Coastal steelhead ESU was federally listed as a threatened species on August 18, 1997 (62 FR 43937); its threatened status was also reaffirmed on January 5, 2006 (71 FR 834; DFG 2006). The ESU includes populations from the Russian River south to Aptos Creek (Santa Cruz Co.), and the drainages of San Francisco, San Pablo, and Suisun Bays.

There are two basic life history types of steelhead: summer (stream-maturing) steelhead, which return to fresh water between March and June with immature gonads and consequently must spend several months in the stream before they are ready to spawn; and winter (ocean-maturing) steelhead, which mature in the ocean and spawn relatively soon after re-entry into fresh water in late fall and early winter (Moyle 2002; McEwan and Jackson 1996). Steelhead in the Policy area are primarily winter steelhead. Summer steelhead are found only in the Mattole River within the Policy area (Moyle 2002).

Figure C-2 depicts the general life history timing, or lifestage periodicity of winter steelhead. Winter steelhead typically begin moving upstream after late fall and early winter rains increase base flow. In some streams, this results in the breaching of sandbars blocking the mouth of lagoons, thereby permitting passage through lower reaches (McEwan and Jackson 1996). Upstream migration tends to begin slightly later in streams that are south of Point Reyes (in December) compared to those north off Point Reyes (in November; Figure C-2). The run can stretch out beyond the coho spawning season, with waves of fish migrating with higher flow events (Shapovalov and Taft 1954). January and February appear to be the peak migration months, extending into March in the Russian River basin where some adults have farther to swim to spawning grounds (Figure C-2). Winter steelhead spawn within a few weeks to a few months from the time they enter fresh water. Peak spawning occurs during January through March, but can extend into spring and early summer months (Figure C-2). After spawning and depending on water temperature, the eggs hatch in approximately 3 to 4 weeks, with fry emerging from the gravel 2 to 3 weeks later. The fry then move to shallow protected areas associated with the stream margin for several weeks (Moyle 2002). They soon move to other areas of the stream and establish feeding locations. Most juveniles inhabit riffles, but some of the larger ones will inhabit pools or deeper runs (Barnhart 1986; Moyle 2002).

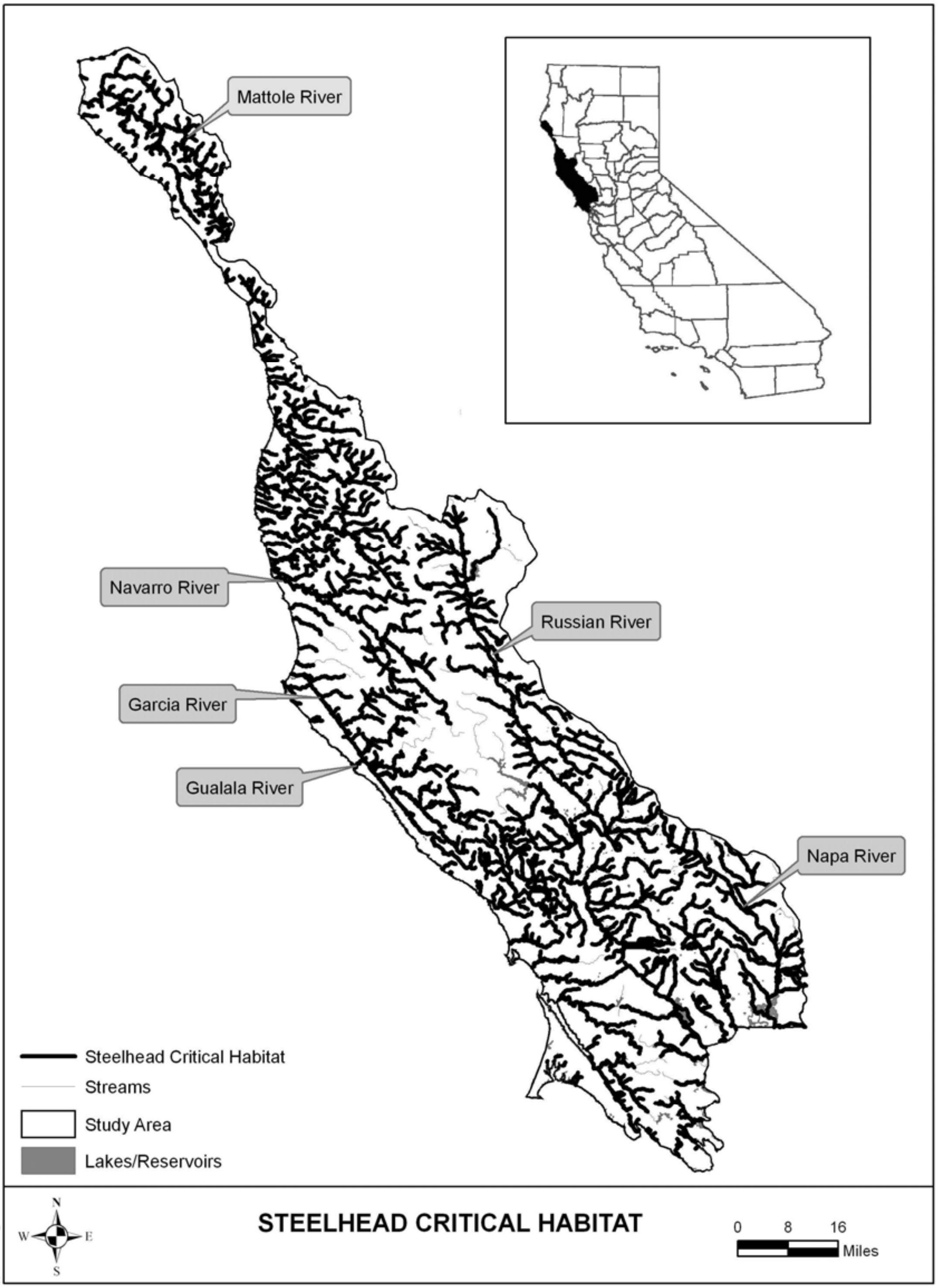


Figure C-1. Federal critical habitat designated for winter steelhead within the Policy area.

Winter Steelhead

Life Stage	**River**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Upstream Migration	North Coast		▐	▒	▒	▒	▌						
	Mattole R		▒	▒	▓	▓	▒	▒	▒				
	Noyo R		▒	▒	▓	▓	▒	▌					
	Navarro R		▒	▒	▒	▒	▒	▒					
	Brush Cr		▐	▒	▒	▒	▒	▒					
	Russian R [1]	▐	▒	▒	▓	▓	▓	▒					
	Lagunitas Cr		▒	▒	▒	▒	▒	▒					
	Redwood Cr			▒	▒	▒	▒	▒	▒				
	Napa R			▒	▓	▓	▒	▒					
	Waddell Cr			▒	▒	▒	▒	▒	▒				
Spawning	North Coast			▐	▓	▓	▓	▒	▌				
	Noyo R					▐	▒	▒	▒				
	Navarro R				▒	▒	▒	▒					
	Brush Cr			▒	▒	▒	▒	▒	▌				
	Russian R				▒	▒	▒	▒					
	Lagunitas Cr		▒	▒	▒	▒	▒	▒					
	Redwood Cr			▒	▒	▒	▒	▒	▒				
	Napa R				▒	▒	▒	▒					
Incubation	Navarro R				▒	▒	▒	▒	▒				
	Brush Cr			▒	▒	▒	▒	▒	▒	▒			
	Russian R				▒	▒	▒	▒	▒				
	Lagunitas Cr		▒	▒	▒	▒	▒	▒	▒	▒			
	Napa R				▒	▒	▒	▒	▒				
Rearing	California	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Outmigration	Navarro R				▒	▒	▒	▒	▒	▒			
	Brush Cr		▒	▒			▒	▒	▒	▒			
	Russian R				▒	▒	▒	▒	▒	▒			
	Lagunitas Cr	▐	▒	▒			▒	▓	▒	▒			
	Napa R		▒	▒			▒	▒					

[1] - Adults noted in mainstem in all months (Entrix 2002)

Figure C-2. Periodicities of winter steelhead life stages in the Policy area (Sources: Shapovalov and Taft 1954; Snider 1984; Snider 1985; Smith 1986; SWRCB 1995, 1997, 1998; Steiner 1996; Stohrer 1998; Gallagher 2000; NCRWQCB 2000; Downie et al. 2002; Entrix 2002, 2004; Chase et al. 2003). Periods of greatest activity are indicated by darker shade, when available in literature reviewed.

Summer steelhead enter the Mattole River between March and June. Fish hold over the summer in clear, cool, deep pools until late winter and spring of the following year before spawning (Downie et al. 2002). Shapovalov and Taft (1954) noted that California summer run steelhead enter predominantly snowmelt runoff streams in April and May and spawn predominantly in November and December.

Steelhead typically spend 2 years in freshwater, but freshwater residence time can range from 1 to 4 years (McEwan and Jackson 1996; Moyle 2002). Emigration in the Policy area usually occurs in late winter and spring, with timing depending on flow and water temperatures (Entrix 2002). Some emigration also occurs in the late fall months (Figure C-2). Steelhead typically spend 1 to 2 years in the ocean before returning to spawn for the first time. Unlike Pacific salmon that spawn only once (semelparous), steelhead are iteroparous and may return to the ocean and spawn again in a later year.

C.2 COHO SALMON

NMFS has identified two coho ESUs in the Policy area: the Central California Coast (CCC) ESU and the Southern Oregon/Northern California Coast (SONCC) ESU. The CCC ESU extends from the San Lorenzo River in Santa Cruz County north to Punta Gorda in Humboldt County. The ESU was federally listed as threatened on October 31, 1996 (61 FR 56138) and state listed as endangered on March 30, 2005 (DFG 2006); it was federally reclassified as endangered on June 28, 2005 (70 FR 37160). The SONCC coho ESU ranges from Punta Gorda north, and includes only the Mattole River basin within the Policy area. The SONCC coho ESU was federally listed as threatened on May 6, 1997 (62 FR 24588), and was later listed by the state as threatened on March 30, 2005 (DFG 2006). Its federal threatened status was reaffirmed on June 28, 2005 (70 FR 37160). Federal critical habitat was designated by NMFS as any accessible stream within the current range for both ESUs on May 5, 1999 (64 FR 24049; Figure C-3). Specific stream segments have yet to be identified to the same level as for steelhead and Chinook. Sustainable coho salmon populations were likely distributed as far south as San Francisco, with occasional ephemeral year-classes farther south in some coastal streams in response to stray spawning and intermittent favorable environmental conditions. Most of the time, floods and dry summers have precluded successful establishment of perennial populations (Kaczynski and Alvarado 2006).

Coho salmon in California have a relatively strict 3-year life cycle, spending about half of their lives in fresh water and half in salt water (Moyle 2002). Figure C-4 depicts the general life history periodicity of coho in the Policy area. Coho do not ascend as far upstream as steelhead or Chinook (Shapovalov and Taft 1954). They spawn mainly in streams that flow directly into the ocean, or in lower tributaries of large rivers within the Policy area. Coho salmon typically enter estuaries after heavy late fall or winter rains breach the sand bars that form at the mouths of many California coastal streams, allowing fish to move into the lagoons (Moyle 2002). Upstream migration begins earlier farther North in the Policy area (Figure C-4). They typically migrate upstream in response to an increase in stream flows caused by fall storms, especially in small streams when water temperatures are around 4-14°C (Moyle et al. 1995; Trihey and Associates, Inc. 1996). When flow conditions are unsuitable, returning adults may wait near the stream mouth for weeks or, in the case of early-run fish, months for conditions to change (Sandercock 1991). Migrating coho salmon require deep and frequent pools for resting and to escape from shallow riffles where they are susceptible to predation.

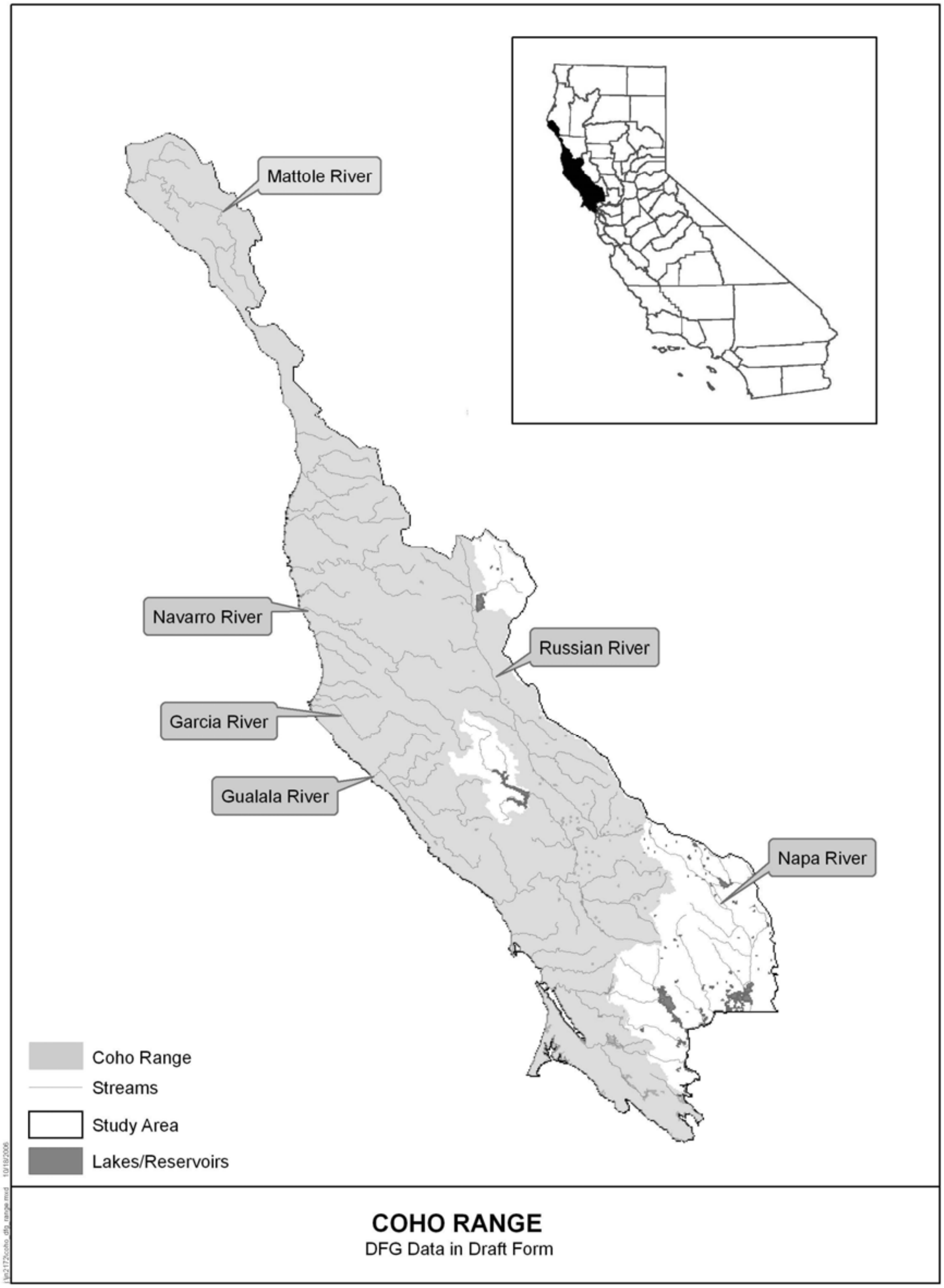
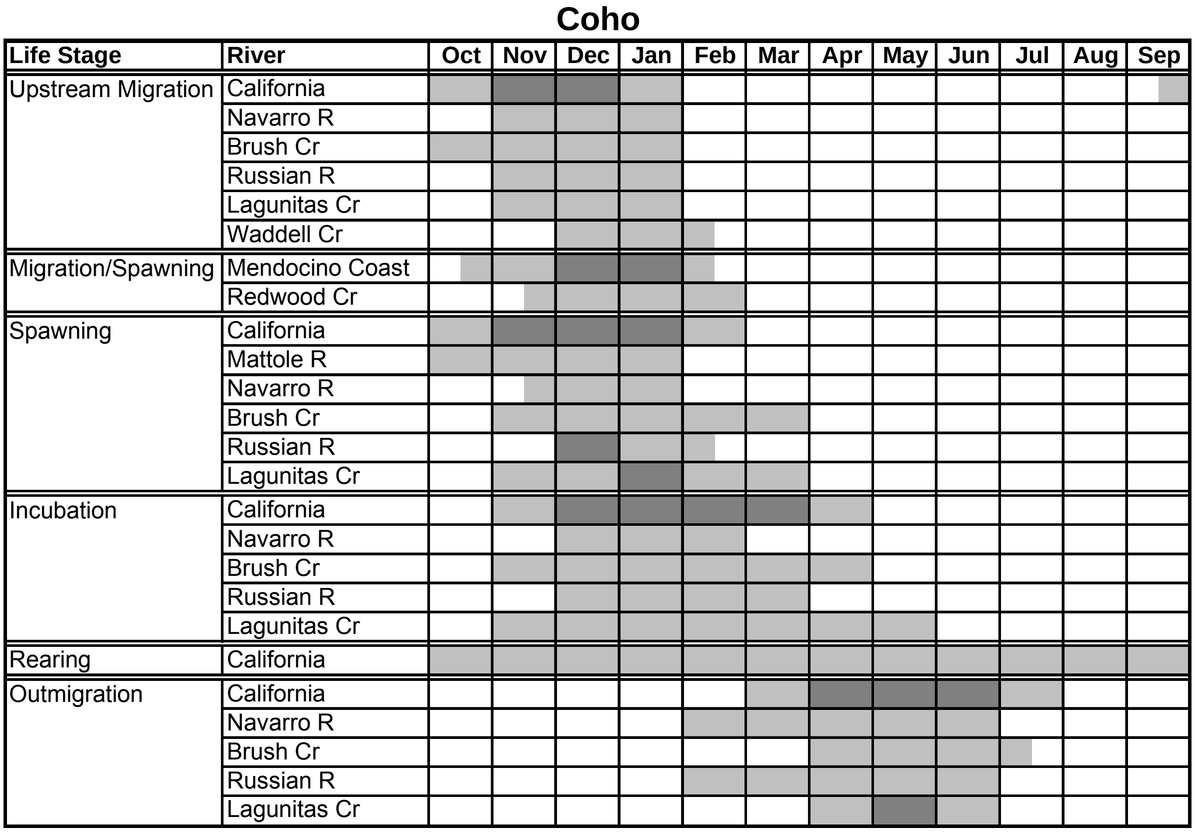


Figure C-3. General range of coho salmon within the Policy area.

Coho salmon spawn mostly in small streams in the Policy area, with peak spawning occurring during the months of December and January (DFG 2002; Figure C-4). On the spawning grounds, coho may seek out sites with groundwater upwelling in addition to favorable depths and velocities. Eggs hatch after incubating in the gravels for 8-12 weeks (Moyle 2002). After hatching, the alevins remain in the interstices of the gravel for 4-10 weeks depending on prevailing water temperatures. Upon emergence, coho salmon fry tend to move to shallow water areas where they feed and continue to grow into juveniles. Juvenile coho rear and overwinter in the stream until the following March or early April, when, after smoltification, they begin migrating downstream to the ocean. Peak downstream migration in California generally occurs from April to late May/early June (Weitkamp et al. 1995; Figure C-4). Stream flow is important in facilitating the downstream migration of coho salmon smolts. Emigration appears to occur earlier in years with low flows (DFG 2002).



Coho

Life Stage	River	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Upstream Migration	California	░	▓	▓	░								▐
	Navarro R		░	░	░								
	Brush Cr	░	░	░	░								
	Russian R		░	░	░								
	Lagunitas Cr		░	░	░								
	Waddell Cr			░	░	▌							
Migration/Spawning	Mendocino Coast	▐	░	▓	▓	▌							
	Redwood Cr		▐	░	░	░							
Spawning	California	░	▓	▓	▓	░							
	Mattole R	░	░	░	░								
	Navarro R		▐	░	░								
	Brush Cr		░	░	░	░	░						
	Russian R			▓	░	▌							
	Lagunitas Cr		░	░	▓	░	░						
Incubation	California		░	▓	▓	▓	▓	░					
	Navarro R			░	░	░							
	Brush Cr		░	░	░	░	░	░					
	Russian R			░	░	░	░						
	Lagunitas Cr		░	░	░	░	░	░	░				
Rearing	California	░	░	░	░	░	░	░	░	░	░	░	░
Outmigration	California						░	▓	▓	▓	░		
	Navarro R					░	░	░	░	░			
	Brush Cr							░	░	░	▌		
	Russian R					░	░	░	░	░			
	Lagunitas Cr							░	▓	░			

Figure C-4. Periodicities of coho salmon life stages in the Policy area (Sources: Shapovalov and Taft 1954; Snider 1984; DFG 1985, 1986, 2004, 2005, 2006, 2007, 2008; Bratovich and Kelley 1988; SWRCB 1995, 1997, 1998; Steiner 1996; NCRWQCB 2000; Downie et al. 2002; Entrix 2002, 2004). Periods of greatest activity are indicated by darker shade, when available in literature reviewed.

C.3 CHINOOK SALMON

The California Coastal Chinook ESU was listed by NMFS as threatened on September 16, 1999; its threatened status was reaffirmed on June 28, 2005 (70 FR 37160). This ESU includes all naturally spawned populations of Chinook salmon from rivers and streams south of the Klamath River to the Russian River, California, as well as seven artificial propagation programs (Good et al. 2005). Federal critical habitat was designated by NMFS on September 2, 2005 (70 FR 52488; Figure C-5). ESU populations are strictly of the fall-run type (spring-run populations are considered to be extinct). Chinook are relatively low in numbers in the northern part of the ESU and are sporadically present in streams in the southern portion of the geographic region encompassing this ESU (NMFS 1999).

Fall-run Chinook salmon exhibit an ocean-type life history adapted for spawning in lowland reaches of big rivers and their tributaries and avoiding high summer temperatures (Moyle 2002; Cook 2003). In the Russian River, Chinook salmon spawn almost exclusively in the mainstem Russian River and in Dry Creek in reaches with gradients between 0.2%-1.0%.

Figure C-6 depicts the general life history periodicity of Chinook in the Policy area. Adult Chinook salmon begin returning to the Russian River earlier in the fall than coho and steelhead, as early as late August through January, but most upstream migration occurs in late October through mid-December (Steiner 1996; Chase et al. 2000, 2001). The location of spawning will vary from one year to another depending on the timing and amount of fall and winter rains (Flosi et al. 1998). Eggs hatch within 4 to 6 weeks and young salmon generally begin outmigration soon after they emerge from the substrate in spring. Initially, fry are typically washed downstream into back- or edge water areas of lower velocities and adequate cover and food. As juveniles grow larger, they move into deeper and faster water (Moyle 2002). In contrast with coho and steelhead, freshwater residence for juvenile Chinook in the Policy area usually ranges only from two to four months, from late February through June.

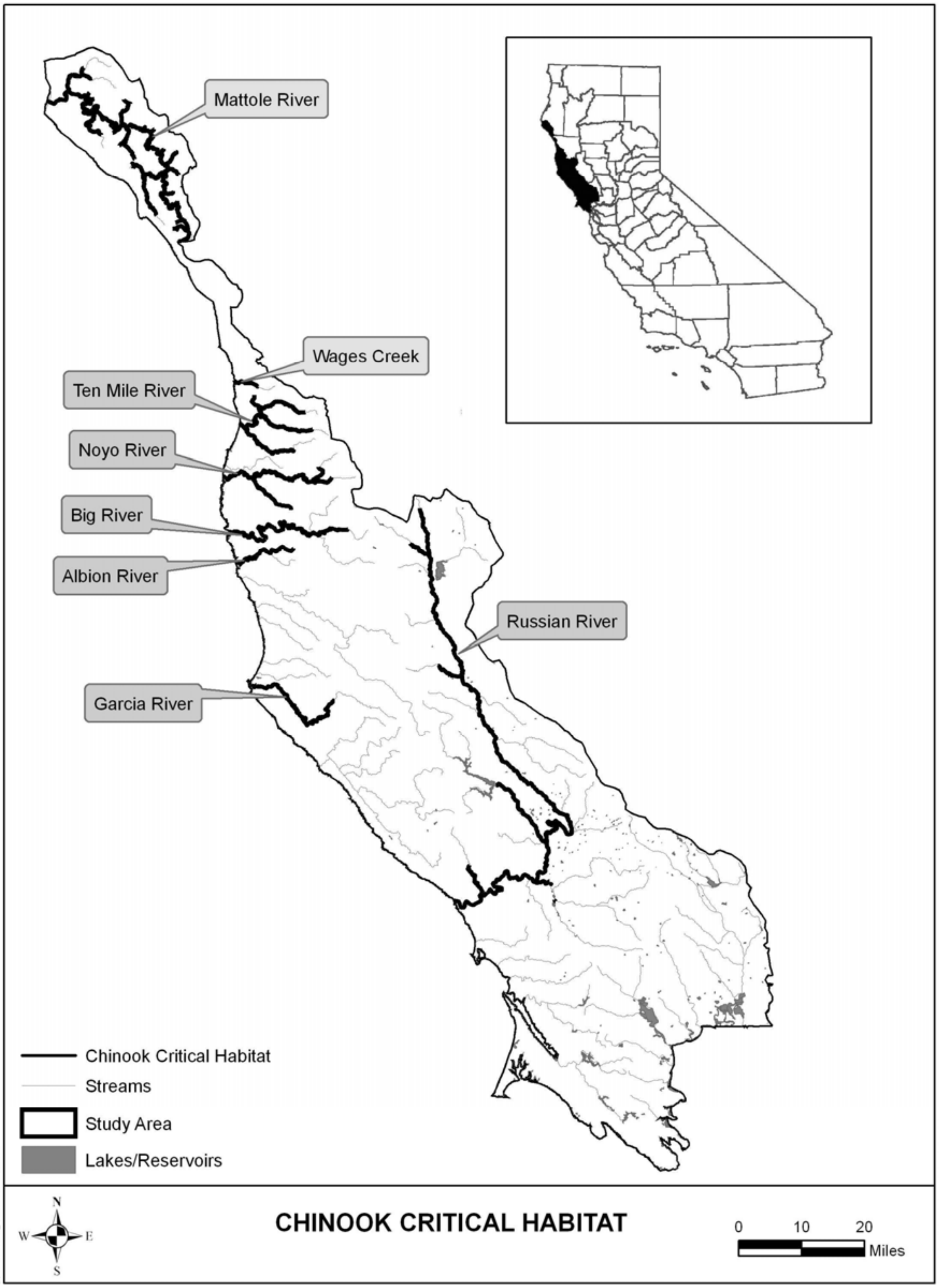
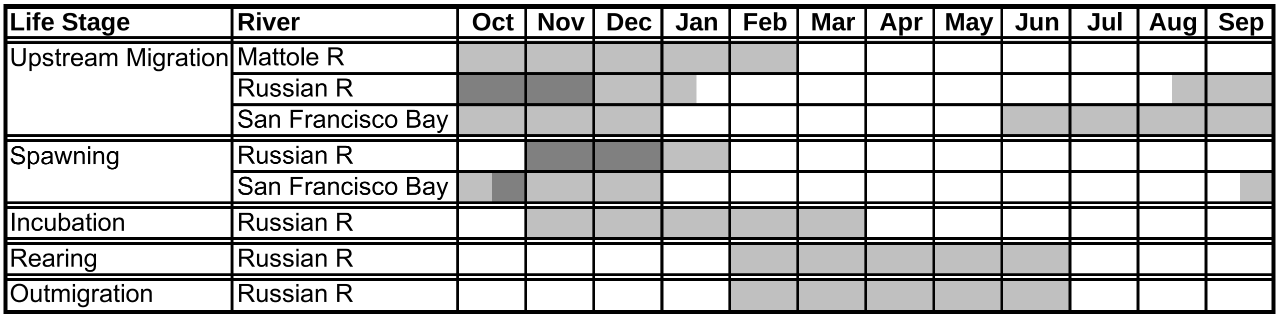


Figure C-5. Federal critical habitat designated for Chinook salmon within the Policy area.

Chinook



Life Stage	**River**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Upstream Migration	Mattole R	░	░	░	░	░							
	Russian R	▓	▓	░	░							░	░
	San Francisco Bay	░	░	░						░	░	░	░
Spawning	Russian R		▓	▓	░								
	San Francisco Bay	░▓	░	░									░
Incubation	Russian R		░	░	░	░	░						
Rearing	Russian R					░	░	░	░	░			
Outmigration	Russian R					░	░	░	░	░			

Figure C-6. Periodicities of Chinook salmon life stages in the Policy area (Sources: Steiner; Chase et al. 2001, 2003; Downie et al. 2002; Entrix 2002, 2004; SEC et al. 2004). Periods of greatest activity are indicated by darker shade, when available in literature reviewed.

APPENDIX D

Defining Protectiveness Levels of Flow Related Habitat Requirements of Anadromous Salmonids at a Regional Scale

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APPENDIX D

DEFINING PROTECTIVENESS LEVELS OF FLOW RELATED HABITAT REQUIREMENTS OF ANADROMOUS SALMONIDS AT A REGIONAL SCALE

In a comprehensive review of instream flow needs, the Instream Flow Council (IFC) (2002) suggested that an ideal policy application involves identifying the resources of concern, defining the level of protection needed, and specifying suitable assessment criteria. The resources of concern have been identified by the DFG and NMFS as anadromous salmonids, specifically steelhead trout, coho salmon, and Chinook salmon. The DFG-NMFS Draft Guidelines were developed with the goal of providing the level of protection needed in terms of the Policy elements controlling diversion season, level of minimum bypass flow, and level of diversion. However, direct assessment criteria for protectiveness were not specifically identified for each Policy element, in part because there are presently no metrics available that clearly and unequivocally define protectiveness in terms of specific instream flow levels applied at a regional level. In the absence of sufficient site-specific habitat-flow data, DFG and NMFS relied instead on general ecologic, hydrologic, and geomorphic concepts to indirectly support guideline recommendations. Even had sufficient site-specific habitat-flow data been available, there is no clear guidance on what levels are protective (and what are not) because of the multitude of factors influencing salmonid production.

This appendix presents the results of a literature and data review that provides insight into the question of defining protectiveness in the context of setting instream flow needs. There is first a general discussion and definition of protectiveness relative to flow-habitat requirements of anadromous salmonids. The information presented in this chapter supports the need for the various policy elements, and provides the context for assessing protectiveness in terms related to specific attributes of salmonid habitat that are affected by instream flow.

D.1 FRAMING THE CONCEPT OF PROTECTIVENESS

The North Coast Instream Flow Policy that will be adopted by the State Water Board is being developed with the primary objective of protecting anadromous salmonid habitat. Each Policy element is assessed for its protectiveness of anadromous salmonids and their habitats at the regional scale, even in streams for which quantitative, site specific data are not available. In the context of the Policy, protectiveness relates to the central question of whether and to what extent water can be diverted from a stream that supports anadromous fish (or that is connected to a stream that does) without negatively impacting the habitat or fish? Given an unimpaired hydrograph for a given stream, the Policy essentially seeks to establish limits on the amount of flow that can be diverted, with the limits presumably set at levels that will not impact the long-term viability of existing anadromous salmonids; i.e., the limits are set to be protective of the resource. However, the definition of protectiveness is not provided in the California constitution or applicable codes. This is not surprising, given the uncertainty in the state of instream flow science generally, as well as the degree of variability inherent in aquatic ecosystems (Castleberry et al. 1996; Arthington et al. 2006). In addition, it is not clear whether the level of protection required corresponds to avoiding jeopardizing the continued existence of the species, as for example in an ESA context at one extreme, or to avoid rendering populations to a less than optimal or good condition at the other.

As part of the process of evaluating extinction risk, NMFS has employed the concept of a Viable Salmonid Population (VSP), which is defined as an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame (NMFS 2000). Four parameters are generally considered by NMFS when determining whether a population is viable – abundance, productivity, spatial structure, and diversity. Of these, the latter one, diversity, most closely relates to the central issue of the level of protectiveness being evaluated in the Policy. The NMFS guidelines on diversity essentially state that a) human-caused factors (e.g., habitat changes, harvest pressure, artificial propagation, and exotic species introductions) should not alter variations in population traits such as run-timing, behavior, age structure, etc.; b) natural processes of dispersal should be maintained; c) natural processes that cause ecological variation should be maintained; and d) uncertainty needs to be factored in when evaluating requisite levels of diversity.

Clearly, the message conveyed by NMFS on the parameter of diversity is that anthropogenic factors should be minimized, and that natural processes that translate into ecological variation be allowed to continue. These two constructs are embodied in the framework of the DFG-NMFS (2002) Draft Guidelines and relate to elements of bypass flows, diversion rates, as well as passage considerations. However, while useful for establishing the categories of elements that need to be considered for protectiveness of anadromous salmonids in an instream flow policy context, the parameters and descriptions do not provide tangible, quantitative targets or metrics from which to gage whether and when VSPs would actually be considered protected. Application of more holistic models related to Population Viability Analysis (PVA) that attempt to capture uncertainty have been proposed and applied to populations when attempting to quantify overall effects of natural and anthropogenic factors on the future viability and sustainability of salmonid populations (Lee and Rieman 1997; Ratner et al. 1997). Such models implicitly incorporate protectiveness into the analysis; i.e., model output indicates whether a population will or will not remain viable/sustainable under different sets of conditions, and hence whether the population would or would not be protected under those conditions. However, these types of modeling efforts are often data intensive and do not explicitly lend themselves toward evaluating flow–related effects on salmonid populations.

Some of the parameters and conditions proposed by NMFS as being important for diversity may have some adverse effects over the short term. For example, maintaining that natural processes are important for diversity implicitly includes preserving phenomena such as large-scale flood events and resulting sediment transport actions that could be inferred as not being protective of the health of salmonid populations from a short-term perspective. However, when expanded to the future, it can be argued and demonstrated (Power et al. 1996; Sparks et al. 1998; Poff et al. 1997) that these large flood events, which may impart short term impacts to a population, are key to the future continuous renewal of high quality physical habitats and ecological functions that promote population viability and health.

From strictly a flow perspective, it is likely that some amount of water can be removed from a stream and still support a viable and sustainable salmonid population. If that amount of water could be determined (i.e., how much), and then defined in terms of timing (i.e., when it could be removed) and rate (i.e., how quickly it could be removed), it would theoretically be possible to relate such in a protectiveness context that could be implemented by the Division.

To help frame the debate, the IFC (2002) defined five levels of instream flow protection status for use by water management agencies and stakeholders in developing instream flow protection programs:

1. Full instream flow protection – streams with no allowances for additional withdrawals because of special conservation status (e.g., wild and scenic);
2. Comprehensive ecologically based instream flow management – flow withdrawals are only allowed when all five major riverine components (hydrology, biology, geomorphology, water quality, and connectivity) are taken under consideration and adjustment is allowed for wet, normal, dry years;
3. Partial ecologically based instream flow management – flow withdrawals are allowed at expense of one or more of the five riverine components above;
4. Threshold level instream flow protection – streams with a minimum flow prescription, typically with little to no annual variation, that may or may not be protective of some or all aquatic resources; typically involves “flat line” instream flow standards;
5. No instream flow conservation – streams with no legally recognized protection for instream flows.

These five levels are generally ordered from more to less protective of instream aquatic biological resources. Castleberry et al. (1996) wrote an essay concerning the philosophy behind the setting of instream flow standards, and because of inherent uncertainty in flow setting methods recommended an adaptive management approach. Specifically, they identified three steps toward developing instream flow standards that would be protective of the aquatic resources affected by stream flow:

- Set conservative interim standards based on available information, including minimum flows and a reasonable annual hydrograph;
- Establish a monitoring program evaluating the protectiveness of the interim standards, and associated impacts; and
- Establish an effective procedure whereby the interim standards can be revised in light of monitoring results and other new information.

Postel and Richter (2003) cited a methodology developed in South Africa by King et al. (2000) that focused on deriving flow prescriptions that result in ecological health. Termed the Building Block Methodology (BBM), it was designed to address the question of how much water is needed in a river system to keep it healthy, and therefore it has relevance to the issue of protectiveness. The BBM was grounded on eight general principles for managing river flows:

1. Modified flow regimes should mimic natural regimes, so that the natural timing of different kinds of flow is preserved.
2. A river's natural perennial or ephemeral character should be retained.
3. Most water should be harvested from a river during the wet months, little should be taken during the dry months.
4. The seasonal pattern of higher base flows in wet seasons should be retained.
5. Floods should be present during the natural wet season.
6. The duration of floods could be shortened but within limits.
7. It is better to retain certain floods at full magnitude and to eliminate others entirely than to preserve all or most floods at diminished levels.
8. The first flood (or one of the first) of the wet season should be fully retained.

The majority of these principles are integrated in some fashion within the framework of the DFG-NMFS (2002) Draft Guidelines.

In the present context of protecting aquatic biological resources under the AB 2121 mandate, it is therefore necessary to approach the concept of protectiveness from a conservative perspective, working from initially restrictive to potentially more liberal diversion limitations. The

IFC (2002) recommended that instream flow guidelines recognize that flow prescriptions should be more resource conservative when there is less information available. This approach is consistent with that of a "precautionary principle" approach advocated by Washington's Independent Science Panel (ISP 2002) which suggested that in the absence of information or where much uncertainty exists, flows should be set that are risk-averse toward eliciting an impact on salmonid populations. The approach also reflects the concept of adaptive management, whereby the burden of proof lies in demonstrating that actions *will not* harm aquatic resources, where a project is presumed to be harmful until proven otherwise. Until recently, the burden of proof has been placed more on demonstrating that an action *will* harm aquatic resources, but that approach has not worked as evidenced by the long term loss of habitats and population declines of anadromous salmonids and other aquatic biota in California and elsewhere (e.g., Nehlsen et al. 1991; Ludwig et al. 1993; NRC 1996; Regier 1996; Curtis and Lovell 2006; Dose 2006; Hartman et al. 2006). The IFC (2002) noted the logical maxim where absence of proof is not proof of absence of effect. The proof needed under an adaptive management framework can be achieved iteratively by identifying and prescribing a conservative action, monitoring the consequences of implementation, and revising the prescription based on the results. In the context of instream flows, future decisions could be made that may allow progressively greater levels of water diversion, after it has been determined that each level does not adversely harm the target resources.

California law establishes the groundwork for a practical definition of protectionof public trust resources, which provides context for protecting against adverse effects of instream flow diversions at the regional scale. The California public trust doctrine protects navigable streams and their tributaries for a variety of uses. These uses include fishing, preservation for ecological study, and provision of food and habitat for fish and other fauna and flora dependent on aquatic ecosystem health (Stevens 2005). California Fish and Game Code Section 5937 provides that the owner of any dam must allow either sufficient water through a fishway or, in the absence of a fishway sufficient water to pass over, around, or through the dam, "to keep in good condition any fish that may be planted or exist below the dam." Section 5937 is a legislative expression of the public trust doctrine (SWRCB Order WR 95-2, p.6). Fish and Game Code Section 5900 defines a dam as any artificial obstruction. A diversion structure that raises the water level artificially may thus be considered a dam. Section 45 of the Fish and Game Code defines "fish" as wild fish, mollusks, crustaceans, invertebrates, or amphibians.

The definition of protectiveness thus depends on criteria distinguishing 'good' from 'not good' conditions. Moyle et al. (1998) described criteria applied in California courts for establishing whether a prescribed instream flow regime in Putah Creek met the 'good' condition standard. They interpreted good condition to mean healthy individual fish living in healthy populations that were part of healthy biotic communities. Healthy individuals were considered to have normal body weight and length; be generally free of parasites, disease, and lesions, have appropriate growth rates for the region, and exhibit normal behavior. Healthy populations contained multiple year classes and a healthy population size, indicating normal reproduction patterns. Because healthy population size was difficult to quantify, healthy habitat conditions were assumed to be a suitable surrogate. The target condition was sufficient habitat available for each life stage when needed. Community health was indicated by ecosystems dominated by co-evolved species using multiple habitat niches, where the species makeup and distributions were resilient to extreme events and were persistent in time and space. Moyle et al. (1998) identified instream flows that favored native resident and anadromous fishes, by providing living space for the entire creek, resident native fish spawning and rearing habitat, anadromous fish habitat, and habitat maintenance functions. The overall flows needed to maintain fish in good condition were embodied in natural flow variability, with specific flow levels targeting various elements of the aquatic ecosystem.

With respect to habitat quantity, assuming all other population regulating factors are non-limiting, there is likely some minimum amount of habitat below which a stream cannot support a viable anadromous salmonid population. In the case of a habitat-flow curve as derived from a PHABSIM (Physical Habitat Simulation System; Bovee and Milhous 1978; Bovee 1982) analysis, this threshold level could theoretically correspond to a point or points on the curve below which small decreases in flow result in rapid losses of habitat quantity (Figure D-1). The peak of the curve, which is defined by the flow that provides the greatest amount of habitat for a given species and life history stage, has often been incorrectly assumed to represent the flow affording maximum production. Such is generally not the case, however, since there are many other flow and non-flow related factors that can influence overall population abundance, in addition to habitat quantity. Nevertheless, the peak of the curve does provide a useful index from which to assess tradeoffs in habitat relative to changes in flow, and correspondingly should also be useful for assessing protectiveness.

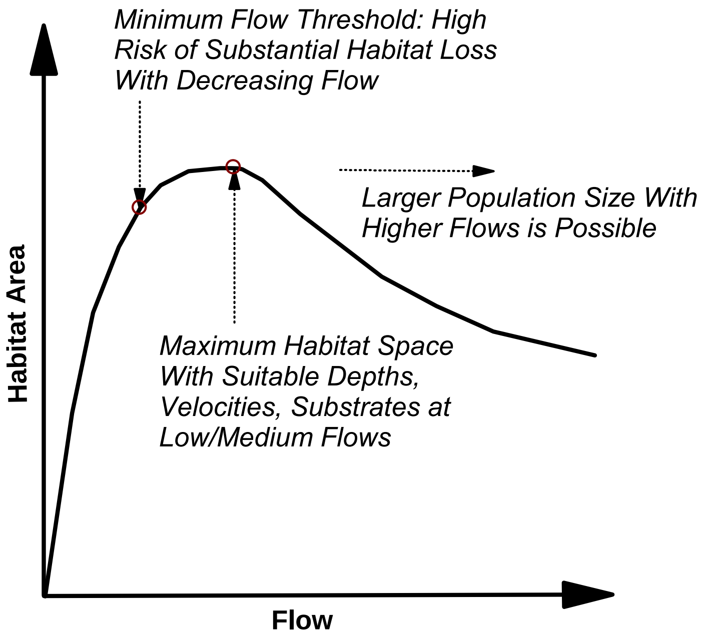

Figure D-1. Conceptual representation of biological significance of habitat-flow curve and specification of a minimum instream flow. The habitat – flow relationship depicted is representative of the type of flow response often seen with spawning habitats. Habitat – flow relationships will differ depending on channel characteristics and specific life stages under consideration (e.g., spawning, adult, juvenile, passage).

D.1.1 Using Hydrologic-Based Instream Flow Standards to Define Protectiveness

Hydrologic-based instream flow standards warrant special mention when discussing how to define protectiveness, because they have been used extensively to set instream flow standards and they form an important basis of the DFG-NMFS (2002) Draft Guidelines. The IFC (2002) defined instream flow standard settings as policies or techniques that use a single, fixed rule to establish minimum instream flow requirements. In practice, instream flow standards based on hydrologic statistics can generally lead to a one-size-fits-all prescription for streams representing a wide variety of channel and flow characteristics. The corresponding levels of uncertainty and risk are high. The IFC (2002) accordingly recommended that a greater level of conservatism be inherent in rule-of-thumb standard(s) compared with ones based on more site-specific channel data. The process leading to the DFG-NMFS (2002) Draft Guidelines generally relied on the use of hydrologic metrics to protect the aquatic biological resources including particularly anadromous salmonids (Appendix A).

The IFC (2002) summarized strengths and weaknesses of hydrologic standard setting techniques. Minimum standards were identified as primarily policy choices rather than fish habitat assessment procedures, and were considered best for reconnaissance level planning. Standards were interpreted to accommodate water use more than conservation. Primary advantages included ease of use and the production of repeatable results. The IFC (2002) noted however, that many hydrologic standards did not result in healthy aquatic ecosystems. In part, this resulted from the use of a single metric, with incomplete to no consideration of flow variability and its importance for maintaining healthy ecosystems. For example, hydrologic metrics such as average annual flow do not reflect seasonal patterns in hydrology.

In the case of the Policy, the New England Aquatic Base Flow (ABF) standard/policy served as an initial hydrologic-based model for the DFG-NMFS Draft Guidelines (W. Hearn, NMFS, personal communication). The ABF method recommends the August median daily average flow as a minimum instantaneous summer low flow requirement, and seasonal releases equal to the median February and April/May flows in the fall/winter and spring periods, respectively, to protect fish spawning and incubation life stages (IFC 2002). The underlying assumptions were that (1) hydrology could be used as a surrogate for habitat, and (2) fish species and their various life history stages were adapted to median flow levels during the respective months of importance when each life stage’s survival would be most vulnerable.

The ABF metrics were derived from an analysis of stream gages in unregulated New England streams. Kulik (1990) noted that the ABF resulted in recommending insufficient flow for projects located in certain high elevation streams, and more flow than was deemed necessary for projects in other areas. Such differences reflected the systematic regional variation in hydrology, and led to a recommendation to revise the ABF based on spatial variation in median August flow (Kulik 1990). Nevertheless, the basic underlying premise that median August flow was a suitable surrogate for habitat needs was not evaluated.

The IFC (2002) identified several aspects of hydrologic-based instream flow standards that warrant consideration. First off, the choice of a specific hydrologic percentage or percentile for maintaining habitat quality should be based, where possible, on site-specific information. Further, the analysis of protectiveness should consider effects of errors in hydrologic data on the precision of the recommended flows, as well as how the level of protectiveness varies with channel size. The analysis should also consider flow variability, which may lead to the derivation and use of different hydrologic metrics for achieving specific protection goals. These recommendations were generally followed as part of the overall evaluation of the protectiveness of the Policy on anadromous salmonids.

D.2 FLOW AND HABITAT NEEDS OF ANADROMOUS SALMONIDS

Anadromous salmonids exhibit complex life histories that require a variety of time dependent flow-related conditions. Beginning with the incubation phase, alevins (newly hatched fish) remain within the streambed until yolk sac absorption, at which time they migrate vertically through the gravel to surface waters and transition to the fry life stage. Ocean type Chinook fry almost immediately begin to drift downstream with the stream currents and move towards estuarine and marine waters (Healey 1991). In contrast, coho salmon and steelhead have a longer freshwater rearing phase, and gradually move to deeper and faster areas of the stream to take up feeding stations as they grow larger. After 1 to 3 years of freshwater rearing, juveniles undergo smoltification, and begin to migrate downstream to the ocean. The marine phase lasts from 1 to 5 years whereupon the adults return to their natal streams and migrate upstream to locate suitable spawning areas.

Different life history stages of anadromous salmonids require different habitats within a given stream (Bjornn and Reiser 1991; Quinn 2005). For example, adult fish that are migrating upstream require deep pools for holding and resting, and a specific range of water depths, water velocities, and substrate sizes for spawning. Likewise, fry and juveniles require specific combinations of water depth and velocity that are typically associated with cover features such as large woody debris, large substrates, and riparian vegetation. Both the quantity and quality of life stage specific habitats within a stream are influenced, and to a large degree controlled by the quantity of flow within the channel.

The following sections discuss in more detail how stream flows affect the habitats of five critical life stages: upstream migration, spawning and incubation, rearing, downstream migration, and estuarine transition (which affects both downstream and returning upstream migrants). Channel and riparian maintenance flows, which are important in creating and maintaining habitat features that are linked to the above life stages are discussed in Section D.3.

D.2.1 Upstream Migration

Adult salmonids returning to streams to spawn must do so at the proper time and with sufficient energy to complete their life cycle (Bjornn and Reiser 1991). Although salmon and trout stocks have evolved such that successful migrations can usually occur under a variety of conditions (owing to differences in migration timing), man-induced and in some cases natural events can result in sufficient delays in migration to impact at least a portion of the spawning population and hence reduced egg and fry production. The State Water Board (SWRCB 1995) noted that the timing of upstream migration is variable and is not triggered by a specific threshold flow rate, but rather a decline in flow following a runoff event.

In general, the degree to which stream flow conditions may become problematic to upstream migrating adults relates directly to their migration period. Thus, stocks that migrate during the late fall and winter under high stream flow conditions (e.g., winter steelhead) would be less likely to encounter flow related impediments than stocks that migrate in late summer or early fall, such as Chinook salmon.

Without sufficient stream flow, adult fish cannot successfully migrate upstream to spawning areas. Passage flow requirements have been evaluated based of the percentage of the average annual flow (Baxter 1961), and on specific water depths and water velocities adult fish can pass through (Thompson 1972) (see Section D.2.1).

Physical barriers such as waterfalls, debris jams, and diversion structures can delay or prevent upstream migration of adults. Salmon and trout have certain swimming and jumping capabilities that vary by species (Reiser and Peacock 1985; Powers and Orsborn 1985; Bell 1991). Stream flow can directly influence the passage conditions at potential barriers. For example, under conditions of low flow, a particular falls may have a total height that creates conditions greater than the combined jumping and swimming capabilities of salmon and trout, and hence, serves as a barrier to upstream migration. Under higher flow conditions, the height of the falls can be reduced (because of increased water surface elevations in the plunge pool) to levels in which adult passage can occur (Powers and Orsborn 1985, Reiser et al. 2006).

Sand bars at the entrance of some California coastal streams create temporary upstream migration barriers to salmon and steelhead trout populations. These populations rely on increased stream flow during the fall to breach the sand bars. In some cases, the flow rate needed to ensure connectivity may be relatively low. For example, Cannata (1998) observed sand bar closure in the Navarro River at flows around 5 cfs; Fisk (1955) considered 25 cfs as the minimum flow needed to allow upstream migration in that system. Average monthly flows exceed or approach 25 cfs in October through July (U.S. Geological Survey [USGS] recorded daily stream flow for station number 11468000).

Adult fish utilize or are associated with cover both during their upstream migrations and during spawning. Cover may be in the form of deep pools, surface turbulence, and undercut banks and overhanging vegetation (Bjornn and Reiser 1991). Such cover can protect the fish from disturbance, predation, high water velocities, and also provide shade for holding fish. The availability and accessibility of these cover components are influenced by stream flow.

Because salmon and trout are poikilotherms (cold blooded), their metabolism and life history functions are closely linked to water temperatures. In the case of upstream migrations, water temperatures that are too warm or too cold have been reported to influence migration timing and may result in delays (Hallock et al. 1970; Bjornn and Reiser 1991; Quinn 2005). Factors that can lead to altered thermal regimes in streams include removal of riparian vegetation and forest canopy, irrigation and domestic water withdrawals, irrigation return flows, and releases of water from reservoirs. In general, the effect of the alterations is to increase water temperatures, but reservoir releases under some circumstances may have a cooling effect. Such effects seasonally depend upon ambient solar radiation levels.

Adult migrating fish have also been shown to be adversely affected by reductions in dissolved oxygen (Davis et al. 1963). Dissolved oxygen in streams and rivers is a product of atmospheric exchange with the water surface. The concentrations of DO in river waters are influenced by surface agitation and resulting re-aeration that typically occurs in riffles and cascades. Stream flow can increase or decrease the degree of re-aeration associated in these areas. In addition, dissolved oxygen concentrations decrease with increasing water temperature. Diversions resulting in elevated water temperatures can thus have a concomitant effect of reducing DO concentrations.

According to Bjornn and Reiser (1991), high turbidity in rivers may delay migrations as reported by Bell (1991) and Cordone and Kelly (1961), but turbidity alone does not seem to affect the homing ability of adults (as noted by Whitman et al. 1982). In general, the highest turbidities in streams occur during high flows.

D.2.2 Spawning and Egg Incubation

Flow is an important influence on the reproductive capacity of anadromous salmonid populations. The conditions that exist during the period in which eggs are deposited in the gravels, embryos incubate and hatch, and fry subsequently emerge can be primary determinants of year-class-strength and the ultimate numbers of fish that may be recruited into the population and return as adults. Spawning and egg incubation success is dependent on both the quantity and quality of spawning habitat, both of which are modified by the amount of stream flow.

Stream flow influences the amount of spawning habitat available within a stream by determining the extent to which spawning gravels are wetted with suitable combinations of water depth and velocity. In general, there is a consistent three stage pattern, depicted in Figure D-1 that is represented in such relationships:

1. An initial increase in suitable habitat area with increasing flows as more spawning area is wetted and combinations of water depth and velocity remain suitable;
2. A leveling off in suitable habitat area as flows continue to increase; and
3. A decrease in suitable habitat area as flows continue to increase and water depths and velocities begin to exceed those utilized by salmon and trout.

These patterns correspond to different areas of the stream bed becoming suitable, with elevation of suitable spawning habitat area generally increasing along the cross-section as flow increases. Embryos in redds constructed closer to the channel thalweg may under certain circumstances be more vulnerable to effects of scour and fine sedimentation than embryos in redds constructed higher up on the cross-section. As a result, flows higher than what might be indicated by a PHABSIM derived WUA-flow curve (i.e., peak of the curve) might actually provide better egg survival and fry emergence.

Stream flow also plays an important role in providing and maintaining the quality of the spawning gravels. High flows mobilize and transport fine sediments from spawning gravels, which is important for increasing gravel permeability, which affects transport of oxygen to, and metabolic wastes from the developing embryos (e.g., Wickett 1954; Sheridan 1962; Wells and McNeil 1970; Reiser and White 1981; Chapman et al. 1982). Seasonal high flows are also important for transporting sediments from riffles and pools, maintaining channel conveyance, creating and maintaining physical habitat structure in the channel, and providing ecological and hydraulic connectivity with floodplain habitats and the riparian zone (Poff et al. 1997). Actions that serve to regulate or alter the natural hydrograph of a stream can dramatically affect how sediments are processed and moved through the system, and can negatively impact ecological functions that relate to anadromous salmonids (Reiser 1998a, b).

Large decreases in stream flow can result in redd dewatering (Hunter 1992; Becker et al. 1982, 1983; Reiser and White 1981, 1983) as depicted in Figure D-2. Low winter flows may also expose eggs to freezing temperatures. If stream flows decline below the depths utilized for spawning such that egg pockets become dewatered, embryo growth could be diminished, alevin size could be reduced, temperatures in the redd could increase or decrease depending on ambient air temperatures, hatching and emergence could be accelerated or delayed (depending on temperature), and if temperatures are extreme and moisture levels low, could result in egg mortality (Becker et al. 1982; Reiser and White 1983). Becker et al. (1982, 1983) determined that earlier stages of egg incubation were more tolerant of dewatering events than latter stages, presumably because metabolic processes requiring the delivery of oxygen and removal of wastes occurs at a higher rate during latter stages.

The timing of spawning of salmon and trout in streams is closely linked to water temperatures (Bjornn and Reiser 1991). In the streams within the mid-California coastal area, water temperatures are important determinants of when fish spawn, how long the eggs incubate (development is directly related to water temperature), and when fry emerge. Factors that may alter such temperatures and therefore affect spawning and incubation have been described earlier and include; flow regulation, flow depletions/diversion, loss of riparian vegetation, and thermal alteration due to changes in flow.

It is important to note that spawning habitat may not necessarily be limiting salmonid production in many of the Policy area streams. For some species that use riverine habitats year-round (e.g., steelhead, coho), low summer stream flows may have an equal or even greater influence on production potential through juvenile rearing habitat limitations. However, this does not negate the importance of managing for winter spawning habitat, especially since the availability of this habitat sets the initial production potential of the number of salmonid fry that may be produced in a given year.

D.2.3 Fry and Juvenile Rearing Habitat

The habitats that constitute rearing areas are diverse and perhaps more complex than any other life history stage. For some stocks of salmon and trout, the upper drainages represent spawning and initial rearing areas, where fry and juveniles can grow in relatively protected areas that are generally free from large predators, and that contain excellent water quality characteristics. The conditions afforded to fry and juvenile anadromous salmonids in many instances establish the overall carrying capacity of the stream and therefore factor directly into defining numbers of returning adults (Quinn 2005). The abundance of younger life stages within a stream can regulate the abundance of older fish (e.g., Bjornn 1978; Quinn 2005). Stream flow is an important determinant of the capacity of a stream to support a certain number of juvenile salmonids. This is depicted conceptually in Figure D-3.

The amount of flow in a river has a direct influence on the distribution and quantity of water depths and velocities utilized by fry and juvenile salmonids, particularly at lower base flows when physical living space becomes limiting. Under suitable/normal conditions, the rearing areas encompassing pool:run:riffle habitats will afford living space for a certain density of fish as set by the limits of food availability, space, cover, and water quality characteristics. Reductions in flow can translate into reductions in those parameters resulting in a reduced carrying capacity, as for example has been demonstrated experimentally by White et al. (1981). Harvey et al. (2006) documented reductions in growth in rainbow trout subjected to reduced flows in the summer compared to trout in adjacent channels in which flows were higher. At higher flows, physical habitat space may become less important and other factors may subsequently control the number of juveniles in a population. Water depths used by fry and juveniles can be quite variable depending on the factors associated with such depths, e.g., substrates, cover, food, velocity, predator density. Newly hatched fry often utilize the extreme edge habitats of a stream where velocities are low and there are few predators. As fish grow they are capable of using deeper waters with limits of use generally related to some other

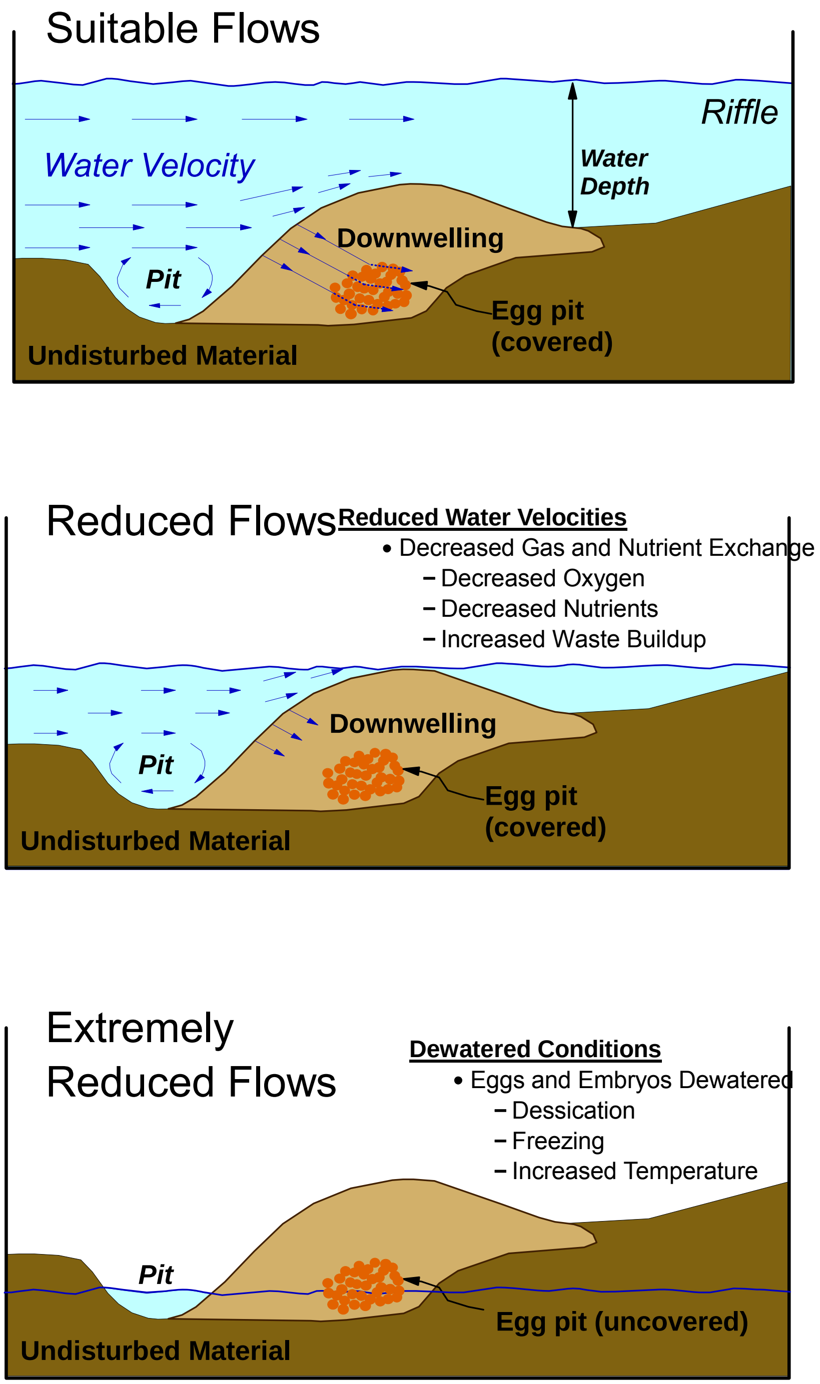

Figure D-2. Conceptual diagram of salmonid spawning nests illustrating generalized effects of stream flow reductions on the intragravel environment (from Reiser 1998a, b).

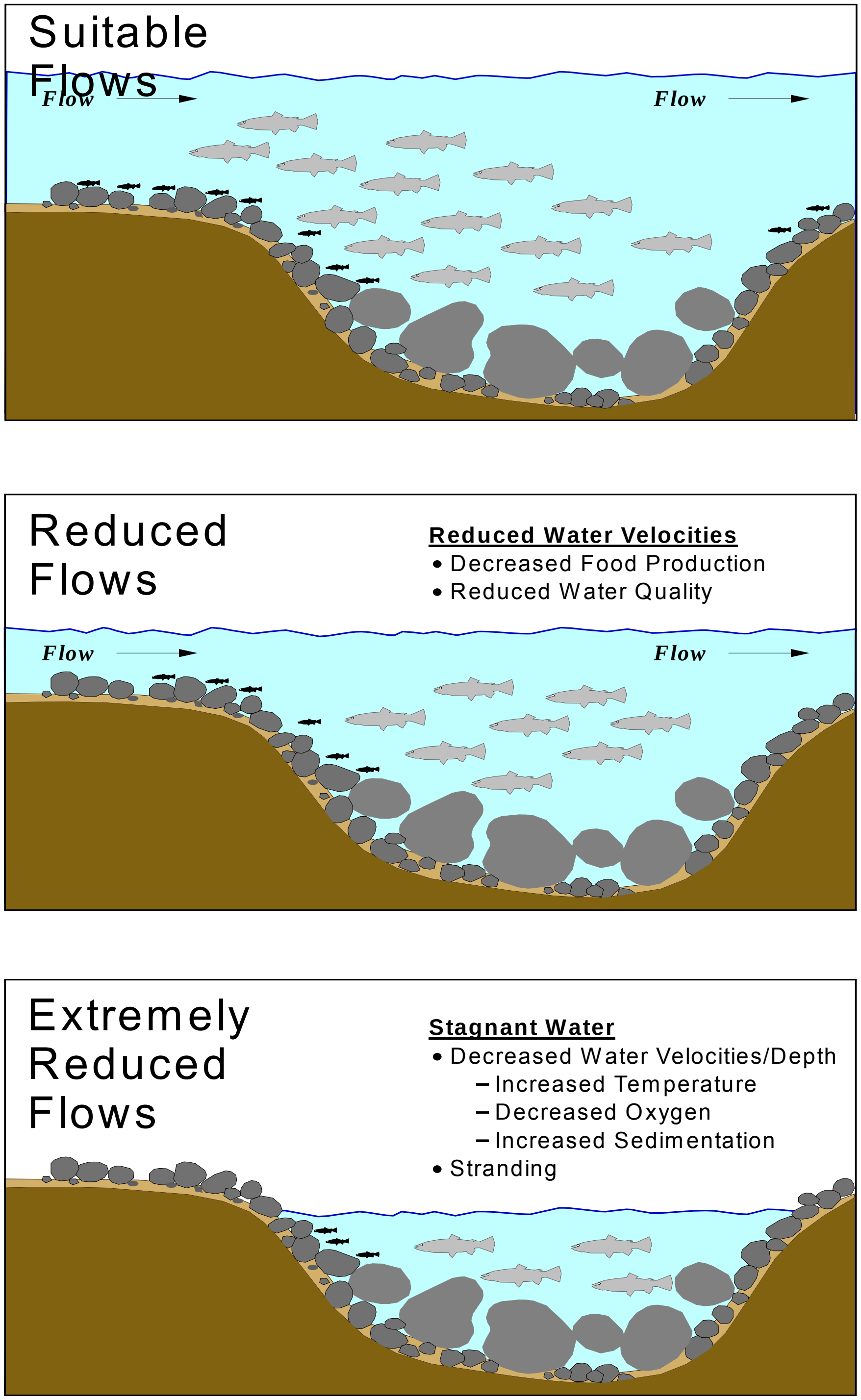

Figure D-3. Conceptual diagram of salmonid spawning nests illustrating generalized effects of stream flow reductions on the intragravel environment (from Reiser 1998a, b).

interrelated parameter such as velocity. Bjornn and Reiser (1991) noted that some salmonids are found in higher densities in pools than other habitat types as a result of space availability. Again, there are probably other factors acting to regulate such densities, for example the presence of LWD or overhanging vegetation can have a direct, positive benefit on increasing the carrying capacity of a given pool.

As fish grow, they become stronger and are often associated with faster water velocities (Smith and Li 1983; Nickelson et al. 1992). Shifts in velocity usage by fish have also been observed seasonally, presumably in response to increased water flows and decreases in water temperature. The shifts are generally from higher velocities in the summer feeding periods to lower velocities during the winter holding periods (Tschaplinski and Hartman 1983; Nickelson et al. 1992). During these periods, coho salmon have been observed moving into side channels, alcoves and beaver ponds containing large woody debris for cover and overwintering habitat (Nickelson et al. 1992). Nickelson et al. (1992) noted that loss of overwintering habitat in coastal Oregon streams likely limited coho production.

Flow reductions, particularly if they occur at a rapid rate such as can occur with hydroelectric peaking and load-following operations, can also result in stranding of fish. Fry can be particularly susceptible to stranding because they are poor swimmers and utilize habitat that is shallow and slow moving (Hunter 1992; DeVries et al. 2001; Hilgert and Madsen 1998; Bauersfeld 1978; Reiser et al. 2005).

High flows are also important for maintaining juvenile habitat quantity and quality, through channel maintenance and flushing flows. In addition to transporting sediments from pools and cobble areas used for rearing and over-wintering, and from riffles serving as food production areas, high flows are necessary to create habitat-structure in the form of large wood and boulder deposits. High flows are also needed to inundate important riparian and floodplain vegetation that serve to increase bank stability, provide shade and contribute allochthonous (out of stream) materials/nutrients to the stream.

Juvenile distributions and health are strongly affected by summer water temperature, which may become elevated to sub-optimal and lethal levels when flows are reduced. Temperatures in rearing habitats can vary daily, seasonally, annually, and spatially, with the degree of variation often associated with an anthropogenic impact such as logging (removal of forest canopy) or irrigation withdrawals (flow depletion). Juvenile salmonids may react to high summer temperatures by seeking out and utilizing thermal refugia (Nielsen et al. 1994). Under some circumstances large, deep pools in Northern California coastal streams have been observed to stratify vertically, providing bottom water an average of 3.5°C cooler than surface waters. These pools were generally associated with tributary confluences, intragravel flow through river bars (i.e., hyporheic flow), and groundwater seeps. Stratification occurred when stream flows were too low to effectively mix water in the pools (Nielsen et al. 1994).

D.2.4 Outmigration

Higher flows are among several factors that cue downstream migration of salmonid smolts (Huntsman 1948; Fast et al. 1991; Cramer 1997). Some of the other factors that have been shown to influence smolt outmigration include water temperature, lunar rhythms, photoperiodicity, and annual physiological rhythms (Clarke and Hirano 1995). Smolt migration also appears to occur in response to flow increases, although the effect is inconsistent and likely reflects the influence of one or more of the other factors noted above. Research results point to the importance of the timing and duration of short-term flow changes to stimulating downstream migration of juvenile salmonids in several cases. Buettner and Brimmer (1996) determined that a 2-fold increase in flow was associated with an 8- to 12-fold increase in migration rate for hatchery Chinook and 3.5- to 4.6-fold increase for wild Chinook salmon, in the upper Snake River. Knapp et al. (1995) determined that pulsing water releases appeared to increase the effectiveness of initiating fish movement in the lower Umatilla River, but sustained fish movement was not positively correlated with sustained high flows. Demko (1996) determined that release of a pulse of stored water stimulated a substantial increase in juvenile Chinook outmigration in the Stanislaus River, California, with increases in fish movement lasting only a few days following the release. Additional detailed study indicated that peak Chinook fry passage occurred during high flows in several years, although smolt migration was not found to be related (Demko et al. 2000). In contrast, Roper and Scarnecchia (1999) found emigration timing of age-0 Chinook to be more strongly related to temperature and lunar phase than stream flow.

Elevated water temperatures in late spring, which may be exacerbated by low flows, can inhibit or reverse smoltification in late outmigrants, especially steelhead (Wedemeyer et al. 1980). This can lead to fish remaining in the stream an extra year, and increased mortality if summer low flows limit holding capacity and survival.

D.2.5 Estuarine Flow Needs

Estuaries are an important interface between the freshwater and saltwater phases of anadromous salmonids for both upstream and downstream migrants (Quinn 2005). There are two flow-related influences on the suitability of estuaries for anadromous salmonids in the Policy area (Fisk 1955; Cannata 1998; MRC 1995; Cook 2004; Entrix 2004):

4. Reducing access to returning adult salmon and steelhead in the fall through sand bar closures across the mouth of the estuary, and
5. Providing suitable freshwater over-summer habitat conditions.

With respect to the first, the primary concern relates to the timing and amount of flow needed to open (breach) the sand bar closures to enable upstream access. The processes controlling breaching are complicated and depend on the resource and basin in question. The timing of natural sandbar breaching can be highly variable and depends on local weather patterns, ocean wave conditions, tides, and inflow to the lagoon (MRC 1995; Entrix 2004). Estuaries in the Policy area tend to become blocked during the low flow summer months, typically some time during July, August, and/or September and particularly during dry years (e.g., Fisk 1955; MRC 1995; Cannata 1998; Entrix 2002, 2004). Breaching has the potential to delay entry of returning adults, with greatest potential effects occurring in the Policy area to Chinook salmon because this species returns the earliest of the three target species. Coho and steelhead tend to begin returning from the ocean later in the fall when sand bars have already been breached.

Relative to the second influence, estuaries in the policy area are used over the summer as rearing habitat by steelhead and Chinook, and conditions are considered degraded when the estuary is breached artificially during the summer months (Cook 2004; Entrix 2004). Peak Chinook salmon downstream migration occurs earlier in the spring, but juvenile fish at the end of the season may be trapped in the lagoon for the summer (Entrix 2004). Available data suggest that freshwater lagoons may provide more productive rearing habitat for salmonids than open systems in the Policy area, allowing juveniles to reach a body size that improves ocean survival over that of smaller fish leaving the estuary in the spring (Smith 1990; MRC 1995; Cook 2004).

D.2.6 Importance of Wet Years to Population Sustainability

As described above, instream flows can be important for setting the year-class strength of a population by affecting the availability of quality spawning substrate and the abundance of fry that seed a stream. Years with high fry production and good outmigration survival can be important for the sustainability of healthy populations, and serve to buffer years of poor production. Four life history characteristics are important for distributing the risk of poor reproduction: age of maturity, the number of age classes from a given brood year that can spawn (all three species), straying, and the extent to which individuals spawn in multiple years (steelhead only).

Chinook salmon, coho salmon, and steelhead trout have flexible life history traits that allow a single brood year to contribute to multiple future broods. Male Chinook salmon, coho salmon, and steelhead trout may mature following one summer of rearing at sea. These relatively small, precocious fish are termed “jacks” and while they generally do not contribute substantially to the fishery, they can contribute a small, but significant portion of genes across brood years. For coho salmon, which otherwise have a strict three-year life cycle, jacks provide the only mechanism for gene transfer across brood years (Young 1999). Male and female Chinook salmon and steelhead trout typically mature at ages 3 to 5 or 3 to 4, respectively (Moyle 2002). Steelhead trout exhibit an additional life history trait that allows a single brood year to contribute to several future broods (termed iteroparity). Unlike Chinook salmon or coho salmon, some steelhead trout survive the rigors of spawning, return to the ocean for one or more additional years of rearing, and may spawn during multiple years. Flexibility in the age of maturity and iteroparity in steelhead trout both result in the ability of a single brood year to contribute adults to spawning runs over a two to four year period.

The ability for a single brood year to contribute to multiple future broods accomplishes two benefits for the conservation of populations. First, it provides for mixing of genes across years, effectively increasing the effective population size, which decreases the risk of inbreeding and genetic drift while increasing local adaptation (Young 1999). Secondly, multiple return years provide a buffer against environmental disturbance (e.g., extreme flood or drought events) that could result in high mortality for a brood year (Young 1999). The corollary to this is that periodic favorable flow regimes that result in relatively high survival during the freshwater lifestages can lead to multiple years of good adult returns to a stream.

Straying, which is when a fish spawns in a non-natal stream, also reduces the risk of wiping out a salmon or steelhead trout population. While the ability to home to natal streams is a well known salmonid trait, homing accuracy is generally not 100 percent. Homing accuracy is typically on the order of 95 percent or higher, but the amount varies considerably among different salmonid species, different populations (including wild vs. hatchery), and at different ages of maturity (Quinn 2005). Straying results in the ability to colonize underutilized habitat, recover from catastrophic disturbances, allows for some genetic mixing among populations, and reduces the risk of population loss that would result from 100 percent homing accuracy (Quinn 2005). Moyle (2002) noted that fall-run Chinook salmon found in mid-California coastal streams have a relatively high rate of straying that allow them to utilize streams or spawning beds during wet years that would be unavailable during other years.

Annual variability in flows results in some years being wet and others dry. Dry years are inherently associated with stressful conditions for anadromous salmonids given the characteristic Mediterranean climate of the Policy area, with greatest flow-related impacts to production and population size occurring during summer low flows. Impacts may also occur in dry years when there are fewer opportunities to migrate upstream and spawn (e.g., Walker Creek, Kelley 1976; Napa River basin, Jackson 2001). All of the reproductive traits described above facilitate population persistence by maximizing reproductive capacity during wet years to compensate for poor freshwater production during dry years, or during protracted periods of low marine survival (Lawson 1993; Hare and Francis 1994; Mantua et al. 1997; Biggs et al. 2005; Kaczynski and Alvarado 2006). In addition, there is evidence that Chinook salmon juvenile survival increases with flow variability in the spring and early summer outmigration period, as defined by the ratio of mean to median flow rate evaluated over the same period (Unwin 1997). Wet years are associated with greater flow variability in Policy area streams during this period and thus would be expected to be associated with higher survival outside the diversion season as well.

Of the three species, coho salmon have the narrowest range of spawning age classes and are thus least able to spread the risk of high mortality (Brown et al. 1994), a characteristic that may help explain their increasing absence with decreasing latitude in the Policy area. Kaczynski and Alvarado (2006) noted that hydrologic conditions become more irregular with more frequent droughts in the southern range of coho salmon, and considered that to be a primary reason for the general inability of coho to persist south of San Francisco. Coronado and Hilborn (1998) found that coho smolt survival was affected by large-scale climatic patterns for stocks in the North Pacific. Botsford and Lawrence (2002) found that marine conditions were important determinants of subsequent coho salmon production from the Gulf of Alaska and the California Current, but that these patterns were not apparent in Chinook salmon. Oceanic conditions have been cited as explaining up to 83% of the variability in adult recruitment in naturally spawned Oregon coho populations (Koslow et al. 2002). Climatic shifts that increase the marine survival also affect coastal and inland watersheds. Large scale climatic conditions that improved marine survival also improved the freshwater rearing conditions for coho salmon in Oregon coastal streams (Lawson et al. 2004); fall freshets, second winter flows, and outmigration flows were positively correlated with coho smolt production. In general, approximately half of the variability in coho salmon recruitment may be due to the freshwater stage (Bradford 1995). Management of the freshwater phase to maximize survival may be particularly important during productive marine regimes, because reducing freshwater survival by creating dry year conditions could potentially negate the beneficial effects of increased marine survival.

Steelhead are most able to spread reproductive risk and have accordingly the widest historic distribution in the Policy area. Even so, years with high flows will generally provide better spawning conditions and allow for increased production, compared to dry years.

D.3 THE NEED TO MAINTAIN FLOW VARIABILITY

Flow variability is important in maintaining healthy aquatic ecosystems because the provision of a single flow cannot simultaneously meet the requirements of all fish species, or allow for important physical processes to occur that control the form and function of stream channels (Bovee 1982; Hill et al. 1991; Poff et al. 1997; IFC 2002; Postel and Richter 2003; Arthington et al. 2006). In addition, flow variability can be important for helping sustain native fish populations in California from declines related to non-native species introductions (Marchetti and Moyle 2001).

Poff et al. (1997) synthesized scientific knowledge in support of the argument that the natural flow regime, as expressed particularly by stream flow quantity and timing, plays a critical role in sustaining native biodiversity and ecosystem integrity in river systems. Various physical and biological attributes of the channel system depend on different levels of flow. For example, flows providing habitat will differ from channel-forming flows, which in turn can differ from floodplain-forming or riparian maintenance flows. Establishment of riparian vegetation can be particularly dependent on flow variation (Rood and Mahoney 1990, 1995; Rood et al. 1999; this is elaborated on in the next section). A specific lifestage of fish or amphibian may depend on availability of floodplain or in-channel habitat availability at specific flow levels. Poff et al. (1997) provided a variety of documented examples of adverse ecological effects to alterations in the natural flow regime, many of which apply to watersheds subject to AB2121 (Table D-1).

Poff et al. (1997), Postel and Richter (2003), and others have argued that focusing predominantly on minimum flows to benefit a small number of species stands in contrast to the observation that what is “good” for the ecosystem may not consistently benefit individual species and vice versa. Flows that are beneficial to one species or life stage may be detrimental to others, as has been noted early on for PHABSIM analyses involving multiple species and life stages (Bovee 1982). Poff et al. (1997) noted that some species do best in wet years, others in dry years, and that the health of the ecosystem reflected the diversity represented by the variety of species with different flow needs. Adaptations by biological species to varying flow and habitat conditions may also facilitate persistence during extreme, more stressful events, and can ultimately influence distributions and abundance through direct and indirect cumulative effects. The impossibility of simultaneously engineering optimal conditions for all species, in conjunction with the variability and uncertainty inherent in linking specific biological and physical responses to flow variation, have led to the conclusion that attempts to restore natural variability appear to be a better solution for ecosystem management and restoration than implementation of minimum flows alone (Poff et al. 1997; Postel and Richter 2003). In addition, Poff et al. (1997) noted that managing for the “average” condition may not achieve desired results because of non-linearities in many geomorphic and ecologic responses to flow magnitude.

Poff et al. (1997), Postel and Richter (2003), and others have provided examples of actions designed to restore various aspects of the aquatic ecosystem from human-caused degradation. In California, actions have included mimicking the timing, magnitude and duration of peak flows below impoundments to restore channel maintenance and riparian succession processes, and provide improved conditions for fish migration. Other actions have included restoring base flows to help restore riparian, fish, and bird habitat.

During the development of analysis of protectiveness of the Policy element alternatives restricting flow diversion, it became apparent that the basis of the Maximum Cumulative Diversion element was linked most directly to the relation of high flows and preserving channel and riparian maintenance flow functions. Physical habitat space, as defined by upstream passage and spawning needs for example, was found to be linked more directly to maintenance of a minimum bypass flow. Channel and riparian maintenance flow needs are described in greater detail below.

Table D-1. Ecological Responses to Alterations in Components of Natural Flow Regime (adapted from Poff et al. 1997).

Flow Component	Specific Alteration	Ecological Response
Magnitude and frequency	Increased variation	Wash-out and/or stranding Loss of sensitive species Increased algal scour and wash-out of organic matter Life cycle disruption Altered energy flow
	Flow stabilization	Invasion or establishment of exotic species, leading to: Local extinction Threat to native commercial species Altered communities Reduced water and nutrients to floodplain plant species, causing: Seedling desiccation Ineffective seed dispersal Loss of scoured habitat patches and secondary channels needed for plant establishment Encroachment of vegetation into channels
Timing	Loss of seasonal flow peaks	Disrupt cues for fish: Spawning Egg hatching Migration Loss of fish access to wetlands or backwaters Modification of aquatic food web structure Reduction or elimination of riparian plant recruitment Invasion of exotic riparian species Reduced plant growth rates

Table D-1. Ecological Responses to Alterations in Components of Natural Flow Regime (adapted from Poff et al. 1997).

Flow Component	Specific Alteration	Ecological Response
Duration	Prolonged low flows	Concentration of aquatic organisms Reduction or elimination of plant cover Diminished plant species diversity Desertification of riparian species composition Physiological stress leading to reduced plant growth rate, morphological change, or mortality
	Prolonged baseflow "spikes"	Downstream loss of floating eggs
	Altered inundation duration	Altered plant cover types
	Prolonged inundation	Change in vegetation functional type Tree mortality Loss of riffle habitat for aquatic species
Rate of change	Rapid changes in river stage	Wash-out and stranding of aquatic species
	Accelerated flood recession	Failure of seedling establishment

D.3.1 Flow Variability and Channel Maintenance Flow Needs

Channel maintenance flows influence the quantity and quality of all types of anadromous salmonid habitat. Channel maintenance is a long-term process whereby the basic habitat structure of a stream is formed and maintained by multiple, variable high flow events that occur on an annual basis. Diversions during high flow conditions will reduce the flow magnitude. With respect to the Policy, the question is how much can flow be reduced before adverse effects begin to occur to anadromous salmonid habitat?

The answer to this question is complicated because channels are generally free to adjust their width, depth, slope, and bed grain size distribution in response to changes in flow regime. These attributes may adjust in concert or individually depending on circumstance (Leopold et al. 1995). Parker (2005) noted that stream channels establish their bankfull width and depth through the co-evolution of the channel and the floodplain. It will be shown below that the main, long-term effect of winter diversions under the Policy will likely be a reduction in channel size as the stream morphology adjusts to a smaller magnitude flow regime. This can be illustrated intuitively by comparing two sites on the same channel network, one upstream and one downstream. Although the same storms influence both sites, the flow magnitudes at the downstream site, and hence channel size, are expected to be greater overall than upstream because of increased drainage area. If the flows at the downstream site were made similar to the upstream site by diverting the additional accreting flow, the channel size of the downstream site would be expected to ultimately approach that of the upstream site, with residual variation determined largely by slope differences and orographic precipitation effects.

It takes more time for a stream's bed slope to change than its width or depth. The length of time required can be sufficiently long that plate tectonics becomes an important factor influencing slope (Parker 2005). Conversely, the grain size distribution may change most rapidly because the bed armor layer grain size distribution will reflect substrate mobility as influenced by the last few floods. Thus, net reductions in channel maintenance flow magnitude, along with the suite of flows above and below it, are likely to result in some "fining" (i.e., an increase in the concentration of fine sediments) of the streambed surface armor layer in the near term (order of magnitude approximately a few to ten years), followed by a more gradual reduction in stream size as reflected by bankfull widths and depths (order of magnitude approximately tens to hundred years, reflecting riparian zone adjustments as well). Slope would be expected to change relatively little over the same periods.

D.3.1.1 Magnitude of Channel Forming Discharge

Diverting water during the high flow period will reduce the magnitude of the suite of flows that transport sediments of all sizes and that maintain channel shape and size characteristics. The appropriate mechanistic criterion in this case concerns how much can be diverted without appreciably changing sediment transport and resulting physical channel characteristics that are important in maintaining anadromous salmonid habitat. A related problem is identifying a suitable metric that characterizes the effect of flow on channel form.

The channel-forming flow or dominant discharge is defined by the U.S. Army Corps of Engineers (2000) as the flow that if maintained indefinitely would produce the same channel geometry as the natural long-term hydrograph. Channels are maintained by a wide range of flows that are sufficient to transport sediment supplied by the streambed. These flows include those that are less than and greater than the channel-forming discharge. Flows less than the channel-forming discharge have less capacity to transport sediment than flows greater than the channel-forming discharge, however, flows less than the channel-forming discharge occur more frequently. Thus, flows less than and greater than the channel-forming discharge are both important for channel maintenance. This conclusion reflects in part the fact that a naturally variable hydrograph is generally more efficient at moving sediment than a constant average flow (Parker 2005).

Two different conceptual definitions have been formulated for the channel-forming discharge: bankfull discharge and effective discharge. Bankfull discharge is the maximum discharge that the channel can convey without flowing onto its floodplain. Parker (2005) noted that establishment of bankfull depth is functionally equivalent to the construction of a floodplain of similar depth. Effective discharge is the discharge that transports the largest portion of the average annual bed-material load (Wolman and Miller 1960). As such, bankfull and effective discharge represent an integration of the range of flows collectively forming and maintaining channel morphology and habitat.

The 1.5-year return peak flow, as derived from an annual maximum flood series, has been identified as a hydrologic metric that can be used as an estimate of the bankfull flow and effective discharge magnitudes (Dunne and Leopold 1978; Leopold 1994; Leopold et al. 1995). Williams (1978) examined 28 rivers from Colorado, Wyoming, Utah, New Mexico, Arizona, and Oregon, and found that the recurrence interval for bankfull flow occurred most frequently at around 1.5 years. Castro and Jackson (2001) examined 76 streams in the Pacific Northwest Region (Oregon, Washington, and Idaho), and found that the mean recurrence interval for bankfull flow was 1.2 years in the humid areas of western Oregon and Washington, and 1.4 to 1.5 years in the drier areas of Idaho and eastern Oregon and Washington. Simon et al. (2004) determined the recurrence interval of effective discharge for more than 500 sites across the United States, using suspended sediment load as a surrogate for bed material load. It was found that the use of the 1.5-year return peak flow as an approximate measure of effective discharge for suspended sediment transport was justified in 17 ecoregions that span a diverse range of hydrologic and topographic conditions.

Thus, generally speaking, the 1.5-year return peak flow should provide an approximate regional hydrologic estimate for the channel-forming discharge in the Policy area, based on either bankfull or effective discharge. However, for any particular stream, the actual channel-forming discharge might be greater than or less than the 1.5-year return peak flow. For example, the recurrence interval for bankfull flow in the 28 streams studied by Williams (1978) ranged from 1.01 to 32 years. Also, the recurrence interval for bankfull flow in the 76 streams studied by Castro and Jackson (2001) ranged from 1.0 to 3.11 years. The recurrence interval, based on a maximum flood series, cannot actually equal 1.0. The smallest recurrence interval reported by Castro and Jackson was likely slightly greater than 1.0, but rounded off to 1.0 for reporting purposes. Leopold (1994) compared the magnitude of bankfull flow with the magnitude of the 1.5-year flood for 42 streams in four regions: the Colorado Front Range; the Upper Green River in Wyoming; Southeast Pennsylvania; and the Salmon River in Idaho. Bankfull flow was approximately equal to the 1.5-year flood overall, but the ratio of bankfull flow to the 1.5-year flood ranged over all streams from a value of 0.26 to 2.3. In principle, then, there is likely some range in the channel forming discharge recurrence interval that applies to the range of streams located in the Policy area. Nonetheless, the 1.5 year flood appears overall to be a reasonable regional metric for implementation in the Policy, where a maximum cumulative diversion rate may be defined as a multiple thereof.

D.3.1.2 The Problem of Defining a Policy Element Diversion Rate that is Protective of Channel Maintenance Processes and Anadromous Salmonid Habitat

Unlike minimum instream flow requirements designed to protect spawning, it is more difficult to base a protective maximum diversion rate on an upper or lower limit percentage of the channel forming, bankfull discharge. This is because the linkages between salmonid habitat needs and bankfull flow are not as clearly quantified as the linkage between biological criteria and spawning habitat or upstream passage instream flows. There is no clear link between reducing the magnitude of high flows and impacts to anadromous salmonids that can be used to define a diversion rate that is protective of salmonid habitat.

Consequently, a reasonable protective approach to regulating diversion rates is to ensure channel maintenance flow and encompassing flood peaks are not changed dramatically. Reductions in the high flow magnitude through specification of a maximum diversion rate will likely ultimately lead to a smaller channel. The question then becomes, what level of change in channel size is acceptable from the perspective of protecting anadromous salmonids, as reflected by a reduction in bankfull flow? To answer this would require population modeling involving numerous assumptions based on incomplete data. It is possible, however, to evaluate what the change in channel size is likely to be at the regional scale, given a reduction in the characteristic channel forming, or bankfull discharge.

If, for example, the maximum cumulative diversion rate from a stream is limited to a small fraction of the channel-forming or dominant discharge, the resultant changes to the channel morphology will likely be relatively small; the channel can respond by adjusting (1) channel width, (2) channel depth, (3) channel slope (e.g., through sinuosity), and (4) grain size distribution of the surface armor layer substrate. Basic geomorphic theory holds that the channel will adjust in order to move the same quantity of sediment with slightly less water (Lane 1955). Expected responses would be smaller width, depth, and substrate grain size, and larger slope (i.e., smaller sinuosity). However, the expected percent change in any one of these characteristics in response to a given percent reduction in the channel forming or bankfull flow would likely be less than that induced for the flow. This is because the effects of the flow adjustment would likely be distributed to varying extents among each of the above noted morphologic characteristics.

It is possible to define general relationships between bankfull flow and the four morphologic characteristics representing the types of streams supporting anadromous salmonids, using a wide range of available data (Parker 2005). Predictions of potential changes in channel width, depth, and slope, and substrate grain size in response to changes in bankfull flow can be made based on these relationships. Specifically, gravel bed stream morphological relationships presented by Parker et al. (2003), based on bankfull characteristics from 62 gravel bed streams in Britain, Alberta, and Idaho, can be used to evaluate relative differences in level of protectiveness of different levels of diversion. The respective morphological relationships consist of the following:

$$S = 0.0976 \left(\frac{\sqrt{g\,D_{50}}\;D_{50}^{2}}{Q_{bf}} \right)^{0.341} \tag{D.1}$$

$$\frac{H_{bf}}{D_{50}} = 0.368 \left(\frac{Q_{bf}}{\sqrt{g\,D_{50}}\;D_{50}^{2}} \right)^{0.405} \tag{D.2}$$

$$\frac{B_{bf}}{D_{50}} = 4.87 \left(\frac{Q_{bf}}{\sqrt{g\,D_{50}}\;D_{50}^{2}} \right)^{0.461} \tag{D.3}$$

$$Q_{bf} = C_z\;B_{bf}\;H_{bf}\;\sqrt{g\,H_{bf}\;S} \tag{D.4}$$

$$C_z = \left(\frac{H_{bf}}{D_{50}} \right)^{0.177} \tag{D.5}$$

where S is the channel slope, D_{50} is the median grain size of the substrate armor layer, Q_{bf} is the bankfull discharge, H_{bf} is the bankfull depth, B_{bf} is the bankfull width, and C_z is a Chezy-type resistance coefficient (Chow 1959; Parker et al. 2003).

These equations can be used to estimate potential changes in width, depth, slope, and substrate size for a specified reduction in bankfull flow. From the morphological relationships, the following response equations may be derived:

$$\frac{B_{bf} + \Delta B_{bf}}{B_{bf}} = \frac{H_{bf} + \Delta H_{bf}}{H_{bf}} = \frac{D_{50} + \Delta D_{50}}{D_{50}} = \left(\frac{Q_{bf} + \Delta Q_{bf}}{Q_{bf}} \right)^{\frac{2}{5}} \qquad \text{(D.5)}$$

Slope change is predicted to be zero. The results indicate that slope is not expected to change measurably with changes in bankfull flow, and that bankfull width, depth, and armor grain size distribution change commensurately at about the same level. These results are not surprising, because the regime equations were designed to preserve dynamic similarity. Results of these analyses are depicted in Figure D-4. The results suggest that a reduction in bankfull flow magnitude by 5%, for example, would be associated with a roughly 2% reduction in width, depth, and/or median grain size.

Of these, the first evidence of change would likely be related to an adjustment in the grain size distribution of the surface armor layer. Changes in substrate size would likely occur more rapidly (e.g., within a decade) than changes in width and depth (multi-decadal time scale), reflecting adjustments in the riparian zone as well. The possibility also exists that the changes in substrate grain size might initially exceed the results shown in Figure D-4 to compensate for the lagged response of changes to width and depth. Changes in substrate size would impact the grain size distribution of the armor layer. Changes in grain size distribution to the subsurface layer are expected to be minimal, as that characteristic reflects more sediment supply than transport capacity (Dietrich et al. 1989).

Unfortunately, the results indicate that changes in channel values are approximately linear with changes in bankfull flow over the likely range of diversion rates that would be permitted under the Policy. As a result, there is no readily discernable asymptotic limit suggested for identifying a protective maximum cumulative diversion threshold. This finding is consistent with current research uncertainty regarding predicting the effects of changing channel maintenance flows on fish habitat in general. The clearest conclusion that can be inferred is that a greater rate of diversion is less protective than a smaller rate, but we cannot identify a clear threshold between protective and non-protective conditions.

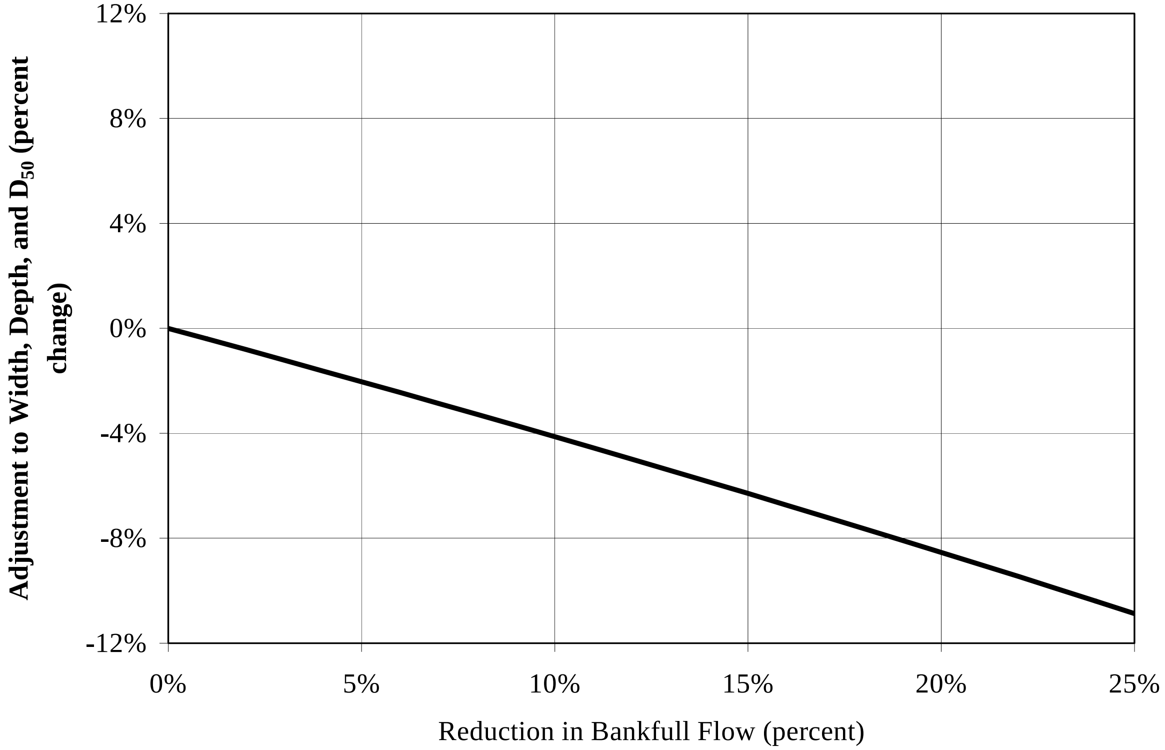

Figure D-4. Predicted long-term potential changes in channel width, depth, and grain size distribution resulting from a reduction in bankfull flow in Policy area streams potentially supporting anadromous salmonids.

Hence, specification of a regionally protective maximum cumulative diversion rate should involve an element of conservativeness, where a level is proposed that is considered by professional judgment to have a low risk of reducing channel size significantly over the long term, and of resulting in reductions in surface grain size distribution over the short term. The levels already suggested in the DFG-NMFS Draft Guidelines, namely the (i) 15% of the winter 20% exceedance flow and (ii) 5% of the 1.5 year flood magnitude metrics, appear in our opinion to have the potential to result in relatively small channel changes according to Figure D-4. The criterion based on the 1.5 year flood would generally permit a greater diversion rate than the first, as will be shown in Appendix J, and thus would be considered less protective with respect to channel maintenance flow needs. Effectiveness monitoring over a period of 10 to 20 years then becomes key to determining protectiveness in this context.

At the same time, a protectiveness analysis should also consider the more direct effects of a proposed maximum diversion rate on availability of spawning habitat and passage opportunities. It is possible that diverting 5% of the 1.5 year flood may be protective for channel maintenance flow needs, but not protective for upstream passage. This possibility reflects the principle introduced at the beginning of this appendix that one flow does not benefit all needs.

D.3.2 Importance of Flow Variability to Riparian Maintenance

Riparian vegetation is an integral part of anadromous salmonid habitat in the Policy area and is intricately dependent on a range of instream flows. It has been assumed above that protecting the natural range of channel forming flows through limiting diversion rate will also protect riparian vegetation. The importance of riparian maintenance flows to anadromous salmonids, and the mechanisms whereby riparian vegetation is dependent on maintaining natural flow variability as much as possible, are described below.

Losses of riparian vegetation can be associated with reductions in salmonid production (Murphy and Meehan 1991; Platts 1991). Removal of riparian vegetation can lead to decreased detrital inputs that most aquatic organisms including anadromous salmonids are directly or indirectly dependent on for their food, increased primary production potential by aquatic plants, increased summer water temperatures, changes in water quality and quantity, and decreased terrestrial habitat for aquatic-origin adult insects (Erman 1984; Knight and Bottorff 1984). The loss of a healthy riparian corridor along a stream also imparts direct impacts to anadromous salmonid populations in terms of decreased bank stability and increased sediment inputs, and lost recruitment of downed logs and other large woody debris that provide instream habitat structure for anadromous salmonids and other fish species (R2 2004). All of these changes have the potential to adversely affect anadromous salmonid populations.

Protection of channel maintenance flows, which are relatively high in magnitude, should effectively protect riparian and floodplain maintenance (Whiting 1998) if diversions do not take all the water above the channel maintenance flow. Riparian maintenance functions include preventing channel encroachment and establishing suitable floodplain conditions for riparian community establishment, growth, and replacement (Schmidt and Potyondy 2004).

Reducing peak flows by diverting water has the potential to affect riparian vegetation primarily through three mechanisms: (i) reduction in groundwater recharge through the stream banks, (ii) reduction of scouring flows that create new surfaces for riparian vegetation to re-establish itself on, and (iii) reduction in growth rates during the early spring. The degree of protectiveness of diversion restrictions reflects the amount of water that may be diverted without adversely affecting the health, diversity, and future potential of the riparian zone as affected by high flows in terms of each of these three factors.

D.3.2.1 Stream Bank Groundwater Recharge

Reduction in stream bank water table levels could potentially influence riparian growth in the spring if the level falls below the root levels earlier than the existing vegetation was adapted to, although the adverse effect of this phenomenon could be offset by additional root growth that often follows declining water tables. For example, the ability of some species such as cottonwoods to establish after germination can depend on the rate at which the water table declines after one or more floods (Mahoney and Rood 1998; Bendix and Hupp 2000). Stella (2005) found that rates of water table decline in excess of 6 cm/day induced close to 100% mortality for three species of cottonwood and willow in the San Joaquin river basin. In any case, diversions may have a minor effect on the water table elevation and the ability of the stream banks to store water, both locally and cumulatively as long as the diversion rate is small relative to the stream flow rate. Accretion flows from the banks and groundwater are most critical to summer habitat compared with winter habitat conditions in Policy area streams. Kondolf et al. (1987) noted that bank storage is a more transient source of surface runoff than groundwater inputs, and can be an important source of water for stream flow mostly in alluvial streams with bank material of high hydraulic conductivity (e.g., sand and gravel). Recharge of bank storage of groundwater occurs during flood stage. Discharge from bank storage was most important on the recession limb of a flood, with most stored water discharged within 2-3 flood periods in the Carmel River. Seasonal recession limbs provided conditions of gradually declining stage over several months. Bank storage contributions were still detected two months after peak flow during a moderately wet year, whereas in an extremely wet year the contribution was undetectable. The reason was thought to reflect the masking effect of higher sustained base flows from upstream over the local, more transient bank storage contribution (Kondolf et al. 1987).

D.3.2.2 Scouring Flows

Depending on the rate of water extraction relative to the instream flow rate, diversions may reduce the frequency and duration of flows high enough to disturb the stream banks and floodplain. These processes are necessary for long term health and spatial extent of the riparian zone, in terms of replacing older vegetation with new and providing suitable colonization surfaces. High flow impacts on riparian vegetation include substrate erosion and creation, mechanical damage, soil saturation, and transport of propagules such as clonal segments or seeds.

The likelihood of a particular species establishing and growing vigorously on a particular landform reflects the suitability of the site for germination and establishment, and environmental conditions including temperature, precipitation, and location in the drainage network that influence long term survival to reproduction (Harris 1999; Bendix and Hupp 2000). Most riparian species germinate in recently deposited alluvium after floods, which may reflect growth of new channel forms or the clearing out of pre-existing vegetation (Mahoney and Rood 1998; Bendix and Hupp 2000). Riparian cottonwood, poplar, and willow seeds need bare, moist surface high enough to be safe from future, frequent disturbance until the trees are established (Scott et al. 1996). Once established and depending on the length of time since the last erosion event, flexible or deeply rooted species such as alder, willow and poplar may be more likely to withstand flood damage and scouring than other riparian species. However, substrate erodibility may ultimately be more important than the physical characteristics of plants in determining flood losses, particularly for species rooting in material that is heavily reworked such as sand and smaller gravel deposits (Bendix 1998, 1999).

Different geomorphic processes influence availability of suitable germination and growth conditions in different stream reaches. For example, McBride and Strahan (1984a) observed that the temporary nature of riffle bars prevents establishment of riparian woody vegetation beyond the pioneer stage in Dry Creek, tributary to the Russian River. Point bars were more stable over time and provided an environment for further development of riparian forests. Plants on point bars reduced water velocity during high flow and caused gravel and smaller particles to accumulate (McBride and Strahan 1984a). Meandering processes occurring in lower gradient reaches are strongly associated with point bar formation, where moderate flood flows with recurrence intervals less than 5 years are important. Where lateral migration is constrained, flood deposition and erosion can be important processes for plant establishment instead (e.g., for cottonwood) and are associated with infrequent, higher flows (> 5 year recurrence interval; Scott et al. 1996).

Spatial variation in riparian forest community composition may more strongly reflect inundation frequency, corresponding substrate size, susceptibility of plants to damage linked to periodic flooding, and subsequent availability of water during the growing season, than seral recovery after a catastrophic event (Bendix and Hupp 2000). McBride and Strahan (1984a, b) found that seedling establishment on gravel bars varied with species and substrate texture on gravel bars studies in Dry Creek. Willows established preferentially on fine sediment surfaces, Fremont cottonwood on fine gravels, and mule fat dominated on larger sediment sizes. Drought induced mortality was highest on gravel bars where the stream dried up completely during the summer. High flows in the subsequent winter scoured remaining seedlings from bars, except in areas protected from the swiftest currents. Bendix and Hupp (2000) observed in general that herbaceous species tend to be found on depositional bars, while vegetation growing on flood-prone channel shelves tends to be found in shrub form with flexible stems and ability to sprout rapidly from damaged stumps. Species that are capable of rapid colonization of flood-cleared surfaces were considered common in streams with severe floods. Floodplain species tend to be sensitive to flood damage but are tolerant of prolonged inundation during flood events. Terrace species may be intolerant of both damage and inundation. In northern California, frequently flooded riparian landforms are dominated by Fremont cottonwood and sand bar willow. Higher, less floodprone surfaces are dominated by less flood-adapted species such as valley oak and California black walnut (Harris 1999; Bendix and Hupp 2000).

If high diversity and density of the riparian zone represent desired conditions for protecting anadromous salmonid habitat, instream flows must therefore include a variable component that allows erosion and deposition process to occur on the floodplain and lower surfaces. Such flows tend to exceed channel maintenance flows in magnitude. Richter and Richter (2000) proposed a modeling approach for identifying the natural flooding characteristics that must be protected to maintain riparian ecosystems along meandering rivers. Duration of flooding above bankfull was considered important for driving lateral channel migration, which in turn drives ecological succession in the riparian forest. The modeling identified a threshold of alteration of flood duration that could lead to substantial changes in the abundance of riparian forest patch types over time. The flow threshold was predicted by their modeling to correspond to maintaining flows above approximately 125% of bankfull flow for 15 days in their study river in Colorado. Chapin et al. (2002) observed that the upper elevational limit of riparian plant distributions reflected flood frequencies in the upper Klamath River basin. On average, a peak flow frequency of 4.6 years (range 3.1-7.6 years) was determined to be needed to sustain stream flow dependent riparian plant communities in most channels surveyed, although steep gradient and incised sites required return periods exceeding 25 years.

D.3.2.3 Reduced Vegetation Growth

The majority of plant species in California exhibit greatest growth in the spring when days are longer and warmer than in the winter, and moisture is still available (Holstein 1984). Stromberg (1993) determined that foliage area, stem basal area, and stand width increased in semiarid streams with growing season flow volume, as represented by mean annual or seasonal discharge. Flow volume and the related attributes of water table recharge and floodplain soil wetting were thought to be primary controls on riparian vegetation abundance. Stromberg and Patten (1990) noted that the relationship between stream flow and tree growth in the riparian zone in the eastern Sierra Nevada reflected distance from stream and height above water table. Black cottonwood growth rates increased linearly with volume of stream flow during the water year, with a four- to fivefold increase in flow correlated with a doubling of annual tree ring width. Growth responses to flow increases occurred for a longer period after diversion began than before. Growth of Jeffrey pine was reduced for a given flow rate after diversion began than before, indicating the importance of variable, high flows which were effectively eliminated by diversion.

In summary, there are numerous ways in which the existence and health of the riparian zone, which in part controls channel form, water quality, and other features of anadromous salmonid habitat suitability, depends on maintaining natural flow variability. Loss of the riparian zone can have significant adverse effects on salmonids and their habitat, including complete loss of formerly useable habitat.

D.4 IDENTIFYING ALTERNATIVE LEVELS OF PROTECTION DEPENDING ON LOCATION IN THE CHANNEL NETWORK

Streams upstream of anadromous habitat are important for salmonids and their ecosystem because of downstream transport processes occurring throughout channel networks (Vannote et al. 1980; Meyer et al. 2007; Wipfli et al. 2007; Freeman et al. 2007). It is reasonable to propose that the level needed in headwater channels may be different from streams supporting anadromous salmonids because different functions must be protected. Clearly, actions that occur upstream of anadromous habitat can adversely affect downstream transport of water, sediment, wood, nutrients, and food at sufficient rates and times as needed by biological and physical processes occurring downstream. Water quality can also be adversely affected in salmonid habitat because of upstream changes in water quality and quantity. Because of these attributes of channel connectivity, headwater streams require a degree of protection from flow diversion and diversion structures even when anadromous salmonids are not present locally.

Whatever the various levels of protection are determined to be needed, implementation of the Policy will necessarily require identifying which level to apply where depending on location in the channel network. To accomplish this, streams may be classified based on relative importance to salmonids and their ecosystem. The DFG-NMFS Draft Guidelines referenced an existing system developed by the California Department of Forestry (Cal. Code Regs., tit. 14, section 916.5, Table 1) which defines three stream classes:

- CDF Class I – Fish always or seasonally present, includes habitat to sustain fish migration and spawning;
- CDF Class II – Fish always or seasonally present offsite within 1000 feet downstream and/or aquatic habitat for non-fish species; excludes Class III waters tributary to Class I waters; and
- CDF Class III – No aquatic life present, water course showing evidence of being capable of sediment transport downstream to Class I or Class II waters under normal high water flow conditions.

The DFG-NMFS (2002) Draft Guidelines relied on the Class III designation to identify specific instances where on-stream reservoirs might be permissible, in part because the CDF system had already been used in other management applications. However, because the CDF classes were developed with forestry impacts in mind, particularly with respect to sedimentation and riparian management, they might not lend themselves strictly to assessing protectiveness of instream flow standards. For example, there have been changes in the way the CDF has defined non-fish species in Class II streams. In a CDF memorandum to regional chiefs dated November 3, 1987, non-fish species included aquatic invertebrates. In a subsequent memorandum to department chiefs dated March 7, 1997, the definition was changed to exclude aquatic invertebrates. While the distinction is assumed here to have made sense from the perspective of forestry management, the original 1987 definition is more appropriate from a water management and salmonid habitat perspective for reasons given below.

To consider whether the CDF system requires modification for use in the Policy, the channel network can also be classified into the following hydrologic and geographic sequential channel types based on their biologic and geomorphic functions, working in the upstream direction from the ocean or San Pablo Bay:

1. Anadromous salmonid habitat for some or all of the year, including passage corridors, upstream to historical limits (CDF Class I);
2. Fish-bearing (order Pisces) for some or all of the year, but not providing anadromous salmonid habitat (typically above natural barriers, or in very steep and/or small channels, CDF Class I)
3. Non-fish bearing, but containing aquatic animals and plants for some or all of the year in a defined channel that transports water and sediment (CDF Class II);
4. Ephemeral, defined channel that transports water and sediment downstream from the channel head (e.g., Montgomery and Dietrich 1989; Benda et al. 2005, CDF Class III); and
5. Ephemeral, terrestrial swales that concentrate and transport surface water through saturation overland flow (e.g., Dunne and Leopold 1978, no CDF Class).

These five biologic/geomorphic stream type classes provide a process-based framework for assessing impacts of reductions in instream flow, to anadromous and other fish species. The system classifies the drainage network based on local characteristics, and on biologic and geomorphic influences farther downstream. The classification level is sufficiently broad that regional differences in site specific attributes of streams should not influence their relevance to assessing the protectiveness of the Policy.

By definition, the first stream type (a) would be associated with Policy elements that are protective of anadromous salmonids residing or potentially residing in those channels. In the context of the Policy, the other stream types would each need to be protected if they ultimately influence food, water, nutrients, channel morphology, and/or substrates directly in type (a) streams, or convey same from upstream. In broader terms, it is important to consider the principle of the river continuum when protecting anadromous salmonid habitat (Vannote et al. 1980). That concept recognizes that there is a longitudinal gradient of physical conditions in streams that determines community structure and functions as the ecosystem progresses from headwaters to a large river. As the hydrologic processes, food resources, nutrient dynamics, and riparian vegetation change with increasing stream size, the composition of the vertebrate and macroinvertebrate communities, and functional feeding groups in particular, will change in response. The productivity of the ecosystem in downstream channels can depend intrinsically on delivery of nutrients, and organic and inorganic matter from upstream (Cummins 1979; Vannote et al. 1980). In addition, channel structure and suitability of salmonid spawning and rearing habitat in larger, downstream channels can depend on delivery of spawning gravels and, in forested basins, wood from upstream headwater channels (Leopold et al. 1995; Benda et al. 1998, 2005).

The second, third, and fourth stream types (b-d) have varying importance to anadromous salmonids and their habitat, with importance of an individual stream likely decreasing in the upslope direction. All three classes route water and sediments downstream to anadromous habitat. Hence, while reductions in flow in any one stream may not have a large individual effect on downstream habitat, a large number of small reductions in instream flows and sediment transport distributed across many streams can cumulatively result in adverse habitat conditions downstream. Certain volumes of water and sediment need to be routed downstream to ensure that anadromous salmonid habitat quantity and quality are not degraded significantly. On the water side, instream flow reductions caused by diversions in any of these stream types can lead to reduced physical habitat space for anadromous salmonids downstream at base flows, and impaired channel maintenance processes at high flows. On the sediment side, interruption of bedload transport upstream can lead to reductions in spawning habitat availability and general channel morphology changes downstream. Streams in the Policy area drain the geologic Franciscan Formation that is associated with high yields of sand and durable gravels (Rantz and Thompson 1967; Kondolf et al. 2001). Hence, gravels originating in even the fourth type (d) of stream can ultimately supply spawning habitat used by anadromous salmonids downstream. Consequently, streams of types (a), (b), and (c) would all need to be protected at a minimum in terms of providing sufficient water and bedload to anadromous habitat in streams of type (a).

Anadromous salmonid populations are also dependent directly or indirectly on the delivery of nutrients and food from upstream channels, irrespective of channel type. The dependence translates through successive levels of the food chain in the upstream direction. For example, while primary and secondary production in a type (d) stream may not contribute directly to anadromous salmonid production when there are other stream classes intervening, production in a type (a) stream may depend to some extent on production in a type (b) stream; production in a type (b) stream may depend on production in a type (c) stream; and so forth to the type (d) stream. This cascade of energy reflects the continuum of the entire river ecosystem (Vannote et al. 1980). Reduction in productivity in the most upstream channelized reaches of the drainage network can therefore ultimately influence productivity in the most downstream reaches if enough of the upstream reaches are affected. Hence protecting upstream aquatic resources in non-anadromous streams is needed in order to protect salmonids downstream.

Swales and similar drainage depressions that comprise the fifth type (e) would by definition not be expected to be important for bedload supply downstream because there is no defined stream channel. In addition, the contributing area is generally small relative to the total drainage area so that concomitant reductions in flow downstream are also expected to be minor.

The existing CDF classification system is generally consistent with biologic/geomorphic stream types (a)-(d), where the primary difference involves the distinction between anadromous and non-anadromous fish bearing streams. The CDF system could therefore be used or modified for the purposes of applying the Policy to streams which historically supported anadromous salmonids. Where necessary, Class I streams could be differentiated based on historical absence of anadromous salmonids (i.e., stream types (a) and (b)). In addition, the original definition of aquatic life under the CDF system, which includes macro-invertebrates, is consistent with protecting salmonid habitat quality overall.

D.5 ESTABLISHING PROTECTIVENESS OF FLOW RESTRICTIONS AT THE REGIONAL SCALE

The discussions above apply to the problem of defining a protective instream flow at any scale, but with greater emphasis on the site over the regional scale. There are correspondingly two main sources of variability influencing the definition of protectiveness, where variability in flow needs at the site scale is compounded by variability across sites. Thus, a consideration of protectiveness at the regional scale must consider a larger number of sources of variation than a consideration at the site scale. An approach is outlined below based on recognition of this two-stage variance problem that is consistent with the goal of establishing a protective Policy at the regional scale.

A fundamental precept in both the SWRCB (1997) Russian River Staff Report and the DFG-NMFS (2002) Draft Guidelines, is that a “one-size-fits-all” approach cannot result in protecting anadromous salmonids in all streams equally. Both approaches recommended site-specific studies for individual situations in which it was found that a new water diversion had the potential to cause adverse impacts to anadromous salmonids or their habitat. Carrying this concept forward into the development of the Policy, it can be interpreted to mean that each element of the Policy should allow diversion until some regional threshold is reached, beyond which site specific studies should be performed to evaluate whether more diversions could result in conditions in some streams that have a reasonable probability of not being protective of (i.e., may impact) anadromous salmonids. Because of inherent variability, not all streams of a given size, slope, elevation, aspect, drainage density, drainage area, precipitation, and other measures of similarity may be able to support the same level of diversion without impacting salmonids. Hence, the threshold level itself is inherently variable across streams. If a relatively simple and practical criterion is to be implemented, the focal issue becomes: at what point do more detailed analyses become necessary to determine how much additional diversion could occur before anadromous salmonids and their habitat in a particular stream can no longer be considered to be protected.

For example, the minimum instream flow element of the Policy can be evaluated at the site specific level in a large number of streams to reasonable accuracy, but for a given attribute such as a measure of channel size or drainage area, there is likely a range of protective bypass flows across all streams of a given size or area (e.g., Hatfield and Bruce 2000). Plotting the flows for each stream against the channel size or area metric would result in a scatter of data points across the graph (Figure D-5), even when the flows are scaled by some standardizing measure such as mean annual flow. In this case, a regression approach through the center of the data scatter (e.g., regressions of Hatfield and Bruce 2000) would result in protective instream flows in some streams, but probably not enough streams to be considered fully protective under all circumstances. Some streams will fall on or near the regression line (e.g., within +/- 10% of the predicted value). A sizable fraction of streams will likely be under-protected and a roughly similar fraction over-protected. The proportions of each vary with variability about the regression line (i.e., data scatter). Hence, setting a guideline based on some measure of central tendency has the potential to result in adversely affecting aquatic ecosystems in a relatively large number of streams. This outcome could be considered at the policy level as being un-protective when the Policy is based on setting a conservative threshold level beyond which more detailed study becomes necessary. Policy standards should be sufficiently broad and conservative (i.e., risk averse) if they are to be applied at the regional level and be protective of anadromous salmonids, especially those listed under the ESA/CESA.

Hence, a more protective approach that avoids (or at worst renders negligible) the possibility of recommending an un-protective minimum instream flow threshold would be to follow the analogy of envelope curves (e.g., Terrell et al. 1996). In the case of Hatfield and Bruce (2000), for example, a regression-derived curve that envelopes the lower 95% of the data would result in recommending instream flows that are protective of 95% of the streams, and probably not too harmful for the remaining 5% (assuming the peak of the WUA-flow curve is considered protective).

This same philosophy could ostensibly be applied in reverse, with the benefit of the doubt assigned to the resource extraction user instead, and where a regression-derived curve envelopes the lower 5% of the data. In this case, 95% of the water users would benefit more than they would under current resource protection regulations.

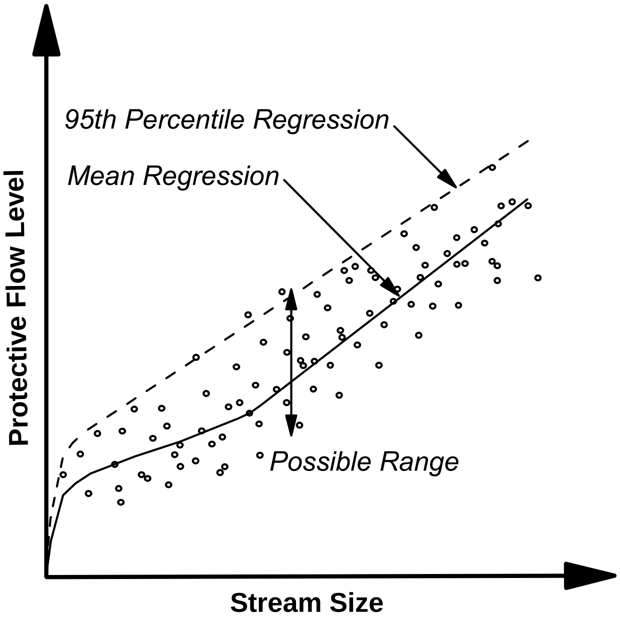

Figure D-5. Conceptual representation of range of protective flows for streams of a given size, and two possible ways of setting protective flow level thresholds as part of a regional policy. Using the 95^{th} percentile line protects nearly all streams, whereas using the mean regression line protects roughly only half the streams. Each data point represents a unique stream or stream reach.

The use of a mean prediction could therefore be considered as balancing needs of instream flow and water users, with the appearance of being a compromise. However, doing so could result in under-protecting roughly half the streams in question, and over-protecting the other half. Upon inspection, this implies an element of unfairness to water users as well. Some users will be lucky enough to have their stream fall in the under-protected region of the predicted instream flow curve, whereas others will have the opposite luck. It therefore seems more equitable and measurable to place the burden of proof on all water users equally, whereby an instream flow guideline assures resource protectiveness first and then each user evaluates to what extent their stream can deviate from the guideline without adversely affecting aquatic ecosystems.

The discussion concerning Figure D-5 up to this point assumes that each site's estimate of protective flow level is accurate and precise. In general, site-specific studies of habitat and instream flow needs have inherent uncertainty about the estimated stream flow magnitude benefiting the entire stream or reach in question (e.g., Williams 1996). This uncertainty likely causes some of the conceptual data scatter represented in Figure D-5. In this case, an average relationship based on many sites may be a more accurate predictor than the site-specific relationship, since each site may not be completely representative of average conditions in a stream and subject to random sampling error effects (Rantz 1964). However, it is unlikely that all of the variability is due to sampling error (Hatfield and Bruce 2000), and thus reliance on a mean regression will still risk leaving some streams unprotected.

Assuming that each data point depicted conceptually in Figure D-5 has site-specific error influencing its plotting position in the graph, it should be acceptable to define a line using a standard statistical method that envelopes most but not necessarily all of the data. For typical instream flow studies, error about the resulting instream flow needs data point will likely be large enough to overlap the envelope predictor equation (cf. Williams 1996).

There is no clear, mechanistically-based choice for choosing one statistical method over another, however, whether it be a regression for some percentile level (e.g., 95th percentile envelope curve) or by adjusting regression coefficients upwards by some multiple of standard error about the coefficient estimate (e.g., a prediction interval; Neter et al. 1983). The simplest approach for a simple or multiple linear regression is to adjust the intercept estimate upwards, leaving the estimated slope coefficients at their mean values. This approach should yield a reasonably protective envelope curve that is within the error bounds of estimates of individual site instream flow needs. The derivation of the minimum bypass flow alternatives, which is detailed in Appendix E, employs this concept by generating regression-derived curves, then adjusting the intercept estimate upwards by three standard errors.

APPENDIX E

Development of Policy Element Alternatives Defining A Range of Protective Levels of Minimum Bypass Flow for Application at the Regional Scale: Upper MBF and Lower MBF Alternatives

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APPENDIX E

DEVELOPMENT OF POLICY ELEMENT ALTERNATIVES DEFINING A RANGE OF PROTECTIVE LEVELS OF MINIMUM BYPASS FLOW FOR APPLICATION AT THE REGIONAL SCALE: UPPER MBF AND LOWER MBF ALTERNATIVES

The term ‘minimum bypass flow’ (MBF) is an instream flow quantity that is designed to protect downstream fish and aquatic biota. In the DFG-NMFS (2002) Draft Guidelines, water cannot be diverted when natural stream flows are at or below the MBF level. During scoping and as part of analysis completed by other parties, several alternative levels of MBF have been proposed for use in the Policy to protect fish habitat, including the DFG-NMFS (2002) Draft Guidelines February median daily flow (MBF1) and the MTTU (2000) 10% exceedance flow (MBF2) proposals. The extent to which the proposed levels of MBF may or may not be protective at the regional scale was evaluated using a limited set of habitat-flow data from a few sites. However, since the Policy is to be applied at the regional scale, results from a small number of sites may not be representative of habitat-flow needs over the entire range of stream types and varied topography found across the Policy area.

This appendix describes the data and analyses used by R2 to develop two additional minimum bypass flow alternatives that define the upper and lower limits of protectiveness for an MBF evaluated at the regional scale. The two alternatives take into consideration the effects of drainage basin size on bypass flow needs. A large amount of data was compiled that represent habitat-flow needs of streams spanning a broad range of physical conditions. Each alternative allows diversion to occur, but provides a different level of protectiveness:

- The first alternative, Upper MBF (MBF3), corresponds to the instream flows at an upper threshold limit (e.g., approximated conceptually by the upper dotted line in Figure D-5, Appendix D). This alternative allows for diversion, but is risk averse and, hence, conservatively protective toward anadromous salmonids.
- The second alternative, Lower MBF (MBF4), corresponds to instream flows at the lower threshold limit of the possible range depicted in Figure D-5, below which there is substantial risk of impacting the sustainability of anadromous salmonid populations. This alternative allows higher water usage and diversions, while still providing some level of protection to anadromous salmonids.

There are three life stages of anadromous salmonids that are directly influenced by a MBF:

- Upstream passage - a minimum instream flow is needed above which adult passage is possible, including within depth-constricted sections of the channel;

- Spawning and incubation – the quantity and quality of spawning habitat is controlled by instream flows that provide suitable depth and velocity combinations over spawning gravels; and

- Juvenile Rearing – the quantity and quality of rearing habitat is controlled by instream flows that provide suitable depths and velocities for rearing, and access to cover and refuge areas during winter months.

The first two of these are the most sensitive with respect to determining a threshold flow below which suitable conditions (passage or spawning) would not be provided. Moreover, rearing habitat would generally be protected by flows that are suitable for spawning. Hence, the remainder of this section evaluates upstream passage and spawning habitat needs at the regional scale. The evaluation will demonstrate that specifying a MBF to protect spawning habitat will generally protect upstream passage needs as well.

E.1 MINIMUM BYPASS FLOWS THAT PROTECT UPSTREAM PASSAGE

Upstream passage flow needs for adult anadromous salmonids depend in part on the channel size, which reflects drainage area and runoff. Generally, in the larger streams of the Sonoma Creek and Russian River basins, late fall and early winter base flows appear sufficient to enable upstream migration of adult Chinook salmon (Entrix 2004; SEC et al. 2004). In small streams, most upstream passage may occur during freshets (MTTU 2000). A regional analysis of upstream passage flows for adult salmon and steelhead in the Salmon and Clearwater River basins in Idaho indicated that for small basins (mean annual flows less than about 25 cfs), upstream passage was afforded in riffles at flows averaging about twice the mean annual flow (R2 2004). In larger basins, the average minimum passage flow was about half the mean annual flow or less depending on stream order, but spawning flows were always higher. As a result, passage was never a limiting factor.

Data from Idaho (R2 2004), Deitch (2006) and the validation sites were compiled and evaluated to compare upstream passage flow needs against drainage area and mean annual flow (see Appendices G and H for derivation and results). These two metrics are easy to estimate (and thus practical for Policy implementation), and reflect location in the drainage network and channel size. Upstream passage flow needs were defined as the minimum flow needed to provide passage over riffle crests and other locations in the channel where depth was most constricted. Passage depths were evaluated for the 2006 validation sites and compared with previously collected data, including data from Idaho (R2 2004) and from various studies in the Policy area (Entrix 2004; Deitch 2006). Mean annual flow was approximated for the various sites using nearby stream gages.

Plots of passage flow needs (scaled by mean annual flow) against drainage area indicated the existence of general relations for specific passage depth criteria that may be used to determine protective upstream passage flow requirements at any drainage network location in the Policy area (Figure E-1). Multiple linear regression analysis was consequently performed to derive a general relationship between passage flow need, mean annual flow, drainage area, and passage depth criterion. Data from Idaho (R2 2004), Deitch (2006) and the validation sites were first transformed into log-10 space, and then regressed. The validation site data consisted of minimum passage flows derived from passage habitat-flow curves (shown in Appendix H) and calculated for the various minimum passage depth criteria listed in Table G-4 of Appendix G. The data sets were used in a least squares, log-linear multiple regression analysis to develop an equation for passage flow based on drainage area. The equation was developed by first taking the estimated passage flow needs, Q_{fp}, for each site and dividing it by the estimated mean annual flow, Q_m, for each site. The log of the ratio of Q_{fp} / Q_m and the log of DA for each site was used in a regression analysis of all data points to develop a relationship for estimating minimum passage depths (MPD). Figure E-2 shows the resulting relationship that is described by the following equation:

$$Q_{fp} = 19.3\ Q_m\ D_{min}^{2.1}\ DA^{-0.72} \qquad \text{(E.1)}$$

Where Q_{fp} = the minimum fish passage flow (cfs), Q_m = mean annual flow (cfs), D_{min} = minimum passage depth criterion (feet), and DA = drainage area (mi^2). The relation appears to be descriptive of streams over a region broader than the Policy area, and is generally consistent across passage depth requirements. That is, a stream location with a given drainage area and mean annual flow is predicted to require on average, more flow for a larger magnitude passage depth criterion than for a shallower criterion in order to provide the respective passage depths over riffles.

The 19.3 coefficient corresponds to the least squares intercept estimate plus three standard errors. This adjustment results in approximating an envelope curve for each passage depth criterion (i.e., an upper 99% confidence limit; Neter et al. 1983). The minimum passage depth and drainage area exponents in Equation (E.1) are the least squares coefficient estimates. The predicted regional MPD curves for specific passage depth criteria do not envelope all of their relevant data, this is shown in Figure E-2 at sites with data points that plot above a given MPD criterion line. As each data point depicted in Figure E-2 has site-specific error influencing its plotting position in the graph (see Section D-5 in Appendix D). Equation (E.1) may still be protective of upstream passage at these sites, unless passage is highly restricted at one location due to atypical site-specific conditions.

Two studies were identified that permitted evaluation of Equation (E.1)'s predictive reliability. In the first, Snider (1985) estimated that passage by steelhead over a critical riffle in lower Brush Creek near Manchester, California, occurred at flows greater than 15 cfs. As a comparison, Equation (E.1) predicts a minimum passage flow of 55 cfs, based on a minimum feasible

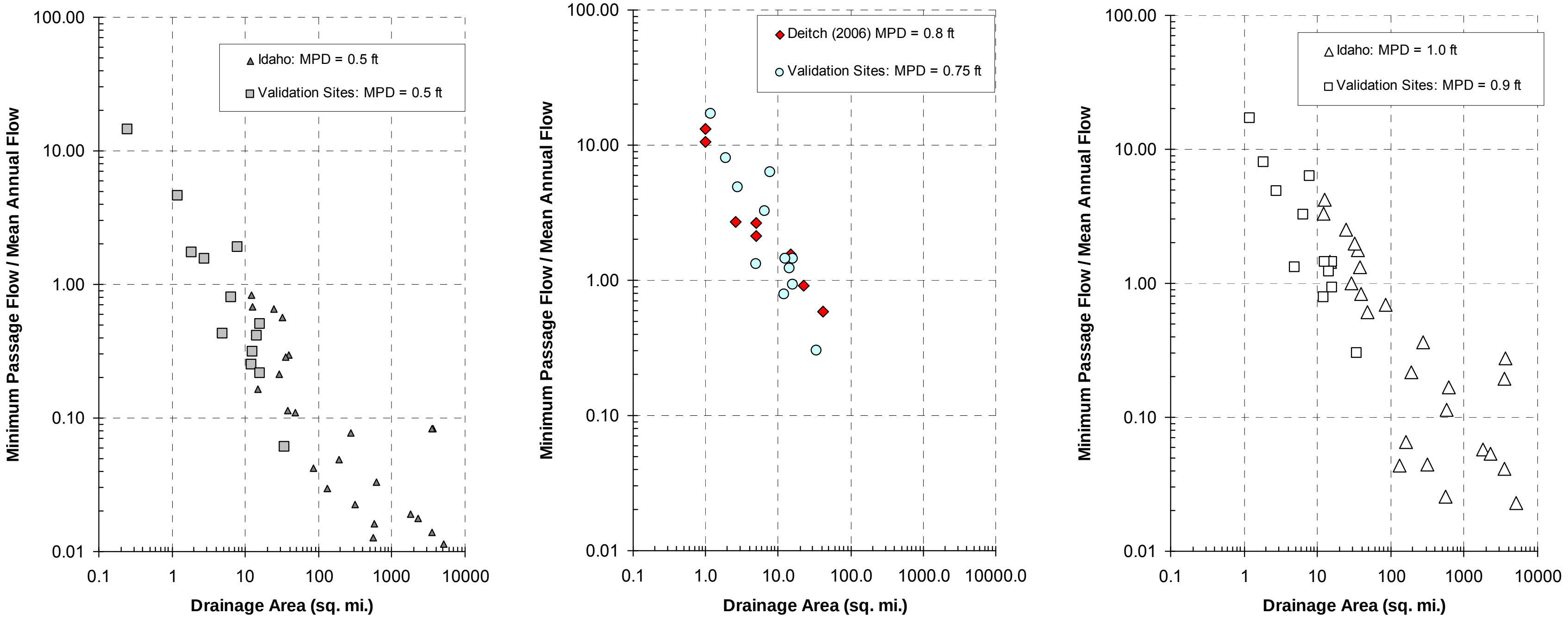

Figure E-1. Variation of estimated minimum upstream passage flow needs, scaled by mean annual flow, with drainage area for selected minimum passage depths (MPD) in riffles.

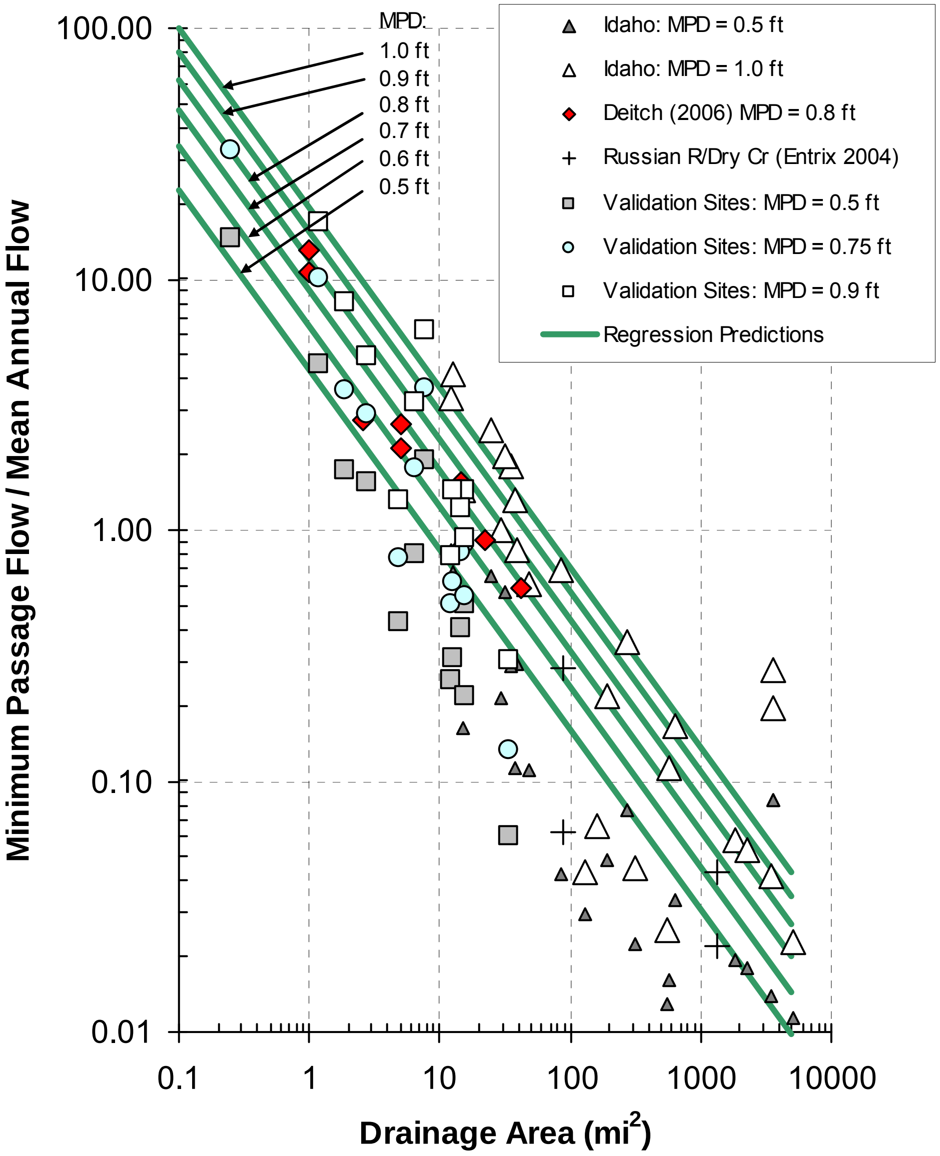

Figure E-2. Comparison of regression predictions for minimum upstream passage flow based on the data presented in Figure E-1, scaled by mean annual flow and plotted against drainage area. The prediction lines for selected minimum passage depth (MPD) criteria are indicated by arrows.

passage depth criterion of 0.7 ft (see Appendix G), 16 mi^2 drainage area, and 44 cfs mean annual flow (SWRCB 1997). This predicted value is about 3.6 times higher than the 15 cfs estimated based on a site-specific evaluation which suggests that application of Equation (E.1) would likely be conservatively protective in lower Brush Creek.

In the second study, Bratovich and Kelley (1988) determined through observation and analysis that a minimum flow of 35 cfs in Lagunitas Creek at Irving Bridge (near Samuel P. Taylor State Park, California) was needed for coho salmon passage over five critical riffles. The nearby Lagunitas Creek 2006 validation site drainage area is 34.3 mi^2 and estimated unimpaired mean annual flow is approximately 72 cfs. The passage flow predicted by Equation (E.1) for this stream at a depth of 0.6 ft is 37 cfs. This estimate is similar to the value determined by Bratovich and Kelley (1988), suggesting that the equation would also provide a reasonable prediction of minimum passage flow at this site.

Based on the above comparisons and the wide range of stream sizes and drainage areas used to derive Equation (E.1), it can be concluded that Equation (E.1) will give predictions of minimum passage flow that are reasonably protective of upstream passage flow needs at the regional scale. However, Equation (E.1) may not fully protect sites that have higher requirements due to unusual site specific conditions.

E.2 AVAILABLE DATA DESCRIBING MINIMUM INSTREAM FLOWS THAT PROTECT SPAWNING HABITAT

As in the case for upstream passage, the amount of flow needed to support spawning habitat generally increases relative to mean annual flow with decreasing basin size (Rantz 1964; Collings et al. 1972b; Smith and Sale 1993; MTTU 2000; Hatfield and Bruce 2000; Vadas 2000). For streams within the Policy area, this relationship may be stronger for steelhead than for Chinook or coho salmon (Vadas 2000). For smaller streams in the Policy area, preferred flows for both salmon and steelhead spawning may occur during a relatively short period of time, during and immediately following storms (e.g., Snider 1984; MTTU 2000).

In the following, spawning flow requirements are evaluated according to drainage area and mean annual flow. These metrics are relatively simple to determine and reflect the influence of important basin size and runoff effects on spawning habitat availability and channel size. Use of mean annual flow as a scaling metric reflects total basin runoff characteristics irrespective of hydrologic process (e.g., snowmelt vs. rainfall runoff).

This section identifies the results of previously published regional and local studies of spawning habitat flow requirements, and compares them with data collected from the validation sites as part of this project. Appendix G describes the methods used to analyze validation site data; Appendix H presents resulting habitat-flow curves.

E.2.1 Published Regional Studies of Spawning Flow Requirements

A number of regional instream flow studies have results applicable to assessing the protectiveness of the MBF for spawning flows. These are summarized below and compared with the analyses of data collected in the validation sites listed in Table G-1 of Appendix G.

In the first study, Rantz (1964) collected data describing Chinook salmon spawning habitat conditions as a function of flow in the Eel and Mad River basins in northern California. Optimum spawning flow was defined as the lowest flow rate maximizing spawnable area with suitable depths, velocities, and substrates. Rantz (1964) used threshold values of depth and velocity to define suitable spawning habitat; an area was either suitable or it was not. Suitable widths were measured across transects at various flows, and converted to total area. Rantz (1964) calculated a ratio of spawnable area with suitable depths and velocities to total area of spawning gravel. While this ratio indicated the same optimum flow as the suitable spawnable area, it also provided an index of the relative availability of spawnable substrates at various flows, with a maximum value of 100% representing all suitable gravels being available at a given flow. Rantz (1964) developed a regression equation for optimum flow for Chinook salmon, using data from nine streams:

$$Q_{Optimum} = 0.89(Q_m)^{1.09}\left(\frac{R_w}{DA}\right)^{1.44} \qquad \text{(E.2)}$$

Where Q_m = mean annual flow (cfs; range = 37-1,280), R_w = stream width (ft; range = 31-271), and DA = drainage area (mi^2; range = 16-393). Although Rantz (1964) noted that the small number of sites used likely limited predictive reliability, some trends were apparent. He noted that for streams with equal mean annual flow, the preferred spawning flow increased with channel width because higher flows were required to achieve the same depths and velocities. Streams that were disproportionately wide relative to drainage area had higher preferred flow than narrower streams.

Several analogous studies were conducted subsequently by the USGS in both rainfall- and snowmelt-runoff systems in Washington State. A pilot study was conducted by Collings et al. (1972a,b) in western Washington. Using data from eight streams, Collings et al. (1972a,b) developed an alternative relationship to that of Rantz (1964) that indicated the magnitude of the optimum spawning flow varied with measures of channel size, and included terms for drainage area, channel slope, bankfull width, and bankfull depth. The influence of channel slope variation was minor, as indicated by a regression exponent near 1.0. Additional analyses were completed by (Collings 1974), and two USGS publications, one for steelhead (Swift 1976) and the other for Pacific salmon (Swift 1979). Swift (1976) derived the following equation for predicting optimum spawning flows for steelhead in streams with drainage areas ranging between 3.5-327 mi^2:

$$Q_{Optimum(Steelhead)} = 16.8(DA)^{0.666} \tag{E.3}$$

Swift (1979) presented the following analogous equations for coho and Chinook salmon based on drainage area and mean annual flow, respectively:

$$\begin{aligned} Q_{Optimum(Coho)} &= 6.78(DA)^{0.756} \\ Q_{Optimum(Coho)} &= 2.13(Q_m)^{0.771} \end{aligned} \tag{E.4a, b}$$

$$\begin{aligned} Q_{Optimum(Chinook)} &= 15.9(DA)^{0.698} \\ Q_{Optimum(Chinook)} &= 4.22(Q_m)^{0.747} \end{aligned} \tag{E.5a, b}$$

Equations were also presented by Swift (1976, 1979) for rearing juvenile salmonids, based on wetted area in the main channel for food production during summer low flow. Those equations resulted in flow recommendations that were inherently lower than flows required for spawning.

The spawning flow data of Rantz (1964) and Swift (1976, 1979) are compared in Figure E-3. Equations E.4 and E.5 are also depicted, along with the results of our regression analysis of the Swift data for steelhead. The effects of channel size and location in the drainage network are evident in the decreasing trend in the data. The California and Washington Chinook data scatter overlap, and indicate greater instream flow needs for spawning than coho salmon for a given drainage area. The steelhead data scatter overlaps with Chinook and coho data.

A considerable data set was also collected between 1989-1995 in Idaho as part of the Snake River Basin Adjudication. The study used the PHABSIM system to define habitat-flow needs for spawning and other life stages for steelhead, Chinook salmon, and other species (Bovee and Milhous 1978; Bovee 1982; R2 2004). PHABSIM calculates habitat area based on the relative suitability of depths, velocities, and substrates over a range of flows, resulting in a habitat area-flow curve. The metric of habitat area is called Weighted Usable Area (WUA). For the present analysis, flow recommendations for steelhead spawning, as defined by the peak of the WUA vs. flow curve, were compiled with mean annual flow estimates. It should be noted that the peak WUA-based flow recommendations differ from the peak optimum habitat curves of Rantz (1964) and Swift (1976, 1979). The Idaho data for steelhead represent maximum spawning habitat as

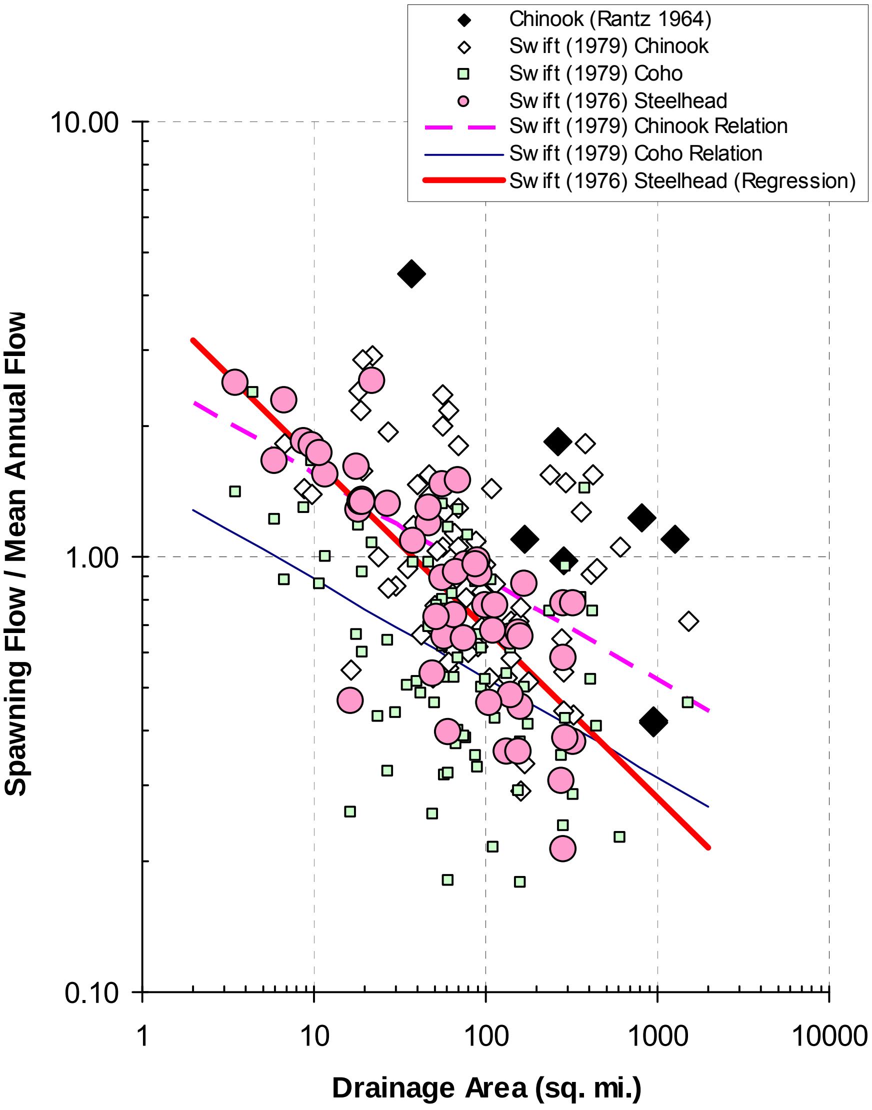

Figure E-3. Comparison of minimum instream flow recommendations for spawning steelhead, Chinook, and coho in streams surveyed variously by Rantz (1964) and Swift (1976, 1979) in California and Washington, distinguished by drainage area. The spawning flow is scaled by the mean annual flow to account for channel size effects on spawning flow needs.

defined by a gently peaked curve generated by PHABSIM, in which areas with sub-optimal depths and velocities contribute to the total amount of habitat predicted. The discrete results of Rantz (1964) and Swift (1976, 1979) are based on only summing areas with optimal depths and velocities. A re-evaluation of their results using PHABSIM, would likely result in a prediction of habitat amounts closer to the minimum flow threshold (also called inflection) point in Figure D-1. In addition, the suitability curves used to define steelhead and Chinook depth and velocity preferences in Idaho were equivalent, reflecting similar regional habitat requirements. As a consequence, the data of Swift (1976, 1979) for steelhead and coho plot generally lower than the Idaho data, while the data of Rantz (1964) and Swift (1979) for Chinook plot closer to the Idaho data for steelhead spawning (Figure E-4). The analysis of the Idaho data corroborates a channel size effect when defining instream flow needs for spawning, as reflected by drainage basin area and mean annual flow. The collective data scatter for all data sets indicates there are upper and lower thresholds that may be defined by relatively simple, practical formulae for prescribing the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives for the MBF element of the Policy.

Recently, Hatfield and Bruce (2000) compiled the results of instream flow studies conducted throughout the United States that were based on the use of PHABSIM. The analysis included the Idaho data. Hatfield and Bruce (2000) found an essentially log-linear relation between the flow maximizing WUA and mean annual flow (range = 4.1-15,100 cfs) for adult and spawning steelhead trout and Chinook salmon, and for other life stages and species. The regression derived for WUA-maximizing flow ($Q_{optimum}$; in cfs) for spawning steelhead was:

$$Q_{optimum\ (steelhead)} = 4.37 \times 10^{-15}\ Q_m^{\ 0.618}\ \text{Longitude}^{7.26} \qquad \text{(E.6)}$$

The regression derived for spawning Chinook was:

$$Q_{optimum\ (Chinook)} = 3.49 \times 10^{-23}\ Q_m^{\ 0.682}\ \text{Longitude}^{11.042} \qquad \text{(E.7)}$$

Regression prediction intervals were relatively large in magnitude, indicating considerable uncertainty in the predictions of basins that were not included in the original data set used to develop the relations. This finding is consistent with the observed scatter in Figures E-3 and E-4 in which it is possible for streams that are similar in terms of hydrologic characteristics to have different instream flow needs for spawning based on undescribed sources of variability such as local slope, lithology, and other factors. Nonetheless, they consistently found that the WUA- maximizing flow decreased relative to mean annual flow with increasing basin or channel size. They inferred that the decline in proportion of mean annual flow with increasing stream size explained in part why PHABSIM- and simple hydrologic-based flow recommendations are not consistent or proportional for all streams.

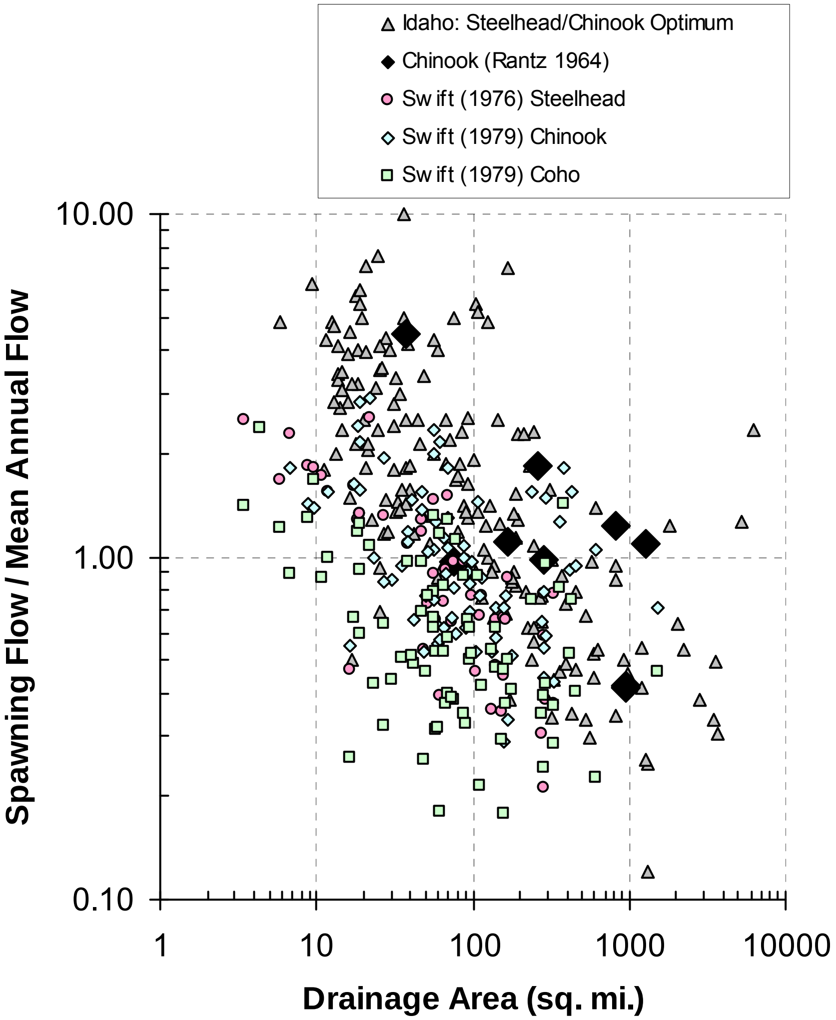

Figure E-4. Comparison of minimum instream flow recommendations for streams surveyed variously by Rantz (1964) and Swift (1976, 1978) in California and Washington, with optimum steelhead spawning flows determined for Idaho streams (R2 2004), distinguished by drainage area. The spawning flow is scaled by the mean annual flow.

Hatfield and Bruce (2000) proposed that the regressions they developed could be used in the context of project scoping, research planning, and adaptive management. In the latter case, they proposed that their relations could be used to estimate a value and range of flows for more detailed experimentation and monitoring. In that sense, the regional relations they developed provide an independent means for assessing the protectiveness of various MBF thresholds.

E.2.2 Previous Instream Flow Recommendations in the Policy Area Related to Anadromous Salmonid Spawning

There have been few intensive instream flow studies conducted in Policy area streams, and the work that has been performed has occurred in relatively large channels. The State Water Board summarized optimum spawning flow estimates derived from habitat-flow data collected in Big Sulphur Creek, Dry Creek, Brush Creek, and Lagunitas Creek (SWRCB 1997). This information is reproduced in Table A-1 in Appendix A of this report.

Three reports were identified in which informal minimum instream flow recommendations were made for selected streams in the Policy area (Walker Creek - Kelley 1976; Pine Gulch Creek and Redwood Creek - Anderson 1978; Redwood Creek - Snider 1984). In another series of reports, Entrix (2002, 2004) reported general minimum instream flow needs for the Russian River and its major tributary, Dry Creek, based on anecdotal data and observations. Suitable spawning conditions for steelhead and Chinook were thought to occur at flows above about 100 cfs and 130 cfs, respectively in the Russian River, and above about 30 cfs and 40 cfs respectively in Dry Creek (Entrix 2004). These collective recommendations appear to represent minimum acceptable instream flows below which spawning habitat would not be protected. These estimates were evaluated here using data from nearby gages for an order of magnitude estimate of spawning flow needs.

In addition, the DWR (1982) published an inventory of instream flow requirements for streams throughout the state, including several distributed across the Policy area. For the purposes of deriving an MBF alternative, the flows listed in DWR (1982) for the winter period were assumed to be intended to protect steelhead and salmon spawning. The magnitudes of the flow requirements were generally lower than the other flow recommendations reviewed for a given stream size. Consequently, it was presumed that the numbers represented characteristic negotiated instream flow levels that serve to balance instream flow needs of fish with other water uses.

The various flow recommendations identified above are compared in Figure E-5, scaled by mean annual flow and plotted against drainage area. The data in Figure E-5 generally plot within the same scatter as the data depicted for steelhead and coho in Figure E-4, albeit within the lower range of the overall data scatter. Most of the data in Figure E-5 indicate a general trend of decreasing proportions of mean annual flow needed for spawning, with increasing channel size. It is interesting that the studies reviewed by the State Water Board (SWRCB 1997) do not, but the reason is unclear.

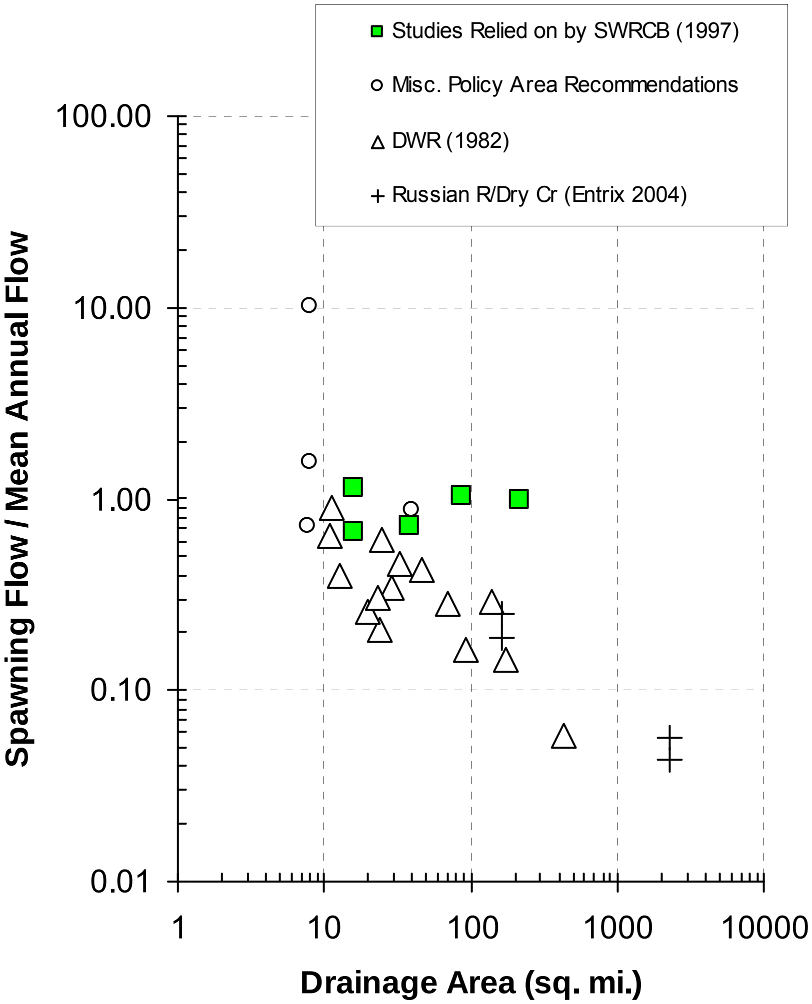

Figure E-5. Comparison of minimum instream flow recommendations for anadromous salmonid spawning in streams in the Policy area, distinguished by drainage area. The spawning flow is scaled by the approximate unimpaired mean annual flow.

Vadas (2000) reviewed various studies of instream flow needs of steelhead and coho in streams located north and south of the Bay Area, including those reviewed by the State Water Board (SWRCB 1997) and DFG-NMFS (2002). Comparable studies from northern California and Washington State were also reviewed. In general, upstream passage flow needs appeared to be similar for steelhead and coho, but steelhead had higher instream flow needs for spawning. Vadas (2000) proposed that the differences reflected general body size, with the smaller coho spawning in shallower, slower habitats. Vadas (2000) also determined that upstream migration and spawning required more water than rearing life stages in California and elsewhere. Optimal instream flow needs were determined to be around 14% to 49% of the mean annual flow for rearing and fry life stages, and 80% to 114% of the mean annual flow for spawning.

E.2.3 Comparison of Validation Site Spawning Flow Requirements With Previous Studies

As described in Appendix G, hydraulic and habitat data were collected in 2006 from 13 validation sites in the Policy area representing drainage areas from around 15 mi^2 and smaller. These data were analyzed for habitat suitability as a function of flow; see Appendix H for respective habitat-flow curves. The validation site results for the smallest flow maximizing spawning habitat (see Appendix H for more complete description) were compared with spawning flow predictions based on Swift (1976) and Hatfield and Bruce (2000). Results for steelhead are presented in Figure E-6 (the scatter for coho and Chinook plot within the same range and trend as depicted for steelhead).

In general, there is a decreasing trend with increasing drainage basin area seen in Figure E-6. The validation site results generally encompass the other regional-based predictions, and are similar in magnitude. These observations indicated that the validation site habitat-flow analyses could be used to help define the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives, based on spawning habitat requirements.

E.3 DEVELOPMENT OF MINIMUM BYPASS FLOW POLICY ELEMENT ALTERNATIVES PROTECTING SPAWNING HABITAT

The consistent trends seen in the various data sources reviewed above indicate that it should be possible to define Upper MBF (MBF3) and Lower MBF (MBF4) alternatives for protecting spawning habitat while accounting for channel size effects. Envelope curves were determined for each alternative level of protectiveness by first developing least-squares regressions through data points considered most representative of the respective alternative's basis, and then shifting each regression equation prediction upwards by 3 standard errors about the regression constant. This procedure results in an approximate 99% prediction limit (Neter et al. 1983). Data points used to represent each alternative, Upper MBF (MBF3) and Lower MBF (MBF4) are listed in Table E-1. Data from SWRCB (1997) were not used because (i) they were derived in a different manner from the Swift and validation site data and (ii) did not follow the

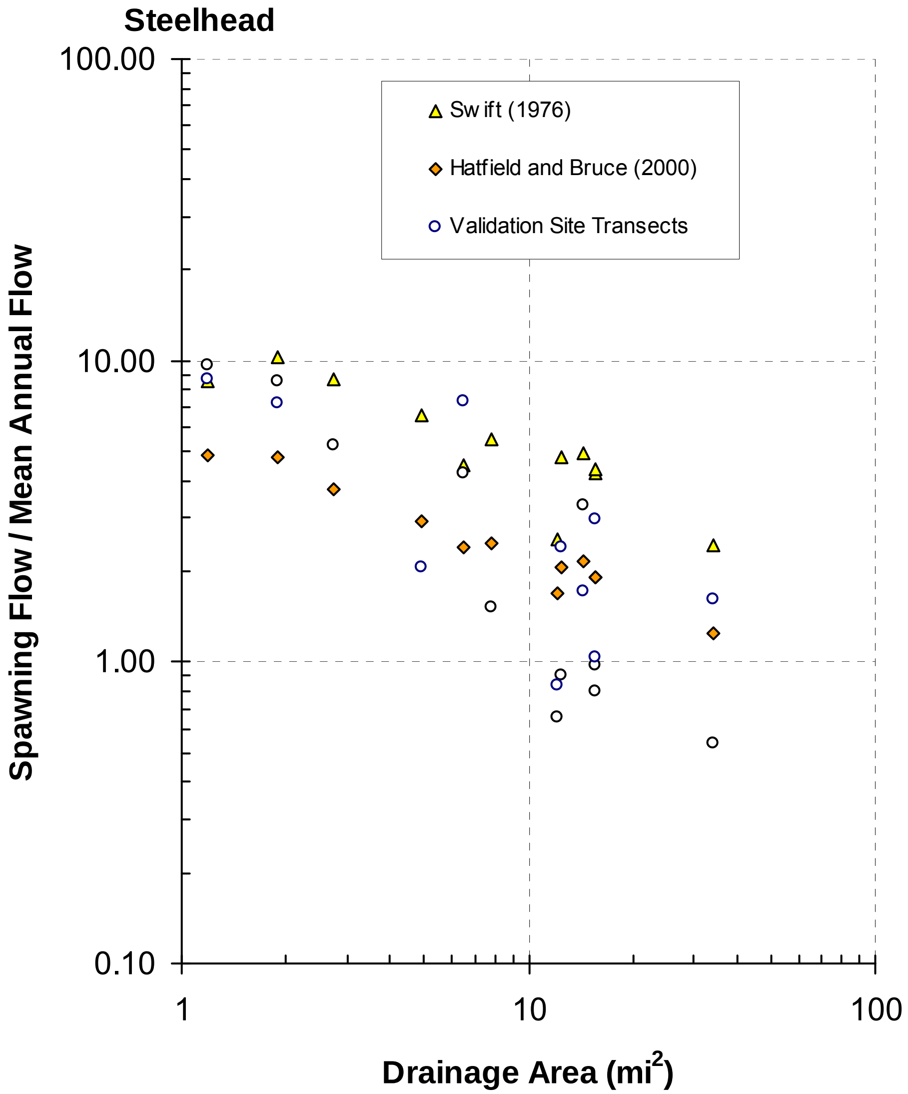

Figure E-6. Comparison of minimum instream flow recommendations for steelhead spawning in Policy area streams sampled in 2006 with predictions based on other regional studies, distinguished by drainage area. The spawning flow is scaled by the approximate unimpaired mean annual flow.

same decreasing trend with stream size seen in the other data used to generate the MBF4 line. The Idaho data were not used because the steelhead habitat suitability index curve for depth that was used there to calculate spawning habitat-flow curves was set identical to the curve for Chinook salmon, whereas in the Policy area, steelhead appear to use slightly shallower depths (see Table G-7 in Appendix G).

Table E-1. Source Data Used to Develop MBF Alternatives

Source	Description	MBF Alternative
Swift (1976)	Flow which provided the maximum spawning habitat availability, above which no further increase of habitat is provided	Upper MBF
Validation Sites 2006	Flow which provided the maximum spawning habitat availability, above which no further increase of habitat is provided	Upper MBF
DWR (1982)	Negotiated minimum instream flow requirements in the Policy area	Lower MBF
Kelley (1976), Anderson (1978) and Snider (1984)	Minimum spawning flow recommendations	Lower MBF
Entrix (2004)	The lowest anecdotal spawning flow for steelhead in Dry Creek below Warm Springs Dam	
Validation Sites 2006	Flow which provided the marginally useable spawning habitat conditions, below which no habitat is available	Lower MBF

E.3.1 Basing the MBF Criterion on Steelhead Habitat Needs

At the site-specific level, protectiveness reflects the species that are or might be present, which potentially introduces a layer of complexity to the development of Policy elements depending on the site in question. The three anadromous species of concern in the Policy area have slightly different spawning habitat requirements, and may also differ in their spatial distribution. Chinook, for example, tend to spawn lower in the drainage network than coho in systems where both occur. In contrast, steelhead that use the same streams as coho and Chinook, generally migrate farther upstream than coho (Shapovalov and Taft 1954). Nevertheless, the instream flow needs of steelhead tend to overlap the other two species' (Figures E-3, E-4). Indeed, based on the similarity of habitat suitability criteria between steelhead and Chinook, providing suitable spawning flows for steelhead should also provide spawning habitat for Chinook. Likewise, the provision of suitable flows for steelhead should also be protective of coho spawning, since coho suitability criteria would result in lower flows.

As a result, steelhead were selected and used as the "indicator species" for development of MBF alternatives and for later evaluation of the protectiveness of flow-related elements relative to spawning habitat for all three target anadromous salmonid species.

E.3.2 Development of the Upper MBF Alternative

The Upper MBF alternative was developed based on the spawning flow data of Swift (1976) and the spawning flows derived for the 2006 validation sites. Both sets of data represented the lowest flow at which maximum spawning habitat availability occurred for steelhead (Figure E-7), but were based on slightly different depth suitability criteria. The validation site data were based on a minimum suitable depth criterion of 0.8 ft (Table G-7 in Appendix G), whereas the data of Swift (1976) were based on a depth criterion equal to 0.7 ft. An initial sensitivity analysis of the validation site data indicated that there were negligible differences across sites for the optimum flows represented, whether a minimum depth criterion of 0.8 ft or 0.6 ft was used. As a result, the Swift (1976) data were combined with the validation data results based on the minimum depth criterion of 0.8 ft selected for the Policy area (see Appendix G) to develop a regional relation, with the Swift (1976) data representing more of the larger drainage area streams, and the validation data representing smaller drainage area streams.

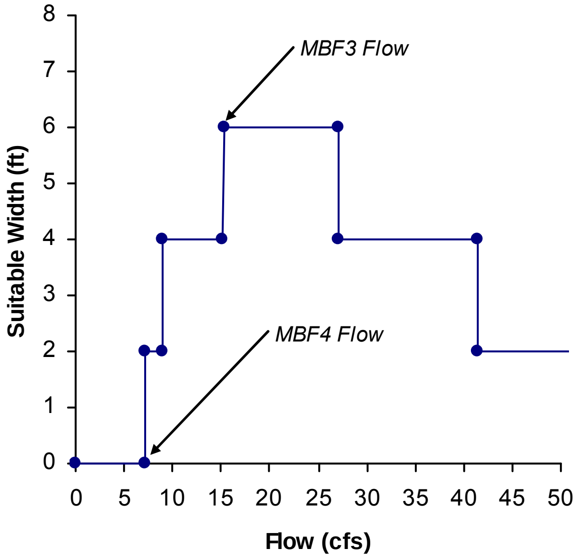

Figure E-7. Depiction of flows used in the development of the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives, as derived from validation site spawning habitat-flow curves shown in Appendix H.

The data sets were used in a least squares, log-linear least squares regression analysis to develop an equation for MBF (Q_{MBF}; cfs) based on drainage area (DA; mi^2). The equation was developed by first taking the estimated Q_{MBF} for each site and dividing it by the estimated mean annual flow (Q_m) for each site. Drainage area was reported by Swift (1976) and by the USGS for the respective validation site gages. The Q_{MBF} was then divided by Q_m and the log of Q_{MBF} /

Q_m and the log of DA for each site used in a regression analysis of all data points to develop the following linear equation:

$$\mathrm{Log}\ (Q_{MBF} / Q_m) = -0.4837(\mathrm{Log\ DA}) + 0.7870 \qquad (E.8a)$$

Since this mean regression line would only protect roughly half of the stream sites in the data set, the log-regression intercept estimate (0.7870) was adjusted upwards by 3 standard errors of regression (3 x 0.0619) above the coefficient estimate to generate an approximate 99% prediction interval for the intercept (Neter et al. 1983). This procedure produced a log-linear equation that shifted the regression line upward among or above most of the data points. The equation should therefore be conservatively protective of the majority of the stream sites used in the analysis. Solving the shifted linear equation for Q_{MBF} and rounding coefficients to 2 significant figures yields the following equation:

$$Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48} \qquad (E.8b)$$

This equation represents a suggested MBF for the Upper MBF (MBF3) alternative for protecting spawning habitat and is plotted in Figure E-8 with the respective data used. The MBF3 line would protect most of the streams analyzed using the depth and velocity criteria developed in Appendix G. Data points above the line are not substantially higher, and the “within-site” errors would likely extend the confidence intervals about the points to below the regression line of Equation (E.8) (cf. Williams 1996). In addition, the validation site transects were generally placed over locations with high quality spawning gravels that had shallower depths, compared to other spawning locations in pool tail regions. Thus, the recommended flow threshold indicated by Equation (E.8) can be considered as conservatively protective of the deeper spawning locations in these streams.

E.3.2.1 Lower and Upper Drainage Area Limits When Applying the Upper MBF Regression Equation

It is important to note that the confidence in regression-based predictions decreases when the relation is used to predict new observations using independent variable data that fall outside the range of the original data set (Neter et al. 1983). Thus, it is important to define the size range of drainage areas for which the Upper MBF (MBF3) equation (Equation E.8) can reasonably be applied.

To estimate the lower limit of drainage area, the stream-by-stream designation of steelhead critical habitat in the Policy was analyzed using the ESRI ArcInfo Geographic Information System (GIS) to determine the drainage areas at the upper extent of critical habitat. A total of 675 drainage basins were identified above the upstream limits to critical habitat. Figure E-9

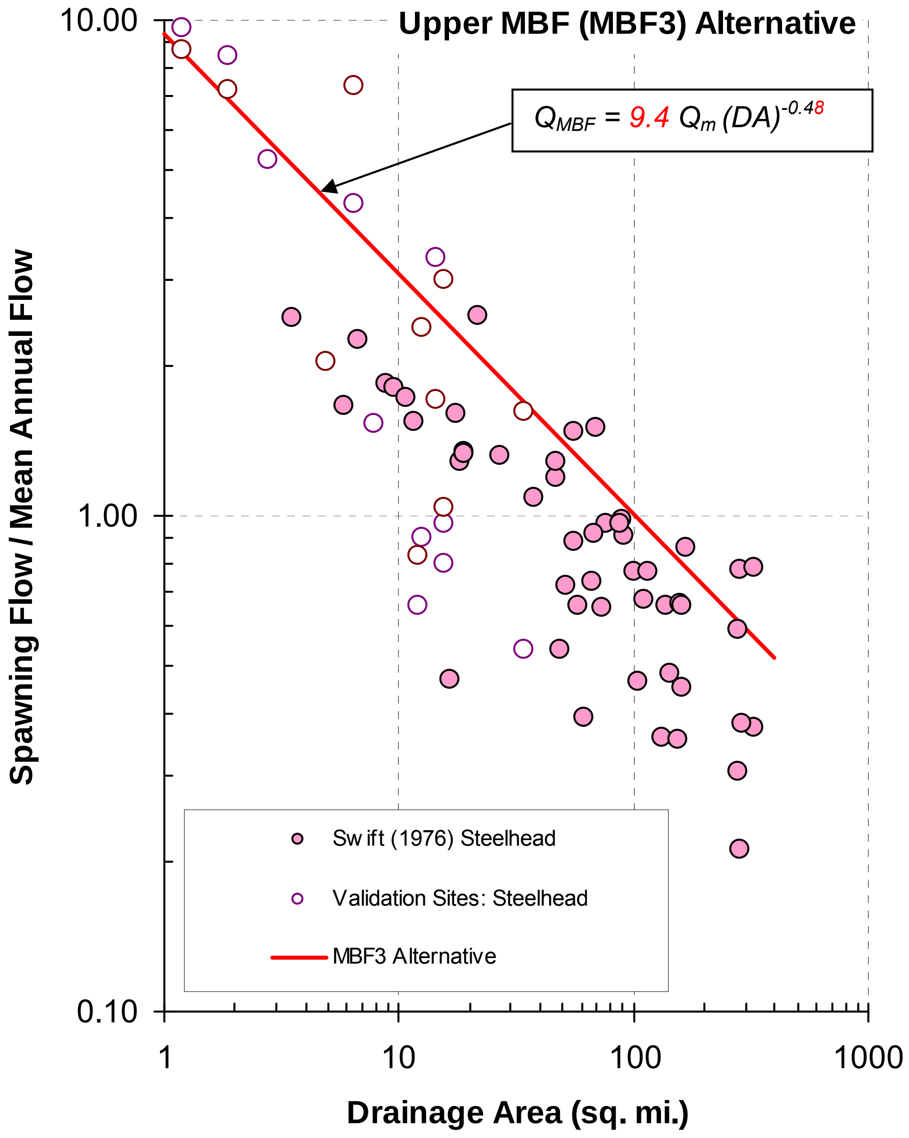

Figure E-8. Upper MBF (MBF3) alternative regression line plotted with the spawning habitat-flow regression data.

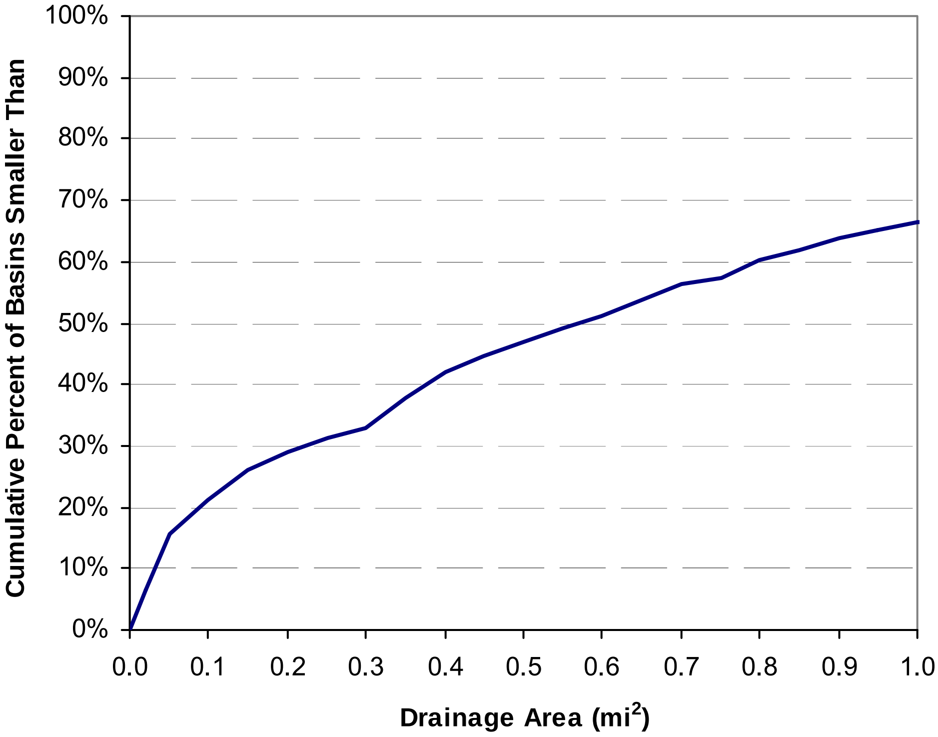

Figure E-9. Percent of headwater basins upstream of steelhead critical habitat in the Policy area with drainage areas smaller than a specified value. For example, roughly half of the delineated headwater basins have a drainage area smaller than 0.6 mi^2.

shows the results of this analysis and indicates that approximately 80% of streams in the Policy area with steelhead critical habitat have drainage areas upstream of the limit of anadromy that are greater than 0.1 mi^2.

Based on the inverse relationship depicted in Figure E-8, which indicates that proportionally more water is needed to meet the protectiveness level as drainage size decreases, there would be no need to apply a regression equation derived for anadromous spawning habitat to non-anadromous habitat in even smaller drainage basins. Doing so would require even more water to be kept instream than is needed to maintain downstream spawning habitats. This suggests that the MBF in non-anadromous habitat should be limited to the flow that meets the MBF requirement for a stream at its upstream point of anadromy. Assuming that the upstream limit of steelhead habitat is known or can be determined for a specific stream, then it should be possible to estimate the required MBF that preserves the regression estimate for that upstream limit. The magnitude of the required flow can be approximated by assuming that the mean annual flow and MBF magnitudes in small basins change proportionally with drainage basin area; i.e., that flow is proportional to $(DA)^b$. Hence, the ratio of MBF in non-anadromous habitat (Q_{MBF-1}) to the MBF at the upstream extent of steelhead habitat in the same channel network (Q_{MBF-2}), would be:

$$\frac{Q_{MBF-1}}{Q_{MBF-2}} = \left(\frac{DA_1}{DA_2}\right)^b \qquad \text{(E.9)}$$

Vogel et al. (1999) estimated an exponent value of 1.1 for the mean annual flow in all of California and parts of western Nevada and southeastern Oregon. However, this estimate was based on a large number of streams that are drier than those found in the Policy area. By comparison, the exponent for Oregon and Washington was around 0.75 (Vogel et al. 1999). It is thus likely that the exponent for mean annual flow in the Policy area is less than or equal to 1.0. The assumption that changes in mean annual flow and MBF in small basins occur in proportion to drainage basin area appears reasonable.

Based on this assumption, it can be shown algebraically using Equations (E.8) and (E.9) that the corresponding MBF limit at any point upstream of steelhead habitat should be approximately equal to $9.4(DA_2)^{-0.48}$ times the local estimated mean annual flow, where DA_2 is the area at the upstream limit of steelhead habitat for the stream in question.

With respect to an upper drainage area limit, extrapolation of Equation (E.8) in large streams would result in recommending low flows relative to mean annual flow. The scatter of the Idaho data in particular, which has better representation of large drainage areas, suggests that the decreasing relation between the MBF/mean annual flow ratio and drainage area is not clearly defined for streams in large drainage areas. In the absence of additional information, it appears reasonable to apply the $0.6Q_m$ level that was originally proposed by the SWRCB (1997) as a lower limit to the MBF in large streams. The $0.6Q_m$ level was based on analyses described by SWRCB (1997), including the observation of other regional criteria of around 60-70% of the mean annual flow, and a review of habitat-flow data suggesting this approximate level for use during dry years. Concern that the $0.6Q_m$ level would not protect small to moderate size drainage basins is not relevant, as smaller basins would be subject to the higher MBF requirements of Equation (E.8). The drainage size marking the transition from the use of Equation (E.8) to application of the $0.6Q_m$ level can be determined by matching the drainage area at which the regression relation predicts the same flow; this occurs at about 295 mi^2.

E.3.3 Development of the Lower MBF Alternative

The Lower MBF (MBF4) alternative was developed to allow for water usage up to a level above which additional diversion would substantially reduce spawning habitat availability. For this, a regression analysis was completed similar to that applied in developing the Upper MBF alternative. The data used in the analysis were extracted from a summary of negotiated instream flow requirements in the Policy area listed in DWR (1982), the recommendations of Kelley (1976) and Anderson (1978), and the lowest anecdotal spawning flow for steelhead in Dry Creek below Warm Springs Dam (Entrix 2004). In addition, the 2006 validation site habitat-flow data summarized in Appendix H were used to estimate minimum spawning flows. These flows, defined as representing marginally useable spawning habitat conditions, were identified as those below which spawning habitat in the pool tail, near the riffle crest, and in runs were no longer available for steelhead and coho (Figure E-7). Validation site results were considered for both species because the majority of the identified negotiated flow recommendations were applied to spawning periods more characteristic of coho and steelhead. The resulting estimates of minimum spawning flow needs for the validation sites plotted along the same scatter trend as the other data (Figure E-10). The overall consistency of the data scatter about a declining trend line suggested that the collective data were suitable for developing the Lower MBF alternative.

The same analytical process used for the Upper MBF was applied in developing the Lower MBF alternative. This resulted in the following least squares, log-linear regression equation which is analogous to Equation (E.8):

$$Q_{MBF} = 5.4\, Q_m\, (DA)^{-0.73} \qquad \text{(E.10)}$$

The 5.4 coefficient corresponds to approximately the upper 99% confidence limit of the least squares estimate of the log-linear regression intercept. This Lower MBF (MBF4) alternative is indicated by the thick envelope line in Figure E-10.

E.3.3.1 Lower and Upper Drainage Area Limits When Applying the Lower MBF Regression Equation

The Lower MBF (MBF4) regression was constrained at the lower range, because it crossed the Upper MBF (MBF3) regression at a drainage area of about 0.10 mi^2. Therefore, for purposes of evaluating protectiveness in streams in smaller drainage areas, the MBF4 alternative was assumed to be the same as for the MBF3 alternative.

The same logic used for specifying a MBF upstream of steelhead habitat as part of the MBF3, applies to the MBF4 (see Section E.3.2). Thus, it can be shown algebraically using Equations (E.10) and (E.9) that the corresponding MBF limit at any point upstream of steelhead habitat should be approximately equal to $5.4(DA_2)^{-0.73}$ times the local estimated mean annual flow at any point upstream of the habitat, where DA_2 is the area at the upstream limit of steelhead habitat for the stream in question.

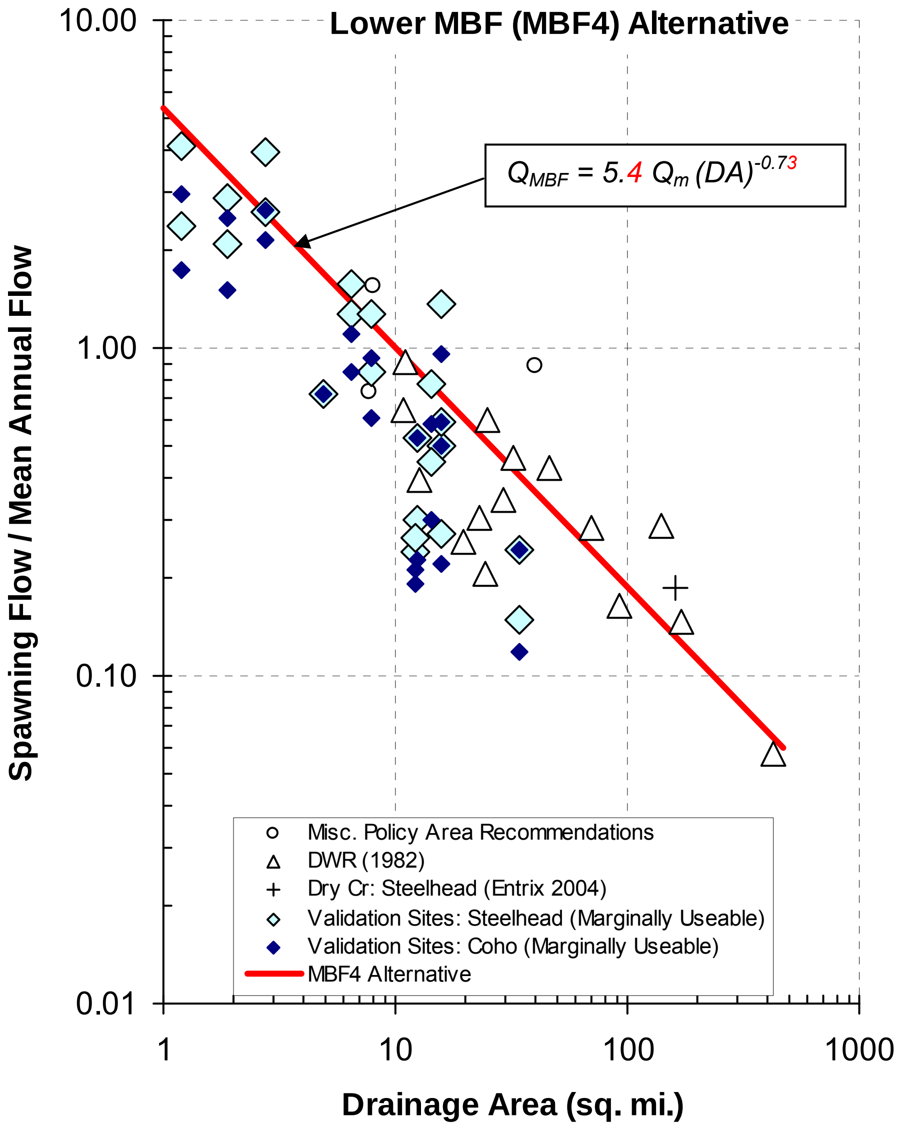

Figure E-10. Lower MBF (MBF4) alternative regression line plotted with the spawning habitat-flow regression data.

With respect to streams in large drainage areas, the lower leg of the MBF4 line was based on the minimum spawning flows reported by Entrix (2004) for the Russian River that were similar in magnitude to the largest drainage area data point from DWR (1982) in Figure E-5. These flows were found to be equivalent to approximately 0.06 times the mean annual flow. The change point in drainage area size occurs where the MBF4 regression predicts this flow to occur, or at about 473 mi^2.

E.4 COMPARISON OF UPPER MBF AND LOWER MBF ALTERNATIVES WITH ALL DATA AND UPSTREAM PASSAGE FLOW REQUIREMENTS

Figure E-11 depicts the Upper MBF (MBF3) and Lower MBF (MBF4) alternatives with the collective spawning flow data compiled from other studies. The two relationships envelope most of the data for steelhead and coho and appear suitable for evaluation as alternatives defining a full range of protectiveness levels.

The MBF3 alternative is based on steelhead instream flow requirements that should also provide for Chinook spawning habitat in deeper water areas with suitable substrates and velocities, which appear to be the more critical parameters defining spawning site selection and success (DeVries 1997). There are a small number of tributaries to the Russian River that also provide critical habitat for Chinook, specifically including lower Austin Creek, lower Mark West Creek, Feliz Creek near Hopland, Mill Creek near Redwood Valley, and the upper Russian River above the East Fork Russian River. Chinook spawning habitat would also likely be protected in these streams by using the MBF3 alternative based on steelhead spawning criteria. It is anticipated that Chinook spawning habitat in the mainstem Russian River and Dry Creek will be mostly protected by flow releases from Warm Springs and Coyote Valley dams (Entrix 2002, 2004).

The magnitude of the MBF3 criterion for spawning appears sufficient to also ensure upstream passage in most cases, as indicated in Figure E-12. Albeit not under ideal passage conditions, the MBF3 alternative for spawning habitat recommends flows that generally still provide for steelhead and coho passage in small streams, and Chinook passage in large streams, which is consistent with their general distributions in the Policy area. This can be seen by comparing the MBF lines with minimum reported passage depth criteria for these three species which are, respectively: 0.5 ft, 0.33 ft, and 0.75 ft (Table G-3 in Appendix G). Even the MBF4 alternative is predicted to result in flows providing minimum passage depths of 0.5 ft for steelhead in riffles, and thus should also be regionally protective of upstream passage (Figure E-12).

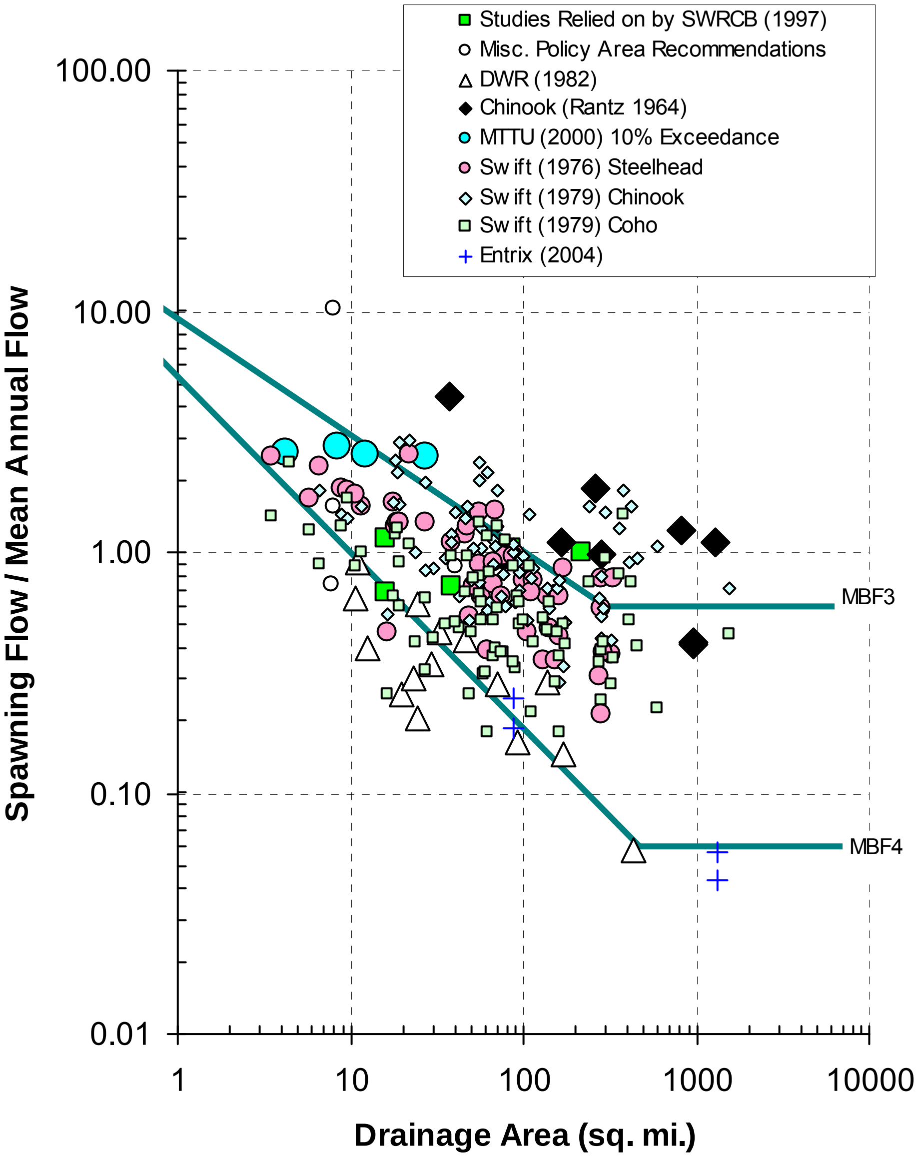

Figure E-11. Upper MBF (MBF3) and Lower MBF (MBF4) alternatives plotted with existing regional and local spawning habitat-flow data.

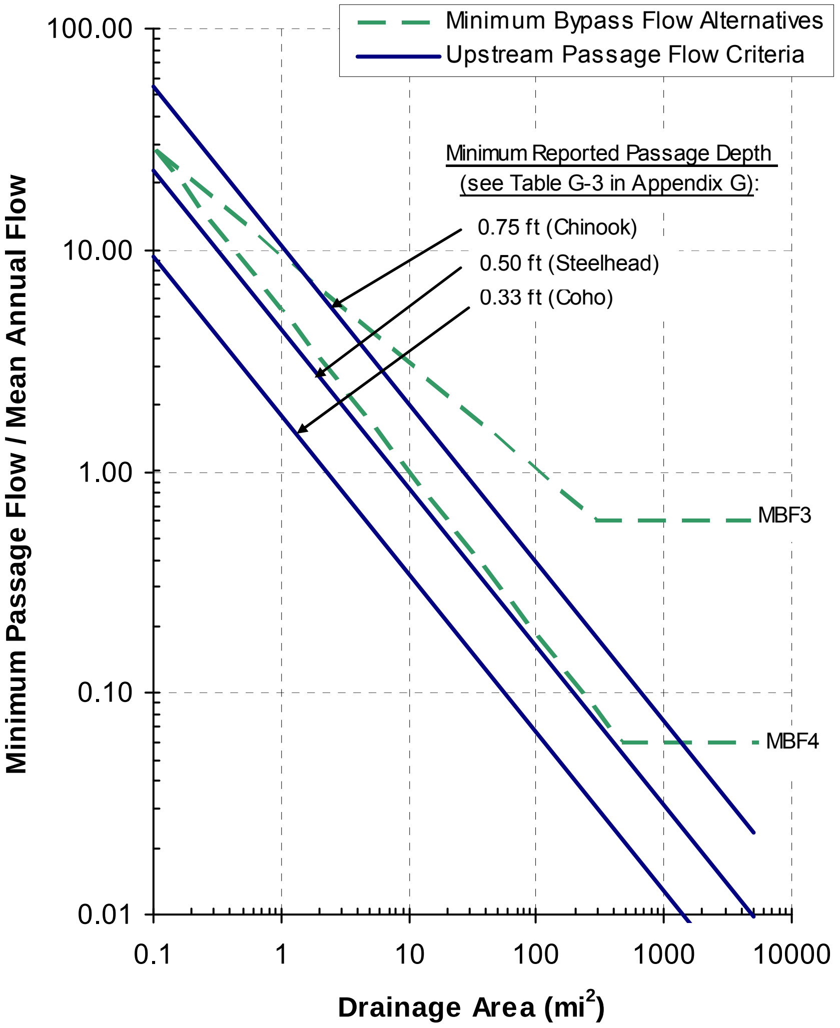

Figure E-12. Comparison of Upper MBF (MBF3; upper dashed line) and Lower MBF (MBF4; lower dashed line) alternatives with upstream passage flow criteria resulting from Equation (E.1) in streams where anadromous salmonids are present. Lines corresponding to specific minimum passage depth (MPD) criteria are indicated by arrows.

E.5 SUMMARY OF MINIMUM BYPASS FLOW ALTERNATIVES

Based on the above analysis and considerations, the Upper MBF (MBF3) alternative (Q_{MBF}) based on protecting spawning habitat and upstream passage is:

- Basin Area < 295 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$ (E.11)
- Basin Area ≥ 295 mi^2: $Q_{MBF} = 0.6\ Q_m$
- Streams Above Anadromy Limit: $Q_{MBF} = 9.4\ Q_m\ (DA_2)^{-0.48}$

where DA_2 is evaluated at the upper limit of anadromy.

The Lower MBF (MBF4) alternative (Q_{MBF}) based on protecting spawning habitat and upstream passage is:

- Basin Area (DA) < 0.1 mi^2: $Q_{MBF} = 9.4\ Q_m\ (DA)^{-0.48}$
- Basin Area = 0.1-473 mi^2: $Q_{MBF} = 5.4\ Q_m\ (DA)^{-0.73}$ (E.12)
- Basin Area ≥ 473 mi^2: $Q_{MBF} = 0.06\ Q_m$
- Streams Above Anadromy Limit: $Q_{MBF} = 9.4\ Q_m\ (DA_2)^{-0.48}$. where $DA_2 < 0.1$ mi^2
  or $Q_{MBF} = 5.4\ Q_m\ (DA_2)^{-0.73}$. where $DA_2 \geq 0.1$ mi^2

where DA_2 is again evaluated at the upper limit of anadromy.

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APPENDIX F

Hydrologic Analysis of Validation Sites

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APPENDIX F
HYDROLOGIC ANALYSIS OF VALIDATION SITES

F.1 VALIDATION SITES

The purpose of this appendix is to describe the hydrologic analyses that were completed at thirteen validation sites in order to develop recommendations on the North Coast Instream Flow Policy.

F.1.1 Validation Site Locations

The group of l3 validation sites was developed based on criteria described in Appendix G. The thirteen validation sites are listed in Table F-1. Passage and/or spawning transects, longitudinal slope, and pebble counts were measured by R2 Resource Consultants, Inc (R2) and Stetson Engineers Inc. (Stetson) at accessible survey locations as close to the gage as possible. The watershed area for each surveyed location was determined using the ESRI ArcInfo 9.2 Geographic Information System (GIS) as shown in Figure F-1.

F.1.2 Gaged Flows

For all thirteen validation sites, gaged data were available from one of three sources: the US Geological Survey (USGS), Napa County Resource Conservation District (NCRCD), and the National Park Service (NPS).

Gage data is summarized in Table F-1. USGS provided data for 11 gages, NCRCD for two gages, and NPS for one gage. Note that both USGS and NPS have measured stream flow for Pine Creek, but for this analysis, only the NPS data were used.

Periods of record for the sites were between October 1958 and September 2005. The sites' drainage areas range from 0.25 square miles (East Fork Russian River Tributary) to 34.3 square miles (Lagunitas Creek).

F.1.2.1 USGS Gage Data

Stetson obtained USGS data from the National Water Information System (NWIS, 2006) and checked the gaged data for errors and missing data. Provisional data were excluded. Missing data were not filled; however, for the purpose of computing statistics, any months with missing data were not included.

F.1.2.2 NCRCD Gage Data

NCRCD data were received as raw 15-minute measurements (NCRCD, 2006). The data were processed into daily average flows. For brief periods (i.e., < 5 days) of missing measurements, data were interpolated. For longer periods of missing data, no correction was made. Generally, NCRCD made continuous measurements in the winter period, but not in the summer period when flows were low or zero. For the purpose of computing statistics, any months with missing data were not included.

Table F-1. Gage Records for Validation Sites.

Gage ID	**Agency**	**Description**	**County**	**Drainage Area (mi^2)**	**Daily Stream Flow Begin Date**	**Daily Stream Flow End Date**
11468010[1]	USGS	Albion River near Comptche	Mendocino	14.4	8/1/1961	10/13/1969
CAS[2]	NCRCD	Carneros Creek at Sattui	Napa	2.75	11/30/2004	5/24/2006
11464050	USGS	Dry Creek Tributary near Hopland	Mendocino	1.19	10/1/1967	9/30/1969
11468850	USGS	Dunn Creek near Rockport	Mendocino	1.88	9/1/1961	9/30/1964
11461400	USGS	EF Russian River Tributary near Potter Valley	Mendocino	0.25	10/1/1958	9/30/1961
11463940	USGS	Franz Creek near Kellogg	Sonoma	15.7	10/1/1963	9/30/1968
HRV	NCRCD	Huichica Creek	Napa	6.11[5]	10/1/2002	9/30/2005
11460400	USGS	Lagunitas Creek at SP Taylor State Park	Marin	34.3	12/21/1982	9/30/2005
Olema[3]	NPS	Olema Creek	Marin	12.6[6]	10/1/1986	4/18/2005
11460170[4]	USGS NPS	Pine Creek at Bolinas	Marin	7.83	6/1/1967 10/1/1998	9/30/1970 9/30/2003
11460920	USGS	Salmon Creek at Bodega	Sonoma	15.7	8/1/1962	10/1/1975
11465800	USGS	Santa Rosa Creek near Santa Rosa	Sonoma	12.5	8/1/1959	10/13/1970
11464860	USGS	Warm Springs Creek near Asti	Sonoma	12.2	8/15/1973	9/30/1983

Notes:

1. The USGS also recorded stream flow at the Albion River gage from 1/31/2001 to 9/30/2003. These data are discontinuous with many periods of missing data and were not used in the analysis.
2. NCRCD has three gaging locations on Carneros Creek. Continuous stream flow records were obtained for gage CAS, CAH (Carneros at Henry Road, drainage area = 5.30 mi^2) and CAO (Carneros at Old Sonoma Road, drainage area = 6.69 mi^2). Field data were measured at the CAS gage and stream flow at this station was used for the hydrologic and habitat analyses.
3. Olema flow records were continuous for the period of record of 1998-2003. Only this continuous period was used for the hydrologic and habitat analyses.
4. Pine Creek data for 10/1/1998-9/30/2003 was used for the hydrologic and habitat analyses.
5. The accessible survey location closest to the Huichica Creek gage was upstream at a drainage area of 4.92 mi^2. Flow at the survey location was estimated by multiplying flow at the gage by the ratio of drainage area (4.92/6.11) and average precipitation (27.897/27.067) of the survey location and gage watersheds.
6. The accessible survey location closest to the Olema Creek gage was upstream at a drainage area of 6.47 mi^2. Flow at the survey location was estimated by multiplying flow at the gage by the ratio of drainage area (6.47/12.6) and average precipitation (36.126/34.938) of the survey location and gage watersheds.

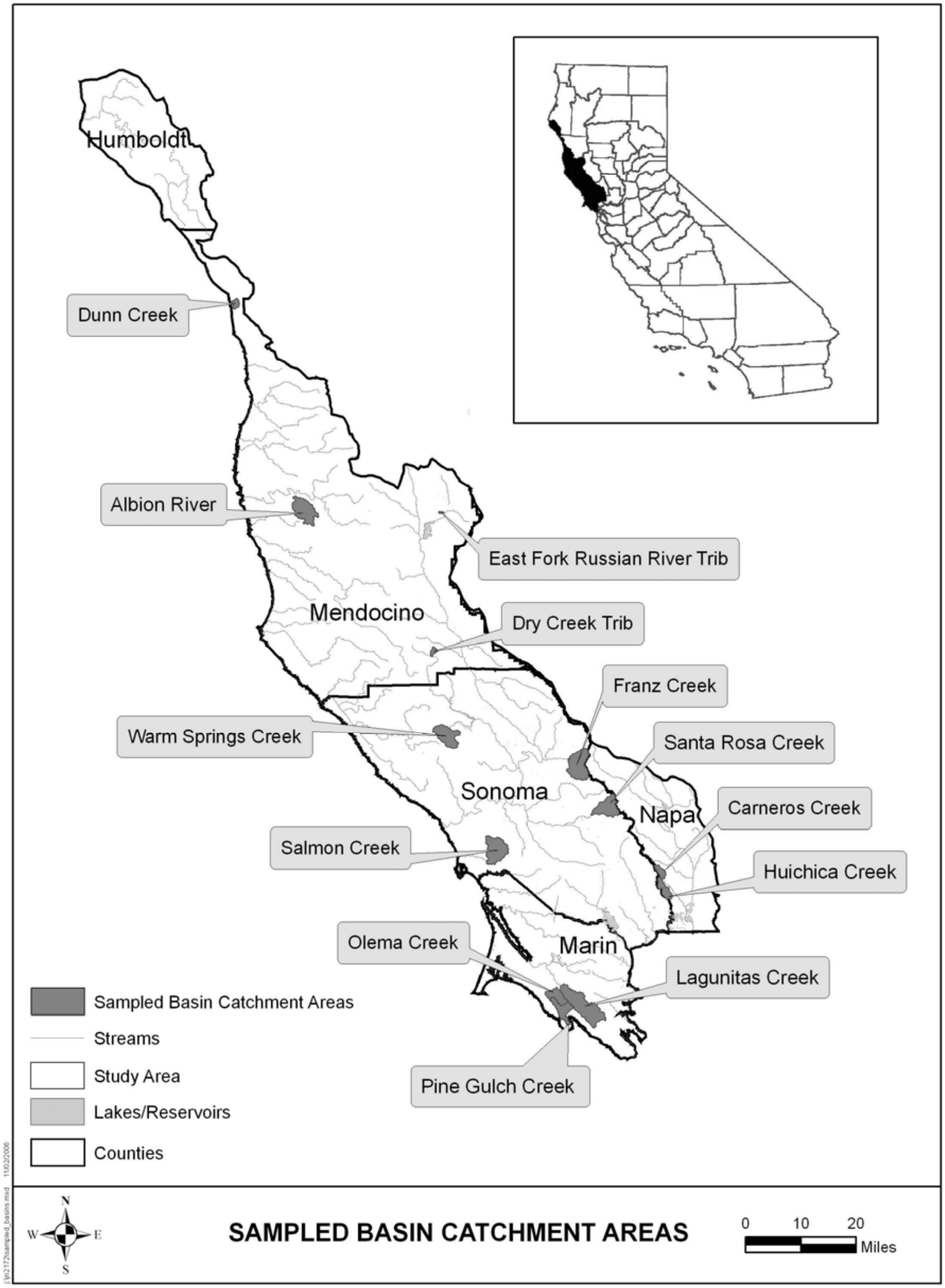

Figure F-1. Locations of validation sites.

F.1.2.3 NPS Gage Data

Stetson obtained NPS gaged data from Brannon Ketcham of Point Reyes National Seashore and Darren Fong of Golden Gate National Recreation Area. Data received were daily average flows. Gaged data were checked for errors and missing data. Missing data were not filled; however, for the purpose of computing statistics, any months with missing data were not included.

F.2 UNIMPAIRED TIME SERIES

Unimpaired flow is the natural flow in a stream without any human alterations to the hydrology; that is, the flow without any diversions or man-made storage. Stetson developed unimpaired flow time series and hydrologic parameters for each validation site.

For the 9 validation sites where permitted diversions and storage regulation during the gaged period of record were not significant (Albion River, Dry Creek Trib, Dunn Creek, EF Russian River Trib, Olema Creek, Pine Creek, Salmon Creek, Santa Rosa Creek, and Warm Springs Creek), gaged flows were used as an estimate of unimpaired flow. Unimpaired flow for one stream (Lagunitas Creek) was previously estimated by Marin Municipal Water District (MMWD) and was used in this study. For the remaining three streams that had significant impairment (Franz, Huichica and Carneros Creeks), Stetson used a hydrologic simulation program to estimate unimpaired flows. For the two validation sites where the survey location was not close to the gage (Huichica and Olema Creeks), the estimated unimpaired flows were multiplied by the ratio of drainage area and average precipitation of the survey location and gage watersheds.

After the unimpaired time series for each validation site were created, Stetson computed hydrologic parameters such as mean annual flow, peak flood magnitude, and flow-duration (exceedance) values. Development of these unimpaired time series and associated hydrologic parameters is described in the sections below.

F.2.1 Estimates of Diversions

The State Water Board stores information on all permitted and pending water rights applications in their Water Rights Information Management System (WRIMS) database.[1] Stetson used this database to determine the level of permitted diversions in the validation sites.

Each water rights application has one or more points of diversion, locations where water may be diverted for direct use or for on-stream or off-stream storage. The applications with points of diversion from the validation site gage watersheds were identified using the GIS. The annual maximum diversion to storage was calculated as the sum of the annual storage[2] for all water

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[1] A copy of the WRIMS database was received from the State Water Board on December 20, 2006

[2] Annual storage is calculated as the lesser of either the maximum storage [MAXIMUM_STORAGE] or the maximum annual use [MAX_USE_ANN].

rights applications in the watershed at the end of the period of flow record (Table F-1).[3] The annual direct diversion was calculated as the sum of the direct diversions less diversions to storage.[4] Where missing, the direct diversion rate was assumed to be 1000 gallons per day and the diversion season was assumed to be the entire year. Estimated maximum annual storage and direct diversion are shown in Table F-2.

F.2.2 Unimpaired Flow Estimated from Gaged Flows

Storage impairment was estimated as the annual storage divided by the annual runoff; total impairment was estimated as the maximum annual total diversions divided by the annual runoff, Table F-2. As observed flows may have already been reduced by as much as the total diversions, annual runoff was estimated as observed flows plus the total diversions.

Sites were considered to be significantly impaired when the when storage impairment was greater than 1% or the total impairment was greater than 5%. Diversions to storage have a greater impact on the hydrograph as they generally occur during a shorter time period which will reduce peak flows. Such peak flows are of importance in the calculation of maximum cumulative diversions. In addition, the full volume of permitted storage is more likely to be diverted, particularly with on-stream water storage, whereas direct diversions may not always be made to the extent of the permit.

Nine of the thirteen validation sites were determined not to have significant impairment during the gaged period of record. The gaged records were used as estimates of the unimpaired flows at these sites.

F.2.3 Lagunitas Creek Unimpaired Flows

The Marin Municipal Water District (MMWD) utilizes water from the Lagunitas Creek watershed as one of its municipal water supply sources. MMWD serves water to approximately 190,000 residents of Marin County. They operate multiple reservoirs within the Lagunitas Creek watershed, the largest of which are Kent Lake and Nicasio Lake. To assist in their facilities operations, MMWD developed a method for estimating daily unimpaired flows on Lagunitas Creek at the S.P. Taylor State Park location (USGS gage location).

Their rainfall runoff model, called ROFF, uses annual and monthly unimpaired volumes, daily rainfall, and antecedent rainfall conditions to estimate daily unimpaired flow. They compared

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[3] Water rights diversions are assumed to begin in the year given in the [YEAR_FIRST_USE] field in the WRIMS database. If this field was not provided by the applicant, diversions are assumed to start when the application was filed as stored in the [APPL_FILE_DATE] field.

[4] Annual direct diversion is calculated as the lesser of either the full direct diversion rate exercised over every day in the diversion, the maximum annual direct diversion [MAX_DD_ANN], or the maximum annual use. If an application has both direct diversion and storage, the annual direct diversion was reduced by the annual storage to represent only the diversions for direct use.

the estimated daily unimpaired flows to the records at the USGS gage and to the flow-duration curve for a nearby similar stream and determined that their model results were consistent with both. MMWD daily unimpaired flows were published for 1955 through 1991 (Roxon, 1992) and were used in this study as the unimpaired flow for Lagunitas Creek.

Table F-2. Estimated Annual Storage and Direct Diversions.

Gage / Validation Site	**Annual Storage (AF)**	**Direct Diversions[1] (cfs)**	**Total Diversions[2] (AF)**	**Annual Runoff[3] (AF)**	**Impairment[4] (% Annual Runoff)**	
					Storage	**Total Diversions**
Albion River Near Comptche	8	0.02	22	14,476	0.1%	0.2%
Carneros Creek at Sattui[6] (CAS)	*38*	*0.00*	*38*	*2,725*	*1.4%*	*1.4%*
Carneros Creek at Henry Rd[5,6] (CAH)	*648*	*0.06*	*691*	*4,757*	*13.6%*	*14.5%*
Carneros Creek at Old Sonoma Bridge[5,6] (CAO)	*1,022*	*4.30*	*4,135*	*8,922*	*11.5%*	*46.3%*
Dry Creek Tributary near Hopland	0	0.00	0	1,590	0.0%	0.0%
Dunn Creek near Rockport	0	0.00	0	1,807	0.0%	0.0%
EF Russian River Tributary near Potter Valley	0	0.00	0	94	0.0%	0.0%
Franz Creek near Kellogg[6]	*300*	*0.85*	*914*	*17,920*	*1.7%*	*5.1%*
Huichica Creek[6]	*929*	*1.51*	*2,020*	*6,724*	*13.8%*	*30.0%*
Lagunitas Creek at SP Taylor State Park[6]	*99,320*	*39.23*	*127,747*	*16,1901*	*61%*	*79%*
Olema Creek	35	0.15	143	18,211	0.2%	0.8%
Pine Creek at Bolinas	0	0.20	145	8,817	0.0%	1.6%
Salmon Creek at Bodega	60	0.66	537	18,604	0.3%	2.9%
Santa Rosa Creek near Santa Rosa	62	0.37	329	14,061	0.4%	2.3%
Warm Springs Creek near Asti	0	0.00	0	25,295	0.0%	0.0%

Notes:

1. Direct Diversions include only diversions for direct use and do not include diversions to storage (Annual Storage).
2. Total Diversions is Annual Storage plus Direct Diversions.
3. Annual Runoff is recorded mean annual flow plus Total Diversions.
4. Storage Impairment is calculated as Annual Storage divided by Annual Runoff; Total Diversions Impairment is Total Diversions divided by Annual Runoff.
5. The lower gages on Carneros Creek (CAH and CAO) were used in the calibration of the HSPF model but were not used in the habitat and spawning analysis.
6. The validation sites where flow was determined to be significantly impaired are italicized.

F.2.4 Simulated Unimpaired Flows

Three validation sites, Carneros, Huichica and Franz Creeks, were significantly impaired during the gaged periods of record. For these sites, unimpaired time series were estimated using Hydrological Simulation Program - Fortran (HSPF) version 12. Model inputs, calibration, and simulation results are described below.

F.2.4.1 HSPF Description

HSPF is a software program (model) that simulates hydrologic processes in land segments and stream channels in response to meteorological conditions. HSPF is available as part of the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software system, available via free download from the US Environmental Protection Agency (EPA, 2006).

The HSPF simulation was run on a daily time step over a continuous period. Model inputs were daily precipitation and evaporation time series and land segment and reach parameters. Model outputs were daily time series of soil moisture and flow. The model setup was calibrated by adjusting parameters for each of the three watersheds to provide the most accurate estimate of natural stream flow (unimpaired flow) when compared to the available gaged stream flow records.

F.2.4.2 Input Data

F.2.4.2.1 Precipitation

Stetson obtained precipitation data from the Western Regional Climate Center (WRCC). All stations used were part of the National Climatic Data Center (NCDC) station network. “Summary of the Day” files, containing daily precipitation, were obtained for all stations in the vicinity of the validation sites. The most representative precipitation station was chosen for each validation site based on proximity, elevation, period of record, and quality of the record of each station. The precipitation station selected for each modeled validation site is listed in Table F-3.

Table F-3. Precipitation Stations Used in Model.

	Precipitation Station	
Modeled Validation Site	**NCDC Station ID**	**Name**
Carneros Creek	048351	Sonoma
Franz Creek	041312	Calistoga
Huichica Creek	048351	Sonoma

Continuous daily precipitation records were generated at each of the required precipitation stations for the period of October 1, 1958 through September 30, 2005. These data were used to simulate flows at the modeled validation sites. Simulation results were only used in the hydrologic and habitat analyses for the period of gaged stream flow record.

Records at Sonoma and Calistoga were both missing approximately 2% of daily entries between October 1, 1958 and September 30, 2005. Records at nearby stations were considered to fill the missing values at each main station. For Sonoma, only one alternative station was required to fill the missing data, while Calistoga required two alternative stations. The two main stations and their alternative stations are listed in Table F-4.

Table F-4. Precipitation Stations Used to Fill Missing Data.

Main Precipitation Stations			**Alternative Stations Used to Fill Missing Data**		
Name	**ID**	**Long-Term Average Precipitation (in)**	**Name**	**ID**	**Long-Term Average Precipitation (in)**
Sonoma	048351	29.85	Napa State Hospital	046074	24.90
Calistoga	041312	38.00	Saint Helena Santa Rosa	047643 047965	35.30 30.55

Missing data were due to two types of errors:

(1) Accumulated errors: Precipitation is not available as daily data but is instead provided as the total precipitation accumulated over a period of days (accumulation period). The Sonoma record contained 12 instances of accumulated errors, while Calistoga contained 8.

The missing period was filled by distributing the accumulated amount over each day in the accumulation period according to the rainfall during the concurrent period at a nearby gage. Table F-5 illustrates how accumulated errors were corrected.

Table F-5. Example of Accumulated Precipitation Error Correction.

Date	**Main Station Precipitation, Raw (in)**	**Alternative Station Precipitation, Raw (in)**	**Main Station Precipitation, Filled (in)**
04/24/63	0	0	0
04/25/63	A	0.40	0.30
04/26/63	0.34	0.05	0.04
04/27/63	0	0	0
04/28/63	0	0	0

From the example raw data in Table F-5, the accumulated period was April 25 and April 26, 1963. On April 25, no precipitation value was reported; on April 26, the value reported was the total accumulated amount that fell on both April 25 and 26. The total accumulated precipitation at the main station is 0.34 inches, while the total for the same period at the alternative station is 0.45 inches. The 0.34 inches at the main station were distributed over the accumulation period according to the daily precipitation distribution at the alternative station: 89% (0.4 in/0.45 in) of the rainfall occurred on 4/25/63, and 11% (0.05 in/0.45 in) occurred on 4/26/63. Accordingly, the estimated daily precipitation at the main station were be 0.30 (89% of 0.34 in) and 0.04 inches (11% of 0.34 in).

In the event that none of the alternative stations had daily precipitation records available or that none of the stations observed rainfall during the accumulation period, the accumulated amount at the main station was distributed equally over the period.

(2) Missing daily values: Daily precipitation values were not reported.

Missing daily values were estimated from the precipitation records at a nearby station. The rainfall amount at the main station was determined using the ratio of the long-term average rainfall at the main station to the long-term average rainfall at the alternative station:

$$P_{main} = P_{alt} \frac{LTA_{main}}{LTA_{alt}}$$

where P_{main} = daily precipitation amount at the main station
P_{alt} = daily precipitation amount at the alternative station
LTA_{main} = long-term average precipitation at the main station
LTA_{alt} = long-term average precipitation at the alternative station

Long-term average precipitation for each station was obtained from the WRCC Climatological Data Summaries for the period of record up to December 31, 2005 (WRCC, 2006), as listed in Table F-4.

After correcting the Sonoma and Calistoga records for accumulated and missing errors, the resulting continuous records for the period October 1, 1958 to September 30, 2005 records were loaded in the HSPF model as inputs.

F.2.4.2.2 Evaporation

Stetson obtained evaporation data from the WRCC (2006) and from the California Irrigation Management Information System (CIMIS) (CIMIS, 2006) and created a continuous daily evaporation record from January 1, 1958 through September 30, 2005 for two stations, Carneros and Windsor. Table F-6 lists the validation sites and their assigned evaporation station. Evaporation stations were assigned to each validation site based on proximity and evapotranspiration zone. Validation site watersheds and evaporation stations were plotted on a map defining 18 different zones of reference evapotranspiration for the state of California (Jones et al, 1999). Land within a zone, for example the “Coastal Plains Heavy Fog Belt” zone, experiences similar levels of evaporation.

Table F-6. Potential Evapotranspiration (PET) Used in Model.

Validation Site	Evaporation Station	ID	Network	Station PET (in)
Carneros Creek	Carneros	109	CIMIS	45.77
Franz Creek	Windsor	103	CIMIS	44.21
Huichica Creek	Carneros	109	CIMIS	45.77

Data obtained from the WRCC were collected from stations in the National Climatic Data Center (NCDC) station network. NCDC evaporation data for some stations in the North Coast region extend back prior to 1958. The earliest CIMIS data were collected in the mid-1980s. Significant gaps in the data were identified at nearly all stations. Records at Carneros and Windsor were missing 89% and 71% of daily entries between October 1, 1958 and September 30, 2005, respectively. The station with the most complete record, Dutton’s Landing, was still missing 60% of daily entries between 1958 and 2005. Because of data gaps, eight or nine alternative stations were required to fill in all the missing data at the main evaporation stations. Alternative stations were assigned to each validation site based on proximity and evaporation zone.

Data errors in the Carneros and Windsor records were due to missing daily values. Unlike the precipitation records, no accumulated errors were reported.

Missing daily values were estimated from the evaporation records at an alternate station. In some cases daily evaporation was available at only one of the eight or nine alternate stations. The evaporation amount at the main station was determined using the ratio of the long-term average evaporation for the month at the main station to the long-term average evaporation for the month at an alternate station:

$$E_{main} = E_{alt} \frac{LTA_{main}}{LTA_{alt}}$$

where E_{main} = daily precipitation amount at the main station
E_{alt} = daily precipitation amount at the alternative station
LTA_{main} = long-term average evaporation at the main station for the month
LTA_{alt} = long-term average evaporation at the alternative station for the month

Long-term average evaporation for each station was obtained from the WRCC Climatological Data Summaries for the period of record up to December 31, 2005 (WRCC, 2006) and from monthly averages reported by CIMIS (CIMIS, 2006).

After filling the Carneros and Windsor records for accumulated and missing errors, the resulting continuous records for the period October 1, 1958 to September 30, 2005 records were loaded in the HSPF model as inputs.

Table F-7. Evaporation Stations Used to Fill Missing Data in Validation Site Evaporation Records.

Main Evaporation Stations			**Alternative Evaporation Stations Used to Fill Missing Data**		
Name	**ID**	**Network**	**Name**	**ID**	**Network**
Carneros	109	CIMIS	Duttons Landing	042580	NOAA/NCDC
			Novato	63	CIMIS
			Point San Pedro	157	CIMIS
			Petaluma East	144	CIMIS
			Grizzly Island Refuge	43650	NOAA/NCDC
			Santa Rosa	83	CIMIS
			Monticello Dam	45818	NOAA/NCDC
			Markley Cove	45360	NOAA/NCDC
			Berryessa Lake	40705	NOAA/NCDC
Windsor	103	CIMIS	Healdsburg	51	CIMIS
			Santa Rosa	83	CIMIS
			Bennett Valley	158	CIMIS
			Warm Springs Dam	049440	NOAA/NCDC
			Oakville	77	CIMIS
			Monticello Dam	045818	NOAA/NCDC
			Markley Cove	045360	NOAA/NCDC
			Berryessa Lake	040705	NOAA/NCDC

F.2.4.2.3 Land Segment and Reach Parameters

In addition to precipitation and evaporation inputs, HSPF requires a description of the watershed. The watershed area is represented as land segments; the stream channels are represented as reaches. Precipitation and evaporation occur on the surface of the land segments, changing the soil moisture conditions on and within the land. The changing soil moisture conditions may result in water leaving the land and entering the reaches (runoff). This runoff moves through the reaches to the watershed outlet.

The stream channels were divided into reaches at each confluence and gaged location. The watershed areas were divided into land segments based on the 1961-1990 mean annual precipitation isohyets (Oregon Climate Service, 1998). A land segment was defined in the GIS at every two-inch precipitation increase. HSPF reaches and land segments are shown in Figure F-2 and Figure F-3. The area of each land segment contributing to each reach was measured in the GIS.

HSPF parameters which describe the land segment are listed in Table F-8; HSPF parameters which describe the reaches are listed in Table F-9. The slope of the land surface, length of reach, and change in elevation over the reach were measured in the GIS. Values noted as 'calibrated' were adjusted during the calibration process until simulated stream flow best matched the gaged records. This is discussed further in the next section.

Each reach also requires input of an FTABLE which gives the reach area, volume and outflow over a range of water depths. The FTABLEs were generated by WinHSPF, a user interface which is provided in the BASINS package. The tables were calculated assuming a trapezoidal cross section and using the reach length, change in elevation, and drainage area (used to estimate mean channel width and mean channel width) measured in the GIS with the default slopes and Manning's *n* provided by WinHSPF.

F.2.4.3 Calibration and Results

During calibration, Stetson adjusted HSPF watershed input parameters to obtain the best possible match between simulated and observed flow. As observed flows were known to be impaired, the total simulated water volume was compared to the observed water volume plus the maximum annual storage and diversion volumes. Simulated and observed hydrograph shapes were compared during seasons when there was likely to be fewer diversions.

The following parameters were varied to calibrate the model:

precipitation multiplier
evaporation multiplier
INFILT
UZSN
LZSN
INTFW
IRC
AGRWC

The USGS has developed a software program, Expert System for Calibration of HSPF (HSPexp), which helps calibrate the watershed parameters. This program compares simulated and observed hydrographs for selected storage and provides expert advice on which parameters should be increased or decreased to improve the calibration. Stetson used the HSPexp program during calibration.

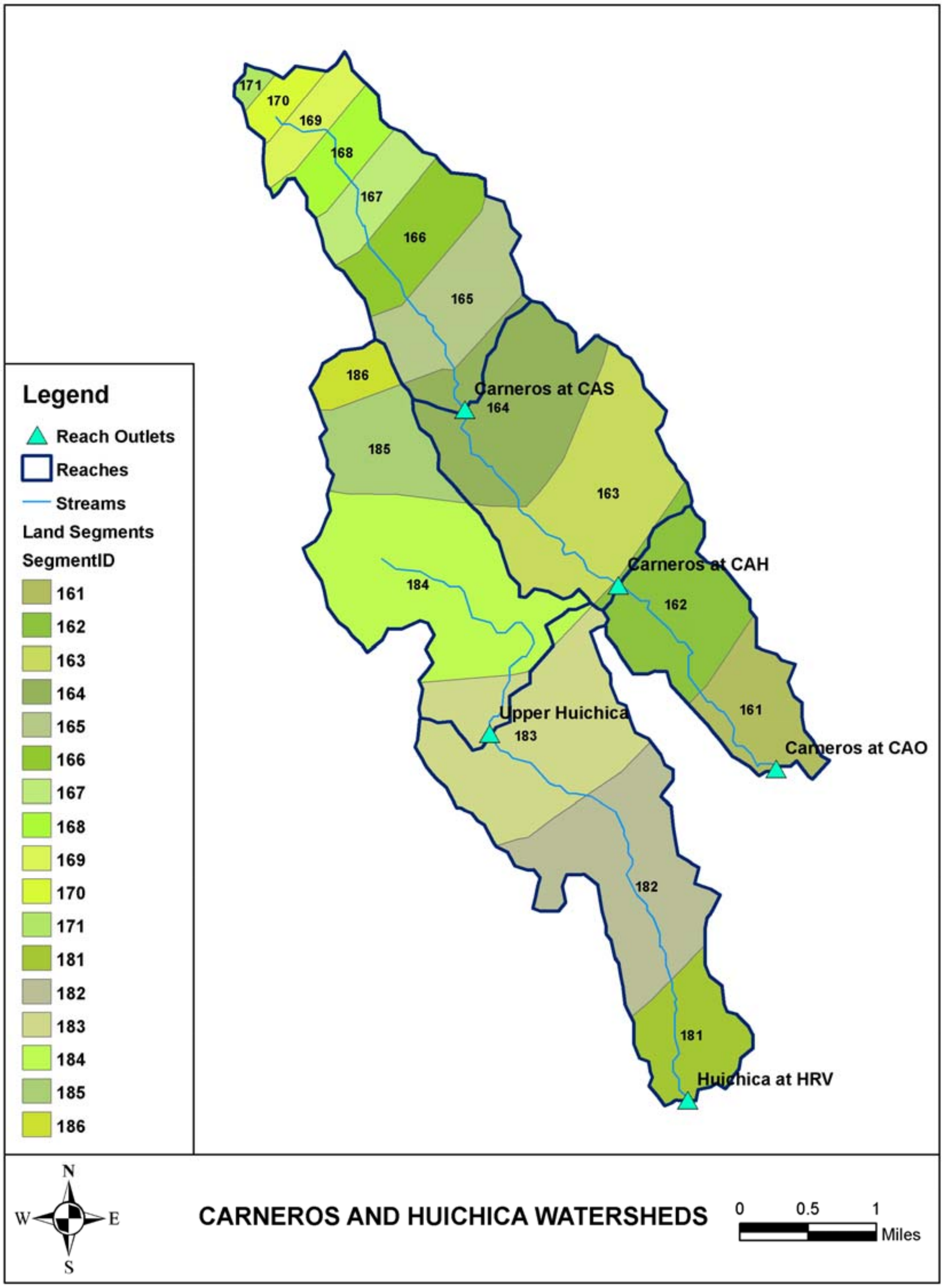

Figure F-2. HSPF reaches and land segments, Carneros and Huichica Watersheds.

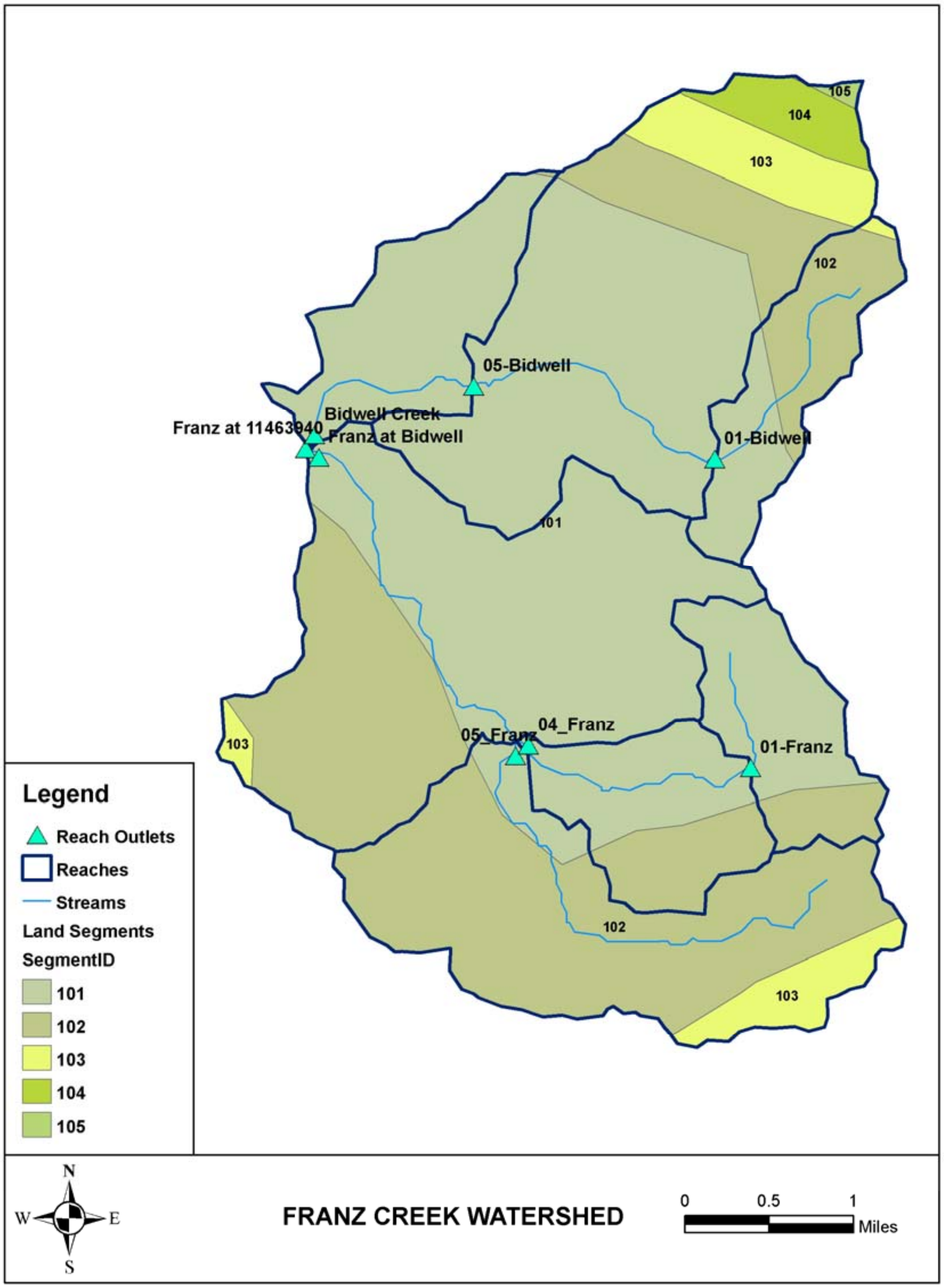

Figure F-3. HSPF reaches and land segments, Franz Creek Watershed.

Table F-8. Land Segment Parameters.

Parameter	Description	Value
AGWETP	fraction of remaining PET which can be satisfied from active groundwater	0
AGWRC	active groundwater recession constant (ratio of active groundwater outflow today to active groundwater outflow yesterday)	calibrated
BASETP	Fraction of remaining PET which can be satisfied from base flow	0
CEPSC	interception storage capacity	0.2 in
DEEPFR	Fraction of groundwater inflow which will enter deep (inactive) groundwater	0
INFEXP	infiltration equation exponent	1.5
INFILD	ratio between the maximum and mean infiltration capacity	2
INFILT	index to the infiltration rate capacity	calibrated
INTFW	interflow inflow parameter	calibrated
IRC	interflow recession parameter (ratio of interflow outflow today to interflow outflow yesterday)	calibrated
KVARY	variability of groundwater recession flow	0
LSUR	length of the assumed overland flow plane	250 ft
LZETP	lower zone evapotranspiration	0.3
LZSN	lower zone nominal storage	calibrated
NSUR	manning’s n for the overland flow plane	0.4
PETMAX	temperature below which potential evapotranspiration (PET) is reduced	40 deg F
PETMIN	minimum temperature when PET occurs, PET is reduced from the input value at PETMAX to 0 at PETMIN	30 deg F
SLSUR	slope of the overland flow plane	GIS
UZSN	upper zone nominal storage	calibrated

Table F-9. Reach Parameters.

Parameter	Description	Value
DB50	Median diameter of the bed sediment	0.01
DELTH	change in water elevation over the length of the reach	GIS
KS	weighting factor for hydraulic routing	0.5
LEN	length of reach	GIS
STCOR	stage correction to calculate stage from depth	0 ft

The first step of calibration was to adjust parameters to get the correct water balance, i.e., until the simulated runoff volume is approximately equal to the observed runoff volume plus the estimated diverted volume. The average precipitation for each land segment was calculated in the GIS as the spatial average of the 1961 – 1990 mean annual precipitation (Oregon Climate Service, 1998). Precipitation inputs to each land segment were multiplied by the ratio of estimated precipitation value on the land segment divided by the long term average at the gage. Land segment evaporation was initially assumed to be the same as the evaporation at the gage. These initial precipitation and evaporation multipliers were adjusted by calibration.

The next step of calibration was to adjust storm volumes and then the hydrograph shape. Storm volumes are affected by the INFILT, UZSN and LZSN which determine how much water enters and is held in the land segments as soil moisture. Hydrograph shape is affected by the INTFW, IRC and AGRWC which determine how quickly water leaves each of the soil moisture storages.

As the observed flows are impaired, the values of the parameters suggested by HSPexp were manually adjusted further to get the best possible fit.

Franz Creek was calibrated to match flows at the USGS gage (11463940). Annual runoff volumes and simulated differences are listed in Table F-10; simulated and observed flows are plotted in Figure F-4.

There were only short periods of observed data at the Carneros Creek at Sattui (CAS) and the Huichica gage and the gage was reported by the NCRCD as being inaccurate at low flows. Simulated and observed flows at the Carneros Creek at Henry Road (CAH) and Old Sonoma Bridge (CAO) were compared to calibrate the watershed parameters. The resulting calibrated parameters were used for both the Carneros and Huichica Creek watersheds.

Annual runoff volumes and simulated differences for Carneros Creek and Huichica Creek are listed in Table F-11; simulated and observed flows are plotted in Figure F-5 and Figure F-6. Simulated flows were higher than observed flows at the beginning of the flow period; this represents the most likely time of diversions to storage.

Table F-10. Comparison of Franz Creek Simulated and Observed Flows

Annual Runoff Volume	**Water Year**					
Water Year	**1964**	**1965**	**1966**	**1967**	**1968**	**Average**
Observed (AF)	5,932	22,445	15,788	27,225	13,616	17,001
Storage (AF)	300	300	300	300	300	300
Direct Diversion (AF)	615	615	615	615	615	615
Minimum Unimpaired[1] (AF)	6,232	22,745	16,088	27,525	13,916	17,301
Maximum Unimpaired[2] (AF)	6,847	23,361	16,704	28,140	14,532	17,917
Simulated (AF)	7,275	23,414	13,272	27,815	15,476	17,451
Minimum Error[3]	**17%**	**3%**	**-18%**	**1%**	**11%**	**1%**
Maximum Error[4]	**6%**	**0%**	**-21%**	**-1%**	**6%**	**-3%**

Notes:

1. Minimum Unimpaired runoff is estimated as the observed runoff volume plus the water rights annual storage.
2. Maximum Unimpaired runoff is estimated as the observed runoff volume plus the water rights annual storage and direct diversions (Table F-2).
3. Minimum error is calculated as the difference between simulated and minimum unimpaired flows divided by the minimum unimpaired flows.
4. Maximum error is calculated as the difference between simulated and maximum unimpaired flows divided by the minimum unimpaired flows.

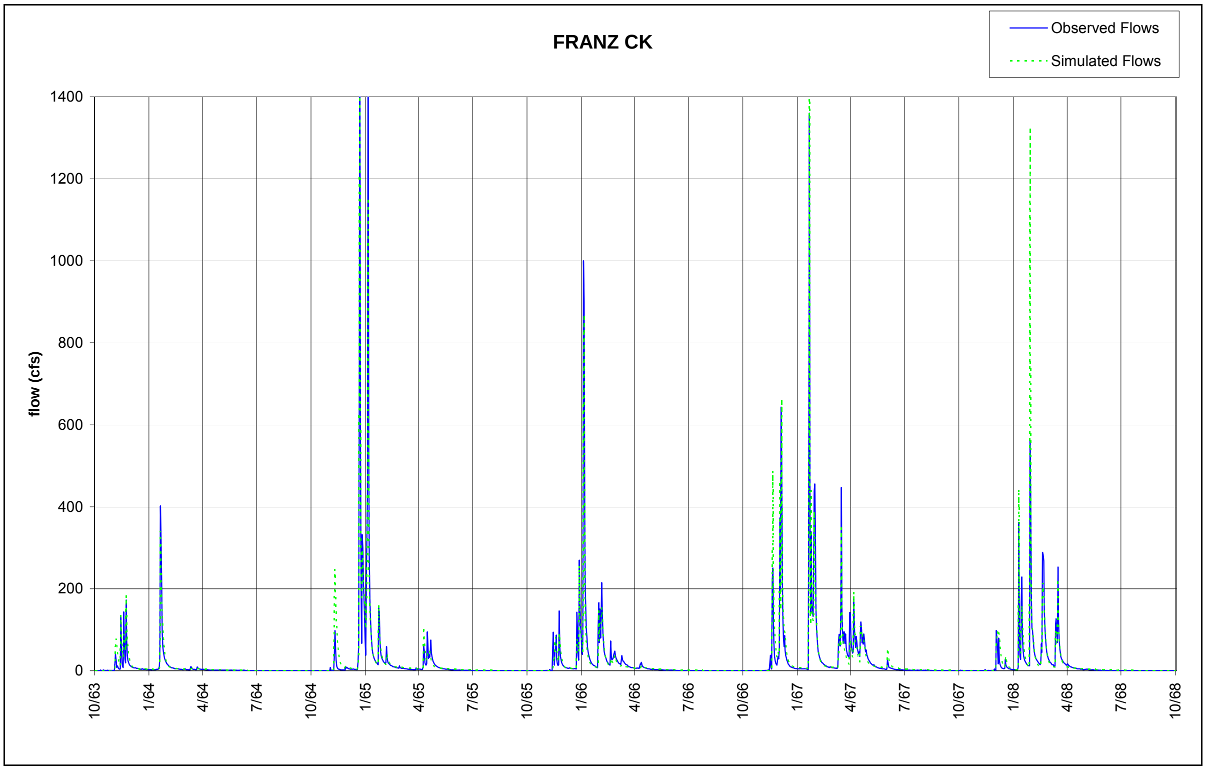

Figure F-4. Franz Creek simulated and observed flows

Table F-11. Comparison of Carneros and Huichica Creeks Simulated and Observed Flows.

Station	**Annual Runoff Volume**	**Water Year**			
		2002	**2003**	**2004**	**2005**
Carneros at Sattui (CAS)	Observed (AF)	n/a	n/a	n/a	2682
	Simulated (AF)				3062
	Differences (% Unimpaired[1])				**13%**
Carneros at Henry Rd (CAH)	Observed	n/a	n/a	n/a	4060
	Simulated				5842
	Differences (% Unimpaired[1])				**23 to 24%**
Carneros at Old Sonoma Bridge (CAO)[2]	Observed	4027	5179	3374	6043
	Simulated	7530	6171	5034	8028
	Differences (% Unimpaired[1])	**-8% to 49%**	**-34% to 0%**	**-33% to 15%**	**-21% to 14%**
Huichica Creek (HRV)	Observed	4330	2575	n/a	n/a
	Simulated	5979	4840		
	Differences (% Unimpaired[1])	**-6% to 14%**	**5% to 38%**		

Notes:

1. Unimpaired runoff is estimated to range from a minimum of the observed runoff volume plus the water rights annual storage to a maximum of the observed runoff volume plus the water rights annual storage and direct diversions (Table F-2). Percent error is calculated as the difference between simulated and unimpaired flows divided by the unimpaired flows.
2. Carneros and Huichica watershed parameters were calibrated at the CAO gage. Precipitation and evaporation multipliers for land segments in the Huichica watershed were adjusted separately to match simulated to estimated unimpaired annual water volumes at the HRV gage.

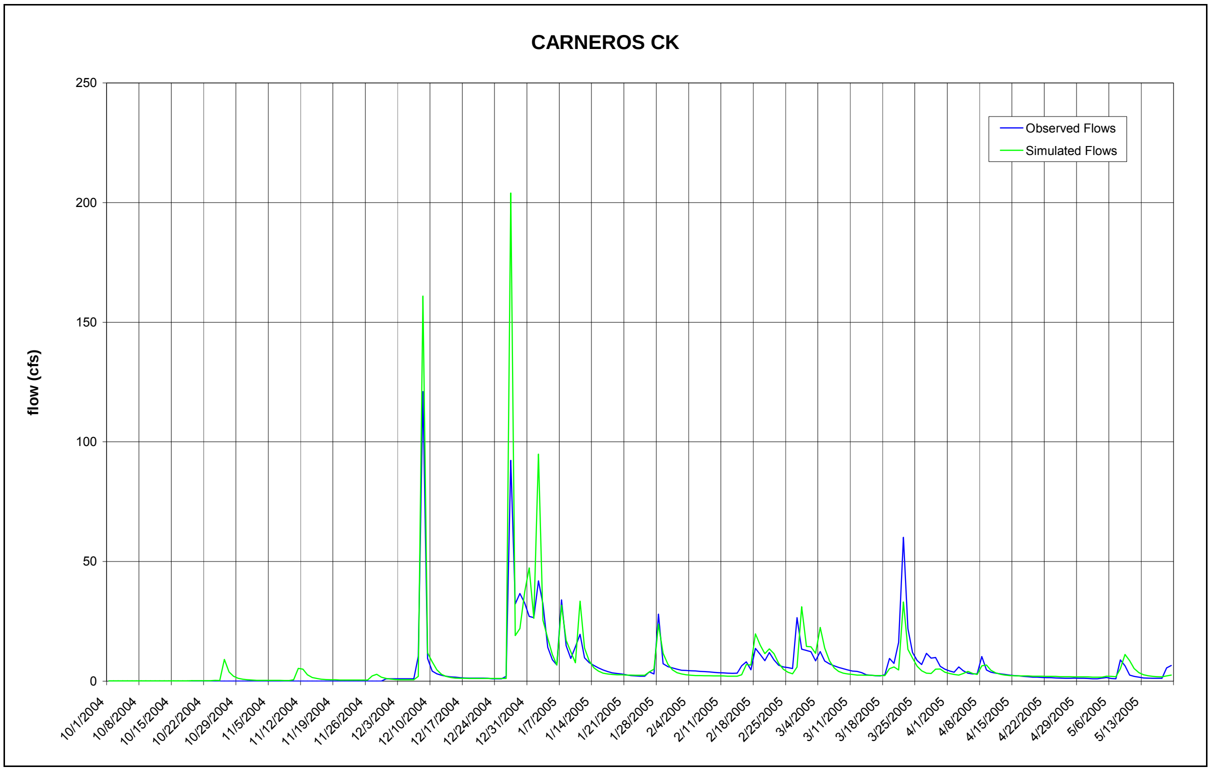

Figure F-5. Carneros Creek (CAS) simulated and observed flows.

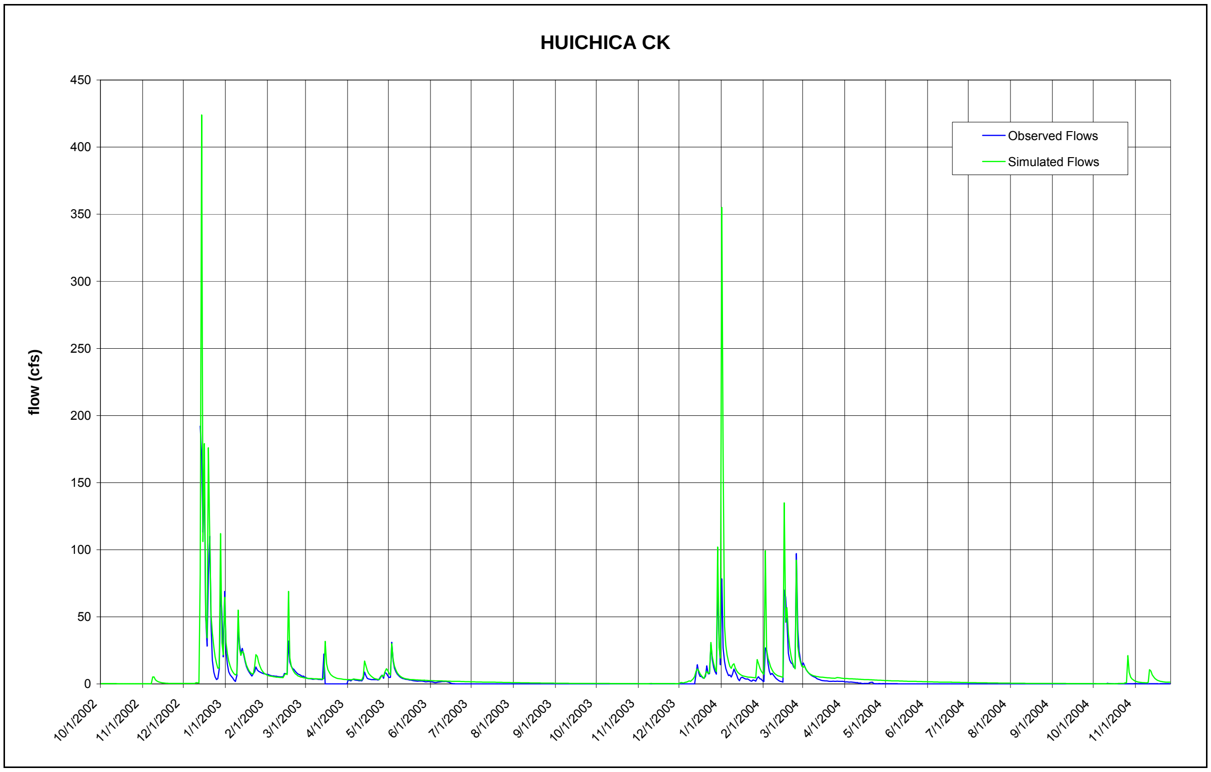

Figure F-6. Huichica Creek simulated and observed flows.

F.2.5 Unimpaired Mean Annual Flow

Unimpaired mean annual flow (Q_m) is one of the parameters used to compute Policy element alternatives for mean bypass flow (MBF3 and MBF4). Stetson computed mean annual unimpaired flow from the unimpaired time series. First, average daily flows in cubic feet per second (cfs) were converted to volumes in acre-feet (AF). Daily flow volumes for each month were then summed together. This summation was only done if the month contained a complete record; that is, any incomplete months were discarded from the unimpaired mean annual flow calculation. In general, USGS data were of high quality and very few months were excluded from statistical calculations. For all USGS gages, there were no gaps in the middle of the periods of record; the only months with missing data occurred at the beginning or end of a period of record when a gage went into or out of service. NPS data were generally of poorer quality than USGS and had months with missing measurements in the middle of continuous records. Simulated flows had no data gaps, so no months were excluded from the statistical analyses.

Annual volumes were computed by summing the monthly volumes for the water year (October through September). An annual total was only computed if all months of the record were complete. Finally, water year annual volumes for complete years only were averaged to obtain an average annual flow volume for the period of record. This quantity was then converted from a volume acre-feet per year to an average flow rate (cfs), resulting in the unimpaired mean annual flow, listed in Table F-12 for each validation site.

Table F-12. Unimpaired Mean Annual Flow for Validation Sites.

Validation Site	**Complete Water Years used to Compute Q_m**	**Unimpaired Mean Annual Flow, Q_m (cfs)**
Albion River near Comptche	8	20
Carneros Creek at Sattui	4	3.8
Dry Creek Tributary near Hopland	2	2.2
Dunn Creek near Rockport	3	2.5
EF Russian River Tributary near Potter Valley	3	0.13
Franz Creek near Kellogg	5	24
Huichica Creek at the survey location	4	7.4
Lagunitas Creek at SP Taylor State Park	37	72
Olema Creek at the survey location	10	13
Pine Creek at Bolinas	4	12
Salmon Creek at Bodega	13	25
Santa Rosa Creek near Santa Rosa	11	19
Warm Springs Creek near Asti	10	35

F.2.6 Unimpaired Instantaneous Flood Frequency

Stetson computed instantaneous peak flood frequency for this study. Instantaneous peak flows are representative of the actual maximum flow rate that would be measured at a single point in time in a stream during a high flow event.

Two of the Policy element alternatives for maximum cumulative diversion (MCD2 and MCD4) are formulated with respect to the instantaneous annual peak unimpaired flow with a return period of 1.5 years. Return period is the inverse of the flood probability: an event with a return period of 1.5 years has a 67% chance of occurring in any one year. The instantaneous 1.5-year peak annual unimpaired flow was estimated for the thirteen validation sites based on available observed data.

Stetson gathered instantaneous flows from existing gage measurements. For USGS gages, instantaneous peak measurements were obtained from the NWIS system (USGS, 2006). For NCRCD gages, 15-minute stream flow measurements were used as estimates of instantaneous measurements. Neither instantaneous nor 15-minute data measurements were available for Lagunitas Creek and Olema Creek. At Carneros, Franz, and Huichica Creeks, the recorded instantaneous peaks are most likely lower than the peaks that would occur in the absence of diversions.

Note that for some USGS gages, the period of record for instantaneous peaks was longer than the period of record for continuous daily stream flow. In these cases, all of the instantaneous peaks were used in the analysis, since having more years increases the accuracy of the flood frequency calculations.

When more than ten years of instantaneous measurements were available, Stetson used methods described in USGS Bulletin 17B (IACWD, 1982) to compute the unimpaired 1.5-year instantaneous peak annual flow. When fewer than ten years were available, Stetson used an alternative method known as the “peaks-over-threshold” method (IACWD, 2002). For many gages, the USGS records all instantaneous peaks above a given threshold each year. The threshold is selected so that approximately three peaks will be recorded in an average year. These are the data used in the peaks-over-threshold method.

The 1.5-year peak flow for the Carneros Creek validation site at the Sattui gage (CAS) was estimated by multiplying the 1.5-year peak flow at the Old Sonoma Road gage (CAO) by the ratio of drainage area and average precipitation. The Huichica survey location was not close to the HRV gage so the 1.5-year peak flow at the gage was multiplied by the ratio of drainage area and average precipitation. The computed unimpaired instantaneous 1.5-year peak flows for each validation site are listed in Table F-13.

Table F-13. Unimpaired Instantaneous 1.5-Year Peak Flood at Validation Sites.

Validation Site	**Unimpaired Instantaneous 1.5-year Peak Flood (cfs)**
Albion River near Comptche	740
Carneros Creek at Sattui[1,3,4]	254
Dry Creek Tributary near Hopland	110
Dunn Creek near Rockport	93
EF Russian River Tributary near Potter Valley	25
Franz Creek near Kellogg[3]	1,230
Huichica Creek at the survey location[3,4, 5]	219
Lagunitas Creek at SP Taylor State Park	*n/a*[2]
Olema Creek at the survey location	*n/a*[2]
Pine Creek at Bolinas[4]	731
Salmon Creek at Bodega	1,380
Santa Rosa Creek near Santa Rosa	1,170
Warm Springs Creek near Asti	857

Notes:

1. The period of record of the Carneros at Sattui (CAS) gage was not long enough to determine the 1.5-year peak flow at this location. Instead, the 1.5-year peak flow for the CAS gage was estimated by multiplying the 1.5-year peak flow at Carneros at Old Sonoma Road (CAO) gage by the ratio of drainage area (2.75/6.69) and average precipitation (36.18/31.58) of the CAS and CAO watersheds.
2. Instantaneous peak flow measurements were not available at Lagunitas and Olema Creeks.
3. Observed flows were used to determine the instantaneous 1.5-year peak flows. At Carneros, Franz and Huichica Creeks, the recorded instantaneous peaks are most likely lower than the peaks that would occur in the absence of diversions.
4. 1.5 year peak flows at Carneros, Huichica, and Pine Creeks were calculated using the peaks over threshold method.
5. The 1.5-year peak flow at the Huichica survey location was estimated by multiplying the 1.5-year peak flow at the Huichica Creek gage (HRV) by the ratio of drainage area (4.92/6.11) and average precipitation (27.897/27.067) of the survey location and gage watersheds.

F.2.7 Unimpaired Flow Exceedances at Validation Sites

Some of the Policy element alternatives for minimum bypass flow (MBF1 and MBF2) and maximum cumulative diversion (MCD1) were based on unimpaired flow exceedances. Flow exceedances are values that represent how often a certain magnitude of flow is expected to occur. A graph of flow exceedances is also known as a flow-duration curve. In such a graph, “percent exceedance” is plotted on the *x*-axis, and corresponding flows are plotted on the y-axis. Points on the graph represent the flow that was exceeded a certain percent of the time. For example, if a graph contains a point at *x* = 40% and *y* = 12 cfs, this means that 40% of the time, the flow was greater than 12 cfs.

Flow exceedances may be computed using a variety of time series. Stream flow may be hourly, daily, monthly, etc. For this study, Stetson used unimpaired daily average flows to compute flow exceedances and create flow-duration curves for each of the thirteen validation sites. Exceedances were computed by calculating the flow at each percentile, from zero to the 99th percentile. Note that the flow at the 50th percentile is also known as the median flow.

Stetson computed daily average flow exceedances for three different time periods within the water year. First, year-round flow exceedances were computed, meaning that the percentile distribution was computed based on every daily average flow measurement from October 1 through September 30.

Flow exceedances were calculated for the winter diversion season from December 15 through March 31. The percentile distribution was computed only for daily average flows during that period (i.e., all flows between April 1 and December 14 were excluded). The 20% exceedance flow from December 15 through March 31 is used to compute the MCD rate under Flow Alternative Scenarios 1 and 3.

Finally, daily average flow exceedances were computed for the month of February only. The median (50% exceedance) flow for February is used to determine MBF1, the alternative proposed in the NMFS-DFG Draft Guidelines.

F.3 SYNTHESIZED IMPAIRED DAILY AVERAGE TIME SERIES

Impaired flow time series were calculated by first selecting one alternative for each of the Policy elements restricting flow diversions (diversion season, minimum bypass flow, and maximum cumulative diversion), then determining the maximum daily diversions that would be allowed for this combination of policy element alternatives, and finally subtracting these maximum daily diversions from the unimpaired flow time series to determine the remaining impaired flow time series.

F.3.1 Methods: Spreadsheet Computations

Selected alternatives for diversion season, minimum bypass flow, and maximum cumulative diversion were applied to the unimpaired time series to create impaired flow time series. Stetson implemented daily flow restrictions and diversion limits in spreadsheets (Microsoft Excel) to compute the maximum allowable daily diversions and the impaired daily flow time series that would remain after this water was diverted.

The Excel spreadsheets were designed such that any combination of the three Policy elements could be used to create an impaired time series. The application of the three Policy elements to compute impaired time series is discussed below. The logic implemented on a daily basis in the spreadsheets is illustrated in Figure F-7.

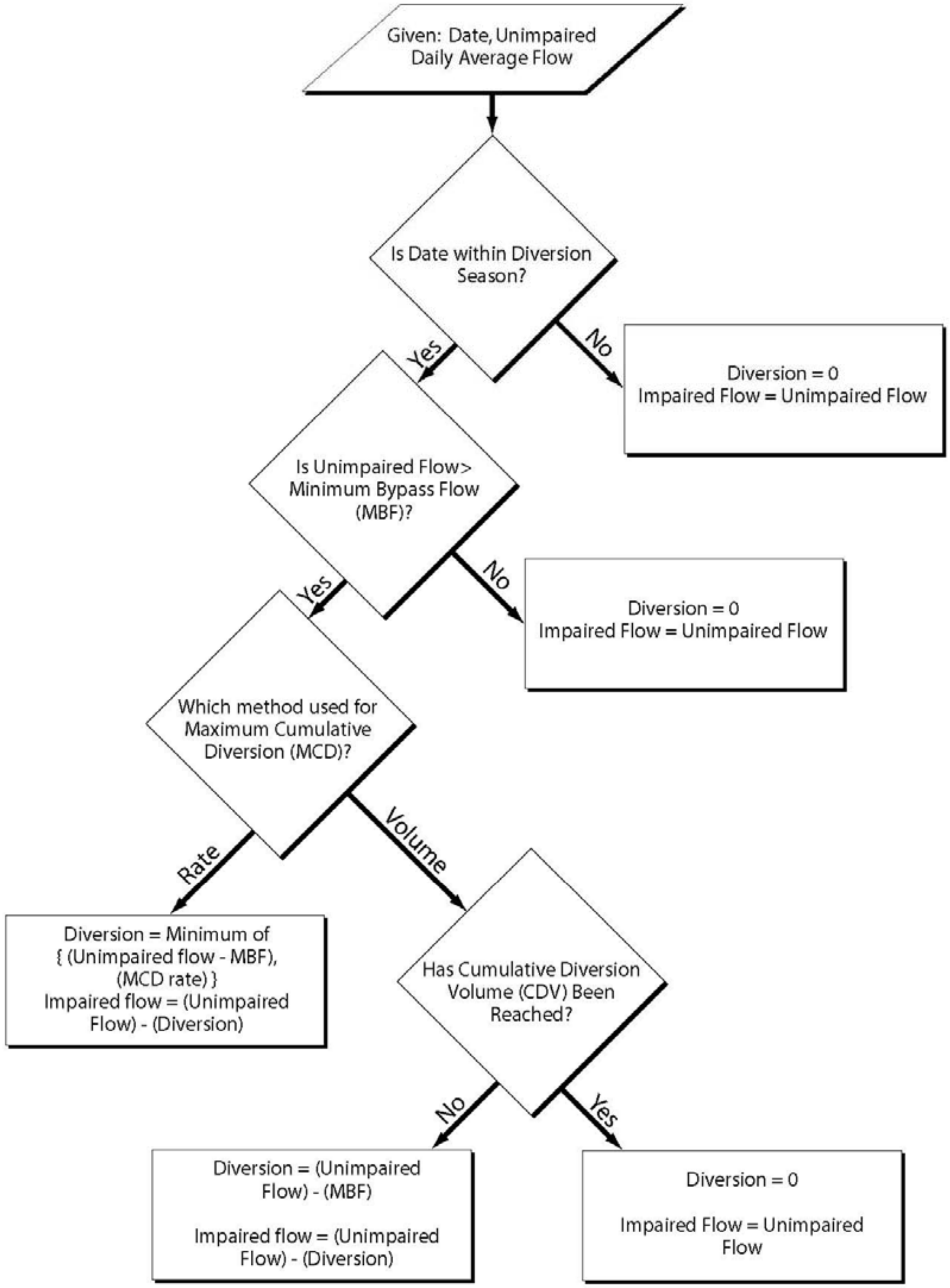

Figure F-7. Logic tree illustrating calculations in spreadsheet to determine daily diversions and impaired flow for policy element flow alternative scenarios

Any combination of the three Policy elements could be implemented to create impaired time series. For the habitat assessment, R2 analyzed impaired time series for Flow Alternative Scenarios 1 through 5 at each of the thirteen validation sites. The Policy element alternatives corresponding to each Flow Alternative Scenario are shown in Table 4-2. Additional combinations of Policy element alternatives were used to create impaired time series for the Sensitivity Scenarios discussed in Section F.4 and Table F-17 of this appendix.

Diversion Season. This is defined as the period over which diversions are allowed. Diversion season alternatives evaluated included: (DS1) December 15 through March 31 (Flow Alternative Scenarios 1, 3, and 5); (DS2) year-round (Flow Alternative Scenario 2); and (DS3) October 1 through March 31 (Flow Alternative Scenario 4 and all Sensitivity Scenarios).

In the spreadsheet, a diversion season start and end date are specified, and no diversions are allowed outside of those dates.

Minimum Bypass Flow (MBF). This is the minimum flow rate below which no diversions are allowed. MBF alternatives include: (MBF1) the February median daily flow (Flow Alternative Scenarios 1 and 5); (MBF2) the ten percent annual exceedance flow (Flow Alternative Scenario 2); (MBF3) an Upper MBF alternative which is a function of drainage area and mean annual flow (Flow Alternative Scenario 3 and all Sensitivity Scenarios); and (MBF4) a Lower MBF alternative, also a function of drainage area and mean annual flow (Flow Alternative Scenario 4). See Chapter 4, Tables 4-2 and 4-3 for a complete list of the combinations of Policy Elements alternatives used to generate each Flow Alternative Scenario used in the habitat assessment. February median flows and ten percent annual exceedance were computed as described in Section F.2.7.

On a daily basis, the spreadsheet checks whether the unimpaired daily flow exceeds the specified MBF. If it does, diversions are allowed up to a maximum of the difference between the unimpaired flow and the MBF. That is, even if diversions are allowed, the impaired flow cannot be less than the MBF. If the unimpaired flow is equal to or less than the MBF, no diversions are allowed.

Maximum Cumulative Diversion (MCD) rate or volume. This is a limit to the total (cumulative) diversions that can be made at or upstream of a point of diversion. The MCD has been implemented by restricting either the daily diversion flow rate (rate) or the total cumulative diversion volume (volume) for the diversion season. Alternatives MCD1, MCD2 and MCD4 restrict the diversion rate, while MCD3 restricts the diversion volume.

MCD rate alternatives include: (MCD1) based on winter exceedance flows (Flow Alternative Scenarios 1 and 3); (MCD2) five percent of the 1.5 year flood magnitude (Flow Alternative

Scenario 4); and (MCD4) which limits changes to the hydrograph falling limb timing (see main text, Figure 3-2, Flow Alternative Scenario 2). If the MCD rate method is used, the daily diversion quantity is restricted to that maximum rate. For example, if the unimpaired flow is 50 cfs, the MBF is 20 cfs, and the MCD rate is 12 cfs, the maximum potential diversion would be 30 cfs (unimpaired flow – MBF); however, the MCD rate restricts this daily diversion to a maximum of 12 cfs. The diversion is 12 cfs, and the impaired flow is 38 cfs (50 cfs – 12 cfs).

If the MCD volume method is used, diversions are not restricted on a daily basis, but instead on a seasonal basis. This method was employed only in MCD 3 (Flow Alternative Scenario 5) based on the draft DFG-NMFS guidelines (2002). The DFG-NMFS guidelines proposed a maximum cumulative diversion volume (CDV) equal to 10% of the estimated unimpaired runoff (EUR) for the diversion season. The ratio of the CDV divided by the EUR is referred to as the cumulative flow impairment index (CFII). There is no limit to the timing of these diversions. For this analysis, it was assumed that water diverters would take all available water until the full CDV was diverted.

In the spreadsheet, EUR was computed from the unimpaired time series, and CDV was computed for a 10% CFII. At the start of the diversion season, flow was impaired by subtracting all the water available for diversion from the unimpaired flow time series, i.e., the diversion was equal to the unimpaired flow minus the MBF. Total volume of diversions was tracked cumulatively. Once total diversions equaled the CDV, no additional diversions were taken and the unimpaired flow was equal to the impaired flow. For example, if the unimpaired flow is 50 cfs, the MBF is 20 cfs, and the CDV has not yet been reached, the allowable diversion is equal to the maximum potential diversion of 30 cfs and the impaired flow is equal to 20 cfs, which is the MBF.

F.3.2 Impaired Mean Annual Flow

After the impaired daily average time series were computed for each Flow Alternative Scenario as described above, Stetson computed mean annual impaired flow for each impaired time series using the same method described in Section F.2.5.

F.3.3 Impaired Instantaneous Flood Frequency

Stetson computed impaired instantaneous flood frequency for each Flow Alternative Scenarios for the purpose of assessing how the policy elements affect peak flows. Since continuous daily average time series were used in this study, estimates of impaired instantaneous flows had to be made separately. Due to the limited nature of instantaneous measurements (only one measurement per year, usually), the daily average time series were necessary to estimate some impaired instantaneous peaks. Thus, at each validation site, both instantaneous and continuous daily average records were required. Also, for this analysis, data with fewer than 8 years were not included since flood frequency calculations are not very accurate with only a small number of data points. After making these considerations, data were only sufficient to compute instantaneous flood frequency at four of the 13 validation sites, Albion River, Salmon Creek, Santa Rosa Creek, and Warm Springs Creek.

Stetson gathered unimpaired instantaneous measurements at the four validation sites as described in Section F.2.6. To compute the impaired instantaneous peak annual flow, Stetson used two methods, one for impairment using the MCD rate method, and one for those using the MCD volume. The process of determining the impaired instantaneous peak is diagrammed in Figure F-8.

If an MCD rate restriction was applied to impair the flow, the instantaneous peak was computed as follows: first, the date of the instantaneous peak was checked to see if it fell within the prescribed diversion season. If it was not in the diversion season, then the impaired instantaneous peak was simply equal to the unimpaired instantaneous peak. If the date did fall within the diversion season, then the impaired peak was equal to the unimpaired peak minus the MCD rate, but no less than the MBF.

If the MCD volume method was applied to impair the flow, the instantaneous peak was determined through a series of steps. First, for each water year, Stetson determined the date that the CDV was reached. This date was important because it divides the diversion season into two distinct periods: before the CDV is reached, all flows higher than the MBF are diverted [5], while after the CDV is reached, no diversions are taken.

Next, the date of the unimpaired instantaneous peak was checked for two conditions: (1) if the date was after the CDV was reached, or (2) if the date was outside of the diversion season. If either of these conditions were true, then the impaired instantaneous peak was equal to the unimpaired instantaneous peak (i.e., the diversions that season did not alter the peak flow).

If the date of the unimpaired instantaneous peak was during the diversion season and before the CDV was reached, some of the annual unimpaired instantaneous peak flow would be diverted. In this case, the impaired peak may not occur on the same date as the unimpaired peak. The impaired daily average time series was used to determine the date of the maximum impaired daily average peak flow.

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[5] The MCD volume method limits the total volume of diversions but does not prescribe the rate or timing of these withdrawals. For this analysis, it was assumed that diverters would take all available water until the full CDV was diverted.

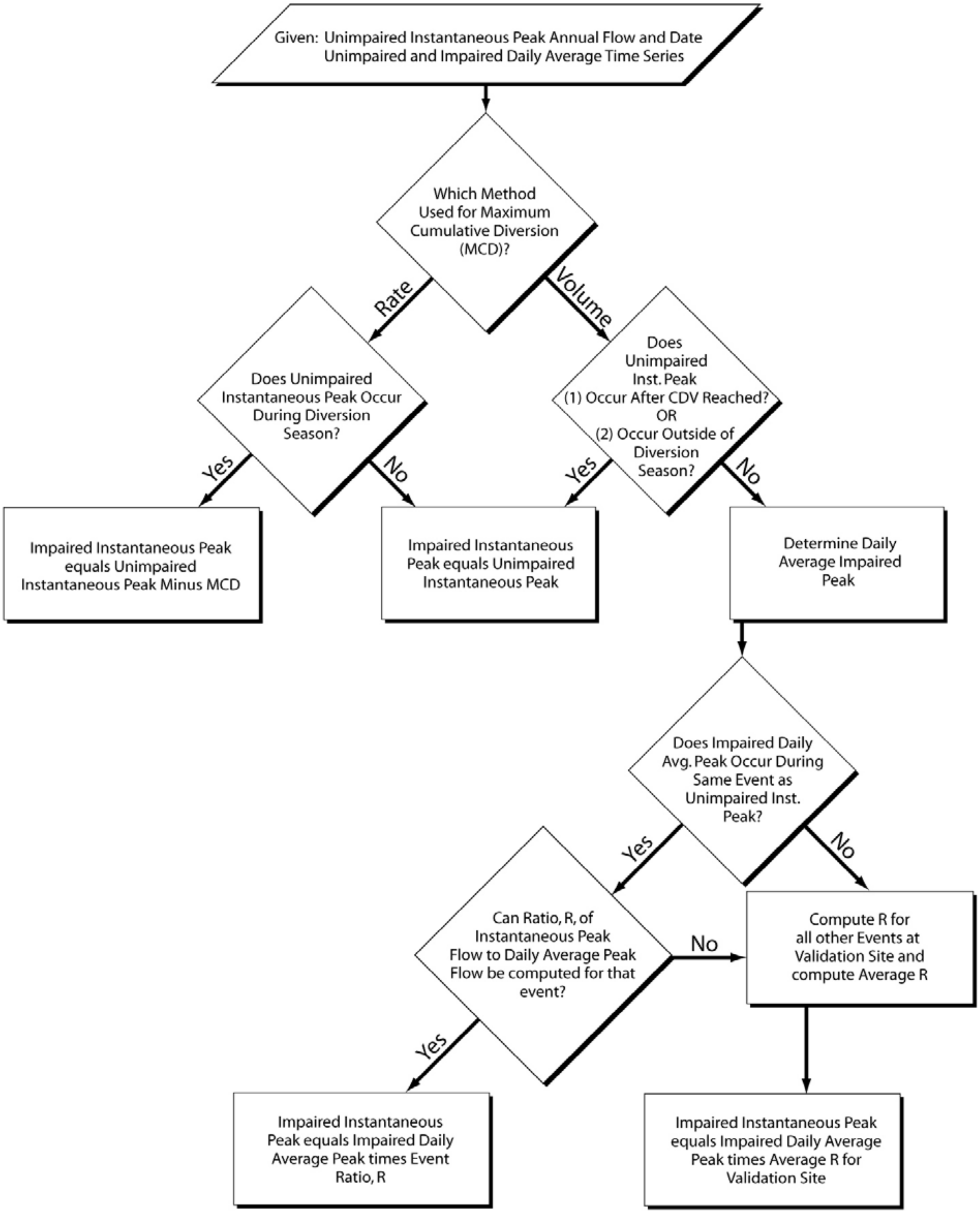

Figure F-8. Logic tree illustrating process to determine impaired instantaneous peak flows.

Due to the limited availability of instantaneous data, the impaired daily average time series was used to estimate the instantaneous peak flows. Once the daily average impaired peak was determined, the daily average flow rate was scaled up to estimate the instantaneous peak flow rate. For all four validation sites, the ratio, R, of the instantaneous unimpaired peak flow to the daily average unimpaired peak flow was computed whenever such measurements were available for the same day:

$$R = U_{p,inst} / U_{p,daily\ avg}$$

where $U_{p,inst}$ = the instantaneous unimpaired peak flow on day X
$U_{p,daily\ avg}$ = the daily average unimpaired peak flow on day X

At the four gages analyzed, there were at least five years per gage for which R could be computed. In scaling the impaired daily average peaks, two methods were used. If the daily average impaired peak occurred during the same event as the unimpaired instantaneous peak and an R value was able to be computed for that event, then that R was used to scale the impaired daily average flow as follows:

$$I_{p,inst} = I_{p,daily\ avg} * R$$

where $I_{p,inst}$ = the instantaneous impaired peak flow on day X
$I_{p,daily\ avg}$ = the daily average impaired peak flow on day X

If no R value was available for the impaired peak event, then the average R for that gage was used to scale the impaired flow:

$$I_{p,inst} = I_{p,daily\ avg} * R_{avg}$$

where R_{avg} = the average of all individual R for the validation site

Using the methods described above, Stetson determined instantaneous peak annual flows for the unimpaired flow and for the flows impaired according to each Flow Alternative Scenario. The values are listed in Table F-14.

After the instantaneous peak annual flows were estimated, a flood frequency analysis was completed. For the four validation sites, the 1.5-year instantaneous peak flows were determined to provide a relative comparison of the unimpaired flow and the flows impaired according to each Flow Alternative Scenario. In order to make comparisons most meaningful, the same period of record was used for the unimpaired flood frequency and the impaired flood frequencies. Note that for the unimpaired flows, instantaneous measurements were available for years in addition to those shown in Table F-14, but were not used in this analysis because comparable impaired peaks could not be computed.[6]

The magnitude of the 1.5-year event was computed based on methods from USGS Bulletin 17B (IACWD, 1982) as described in Section F.2.6. Generally, this method provides guidelines for excluding statistical outliers in the frequency calculation. However, for the calculation of unimpaired and impaired peak flows at these four validation sites, no outliers were excluded. This provided consistency between the unimpaired and impaired cases. For example, if the unimpaired analysis was based upon ten peak floods, the impaired frequency analysis was also based on ten events from the same ten years. The resulting estimates of unimpaired and impaired instantaneous flood frequency for each Flow Alternative Scenarios are listed in Table F-15.

F 3.4 Analysis of Falling Limb of Impaired and Unimpaired Hydrographs

A flood hydrograph can be divided into two sections, called the rising and falling limbs. The limbs are separated by the peak stream flow runoff of the event. The rising limb is the portion of the hydrograph in which stream flow runoff (discharge) is increasing. After the peak of the event, stream flow decreases; this section of the hydrograph is referred to as the falling limb (sometimes also referred to as the receding limb or recession limb). The rising and falling limbs of an event hydrograph are illustrated in Figure F-9.

McBain and Trush and Trout Unlimited (MTTU, 2000) recommended that the maximum diversion rate of the Policy should be set based on the timing of the falling limb of peak flood events. In general, diversions in a stream will cause the impaired hydrograph for a flood event to be of shorter duration that the unimpaired hydrograph. MTTU recommended that a maximum diversion rate be imposed such that diversions would shorten the timing of the falling limb by no more than half a day.

R2 computed the MTTU MCD rate following the procedure illustrated in Figure 3-2 of the main text and described here in detail. First, events that exceeded the 1.5-yr flood were selected from the unimpaired daily flow time series. The selected events are given in Table F-16, and the 1.5-year flood magnitudes are those from Table F-13.

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[6] Note that the unimpaired flood frequency computed here differs from that computed in section F.2.6. In that analysis, all years of unimpaired instantaneous measurements were included to provide the most accurate estimate of the 1.5-year peak event. In this analysis, however, a meaningful comparison between the unimpaired and impaired peaks could be made only if the periods of record for the computed peaks were the same. For this reason, the 1.5-year peaks reported in Table F-15 may differ from those reported in Table F-13.

Table F-14. Estimated Instantaneous Peak Annual Flows for Four USGS Gages.

		Instantaneous Peak Annual Flow (cfs)					
Validation Site	**Water Year**	**Unimpaired**	**Flow Alt. Scenario 1**	**Flow Alt. Scenario 2**	**Flow Alt. Scenario 3**	**Flow Alt. Scenario 4**	**Flow Alt. Scenario 5**
Albion River	1962	1,310	1,299	1,300	1,299	1,273	1,310
Albion River	1963	934	923	924	923	897	510
Albion River	1964	1,090	1,079	1,080	1,079	1,053	646
Albion River	1965	2,050	2,039	2,040	2,039	2,013	1,968
Albion River	1966	2,390	2,379	2,380	2,379	2,353	2,045
Albion River	1967	840	829	830	829	803	615
Albion River	1968	615	604	605	604	578	330
Albion River	1969	1,620	1,609	1,610	1,609	1,583	1,620
Salmon Creek	1963	1,430	1,418	1,417	1,418	1,361	1,430
Salmon Creek	1964	1,220	1,208	1,207	1,208	1,151	419
Salmon Creek	1965	1,540	1,528	1,527	1,528	1,471	1,540
Salmon Creek	1966	1,960	1,948	1,947	1,948	1,891	1,960
Salmon Creek	1967	1,760	1,748	1,747	1,748	1,691	1,760
Salmon Creek	1968	1,370	1,358	1,357	1,358	1,301	1,370
Salmon Creek	1969	1,650	1,638	1,637	1,638	1,581	1,411
Salmon Creek	1970	1,790	1,778	1,777	1,778	1,721	1,790
Salmon Creek	1971	1,380	1,380	1,367	1,380	1,311	1,380
Salmon Creek	1972	537	525	524	525	468	132
Salmon Creek	1973	2,260	2,248	2,247	2,248	2,191	2,260
Salmon Creek	1974	1,760	1,748	1,747	1,748	1,691	1,760
Salmon Creek	1975	1,950	1,938	1,937	1,938	1,881	1,950
Santa Rosa Ck	1960	3,200	3,192	3,193	3,192	3,141	3,200
Santa Rosa Ck	1961	550	542	543	542	491	205
Santa Rosa Ck	1962	1,140	1,132	1,133	1,132	1,081	1,010
Santa Rosa Ck	1963	1,250	1,242	1,243	1,242	1,191	1,250
Santa Rosa Ck	1964	1,040	1,032	1,033	1,032	981	173
Santa Rosa Ck	1965	2,480	2,472	2,473	2,472	2,421	2,480
Santa Rosa Ck	1966	1,590	1,582	1,583	1,582	1,531	1,590
Santa Rosa Ck	1967	1,830	1,822	1,823	1,822	1,771	1,328
Santa Rosa Ck	1968	1,040	1,032	1,033	1,032	981	547
Santa Rosa Ck	1969	1,180	1,172	1,173	1,172	1,121	1,180
Santa Rosa Ck	1970	2,150	2,142	2,143	2,142	2,091	2,150
Warm Springs Ck	1974	2,230	2,210	2,219	2,210	2,187	2,230

Table F-14. Estimated Instantaneous Peak Annual Flows for Four USGS Gages.

		Instantaneous Peak Annual Flow (cfs)					
Validation Site	**Water Year**	**Unimpaired**	**Flow Alt. Scenario 1**	**Flow Alt. Scenario 2**	**Flow Alt. Scenario 3**	**Flow Alt. Scenario 4**	**Flow Alt. Scenario 5**
Warm Springs Ck	1975	908	888	897	888	865	908
Warm Springs Ck	1976	204	204	193	204	204	187
Warm Springs Ck	1977	57	39	57	57	30	39
Warm Springs Ck	1978	2,320	2,300	2,309	2,300	2,277	2,320
Warm Springs Ck	1979	1,030	1,010	1,019	1,010	987	613
Warm Springs Ck	1980	1,670	1,650	1,659	1,650	1,627	1,670
Warm Springs Ck	1981	1,020	1,020	1,009	1,020	977	997
Warm Springs Ck	1982	1,580	1,560	1,569	1,560	1,537	1,580
Warm Springs Ck	1983	2,660	2,640	2,649	2,640	2,617	2,660

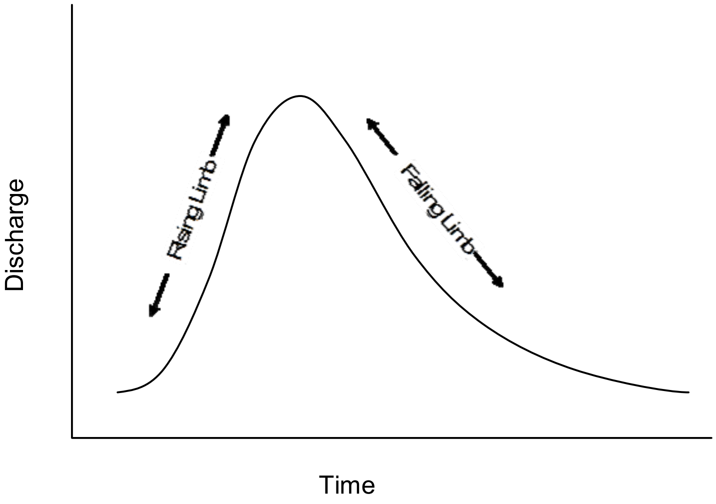

Figure F-9. Rising and falling limbs of a flood event.

The event hydrographs were plotted and a line equal to the MBF (from Table 4-3 of main text, Flow Alternative Scenario 2) was drawn parallel to the abscissa. The time that the falling limb of the unimpaired hydrograph intercepted the MBF was calculated. Next, the flow that occurred half a day earlier than that intercept was computed using linear interpolation. The difference between that flow and the MBF was the MCD rate for that event.

This procedure was repeated for all selected events at each validation site. The MCD rate for each validation site was computed by taking the average of the rates computed for each event. The computed MCD rates for the MTTU alternative (MCD4) are given in Table F-16.

Table F-15. Instantaneous 1.5-Year Peak Annual Flows for Flow Alternative Scenarios

	Instantaneous 1.5-year Peak Annual Flow (cfs)					
Validation Site	**Unimpaired**	**Flow Alternative Scenario 1**	**Flow Alternative Scenario 2**	**Flow Alternative Scenario 3**	**Flow Alternative Scenario 4**	**Flow Alternative Scenario 5**
Albion River	1,017	1,006	1,007	1,006	978	706
Salmon Creek	1,439	1,429	1,426	1,429	1,370	1,135
Santa Rosa Creek	1,170	1,161	1,162	1,161	1,108	734
Warm Springs Creek	690	666	678	683	644	603

Table F-16. Flood Events Used to Compute MCD Rate for the MTTU (2000) Element Alternative (MCD4).

	Events Evaluated		
Validation Site	**Date of Peak[1]**	**Calculated Event MCD Rate (cfs)**	**Average Validation Site MCD Rate (cfs)**
Albion River Near Comptche	12/22/64	4.4	10
	01/04/66	16	
Carneros Creek at Sattui[2]	12/27/04	9.0	9.0
Dry Creek Tributary near Hopland[2]	01/31/69	3.2	3.2
Dunn Creek near Rockport[2]	04/06/63	0.10	0.10
EF Russian River Tributary near Potter Valley	02/08/60	0.10	0.10
Franz Creek near Kellogg	01/05/65	7.0	7.6
	01/29/67	7.3	
	01/29/68	8.4	
Huichica Creek at the survey location[2]	12/27/04	1.8	1.8
Lagunitas Creek at SP Taylor State Park	*n/a*	*n/a*	*n/a*
Olema Creek at the survey location	*n/a*	*n/a*	*n/a*
Pine Creek at Bolinas[2]	02/17/99	1.1	1.1
Salmon Creek at Bodega[2]	01/11/73	13	13
Santa Rosa Creek near Santa Rosa	02/08/60	7.2	7.2
Warm Springs Creek near Asti	01/16/74	10	11
	01/16/78	4.0	
	12/19/81	13	
	03/13/83	16	

Notes:

1. Date given is the date of the event's peak average daily flow.
2. The peak daily average event at this site was less than the 1.5-yr flood magnitude. The hydrograph of the largest event at this site was used to calculate the MCD.

F.4 SENSITIVITY ANALYSIS OF MCD RATE AND VOLUME POLICY ELEMENT ALTERNATIVE

The impacts of the diversion season and minimum bypass flow Policy elements are readily distinguishable in the impaired hydrographs for each Flow Alternative Scenario, however the extent to which the maximum cumulative diversion rate or volume limits diversions beyond the restrictions placed by the two Policy elements is not as simple to discern. To isolate the effect of the MCD alternative on the impaired hydrograph, Stetson generated and compared four MCD sensitivity analysis scenarios (termed henceforth Sensitivity Scenarios)

In each Sensitivity Scenario, the diversion season and MBF were the same, and only the selection of the MCD alternative varied. Stetson created impaired time series for eleven validation sites for each Sensitivity Scenario and computed statistics to assess the magnitude and frequency of diversions. Sensitivity Scenarios were not assessed for Lagunitas and Olema Creeks since MCD2 (Sensitivity Scenario 4) could not be computed due to lack of instantaneous peak measurements. Flood frequency was also compared for four of the validation sites.

Results of the MCD sensitivity analysis indicate that, in general, diversions occur less frequently but at much higher rates when the MCD volume method is employed. Maximum diversion rates are generally an order of magnitude higher in the MCD volume scenario. Also, the MCD volume method allows a more significant reduction of peak annual floods than the MCD rate methods.

F.4.1 Methods for Sensitivity Analysis

In each Sensitivity Scenario, the diversion season and minimum bypass flow were held constant, while the MCD was varied. The Policy element alternatives used in each Sensitivity Scenario are summarized in Table F-17.

The diversion season and minimum bypass flow for all four Sensitivity Scenarios were the same: the diversion season was October 1 through March 31 (DS3); the MBF was the Upper MBF alternative, a function of drainage area and mean annual flow (MBF3). Values used for MBF are given in Table F-18.

There are four MCD alternatives, one is analyzed in each Sensitivity Scenarios. Sensitivity Scenario 1 used MCD3, the MCD volume method specified by the DFG-NMFS draft guidelines (same method as Flow Alternative Scenario 5). The maximum volume was determined based on a CFII equal to 10%. Sensitivity Scenario 2 used MCD4, a rate computed at each validation site using the method recommended by MTTU as described in Section F.3.4 and used in Flow Alternative Scenario 2. Sensitivity Scenario 3 used MCD1, 15% of the 20% winter exceedance (used in both Flow Alternative Scenarios 1 and 3). These rates were developed based on drainage area and mean annual flow of each site. Sensitivity Scenario 4 used MCD2, a rate computed as 5% of the 1.5-year flood (Flow Alternative Scenario 4).

Table F-17. Policy Element Alternatives Used in Sensitivity Scenarios.

Policy Element	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Diversion Season	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31	**DS3** Oct 1 – Mar 31
Minimum Bypass Flow (MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)	**MBF3** Function of drainage area and mean annual flow (Upper MBF)
Maximum Cumulative Diversion (MCD)	**MCD3** Volume: CFII = 10% (DFG-NMFS)	**MCD4** Rate: Calculated for each site following the procedure depicted in Figure 3-2 (MTTU)	**MCD1** Rate: 15% of Winter 20% Exceedance (DFG-NMFS)	**MCD2** Rate: 5% of 1.5-year Flood (DFG-NMFS)

Table F-18. Minimum Bypass Flows for All Sensitivity Scenarios.

Validation Site	**Sensitivity Scenarios 1-4 Minimum Bypass Flow (cfs)**
Albion River	52
Carneros Creek	22
Dry Creek Trib	19
Dunn Creek	17
E. Fk. Russian River Trib	2.4
Franz Creek	60
Huichica Creek	32
Pine Gulch Creek	42
Salmon Creek	63
Santa Rosa Creek	53
Warm Springs Creek	99

MCD values for all four Sensitivity Scenarios are given in Table F-19. The range of the rate of withdrawal of the MCD volume is also given. The minimum rate of withdrawal was calculated assuming the entire cumulative diversion volume (CDV) was taken out at a constant rate over the duration of the diversion season. For example, CDV for Albion equals 1,277 acre-feet. There are approximately 182 days in the winter period, so the equivalent constant flow rate over the winter period is: (1,277 acre-feet) ÷ (182 days) ÷ (1.9835 acre-feet/cfs-day) = 3.5 cfs. The maximum rate of withdrawal listed for Sensitivity Scenario 1 in Table F-19 is the maximum daily diversion rate which would occur during the period if flow was impaired by diverting all possible water until the CDV was met, i.e., the maximum daily diversion taken from the unimpaired time series to generate the impaired time series for Sensitivity Scenario 1.

Table F-19. Maximum Cumulative Diversion (MCD) Rate and Volume for Sensitivity Scenarios.

	MCD Volume: Sensitivity Scenario 1			**MCD Rate: Sensitivity Scenarios 2-4**		
		CDV Withdrawal Rate (cfs)		**Maximum Diversion Rate (cfs)**		
Validation Site	**Cumulative Diversion Volume (CDV) for Season (acre-feet)**	**Minimum[1]**	**Maximum[2]**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	1,277	3.5	478	10	11	37
Carneros Creek	240	0.7	121	9	1.5	13
Dry Creek Trib	154	0.4	31	3.2	1.5	5.5
Dunn Creek	123	0.3	45	0.1	0.8	4.7
E. Fk. Russian River Trib	9.1	0.0	3.0	0.1	0.1	1.3
Franz Creek	1,546	4.3	428	7.6	9.2	62
Huichica Creek	467	1.3	235	1.8	3.0	11
Pine Gulch Creek	789	2.2	307	1.1	6.2	37
Salmon Creek	1,633	4.5	554	13	12	69
Santa Rosa Creek	1,209	3.3	456	7.2	8.3	59
Warm Springs Creek	2,190	6.1	467	11	20	43

Notes:

1. Minimum rate of withdrawal was calculated as the constant rate which would result in a total diverted volume over the duration of the diversion season equal to the CDV.
2. Maximum rate of withdrawal was calculated as the maximum daily diversion rate which would occur during the period of record if flows were impaired by diverting all possible water until the CDV was met during each diversion season.

To compare the magnitudes of the various diversion rates listed in Table F-19, the diversion rates have been expressed as a percentage of the unimpaired 1.5-year peak annual flood magnitude in Table F-20. The unimpaired 1.5-year peak annual flood magnitudes are those computed in Section 2.6 (listed in Table F-13 and repeated in Table F-20). For Sensitivity Scenario 1, since only the seasonal volume is specified, the average and maximum diversion rates have been expressed in terms of the unimpaired 1.5-year peak magnitude. Clearly, Sensitivity Scenario 1 has the highest allowable maximum diversion rates, followed by Sensitivity Scenario 4 (for which maximum diversion rates were defined as being 5% of the unimpaired 1.5-year peak annual flood). Sensitivity Scenarios 2 and 3 have maximum diversion rates which are all less than 5% of the unimpaired 1.5-year peak annual flood.

Table F-20. Comparison of Sensitivity Scenarios: Diversion Rates from Table F-19 Expressed in Terms of Unimpaired 1.5-Year Peak Flood.

		Diversion rates expressed as percent of unimpaired flood magnitude				
		Sensitivity Scenario 1		**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Validation Site	**Unimpaired 1.5-year Peak Annual Flood Magnitude (cfs)**	**Minimum**	**Maximum**			
Albion River	740	0.5%	64.5%	1.4%	1.5%	5%
Carneros Creek	254	0.3%	47.7%	3.5%	0.6%	5%
Dry Creek Trib	110	0.4%	28.2%	2.9%	1.4%	5%
Dunn Creek	93	0.4%	48.4%	0.1%	0.9%	5%
E. Fk. Russian River Trib	25	0.1%	12.0%	0.4%	0.4%	5%
Franz Creek	1,230	0.3%	34.8%	0.6%	0.7%	5%
Huichica Creek	219	0.6%	107.5%	0.8%	1.4%	5%
Pine Gulch Creek	731	0.3%	42.0%	0.2%	0.8%	5%
Salmon Creek	1,380	0.3%	40.1%	0.9%	0.9%	5%
Santa Rosa Creek	1,170	0.3%	39.0%	0.6%	0.7%	5%
Warm Springs Creek	857	0.7%	54.5%	1.3%	2.3%	5%

F.4.2 Results and Discussion

Figure F-10 illustrates the differences between the MCD rate and volume methods. The upper graph in the figure shows typical unimpaired and impaired hydrographs that result from limiting seasonal diversions to the MCD volume (Sensitivity Scenario 1). As shown in the figure, during early events (i.e., those around January 20 and February 9) before the CDV is reached, all of the water above the MBF is diverted[7]. The diversion rate is up to 135 cfs. In mid-February, cumulative diversions for the season reach the CDV limit and no additional diversions are taken for the remainder of the diversion season. In general, when the MCD volume method is applied, peaks early in the season are reduced to the level of the MBF, while peaks later in the season remain at unimpaired levels. Before the CDV is reached, diversions were limited only by the availability of water; any water above the MBF was diverted no matter how high the diversion rate.

The lower graph of Figure F-10 shows the unimpaired and impaired hydrographs when a MCD rate is used to restrict annual diversions (used in Sensitivity Scenarios 2, 3, and 4). Diversions are limited by a fixed flow rate (in this case 20 cfs). Contrary to the top graph, diversions never exceed 20 cfs, and they occur until the end of the diversion season whenever water is available (i.e., if flows are greater than the MBF). Note that for both of the graphs in diversion season and MBF are identical and the differences in the impaired time series are due strictly to differences in the MCD method.

F.4.2.1 Summary of Diversion Rates, Frequency, and Quantity

Statistics for the unimpaired and impaired hydrographs for each validation site for each Sensitivity Scenario were computed. Table F-21 gives the maximum diversion rate for each Sensitivity Scenario. For Sensitivity Scenarios 2 through 4, since the maximum diversion rate is fixed, the results are as expected and match the rates specified in Table F-19. For Sensitivity Scenario 1, maximum daily flow rates are not restricted, and accordingly, the rates in Table F-21 are much higher for Sensitivity Scenario 1 than for the other three scenarios. In general, Sensitivity Scenario 1 maximum diversion rates are an order of magnitude larger than the other three scenarios' MCD rates.

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[7] The MCD volume method does not specify limits to the timing or rate of withdrawal; this is left to the discretion of the water diverter and limited only by diversion capacity. This analysis assumed that water diverters would take all available water until the maximum CDV was diverted.

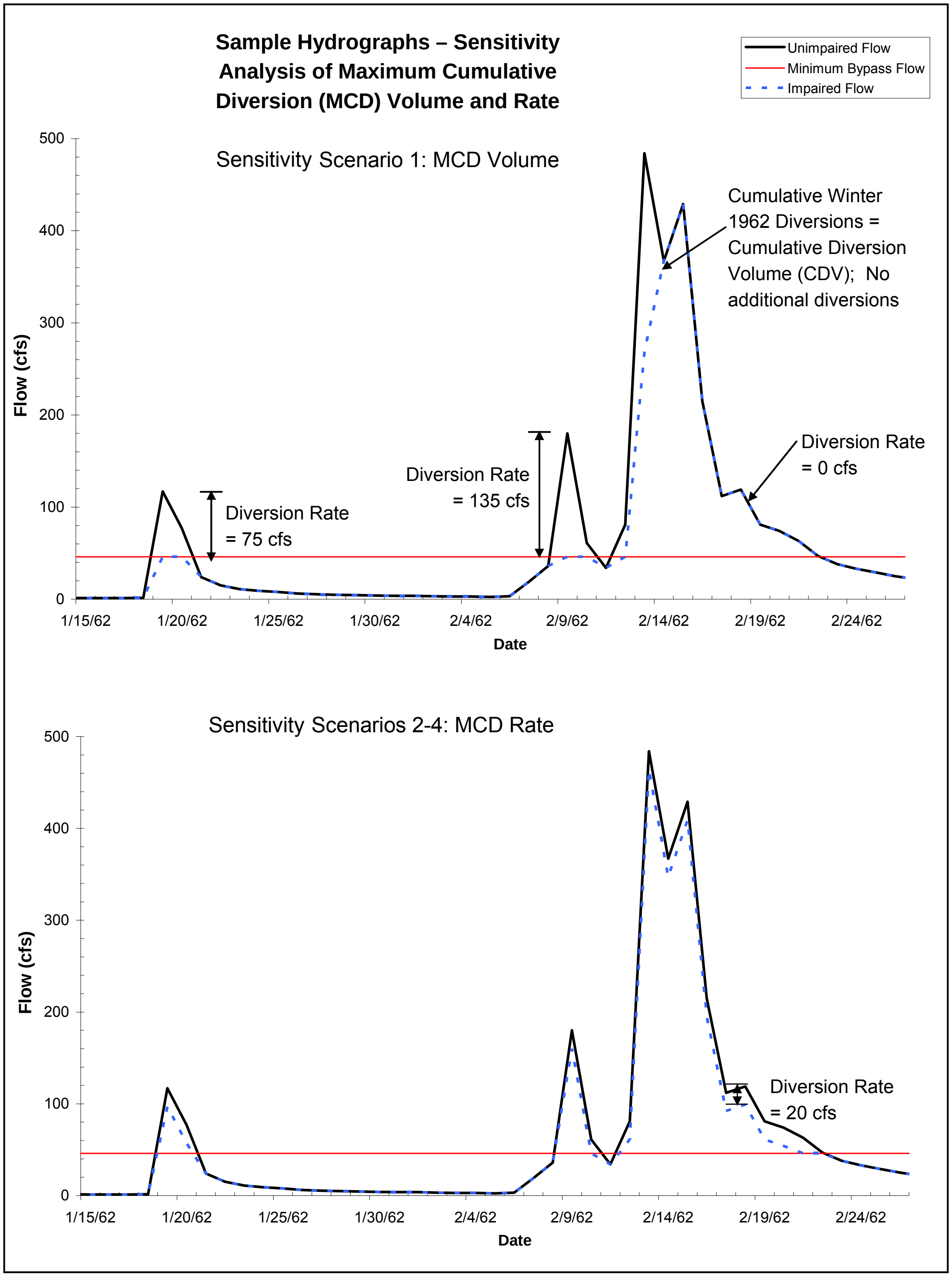

Figure F-10. Hydrographs of unimpaired and impaired flow illustrating differences between MCD volume and rate alternatives.

Table F-21. Maximum Daily Diversion Rate for Sensitivity Scenarios (based on daily average flows).

	Maximum Average Daily Diversion (cfs)			
Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	478	10	11	37
Carneros Creek	121	9.0	1.5	13
Dry Creek Trib	31	3.2	1.5	5.5
Dunn Creek	45	0.10	0.80	4.7
E. Fk. Russian River Trib	3.0	0.10	0.10	1.3
Franz Creek	428	7.6	9.2	62
Huichica Creek	235	1.8	3.0	11
Pine Gulch Creek	307	1.1	6.2	37
Salmon Creek	554	13	12	69
Santa Rosa Creek	456	7.2	8.3	59
Warm Springs Creek	467	11	20	43

An analysis of the median diversion rates, given in Table F-22, shows that median flow rates in Sensitivity Scenario 1 are larger than the median flow rates for Sensitivity Scenarios 2 and 3. However, median diversion rates for Sensitivity Scenario 4 (which involves the 5% of the 1.5 year flood level MCD alternative) are larger for some validation sites, and smaller for other validation sites when compared to Sensitivity Scenario 1 diversion rates. Also, for Sensitivity Scenarios 2 and 3, median diversion rates are equal to maximum diversion rates in Table F-21, indicating that more than half of the time that diversions are taken, they are taken at the maximum rate. For Sensitivity Scenario 4, however, the median is less than the maximum rate, meaning that diversions occur at the maximum rate less frequently.

An important statistic to note in the sensitivity analysis is how often diversions are allowed to occur. Table F-23 shows the percent of days of the year in which diversions occurred. Note that at each validation site, the period of record for each Sensitivity Scenario was identical. Clearly, Sensitivity Scenario 1 diversions occur less frequently than Sensitivity Scenarios 2 through 4. For example, at Pine Creek, Sensitivity Scenario 1 diversions occur in 1.5% of the days in the period of record, while diversions occur in 5.5% of the days for Sensitivity Scenarios 2 through 4. This supports the assertion that the MCD volume method diverts water at higher rates over a shorter period of time, while the MCD rate method diverts water at lower, more constant rates, over a longer period of time.

Table F-22. Median Daily Diversion Rate for Sensitivity Scenarios (based on daily average flows).

	Median Average Daily Diversion (cfs)			
Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	44	10	11	37
Carneros Creek	61	9.0	1.5	13
Dry Creek Trib	8.0	3.2	1.5	5.5
Dunn Creek	5.0	0.10	0.80	4.4
E. Fk. Russian River Trib	0.80	0.10	0.10	0.70
Franz Creek	35	7.6	9.2	54.1
Huichica Creek	117	1.8	3.0	11
Pine Gulch Creek	31	1.1	6.2	29
Salmon Creek	88	13	12	69
Santa Rosa Creek	57	7.2	8.3	59
Warm Springs Creek	85	11	20	43

Table F-23. Percent of Days Diversions are Allowed for Sensitivity Scenarios.

	Percent of Days Diversion Allowed			
Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	2.1%	8.1%	8.1%	8.1%
Carneros Creek	0.5%	3.1%	3.1%	3.1%
Dry Creek Trib	1.8%	2.9%	2.9%	2.9%
Dunn Creek	0.9%	1.1%	1.1%	1.1%
E. Fk. Russian River Trib	0.7%	1.1%	1.1%	1.1%
Franz Creek	2.6%	8.4%	8.4%	8.4%
Huichica Creek	0.5%	4.1%	4.1%	4.1%
Pine Gulch Creek	1.5%	5.5%	5.5%	5.5%
Salmon Creek	1.7%	8.0%	8.0%	8.0%
Santa Rosa Creek	1.5%	6.5%	6.5%	6.5%
Warm Springs Creek	2.1%	8.5%	8.5%	8.5%

Finally, the total quantity of water diverted in each Sensitivity Scenario was computed. Table F-24 shows the total quantity of water diverted, expressed as a percentage of the total unimpaired flow during the entire period of record. Again, at each validation site, all four scenarios were analyzed over an identical period of record. In general, more water is diverted in Sensitivity Scenario 4 than in all other Sensitivity Scenarios. The next highest diversion quantities are in Sensitivity Scenario 1. Sensitivity Scenarios 2 and 3 have diversion quantities that are less than Sensitivity Scenarios 3 and 4, but compared to each other, diversion quantities vary depending on the validation site.

Table F-24. Percent of Total Unimpaired Flow Diverted for Sensitivity Scenarios.

	Percent of Total Unimpaired Flow Diverted			
Validation Site	**Sensitivity Scenario 1**	**Sensitivity Scenario 2**	**Sensitivity Scenario 3**	**Sensitivity Scenario 4**
Albion River	8.8%	3.9%	4.2%	12.2%
Carneros Creek	8.8%	6.0%	1.2%	8.1%
Dry Creek Trib	8.3%	3.8%	1.9%	6.0%
Dunn Creek	3.2%	0.0%	0.3%	1.6%
E. Fk. Russian River Trib	7.4%	0.9%	0.9%	6.3%
Franz Creek	8.9%	2.6%	3.1%	15.1%
Huichica Creek	8.7%	1.0%	1.6%	5.1%
Pine Gulch Creek	8.1%	0.6%	2.9%	12.5%
Salmon Creek	8.8%	4.0%	3.7%	16.3%
Santa Rosa Creek	8.2%	2.4%	2.7%	14.6%
Warm Springs Creek	7.0%	2.6%	4.6%	9.2%

F.4.2.2 Flood Frequency of Sensitivity Scenarios

In order to assess how the MCD affects peak annual flows, Stetson computed flood frequency for the Sensitivity Scenarios. All procedures and assumptions were identical to those discussed in Section F.3.3, except that Stetson computed flood frequency for the four impaired Sensitivity Scenarios instead of the five Flow Alternative Scenarios.

The peak annual instantaneous flows were computed at four validation sites (Albion, Salmon, Santa Rosa, and Warm Springs) and are given in Table F-25. From these flows, 1.5-year peak annual instantaneous flows, listed in Table F-26, were estimated.

Table F-25. Estimated Instantaneous Peak Annual Flood Magnitudes for Four USGS Gages.

		Instantaneous Peak Annual Flood Magnitude (cfs)				
Validation Site	**Water Year**	**Unimpaired**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Albion River	1962	1,310	1,310	1,300	1,299	1,273
Albion River	1963	934	710	924	923	897
Albion River	1964	1,090	836	1,080	1,079	1,053
Albion River	1965	2,050	1,968	2,040	2,039	2,013
Albion River	1966	2,390	1,551	2,380	2,379	2,353
Albion River	1967	840	777	830	829	803
Albion River	1968	615	329	605	604	578
Albion River	1969	1,620	1,620	1,610	1,609	1,583
Salmon Creek	1963	1,430	1,430	1,417	1,418	1,361
Salmon Creek	1964	1,220	63	1,207	1,208	1,151
Salmon Creek	1965	1,540	1,540	1,527	1,528	1,471
Salmon Creek	1966	1,960	1,960	1,947	1,948	1,891
Salmon Creek	1967	1,760	1,760	1,747	1,748	1,691
Salmon Creek	1968	1,370	1,370	1,357	1,358	1,301
Salmon Creek	1969	1,650	1,411	1,637	1,638	1,581
Salmon Creek	1970	1,790	1,790	1,777	1,778	1,721
Salmon Creek	1971	1,380	1,380	1,367	1,368	1,311
Salmon Creek	1972	537	63	524	525	468
Salmon Creek	1973	2,260	2,260	2,247	2,248	2,191
Salmon Creek	1974	1,760	1,760	1,747	1,748	1,691
Salmon Creek	1975	1,950	1,950	1,937	1,938	1,881
Santa Rosa Creek	1960	3,200	2,945	3,193	3,192	3,141
Santa Rosa Creek	1961	550	53	543	542	491
Santa Rosa Creek	1962	1,140	1,010	1,133	1,132	1,081
Santa Rosa Creek	1963	1,250	1,250	1,243	1,242	1,191
Santa Rosa Creek	1964	1,040	53	1,033	1,032	981
Santa Rosa Creek	1965	2,480	2,480	2,473	2,472	2,421
Santa Rosa Creek	1966	1,590	1,325	1,583	1,582	1,531
Santa Rosa Creek	1967	1,830	1,830	1,823	1,822	1,771
Santa Rosa Creek	1968	1,040	392	1,033	1,032	981

Table F-25. Estimated Instantaneous Peak Annual Flood Magnitudes for Four USGS Gages.

Validation Site	Water Year	Instantaneous Peak Annual Flood Magnitude (cfs) Unimpaired	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Santa Rosa Creek	1969	1,180	1,180	1,173	1,172	1,121
Santa Rosa Creek	1970	2,150	2,150	2,143	2,142	2,091
Warm Springs Creek	1974	2,230	2,230	2,219	2,210	2,187
Warm Springs Creek	1975	908	908	897	888	865
Warm Springs Creek	1976	204	204	204	204	204
Warm Springs Creek	1977	57	57	57	57	57
Warm Springs Creek	1978	2,320	2,320	2,309	2,300	2,277
Warm Springs Creek	1979	1,030	613	1,019	1,010	987
Warm Springs Creek	1980	1,670	1,670	1,659	1,650	1,627
Warm Springs Creek	1981	1,020	778	1,009	1,000	977
Warm Springs Creek	1982	1,580	1,580	1,569	1,560	1,537
Warm Springs Creek	1983	2,660	2,660	2,649	2,640	2,617

Table F-26. Instantaneous 1.5-Year Peak Annual Flows for Sensitivity Scenarios.

Validation Site	Instantaneous 1.5-year Peak Annual Flow (cfs) Unimpaired	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Albion River	1,017	819	1,007	1,006	978
Salmon Creek	1,439	829	1,426	1,427	1,370
Santa Rosa Creek	1,170	526	1,162	1,161	1,108
Warm Springs Creek	690	607	685	681	671

The peak flows listed in Table F-26 show that Sensitivity Scenario 1, the MCD volume method, leads to the largest decrease in peak flow of any MCD element alternative. At all four validation sites, the lowest peak annual flow occurs in Sensitivity Scenario 1. The next lowest peaks are seen in Sensitivity Scenario 4. Sensitivity Scenarios 2 and 3 have smaller impacts on the peak flows than Sensitivity Scenarios 1 and 4, but vary depending on the validation site.

The MCD Sensitivity Scenarios which use the rate method (2, 3, and 4), as expected, lead to reductions in peak flows that are approximately proportional to the MCD rate for each Sensitivity

Scenario. For example, at Salmon Creek, the MCD rate for Sensitivity Scenario 2 is 13 cfs (from Table F-19). In Table F-26, the difference between the unimpaired peak flow and the Sensitivity Scenario 2 peak flow is 13 cfs. In some cases, the difference between the peaks flows is not exactly equal to the MCD rate; this is because in at least one year, the unimpaired peak flow was not during the diversion season, so the impaired peak was not reduced. This is the case for one year for the Warm Springs validation site (see Table F-25, Warm Springs WY1976). Another exception is when flows are extremely low, all impaired peaks are equal to the unimpaired peak (see Table F-25, Warm Springs WY1977).

Using the values from Table F-25, Stetson prepared graphs of the exceedance probability for each of the four validation sites (Figure F-11 through Figure F-14). The graphs were prepared based on the unimpaired peak annual instantaneous exceedance probability. The unimpaired peaks have been plotted on the graph for each year in the period of record. For comparison, the impaired peaks in each year are shown. Decreases in the annual peak caused by the different MCD element alternatives are visible. For example, in Figure F-11 (Albion River), the largest unimpaired peak occurs in 1966. For Sensitivity Scenarios 2 through 4, the annual peak that year is just slightly lower than the unimpaired peak. However, for Sensitivity Scenario 1, the annual peak is approximately 25% lower than the unimpaired peak. This demonstrates that the MCD volume method (MCD3) tested in Sensitivity Scenario 1 may cause a significant decrease in the peak flows during certain years. Such decreases are similarly evident in the graphs for Salmon Creek (i.e., 1964, 1972), Santa Rosa Creek (i.e., 1968, 1964, 1961) and Warm Springs Creek (i.e., 1981, 1979).

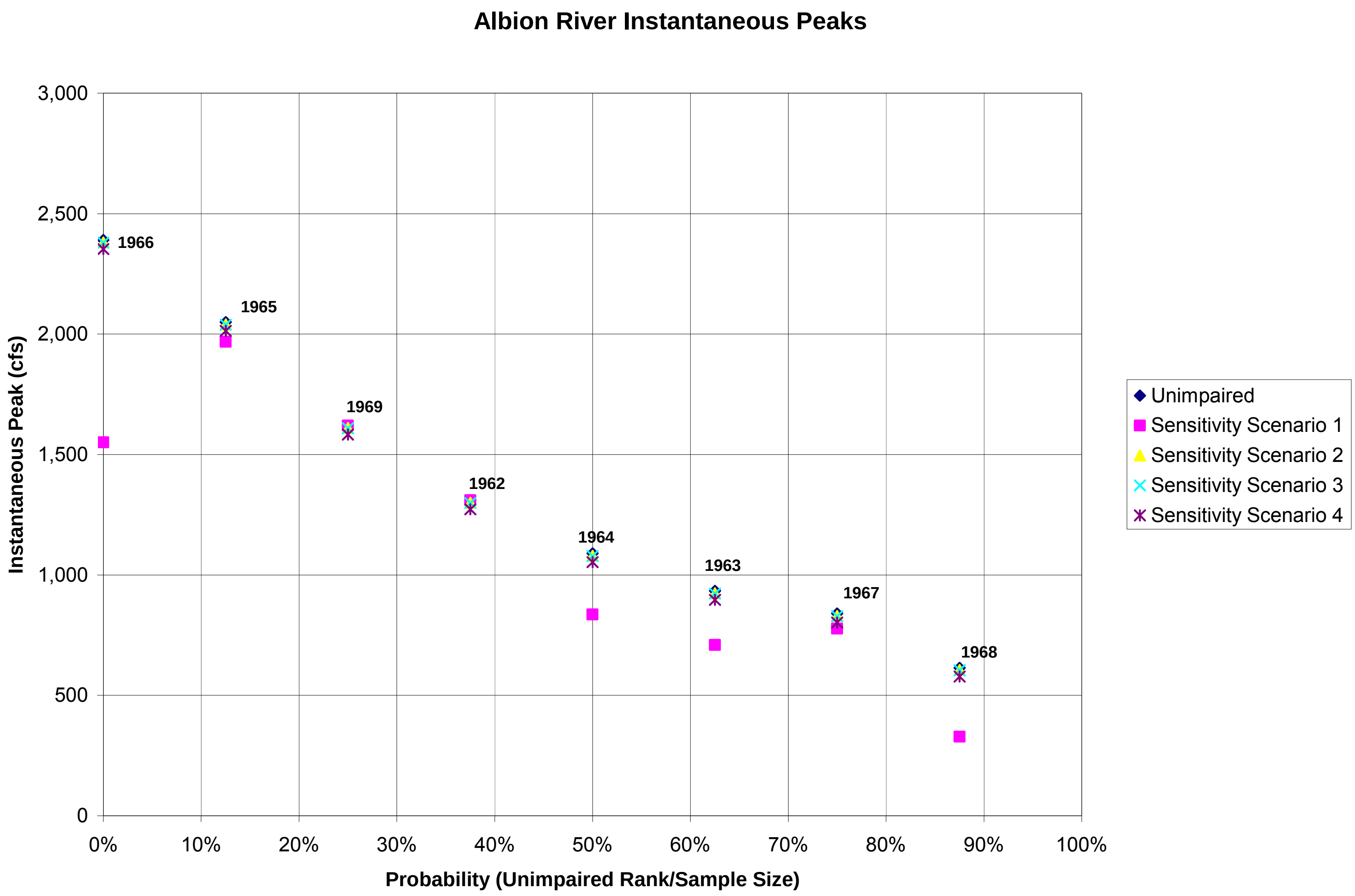

Figure F-11. Albion River instantaneous annual peak flows for Sensitivity Scenarios.

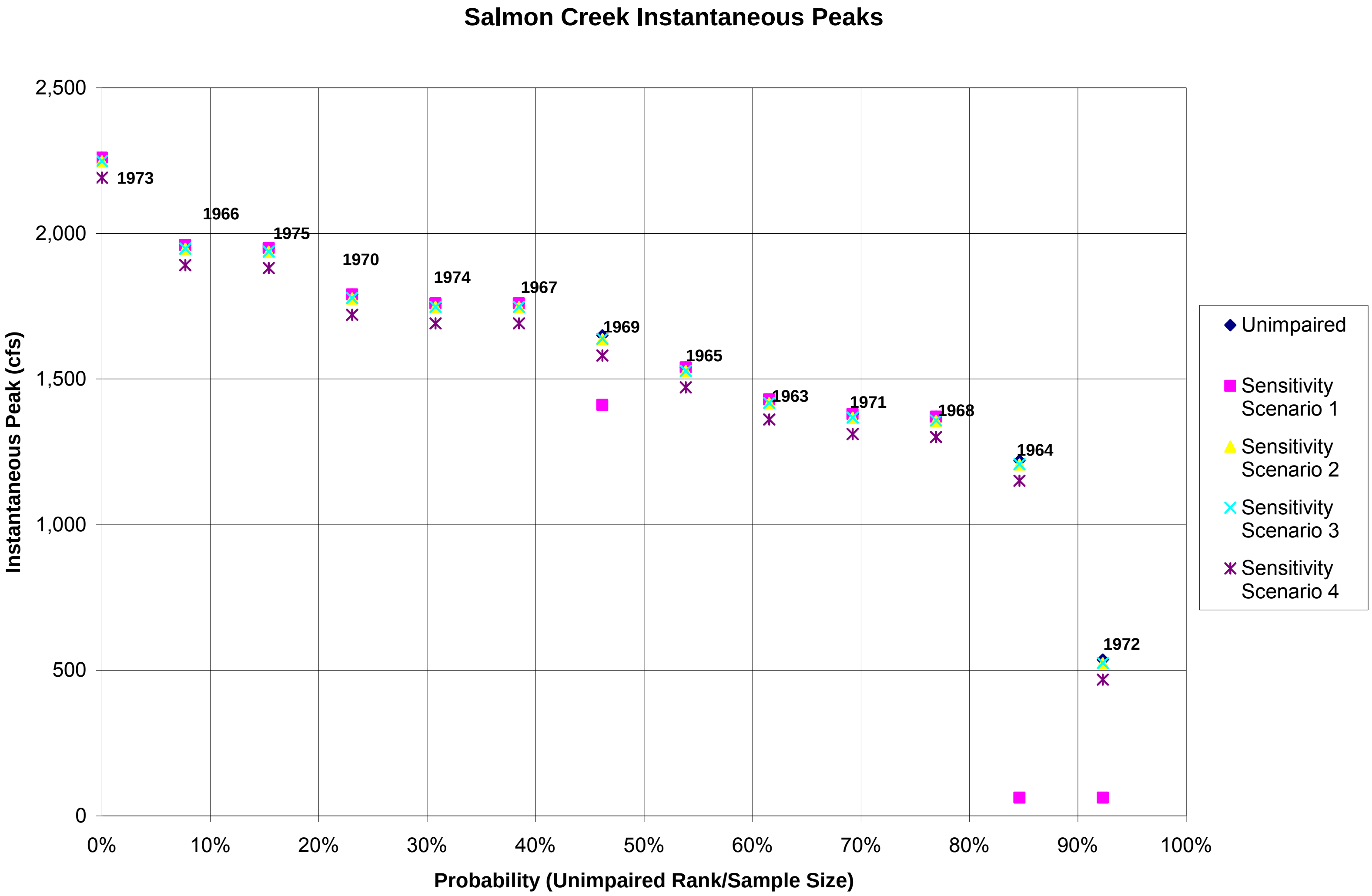

Figure F-12. Salmon Creek instantaneous annual peak flows for Sensitivity Scenarios.

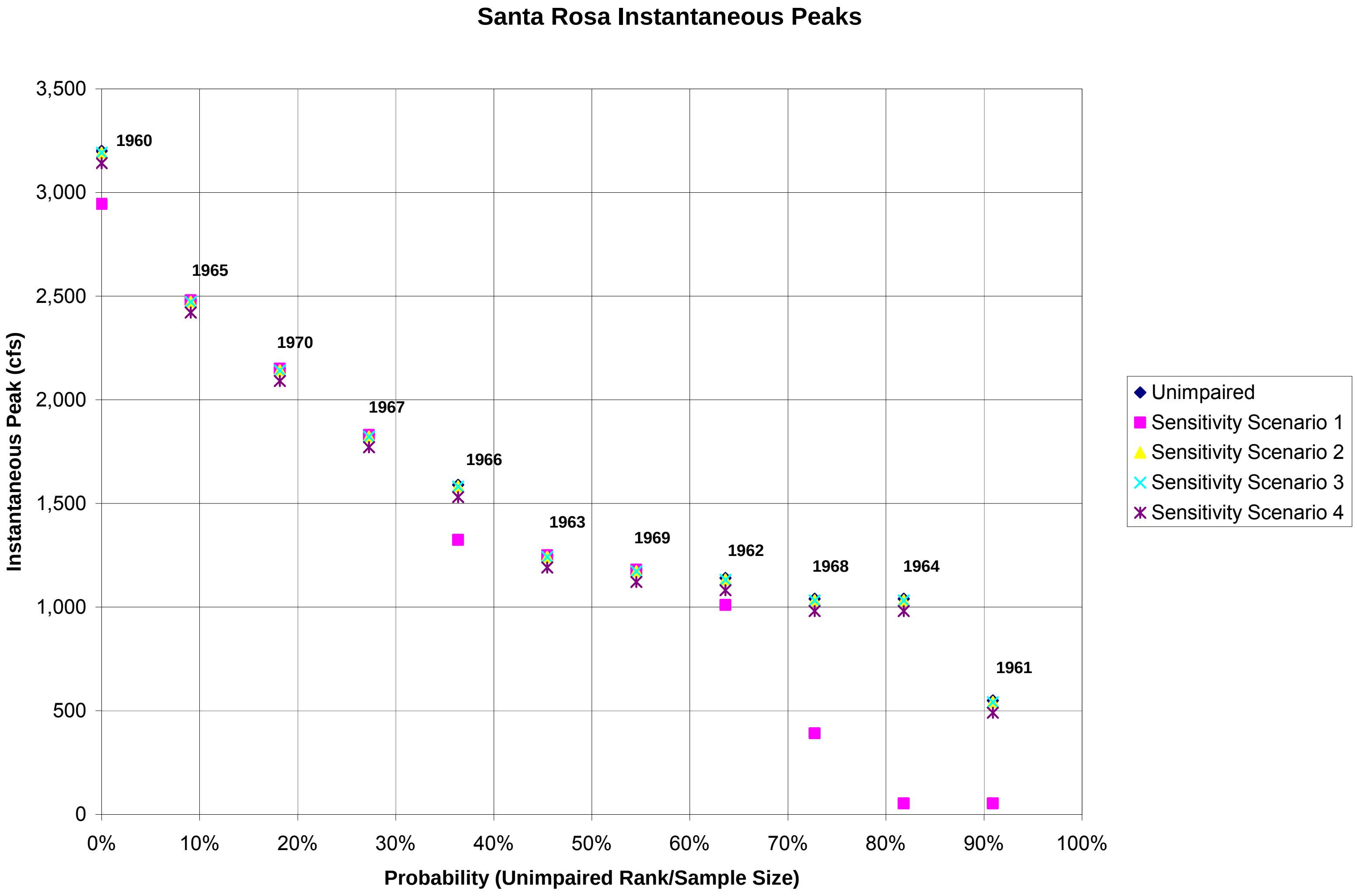

Figure F-13. Santa Rosa Creek instantaneous annual peak flows for Sensitivity Scenarios.

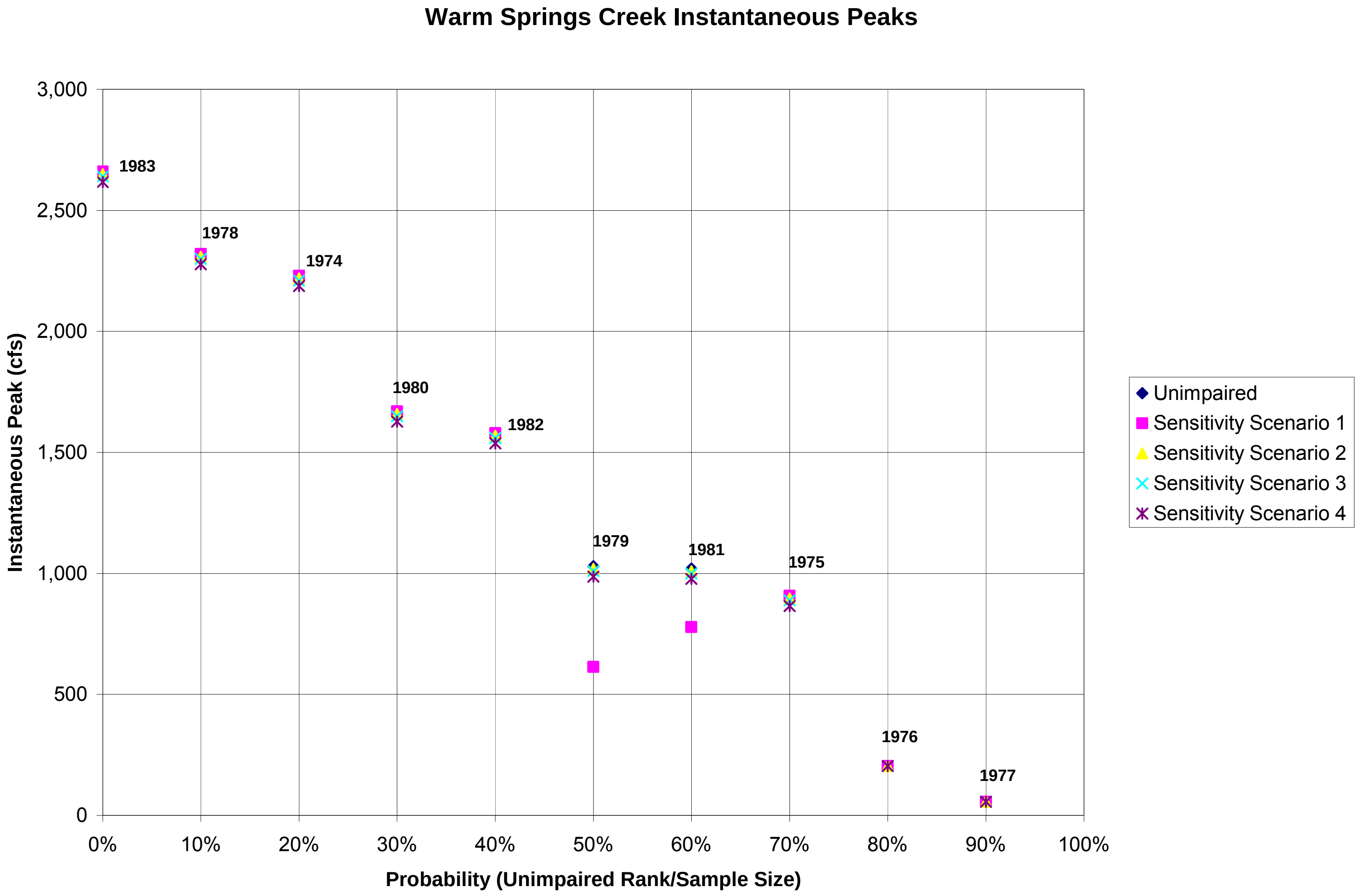

Figure F-14. Warm Springs Creek instantaneous annual peak flows for Sensitivity Scenarios.

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APPENDIX G

Approach for Assessing Effects of Policy Element Alternatives on Upstream Passage and Spawning Habitat Availability

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APPENDIX G

APPROACH FOR ASSESSING EFFECTS OF POLICY ELEMENT ALTERNATIVES ON UPSTREAM PASSAGE AND SPAWNING HABITAT AVAILABILITY

This appendix describes the approach used to assess the protectiveness of Policy element alternatives on upstream passage and spawning habitat.

An assessment of protectiveness should consider scale-related variations in channel size, flow, and fish habitat availability. The importance of basin size to developing a protective instream flow Policy at the regional level can be evaluated via various levels of complexity and effort. At the greater data intensive level, habitat-flow and hydraulic geometry data could be collected extensively in a range of streams and used to develop a regional relationship that describes the variability in channel size, fish habitat, and instream flow needs (e.g., Arthington et al. 2006). Runoff records and habitat-flow relations could be developed for each sampled stream and results compared across basin size and hydrologic response (e.g., a flashy stream vs. one with a more sustained base flow). Such a study would take many years and involve a large number of streams, and hence, could not be conducted within the time frame allowed for the development of the Policy.

A simpler, yet still biologically meaningful approach was used to evaluate the level of protectiveness of the Policy element alternatives that restrict flow (diversion season, minimum bypass flow and maximum cumulative diversion) on upstream passage and spawning habitat needs for anadromous salmonids. For this, R2 and Stetson collected basic cross-section data in 13 validation streams within the Policy area in 2006 (called the 2006 validation sites in this report). The overall analysis process is depicted conceptually in Figures G-1 through G-3 and consisted of the following main steps:

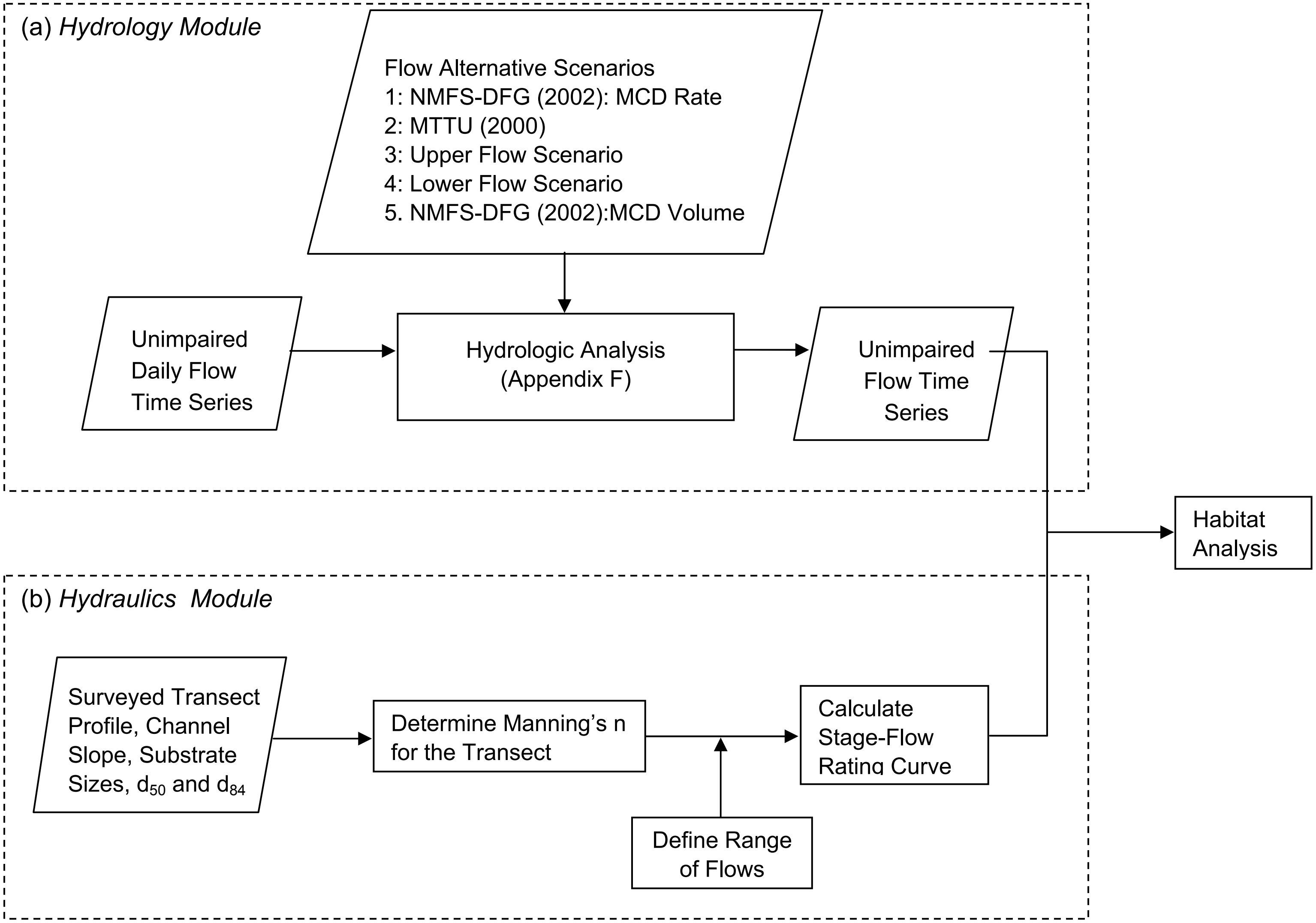

Figure G-1. Flow chart for hydrology module (upper portion) and hydraulic module (lower portion)

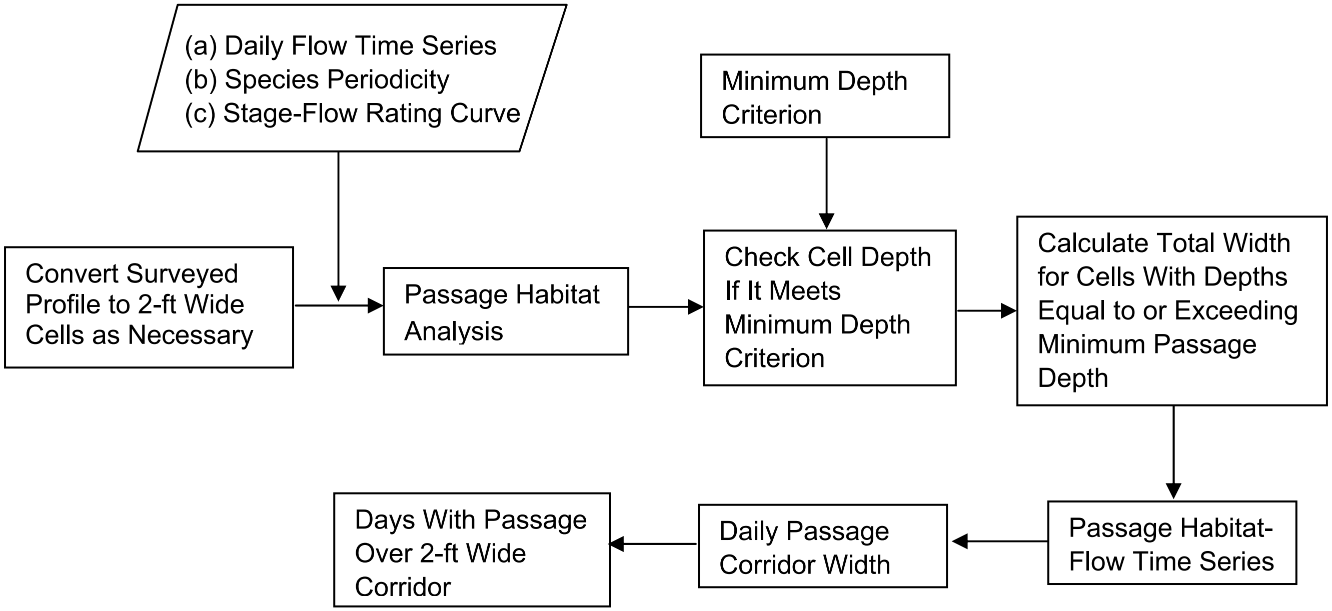

Figure G.2. Flow Chart for Passage Habitat Analysis

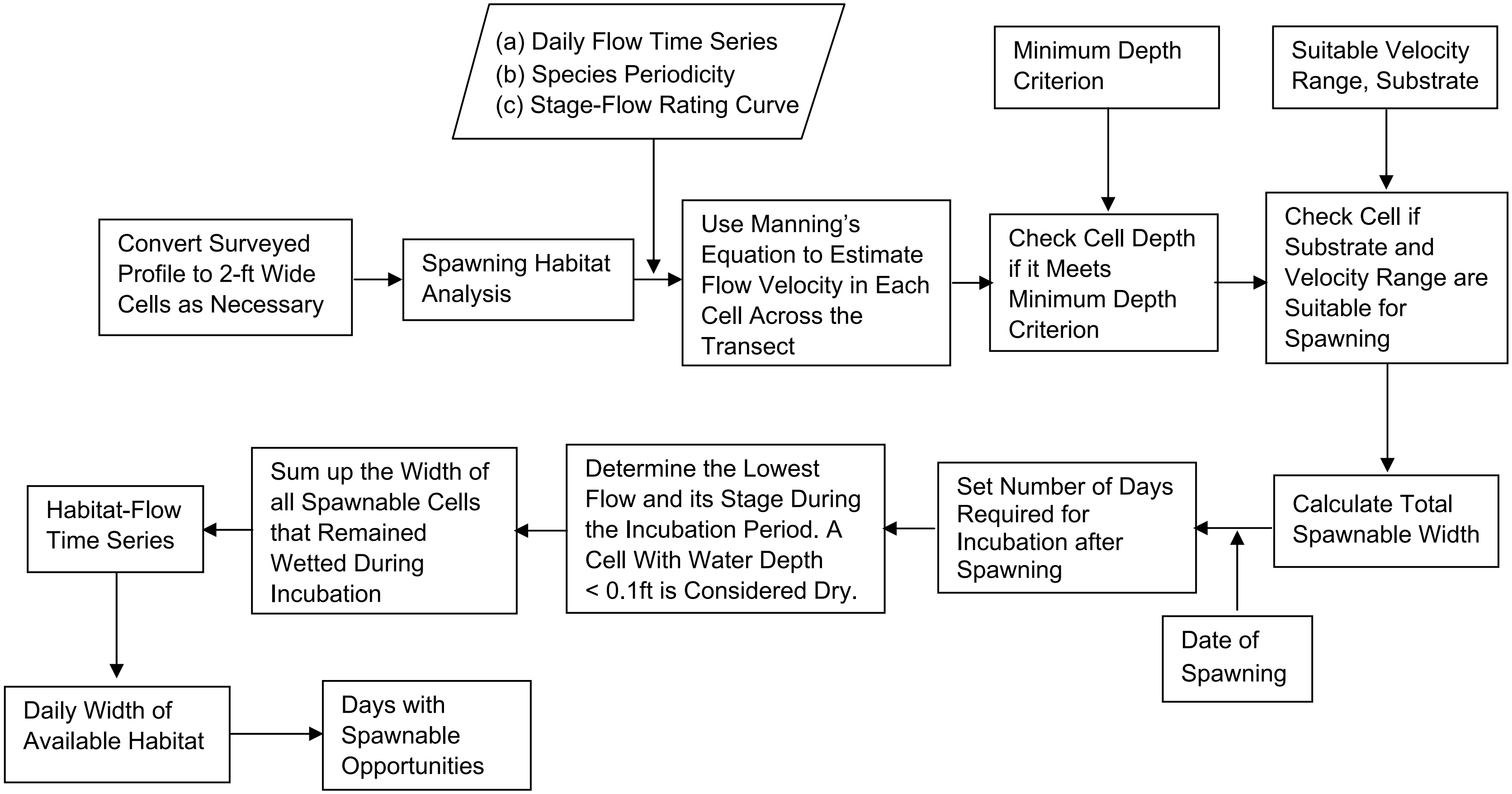

Figure G.3 Flow Chart for Spawning Habitat Analysis.

- Impaired daily times series of flows were calculated for Flow Alternative Scenarios 1 to 5 (described in Table 4-2) by withdrawing the maximum diversions allowed by the selected set of Policy element alternatives as described in Appendix F
- Cross-section data were collected to estimate hydraulic conditions at 1 to 2 passage locations and spawning habitats in each stream over a range of flows.
- The resulting estimated hydraulic conditions were compared with passage and spawning habitat suitability criteria derived from an extensive review of the literature to generate a set of simplified habitat-flow curves.
- The habitat-flow relations were then used to generate daily habitat time series for passage and spawning for the daily time series of flows for the estimated unimpaired condition and the five Flow Alternative Scenarios over the period of record. Habitat time series are useful for evaluating effective habitat availability over time frames important to various species and life stages (Bovee 1982).
- Passage and spawning/incubation timing were considered in the time series analysis, and the frequency with which each type of habitat was available was assessed directly for all years for which data were available.
- The resulting habitat time series were then compared between Flow Alternative Scenarios and against unimpaired flow conditions. The primary metric for assessing effects to passage and spawning habitat was the number of days that opportunities were available, in each water year. Protectiveness was judged based on relative differences in the average number of days per water year compared with unimpaired flow conditions. Differences were expressed in terms of number of days, and percent change from the number of days available under unimpaired flow conditions.

The resulting habitat time series were then compared between alternatives and against unimpaired flow conditions. The primary metric for assessing effects to passage and spawning habitat was the number of days that opportunities were afforded for each, in each water year. Protectiveness was judged based on relative differences in the average number of days/year compared with unimpaired flow conditions. Differences were expressed in terms of number of days, and percent change from the number of days available under unimpaired flow conditions.

The following sections describe specific components of the hydraulic and habitat analyses. Details on the hydrologic analyses are given in Appendix F.

G.1 FIELD DATA COLLECTION

Up to two passage and two spawning transects were measured in each site, with the number of transects depending on habitat availability within the reach sampled. Passage transects were placed at locations in each validation site that would require more flow than elsewhere in a reach to meet passage depth criteria; transects were typically placed over wide, shallow riffles or in a few cases where a limiting critical depth occurred in the hydraulic sense (e.g., Chow 1959). Spawning transects were located upstream of riffle crests in pool or run tails. These locations are typically used by steelhead and coho in small to mid-size streams **(**Shapovalov and Taft 1954). Spawning transects placed near riffle crests were generally located downstream of deeper cross-sections that provided spawning habitat. The sampled locations were selected to have a lower probability of egg pocket scour near the thalweg than deeper locations nearer the pool edge, based on potential for sediment transport rate imbalances that are the cause of deep scour (DeVries 2000). Alternatively, spawning transects were placed in riffle or run habitats depending on predominant spawning habitat characteristics. Pocket gravels behind boulders were avoided because they could not be easily modeled, and flows rendering such habitats suitable are less related to channel size.

The data collected included:

- Cross-section bed profiles and depth/velocity distributions, surveyed approximately every 2 ft, provided there was no major change in bathymetry or substrate type, (2 ft approximates the width of small steelhead and coho redds, and is roughly half the width of an average steelhead redd; Shapovalov and Taft 1954; 2 ft also affords a minimum passage lane);
- Visual assessment of substrate suitability for spawning across the channel based on dominant grain size (i.e., gravel of a broad size range suitable for spawning by both steelhead and coho);
- Grain size distribution characteristics across the transect based on pebble counts, or characterized visually when patches of spawning gravel were interspersed (for use in estimating the effects of relative roughness on predicted stage-discharge relations); and
- Longitudinal slope.

The data were collected in streams near current or historic gage locations within the Policy area, for which available flow records represented relatively unimpaired conditions, or for which unimpaired conditions could be reasonably estimated. Given that the DFG-NMFS (2002) Draft Guidelines were based on the results of existing habitat-flow studies in streams with drainage areas greater than about 15 mi^2, sampling efforts for this assessment focused primarily on smaller (less than 15 mi^2) stream channels. Analyses conducted by MTTU (2000) indicated that this range of channel sizes may exhibit the greatest variation in the ratio of instream flows to mean annual flow and other hydrologic flow frequency metrics. The validation sites and numbers of transects are presented in Table G-1; validation site locations are depicted in Figure G-4.

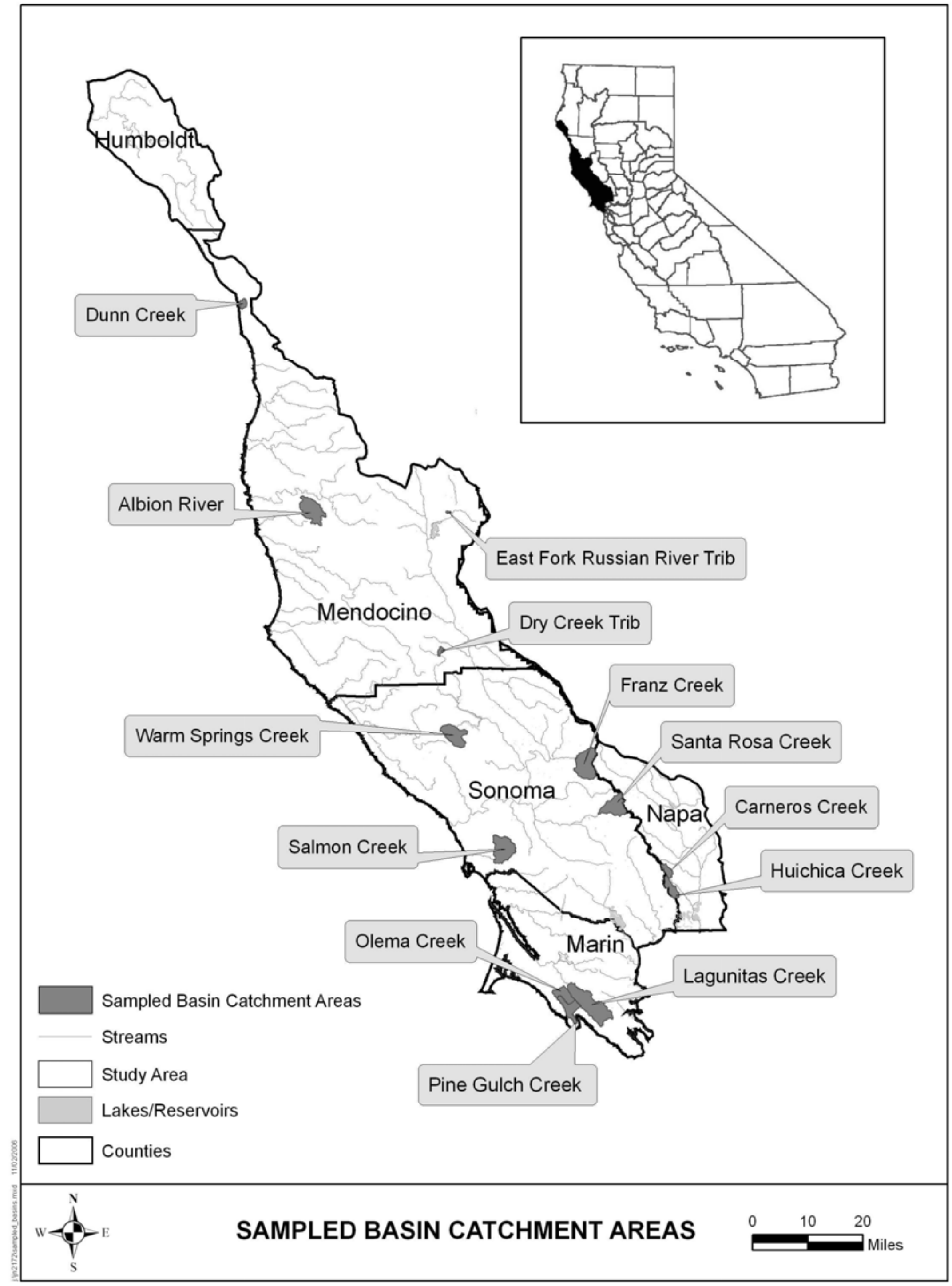

Figure G-4. Locations of validation sites sampled for passage and spawning transects that were evaluated for protectiveness of Policy element alternatives involving restrictions on flow.

Table G-1. Validation Sites Where Transects were Surveyed to Characterize Passage and Spawning Conditions Associated with Policy Elements Alternatives Regarding Restrictions on Flow.

				Number of Transects		
Stream	**Date Visited**	**Drainage Area (mi2)**	**Reach Slope (%)**	**Passage**	**Spawning**	**Water Years Analyzed**
Lagunitas Creek	8/28/2006	34.3	0.53	2	2	1956-1992
Olema Creek	8/28/2006	6.47	0.91	2	2	1987-2003
Pine Gulch Creek	8/28/2006	7.83	1.14	2	2	1999-2003
Huichica Creek	8/29/2006	4.92	0.79	1	1	2002-2005
Carneros Creek	8/29/2006	2.75	1.10	2	2	2002-2005
Salmon Creek	8/30/2006	15.7	0.69	2	2	1963-1975
Warm Springs Creek	8/30/2006	12.2	0.71	2	2	1974-1983
Dry Creek Trib	8/30/2006	1.19	2.04	1	1	1968-1969
Dunn Creek	8/31/2006	1.88	1.58	2	2	1962-1964
Albion River	8/31/2006	14.4	1.01	2	2	1962-1969
E. Fk. Russian River Trib	8/31/2006	0.25	2.50	1	0	1959-1961
Franz Creek	9/1/2006	15.7	0.29	2	2	1964-1968
Santa Rosa Creek	9/1/2006	12.5	1.37	1	2	1960-1970

G.2 HYDRAULIC ANALYSES

The transect cross-section stationing and bed elevation data were first reduced to a profile of uniformly spaced, 2 ft wide cells to approximate the minimum width of steelhead and coho redds and minimum passage lane width. This uniform discretization was applied primarily to model suitable width of habitat in increments corresponding to individual redds. This avoided predicting habitat being available at flows lower than those needed to support a redd. The resulting habitat-flow curves provided an order of magnitude characterization of habitat availability that could be directly converted to number of redds. In most cases, the survey data had been collected at 2 ft increments over spawning habitat, but smaller scale cross-channel variation in elevation and substrate suitability for spawning required finer resolution surveying in some cases. Figure G-5 depicts an example of how finer scale survey data were converted to 2-ft wide cells for subsequent use in hydraulic and habitat analysis.

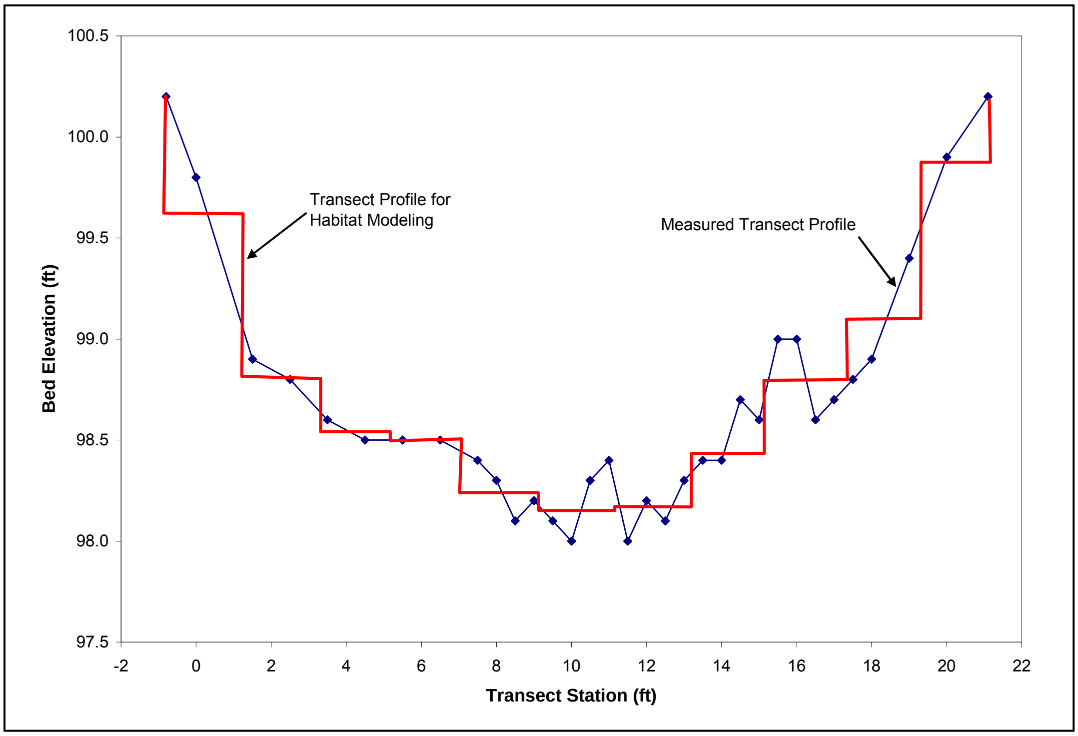

Figure G.5. Example of conversion of measured transect profile to 2-ft wide cells for subsequent hydraulic and habitat modeling.

Stage-flow rating curves were then developed for each cross-section. This required consideration of channel roughness. The average channel Manning's n coefficient magnitude was estimated using values recommended in Chow (1959) and reported in Barnes (1967). Photos taken during data collection were used to assist in deriving n values using these two references. The resulting n-value was then adjusted using the procedure developed by Cowan (1956) to take into account other channel characteristics not considered in the initial n-value. The final n-value was accordingly computed using:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5 \tag{G.1}$$

where n_o was the primary roughness value derived initially, and n_1, n_2, n_3, n_4, m_5, were the correction factors to account for surface irregularities, shape of transect profiles, channel obstruction, presence of vegetation, and channel meandering, respectively.

At lower flows, Manning's n values will generally be larger due to greater relative roughness, where the size of roughness elements comprising the streambed become proportionally larger relative to the flow depth. Flow resistance was estimated for lower flow conditions using the relative roughness equation developed by Limerinos (1970):

$$n = \frac{0.0926R^{1/6}}{1.16 + 2.0\log(\frac{R}{D_{84}})} \qquad \text{(G.2)}$$

where R is the hydraulic radius and D_{84} is the particle size for which 84% of particles are smaller. The D_{84} was estimated from pebble counts when collected, or as a multiple of a visual estimate of D_{50} when a pebble count was not collected. The multiplier value was estimated to be 1.6 based on the pebble count data collected at the other sites. Table G-2 lists the estimated values of D_{50} and D_{84}.

To estimate the flow below which relative roughness would be predicted to increase most significantly, the n values calculated for a range of flows using Equation (G.2) were compared with the n-value computed using Equation (G.1). For flows above that resulting in comparable n-value, the Manning's n coefficient used to estimate stage was set equal to the constant Equation (G.1) value. For lower flows, Equation (g.2) was applied. For example: Franz Creek had an estimated D_{84} =1.4 inches and n value of 0.037 determined using photos and Equation (G.1). Inserting n = 0.037 into Equation (G.2) gave a value of R = 0.35 ft, which corresponded to the estimated hydraulic radius for 15.6 cfs. For flows below 15.6 cfs, the n coefficients were estimated using Equation (G.2), while the n coefficient was held constant at n = 0.037 for higher flows.

Stage-flow rating curves were then derived using Manning's equation applied to the adjusted cross-section geometry and surveyed slope:

$$Q = \frac{1.486}{n} R^{2/3} S^{1/2} A \qquad \text{(G.3)}$$

Where A = cross-sectional area. Velocity was estimated for each 2-ft wide cell to model the suitability of spawning habitat at each flow. In the absence of usable field velocity measurements because of low flows during the time of sampling, Manning's equation was used to also estimate the velocity for each cell. Velocity v_i in each cell *i* was calculated as:

$$\mathrm{v_i} = \frac{1.486}{n} d_i^{2/3} S^{1/2} \qquad \text{(G.4)}$$

where d_i is cell water depth (ft), S is the channel slope assumed constant for all flow conditions. The total flow Q_C was calculated as:

$$Q_C = \sum_{i=1}^{i=p} v_i a_i \tag{G.5}$$

where p is the total number of wetted 2-ft cells in the transect, and a_i is the cell flow area (equal to $2d_i$ ft^2). Because the resulting value of Q_C calculated using Equation (G.5) was generally not equal to the actual daily value of flow Q, adjustment to the velocity v_i was needed to meet the continuity condition. The adjustment was accordingly made using the ratio $\alpha = Q/Q_C$, where the adjusted velocity in each cell was:

$$\mathrm{v}_{\mathrm{i},\alpha} = \alpha \mathrm{v}_{\mathrm{i}} \tag{G.6}$$

The adjusted velocity $v_{i,\alpha}$ was then compared with habitat suitability criteria in the spawning habitat analysis.

Table G-2. Values of Substrate Grain Size Distribution Percentiles Used in the Modeling of Channel Roughness

Stream	**D_{50} (inches)**	**D_{84} (inches)**
Lagunitas Creek	1.6	2.6
Olema Creek	1.8	2.7
Pine Gulch Creek	0.8	1.2
Huichica Creek	1.2	1.9
Carneros Creek	0.5	0.8
Salmon Creek	1.1	1.6
Warm Springs Creek	0.8	1.4
Dry Creek	1.2	1.9
Dunn Creek	0.8	1.4
Albion River	0.8	1.2
E.F. Russian River Trib	2.4	3.5
Franz Creek	0.7	1.4
Santa Rosa Creek	0.7	1.1

G.3 PASSAGE AND SPAWNING HABITAT ANALYSIS

Habitat analyses were performed for upstream passage and spawning in two stages. First, habitat-flow curves were generated by comparing hydraulic characteristics at a given flow calculated for each 2-ft wide transect cell, with binary habitat suitability criteria specific to the species (steelhead, coho, and Chinook) and habitat attribute (passage and spawning). Usability was defined as an either/or condition, where a cell was either usable if its hydraulic characteristic(s) met suitability criteria, or unusable otherwise. The total width of usable habitat per transect was computed by summing all usable 2-ft wide cells. This was performed for a range of flows to generate habitat-flow relationships for each transect and habitat attribute. Habitat usability was defined for upstream passage using suitability criteria for depth alone. Habitat usability was defined for spawning using suitability criteria for depth and velocity, with suitability of the cell's substrate for spawning determined in the field. The resulting habitat-flow relationships are plotted for both upstream passage and spawning in Appendix H.

The habitat-flow relationships were then used to calculate a daily habitat time series for each of the six daily flow time series considered (i.e., unimpaired flow and five impaired Flow Alternative Scenarios). Periodicity information presented in Appendix B was used to identify the dates between which upstream passage and spawning could occur, for each of the three anadromous salmonid species. Methods differed slightly for upstream passage and spawning analyses (Figures G-2, G-3):

- For passage, a cell was considered usable on a given day when the depth for the flow occurring that day equaled or exceeded the minimum passage depth suitability criterion. The lowest flow resulting in the first usable cell on either transect equaled the minimum flow needed for upstream passage.
- For spawning, a cell with suitable spawning substrates was considered usable for spawning when the depth for the flow occurring that day equaled or exceeded the minimum spawning depth suitability criterion, and the velocity was between lower and upper suitability criteria. Spawning was considered successful if a cell was found to be wetted by a minimum depth criterion over the estimated duration of incubation. Only those cells that remained sufficiently wetted over the estimated incubation period were considered usable for spawning.

The number of days for which passage and spawning opportunities existed during the period each species could migrate and spawn was then summed over each water year. Protectiveness was assessed in terms of differences in the number of days/water year that habitat opportunities existed for each impaired Flow Alternative Scenario, compared with unimpaired flow conditions.

Details are provided on the development of suitability criteria, incubation duration estimation, and general analysis steps for upstream passage and spawning habitat in the following, respective sub-sections.

G.3.1 Development and Analysis of Upstream Passage Habitat Suitability Criteria

Successful passage of adult anadromous salmonids to upstream spawning grounds is critical to the perpetuation of the species. Physical barriers such as waterfalls, log jams, or dams are the most common types of upstream passage barriers. Water quality can sometimes lead to the blocking of adult salmonid migrations, in the form of temperature or chemical barriers. Water quantity also affects upstream passage success, at either low or high flows. Upstream passage barriers are generally location-specific, where analysis requires detailed knowledge of the barrier characteristics at specific flows.

There are generally two ways in which flow can lead to passage restrictions. At low flows, the stream becomes too shallow for successful navigation upstream, preventing passage because of excessive fish body size. At high flows, the velocities may become so severe that the fish encounters an energetic barrier. In the latter case, the migrating fish is usually able to swim upstream along the edge of the channel where the water is slower than in the middle of the channel, at any flow no matter how high. The only time velocity becomes an effective barrier is when the entire flow of the channel becomes concentrated into a fast chute, the length and speed of which combine to overcome the fish’s swimming ability, and the structure of the barrier precludes the fish’s ability to leap over it. Since minimum flows are the focus of water rights considerations, potential passage barriers due to high flow are not relevant here. The issue for the Policy area is mainly related to addressing to what extent depth can become a significant barrier or impediment to passage in streams with altered flows (McEwan and Jackson 1996).

Low flow barriers are less location-specific than velocity barriers, and can occur at many places throughout the stream. The main criterion for successful upstream passage at low flows is depth. Many minimum-depth criteria can be found in the literature for salmonids, varying with species and investigation. The majority of studies have focused on the design of fish ladders, culverts, spawning channels, and other man-made structures, emphasizing not only the conditions within the structure, but also at the entrance and exit (e.g., Chambers et al. 1955; Thompson 1970; Slatick 1975; Evans and Johnston 1980; Bell 1991). Fewer studies have evaluated fish passage conditions in natural channels (e.g., Mosley 1982; Thompson 1972).

G.3.1.1 Compilation of Upstream Passage Suitability Criteria

Various investigators have suggested different methods and criteria for minimum passage depth (Table G-3). The method of Thompson (1972) has been widely applied in flow - passage assessments; the method involves minimum depth criteria for adult trout and salmon coupled with an appropriate lane width for passage. Thompson (1972) established a curved transect that followed the shallowest contour across a stream channel. For each transect, the flow is selected which meets minimum depth and maximum velocity criteria on at least 25 percent of the total transect width and a continuous portion equaling at least 10 percent of its total width. The result averaged from all transects is the minimum flow recommended for passage. Mosley

(1982) noted that Thompson's (1972) criteria were based on fish body size considerations rather than on controlled observations of fish behavior, and could be considered conservative. Mosley (1982) further noted that salmonids have been regularly observed to move upstream in water "very much" shallower than the criteria over distances of "some" meters. However, Mosley (1982) also pointed out that the effects of movement in water shallower than the criteria could be associated with abrasion and loss of spawning condition, and that the number and extent of shallow water passages needed to cause an effect were unknown. Bell (1991) recommended a narrower minimum passage width of 1 ft for large bodied salmon in the design of fishways. In the design of culverts, he recommended a minimum passage depth equal to the body size of the largest adult salmonid expected. The distance fish must travel through shallow water areas is also a critical factor (Barnhart 1986). Lang et al. (2004) determined the limiting depth to be the shallowest point over a riffle following the thalweg in the stream wise direction. Snider (1985) used a similar approach in Brush Creek and observed that a limiting passage corridor depth of 0.45 ft extending 40 ft long in a critical passage riffle was associated with steelhead downstream but not upstream, from which blockage could be inferred.

Table G-3. Summary of Relevant Upstream Passage Depth Criteria for Adult Salmon and Steelhead.

Author(s)	Depth (ft)	Comments
Thompson (1970)	1.0-1.25	Weir design, salmon and steelhead
Thompson (1972)	0.6	Coho, steelhead
	0.8	Chinook
Evans and Johnston (1980)	1.0	Culvert design minimum for salmon
Powers and Orsborn (1985)	0.4	Minimum chute depth for coho, will not pass all fish
	0.75	Dane's (1978) culvert design minimum for salmon
	1.0	Weir design for salmon, various references
Snider (1985)	0.45	Observed to block steelhead passage in Brush Creek
Bell (1991)	0.5	Minimum depth over weir; design value for salmon
	0.53	Minimum culvert passage depth for steelhead, using assumed maximum body height for steelhead (see text; 1.0 ft recommended for salmon in 1986 edition)
MTTU (2000)	0.8	Minimum safe passage depth based on adult salmonid body height of 0.6 ft plus one inch clearance off bottom
DFG (2002)	0.33	Minimum passage depth for coho
	0.6	DFG preferred passage depth for coho

Two principles are important with respect to selecting minimum passage depth criteria. First, Powers and Orsborn (1985) emphasized that flow depth needed to be greater than body depth in passage designs for the fish to make full use of its propulsive power. Orsborn and Powers (1985) noted the general length to height ratio equaled 5 for fish. For older steelhead that reached a mean length of approximately 32 inches in Waddell Creek (Shapovalov and Taft 1954), this equates to a design body height of 0.53 ft. Younger fish with a length averaging around 22 inches would have a design body height of approximately 0.36 ft.

Second, Evans and Johnston (1980) emphasized that fish passage structures must be designed for the successful passage of all fish, not just the most fit. The ability of the fish to overcome barriers decreases over time and distance (Paulik 1959; Powers and Orsborn 1985). In addition, specific passage locations may require subsequent recovery time before the fish is sufficiently fit to continue upstream. For example, Paulik and DeLacy (1957) determined it may take 6 hours for a steelhead to recover from an exhaustive swimming effort. Effects of strenuous muscular exertion and delay on upstream migrant salmon are detrimental to survival and these effects may have a cumulative and delayed action (Paulik 1959). Lang et al. (2004) noted that the condition of salmon and steelhead can deteriorate substantially prior to spawning in coastal California streams, when the fish are forced to spend time holding until the next freshet. Accordingly, they recommended that passage criteria for culverts should reflect weaker swimming adult fish irrespective of the distance to the ocean.

G.3.1.2 Identification of Passage Depth Criteria for Use in the Protectiveness Analysis

The ideas above lead to the conclusion that an upstream passage design criterion should not be set at the absolute minimum depth at which only a percentage of the fish can move upstream. Rather, the ideal criterion should enable passage of all possible sizes of individual fish. In addition, under ideal conditions of suitability for passage, there should be sufficient clearance underneath the fish so that contact with the streambed and abrasion are minimized, assumed here to be approximately 0.1 ft. However, in applying passage depth criteria, it must be recognized that the occurrence of critical depth at riffle crests can limit the depths available for passage under unimpaired flow conditions, where fish are naturally forced to pass through sections shallower than desired based on conservative design criteria. In such cases, application of a minimum passable criterion can be used to evaluate the threshold for passage.

Given the above considerations and the criteria listed in Table G-3, threshold upstream passage depth criteria were identified for evaluating the protectiveness of alternative elements proposed for application under the Policy (Table G-4).

Table G-4. Minimum Upstream Passage Depth Criteria for Analyzing the Protectiveness of the Policy for Upstream Passage Needs.

Species	Minimum Passage Depth Criterion (ft)
Steelhead	0.7
Coho	0.6
Chinook	0.9

G.3.1.3 Times of Year When Upstream Passage Was Analyzed

Upstream passage conditions were evaluated for the following periods for each species, reflecting the intersection of periodicity information presented in Appendix C and the range of start and end dates proposed as Policy element alternatives for the winter diversion season[8]:

Steelhead:	11/1 – 3/31 (reflects most streams except mainstem Russian River)
Coho:	10/1 – 2/28 (reflects observations in Brush Creek)
Chinook:	10/1 – 1/31 (reflects proposed alternative start to diversion season)

The effects of Policy diversion season alternatives were evaluated as they intersected the above periods (results are presented in Chapter 4 and Appendices I and J). For example, passage conditions prior to December 15 were not different between unimpaired flow conditions and flow conditions resulting from implementation of the diversion season proposed in the DFG-NMFS (2002) Draft Guidelines, December 15 to March 31 (DS1) because flows during that period would not be impaired (i.e., there would be no new diversions permitted before December 15 under the DFG-NMFS Draft Guidelines).

G.3.2 Development and Analysis of Spawning and Incubation Habitat Criteria

Spawning habitat conditions were evaluated in terms of the availability of spawning habitat and whether potential redd sites remained inundated through emergence. Thus, the analysis required identifying criteria for suitable spawning habitat, and understanding and setting reasonable time periods that would encompass the duration of the spawning act (i.e., length of time a pair of adult salmonids require to complete spawning – from redd construction to egg deposition and redd covering), and the length of the incubation period (i.e., from time of egg deposition to fry emergence), as described below.

In this analysis, spawning habitat suitability was defined by combinations of depth, velocity, and substrate characteristics. Thus, if a section of streambed met certain spawning criteria (see

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[8] The year-round diversion season alternative (DS2) proposed by MTTU (2000) is not protective of summer rearing habitat. Passage and spawning habitat was assessed over the full period of the remaining diversion season alternatives, from October 1 to March 31.

below), it was considered suitable for spawning, independent of its suitability for incubation. There are two ways of representing the suitability of each of these parameters for spawning. The first is to consider habitat suitability of a parameter as a continuous range of probability-of-use values between 0 and 1 (i.e., continuous habitat suitability index, or HSI curves; e.g., Bovee 1978; Snider 1985; Smith 1986; Sanford and Seppeler 1990). The second is to consider spawning habitat in a binary context where habitats are either useable or not (i.e., a threshold suitability index equal to 0 or 1 only; e.g., OSGC 1963; Rantz 1964; Thompson 1972; Collings et al. 1972b). For this analysis, the second approach was used to allow a first order evaluation of the effects of flows on spawning habitat suitability.

G.3.2.1 Compilation of Spawning Habitat Suitability Criteria

A variety of literature sources were compiled and reviewed to identify candidate suitability threshold criteria (Tables G-5, G-6). In addition, Smith (1986) applied Bovee's (1978) continuous depth and velocity HSI curves to an instream flow study in Lagunitas Creek; the curves reported by Smith (1986) were converted to threshold criteria for comparison. HSI curves are typically multiplied to generate a composite suitability index, assuming each parameter is selected independently by spawning salmonids. A composite depth-velocity suitability index equal to 0.5 was used as a cut-off point to generate a binomial condition, where composite values exceeding 0.5 (or, 50%) were assumed to be generally suitable, and lower values unsuitable. Accordingly, a depth or velocity magnitude was considered suitable if its HSI value exceeded 0.7 (i.e., a 0.7 HSI for depth times a 0.7 HSI for velocity results in a composite, or joint suitability of 0.49 ≈ 0.5).

In selecting threshold depth and velocity criteria, a variety of representations may be applied (Tables G-5, G-6). Where a range of depths or velocities have been reported to be used, the lower value of the range could be considered as the minimum acceptable or preferred. However, the actual value applied depends in part on the purpose for which the data will be used, and part on judgment. For example, even though Bell (1991) noted salmon generally spawn at a minimum depth of 0.75 ft, he recommended 1.5 ft for spawning channel design. Velocity was recommended to be less than sustained swimming speed, between 1.5-3.0 ft/s. DFG (2002) noted that coho salmon spawn mostly in small streams where flow is 2.9-3.4 cfs, and depths and velocities range between about 0.33-1.2 ft and 1 ft/s to 1.8 ft/s, respectively. Rather than selecting the lowest value of the depth range, DFG specified a minimum preferred depth of 0.6 ft (Table G-5). MTTU (2000) estimated steelhead and Chinook body heights as 0.6 ft and 0.8 ft, respectively. They evaluated minimum depth criteria at the deepest area in spawning habitat, and established a minimum depth criterion equal to 0.8 ft for adult salmonids based on body dimension and clearance above the streambed. OSGC (1963) developed threshold criteria based on data collected at numerous redds.

Table G-5. Summary of Minimum Depth Criteria Reported for Salmon and Steelhead Spawning.

Author(s)	Depth (ft)	Comments
		Steelhead
OSGC (1963)	0.6	Minimum depth
Thompson (1972)	0.6	Minimum depth
Swift (1976)	0.7	Preferred minimum depth
Smith (1986)	0.9	Lagunitas Creek HSI >0.70
Bratovich and Kelley (1988)	≥0.6	Spawning depths in Lagunitas Creek
Keeley and Slaney (1996)	0.85	Range minimum
	1.3	Mean value of range
Moyle (2002)	0.33	Minimum depth
SEC et al. (2004)	0.6	Preferred minimum depth
		Coho
OSGC (1963)	0.6	Minimum depth
Collings et al. (1972b)	1.0	Preferred minimum depth
Thompson (1972)	0.6	Minimum depth
Swift (1979)	0.5	Preferred minimum depth
Smith (1986)	0.43	Lagunitas Creek HSI >0.70
Bratovich and Kelley (1988)	≥0.5	Spawning depths in Lagunitas Creek
Keeley and Slaney (1996)	0.5	Range minimum
	0.8	Mean value of range
DFG (2002)	0.33	Range minimum in streams with flow 2.9-3.4 cfs
	0.6	Specified minimum depth
SEC et al. (2004)	0.6	Preferred minimum depth
		Chinook
OSGC (1963)	0.8	Minimum depth
Rantz (1964)	0.83	Favorable minimum depth
Collings et al. (1972b)	1.0	Fall Chinook preferred minimum depth
Thompson (1972)	0.8	Minimum depth
Swift (1979)	1.0	Preferred minimum depth
Keeley and Slaney (1996)	0.85	Range minimum
	1.3	Mean value of range
Moyle (2002)	0.8	Minimum typical depth

Table G-6. Summary of General Velocity Ranges Reported for Salmon and Steelhead Spawning.

Author(s)	Velocity (ft/s)	Comments
		Steelhead
OSGC (1963)	1.0-2.5	Proper range
Thompson (1972)	1.0-3.0	Suitable range
Swift (1976)	1.2-3.3	Preferred Range
Smith (1986)	1.4-2.6	Lagunitas Creek HSI >0.70
Bratovich and Kelley (1988)	0.7-2.0	Velocity range used in Lagunitas Creek
Keeley and Slaney (1996)	1.3 (0.9-2.3)	Mean value of range (range)
Moyle (2002)	0.65-5	Typical range
SEC et al. (2004)	2.0-3.8	Preferred range
		Coho
OSGC (1963)	1.0-2.5	Proper range
Collings et al. (1972b)	1.2-1.8	Preferred velocity range measured 0.4 ft above streambed
Thompson (1972)	1.0-3.0	Suitable range
Swift (1979)	0.25-2.5	Preferred Range
Smith (1986)	0.9-1.8	Lagunitas Creek HSI >0.70
Bratovich and Kelley (1988)	0.7-2.6	Velocity range used in Lagunitas Creek
Keeley and Slaney (1996)	0.8 (0.5-1.0)	Mean value of range (range)
DFG (2002)	1.0-1.8	Range in streams with flow 2.9-3.4 cfs
	1-3	Range used
SEC et al. (2004)		Preferred minimum depth
		Chinook
OSGC (1963)	1.0-2.5	Proper range
Rantz (1964)	1-3	Favorable range measured 0.3 ft above streambed
Collings et al. (1972b)	1.0-2.25	Fall Chinook preferred velocity range measured 0.4 ft above streambed
Thompson (1972)	1.0-3.0	Suitable range
Swift (1979)	1.0-3.0	Preferred Range
Keeley and Slaney (1996)	1.3 (0.9-2.8)	Mean value of range (range)
Moyle (2002)	1.0-2.6	Most spawning

G.3.2.2 Identification of Spawning Criteria for Use in the Protectiveness Analysis

The selection of depth and velocity criteria to be used in the spawning analysis was based on a review of similar criteria derived from a variety of investigators (Table G-5 and Table G-6). The review resulted in the selection of criteria presented in Table G-7. In general, the selected minimum depth criteria were about 0.2 ft greater than minimum reported values, and hence can be considered conservatively protective with respect to providing suitable depths for spawning. For velocity, the criteria proposed by Thompson (1972) typically exceed the range of values reported by other investigators for favorable or proper conditions. The Thompson (1972) criteria should therefore be conservatively protective of spawning habitats and were selected for analysis. The criteria were narrowed slightly for coho, reflecting their slightly smaller body size compared with steelhead and Chinook.

Potential spawning substrates were visually defined in the field as patches where the dominant substrate was judged to fall within the general range of D_{50} values used by steelhead and coho (Kondolf and Wolman 1993)(approximately 10-45 mm; Table G-7).

Table G-7. Minimum Depth, Favorable Velocity, and Substrate Spawning Criteria for Analyzing the Protectiveness of the Policy for Spawning Habitat Needs.

Species	Minimum Depth (ft)	Favorable Velocities (ft/s)	Useable Substrate D_{50} (mm)
Steelhead	0.8	1.0-3.0	12-46
Coho	0.8	1.0-2.6	5.4-35
Chinook	1.0	1.0-3.0	11-78

G.3.2.3 Identification of Incubation Habitat Depth Requirement

Successful incubation requires sufficient, continuous inundation by water to ensure delivery of oxygen, removal of metabolic wastes, and prevention of excessive warming or freezing (Bjornn and Reiser 1991). Steelhead and Chinook embryos can withstand periodic dewatering for a number of weeks following fertilization, provided the eggs remain moist and water temperatures are within acceptable limits for incubation (Reiser and White 1983). However, both egg growth and the size of alevins can be reduced when eggs are exposed to prolonged periods of dewatering (Becker et al. 1982; Reiser and White 1981). Embryos that are exposed for various periods of time may also prematurely hatch and emerge in response to elevated temperatures and accelerated development, resulting in increased mortality (Becker et al. 1982). Becker et al. (1982, 1983) noted that the egg phases were considerably more tolerant of temporary dewatering than the alevin phase, which has fully functioning gills. For example, advanced alevins are unable to withstand even one hour of repeated dewatering (Becker et al. 1982), and less than 6 hours of a one-time dewatering (Becker et al. 1983).

Egg burial depths for steelhead, coho, and Chinook generally exceed 0.5 ft (15 cm; DeVries 1997). In principle, a redd could withstand short term dewatering to this depth below the surface. However, intragravel velocities are likely to decrease, and gravel temperatures either increase or decrease depending on air temperature. Hence, to be protective of incubating eggs, the stream level should remain at or above the redd surface elevation for the duration of incubation. In addition, a minimal water depth is necessary so that alevins can emerge and move into the channel successfully. For this analysis, the minimum depth for incubation was assumed to be approximately 0.1 ft above the bed surface.

G.3.2.4 Redd Construction and Incubation Duration

It was assumed that for anadromous salmonid reproduction to be successful, water must be available throughout the duration of the spawning act and the period of incubation. An evaluation of the protectiveness of the Policy was completed by computing the amount of spawning habitat that remains continuously wetted over the combined redd construction and incubation period.

i. Duration of Redd Construction

Shapovalov and Taft (1954) noted that individual steelhead can take as little as approximately 12 hours or in some cases, more than a week to complete redd construction activities. Bratovich and Kelley (1988) noted that steelhead appeared to spawn quickly and left the redd soon after spawning. Trush (1991) observed redds completed within a 30 hour period, and considered 3 days as a conservative estimate of spawning duration in the small streams he surveyed. He noted that steelhead would ascend the channel, spawn, and emigrate back downstream all within the time frame of a single storm hydrograph. Gallagher (2000) estimated average stream residency of steelhead in the Noyo River, including pre- and post-spawning, to be 11 days. Shapovalov and Taft (1954) and Moyle (2002) both reported that coho can take a week or more to complete their spawning. Sandercock (1991) reported coho redd construction may take up to five days. Wydoski and Whitney reported that the average length of time spent on the spawning grounds by ripe coho is about 11 days for females and 12 to 15 days for males. Cook (2003) noted that Russian River Chinook begin spawning within a few days or weeks of arriving at the spawning ground. Healey (1991) noted that individual Chinook females spend at least 4 days defending a redd after spawning begins.

ii. Incubation

Water temperature controls the length of the incubation period, with the duration decreasing with increasing temperature. There are also inherent differences in the length of egg incubation between species, that likely reflect adaptations to their general life history periodicity and thermal environment over the incubation period (Quinn 2005). The literature indicates that incubation time for the same constant water temperature increases from steelhead to coho to Chinook (Figure G-6). Steelhead spawn in the spring and thus, must emerge before water temperatures reach summer levels. Coho spawn later and in smaller streams than Chinook, and both emerge earlier in the year than steelhead.

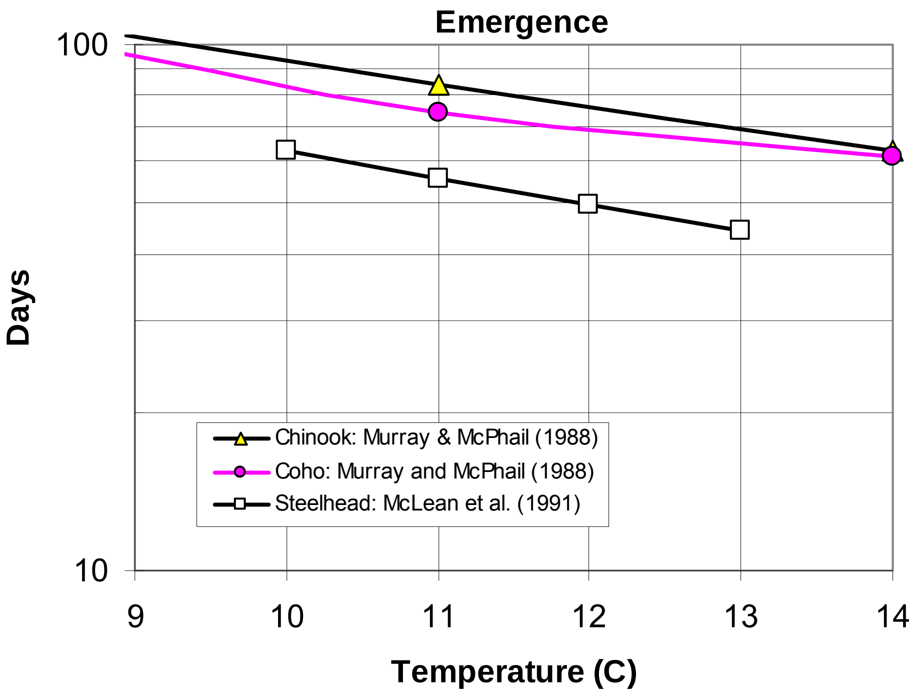

Figure G-6. Comparison of times from fertilization to emergence of steelhead, coho, and Chinook as a function of water temperatures commonly occurring in the Policy area during the winter and early spring.

Steelhead: Developing steelhead alevins may reside in the gravel for many weeks after hatching before emerging. For example, Leitritz and Lewis (1980) noted that the time to hatch for steelhead in California was about 30 days at 10.6ºC; Shapovalov (1937) noted that steelhead emergence from experimental gravel occurred between 49-64 days after fertilization at a temperature around 10.6ºC. Shapovalov and Taft (1954) noted the time to hatch in Waddell Creek was usually between 25-35 days, with emergence occurring 2-6 weeks post-hatch. The pre- and post-hatch stages differ in sensitivity to temporary dewatering as indicated above, where dewatering events occurring later in the development process are likely to be more detrimental than earlier dewatering events. Maintenance of sufficient instream flows may therefore become even more critical in March and April just as water availability decreases, than earlier in the winter period.

Crisp (1981) developed a model of median time to hatch for rainbow trout, which is applicable to steelhead, where:

$$\log(\text{days to 50\% hatch}) = -2.0961 (\log(T + 6.0)) + 4.0313$$

McLean et al. (1991) developed a comparable model for steelhead emergence, where the number of days after fertilization (D) is:

$$D = \frac{922050}{(T + 14.20)^{3.01}}$$

These relations are plotted in Figure G-7 for comparison.

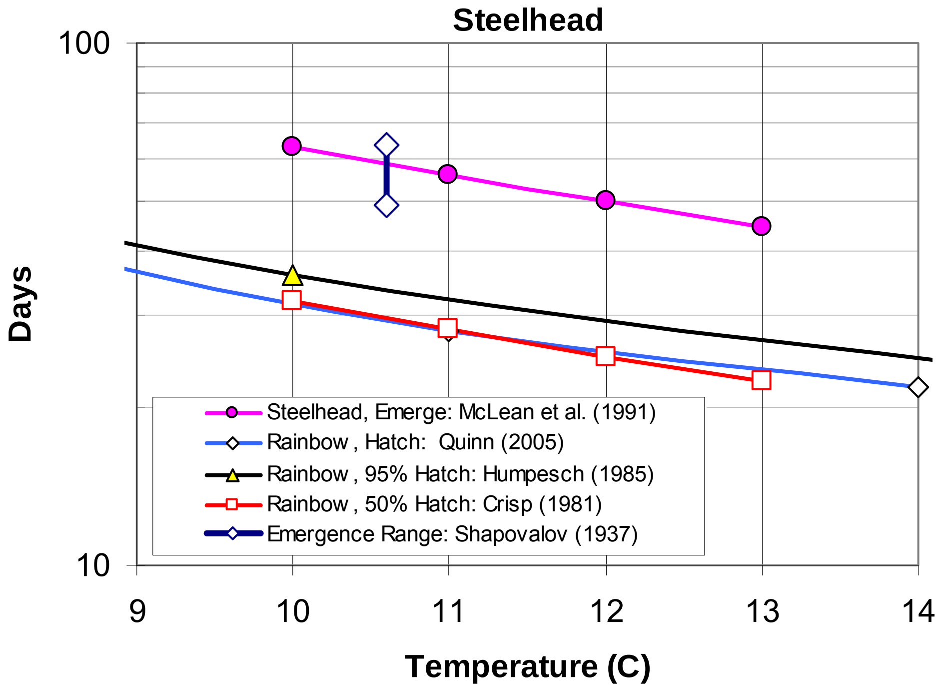

Figure G-7. Comparison of times from fertilization to hatching and emergence of steelhead as a function of water temperatures commonly occurring in the Policy area during the winter and early spring.

Coho: Developing coho alevins may reside in the gravel for many weeks after hatching before emerging. Shapovalov and Taft (1954) noted the time to hatch varied from about 38 d at 10.7ºC to 48 d at 8.9ºC. The time to hatch in Waddell Creek was observed to take from 35-50 days, with emergence occurring 2 to 7 weeks after hatching, depending on temperature and silt levels. Peak emergence occurred approximately 3 weeks post-hatch. DFG (2002) noted that coho embryos in California remain in the gravel between 2-10 weeks after hatching.

Beacham and Murray (1990) developed a model to compute the number of days to emergence (D) as a function of temperature:

$$\ln(D) = 7.018 - 1.069 \ln (T + 2.062)$$

McLean et al. (1991) developed another model for coho, where the number of days to emergence after fertilization (D) is:

$$D = \frac{923367}{(T + 15.03)^{2.90}}$$

These relations are plotted in Figure G-8 for comparison.

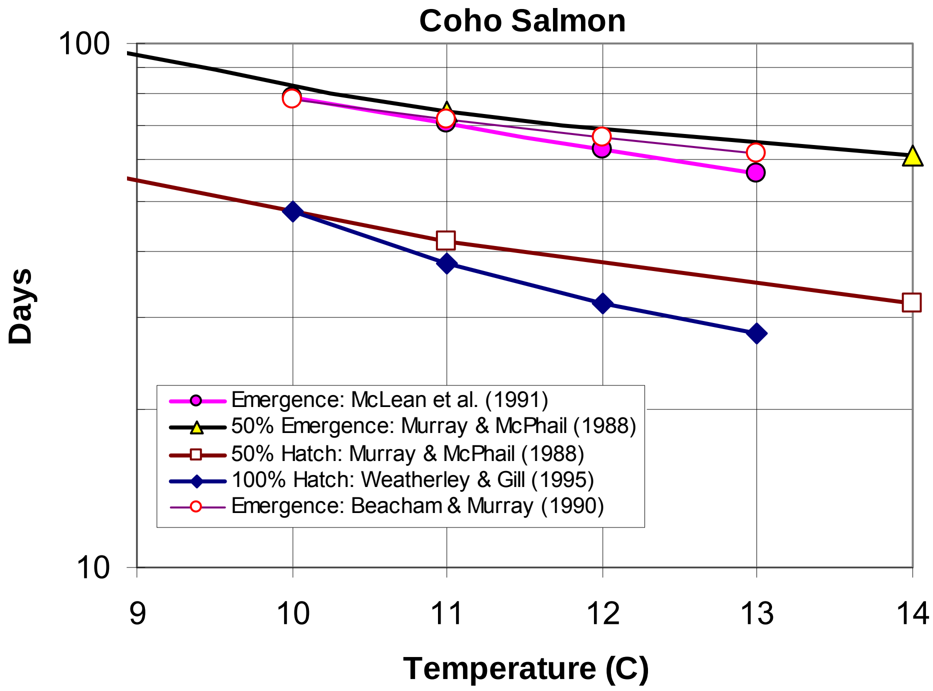

Figure G-8. Comparison of times from fertilization to hatching and emergence of coho as a function of water temperatures commonly occurring in the Policy area during the winter and early spring.

Chinook: A variety of incubation time data are available for Chinook (Figure G-9). Crisp (1981) developed a model of median time to hatch for Chinook salmon:

$$\log (\text{days to 50\% hatch}) = -1.8126 (\log (T + 6.0)) + 3.9166$$

Beacham and Murray (1990) developed a model for days to emergence (D) as a function of temperature:

$$\ln(D) = 10.404 - 2.043 \ln (T + 7.575)$$

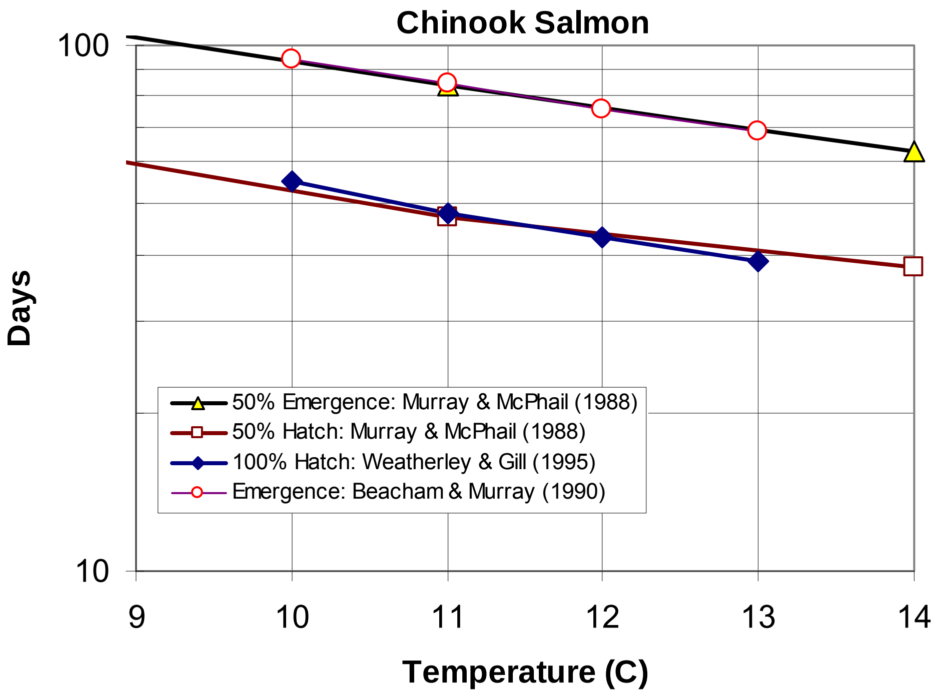

Figure G-9. Comparison of times from fertilization to hatching and emergence of Chinook as a function of water temperatures commonly occurring in the Policy area during the winter and early spring.

iii. Total Duration of Spawning and Intragravel Residence

Coho and steelhead may begin spawning as soon as they reach natal spawning grounds (Shapovalov and Taft 1954; NCRWQCB 2000; MTTU 2000). Available information for the Policy area generally indicates that the duration of spawning in small streams is shorter than in large streams, reflecting in large part, a shorter duration of elevated flows with decreasing channel size (MTTU 2000). However, smaller streams tend to have colder water temperatures than larger ones during the winter, which increases the incubation time. A review of recent USGS water temperature data for mid- to large size streams (drainage areas > 30 mi^2) in the Policy area indicates that water temperatures generally range around 10ºC to 11ºC during the December-February period, and around 12ºC to13ºC during the March-April period. Fong (1996) noted similar to slightly cooler temperatures in Redwood Creek, a small stream in Marin

County. This suggests applying two general seasonal criteria for incubation duration depending on date of spawning. The corresponding approximate times to emergence indicated in Figures G-7 to G-9 for these temperatures are presented accordingly for each species in Table G-8. In addition, it was assumed that a minimum of five days are needed for spawning in both large and small streams. Although spawning may occur in as little as one day in smaller flashier streams, the required incubation times may be longer due to cooler temperatures.

The duration of spawning and incubation used in the analysis varied depending on the date that spawning occurred and the species, reflecting the effect of water temperature. If the total duration specified in Table G-8 for a species spawning between November 1-February 28, exceeded the number of days calculated from the date of spawning to March 1, then the duration of incubation extending into the March 1- April 30 period was set to equal the larger value of either (i) the March 1-April 30 duration period (listed in Table G-8), or (ii) the number of days calculated between the start date and March 1. This "weighted" the longer incubation period associated with late winter spawning (and colder water temperatures), relative to the shorter incubation period associated with spring spawning (and warmer water temperatures).

Table G-8. Summary of Incubation Time, and Maximum Intragravel Residence Time from Initiation of Spawning to Emergence, for Anadromous Salmonids in the Policy Area. The Total Duration Numbers were Used in the Analysis.

Species	Approximate Time to Emergence From Fertilization (days)		Total Duration of Vulnerability to Dewatering (days)	
	Nov 1–Feb 28	**Mar 1–April 30**	**Nov 1–Feb 28**	**Mar 1–April 30**
Steelhead	60	47	65	52
Coho	75	62	80	67
Chinook	90	70	95	75

G.3.2.5 Times of Year When Spawning Was Analyzed

Spawning was considered possible over the following periods for each species, reflecting the intersection of periodicity information presented in Appendix C and the range of start and end dates proposed as Policy element alternatives for the winter diversion season:

Steelhead:	12/1 – 3/31 (excepts data from heavily regulated Lagunitas Creek)
Coho:	11/1 – 2/28 (excepts Mattole River – low risk of big diversion impact)
Chinook:	11/1 – 1/31 (based on Russian River system)

The effects of alternative variations in the Policy diversion season element were evaluated as they intersected the above periods (results are presented in Chapter 4 and Appendices I and J).

APPENDIX H

Upstream Passage and Spawning Habitat-Flow Relationships Derived for Validation Sites

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APPENDIX H
UPSTREAM PASSAGE AND SPAWNING HABITAT-FLOW RELATIONSHIPS DERIVED FOR VALIDATION SITES

The following graphs depict the habitat-flow relationships calculated for each transect sampled in September 2006 at the 13 validation sites. For most sites, four transects were sampled, including two spawning transects and two passage transects. For some sites, only three (Santa Rosa Creek), two (Huichica Creek and Dry Creek Tributary), or one transect (EF Russian River Tributary) were sampled depending on site conditions and accessibility to representative locations. Results are presented for each validation site in order from smallest to largest drainage area.

Each of the lines in the graphs represent habitat calculated for a transect placed across either a restrictive (at low flow) upstream passage location, or across higher quality spawning habitat (typically located between the pool edge and riffle crest). Habitat is quantified as a suitable width. In some cases there was no habitat; this is indicated by lines missing in the graph for specific legend labels.

The graphs are stepped in increments of 2 feet, reflecting the discretization of the channel profile into 2-ft wide cells approximating the minimum width of steelhead and coho redds (for spawning), or of a suitable corridor width for adult upstream passage. The graphs should be interpreted as follows:

- Passage begins at the lowest flow that width becomes non-zero. In the analysis of protectiveness, the limiting upstream passage flow for the site is set equal to the transect requiring the highest initial passage flow.
- The “optimum” flow providing maximum spawning habitat availability on a transect occurs at the lowest flow at which the greatest amount of spawning habitat is available. This protocol is functionally equivalent to that used by Rantz (1964) and Swift (1976, 1979). In the analysis of protectiveness, the limiting optimum spawning flow for the site is set equal to the transect requiring the lowest optimum flow. This limiting optimum spawning flow is the flow used to determine the Upper MBF (MBF3) alternative as discussed in Section E.3.2.
- The flow providing marginally useable spawning habitat conditions on a transect, occurs at the lowest flow for which suitable width is non-zero. Flows below this level do not provide spawning habitat on the transect and are thus not protective at all. In the analysis of protectiveness, the limiting spawning flow for the site is set equal to the transect requiring the lowest flow for which suitable width is non-zero. This limiting spawning flow is the flow used to determine the Lower MBF (MBF4) alternative as discussed in Section E.3.3.

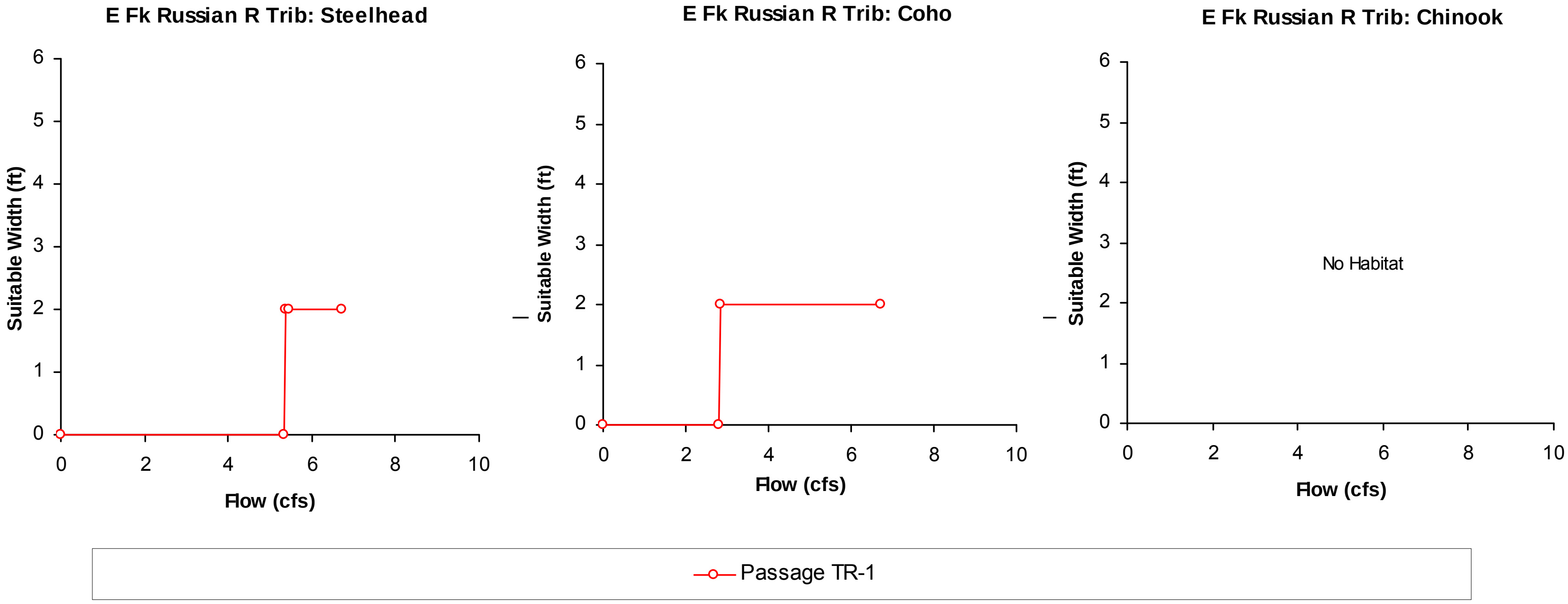

Figure H-1. Habitat-flow curves calculated for the upstream passage transect sampled in the East Fork Russian River Tributary validation site. No spawning habitat transects available at this site.

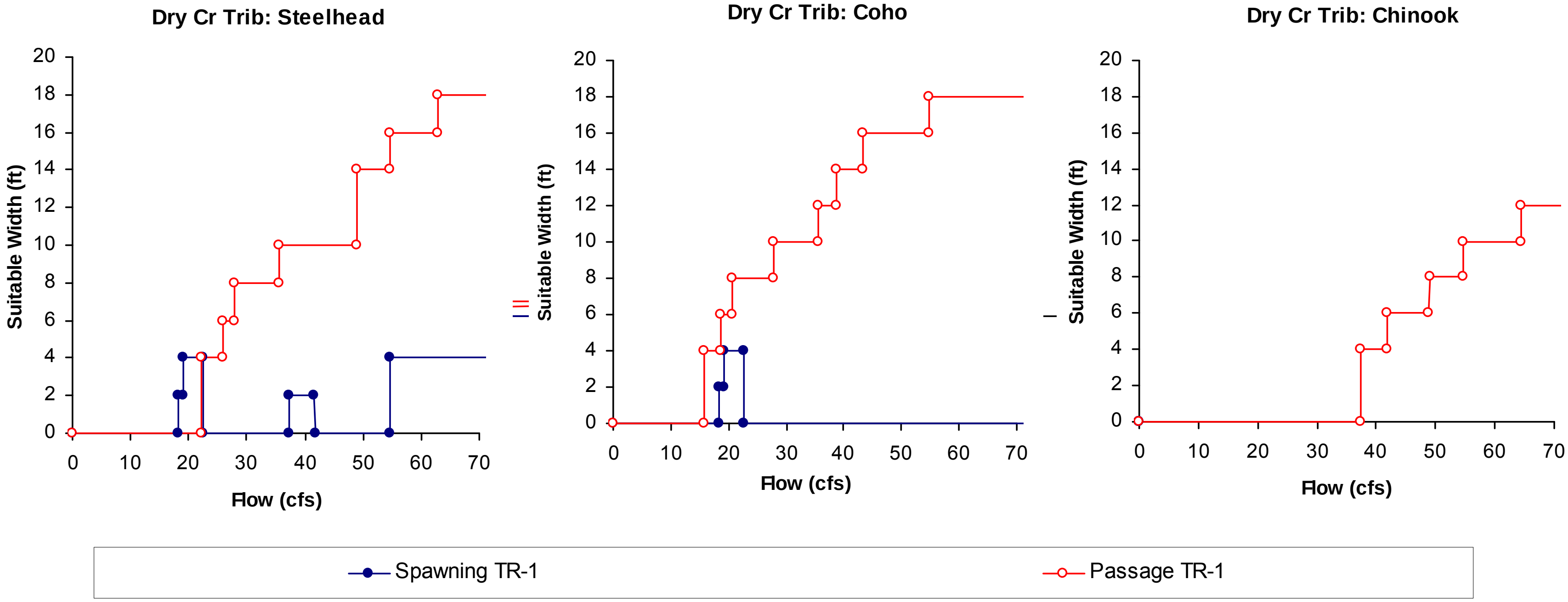

Figure H-2. Habitat-flow curves calculated for the upstream passage and spawning transects sampled in the Dry Creek Tributary validation site.

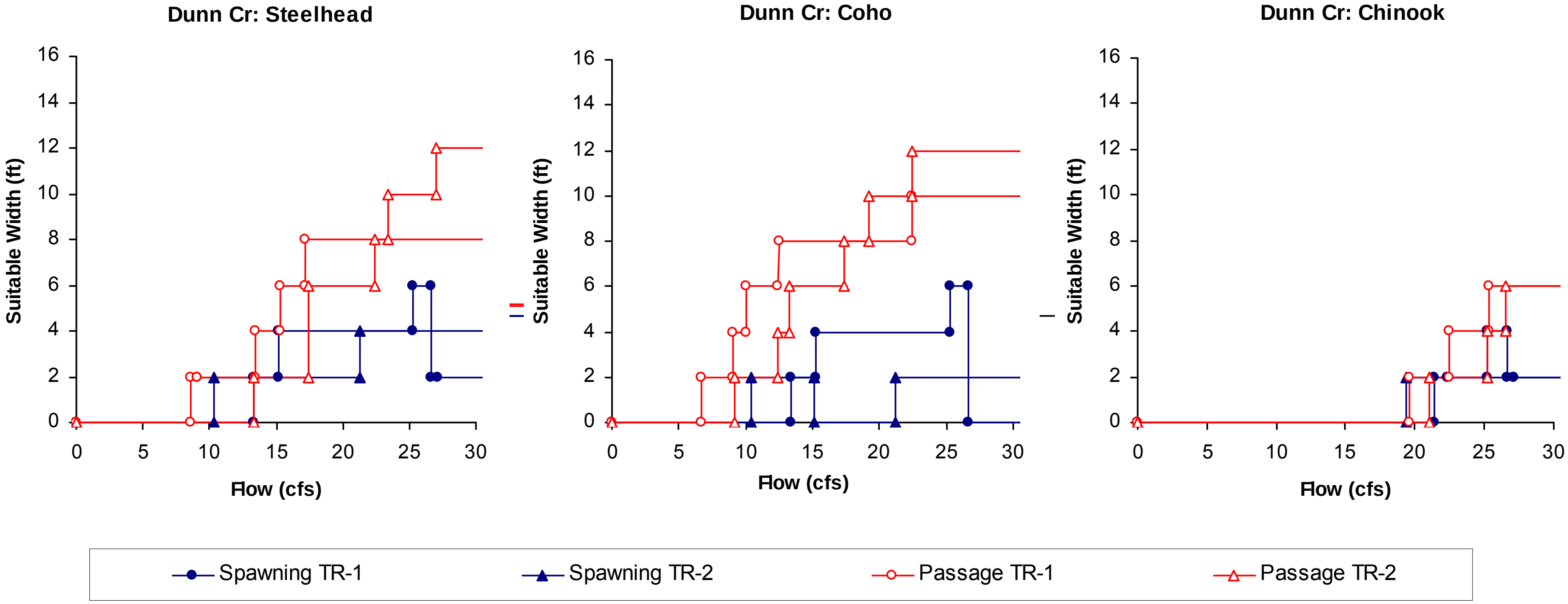

Figure H-3. Habitat-flow curves calculated for the upstream passage and spawning transects sampled in the Dunn Creek Tributary validation site.

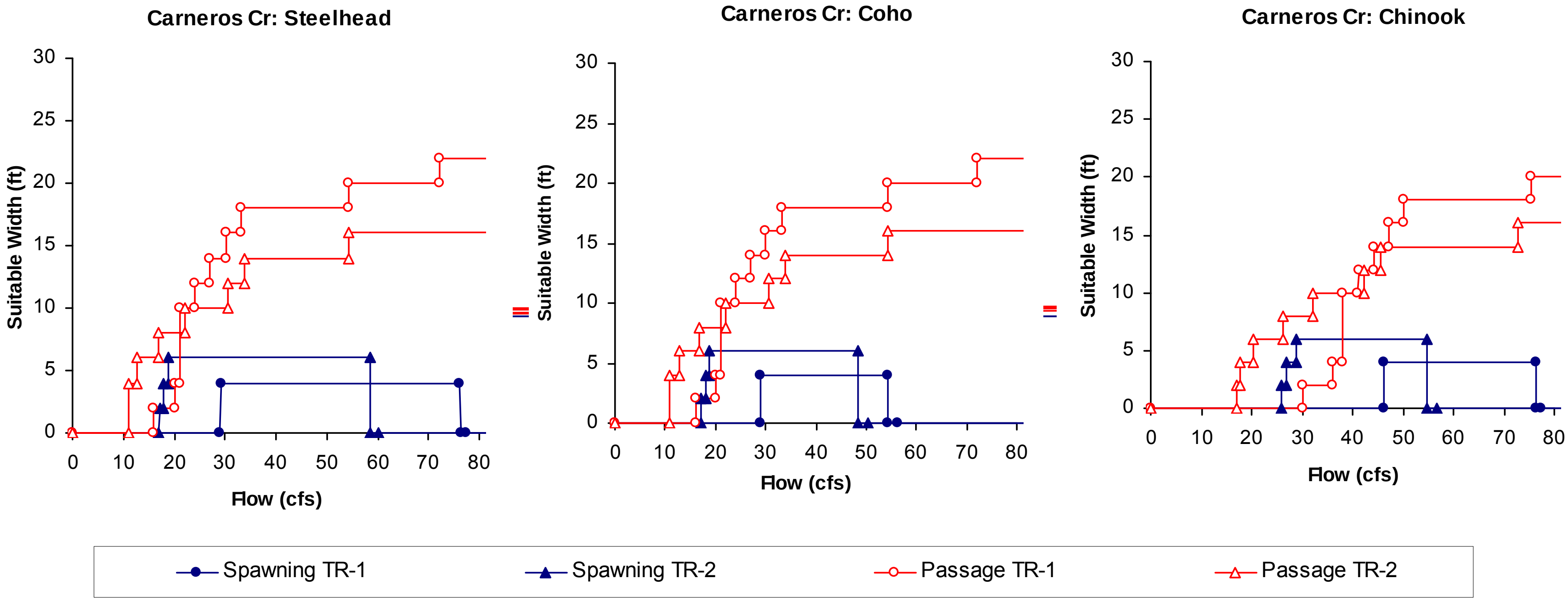

Figure H-4. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Carneros Creek validation site.

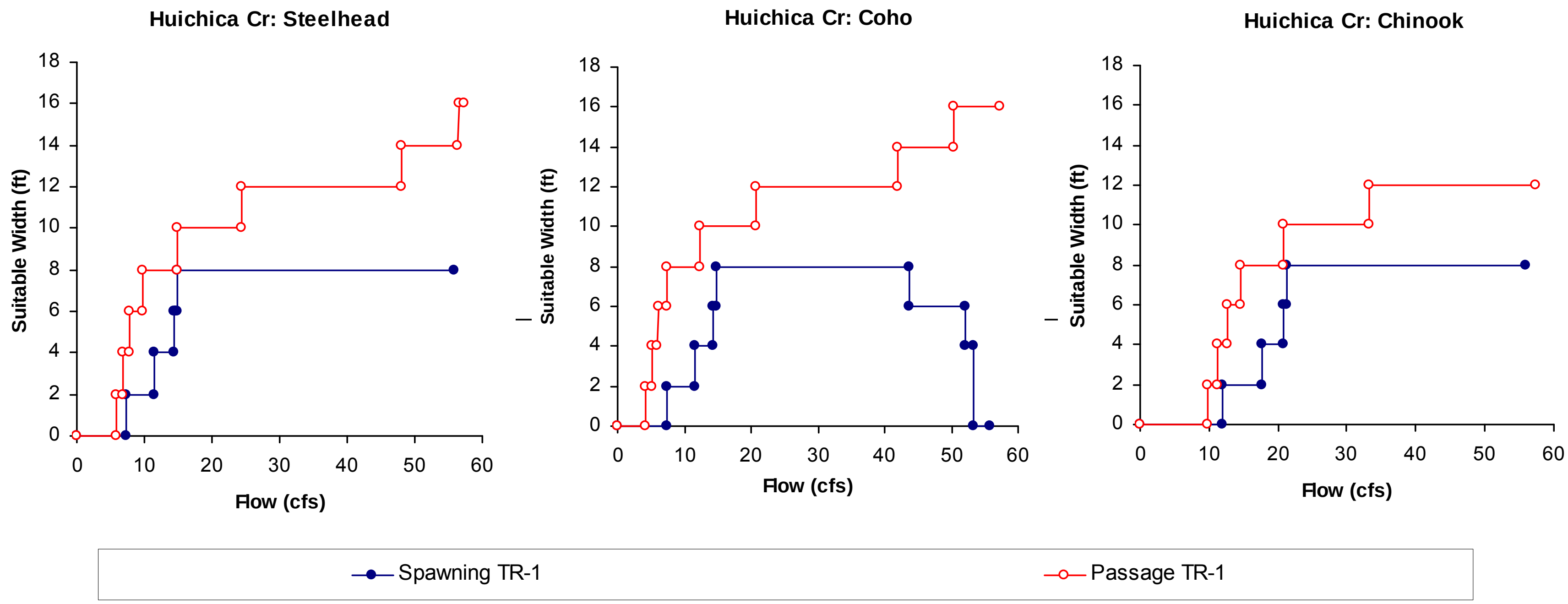

Figure H-5. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Huichica Creek validation site.

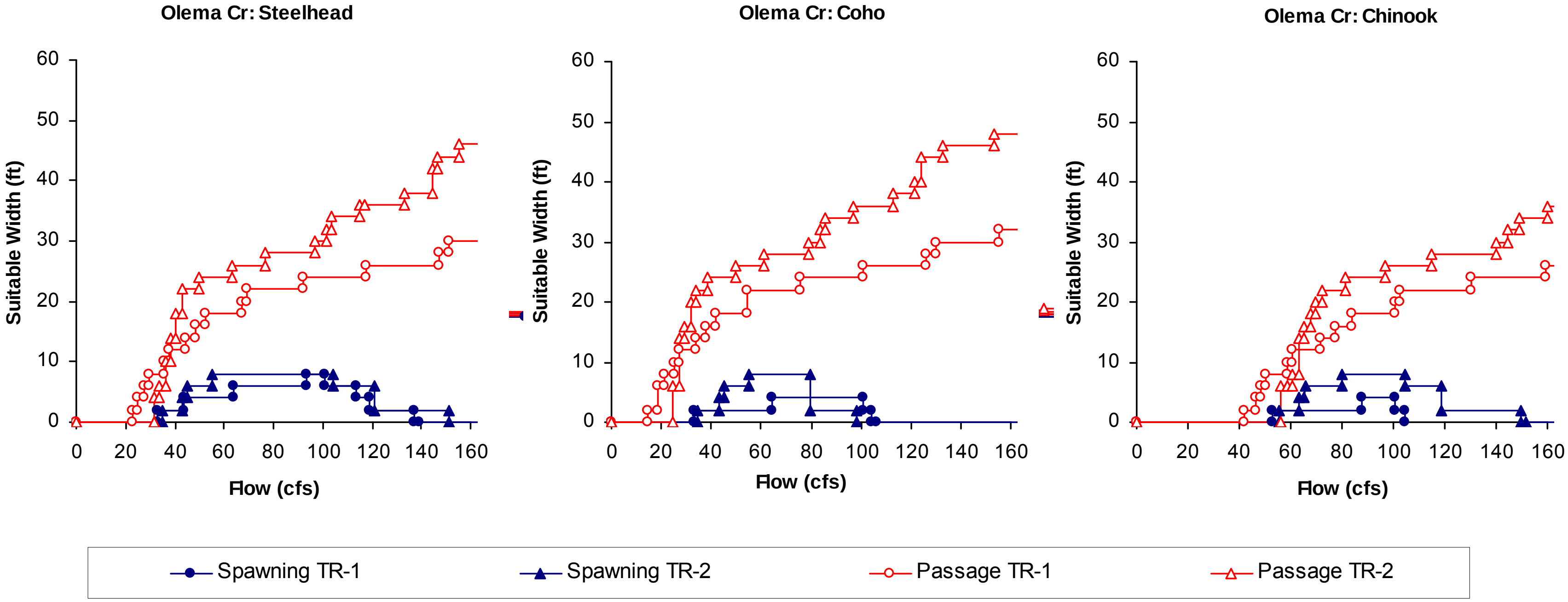

Figure H-6. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Olema Creek validation site.

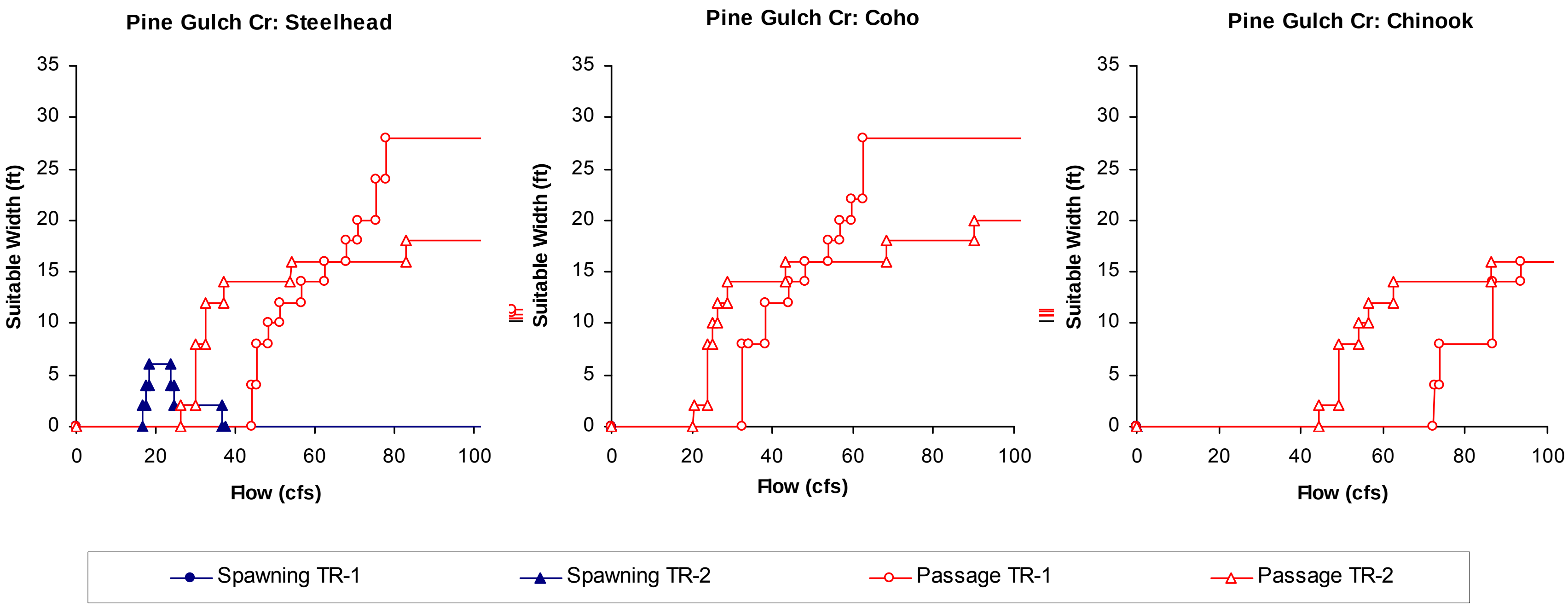

Figure H-7. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Pine Gulch Creek validation site.

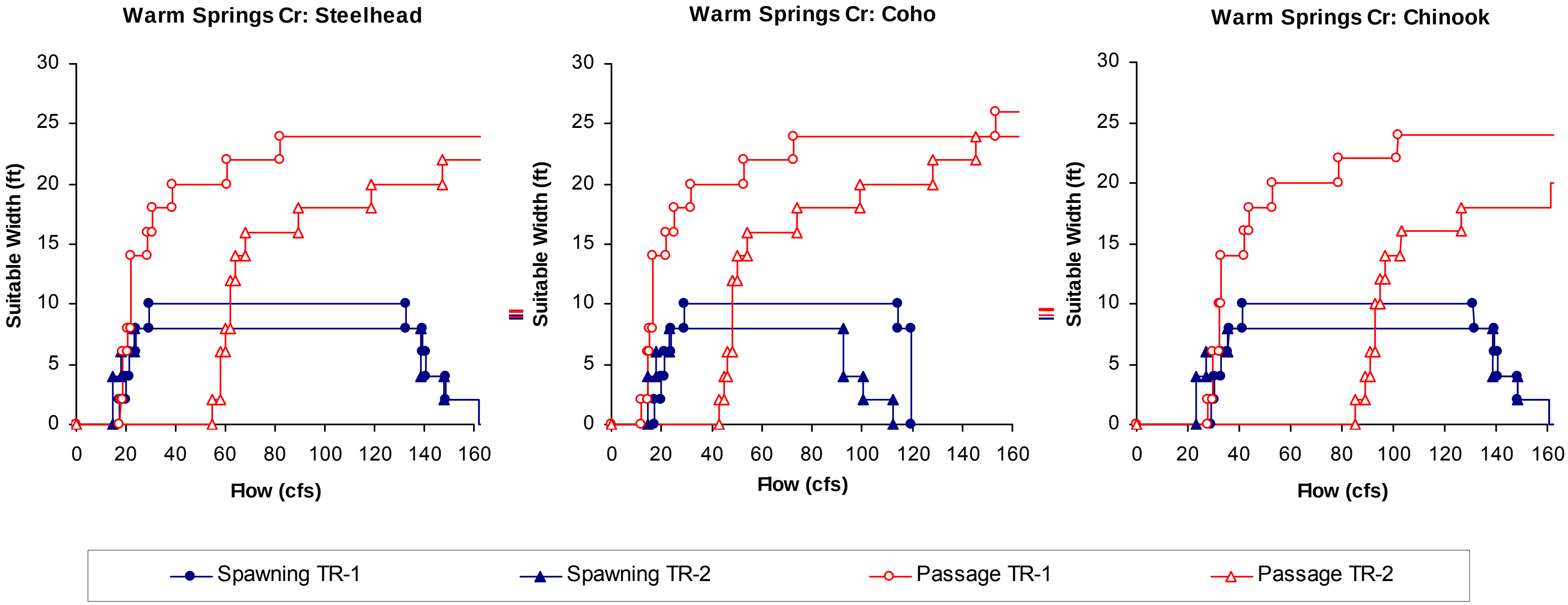

Figure H-8. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Warm Springs Creek validation site.

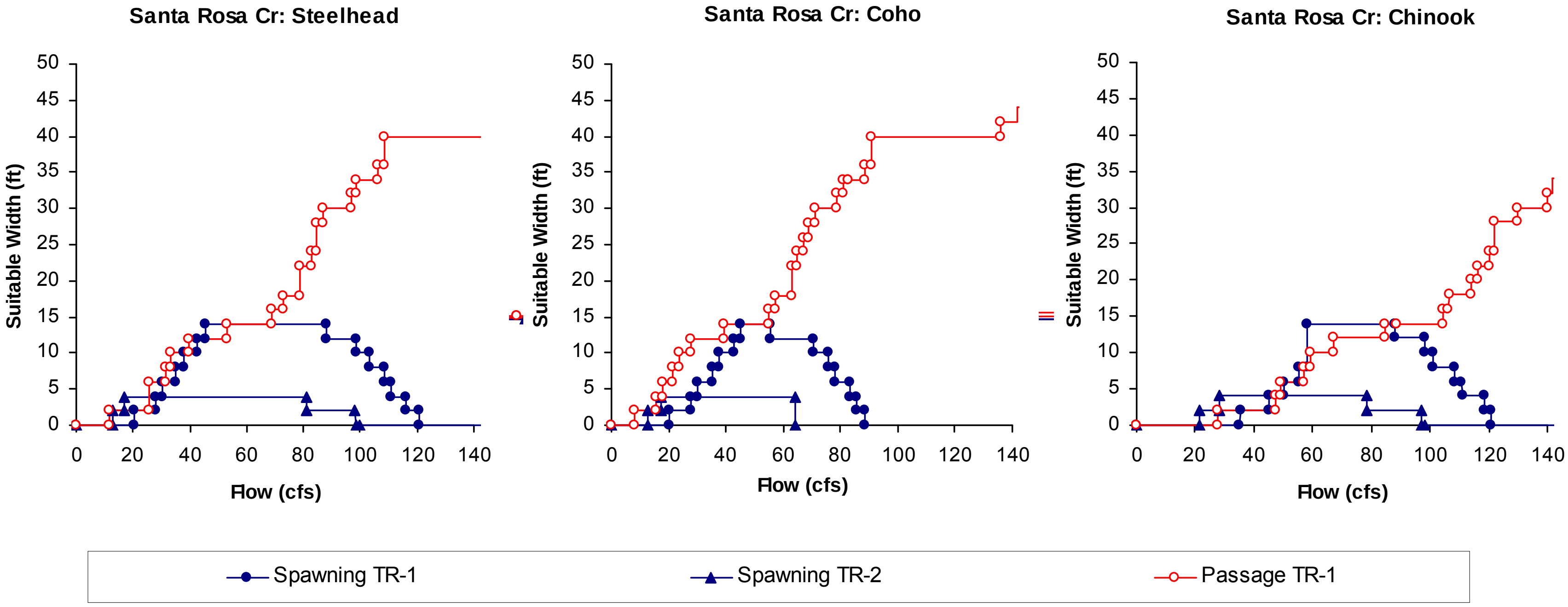

Figure H-9. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Santa Rosa Creek validation site.

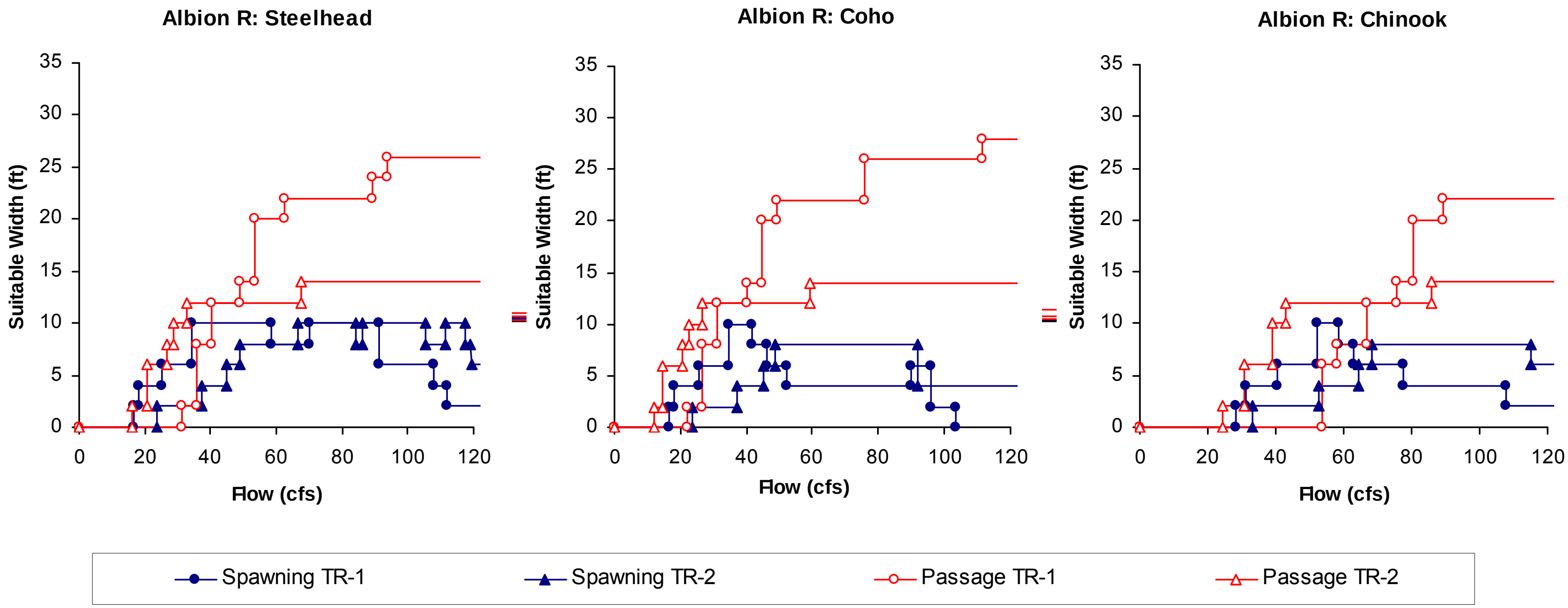

Figure H-10. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Albion River validation site.

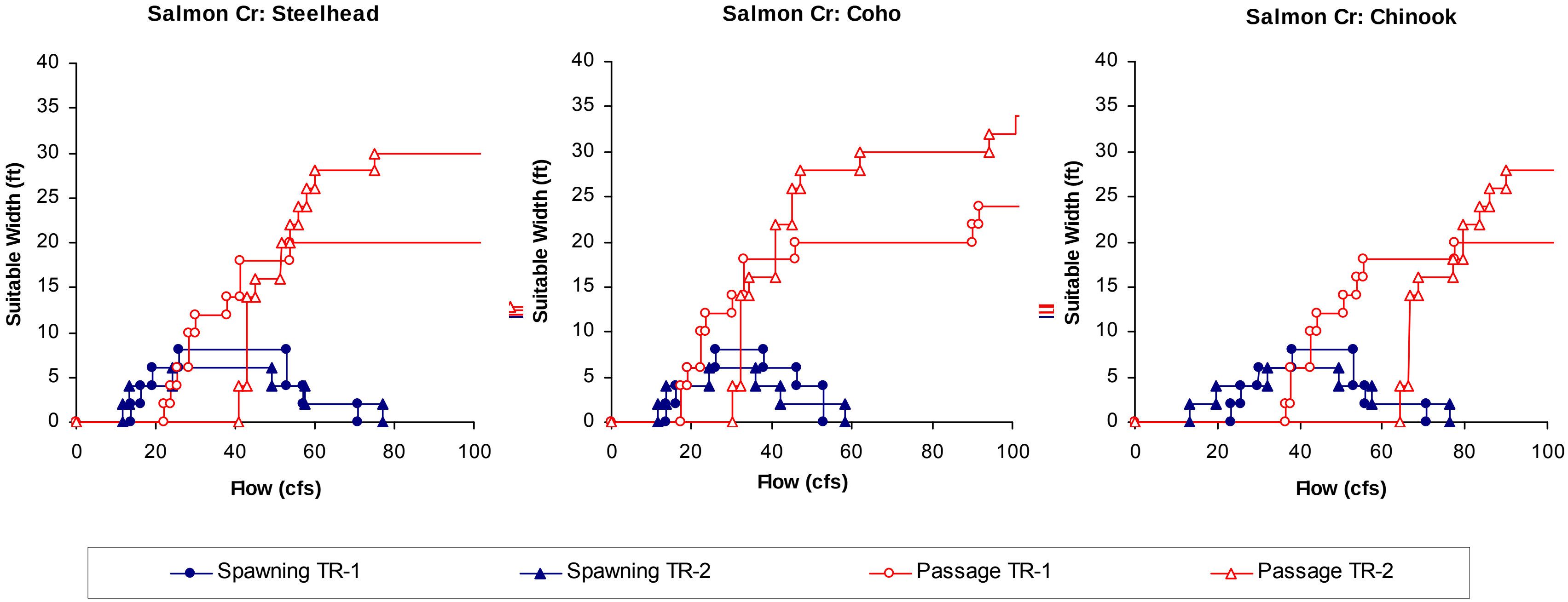

Figure H-11. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Salmon Creek validation site.

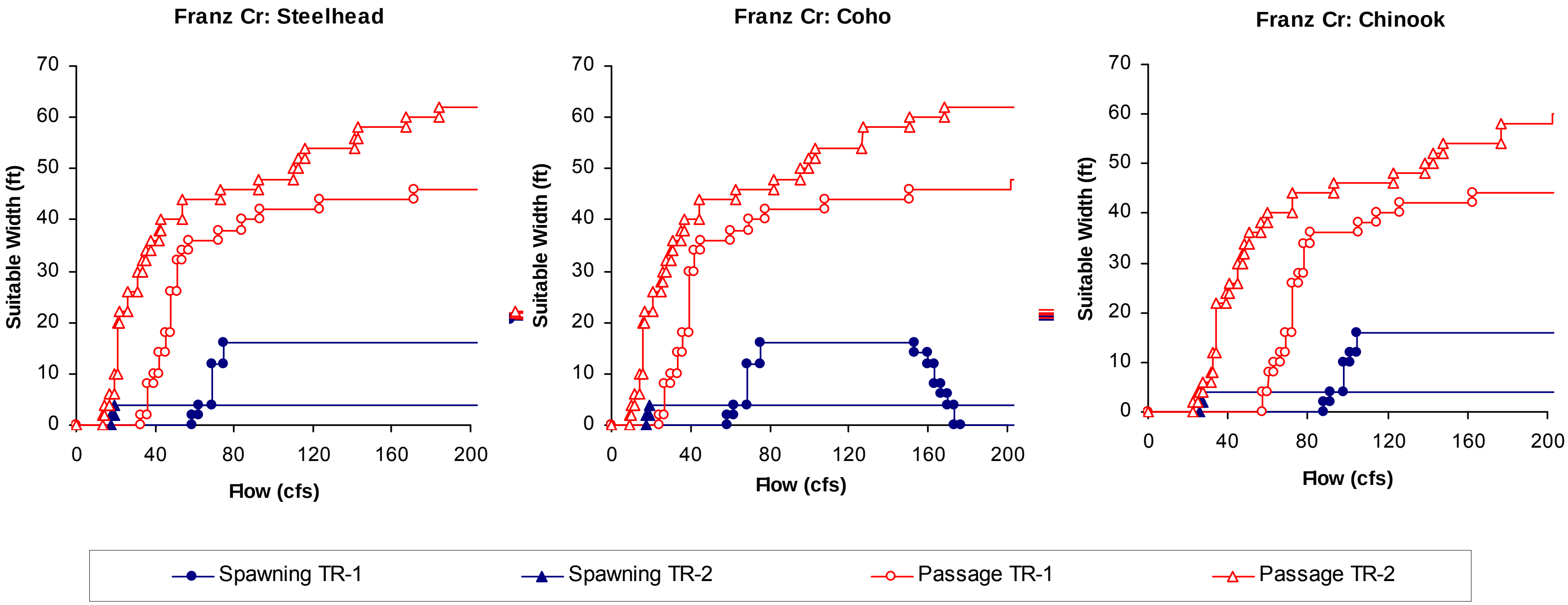

Figure H-12. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Franz Creek validation site.

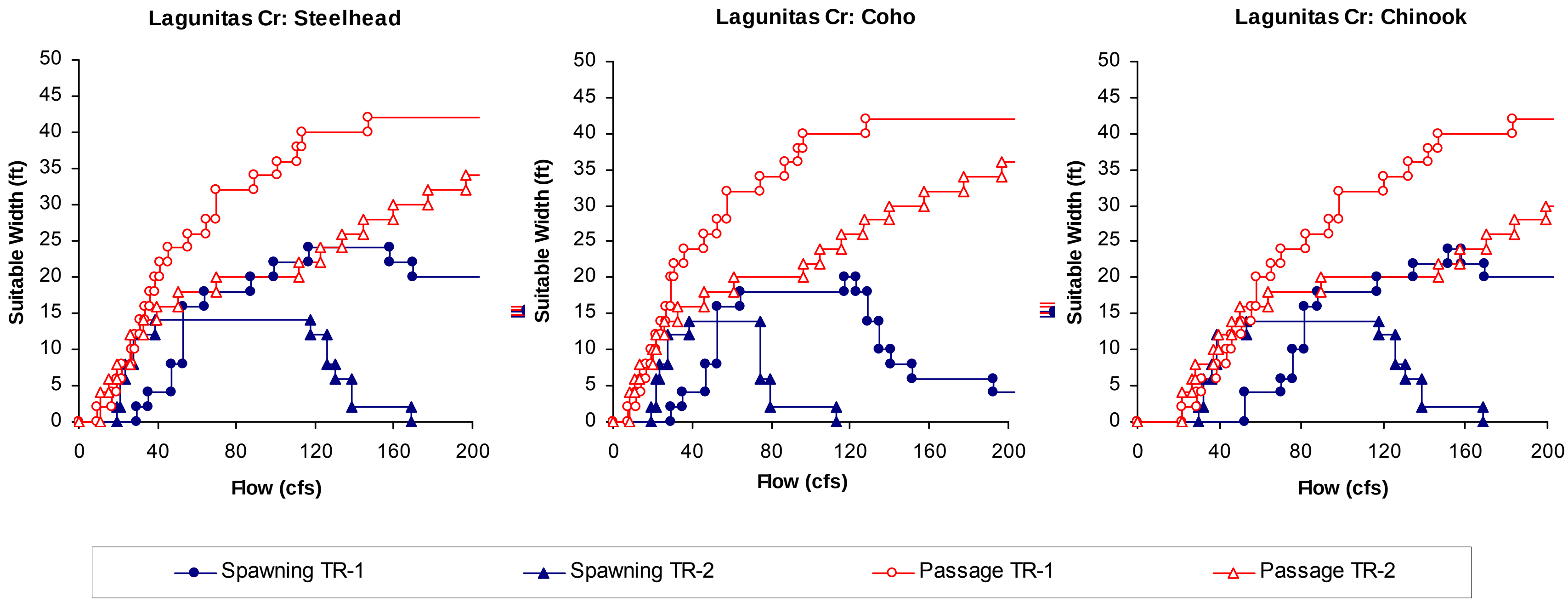

Figure H-13. Habitat-flow curves calculated for upstream passage and spawning transects sampled in the Lagunitas Creek validation site.

APPENDIX I

Results of Validation Site Protectiveness Analyses:

Number of Days Per Water Year with Upstream Passage and Spawning Opportunities During the 10/1-3/31 Period

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APPENDIX I

RESULTS OF VALIDATION SITE PROTECTIVENESS ANALYSES:

NUMBER OF DAYS PER WATER YEAR WITH UPSTREAM PASSAGE AND SPAWNING OPPORTUNITIES DURING THE 10/1-3/31 PERIOD

This appendix provides the results of the passage and spawning habitat analysis (described in Appendix G) in terms of the minimum, mean and maximum number of days per water year of passage and spawning opportunities during the October 1 to March 31 period. Results are given for the unimpaired flow conditions and for flows impaired to the maximum extent allowed by the Policy element alternatives selected for five specific Flow Alternative Scenarios, described in Table I-1. Results are presented graphically for each validation site in order from smallest to largest drainage area.

‘No Habitat’ indicates validation sites that do not have sufficient habitat (defined as suitable width) under any flow condition to provide either passage or spawning opportunities (as indicated) for the indicated species.

Table I-1. Flow Alternative Scenarios Evaluated in the Analysis of Protectiveness.

Flow Alternative Scenario	Description, Policy Element Alternative Criteria Used		
Unimpaired	Flow conditions using the estimated natural hydrology described in the previous section		
Alternative Scenario 1 *(DFG-NMFS 2002 Criteria)*	Flow conditions impaired with the maximum diversions permitted by the following Policy Element Alternatives: DS1 12/15-3/31	MBF1 February median daily flow	MCD1 Rate 15% of 20% winter exceedance flow
Alternative Scenario 2 *(MTTU 2000 Criteria)*	DS2 Year round	MBF2 10% exceedance flow	MCD4 Rate Calculated for each site following the procedure depicted in Figure 3-2
Alternative Scenario 3 *(Upper Flow Scenario)*	DS1 12/15-3/31	MBF3 Upper MBF specified as a function of drainage area and mean annual flow	MCD1 Rate 15% of 20% winter exceedance flow
Alternative Scenario 4 *(Lower Flow Scenario)*	DS3 10/1-3/31	MBF4 Lower MBF specified as a function of drainage area and mean annual flow	MCD2 Rate 5% of 1.5 year flood magnitude
Alternative Scenario 5 *(DFG-NMFS 2002 Criteria)*	DS1 12/15-3/31	MBF1 February median daily flow	MCD3 Volume CFII = 10% estimated unimpaired runoff

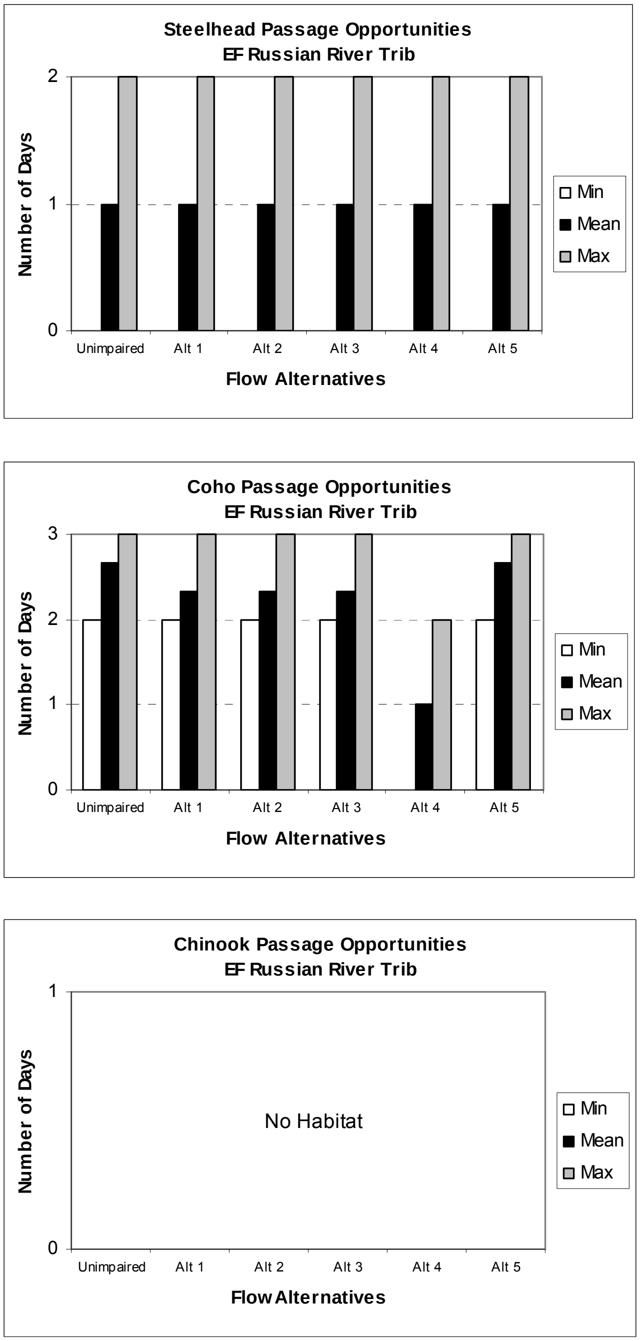
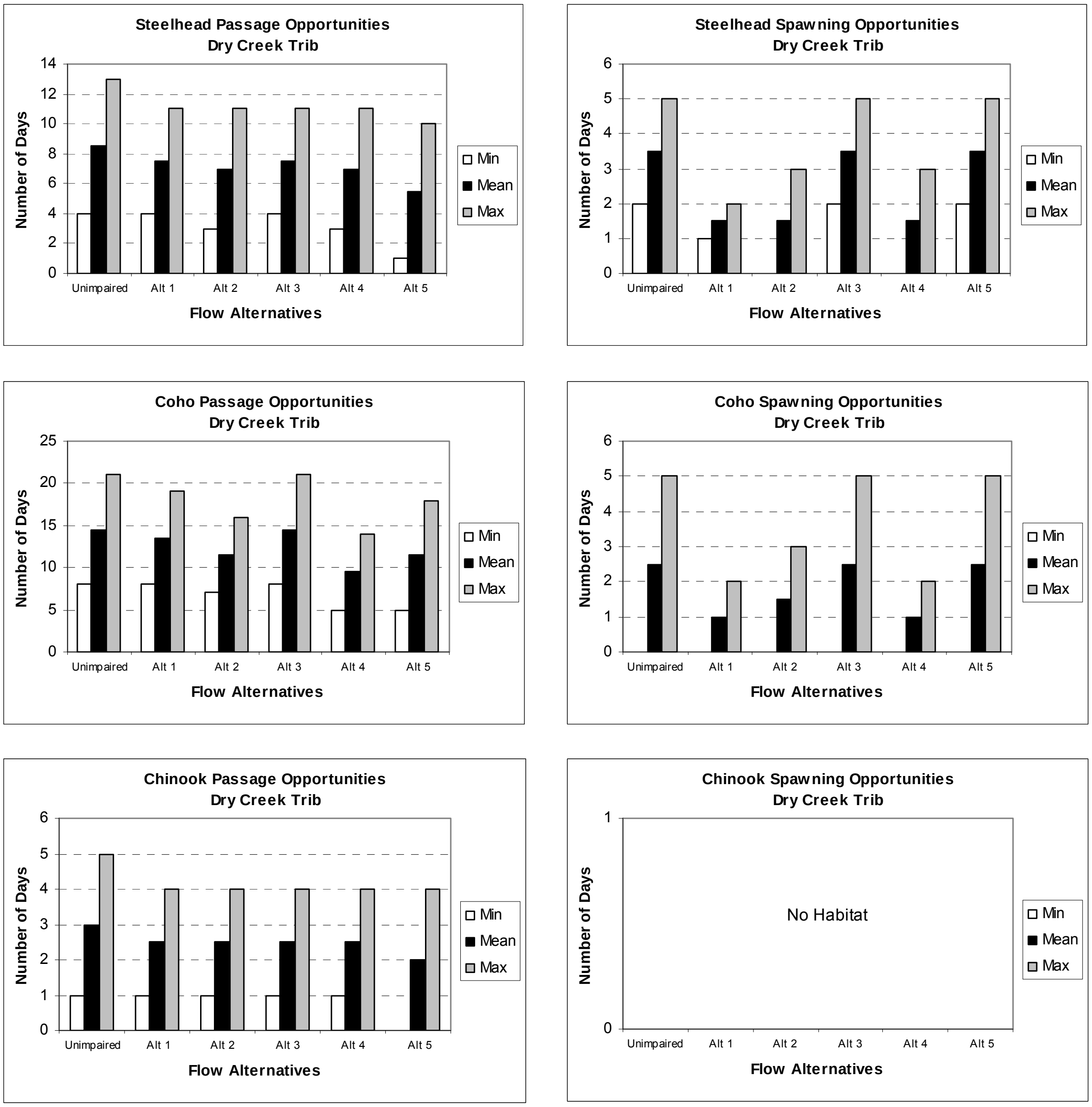


Figure I-1. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage in the East Fork Russian River Tributary validation site (drainage area = 0.25 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage periods, for the period of record at a nearby USGS stream gage. Spawning opportunities were not assessed.



Steelhead Passage Opportunities Dry Creek Trib

Steelhead Spawning Opportunities Dry Creek Trib

Coho Passage Opportunities Dry Creek Trib

Coho Spawning Opportunities Dry Creek Trib

Chinook Passage Opportunities Dry Creek Trib

Chinook Spawning Opportunities Dry Creek Trib

Figure I-2. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Dry Creek Tributary validation site (drainage area = 1.19 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

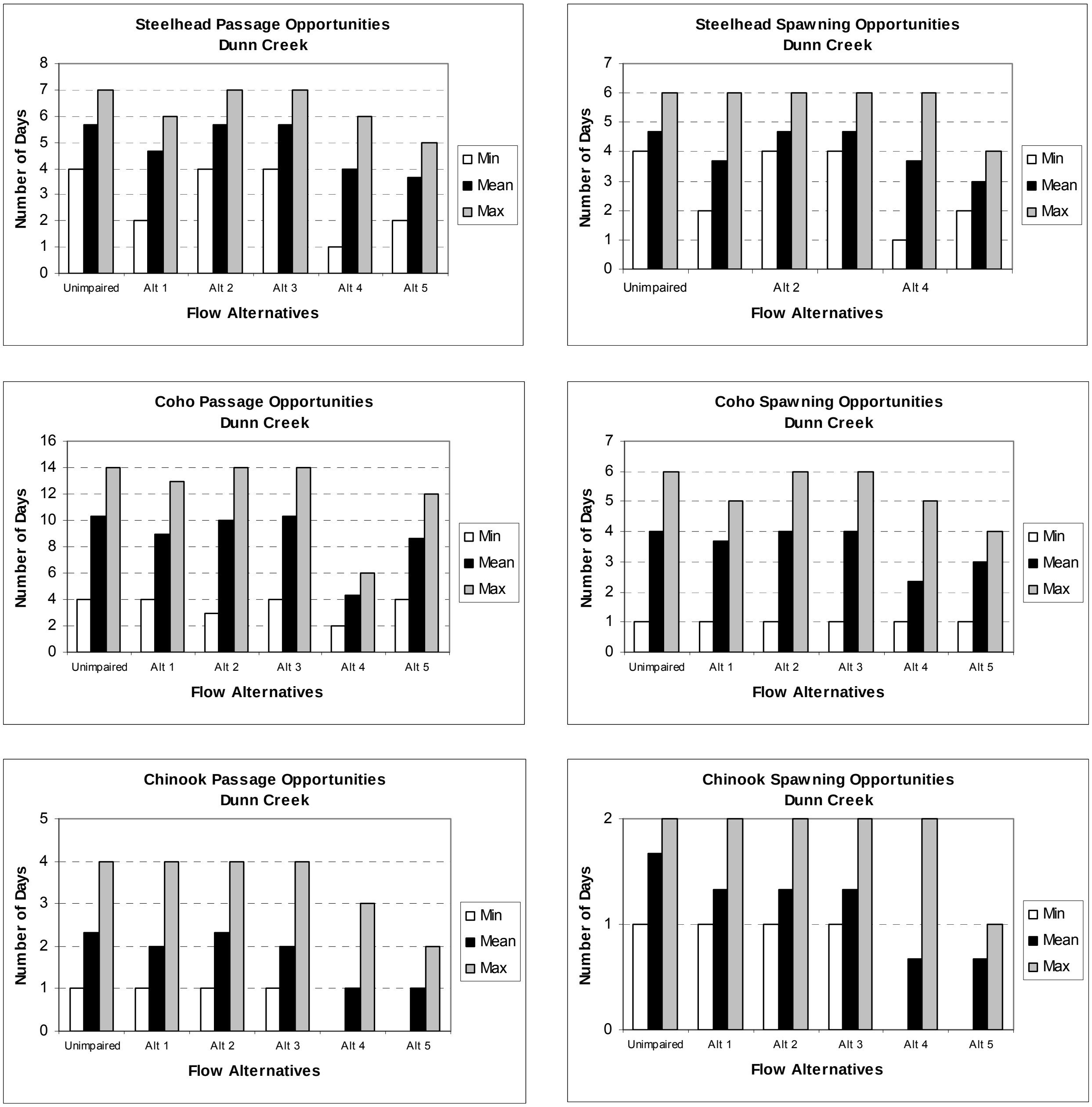


Figure I-3. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Dunn Creek validation site (drainage area = 1.88 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

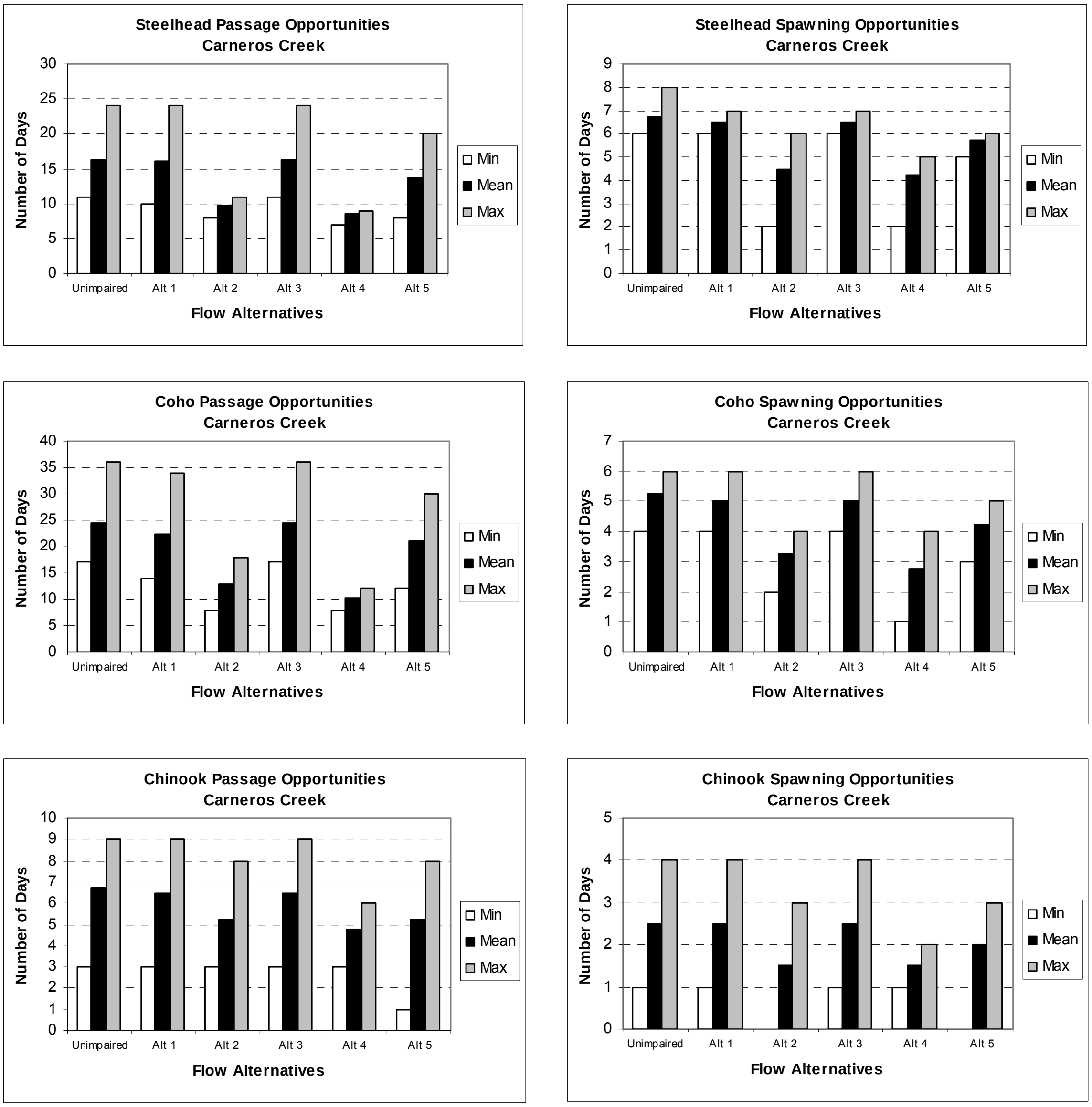


Figure I-4. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Carneros Creek validation site (drainage area = 2.75 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

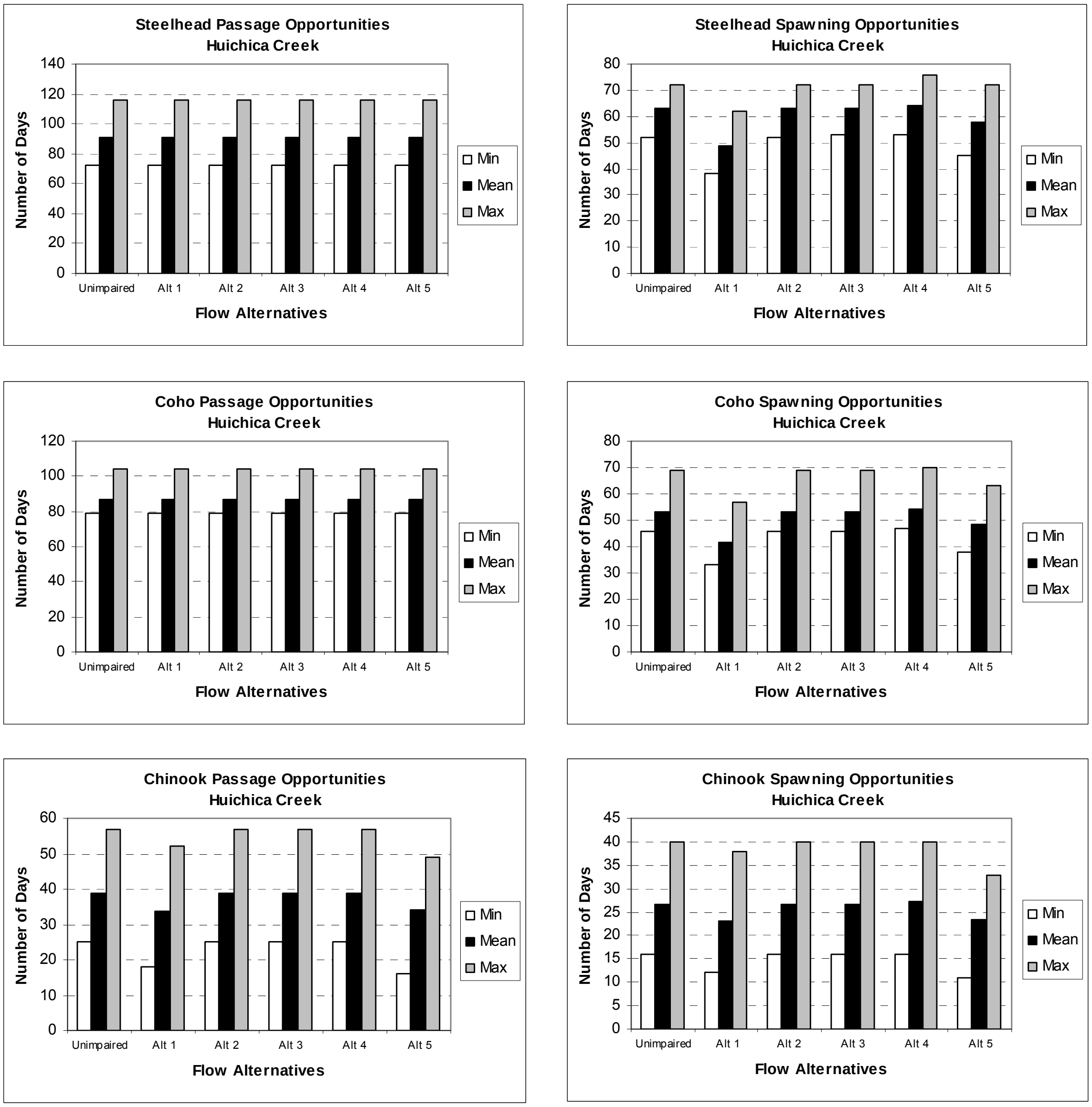


Figure I-5. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Huichica Creek validation site (drainage area = 4.92 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

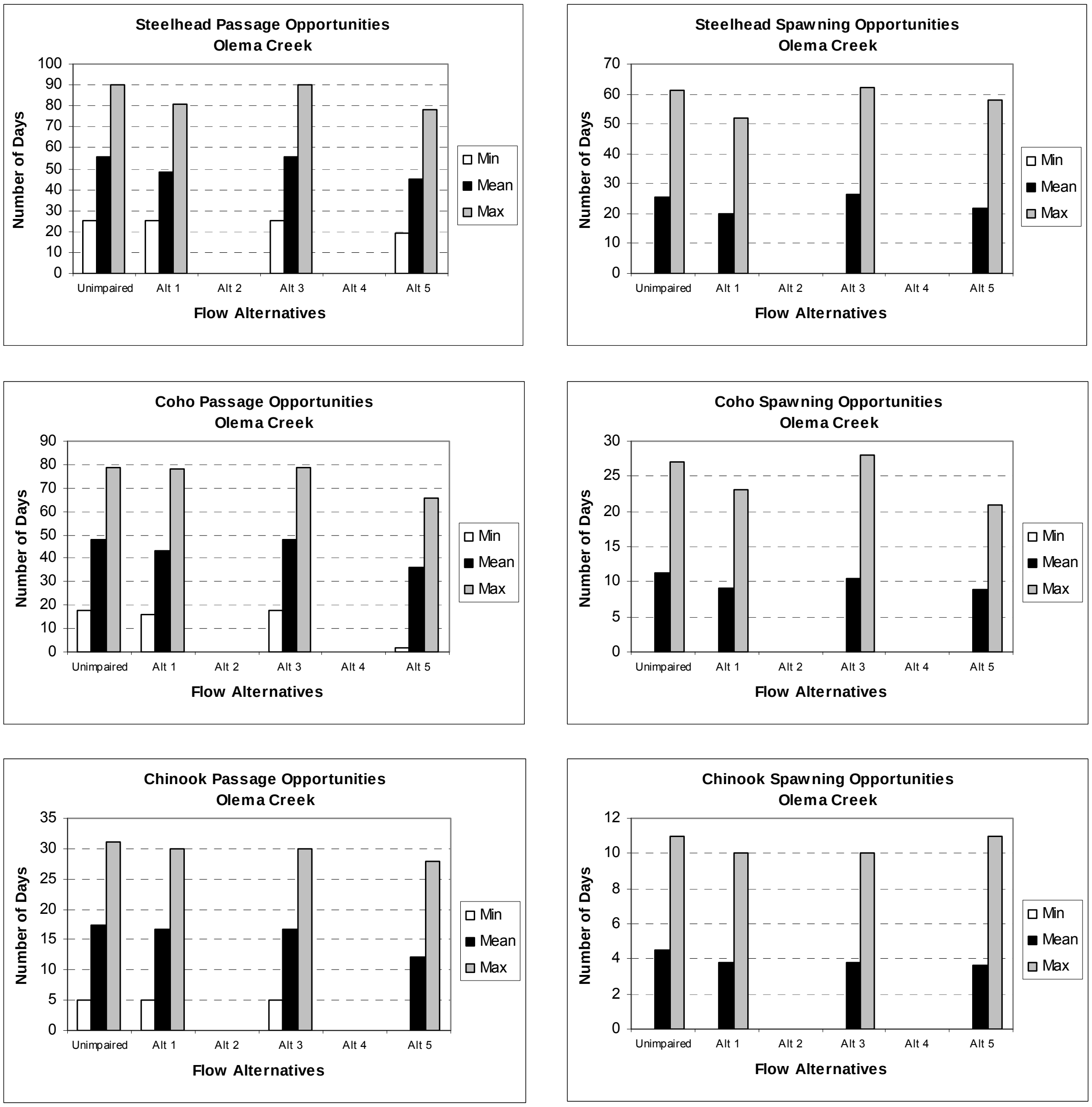


Figure I-6. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Olema Creek validation site (drainage area = 6.47 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

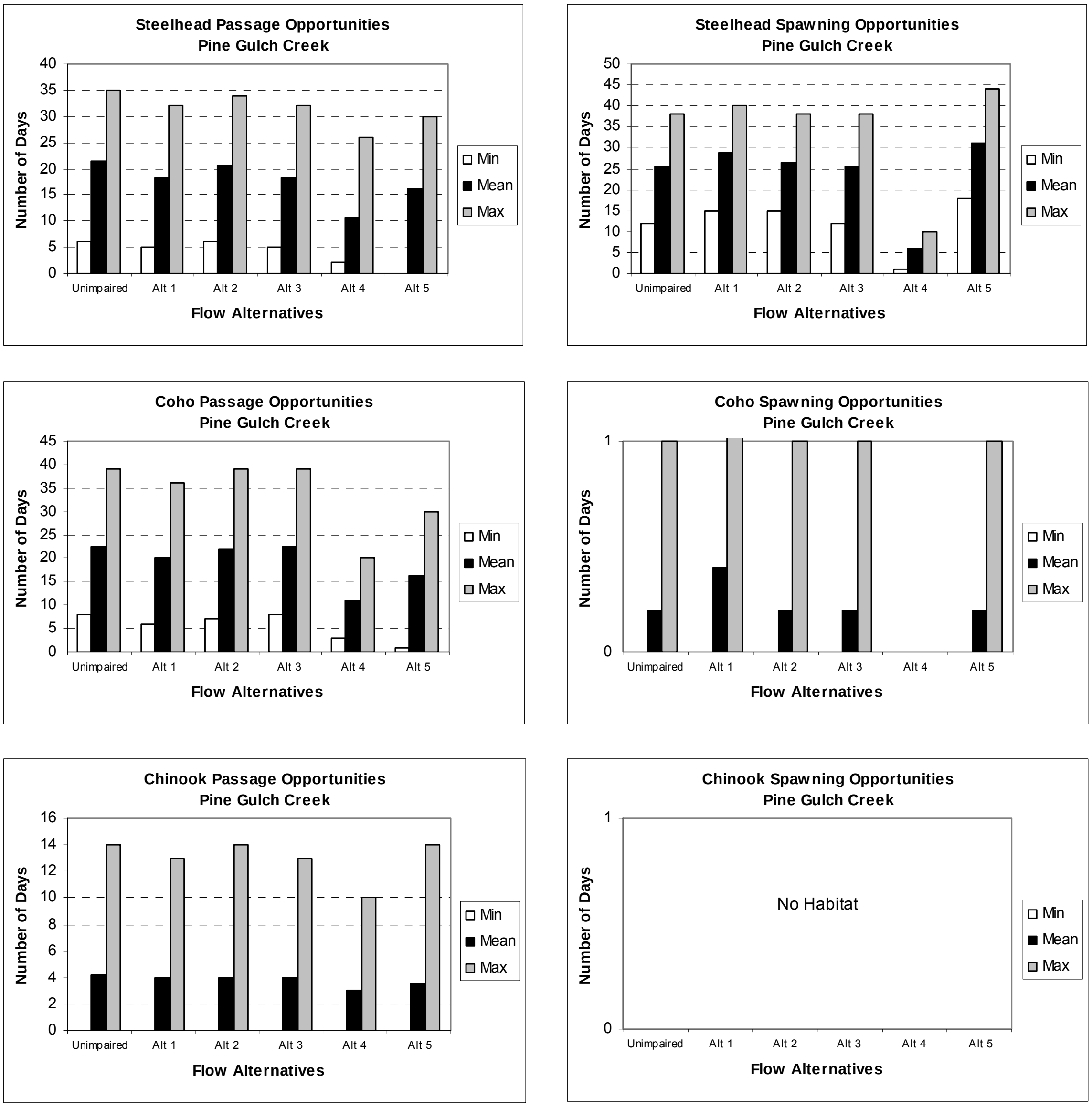


Figure I-7. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Pine Gulch Creek validation site (drainage area = 7.83 mi^2) expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

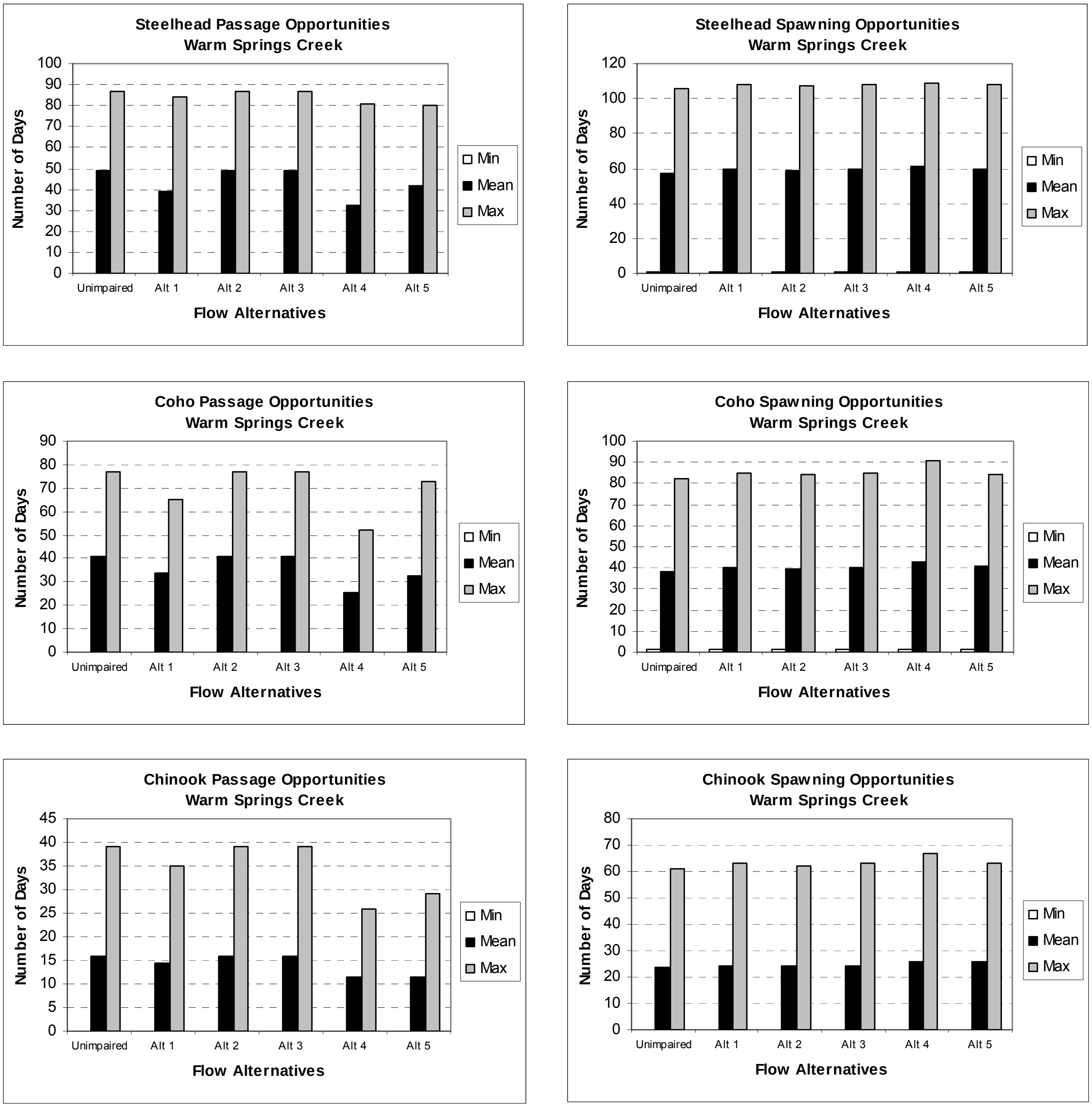


Figure I-8. Comparison of alternative Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Warm Springs Creek validation site (drainage area = 12.2 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

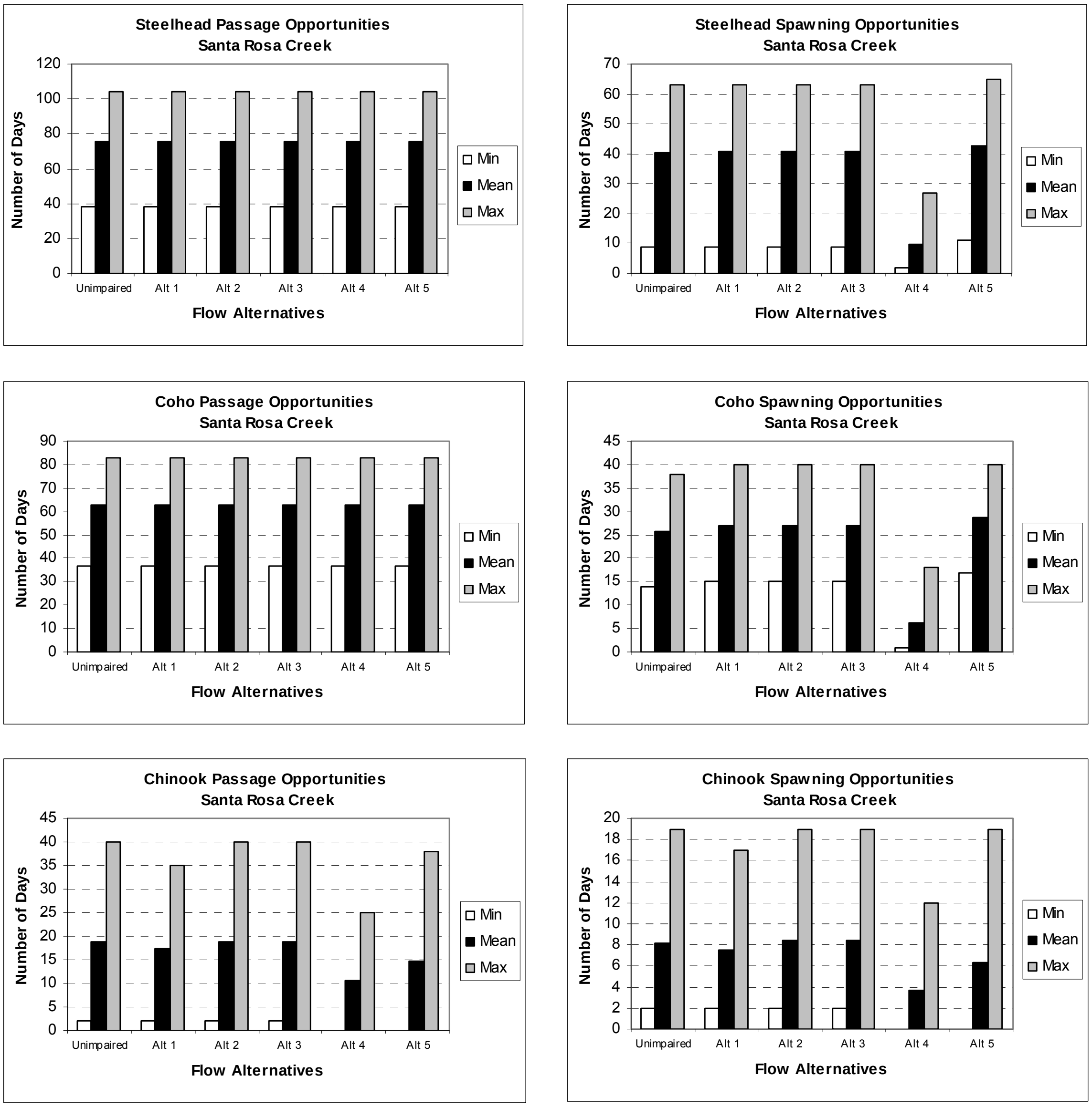


Figure I-9. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Santa Rosa Creek validation site (drainage area = 12.5 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

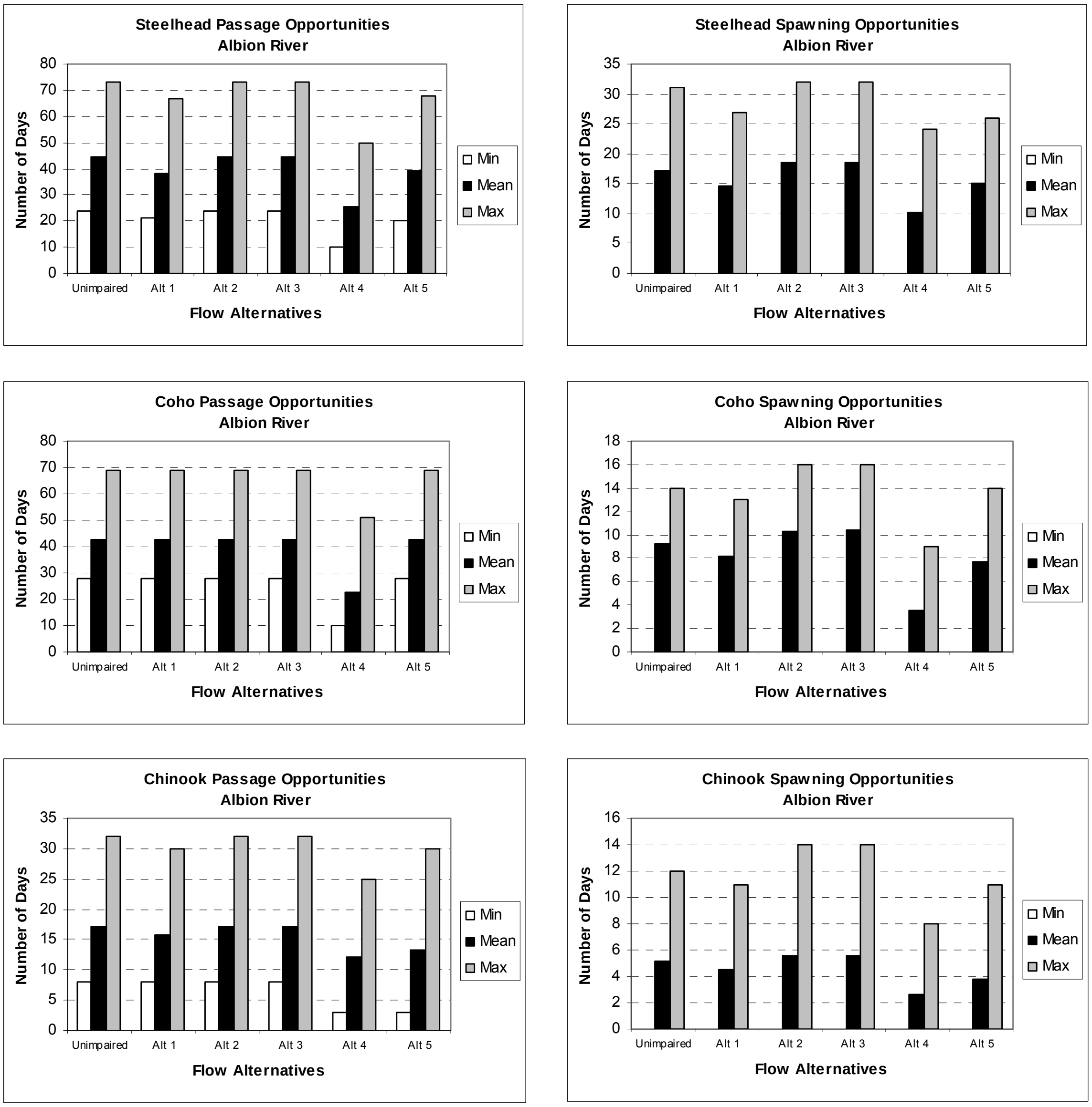


Figure I-10. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Albion River validation site (drainage area = 14.4 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

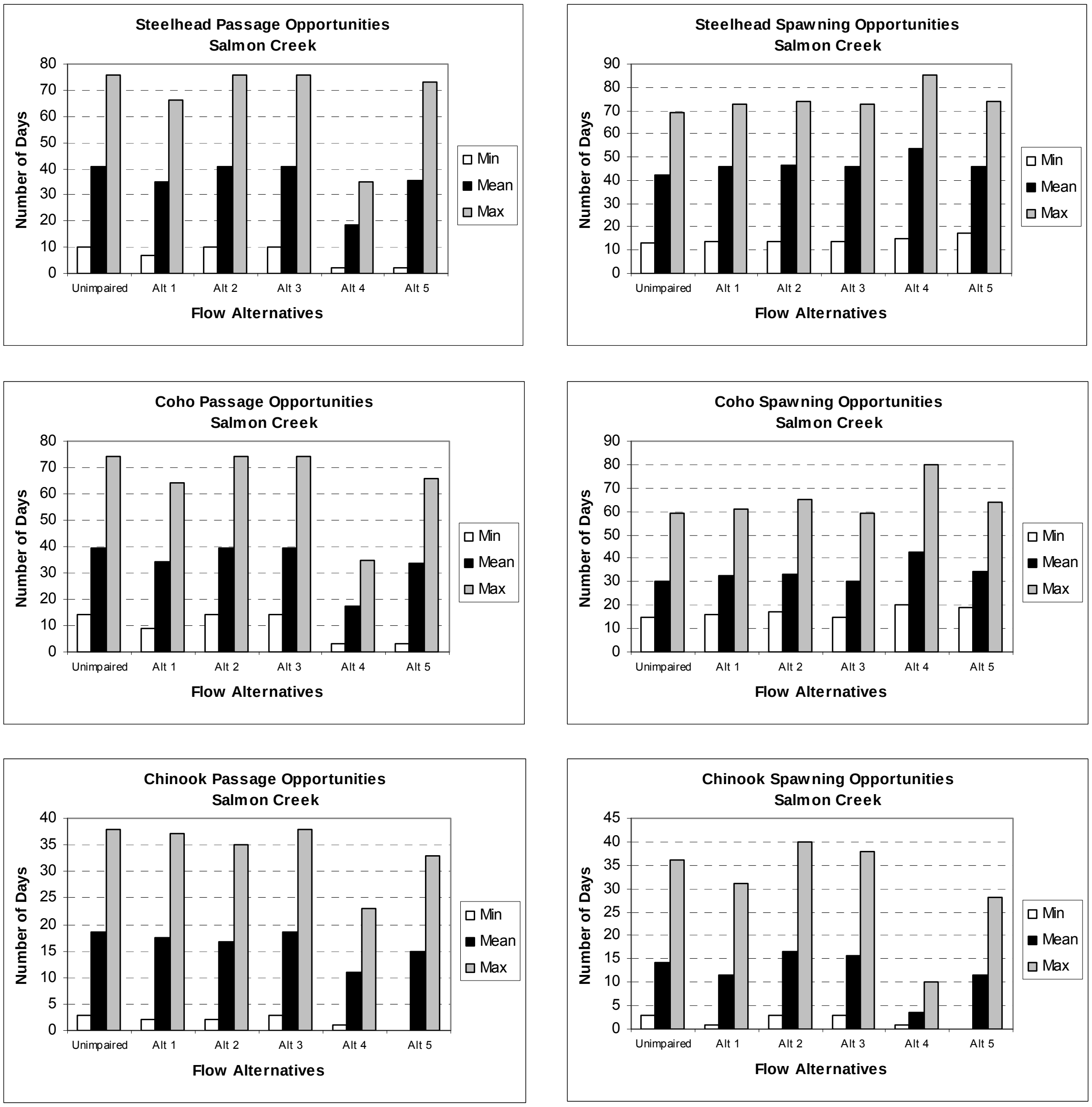


Figure I-11. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Salmon Creek validation site (drainage area = 15.7 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.

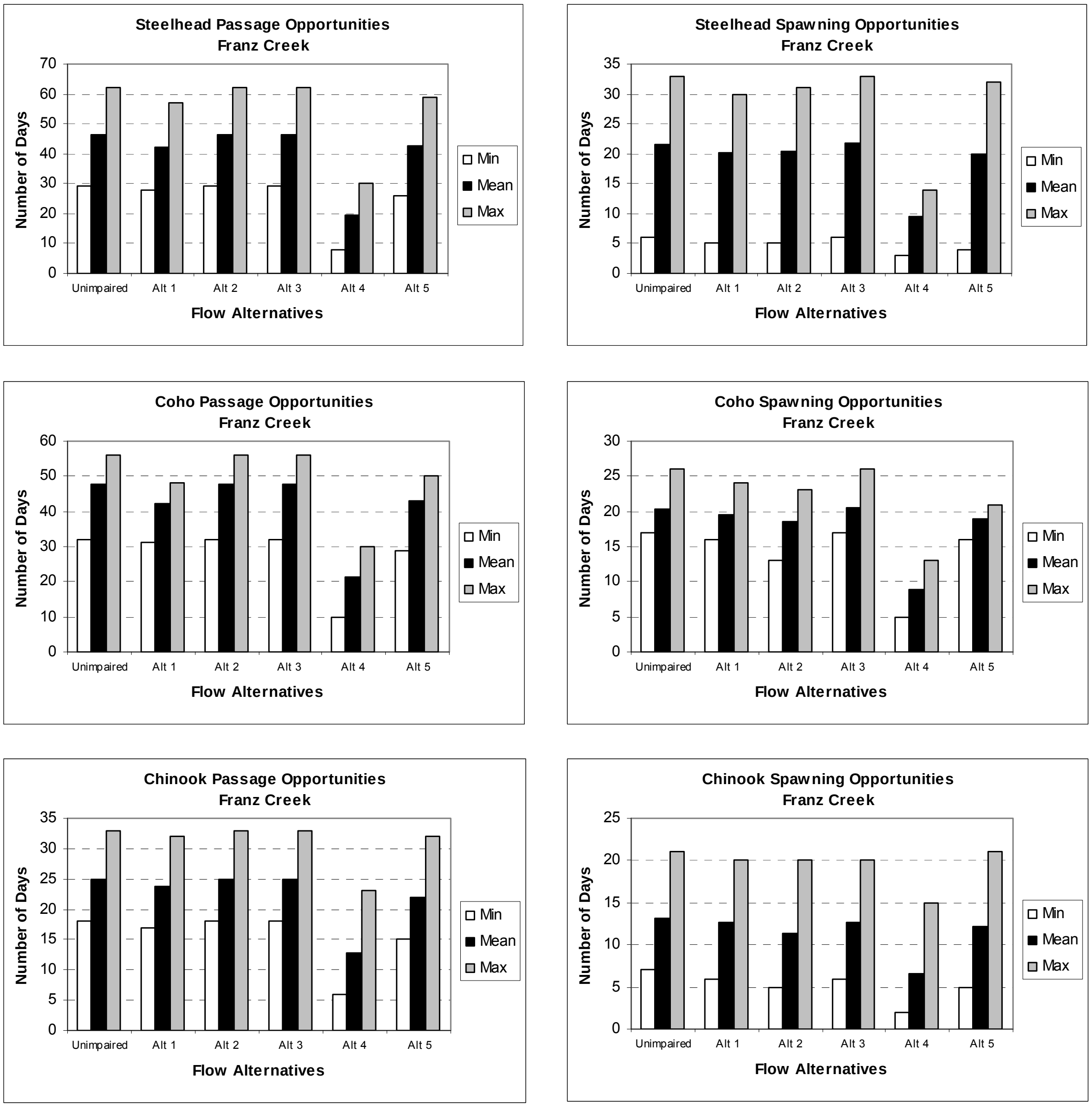
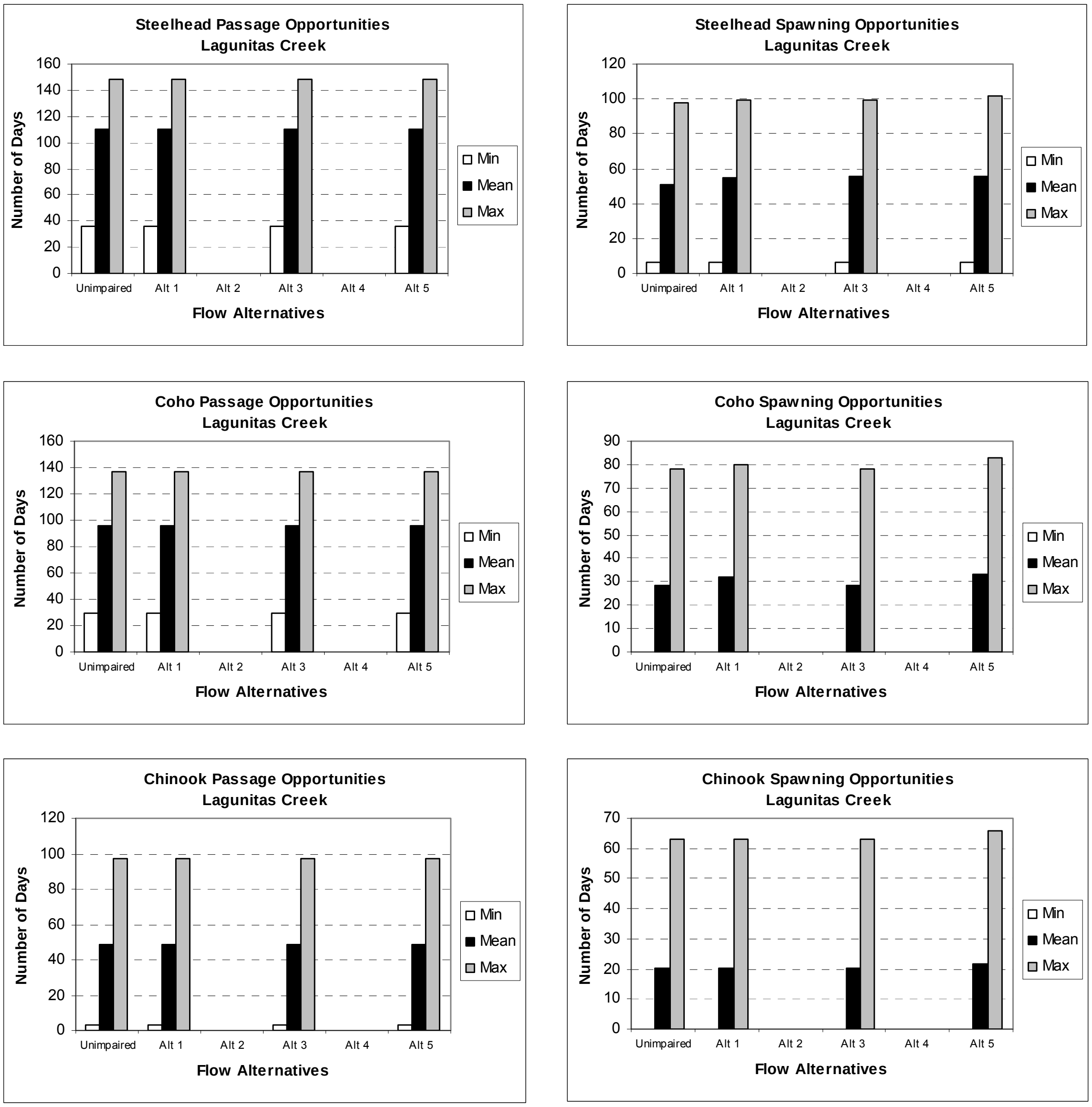


Figure I-12. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Franz Creek validation site (drainage area = 15.7 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated for each species' passage and spawning periods, for the period of record at a nearby USGS stream gage.



Steelhead Passage Opportunities
Lagunitas Creek

Steelhead Spawning Opportunities
Lagunitas Creek

Coho Passage Opportunities
Lagunitas Creek

Coho Spawning Opportunities
Lagunitas Creek

Chinook Passage Opportunities
Lagunitas Creek

Chinook Spawning Opportunities
Lagunitas Creek

Figure I-13. Comparison of Flow Alternative Scenarios 1 to 5 and unimpaired flow conditions for upstream passage and spawning in the Lagunitas Creek validation site (drainage area = 34.3 mi^2), expressed as number of days per water year. Minimum, mean, and maximum values are evaluated between 10/1-3/31 over the period of record at a nearby USGS stream gage.

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APPENDIX J

Properties and Behavior of the Cumulative Flow Impairment Index (CFII)

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APPENDIX J

PROPERTIES AND BEHAVIOR OF THE CUMULATIVE FLOW IMPAIRMENT INDEX (CFII)

The DFG-NMFS (2002) Draft Guidelines contained the following two options for maintaining natural flow variability and avoiding cumulative effects due to diversion:

a. Limiting the cumulative instantaneous rate of withdrawal to 15% of the winter 20% exceedance flow during the period December 15-March 31, subject to a limiting cumulative rate of withdrawal that does not appreciably diminish (qualified as <5% of) the natural hydrograph flows needed for channel maintenance and upstream fish passage;

   OR:

b. Limiting the total cumulative volume of water to be diverted at historical limits of anadromous fish distributions to 10% of the unimpaired runoff during the period December 15-March 31 during normal water years, using a Cumulative Flow Impairment Index (CFII); hydrologic analysis is required for projects with CFIIs between 5%-10% to demonstrate that the diversion will not cause or exacerbate significant cumulative effects to salmonid migration and spawning flows.

The procedure proposed for calculating the CFII was:

$$CFII = \frac{Cumulative\ Diverted\ Volume\ From\ 10/1-3/31}{Estimated\ Unimpaired\ Runoff\ \ From\ 12/15-3/31}$$

The CFII was proposed to be evaluated at various points of interest (POIs) representing the point of diversion (POD) and the confluences of major intervening tributaries between the POD and the mainstem coastal rivers or estuary, depending on overall basin size. The locations of POIs would be determined by NMFS and DFG staff. The Cumulative Diverted Volume (CDV) would be computed based on the total amount of water represented by existing water rights that could be exercised during the period indicated in an average water year, including pre-1914 rights, riparian rights, small domestic and stock pond certificates and registrations, and other appropriative rights, plus the proposed diversion. The Estimated Unimpaired Runoff (EUR) would be similarly calculated for an average year, using standard hydrologic techniques. The specific technique would be at the discretion of the applicant and could reflect available information as opposed to requiring collection of new data.

Cases where the calculated CFII exceeds 5% and there is an appreciable impairment on the hydrograph would require a site specific study to address geomorphic effects (including channel maintenance, sedimentation, and estuarine disconnection from the ocean), anadromous salmonid spawning habitat (including identifying minimum bypass flow and maximum instantaneous rate of withdrawal), and salmonid upstream passage.

The CFII was developed based on a review and technical evaluation of stream flow time series that considered the level of impairment and operational practices of diverters, with a focus on differences in flow rate and volume. Its goal was to ensure that diversions of all types, including riparian and pre-1914 rights, did not cumulatively decrease downstream flows below levels considered protective of anadromous salmonids. The CFII was particularly applicable to watersheds where existing permits for on-stream storage would always exceed any limits to instantaneous withdrawal rates (SWRCB 2001). A key assumption of the CFII was that around a 10% reduction in cumulative runoff volume caused by diversion was the level above which additional diversion would negatively affect channel and riparian maintenance processes and upstream passage conditions. Requests for diversion above this cumulative level required detailed study and analysis of the effects to these processes.

There are a number of technical considerations that enter into the evaluation of protectiveness of the CFII including:

1. Implications of Applying Different Time Frames of CDV and EUR – Are the differences in time frames between the CDV (10/1 to 3/31) and EUR (12/15 to 3/31) biologically significant?
2. Influence of Rate of Withdrawal, MBF and Diversion Season – How does the rate of withdrawal chosen by the diverter and the value of the minimum bypass flow and the diversion season influence the protectiveness of the CFII?
3. Channel Maintenance Processes - Is regulation using a volume limit, as provided by the CFII, protective of channel maintenance processes?
4. Incremental Benefits of 5% and 10% Reductions – What are the physical and biological benefits to anadromous salmonids of the 5% and 10% reductions in cumulative volume?

These issues and questions are addressed below in the context of establishing a metric for controlling diversion and protecting anadromous salmonids and their habitat. The 10% level is assumed to be a worst case, effective upper limit to diversion and is the criterion evaluated here for protectiveness.

J.1 BIOLOGICAL AND PHYSICAL SIGNIFICANCE OF DIFFERENT TIME FRAMES FOR CDV AND EUR

This issue relates to the use of different time frames for computing the CDV and EUR values used in the CFII (EUR – 12/15 to 3/31; CDV – 10/1 to 3/31). This difference was noted during the scoping process and was accompanied by a suggestion of using temporally consistent periods, as is typically required for making water availability and demand comparisons. Temporal consistency would also likely be important for discerning effects to anadromous salmonids in a mechanistically consistent way. For example, it is difficult to link the effect of diversions occurring before December 15 with spawning habitat availability after that date, unless it can be demonstrated both conceptually and with data that base flows (which control spawning habitat availability overall based on the need for redd inundation) later in the winter are directly dependent on antecedent conditions. Given that runoff patterns during most of the winter generally reflect the time since the preceding rainfall event, demonstrating such a link is difficult. Thus, the difference in time frames confounds the evaluation of protectiveness, specifically with respect to assigning biological significance to the 5% and 10% CFII thresholds.

It is recommended that if the CFII is applied, it be based on a CDV and EUR calculated over the full diversion season.

J.2 CHARACTERISTICS OF CALCULATING THE CFII THAT AFFECT PROTECTIVENESS OF THE CRITERION

The CFII was recommended as a method of determining which water right applications can be permitted without further study. In effect, the CFII provides a way to identify potential “hot spot” POI locations at which the DFG-NMFS (2002) Draft Guidelines recommend detailed evaluation of potential cumulative impacts. However, the DFG-NMFS (2002) Draft Guidelines did not provide criteria for what constituted a potential hydrologic impact, nor criteria for evaluating the results of the site specific studies. In addition, there are no specific guidelines for how the CFII criterion may be met, whether it be through an unlimited diversion rate until the CFII criterion is met, or through diversions spread out more evenly in time and space. Indeed, the CFII defines a total cumulative *volume* of diversions that can be permitted in or upstream of a point in a watershed. The CFII does not restrict the total cumulative *rate* of withdrawal. The actual volume of water that would be available for diversion in any given water year and the resulting diversion rate at which these diversions may be made depends on the site-specific hydrology and Policy limitations on diversion season and the minimum bypass flow.

Resulting diversion rates could therefore range from a minimum equal to the CDV volume divided by the length of the diversion season, to a maximum of the highest peak flow during the diversion season less any minimum bypass flow requirements (as shown for the validation sites in Table F-19, Appendix F). Depending on the rate of withdrawal implemented by diverters, the same CFII limit can result in characteristically different hydrographs and different levels of protectiveness depending on the way the CFII is implemented. In addition, the date the CFII limit (a cumulative diverted volume corresponding to a given percent of the estimated unimpaired flow) is reached will depend explicitly on the diversion season start date and minimum bypass flow. The difficulty in identifying a protective level becomes apparent when it is considered that the same value of CFII can be reached on different dates when different diversion season or minimum bypass flow alternatives are applied. The effect of diversion season and minimum bypass flow may or may not be biologically significant, depending on which alternatives are ultimately adopted as Policy. Overall, the CFII acts primarily as a hydrologic limit and does not directly reflect cumulative effects to habitat, nor protectiveness with respect to the duration of the diversion season.

In reflection of these characteristics, and in order to use a consistent approach in comparing the CFII volume-based alternative to the other three rate-based MCD alternatives, the following assumptions were applied in generating impaired hydrographs for assessing the protectiveness of the CFII alternative:

1. There is no maximum limit imposed on the instantaneous rate of diversion.

2. The diversion demand is set equal to 10% of the estimated unimpaired runoff volume from December 15 until March 31.

3. All flows above the MBF are diverted until the diversion demand is satisfied.

The calculations used to generate the impaired hydrograph are described in Section F.3.1 of Appendix F. The above assumptions provide a worst-case evaluation of the 10% CFII threshold with respect to hydrograph impairment during the beginning of the diversion season. These conditions would occur directly below an on-stream dam that cannot bypass flows when the reservoir is storing inflows (i.e., a fill-and-spill reservoir during the fill period). At other diversions, the diverter may choose when and how much to divert, depending on water availability and the maximum limits on their instantaneous rates of diversion. The cumulative effects of diversions at the POI locations may be reduced depending on the timing and spacing of individual withdrawals and routing effects.

J.3 PHYSICAL AND BIOLOGICAL SIGNIFICANCE OF THE CFII METRIC

Even with consistent time frames for calculating EUR and CDV, it would still be difficult to assign biological and physical significance to a cumulative volume without first considering effects of diversion rate. At a fundamental level, cumulative volume reflects an integration of variable flow rates occurring over time, with non-linear responses to flow leading to potentially very different physical and biological responses corresponding to the same net volume. Most ecological and geomorphic responses reflect individual signals stemming from flow magnitude, frequency and/or duration. This appears particularly the case for anadromous salmonids, which respond most directly to instantaneous flow rate in terms of habitat selection and upstream passage timing. For example, anadromous salmonids migrate upstream primarily in response to changes in flow. Thus, it is the diversion rate that has the most direct relation to salmonid habitat compared with diversion volume, predominantly in terms of spawning habitat availability, upstream passage, and channel and riparian maintenance flows.

J.3.1 Physical Significance

Because of the wide range of possible permutations of peak flow rate, duration, and frequency, and the non-linearity inherent in such processes including especially bedload transport rate, the same cumulative flow volume will not necessarily result in the same net effect on the channel and riparian zone. Correspondingly, most scientific advances in linking channel form to flow have been made in terms of surrogate flow rates, such as the 1.5 year flood as discussed in Appendix D. Fortunately, such metrics were derived originally from consideration of the integration of flow magnitude, duration and frequency (e.g., Wolman and Miller 1960), where establishing a protective instream flow rate and maximum diversion rate based on an instantaneous measure of flow rate already includes consideration of cumulative flow volume.

The protectiveness of limitations on the maximum cumulative diversion on channel maintenance flows differ depending on the method of limitation (rate or volume). Using a rate method, the expected effect would be a reduction in channel size and readjustment that reflects a lower flow magnitude, but with a similar frequency of runoff events, as described in Appendix D. The quality of habitat would not be expected to change substantially, mostly the quantity. A relatively small diversion rate relative to the bankfull flow would be expected to result in a relatively small reduction in channel size (cf. Figure D-4 in Appendix D).

The CFII volume method allows water to be diverted at any rate of withdrawal. This discussion of protectiveness assumes that diversions are made at the maximum rate until the cumulative diversion volume has been met. At this high rate of withdrawal, the total diverted volume criterion is usually met before the end of the diversion season. In some instances, the quantity of diversion could result in a flat-lining of the hydrograph, whereby essentially the only flow allowed downstream would be the MBF. Predicting the physical effects of flat-lining of the peak hydrograph is difficult and generally not possible without doing a site-specific analysis of flows, sediment transport, and channel stability. Flume studies conducted by Parker et al. (2003) suggest that flat-lining is likely to lead to a reduction in habitat complexity and an increased concentration of fine sediments in the stream bed. However, studies have not been conducted to determine the allowable frequency or duration of such flat-lining events before adverse effects at a regional scale. Thus, there is currently no direct physical or biological basis for concluding that one level of CFII is protective at the regional scale, and another level is not. Furthermore there is no clear way to compute a protective CFII criterion based on an analysis of flow rates without performing a site-specific study.

The sensitivity analysis in Appendix F indicates that implementing the CFII metric without limiting diversion rate has the potential to substantially change the flood frequency characteristics of a stream to a greater extent than the other MCD element alternatives. As described in Appendix D, reductions in the bankfull flow, approximated by the 1.5 year flood peak flow rate, are predicted to result in roughly proportional reductions in channel size and streambed grain size. Table J-1 summarizes predicted estimates of percent reductions of the 1.5 year flood magnitude caused by implementing the Flow Alternative Scenarios described in Appendix I for the four validation sites with the longest stream gage records. The CFII = 10% alternative in Flow Alternative Scenario 5 could result in the greatest predicted change in the 1.5 year flood peak flow rate, at levels that could result in large changes in channel morphologic characteristics.

Table J-1. Estimated Reduction in the 1.5 Year Flood Peak Flow Rate Associated with Implementation of the Five Flow Alternative Scenarios, in Four Validation Sites with at Least Ten Years of Stream Flow Records.

		Percent Reduction in 1.5 Year Flood Magnitude by Flow Alternative Scenario				
Validation Site	**Unimpaired 1.5 Year Flood (cfs)**	**Flow Alternative Scenario 1** **(MCD1: 15% of 20% Winter Exceedance Flow)**	**Flow Alternative Scenario 2** **(MCD4: Reduce MBF Duration for 1.5 Year Flood by ½ Day)**	**Flow Alternative Scenario 3** **(MCD1: 15% of 20% Winter Exceedance Flow**	**Flow Alternative Scenario 4** **(MCD2: 5% of 1.5 Year Flood Flow Rate**	**Flow Alternative Scenario 5** **(MCD3: CFII=10%)**
Albion R	1,020	1%	1%	1%	5%	31%
Salmon Cr	1,440	1%	1%	1%	5%	21%
Santa Rosa Cr	1,170	1%	1%	1%	5%	37%
Warm Springs Cr	690	3%	2%	1%	5%	13%

The estimated unimpaired 1.5 year floods reported in Table 4-4 (and in Table F-15 in Appendix F) may differ from those reported in Table F-13 in Appendix F. The unimpaired 1.5 year floods computed in Table 4-4 for comparison of the unimpaired and impaired scenarios were calculated only for the period of complete record of both unimpaired and impaired peak data to provide a meaningful comparison, as described in Section F.3.3 and also reported in Table F-15 in Appendix F. The unimpaired 1.5 year floods computed for each of the 11 validation sites for use in determining MCD2 and MCD4 were calculated from the full period of record of unimpaired instantaneous measurements to provide the most accurate estimate of the 1.5-year flood event, as described in Section F.2.6 and reported in Table F-13 in Appendix F.

Riparian maintenance flow needs may be most reflective of water volume, where studies have shown a correlation between the water table level, extent of the riparian zone, and mean annual flow volume (e.g., Stromberg 1993). However, this reflects a process that operates on a relatively long time scale, and is thus difficult to link with diversion rate over a variable hydrograph. Channel morphology reflects flow duration to a certain extent as well, but as long as flows are sufficiently high to transport bedload of all sizes present, then some channel maintenance functions are preserved albeit at a slower geologic rate (see Appendix D).

J.3.2 Biological Significance

Direct biological effects of flat-lining a hydrograph peak at the MBF level by means of an unlimited MCD rate would most likely to be manifest for Chinook and coho salmon, which enter, migrate upstream, and spawn in Policy area streams early relative to the diversion season. It is possible that upstream passage of Chinook could be particularly adversely affected because of greater minimum depth criterion that may not be protected by the minimum bypass flow in more than a few streams (see the analysis of upstream passage criteria relative to minimum bypass flow criteria in Appendix E).

Worst case application of the CFII=10% limit would result in hydrograph peaks that are flat-lined at the MBF during the first part of the diversion season. In the worst case scenario of Flow Alternative Scenario 5, the period over which hydrographs of runoff events in the validation sites would be flat-lined at the February median flow, until the CFII=10% limit is reached, would range from as short as 1 day to as long as 75 days after the diversion season begins. Under average conditions, Chinook and coho salmon, and possibly steelhead, could correspondingly experience reduced opportunities for upstream passage and spawning for up to the first 2 months or so of the diversion season in some streams (also see results in Appendix I and sensitivity analysis in Appendix F). Some streams would likely not be so affected, but more than a few would.

In comparison, for the case of Flow Alternative Scenario 1 (which involves a maximum cumulative diversion rate of 15% of the 20% exceedance flow), diversion may occur practically the entire season without diverting an equivalent total volume of water, and hydrograph peaks are preserved throughout the diversion season. In nearly all cases, the total diversions generally did not reach a volume equivalent to 10% of the estimated unimpaired runoff in validation sites with drainage areas smaller than about 10 mi^2. Passage and spawning would likely be relatively unaffected early in the diversion season in all or most streams.

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APPENDIX K

Recommendations for Monitoring the Effectiveness of the North Coast Instream Flow Policy for Protecting Anadromous Salmonids

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APPENDIX K

RECOMMENDATIONS FOR MONITORING THE EFFECTIVENESS OF THE NORTH COAST INSTREAM FLOW POLICY FOR PROTECTING ANADROMOUS SALMONIDS

This appendix describes a framework monitoring program that is recommended for evaluating the effectiveness of the North Coast Instream Flow Policy for protecting anadromous salmonids and their habitats. The program specifically targets the Policy elements aimed at maintaining minimum bypass flows, protecting natural flow variability, avoiding cumulative impacts, providing suitable fish passage at diversions and on-stream dams, all with respect to protecting anadromous salmonids and their habitats. The program is focused on testing the overall hypothesis (Ho) that:

Ho – the combination of elements within the Policy as applied to a given stream or watershed, will protect existing, and/or allow for the recovery/restoration of historically present anadromous salmonids, whereby four secondary hypotheses testing specific Policy elements also include:

- Ho_1 – the minimum bypass flow standard provides flows that will allow for successful upstream passage of anadromous salmonids,
- Ho_2 – the minimum bypass flow standard provides flows that will allow for successful reproduction of anadromous salmonids,
- Ho_3 – the cumulative diversion rate or volume restriction will limit new or increased diversions from a stream unless remaining instream flows would be adequate to a) maintain the timing, form, and functional qualities of the natural flow variability, b) provide for channel maintenance and habitat formation, and c) protect anadromous salmonid habitats, and
- Ho_4 – the measures focused on restricting on-stream dams will ensure that the approval of new or existing unauthorized projects will not adversely affect existing anadromous salmonids or impede the restoration/recovery of historically present anadromous salmonids.

Although results of the technical analyses reported in the main report and preceding appendices indicated that Policy measures should be “protective” of anadromous salmonids, the assessment relied primarily upon existing data and information supplemented with a modicum of empirical field data collected from 13 streams within the Policy area. These data and information were the best available at the time and allowed for a quantitative evaluation of various Policy elements relative to specific anadromous fish passage, spawning, and rearing habitat criteria. Time constraints imposed by AB 2121 precluded conducting detailed long-term (multiple years) field experiments to directly evaluate potential biological responses to Policy elements. A few short-term (i.e., 6 to 12 months) experiments, such as tests of various flows vs. fish passage conditions and observations of fish passage success and tests of flows vs. spawning habitat availability over a range of channel sizes, might have rendered some useful information. However, it was not possible to implement such experiments under the legislative time constraints imposed for development of the Policy. Thus, questions remain as to whether implementation of the Policy would effectively protect anadromous salmonids over longer time scales, say, in the range of 10 to 20 year time horizons that would correspond to 3 to 6 generations of anadromous salmonids. This time frame should also be sufficiently long to allow detection of changes in channel morphology and composition of riparian vegetation. Such an assessment requires development and implementation of a longer-term monitoring program, as described below.

Due to the wide range of geographical and temporal scales exhibited in the Policy area streams, the recommended monitoring program is relatively general in nature, and should be viewed as the starting point from which more detailed, site-specific monitoring plans can be derived. Site-specific plans can be tailored to match a stream's unique biological, hydrological and physical characteristics, and to address stream and/or basin specific resource management objectives.

K.1 IMPORTANCE AND TYPES OF MONITORING

Given the complexity of aquatic ecosystems, it is difficult to predict with certainty how they will respond to anthropogenic influences. This uncertainty in response is compounded by a number of unknown influencing forces and interactions, as well as the unpredictability associated with factors influenced by climate and weather. Yet resource managers must still proceed even though they cannot fully predict the effects of their decisions on the ecological resources. Truly understanding these effects can only be accomplished via ecological monitoring, which has become important in both regulatory and scientific forums. With the recent ESA listings of a number of anadromous salmonids in California, Oregon and Washington, there have been many technical papers, reports, and books that have served to describe ecological monitoring concepts and types of monitoring generally, statistical considerations when designing monitoring programs, and more specifically the types and rationale for selected physical and biological metrics (e.g., Kershner 1997, Conquest and Ralph 1998; Roni 2005).

An increased emphasis on monitoring, while important from the standpoint of highlighting its role in understanding how management actions may influence aquatic ecosystems, has also created confusion regarding overall focus of monitoring. For example, the purpose of monitoring under an ESA context is to determine when listed ESUs or distinct population segments (DPS) have recovered sufficiently to no longer warrant protection (and could be de-listed), as well as to provide data to assess the status of other species (ISP 2000). Monitoring under this paradigm is generally focused at the scale of populations and, in the case of the NMFS Technical

Recovery Team process, is specifically focused on four characteristics of viable salmonid populations – 1) abundance and productivity, 2) status and trends, 3) spatial distribution, and 4) diversity (McElhaney et al. 2000; NMFS 2000). Contrast this with monitoring focused on evaluating watershed restoration actions in which responses are measured relative to different physical and hydrologic parameters (e.g., channel width and depth, grain size distribution, large woody debris, etc.), or with water quality monitoring programs that may focus on contaminants and other constituents (e.g., dissolved gases, temperature, etc.). The first challenge then, in developing a monitoring program applicable to evaluating actions of the Policy is to determine the most appropriate monitoring focus. In the case of evaluating protectiveness of the Policy for adaptive management purposes, monitoring of habitat conditions would provide results that could be related most directly to Policy elements. In contrast, monitoring of salmonid population attributes would need to be more extensive to include consideration of factors outside of the control of the Policy.

K.1.1 Monitoring Types

In general, monitoring programs can be assigned into one of three types, depending on the objectives and questions to be addressed. These include: 1) compliance/implementation monitoring; (2) effectiveness monitoring; and (3) validation monitoring. Some authors have refined these categories to include other types such as trend monitoring, baseline monitoring, status monitoring, and others (MacDonald et al. 1991; Roni 2005). However, the first three types are the most relevant with respect to assessing the protectiveness of the Policy.

Compliance monitoring is the simplest of the three, and is used to determine if an intended action was implemented as planned. Compliance monitoring can also be utilized to determine if a measured attribute (such as flow) is consistent with a prescribed requirement, and the degree to which regulated actions are in compliance with regulatory permits, laws, etc. An example of compliance monitoring would be the installation of a gage below a diversion point to ensure bypass flow requirements are met. Certain aspects of the Policy would be subject to compliance monitoring, the example just noted being one.

Effectiveness monitoring is intended to determine if implemented management actions actually achieve their goals and objectives. Effectiveness monitoring provides status assessments of the target resources and changes in key conditions/parameters over long temporal scales to assess whether management objectives have been achieved.

Validation monitoring, which is sometimes also called research monitoring, is used to test various hypotheses and conceptual models that have been used to predict relationships between/among variables. Validation monitoring evaluates whether the hypothetical relationship between actions and their effects (i.e., cause and effect) occurs as expected. Validation monitoring is often used to evaluate the assumptions used in choosing an action to implement. For example, validation monitoring would be appropriate for testing the hypothesis that gravel supplementation will increase salmonid production in a stream, or the hypothesis that increased stream flows during the spawning period will increase salmonid production. Validation monitoring could be incorporated into various elements of the Policy, but this would entail carefully identifying specific hypothesis to be tested and would be targeted at specific streams or rivers, rather than the entire Policy area.

Although the analysis completed and reported on in the report indicates that the Policy should be "protective" of anadromous salmonid resources, some uncertainty still remains as to whether this protectiveness would actually be afforded to these resources when the Policy is put into action. Clearly, effectiveness monitoring is the most appropriate of the three types for addressing this uncertainty, subject of course to compliance monitoring that ensures the Policy elements are being followed in the first place.

K.2 ADAPTIVE MANAGEMENT IN MONITORING

Monitoring is often used in an adaptive management framework as a means to provide a feedback loop that links back to management actions. Adaptive management is an approach to resource management policy that assumes policies can be experiments from which scientists, policy makers and the public can learn (Lee 1993). Walters (1986), and Hilborn and Walters (1992) suggested that in the face of uncertainty regarding the response of a resource to alternative policies, resource managers can implement a probative policy that has a high likelihood of reducing that uncertainty. Such a policy does not have to be implemented everywhere. In fact, it might even be beneficial to enact different policies in different places to observe how they perform.

The overall flow related hypothesis of the Policy is that the restrictions imposed on timing and magnitude of diversions and the minimum bypass flow requirements are fully protective of anadromous salmonids. Once the Policy is implemented, the results of the monitoring program should be used to test whether the hypothesis should be accepted or rejected, and if the latter, what if any modifications are needed. Along these lines, Hilborn and Walters (1992) and Hilborn (1992) point out there are two other approaches to learning. One of them is passive learning, the second is reactive (active) or evolutionary learning. With passive learning, a "best guess" policy is chosen using the available data, assumed to be true, implemented and then monitored to determine any weakness or errors. If problems develop, some future management action is taken to hopefully correct the policy prior to any catastrophic consequences. Hilborn and Walters (1992) point out that passive management can be optimal when uncertainties are small or alternative learning approaches (assuming there is a cognizant choice in approach) are unlikely to add any additional information relative to a passive approach.

The second form of learning is reactive or evolutionary learning, which Hilborn (1992) associates with "blind faith" management. In this paradigm, management simply tries a variety of policies, with little or no targeted monitoring, until it becomes clear which policy works best. Hilborn and Walters (1992) and Hilborn (1992) also refer to this latter approach to learning as trial-and-error. Hilborn (1992) points out that a blind faith approach can be "a very reasonable policy under certain circumstances, particularly when monitoring and evaluation costs are high or the time required for evaluation is very long." Hilborn and Walters (1992) identified six steps in adaptive fisheries management that utilizes active learning. Slightly modified to be more general, these are:

1. Identification of alternative resource response hypotheses;
2. Assessment of whether further steps are necessary by estimating the expected value of perfect information (i.e., is there a reasonable return on the effort to obtain better information?);
3. Development of models for future learning about hypotheses;
4. Identification of adaptive policy options;
5. Development of performance criteria for comparing options; and
6. Formal comparison of options using tools of statistical decision analysis.

In an active learning paradigm, each of these steps should be followed prior to implementing an experimental policy. Given that the State Water Board plans to implement the Policy soon, and that essentially none of these steps have been followed, it is apparent that a strict interpretation of adaptive management with active learning cannot be completed in the current context.

Rather, the form of the Policy is expected to be better suited to the "passive learning" model in which the specific elements were derived using the best available information, the Policy should be implemented, responses monitored, and adjustments in the Policy made as indicated by monitoring results. Indeed, the general premise of monitoring and adaptive management is that a properly designed and implemented monitoring program would provide future information regarding how targeted ecological resources are responding to management actions, and importantly, that such responses can guide decisions regarding future management actions.

K.3 EFFECTIVENESS MONITORING PROGRAM

The primary monitoring program for evaluating the protectiveness of the Policy should utilize an effectiveness monitoring approach subsumed within an adaptive management framework, hereinafter referred to as the Monitoring Program. This approach should be applied to the Policy in a fashion that would monitor the ecological responses of various Policy elements, and use the monitoring response information to evaluate the protectiveness of the elements and to make necessary adjustments.

There are a number of action items and components, some institutional and some technical, that should be addressed and/or incorporated as part of the Monitoring Program (Figure K-1). These include:

- Defining a set of clearly articulated goals and objectives that capture the major questions needing to be addressed;
- Establishing a centralized Monitoring Oversight Committee (MOC) to coordinate and oversee all monitoring activities related to implementation of the Policy;
- Developing appropriate, statistically derived sampling designs;
- Selecting and monitoring appropriate indicators and metrics that are sensitive to effects of flow regulation;
- Standardizing sampling protocols to allow comparisons among locations, times and site specific programs;
- Establishing appropriate Quality Assurance and Quality Control measures for data validation;
- Providing for data dissemination and access by other users and interested parties;
- Providing a funding base sufficient to sustain a long-term monitoring program; and
- Developing and implementing a Decision Analysis/Support process that can be used for evaluating monitoring results and determining whether and what changes are needed in the Policy.

These considerations and components are described further below.

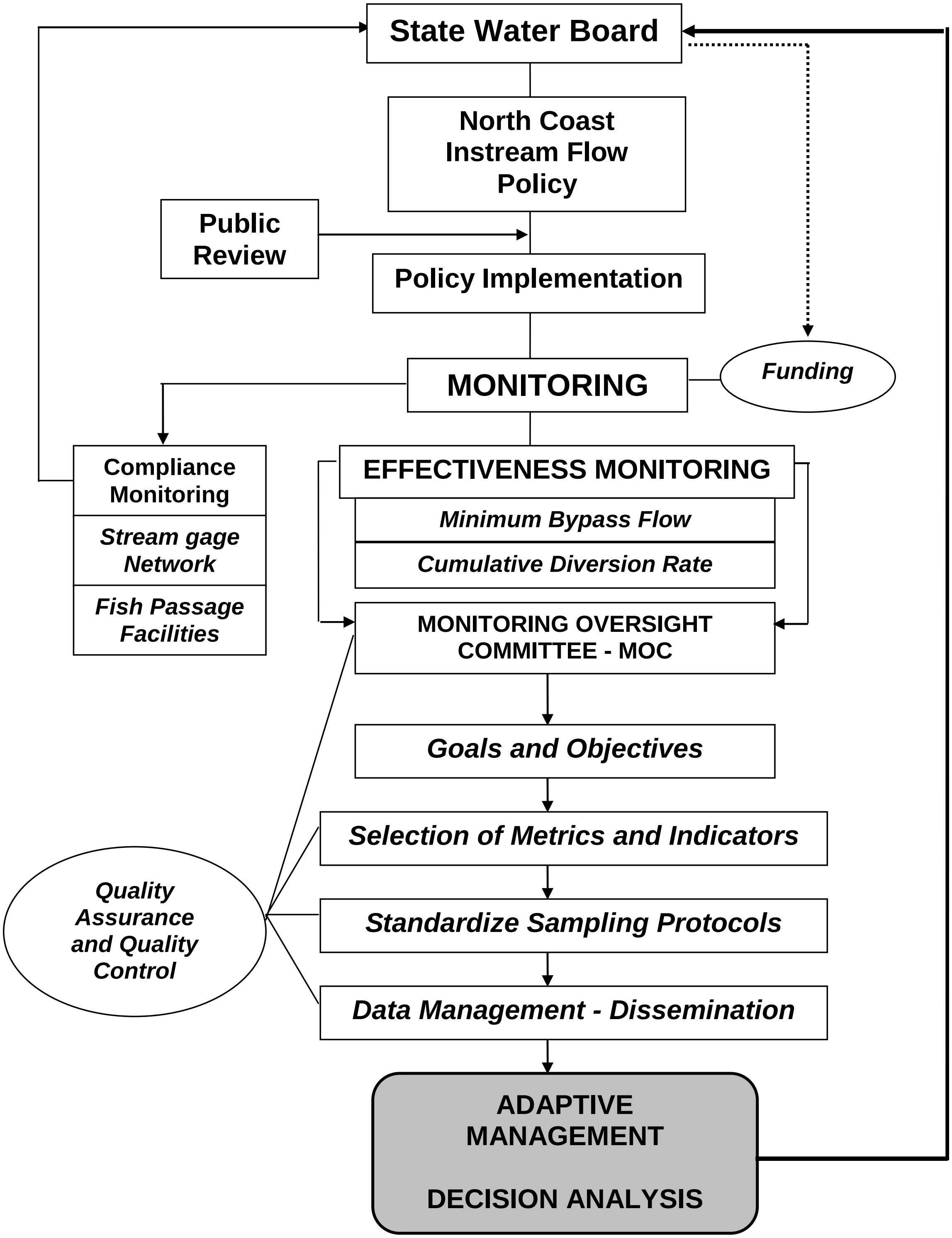

Figure K-1. General components and actions associated with monitoring the protectiveness of North Coast Instream Flow Policy elements.

K.3.1 Monitoring Program Goals and Objectives

The overall goal of the Policy is to establish principles and guidelines that are designed to allow the diversion of a certain amount of water from Policy area streams during certain periods of time, to the extent that such diversion would still be protective of anadromous salmonids (Chinook salmon, coho salmon, and steelhead trout) and their habitats. This represents the fundamental goal toward which the State Water Board will have to monitor the effectiveness of the Policy.

Policy objectives are to provide:

- Adequate stream flows for anadromous fish to utilize and maintain spawning habitat at existing levels, sustain egg incubation, and promote fry emergence;
- Adequate stream flows to allow successful upstream passage of anadromous salmonids throughout the length of stream of their current and historical distribution;
- Adequate stream flows to maintain existing levels of rearing habitat for fry and juvenile anadromous salmonids: Such flows will meet both the spatial and water quality requirements, as well as food production and supply that may even originate upstream above the upper extent of anadromous salmonids but is nonetheless important as food in the form of invertebrate drift and supplying the cascade of energy downstream (Vannote et al. 1980);
- Adequate stream flows for maintaining habitat form and function so that habitat quantity and quality are not degraded over the long term (primarily channel and riparian maintenance flows); and

These objectives collectively represent the major drivers governing the what, where, how, and how often questions associated with the development of sampling designs, selection of parameters and metrics to be monitored, standardization of sampling protocols, and the decision analysis for evaluating the adequacy (i.e., protectiveness) of respective Policy objectives.

K.3.2 Establishment of Monitoring Oversight Committee

It is recommended the State Water Board form a nine member Monitoring Oversight Committee (MOC) as a first step in the process of developing a coordinated monitoring plan, designed with input from a variety of state and federal agencies, and academic institutions, as recommended by Moyle et al. (2000). It is recommended that a State Water Board senior staff member with a high level of experience in water resources management and a good understanding of hydrology, fluvial geomorphology, and salmonid biology chair the MOC. The chairperson would act as the liaison between the MOC and the State Water Board and direct various MOC staff in preparation of the monitoring plan.

Membership – Recommended membership in the MOC should consist of, in addition to the chairperson, one more technical specialist from the State Water Board, and one representative from each of the following agencies/academic institutions: DFG, NMFS, USFWS, USGS, California Department of Water Resources (DWR), and two independent scientists from academic institutions. The MOC may also solicit input from other entities (e.g., county water districts and agencies) and stakeholders who may be involved in ongoing monitoring programs on certain streams and rivers, and therefore possess stream-specific information. Also, the MOC may engage the services of certain technical specialists (e.g., statisticians; aquatic ecologists, geomorphologists, fish biologists, and others) to assist in preparing parts of the Monitoring Program. The MOC would be tasked with preparation of a draft Monitoring Program designed to address the specific objectives noted above.

Activities – One of the first tasks completed by the MOC should be an evaluation of options for completing the Monitoring Program. This should include a review of past and ongoing biological and ecological monitoring programs within the Policy area, such as those being conducted by local, regional, state and federal agencies and other stakeholder groups that may be targeting specific watersheds or basins. Emphasis should be placed on determining the spatial extent and temporal duration of these monitoring programs, and the applicability of measured parameters for detecting flow induced effects of Policy implementation. The extent to which modifications to the programs could be made to better address flow effects would also be assessed. The option of adapting one or more existing monitoring programs to meet the objectives noted in the above section may prove useful in capitalizing on existing sources of funding, reducing potential redundancy in monitoring, and facilitate data and information exchange. However, if it is determined that existing programs will not address the stated goals and objectives, then the MOC should proceed with development of an entirely new program specifically designed to test the primary and secondary hypothesis related to Policy implementation.

Other activities (presented somewhat chronologically) to be completed by the MOC during development of a detailed plan should include, but are not limited to:

- Developing the process to be used and schedule to be followed for development of a detailed plan;
- Development and prioritization of hypotheses to be tested;
- Selection of parameters to be measured and metrics to be used to test hypotheses;
- Refining and understanding issues of temporal and spatial scale (see Moyle et al. 2000);
- Development of sampling designs, draft field protocols, and sampling schedules;

- Developing and implementing data and information management procedures;
- Preparing and implementing quality assurance and quality control protocols;
- Developing decision analysis procedures that link monitoring results back to Policy objectives and hypothesis;
- Identifying funding needs and potential funding sources; and
- Coordination with other federal, state, and local monitoring efforts.

In addition to preparation and administration of a detailed Monitoring Program, the MOC should also produce a number of issue-oriented white papers designed to describe specific components of the Monitoring Program, or address sampling and data analysis issues.

Science Review Panel – It is recommended that an independent science review panel be appointed by the State Water Board to review key work products (including the Monitoring Program) developed by the MOC before being released to the public and prior to implementation.

K.3.3 Selection of Appropriate Sampling Designs

As noted in Appendix B, the Policy area is large and contains over 3,400 classified stream segments of varying drainage area. Regardless of whether the Monitoring Program evolves from existing programs or consists of an entirely new program, monitoring of all systems is impractical from a funding perspective, and moreover, is not necessary provided the monitoring is founded on a strong statistically derived sampling design. The Monitoring Program should include sampling at a variety of spatial and temporal scales.

There is an inherent problem when attempting to detect responses of anadromous salmonids to Policy actions or habitat alterations within a given stream, in that the factors actually imparting an effect may be outside of the area for which Policy actions occur. For example, if population regulating factors relate more to ocean conditions and/or harvest limits than to effects imposed during the freshwater residency period of anadromous salmonids, then actions invoked and resulting responses that may occur may be masked due to the overriding effects of such conditions. In these cases, it does not mean that a particular action is not having an effect; it simply means it cannot be detected.

There are at least two approaches that could be used to attempt to account for or simply discount factors extrinsic to the Policy area. The first (account for) is to establish and monitor a range of watersheds that would include both test and reference streams, with test streams being subjected to Policy actions, while reference streams would not. In practice, reference and test streams need to share similar physical, hydrologic and chemical characteristics, except for the specific anthropogenic factor being considered. In this case, the test and reference streams should be as similar as possible except that the test stream would be subjected to the Policy action, while the reference stream would not. This type of approach is being applied in the state of Washington to assess effects of habitat restoration actions on anadromous salmonids. The approach, termed Intensively Monitored Watersheds (IMW) is focused in part on monitoring a suite of biological and physical parameters in test and reference stream segments, with restoration actions limited to the test streams (IMW Scientific Oversight Committee 2006). Although more focused on defining cause-effect relationships (i.e., validation monitoring), this type of approach could be useful for detecting effects of Policy implementation.

The second approach (discount) is simply to monitor selected metrics that are not influenced by factors external to the stream or watershed and that are not directly connected to population levels of anadromous salmonids. Such factors may include both biotic (e.g., benthic macroinvertebrates; resident fish) and abiotic factors (e.g., substrate composition, channel width, sediment concentration).

Both approaches (and others) would require monitoring of a sufficiently long duration to allow the detection of changes from Policy implementation. In the context of this Monitoring Program, short term is defined as periods of from 5 to 10 years, moderate term as 10 to 20 years, and long term as greater than 20 years.

To address these and other sampling design issues it will be critical for statisticians to be involved early on in the development of the Monitoring Program. In addition to the above issues, statisticians would be useful to address issues of sampling and sub-sampling, accuracy and precision of data, replication, and controls. Importantly, decisions adaptively made from the monitoring must be based on unbiased information that is representative of biological or physical responses due to Policy implementation.

K.3.4 Selecting and Monitoring Appropriate Indicators and Metrics

Choice of indicators and metrics to be measured will depend on specific Policy objectives and hypothesis to be tested. These would include metrics to assess Policy elements associated with the period of allowable diversion, minimum bypass flow, cumulative diversion rate, and to some extent fish passage and protection. In general, monitoring programs include a suite of metrics that collectively serve to evaluate the ecological response(s) of management actions. In terms of the Monitoring Program for the Policy, two types of indicators will be important; 1) effectiveness monitoring indicators that serve to detect potential changes in physical, geomorphological, and biological characteristics of streams attributable to Policy actions; and 2) compliance indicators, which address compliance activities associated with implementation of the Policy (can be done by the Division under the enforcement program established in the Policy).

K.3.4.1 Effectiveness Monitoring

There are four Policy elements for which effectiveness monitoring could be applied. These include the elements related to the diversion season, minimum bypass flows, the maximum diversion rate, and passage requirements. For each of these, there are a number of metrics/indicators that could be monitored, some of which are listed in Table K-1 and discussed below. In doing so, it must be emphasized that there is no single set of metrics that will address all of the objectives and hypotheses raised regarding effects of Policy activities. Rather, there will likely be a suite of metrics, some standardized across geographic areas, and some that are scale-specific.

Diversion Season

The selection of the diversion season as defined under the Policy (i.e., December 15 to March 31; or alternative – October 1 to March 31) presupposes that this period is the most biologically benign relative to incurrence of flow related impacts on anadromous salmonids. The intent is to allow the diversion of additional water from a stream only during periods of relatively high flows that typically occur during the wettest part of the hydrograph. Testing of the protectiveness of this element thus involves aligning the timing of the peak flow hydrographs and the selected diversion season with important life history periodicity information for anadromous salmonid species and lifestages of concern. Life history periodicity information is generally well understood for anadromous salmonids in the Policy area (see Appendices B and C), and is primarily related to adult upstream passage and spawning, and to some extent juvenile rearing. Since the underlying premise of protectiveness during this time would be implicitly tested as part of the evaluation of the minimum bypass flow element, there are likely few if any additional metrics/indicators (beyond those applied to the minimum bypass flow) needed to assess this element of the Policy.

Minimum Bypass Flow

Since it was determined that upstream passage should generally be protected by the minimum bypass flow element (see Appendices H, I, and J), effectiveness monitoring should focus on simple measures of spawning and reproductive success and persistence during base flows, as a means to test Policy protectiveness. In regards to spawning and incubation flows, habitat availability versus flow relationships can be examined at a variety of locations. Such an evaluation was conducted at a limited number of channel cross-sections and sites as part of this Policy assessment. This approach should be expanded to include a variety of streams of variable size and topographic settings across the range present in the Policy area.

Table K-1. Policy Elements and Potential Effectiveness Monitoring Metrics Useful for Assessing Protectiveness of the North Coast Instream Flow Policy on Anadromous Salmonids.

Policy Element	**Potential Monitoring Metrics**
Diversion Season	• Monitoring of this element captured in metrics specified under "minimum bypass flow."
Minimum Bypass Flows	• Derive spawning habitat vs. flow relationships from sites selected within a stratified subset of streams representative of Policy area streams; comparisons to Policy-imposed bypass flows. • Complete passage corridor analysis within the same subset of streams; comparisons with Policy-imposed bypass flows. • Spawning surveys within same subset of streams; monitoring for trends post-implementation of Policy; if possible – comparison with trends in similar streams not subjected to Policy. • Redd marking and monitoring to evaluate "watering" duration from creation to projected fry emergence. • Biological monitoring (e.g., fry/smolt production – via outmigrant traps, screw traps, snorkeling, etc.) of anadromous salmonid populations within subset of streams; if possible – comparison with trends in similar streams not subjected to Policy.
Maximum Diversion Rate	• Substrate quality monitoring – within subset of streams representative of Policy area streams; - Core sampling (bulk, grab, freeze-core) - Pebble counts - Ocular – embeddedness - Intragravel sediment monitoring • Cross-sectional profiles – subset of streams • Riparian corridor mapping/species composition – subset of streams • Benthic macroinvertebrate (BMI) monitoring – subset of streams
Passage Considerations	• Spawning surveys above on-stream reservoirs or diversion structures • Compliance monitoring of individual structures to ensure proper operation (or, enforcement)

For the assessment of spawning, the simplified approach described in Chapter 4 considered the number of cell-days from a habitat time-series prepared over the spawning season that met HSI depth, velocity, and substrate criteria across measured transects as a metric. Inclusion in the study of ungaged basins would require data collection over two or more (preferably three or more) flow levels to develop stage-discharge relationships and other hydraulic parameters for modeling the site. In addition to broadening the number of sites examined, the number of transects within a site should be expanded to represent more of the variability that could occur within a spawning reach. A statistically robust sampling scheme should allow for development of a more thoroughly derived regional, or stratified regional, relationship between basin size and flow needs for spawning. These empirically derived relationships can then be reviewed to determine whether bypass flow requirements as imposed by default via the Policy would be similar to those based on site-specific data.

Selection of specific sites could be coupled with spawning/redd surveys to verify habitat suitability of the study areas. Verification of modeled results and regional relationship(s), if developed, could occur by comparing flow, depths, velocities, and substrate at unmeasured sites where spawning is occurring, to the models. Water depths at marked redds could likewise be tracked to determine if they remain covered with water over the period of incubation. Some biological monitoring focused on assessing anadromous salmonid production over time could also be implemented at a subset of sites. This could include fry/smolt outmigrant trapping, snorkel surveys, etc., that are designed to evaluate yearly smolt production. Ideally, to account for ocean effects, this monitoring would be conducted using a paired-reference stream approach, where one set of streams would be subjected to Policy elements, and a second set would not. The design and implementation of spawning surveys should capitalize on data and information from historical as well as ongoing surveys, with the goal of avoiding duplication of efforts.

Similar to spawning and incubation, an expansion of the number of basins and sites examined for passage flow needs could supplement and refine the current analysis for protectiveness. Spawning surveys can be used to identify the upstream extent of spawning under different flow conditions, but could be confounded by escapement size (i.e., the number of adult anadromous salmonids returning to a given stream will influence the ability to detect redds). It can be assumed that all riffles downstream of the upper extent of observed adult anadromous salmonid migration met minimum passage criteria at some time during the period of upstream migration. However, it cannot be assumed that all flows up to that point were passable. Cursory observations during spawning surveys coupled with spot measurements of velocity and depth could be used to identify a group of potential critical riffles possessing marginal passage conditions that could be selected for more focused investigation. A combination of high flows and escapements could expand spawning to areas that would not otherwise be used during lower flow conditions. However, the timing, intensity and locale of storm/flow events can create widely disparate passage conditions in streams even within a single basin. To the extent possible, the identification of critical riffle areas should occur in conjunction with spawning surveys. However, these should be supplemented as needed with surveys specifically focused on identifying critical passage riffles. The experience of local field biologists and use of spawning surveys, if sufficiently detailed spatially, can be a great aid to identifying critical riffles and limiting the amount of area to be surveyed for spawning.

Maximum Cumulative Diversion Rate

Analysis of the potential effects of the maximum cumulative diversion rate restriction suggests that with the reduction in channel maintenance flows, there may be an increase in the characteristic grain size in the surface layer of the stream bed in the near term (~10 years), and an eventual shrinking of the channel over the longer term (~10-30 years), which may result in changes in riparian vegetation species composition, density and diversity. The degree and extent of such changes, if they occur, will likely vary depending on prevailing stream/channel characteristics (e.g., slope, substrate composition, local geology, riparian vegetation, etc.), and the timing and number of individual diversions within a basin. Metrics to be monitored should therefore largely focus on those sensitive to detecting changes in substrate composition (in particular, fine sediment accumulation), channel size and form, and riparian community composition.

Changes in substrate size characteristics can be monitored using a variety of techniques (Table K-1; Reiser 1998a). Detecting change implies there is some pre-defined baseline condition that will be used to compare with future conditions. Since the focus of the Monitoring Program is on evaluating the effects of the Policy elements on various physical and hydraulic parameters, pre-Policy implementation sampling will be needed to establish baseline conditions from which to compare post-Policy implementation conditions.

Changes in the presence of fines in spawning gravels can be examined by sieving bulk substrate samples collected using a McNeil type sampler (McNeil and Ahnell 1964) or other devices (Grost et al. 1991), subject to sample weight constraints to increase precision (Church et al. 1987). Although more costly, use of freeze core substrate samplers (Everest et al. 1980; Walkotten 1976) may prove useful for some systems where it is important to discriminate and quantify sediment deposition within different layers of the substrate. Installation and monitoring of intergravel sediment traps (Wesche et al.1989; Lachance and Dube 2004; Hedrick et al. 2005) may also prove useful in some stream systems. Where the desired resolution does not include fine materials or extremely large particles, pebble counts (Wolman 1954) could be used to monitor potential changes in substrate size distributions over time. Another ocular assessment technique (although largely qualitative) that could be used to assess sediment deposition is the measurement of embeddedness (Platts et al. 1983; Plafkin et al. 1989) defined as the degree (expressed as a percentage) to which larger particles (boulders, cobble, gravel) are surrounded or covered by fine sediment. There are a variety of metrics that have been developed/derived that relate the results of substrate characterizations to effects on salmonid egg survival and fry emergence. These include computations of the percentages of fine sediments (of different size classes), the fredle index, sorting coefficient, geometric mean diameter and others (Platts et al. 1983).

In terms of channel shape and size, bed elevation measurements taken at specified intervals across permanently marked transects can serve as reference points from which to gauge channel aggradation and degradation, as well as changes in channel width. These same transects, when extended beyond the channel, can provide interval markers from which to assess changes in the composition, diversity and density of the riparian community.

Some potential ecological effects of withdrawals may also be worth monitoring. For example sampling of the benthic macroinvertebrate (BMI) community may provide an indication of significant flow alteration or changes in substrate characteristics including increased sediment deposition. BMI are a mainstay to anadromous trout and salmon diets during the freshwater residence period. Consequently, changes to BMI density and/or diversity could have secondary effects on Chinook salmon, coho salmon, or steelhead trout. Monitoring BMI in smaller, non-fish or non-anadromous salmonid bearing streams could likewise be important, since the invertebrate communities in these systems may be the primary providers of food to downstream salmonids via invertebrate drift. There are a variety of BMI sampling protocols that could be followed, including the DFG's (2003b) Aquatic Bioassessment Procedure, the Rapid Bioassessment Protocol (Plafkin et al. 1989), and others. Currently, there is no standardized multi-metric Index of Biotic Integrity (IBI) for the Policy area. Barbour et al. (1999) and Karr (1999) discuss the development of IBI metrics and provide an existing pool of potential BMI metrics that could be used.

The potential effects of surface flow withdrawals under the Policy on riparian function are anticipated to be insignificant, but some monitoring to verify this conclusion may be warranted. Riparian functions include stream bank stabilization, sediment filtration, shade, leaf and litter inputs, and large woody debris. If water withdrawals under the policy change the density or diversity of riparian vegetation, one or more of these functions could be impaired. For example, if bushy vegetation is replaced with herbaceous vegetation and a decrease in root strength along stream banks, increases in bank sloughing and fine sediment input that could be transported downstream might result. Monitoring the riparian community (density, diversity) along extended cross-channel transects over time, coupled with photographs taken from permanently marked photo points provides one way of detecting changes resulting from Policy implementation. Similar to the substrate metrics, it will be important to first establish a baseline that represents pre-Policy conditions and to which post-Policy effects can be compared.

Fish Passage

Effectiveness monitoring for fish passage may not be warranted unless new innovative methods are utilized or a unique application is needed with a complex design. This element requires primarily compliance monitoring. Criteria for passage design at low-head diversion dams are fairly well established, and required permits for their construction will result in design review by regulating agencies. If compliance monitoring demonstrates that a passage facility was built as designed, there should be a high likelihood that the facility is also effective at passing fish.

K.3.4.2 Uncertainty and Compliance Monitoring

Moyle et al. (2000) described a number of uncertainties potentially confounding the success of implementation of the DFG-NMFS (2000) Draft Guidelines, at least two of which related to surface hydrology and that could be addressed via compliance monitoring. Perhaps the most important of the two relates to surface flow in ungaged headwater streams and is linked to the issue of spatial scales. As Moyle et al. (2000) noted, stream gages are typically located in the lower reaches of streams even though orographic effects can cause substantial variability in precipitation, particularly in higher elevation headwater streams. Consequently, there is some risk that hydrologic models calibrated to distant downstream flow gages, or generalized relationships (e.g., to drainage area) may result in erroneous conclusions regarding the available unallocated surface flow in headwater streams. Because the amount of surface flow is a key metric, and most new permit applications for diversions are likely to occur on headwater streams, reducing the uncertainty regarding the magnitude of surface flow in these streams is critical for not only implementing the Policy properly, but also for determining its effectiveness.

It is recommended that a compliance monitoring program consisting of the installation and monitoring of a stream gage network at varied watershed elevations be considered as a means to reduce this uncertainty and refine the discharge relationships.

The second important hydrologic uncertainty is the amount of surface flow being withdrawn by unauthorized diversions and the actual amount of withdrawals by authorized diversions. This uncertainty can again be addressed to some extent, through installation and monitoring of a more robust stream gage network designed to monitor stream flows at key locations within a watershed. There will be limits to how much this uncertainty can be reduced because of the number and difficulty of monitoring withdrawals at authorized diversions, let alone unauthorized diversions.

It is recommended that the MOC consider options to address this that may include inventories based upon aerial photographic analysis and field surveys, as well as implementation of a stream gage network.

K.3.5 Standardization of Sampling Protocols

Replication and repeatability are fundamental precepts in the design and conduct of statistically rigorous monitoring programs. Unless standards are implemented it will be more difficult to compare data sets collected at different times and places in the Policy area and draw appropriate conclusions. To the extent possible, the monitoring of all metrics should be completed using standardized sampling protocols and data analysis techniques. If new protocols are developed to measure particular attributes it may be useful to test the protocols prior to implementing them on a wide-scale study effort. This will ensure statistical replication, reduce measurement error, and increase the reliability of the data so collected for use in decision-making. The MOC should ensure that detailed sampling protocols are drafted, reviewed and approved for each of the metrics selected for inclusion in the Monitoring Program. All personnel proposed to lead and direct the collection of monitoring data within a specific stream should be familiar with sampling protocols, trained and demonstrate proficiency in the collection of respective data, and receive written approval by the MOC, before actively engaging in monitoring activities.

Specific protocols to be applied will depend on metrics to be assessed. It is anticipated that in general, protocols for monitoring the metrics identified in Section K.3.4 have already been developed and described in one or more reference documents. For example, numerous field protocols are described on the website of the Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP), and are also available in a variety of reference documents including Flosi and Reynolds (1994), Stolnack et al. (2005), Johnson et al. (2001), Platts et al. (1983), Calfish[1], USGS Technical Memoranda[1], and DFG's bioassessment procedure, etc.). These and other protocol descriptions should be referred to when developing the details of a monitoring plan. Compatibility with other monitoring programs in the Policy area should be a consideration when selecting protocols.

K.3.6 Establishment of Quality Assurance/Quality Control Program

Since the data collected as part of the effectiveness monitoring program would be used by the State Water Board in a decision-analysis framework, the validity of those data is critical. The MOC should therefore establish a rigorous Quality Assurance/Quality Control (QA/QC) Program designed to ensure that all data to be relied on have been collected and compiled in accordance with QA/QC protocols, and hence have been validated for use in the decision analysis process. The QA/QC program should have the following general components:

- *Program Organization* – describes overall reporting relationships and responsibilities among agencies and other stakeholders relative to data collection and management, data flow, and database development and management;

- *Sampling Protocols* – presents and describes detailed sampling methodologies to be followed when collecting data required as part of the monitoring program; the sampling protocols should be those as identified and approved by the MOC;

- *Quality Assurance (QA) Objectives for Measurement Data* – lists hypotheses to be tested and objectives for data collection, and defines characteristics of the data to be collected including accuracy, precision, completeness, representativeness, and comparability;

- *Data Transfer Protocols* – describes methods for data transfer from the field, laboratory (if applicable) etc. into a designated data repository, ensures traceability of information and data from its origin to final end users;

- *Calibration and Preventative Maintenance Procedures and Frequency* – ensures that all field data are maintained in accordance with manufacturers specifications;

- *Data Reduction, Validation, and Reporting* – defines process to be followed that will render data as collected under the monitoring program as valid or invalid; and

- *Quality Assurance Audits and Corrective Actions* – outlines the process the MOC should use in conducting periodic audits of the overall program or program components, designed to document proper adherence to the monitoring program and collection of data in accordance with specified sampling protocols.

K.3.7 Data Dissemination

It is envisioned that many agencies and entities would be involved in the implementation of various components of the Monitoring Program. It is also anticipated that the data so collected would be of interest to a wide range of personnel, including agency representatives, scientists, and the general public. The MOC should explore ways to facilitate the dissemination of these data, while at the same time preserving data integrity. The State Water Board could serve as the central holder/organizer of the Monitoring Program data and database; individual entities/agencies conducting stream-specific monitoring could be responsible for managing and disseminating those data, provided electronic linkages between database sources are established; or an existing regional information management system (e.g., California Environmental Resources Evaluation System) could be used.

The general types of information and data to be managed include numeric and text data collected in the field, raw output from data analysis, digital photos, GIS map coverages, and electronic documents (e.g., study plans, reports, meeting notes, etc.). The creation and maintenance of metadata is an important part of an information management system. Metadata provides documentation about a dataset including its structure, data units, source, points of contact, and other information. Metadata is critical for understanding the limitations of a dataset, and for enabling use of the data in ancillary analyses not performed by the original study scientists. Relative to data types, the MOC should consider the scope and context of the Monitoring Program, in general, and plan for the appropriate level of coordination, infrastructure (computer hardware and software), and staff needed to enable efficient input and dissemination of data and information, while still maintaining the integrity of the data. Development of stream-specific study designs will need to consider their compatibility with data structures that may already exist in the management system, while development of an overall management system would need to consider the types of data likely to be collected or produced by the various monitoring components.

K.3.8 Funding Support

It is recommended that the State Water Board commit sufficient funding support to allow implementation and continuance of the Monitoring Program described herein, and as may be modified and expanded in the future. It is also recommended that the State Water Board seek to retain existing and create new collaborative partnerships with other agencies and stakeholders as a means to increase monitoring efficiency while at the same time reducing costs. Identifying the exact amount and sources of funding needed for this program will require a high level of detailed planning. Although monitoring can be expensive, obtaining adequate funding will be critical to the success of the Monitoring Program.

K.3.9 Adaptive Management – Decision Analysis

The Monitoring Program described above was framed within an adaptive management construct that embodies decision analysis. Thus, it is recommended that the State Water Board develop a formal decision-analysis process to address questions related to which (if any) Policy elements warrant modification; what type of modification is needed (i.e., is the element over or under-protective); and whether changes in the Monitoring Program are warranted in order to be able to detect potential response. Monitoring describes what is biologically possible under a given set of Policy conditions. From this, scientists can estimate the probability of different biological conditions evolving, such as suitable spawning habitats, population increases etc. These estimates can prove useful in helping to formulate decisions regarding the extent to which the Policy elements should be modified. However, in general, recommendations from the MOC should be limited to objective determinations of the protectiveness of different Policy elements rather than recommending specific adjustments. The degree of adjustment to be implemented is largely a policy decision that would require broader input than the MOC, and would require specific action by the State Water Board.

K.4 MONITORING PROGRAM: PRELIMINARY STUDY DESIGN

This section provides suggestions relative to study design development and the selection of study sites and metrics for evaluation, and is intended to assist the State Water Board in planning the overall scope and budget for the Monitoring Program. It is anticipated that the implementation of the Monitoring Program as described above will occur in phases, with initial efforts focused on 1) establishing the MOC and 2) identifying the overall goals and objectives (Figure K-1) that will form the basis for selecting study sites and the specific metrics to be monitored. To the extent possible, monitoring sites should be established that can be used to assess both the effectiveness of specific Policy elements, and from an enforcement standpoint, compliance with specified instream flows, diversion rates, and passage requirements. Clearly, efficiencies are gained and overall monitoring costs reduced when sites can be selected that serve more than one purpose.

The Monitoring Program study design should focus on answering the null hypotheses identified at the beginning of this appendix. In addition to measurements of flow, a variety of other metrics may be monitored for each hypothesis, with the final list dependent on specific questions to be addressed (Table K-2). Of the four hypothesis noted in Table K-2, the third has the greatest uncertainty associated with it in terms of what maximum level of change equates with protectiveness. Monitoring will thus be a critical part of the Policy for establishing protectiveness of the MCD. In addition, data collection and analysis related to this hypothesis will be useful for Division staff at a later date as they process future applications for water rights.

While there is no firm guide on the number of streams to sample and study sites to establish, the large geographic area encompassed by the Policy and the diversity of streams within suggests the need to stratify the area based on drainage area classes and hydrologic sub-regions, and then selecting a subset of sites from each for detailed monitoring. This approach is intended to ensure some representative sampling within different basin size classes and hydrologic sub-regions, and thus, would lend itself to statistical analysis.

At a minimum, sampling should include the 13 streams listed in Table 4-1 that were used to assess protectiveness. The list would need to be expanded, however, as the 13 evaluated were selected, in part, because of their easy accessibility. Sites that were considered for the protectiveness analysis but not sampled because of access, time, and/or water availability limitations included: Redwood Creek near Muir Beach (National Park Service gage), San Geronimo Creek (Marin Municipal Water District gage), Morse Creek near Bolinas (USGS gage 11460160), Pudding Creek near Fort Bragg (Soda Creek near Boonville (USGS gage 11467850), Russian River near Redwood Valley (USGS gage 11460940), and Big Sulphur Creek (two sites near USGS gages 11463160 and 11463170). With suitable planning and discussion with biologists from various institutions, additional sites can likely be identified for sampling.

For purposes of statistical replication, it is necessary to sample a number of streams with similar characteristics forming a group often called a class or stratum. Similarity may be established any number of ways, ranging from the use of formal stream classification schemes (e.g., Montgomery and Buffington 1997) to statistical stratification and multivariate analyses (e.g., cluster analysis of various physical attributes of the stream). The number of streams necessary to represent each class will reflect in part, inherent variability within a class; that is, the greater the variability within a class, the greater the number of sites required for a specified level of statistical power. In addition, replication is necessary within a given stream. At least three samples of a given metric would be required per stream to be able to describe variability. A greater number of samples is desirable but may not be practicable depending on budget.

As an example of the above, assuming that: a) the Policy area is stratified into six drainage area classes including <1 mi^2, 1-3 mi^2, 3-5 mi^2, 5-10 mi^2, 10-30 mi^2, and >30 mi^2; b) the Policy area contains a minimum of three basic hydrologic sub-regions (coastal north, coastal south, and inland); and 3) a minimum of three sites are established per stream-hydrologic class combination, a total of 6 x 3 x 3 = 54 sites would be established for monitoring (Table K-2). This number would vary depending on the final number of drainage area and hydrologic classes selected. The actual number of sites would also need to be adjusted to account for existing stream gaging stations as well as other sites that may be part of other biological monitoring programs that are already collecting data relevant to assessing the Policy effectiveness. These latter sites could include those used by CDFG or other agencies and stakeholders as part of long-term biological monitoring programs.

Given the importance of flow quantification to the Policy, most/all of the active and inactive stream gage sites should be considered for incorporation (either from an effectiveness or compliance standpoint) into the Monitoring Program. Given that there are currently 88 USGS stream gages within the Policy area, 31of which are active (Figure K-2), and assuming that the above 54 sites could be represented by a subset of the gaging stations, an additional 34 sites (represented by gage sites – i.e., 34 sites + 54 = 88) should be considered for inclusion into the Monitoring Program (Table K-2). However, the final number of sites and overall scope of the program would clearly need to be based on additional considerations including costs and funding support. It is in this matter that the MOC can be instrumental in achieving consensus on an acceptable Monitoring Program.

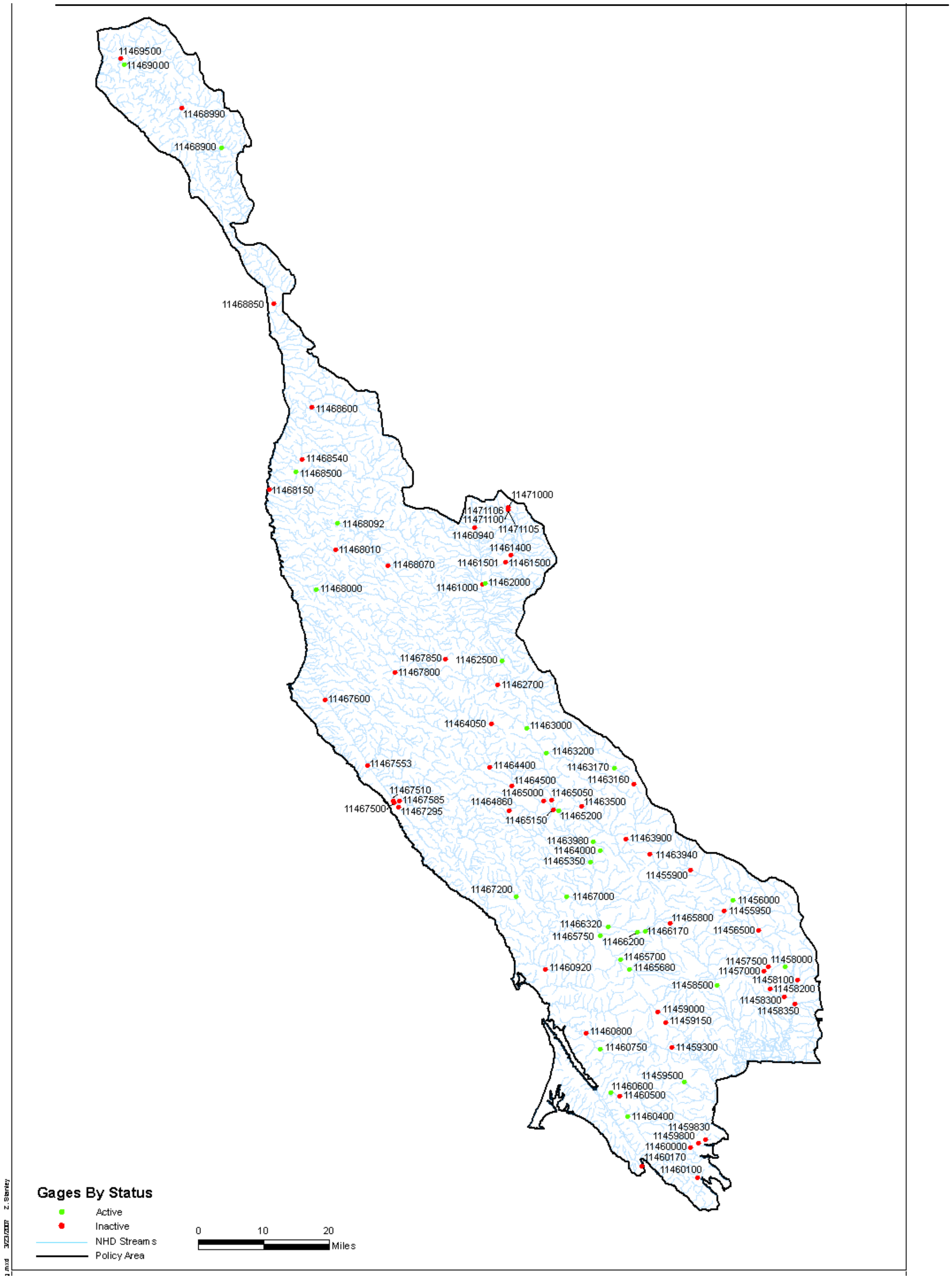

Figure K-2. Active and inactive stream gages in Policy Area.

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Table K-2. Potential Monitoring Metrics and Estimated Number of Monitoring Sites Needed to Evaluate the Effectiveness of Various Elements of the North Coast Instream Flow Policy.

Policy Element/Hypothesis	Potential Metrics for Monitoring Effectiveness	Estimated Number of Monitoring Sites
Minimum Bypass Flow (MBF): **Ho₁** – *the MBF standard provides flows that will allow for successful upstream passage of anadromous salmonids*	• Flow gaging • Spawner and redd counts, timed to occur between high flow events (in streams used currently). • Identification and physical characterization of critical passage constriction locations, including developing depth-flow rating curves. • Observation of passage attempts at critical passage locations coupled with flow and depth measurements (in streams used currently).	• Need representation of streams based on drainage areas, hydrologic sub-regions, and replication = 1) six drainage area classes: <1 mi^2, 1-3 mi^2, 3-5 mi^2, 5-10 mi^2, 10-30 mi^2, and >30 mi^2; 2) a minimum of three basic hydrologic sub-regions within the Policy area (coastal north, coastal south, and inland); 3) a minimum of three sites per stream-hydrologic class combination results in recommendation of a total of 6 x 3 x 3 = 54 sites for monitoring • Assume monitoring at/near all existing (active and inactive) stream gages = **88 sites (includes 54 sites plus additional 34)** • Final number of sites may increase or decrease depending on extent of existing monitoring programs

Table K-2. Potential Monitoring Metrics and Estimated Number of Monitoring Sites Needed to Evaluate the Effectiveness of Various Elements of the North Coast Instream Flow Policy.

Policy Element/Hypothesis	Potential Metrics for Monitoring Effectiveness	Estimated Number of Monitoring Sites
Minimum Bypass Flow (MBF): **Ho$_2$** – *the MBF standard provides flows that will allow for successful reproduction of anadromous salmonids*	• Flow gaging • Spawner and redd counts, timed to occur between high flow events (in streams used currently). • Monitoring of redd inundation at index sites over the incubation period (in streams used currently). • Physical characterization of redds (if present) and spawning habitat availability relative to location in the channel at index sites, involving: o Mapping of depths over spawning habitat at different flow levels, or (in some cases) o A spawning habitat-flow modeling analysis (e.g., PHABSIM).	• Need representation of streams based on drainage areas, hydrologic sub-regions, and replication = 1) six drainage area classes: <1 mi^2, 1-3 mi^2, 3-5 mi^2, 5-10 mi^2, 10-30 mi^2, and >30 mi^2; 2) a minimum of three basic hydrologic sub-regions within the Policy area (coastal north, coastal south, and inland); 3) a minimum of three sites per stream-hydrologic class combination results in recommendation of a total of 6 x 3 x 3 = 54 sites for monitoring • Assume monitoring at/near all existing (active and inactive) stream gages = **88 sites (includes 54 sites plus additional 34)** • Final number of sites may increase or decrease depending on extent of existing monitoring programs

Table K-2. Potential Monitoring Metrics and Estimated Number of Monitoring Sites Needed to Evaluate the Effectiveness of Various Elements of the North Coast Instream Flow Policy.

Policy Element/Hypothesis	Potential Metrics for Monitoring Effectiveness	Estimated Number of Monitoring Sites
Maximum Cumulative Diversion Rate (MCD) or Cumulative Flow Impairment Index (CFII): **Ho$_3$** *–the MCD or CFII restriction will limit new or increased diversions from a stream unless remaining instream flows would be adequate to a) maintain the timing, form, and functional qualities of the natural flow variability, b) provide for channel maintenance and habitat formation, and c) protect anadromous salmonid habitats,*	• Channel width, depth, and grain size distributions and sinuosity measurements at index sites, coupled with a regional assessment of variation in these metrics. • Riparian zone transect surveys for community composition and health. • Macroinvertebrate sampling to document community composition and health	• **Same as MBF =88 sites**, although may only need to monitor stated metrics at a subset of sites.
On-stream Dams: **Ho$_4$** – *the measures focused on restricting on-stream dams and providing fish passage and screening facilities will ensure that approval of new or existing unauthorized projects will not adversely affect existing anadromous salmonids, or impede the restoration/recovery of historically present anadromous salmonids*	• Annual gravel and cobble accumulations in existing on-stream reservoirs, and quantification of channel storage in spawning habitat downstream. • Spawner and redd counts above and below selected reservoirs and diversions meeting Policy requirements (in streams used currently). • Macro-invertebrate sampling in Class II streams to verify status.	• Dependent on number of on-stream reservoirs and mainstem channel diversions within Policy area

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