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.

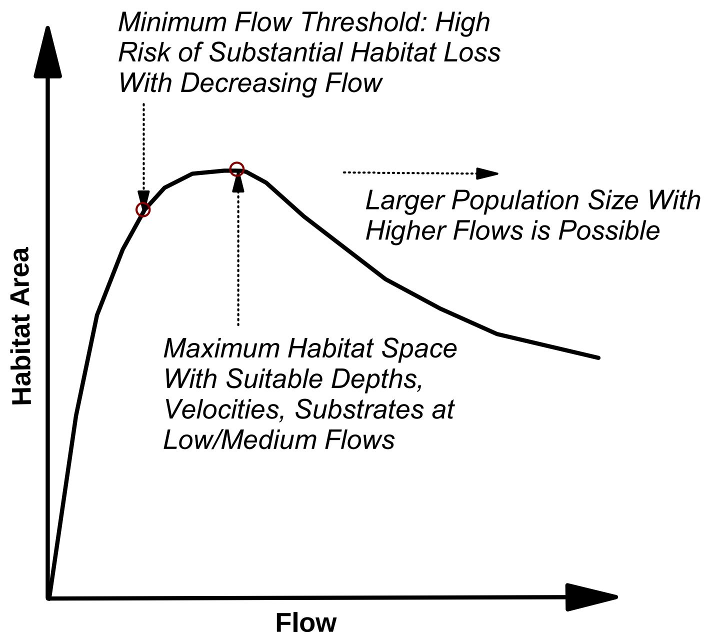

Figure D-1. Conceptual representation of biological significance of habitat-flow curve and specification of a minimum instream flow. The habitat – flow relationship depicted is representative of the type of flow response often seen with spawning habitats. Habitat – flow relationships will differ depending 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

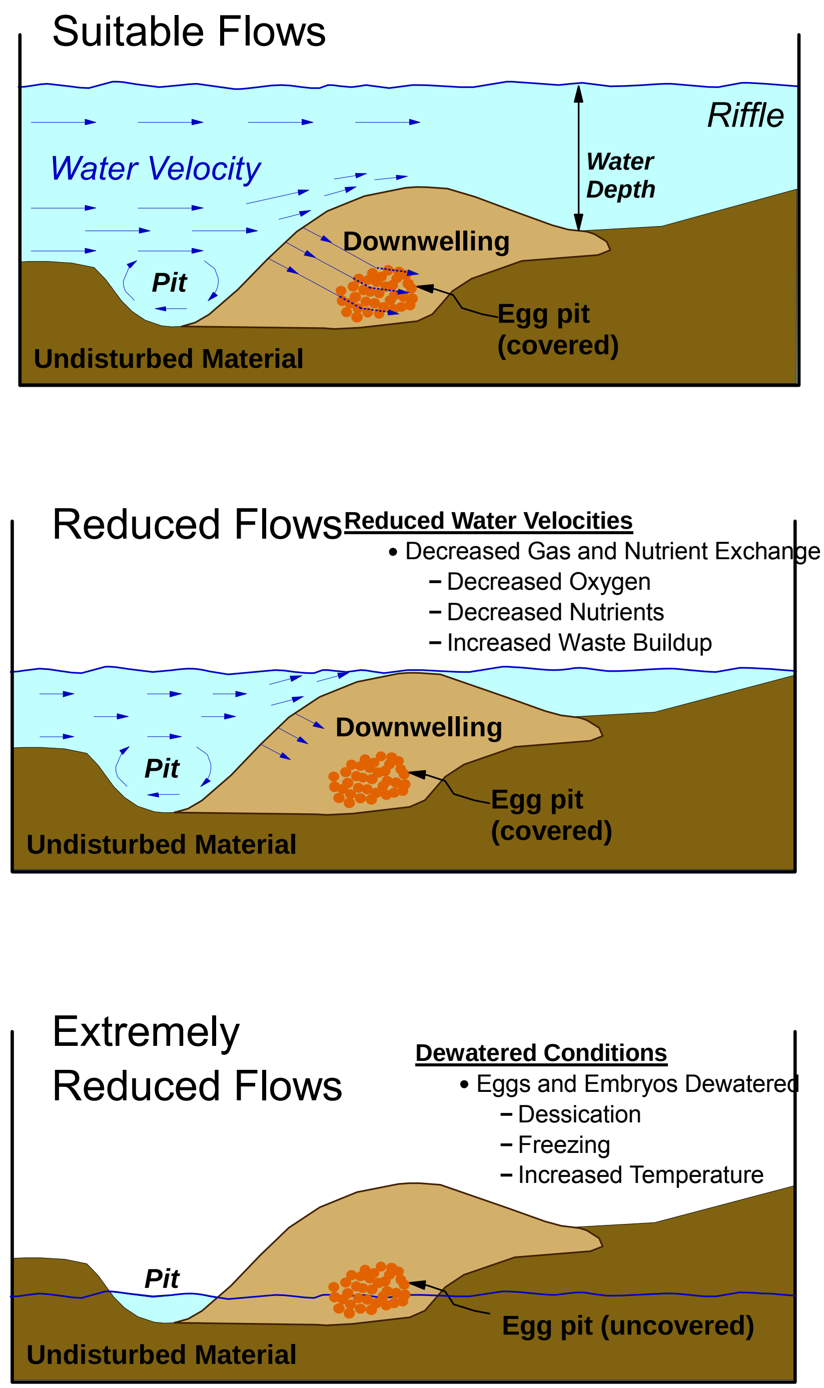

Figure D-2. Conceptual diagram of salmonid spawning nests illustrating generalized effects of stream flow reductions on the intragravel environment (from Reiser 1998a, b).

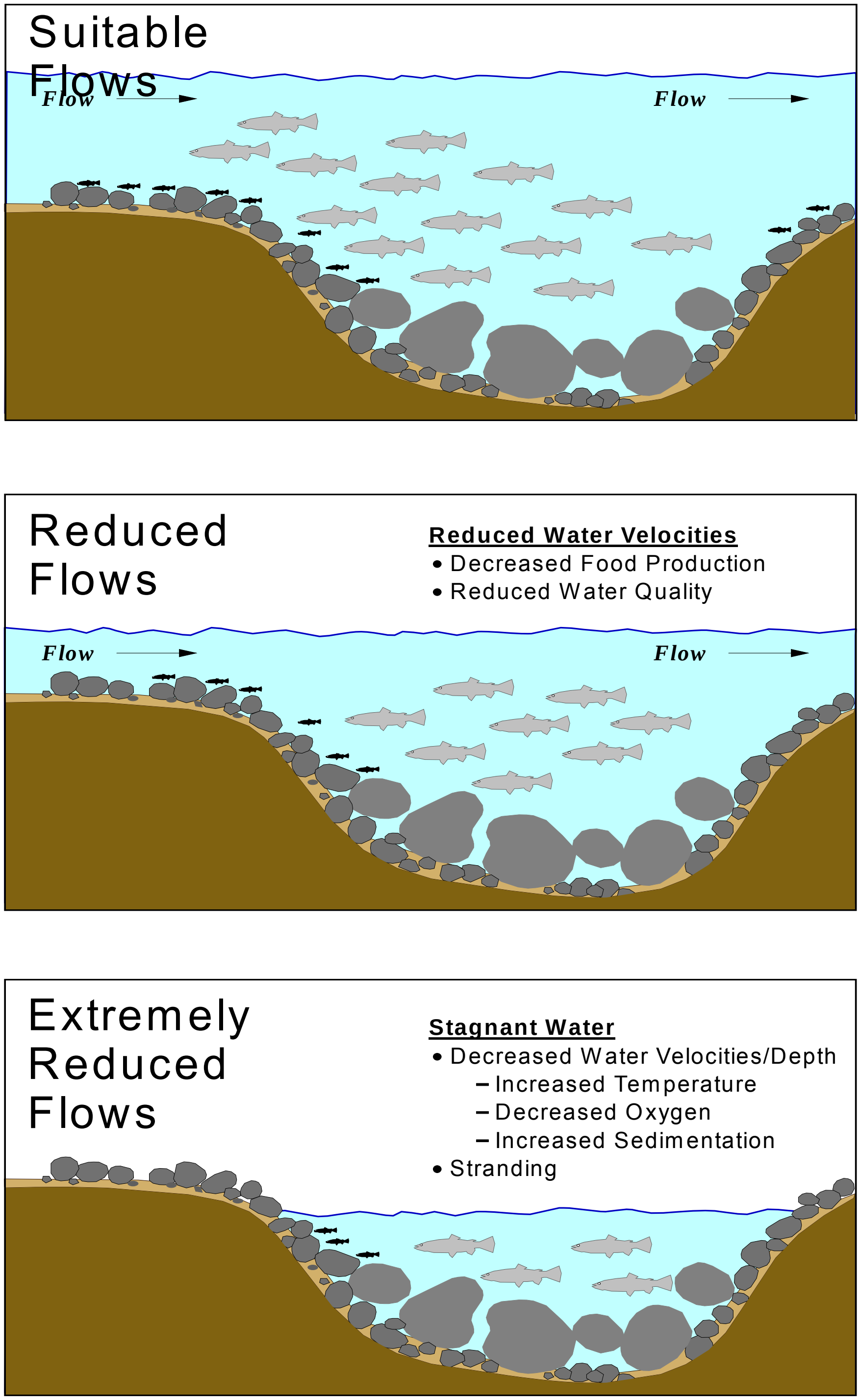

Figure D-3. Conceptual diagram of salmonid spawning nests illustrating generalized effects of stream flow reductions on the intragravel environment (from Reiser 1998a, b).

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.

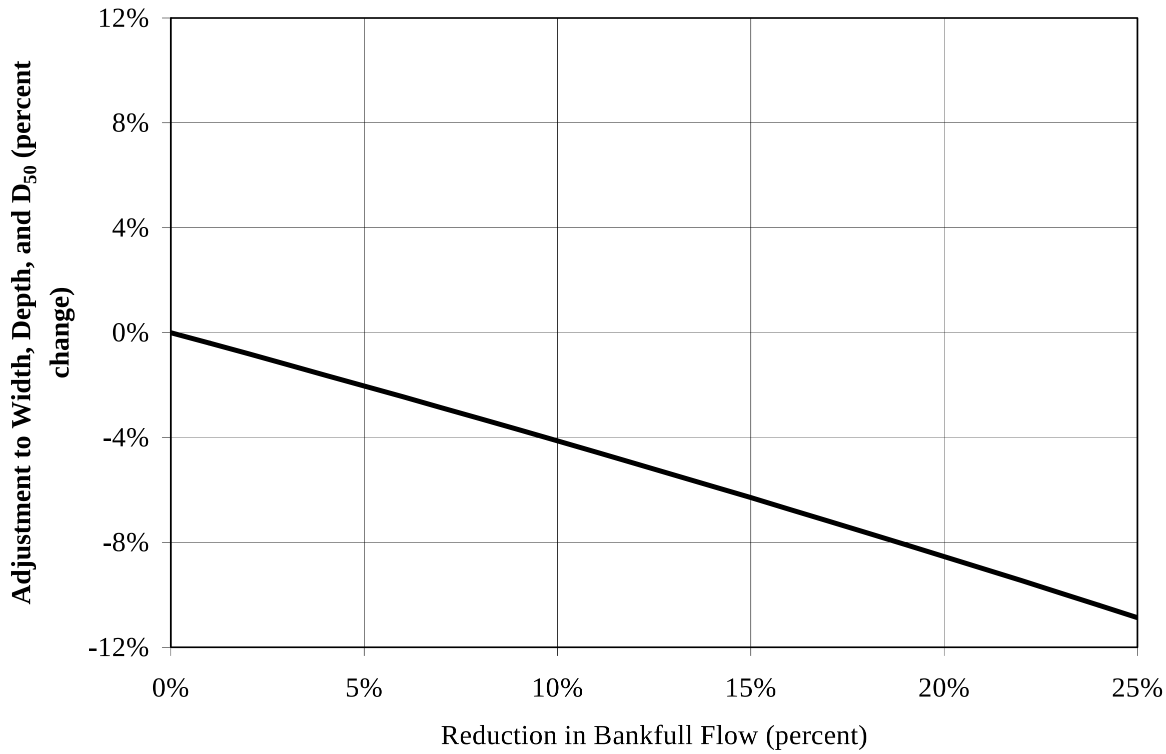

Figure D-4. Predicted long-term potential changes in channel width, depth, and grain size distribution resulting from a reduction in bankfull flow in Policy area streams potentially supporting anadromous salmonids.

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.

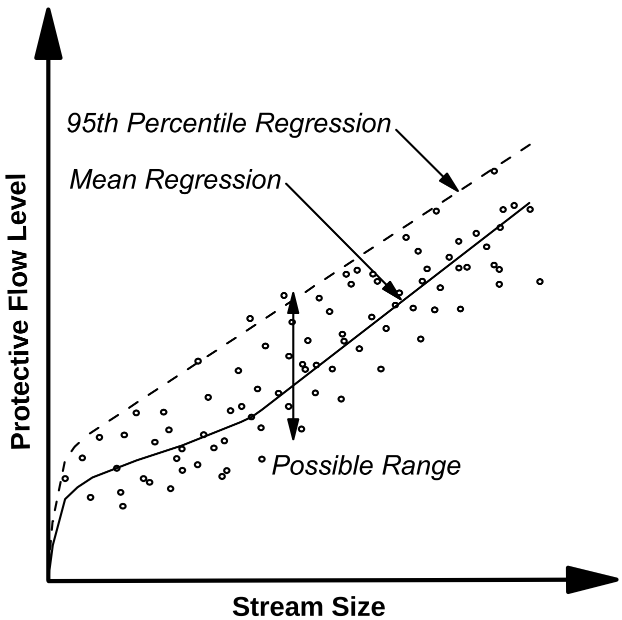

Figure D-5. Conceptual representation of range of protective flows for streams of a given size, and two possible ways of setting protective flow level thresholds as part of a regional policy. Using the 95th percentile line protects nearly all streams, whereas using the mean regression line protects roughly 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.