APPENDIX J

Properties and Behavior of the Cumulative Flow Impairment Index (CFII)

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PROPERTIES AND BEHAVIOR OF THE CUMULATIVE FLOW IMPAIRMENT INDEX (CFII)

The DFG-NMFS (2002) Draft Guidelines contained the following two options for maintaining natural flow variability and avoiding cumulative effects due to diversion:

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

   OR:

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

The procedure proposed for calculating the CFII was:

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

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

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

The CFII was developed based on a review and technical evaluation of stream flow time series that considered the level of impairment and operational practices of diverters, with a focus on differences in flow rate and volume. Its goal was to ensure that diversions of all types, including riparian and pre-1914 rights, did not cumulatively decrease downstream flows below levels considered protective of anadromous salmonids. The CFII was particularly applicable to watersheds where existing permits for on-stream storage would always exceed any limits to instantaneous withdrawal rates (SWRCB 2001). A key assumption of the CFII was that around a 10% reduction in cumulative runoff volume caused by diversion was the level above which additional diversion would negatively affect channel and riparian maintenance processes and upstream passage conditions. Requests for diversion above this cumulative level required detailed study and analysis of the effects to these processes.

There are a number of technical considerations that enter into the evaluation of protectiveness of the CFII including:

1. Implications of Applying Different Time Frames of CDV and EUR – Are the differences in time frames between the CDV (10/1 to 3/31) and EUR (12/15 to 3/31) biologically significant?
2. Influence of Rate of Withdrawal, MBF and Diversion Season – How does the rate of withdrawal chosen by the diverter and the value of the minimum bypass flow and the diversion season influence the protectiveness of the CFII?
3. Channel Maintenance Processes - Is regulation using a volume limit, as provided by the CFII, protective of channel maintenance processes?
4. Incremental Benefits of 5% and 10% Reductions – What are the physical and biological benefits to anadromous salmonids of the 5% and 10% reductions in cumulative volume?

These issues and questions are addressed below in the context of establishing a metric for controlling diversion and protecting anadromous salmonids and their habitat. The 10% level is assumed to be a worst case, effective upper limit to diversion and is the criterion evaluated here for protectiveness.

J.1 BIOLOGICAL AND PHYSICAL SIGNIFICANCE OF DIFFERENT TIME FRAMES FOR CDV AND EUR

This issue relates to the use of different time frames for computing the CDV and EUR values used in the CFII (EUR – 12/15 to 3/31; CDV – 10/1 to 3/31). This difference was noted during the scoping process and was accompanied by a suggestion of using temporally consistent periods, as is typically required for making water availability and demand comparisons. Temporal consistency would also likely be important for discerning effects to anadromous salmonids in a mechanistically consistent way. For example, it is difficult to link the effect of diversions occurring before December 15 with spawning habitat availability after that date, unless it can be demonstrated both conceptually and with data that base flows (which control spawning habitat availability overall based on the need for redd inundation) later in the winter are directly dependent on antecedent conditions. Given that runoff patterns during most of the winter generally reflect the time since the preceding rainfall event, demonstrating such a link is difficult. Thus, the difference in time frames confounds the evaluation of protectiveness, specifically with respect to assigning biological significance to the 5% and 10% CFII thresholds.

It is recommended that if the CFII is applied, it be based on a CDV and EUR calculated over the full diversion season.

J.2 CHARACTERISTICS OF CALCULATING THE CFII THAT AFFECT PROTECTIVENESS OF THE CRITERION

The CFII was recommended as a method of determining which water right applications can be permitted without further study. In effect, the CFII provides a way to identify potential “hot spot” POI locations at which the DFG-NMFS (2002) Draft Guidelines recommend detailed evaluation of potential cumulative impacts. However, the DFG-NMFS (2002) Draft Guidelines did not provide criteria for what constituted a potential hydrologic impact, or criteria for evaluating the results of the site specific studies. In addition, there are no specific guidelines for how the CFII criterion may be met, whether it be through an unlimited diversion rate, or through diversions spread out more evenly in time and space. In its definition, the CFII represents the total cumulative *volume* of diversions that can be permitted in or upstream of a point in a watershed. Importantly, the CFII does not restrict the total cumulative *rate* of withdrawal. The actual volume of water that would be available for diversion in any given water year and the resulting diversion rate at which these diversions may be made depends on the site-specific hydrology and Policy limitations on diversion season and the minimum bypass flow.

Resulting diversion rates could therefore range from a minimum equal to the CDV volume divided by the length of the diversion season, to a maximum of the highest peak flow during the diversion season less any minimum bypass flow requirements (as shown for the validation sites in Table F-19, Appendix F). Depending on the rate of withdrawal implemented by diverters, the same CFII limit can result in characteristically different hydrographs and different levels of protectiveness depending on the way the CFII is implemented. In addition, the date the CFII limit (a cumulative diverted volume corresponding to a given percent of the estimated unimpaired flow) is reached will depend explicitly on the diversion season start date and minimum bypass flow. The difficulty in identifying a protective level becomes apparent when it is considered that the same value of CFII can be reached on different dates when different diversion season or minimum bypass flow alternatives are applied. The effect of diversion season and minimum bypass flow may or may not be biologically significant, depending on which alternatives are ultimately adopted as Policy. Overall, the CFII acts primarily as a hydrologic limit and does not directly reflect cumulative effects to habitat, nor protectiveness with respect to the duration of the diversion season.

In reflection of these characteristics, and in order to use a consistent approach in comparing the CFII volume-based alternative to the other three rate-based MCD alternatives, the following assumptions were applied in generating impaired hydrographs for assessing the protectiveness of the CFII alternative:

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

The calculations used to generate the impaired hydrograph are described in Section F.3.1 of Appendix F. The above assumptions provide a worst-case evaluation of the 10% CFII threshold with respect to hydrograph impairment during the beginning of the diversion season. These conditions could occur directly below an on-stream dam that cannot bypass flows when the reservoir is storing inflows (i.e., a fill-and-spill reservoir during the fill period). At other diversions, the diverter may choose when and how much to divert, depending on water availability and the maximum limits on their instantaneous rates of diversion. Thus, the cumulative effects of diversions at the POI locations may be reduced depending on the timing and spacing of individual withdrawals and routing effects.

J.3 PHYSICAL AND BIOLOGICAL SIGNIFICANCE OF THE CFII METRIC

Even with consistent time frames for calculating EUR and CDV, it would still be difficult to assign biological and physical significance to a cumulative volume without first considering effects of diversion rate. At a fundamental level, cumulative volume reflects an integration of variable flow rates occurring over time, with non-linear responses to flow leading to potentially very different physical and biological responses corresponding to the same net volume. Most ecological and geomorphic responses reflect individual signals stemming from flow magnitude, frequency and/or duration. This appears to be the case particularly for anadromous salmonids, which respond most directly to instantaneous flow rate in terms of habitat selection and upstream passage timing. For example, anadromous salmonids migrate upstream primarily in response to changes in flow. Thus, it is the diversion rate that has the most direct relation to salmonid habitat compared with diversion volume, predominantly in terms of spawning habitat availability, upstream passage, and channel and riparian maintenance flows.

J.3.1 Physical Significance

Because of the wide range of possible permutations of peak flow rate, duration, and frequency, and the non-linearity inherent in such processes including especially bedload transport rate, the same cumulative flow volume will not necessarily result in the same net effect on the channel and riparian zone. Correspondingly, most scientific advances in linking channel form to flow have been made in terms of surrogate flow rates, such as the 1.5 year flood as discussed in Appendix D. Fortunately, such metrics were derived originally from consideration of the integration of flow magnitude, duration and frequency (e.g., Wolman and Miller 1960), where establishing a protective instream flow rate and maximum diversion rate based on an instantaneous measure of flow rate already includes consideration of cumulative flow volume.

The protectiveness of limitations on the maximum cumulative diversion on channel maintenance flows differ depending on the method of limitation (rate or volume). Using a rate method, the expected effect would be a reduction in channel size and readjustment that reflects a lower flow magnitude, but with a similar frequency of runoff events, as described in Appendix D. The quality of habitat would not be expected to change substantially, mostly the quantity. A relatively small diversion rate relative to the bankfull flow would be expected to result in a relatively small reduction in channel size (cf. Figure D-4 in Appendix D).

The CFII volume method allows water to be diverted at any rate of withdrawal. For purposes of this discussion of protectiveness, it was assumed that diversions are made at the maximum rate, until the cumulative diversion volume has been met. At this high rate of withdrawal, the total diverted volume criterion is usually met before the end of the diversion season. In some instances, the quantity of diversion could result in a flat-lining of the hydrograph, whereby essentially the only flow allowed downstream would be the MBF. Predicting the physical effects of flat-lining of the peak hydrograph is difficult and generally not possible without doing a site-specific analysis of flows, sediment transport, and channel stability. Flume studies conducted by Parker et al. (2003) suggest that flat-lining is likely to lead to a reduction in habitat complexity and an increased concentration of fine sediments in the stream bed. However, studies have not been conducted to determine the allowable frequency or duration of such flat-lining events before adverse effects at a regional scale. Thus, there is currently no direct physical or biological basis for concluding that one level of CFII is protective at the regional scale, and another level is not. Furthermore there is no clear way to compute a protective CFII criterion based on an analysis of flow rates without performing a site-specific study.

The sensitivity analysis in Appendix F indicates that implementing the CFII metric without limiting diversion rate has the potential to substantially change the flood frequency characteristics of a stream to a greater extent than the other MCD element alternatives. As described in Appendix D, reductions in the bankfull flow, approximated by the 1.5 year flood peak flow rate, are predicted to result in roughly proportional reductions in channel size and streambed grain size. Table J-1 summarizes predicted estimates of percent reductions of the 1.5 year flood magnitude caused by implementing the Flow Alternative Scenarios described in Appendix I for the four validation sites with the longest stream gage records. The CFII = 10% alternative in Flow Alternative Scenario 5 could result in the greatest predicted change in the 1.5 year flood peak flow rate, at levels that could result in large changes in channel morphologic characteristics.

Table J-1. Estimated Reduction in the 1.5 Year Flood Peak Flow Rate Associated with Implementation of the Five Flow Alternative Scenarios, in Four Validation Sites with at Least Ten Years of Stream Flow Records.

		Percent Reduction in 1.5 Year Flood Magnitude by Flow Alternative Scenario				
Validation Site	**Unimpaired 1.5 Year Flood (cfs)**	**Flow Alternative Scenario 1** (MCD1: 15% of 20% Winter Exceedance Flow)	**Flow Alternative Scenario 2** (MCD4: Reduce MBF Duration for 1.5 Year Flood by ½ Day)	**Flow Alternative Scenario 3** (MCD1: 15% of 20% Winter Exceedance Flow	**Flow Alternative Scenario 4** (MCD2: 5% of 1.5 Year Flood Flow Rate	**Flow Alternative Scenario 5** (MCD3: CFII=10%)
Albion R	1,017	1%	1%	1%	5%	30%
Salmon Cr	1,439	1%	1%	1%	5%	20%
Santa Rosa Cr	1,170	1%	1%	1%	5%	37%
Warm Springs Cr	690	3%	2%	1%	5%	11%

Riparian maintenance flow needs may be most reflective of water volume, where studies have shown a correlation between the water table level, extent of the riparian zone, and mean annual flow volume (e.g., Stromberg 1993). However, this reflects a process that operates on a relatively long time scale, and is thus difficult to link with diversion rate over a variable hydrograph. Channel morphology reflects flow duration to a certain extent as well, but as long as flows are sufficiently high to transport bedload of all sizes present, then some channel maintenance functions are preserved albeit at a slower geologic rate (see Appendix D).

J.3.2 Biological Significance

Direct biological effects of flat-lining a hydrograph peak at the MBF level by means of an unlimited MCD rate would most likely to be manifest for Chinook and coho salmon, which enter, migrate upstream, and spawn in Policy area streams early relative to the diversion season. It is possible that upstream passage of Chinook could be particularly adversely affected because of greater minimum depth criterion that may not be protected by the minimum bypass flow in more than a few streams (see the analysis of upstream passage criteria relative to minimum bypass flow criteria in Appendix E).

Worst case application of the CFII=10% limit would result in hydrograph peaks that are flat-lined at the MBF during the first part of the diversion season. Review of the hydrology and sensitivity analysis data in Appendix F indicates that in the worst case scenario of Flow Alternative Scenario 5, the period over which hydrograph flat-lining would occur would range from as short as 1 day to as long as 75 days after the diversion season begins, depending on the year. Under average conditions, Chinook and coho salmon, and possibly steelhead, could correspondingly experience reduced opportunities for upstream passage and spawning for up to the first 2 months of the diversion season in some streams (also see results in Appendix I and sensitivity analysis in Appendix F).

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