Review of the Scientific Basis for the Proposed "North Coast In-Stream Flow Policy"

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1. **Introduction**:

This report reviews the scientific basis for the proposed "North Coast In-Stream Flow Policy," referred hereafter as the NCISFP. The NCISFP is designed to protect the habitat of anadromous fish, represented by three salmonid species, relative to potential water diversions, impoundments and other water resources activities in streams and rivers along the North Coast of California. As preparation, I reviewed all documents provided including the NCISFP report: Scientific Basis and Development of Alternatives, Appendices A-K, public comments as well as appropriate peer reviewed literature and reports.

The NCISFP addresses a significant issue balancing the use and protection of ecosystem services, that of freshwater provision for domestic, agricultural, industrial and commercial use, and the maintenance of habitat for endangered species. The scientific questions raised involves the sensitivity and vulnerability of a set of channel hydraulic and geomorphic properties that are considered key attributes of salmonid habitat at the reach level, but with important implications for the spatial patterns of potential habitat quality at the stream and river network level. The responses are complex and include feedbacks between water flow, sediment transport and storage, geomorphic channel and riparian form, and potential interactions with riparian ecosystems. The direct linkage of biological outcomes from a set of physical changes in the environment is often not direct as there are many confounding issues both inside the area of interest, and in the case of anadromous species, well outside of the area.

The scientific knowledge base, in terms of precedence and information at necessary spatial and temporal scales, provides a degree of uncertainty regarding potential outcomes of individual and cumulative water resources practices relative to the outcomes that might occur in the absence or modification of these practices. Ideally, a more detailed analysis of flow records, channel conditions, sediment transport and biological activity would have provided a more complete scientific basis for developing the policy choices. The documents provided for review contain a set of references to the limited time and budget available for data collection and analysis, and present very limited field sampling at one specific time, with flow records drawn from different periods of time. Given these limitations, the approach adopted in the proposed policy, to provide more conservative restrictions on in-stream water use at the regional level, is a sound strategy as it provides for protection of threatened ecological systems, while promoting an adaptive management framework that encourages the collection of more site specific information and improvement of the knowledge base that can support modifications to the broad policy where it is appropriate.

While this review addresses the scientific basis of the proposed restrictions on surface water use, there are a set of potential unintended consequences, such as increased use of groundwater, that are beyond the scope of this review but need to be considered as part of a full watershed framework. This framework should also consider increased demand for water due to changes in population and economic activity, and changes in runoff production of unimpaired flow regimes due to trends in land use and potential climate change. Comments made in this review, while recognizing the resource limitations imposed on the scope of the studies used to generate and recommend alternate flow diversion policies, also include recommendations where additional information could have significant bearings on results. We re-emphasize that in the absence of additional information, the conservative approach taken is warranted, as adjustments to the policy may be justified by more detailed and local-scale information.

2. River reach and network framework

A critical aspect of this problem is the network connectivity of all reaches and cumulative impact within each watershed. The quality of habitat within each reach are dependent on the characteristics of upstream and downstream reaches. The cumulative impacts of water diversions from all areas of the drainage network requires consideration of the network as an entity, and not just the sum of all individual reaches. This may have some implications for statistical and other analytical methodologies employed. Reach conditions are likely strongly autocorrelated due to the effects of local geology, climate and land use, as well as the water and sediment cascade linking the network. Statistical analysis and prediction of the application of the different instruments in the policy (e.g. MBF, MCD, seasonal limits) and their interactions are carried out using envelope, rather than best fit, relationships to promote protectiveness. However, additional consideration and analysis may need to be designed to analyze the impacts of sequential dependencies of reach conditions as they will not be randomly distributed.

As an example, passage characteristics to a reach are a function of all downstream reaches. Statistical analysis designed to predict fish passage flow level requirements for any reach needs to consider not just the probability of passage restrictions in the local reach, but the potential for restrictions in the population of reaches downstream. Considerations of channel substrate conditions within a reach requires an analysis and protectiveness of flow conditions in all upstream sediment production sites (low order, or colluvial, reaches), including those above the level of salmon habitat.

Another critical aspect to consider is the rate-of-change of discharge downstream through the stream and river network. Most attention in the documents provided has been on impacts in flow depth and width relative to habitat suitability. This discharge pattern is important to sediment transport and storage dynamics and therefore, habitat conditions.

Specifically, it is not just the magnitude of flow that is important to the processes of erosion and deposition at the reach level, but the change in flow magnitude downstream. Unimpaired flows increase in rough proportion to drainage area, although departures from this trend may occur due to persistent or short term differences in precipitation with elevation or location, landuse/landcover, and groundwater conditions. Downstream increases in flow occur largely at channel junctions as step changes. The cumulative diversion quantity specified by minimum bypass flow and peak flow regulations are designed to be applied on the basis of drainage area. Therefore, diversion limits also change as step functions at major channel junctions, which may have both local and network scale implications for sediment transport. While unimpaired flows in this area typically increase monotonically downstream, water diversions will locally reduce this increase depending on baseflow and peak flow diversion limits. The spacing and magnitude of diversions may lead to unanticipated changes in channel form and substrate due to alterations in local sediment balance. Long term alteration of these patterns may result in perturbations to the downstream hydraulic geometry, as well as bed sediment grain size, and seasonal variations in bed composition. Study resource limitations have been cited as a reason for not incorporating more detailed and quantitative considerations of sediment transport dynamics, but this may be an area that will require more attention as the NCISFP is implemented and managed.

A potentially controversial policy element is the extension of the flow diversion restrictions and regulations on impoundments into smaller channels above the limit of salmonid habitat. This takes the form of both the MBF and the MCD and includes small, colluvial channels (without alluvial deposits) that may be ephemeral or at least intermittent. It is pointed out here that these small order streams drain the majority of the landscape (1st order streams drain 50% or more of any watershed), and as such are the primary source of water and fluvial sediment delivered to the larger, alluvial streams. In particular, coarse hillslope derived sediment are stored in these reaches until sufficiently high flows are generated to move material into the main channels by a combination of fluvial flow and periodic debris flows. While debris flows into higher order channels do occur, it is likely that the vast majority of coarse grained material delivered to larger streams with salmonid habitat are generated from small, headwater catchments. The gravel substrates, derived from the low order channels as part of the geomorphic sediment transport cascade are critical to salmonid habitat (e.g. Kondolph and Wolman 1993). In addition, the majority of water flow, both base flow and storm flow, are generated in these small catchments. It is emphasized that it is the number and ubiquity of these catchments and small channels that provides cumulative impact. Therefore, extension of diversion regulations into the headwaters is an important element of this policy in terms of cumulative impact.

2. Minimum Bypass Flow

The recommended MBF is geared towards maintaining minimum depth and width for passage based on current mean channel dimensions (conditioned on drainage area). In order to increase protectiveness for smaller channels, the MBF is given as a decreasing proportion of the mean annual flow with increasing drainage area, allowing greater proportional diversion downstream. While this maintains an increase in discharge downstream along a stream reach (or with minor tributaries entering), the rate of increase is significantly reduced compared to unimpaired flows as shown in figure 3-1 of the NCISFP Scientific Basis document. Discharge per unit drainage area could decrease significantly downstream under the recommended MBF. This has the potential to increase sedimentation downstream when flow is maintained at the MBF, particularly of sand sized and finer grained material.

Drainage area increases through a fluvial network occurs in a set of gradual increases between tributary junctions, and large step increases at channel junctions. As an example, two 10 sq.mi. merging would form a 20 sq.mi. catchment with roughly twice the mean annual flow. The information given for the 13 sampled sites shows that mean annual flow increases just under 2 cfs per square mile of drainage area. Under the recommended MBF (using eq.3.1, MBF Option 3), the MBF in each of the smaller catchments would be ~59 cfs each (118 cfs combined), while the MBF in the resulting 20 sq.mi. catchment would be ~85 cfs. While discharge is still increasing from either of the smaller streams into the resultant stream, the combined flow requirement actually drops. This indicates that below the junction, either at a point or a set of points, additional diversions could drop the total discharge by 33 cfs, or 28%. This amount is well within the MCD set at 5% of the 1.5 year flood given by the recommended MCD Option 2. Depending on the form of the sediment transport–discharge relationship, this may result in significant deposition of fine grained sediment in the downstream reach, which could degrade habitat quality until sufficient flushing flows occur. If fine grained sediment transport at these times is largely supply limited, it may not be an issue. However, the first few increased flows of the year may flush fine grained sediment, perhaps without mobilizing coarser grain sizes, which may accumulate in reaches where discharge is drawn down. Some additional analysis may make use of any existing suspended sediment information to see if this has the potential to have any significant impact on substrate conditions required for different salmonid life cycles.

As an additional example, figure 1 shows estimates of the MBF for Austin Creek, a tributary of the Russian River below Guerneville. Calculations for this site were carried out using information drawn from the National Hydrography Dataset (NHDplus - http://www.horizon-systems.com/nhdplus) and information reported in the NCISFP. The two, nearly equal sized subtributaries outlined in the box in figure 1 would have an MBF on the order of 90 cfs each (~180 cfs combined). The confluent stream reach would have a MBF of ~140 cfs. As the sediment cascade is adjusted to the long term water discharge, gradient and roughness elements, channel form and substrate may show significant change to the potential rapid drawdown (~40 cfs at the MBF) of the total flow. Some estimate of the sediment transport in each of the tributaries and the confluent stream at the unimpaired and the impaired flows should be carried out to determine the magnitude and significance of this adjustment.

Finally, it appears that the analysis for protectiveness of passage is based on a species specific depth requirement within a minimum of a two foot width. Considering the appearance of migrating fish in "waves" following increases in flow conditions, it would be useful if it is possible to quantify "passage" protectiveness as a function of both effective width above threshold depth, and the expected density of fish migration. This is getting outside of my area of expertise, but the question arises as to the effects of "traffic congestion" as large numbers of salmon attempt to migrate through potentially narrow passable channel segments.

3. Maximum Cumulative Diversion

Environmental flows are often promoted by setting up mechanisms for "peak harvesting" where diversions are targeted towards hydrograph peaks. In the current application, a major concern for channel maintenance is the preservation of sufficiently large events and variability of flow to mobilize and transport stream gravels, and to maintain channel form, dimensions and complexity. While, sediment transport can occur over the full range of the flow distribution, coarser grain size mobilization is restricted to higher flows, and total sediment transport rises nonlinearly with discharge. A full magnitude and frequency analysis of transport by size class would be very valuable for setting the MCD policy, but in the absence of this analysis, literature and judgement have been used to develop alternatives that will maintain channel forming flows and sediment transport function at the regional level.

The recommended option (MCD2) of allowing a diversion rate limitation rather than a cumulative volume limitation eliminates the potential of eradicating all early season flows up to the volume limitation. This is preferred to the CFII method in this case, but its advantages (without a cumulative volume limit) will vary depending on the hydrologic conditions for each year and will be less protective than MCD1. However, the chosen MCD2 option of 5% of the 1.5 year flood has the impact of reducing the flow to the MBF rate in the Salmon Creek example given in the NCISFP document, for all flows less than the MCD plus the MBF.

For the example of two 10 sq.mi. catchments merging into a 20 sq.mi. catchment discussed above, and extrapolating by drainage area from the MCD for the 13 sample sites, the 20 sq.mi. MCD would be ~80 cfs (figure 2). Therefore, for all flows up to ~165 cfs (the MBF plus the MCD) in the confluent stream, discharge would be dropped to the MBF. The "flat-lining" of the hydrograph for low to moderate flows through the year has the potential to increase fine sediment deposition, as the MBF allows proportionally larger diversions with increasing drainage area (as discussed above).

A more cautious approach may be to consider a cumulative volume limitation to this element of the policy, in addition to the rate limitation, until a more detailed analysis of cumulative sediment transport across the flow range is carried out, or more site specific information is generated for individual cases. This would add the benefit of the volume limitation which would provide unimpaired flows later in the year and with more natural *increases* in flow downstream with drainage area.

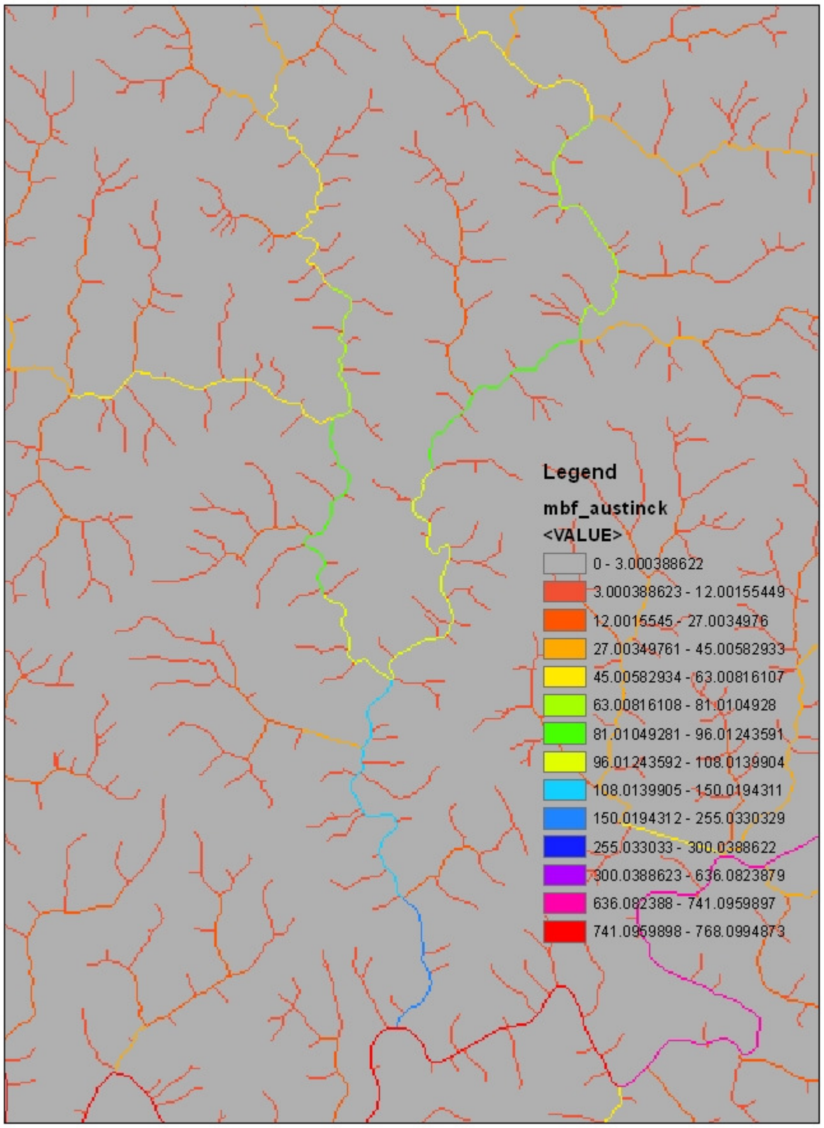

Figure 1: Estimated MBF (CFS) the Austin Creek network. Tributary channels in the box have MBF ~90 cfs each, while the confluent stream MBF ~140 cfs. Computations were carried out using information from the NHDplus and sampled information from the 13 gauged sites reported in the NCISFP documents.

The use of an index event (the 1.5 year flood) as a surrogate for the effects of cumulative sediment transport and geomorphic work over the full distribution of flow levels, is based on the concept of the effective discharge (Wolman and Miller 1960). This discharge flow for sediment transport is computed from a magnitude and frequency analysis given a discharge-sediment transport relation and the flow duration curve. The effective flow is often thought to correspond to the bankfull level, which equates the maximum transport flow to a flow resulting in the cross-sectional dimensions of the channel. The frequency of this event varies widely depending on climate and watershed conditions, and the 1.5 year return period chosen here is done so in the absence of more detailed analysis. A more detailed analysis might be done to generate these flow levels as the policy is implemented, and the impact of using a surrogate flow rather than a full magnitude and frequency analysis by using reasonable bedload equations can be generated (e.g. see Streeter and Pitlick 1998, Mueller and Pitlick 2005, Buffington and Montgomery 1999a,b, Buffington et al 2004, Barry et al 2004).

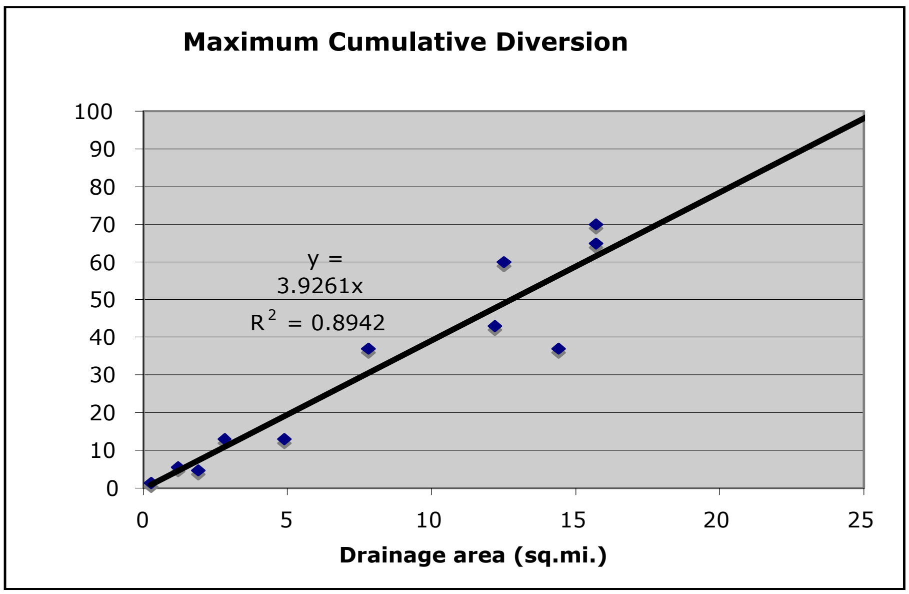

Figure 2: The maximum cumulative diversion rate based on the 5% of the 1.5 year flood extrapolated by drainage area from the sampled stream sites.

4. Seasonal limits on diversion

The seasonal limits on diversions are designed to protect habitat during critical biological periods, with specific concern for low flow periods. Stream temperature and flow quantity are considered in the choices of the following options:

1. No seasonal limits on diversions,
2. Diversions allowed between October 1 and March 31, and
3. Diversions allowed between December 15 and March 31.

As noted in the document, the protectiveness of these limits is strongly dependent on the flow regulations that are in effect, particularly the MBF as discussed above. The recommended limits of October 1 to March 31 is a compromise between the two other options (all year diversions and December 15-March 31), but places the beginning of the diversion season at the beginning of flow increases and Chinook migration in most years.

Temperature thresholds for salmon appear to drop into acceptable ranges in October based on streamflow records. However, little information is given regarding stream temperature patterns as a function of both time and flow conditions, which would be useful to evaluate the impacts of reduced flow in early to mid Autumn. If this information is not available at a set of the USGS or other gauging stations in the area, there are a set of streamflow temperature models that might provide useful information. Some consideration should be given to expected trends in these seasonal fluctuations due to both potential climate change, and to changes in riparian canopy cover with expected land use change or forest pathogens (e.g. Sudden Oak Death).

The MBF that is recommended is postulated to provide sufficient habitat protection for the earlier (October 1) diversion start date in terms of reach specific depth and width conditions for passage and spawning. However, as discussed above, missing from the analysis is a consideration of the timing of sediment production as flow conditions start to increase in the October and November time frame. The concern discussed above regarding potential consequences of the Minimum Bypass Flow and the Maximum Cumulative Diversion elements in terms of sediment balance is particularly important during the initial increases in flow due to the nature of the base and peak flows which build as the watershed is recharged, and as the first waves of migrating fish appear in the regional streams. Potential flat-lining of the smaller hydrographs resulting from the first fall storms, and proportional reductions in flow downstream using the drainage area dependent MBF policy may result in increased deposition in the larger streams at critical migration and spawning times.

5. In-stream impoundments and fish screens

The restrictions set for new and existing in-stream impoundments and diversion fish-screens appear to be reasonable, based on available understanding and information on migration barriers. Above the limit of target species habitat, the supply of sediment and woody debris needs to be maintained as a major source of downstream habitat material, as discussed above. This requires the gravel and wood management plans as part of any impoundment operation.

6. Monitoring, compliance, effectiveness, validation

The recommended policy elements are set at the regional level and based on limited local analysis due to available resources and time, and incomplete knowledge of physical-biological interactions. As such, there is a reasonable amount of uncertainty associated with the long-term impacts of policy element implementation, requiring a coherent monitoring strategy for compliance, effectiveness and validation of the expected impacts. As recommended in the policy document, a significant increase in the stream gauging network is required, with real-time capability, likely co-funded with the USGS to take advantage of the National Water Information System (NWIS) real-time discharge system.

Information contained in the recently released NHDplus (www.horizon-systems.com/nhdplus) would serve as a base, but would need to be augmented to cover smaller streams than included in the national NHDplus using a combination of more detailed terrain and land cover analysis, and implementation of fully distributed watershed models. Adaptation of methods to estimate higher order moments of flow duration curves are becoming available over the web. The USGS Streamstats program that is in the process of implementation (www.usgs.gov/osw/streamstats/index.html) would be a useful base to work from. Monitoring and management of the finite water resource network calls for the development of a more advanced sensor network to monitor stream temperature, turbidity, suspended sediment transport in addition to flow. The State of California should be in the position to develop and implement this type of network in collaboration with federal agencies and the university system.

7. Adaptive management – learning by doing and site specific studies

Hypothesis driven monitoring would enable specific measurement and testing for the presence of deleterious impacts of water resources development on salmonid habitat, within the scope and limits of the NCISFP. Survey of current channel conditions as a baseline and a remeasurement period should be initiated with a spatially nested program to test for both regional and locally correlated trends associated with the presence and absence of specific diversion conditions. It is important that the hypothesis driven monitoring have clearly defined tests for the impacts of the policy instruments, including their interactions, with set metrics and outcomes for results. The approach proposed in the NCISFP scientific basis documents is well considered, and requires active support and implementation.

In addition to the distributed monitoring system, the State of California should consider implementing a distributed hydrologic model to estimate the cumulative impacts of development and water diversions in the set of watersheds of interest. An integrated GIS-spatial watershed model that incorporates natural runoff production, stream routing and all water diversions and return flows should be developed. The model should have the ability to assimilate real-time streamflow, as well as meteorological information from precipitation gauge and radar sources. A series of recommendations and prototype designs for integrated modeling and real time monitoring have been put forward over the last few years and there is considerable talent and expertise in California to implement this type of system. As part of an adaptive management approach, the modeling system would provide a formal set of expectations of different water resources policies in the watersheds. Continuous monitoring allows both testing and updating of the model, including assimilation of observations directly into the model structure.

A set of specific concerns regarding policy instruments could be investigated in site specific studies and experimentation. These would include the impacts of MBF adjustments to stream discharge at major tributary junctions in terms of potential magnitude and timing of sedimentation, progressive change in channel form by the impacts of the MCD on hydrograph form, particularly the more extensive periods of "flat-lining" at the MBF.

Overall, the recommendations for implementation of a monitoring framework overseen by a committee of state, federal and county government, and academic personnel with a mix of skills in aquatic ecology, hydrology, and geomorphology is important and justified. Specific additional skills in statistics, GIS, distributed modeling and sensor networks would be useful, but may be available as ancillary members. It is important that members of this committee have their roles clearly defined, and that the committee's work is prescribed to offer objective analysis and interpretation of monitoring results to decision makers.

8. Summary

The task of balancing water rights with the requirement of protecting endangered species is complex and requires decision making under considerable uncertainty. The "precautionary principle" adapted within the proposed NCISFP is an important element as it places a priority on protecting threatened habitat that would be difficult to replace, while encouraging the collection of additional information and building the knowledge base to both reduce uncertainty at the regional level and provide more specific guidelines locally.

As discussed above, the implementation of this policy and the outcomes of monitoring need to be considered within the framework of potential changes in land use and climate. The long term evolution of the policy instruments requires the adaptive management approach that is advocated, as well as an integrated watershed framework that includes consideration of potential feedbacks to the regulatory system as envisioned and as actually put into practice. Such feedbacks can include the development of alternative water sources by municipalities, agriculture and private land owners, unexpected sedimentation resulting from water diversion patterns, and potential decommissioning or modification of existing water resources infrastructure.

One area to consider in terms of outcomes is the emphasis on passage and habitat conditions for spawning, incubation, rearing, and outmigration that appears to drive the MBF proposals. An implicit assumption is that sediment transport processes at these lower flow levels are not significant. However, even if the magnitude of transport is small and do not mobilize significant amounts of coarser grained material, impacts on fine grained transport and deposition should be considered as proportional reductions of flows increases downstream (by increased proportional diversion rates). Interactions with MCD and seasonal limits on diversions need to be considered as part of this framework, given the tendency for water diversions to preferentially occur early in the season as supplies at the beginning of the fall are low and to assure adequate supply given the uncertainty of later flows.

Overall, and within the apparent limitations on resources made available for new data collection, a more comprehensive set of analyses of flow scenarios, and the uncertainties cited above, the policy framework is carefully thought out with acknowledgement of the current limits of predictability. The framework of adaptive management, if properly implemented and supported by comprehensive monitoring and analysis, should provide the ability to maintain protection of salmonid habitat, while allowing justifiable water resources development.

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