ASSESSMENT OF THE ESTUARINE ANALYSIS

for the

RUSSIAN RIVER WATER SUPPLY AND FLOOD CONTROL

BIOLOGICAL OPINION

John L. Largier

March 2008

EXECUTIVE SUMMARY

This review seeks to "evaluate and comment on the use of the best available scientific and commercial information in the *estuarine-related analysis* of the draft Biological Opinion (BO) for the Russian River Water Supply and Flood Control Project" (Statement of Work). The review is directed at assessing the credibility of the conclusion of the BO – that the regulated elevated inflows and systematic artificial breaching of the Russian River estuary collectively cause an adverse effect on rearing habitat for steelhead in the estuary. This review is centered on the physical aspects of hydrology and geomorphology of the estuary, and on estuarine ecology – topics in which the reviewer has recognized expertise.

The BO report makes a scientifically credible argument that estuarine rearing habitat for juvenile steelhead will be significantly enhanced by reducing summer flow in the Russian River. The fuller argument is that the mouth of the estuary will remain closed after it first closes in the dry season and that the saline water in the estuary will be expelled over a period of weeks. This will yield a freshwater lagoon that supports abundant invertebrate biomass and precludes adverse water quality (low DO, high salinity, high temperature).

This argument is comprised of five expectations, each of which can be assessed in terms of scientific understanding: (i) mouth dynamics, (ii) transition to a freshwater lagoon, (iii) stratification & water quality, (iv) invertebrate ecology, and (v) juvenile steelhead ecology. The first three topics are the focus of this review.

A set of recommendations is made for increasing science-based confidence in the BO. Most importantly, a set of desktop, mechanism-based analyses can be conducted that will improve insight and allow quantification of the BO argument. These are strongly recommended. Further field studies may be merited following those analyses. If implemented, it is strongly recommended that a pilot phase be monitored closely and that ongoing monitoring is included in an adaptive management approach to managing water flows on the Russian River.

This review points out the interplay between maximum estuarine waterlevel and minimum river flow, introducing management options within the objective of maintaining a closed mouth during late summer. Secondly, this review introduces the option of an "overflow" mouth state, with the twin benefits of allowing greater river flow and also allowing late-season out-migration of juvenile salmonids without allowing seawater intrusion into the estuary. Thirdly, the review finds a lack of clarity on the mechanisms that define juvenile steelhead habitat and suggests an approach more firmly founded on a mechanistic understanding. This is necessary if one wishes to determine whether several short stratification events jeopardize habitat more or less than one longer anoxic stratification event that is required for transition to a freshwater lagoon.

1. BACKGROUND

The Russian River is found 100 km north of San Francisco on the Sonoma County coast. The watershed has an area of 3847 km^2 and the estuary extends about 11 km from the mouth at Jenner to the village at Duncan Mills (SCWA, 2006b). The river flow rate varies between maxima over 1000 m^3/s after winter rains to minima less than 5 m^3/s during the dry summer. It is expected that late summer flows were perhaps as low as 1 m^3/s prior to human interventions in river flow that started a century ago. Present-day summer flows are regulated by the State Water Board decision D-1610. In the last 10-20 years there have been several studies of the river and estuary, including Goodwin and Cuffe (1993), Merrit-Smith (1996, 1997, 1998, 1999, 2000), SCWA (2004), and the subject Biological Opinion (NMFS 2007).

The Russian River and estuary is used by three salmonids: coho salmon, Chinook, and steelhead. Each population has different timing of migration through the estuary and each population uses the estuary in different ways for rearing and smoltification. The NMFS Biological Opinion (BO) argues that the primary loss of value of the estuary to salmonids is in the form of the loss of rearing habitat for juvenile steelhead in late summer, when the river is dry and warm.

2. DESCRIPTION OF REVIEW ACTIVITIES

This review is a response to the request to "evaluate and comment on the use of the best available scientific and commercial information in the *estuarine-related analysis* of the draft Biological Opinion (BO) for the Russian River Water Supply and Flood Control Project" (Statement of Work). It is recognized that NMFS is not obligated to independently develop new scientific data for this BO. The review is directed at an assessment of the credibility of the conclusion of the draft BO – that the regulated elevated inflows and systematic artificial breaching of the Russian River estuary collectively cause an adverse effect on rearing habitat for steelhead in the lower Russian River (i.e., estuary) – or, more specifically, that "the systematic breaching of the estuarine bar reduces the estuary's carrying capacity for juvenile steelhead" (BO, p.172). Following the reviewer brief, "the review will focus on the technical aspects of the estuarine-related portions of the NMFS draft biological opinion; the review will not determine if NMFS conclusions regarding the project's potential to adversely modify critical habitat or jeopardize the continued existence or recovery of listed salmonids are correct." The review addresses the question whether the data, literature and analysis in the BO provide reasonable support for the conclusion. Or, is there other scientific information that should be considered? Further, were key published or unpublished studies missed? What uncertainties were not addressed? This review is centered on the physical aspects of hydrology and geomorphology of the estuary, and on estuarine ecology – topics in which the reviewer has expertise, specifically in west-coast estuaries that are characterized by long dry summers and the presence of strong waves at the mouth. Specific expertise in salmonid biology is limited.

3. SUMMARY OF ANALYSES & COMMENTS – ASSESSMENT OF REPORT

Summary of argument and considerations … The BO lays out an argument that repeated opening of the estuary mouth in summer represents a perturbed state with a significant degradation of habitat for steelhead juvenile rearing. The management actions responsible for this are enhanced summer flow rates and mechanical breaching of the mouth. It is suggested that summer flows should be lower and that the mouth should be allowed to remain closed.

Additional salmonid habitat implications are identified, both positive and negative, but these are equivocal and it is expected that these additional effects are of lesser consequence for survival and recovery of salmonid populations in the Russian River. Further, there are several actions and benefits identified up-stream from the estuary, which are not addressed here. Clearly, the overall impact on salmonid population viability and strength must be based on all of these habitat considerations. The BO lacks a complete quantitative analysis of population levels, and it is not clear whether the suggested management actions will have a major beneficial impact on these populations, even in the face of uncertainty associated with the ocean period and climate change.

The argument in the BO is based on a set of expectations:

(1) <u>Closed mouth</u>: If the flow is low enough (and the bar is not mechanically breached*), the mouth will not open*. It is expected that inflow to the estuary (surface and groundwater) will be matched by outflow through the sandbar combined with evaporative water loss.

(2) <u>Freshwater estuary</u>: If the mouth remains closed for a long enough period, the deeper saline water will be expelled through the sandbar and *the closed estuary will be fresh* (or very low salinity).

(3) <u>Water quality</u>: The closed freshwater estuary will exhibit *moderate temperatures and adequate dissolved oxygen*. It is expected that the water column is not stratified and thus oxygenated throughout, and that the cool coastal climate will ensure moderate temperatures.

(4) <u>Invertebrates</u>: The closed freshwater estuary will support *an abundance of invertebrates*. While there may be a decline in invertebrate populations during transition from stratified to freshwater conditions, the subsequent abundance of invertebrates will more than compensate for lower levels of invertebrates in an open estuary.

(5) <u>Steelhead habitat</u>: Juvenile steelhead prefer this environment and also show *higher rates of growth in the estuary* during summer. It is expected that the enhanced growth (and subsequent ocean survival) is due to the abundant food in the form of invertebrate biomass in the summer estuary.

Each of these expectations needs to be assessed in terms of whether there is adequate scientific support for it. Relevant science is drawn from prior studies on the Russian River. However, summer flows in the Russian River have been enhanced for decades and there are no recent examples of a prolonged closure in summer. Thus, reference is also made to studies in comparable Californian bar-built steelhead estuaries that do exhibit prolonged closure and freshwater conditions in late summer. There is limited reference to more fundamental studies of estuarine processes, e.g., mouth closure dynamics, estuarine stratification dynamics, dissolved oxygen balances, and estuarine invertebrate ecology.

3-1. Closed mouth.

As described in the BO report, the mouth can be expected to close in summer if the river flow is low enough. This expectation is well supported by theory and observations in the literature, and by observations of closure events on the Russian River over the last couple of decades.

However, there is little analysis of the dynamics of this process and an apparent lack of recognition of the importance of summer wave events. Goodwin & Cuffe (1993) and Behrens et al. (2008a, b) provide detailed analysis of the behavior of the Russian River mouth. Further, they both cite several key references on how wave-driven processes that tend to close the mouth interplay with tide- and river-driven processes that tend to scour the mouth open. Further discussion is in Philip Williams & Associates (2004, 2005). The process is more complicated than suggested in referring to Dean (1974) on page 82. Behrens et al.'s analyses are based on over 20 years of mouth observations, but they are only now being published in the form of a MS thesis (UC Davis) and it will be some months before the journal papers are completed. The interplay between waves, river and tide is evident in the narrowing of the mouth during summer (low river flow) neap tides and widening during summer spring tides. In contrast, in winter, the mouth width varies with river flow.

The rough seasonal cycle observed under existing river-flow conditions suggest that there is a general seasonal cycle that may be expected in the absence of enhanced summer river flow. Following an open mouth during wet weather in winter and early spring, the mouth is prone to closure as the river flow decreases (early or late spring, depending on annual conditions). However, closure of the mouth requires a beach-building wave event, which may not happen for many months during the summer, delaying closure. Once closed, the mouth will only remain closed if (i) it is not mechanically opened, and (ii) the river flow rate does not exceed the potential for water loss via evaporation and flow through the sandbar. If this condition is met, the mouth should remain closed until river flow is again enhanced in late fall or early winter. However, if the mouth does open again, or remains open, there is a high likelihood of closure in fall associated with the arrival of the first big "winter" swell from the North Pacific. During the winter, the mouth may close during dry periods as there are many beach-building wave events and a rapid decrease in river flow given that the Russian River watershed is relatively local (short-tailed hydrograph).

With an interest in seeing a closed mouth during summer, the primary question is whether the river flow rate Q_r remains less than a critical value Q_{r1} (the combined losses via evaporation and flow through the sandbar). While this is appreciated in the report, there is no attempt to estimate this critical value or to provide any analysis of primary factors determining this critical value. The mass balance controlling water level in the estuary is outlined by Goodwin and Cuffe (1993): total inflow less total outflow equals change in estuary waterlevel.

$$(Q_r + Q_g + Q_t) - (Q_s + Q_e + Q_w) = A.\partial_t\eta \qquad \text{(Eqn 1)}$$

where Q_r is river flow rate, Q_g is groundwater inflow rate, Q_t is any inflow due to tributaries or storm drains discharging directly to the estuary, Q_s is flow rate through the sandbar (seepage), Q_e is the evaporation volume rate, Q_w is any withdrawal from the estuary, A is estuarine surface area, and η is the waterlevel so that $\partial_t\eta$ is the time rate of change in waterlevel.

While estimates can be made for Q_g and Q_t and Q_e and Q_w it turns out that the primary balance is between river flow Q_r seepage rate Q_s and changes in waterlevel $\partial_t\eta$. Aiming for a steady waterlevel ($\partial_t\eta=0$), one needs $Q_r = Q_s$ if one wants the mouth to remain closed. However, Q_s follows a Darcy relationship so that flow rate depends on the nature of the sand, the thickness of the sandbar, the cross-sectional area of the sandbar, and the pressure difference between estuary and ocean (the head difference $\Delta\eta = \eta_{estuary} - \eta_{ocean}$). As the estuary waterlevel $\eta_{estuary}$ increases, so does the head difference $\Delta\eta$ and the cross-sectional area. So, the higher the estuary waterlevel, the greater the river flow rate that can be accommodated with a steady waterlevel. Clearly this balance between estuary waterlevel and river flow rate needs further investigation before suggesting allowable summer river flow rates.

One would expect that the estuary may have remained closed during summers prior to human intervention for four reasons: (i) it was not mechanically opened; (ii) the late summer river flows were lower; (iii) the estuary waterlevel could rise to the crest of the berm (typically 10-15'), resulting in greater seepage flow; and (iv) if there was a small excess inflow to the estuary, this would be allowed to overflow without the berm being broken – small flows will be too slow and frictional to scour a channel through the berm (as is observed in a number of estuaries, e.g., Salmon Creek in spring). This fourth factor has not been quantified, but that is possible to do. One can envisage a management approach that is defined not by a fixed river flow rate, but by the need to maintain a closed mouth, which would allow some flexibility in flow rate management. Clearly, estuary management includes a tradeoff between higher estuary waterlevels and lower river flow rates.

There is some concern about the extent of the rockwork beneath the sand at the mouth of the estuary. This can be assessed from original design drawings, or through acoustic surveys. However, a rough application of Eqn 1 during times when $\partial_t\eta$ is non-zero suggests that Q_s is significant and more than adequate to balance river flow rates if the estuary water level is higher and/or the river flow rate is lower than in present management protocols. Again, this needs a proper assessment.

There are several engineering options for dealing with excess river flow to the lagoon, although it is likely that these options are unrealistic in terms of environmental or economic costs. Options for lowering estuary waterlevels (to preclude premature breaching of the berm) include a standpipe, a siphon system and/or a pump system.

The “overflow mouth” state may not be initially appealing as an engineering option, but it is a natural scenario observed at the mouth of many perched lagoons and quite possibly a situation that would have been seen at the mouth of the Russian River prior to human intervention. The one distinct advantage of this mouth state is that it does not preclude out-migration of smolts (albeit at some predation risk in a shallow flow across the beach), but it does simultaneously preclude intrusion of seawater and thus allows the desired freshening of the estuary to proceed.

3-2. Freshwater estuary.

Expulsion of saline waters through the sandbar has been observed in several other California estuaries and can be expected to occur in the Russian River – as suggested in the BO report. However, one cannot simply infer that this will happen and a series of real-world tests are required. Given that there are few authoritative studies of this process of expelling the denser saline waters from a bar-built estuary, there are no obvious references missing from the BO report.

Nevertheless, this freshening process can be explored through asking how rapidly the dense saline water is expelled from the closed estuary. If this transition takes longer than the mouth is closed, then the estuary will not become fresh (e.g., the Navarro does not expel the lower saline layer in spite of remaining closed in summer, Cannata 1998). Secondly, a slow transition results in a prolonged anoxic period (see below). This may be due to inadequate permeability of the sandbar or inadequate waterlevel head in the estuary. An estimate of the rate of seepage through the sandbar can be obtained from the fact that one must have $Q_r + Q_g + Q_t = Q_s + Q_e + Q_w$ for a steady waterlevel (or $Q_s \sim Q_r$ as described above). The expulsion time is then roughly estimated by V/Q_s where V is the estuary volume. Taking into account observed changes in waterlevel during closed phases in the Russian River, it appears that Q_s may be as much as 100cfs (about 2.8 m^3/s) when the waterlevel is of the order of 7ft –

this rough estimate needs to be validated through a rigorous study. With this efflux, the saline waters, which occupied some significant part of the volume when the estuary closes (estimate as 2.5 x 10^6 m^3 from Goodwin and Cuffe, 1993), should be expelled in about 10 days. Given that it may take 10-20 days for the estuary waterlevel to rise to 7ft, this rough calculation suggests that the saline water may be expelled from the Russian River in about a month. However, this analysis needs to be done rigorously and any certainty about whether this indeed happens or not must be based on observations of it happening in the Russian River. Nevertheless, this suggests that not only is it important to keep the estuary waterlevel well above the tidally fluctuating ocean waterlevel, but the estuary waterlevel should be allowed to rise to a level sufficient to ensure rapid transition to a freshwater lagoon.

Three further phenomena are worth noting:

(1) It can be expected that dense saline water will remain in the deeper sections of the estuary basin, where trapped by intervening shallower areas. This saline water will not be pushed through the shallow areas, even if they are permeable, because there will be negligible waterlevel difference across the shallows (and thus negligible pressure gradient through the obstruction). Further, with weak flow through the estuary, vertical mixing will be weak and these deep, trapped saline layers can be expected to remain throughout the summer (cf., Largier et al 1992; Largier & Slinger 1991). An analysis of the bathymetry of the estuary will provide an estimate of the percentage of the bed that is covered by these saline waters, which may be persistently anoxic.

(2) As the expulsion of saline waters should start immediately following mouth closure, it would be worth reviewing existing data to see if this is happening. In the case of prolonged closures (e.g., 2-3 weeks in October 2004), there should be enough of a waterlevel buildup to bring about significant change. However, caution must be shown in interpreting salinity time-series data near the mouth as one will see decreasing salinity immediately following closure due to gravitational adjustment of isopycnals (and thus leveling of the isohalines). This is the probable explanation for the observed drop in bottom salinity at the mouth, Penny Island and Bridgehaven stations in October 2005 (SCWA 2006). Also, these changes may be due to mixing with low-salinity surface waters. Further problems in interpretation arise if the salinity sensor is attached to a float and may move away from the bed as the waterlevel rises.

(3) Installation of siphon pipes could speed up the outflow of saline waters.

3-3. Water quality.

The BO report suggests that lower summer river flow (and no mechanical breaching) would allow the mouth to remain closed, resulting in a freshwater lagoon after the saline water has been expelled through the sandbar. It is the water properties that emanate from this condition that are considered beneficial for the rearing of steelhead juveniles in the estuary in late summer. The freshwater lagoon is expected to have low salinity, moderate temperatures and adequate dissolved oxygen. These are reasonable expectations, and supported by citing these conditions in comparable Californian estuaries.

Again, however, there is no reference to studies of stratification processes or the biochemical processes that control the level of dissolved oxygen. An understanding of these processes would increase the confidence that these water quality benefits would indeed accrue if the mouth remains closed, and it would provide insight as to scenarios in which the desired water quality may not be achieved even with a closed mouth.

Once the freshwater lagoon has been established, it is expected that the salinity will be low. Further, the water temperatures will be moderate throughout the water column (similar to present summer surface temperatures) due to the cool maritime weather period – and stratification is expected to be absent. This leads to mixing of waters throughout the water column and maintenance of adequate levels of dissolved oxygen in the estuary. This environment is expected to host an abundant community of invertebrates as a food supply for juvenile steelhead and the water properties are expected to be acceptable for juvenile habitation.

The distribution of salinity in the estuary is readily understandable through analysis of observations combined with hydrodynamic theory (e.g., Largier et al 1992; Largier and Slinger 1991; Largier 1992; Slinger et al 1995). With information on the direct influence of salinity on juvenile steelhead, the extent of the salinity-defined habitat can be quantified.

The spatio-temporal pattern of DO levels deserves specific attention, both relating to causes (what controls DO in the estuary?) and consequences (what are critical DO levels for invertebrate populations or for juvenile steelhead?). How quickly does hypoxia develop, at what depths, and for how long does it last? In essence, how much rearing habitat is thus lost in the prolonged stratification event that is the transition to a freshwater lagoon versus how much is lost in a series of short-term closures? Existing data show a rapid decrease in bottom DO within a day or two of closure, with hypoxia after about five days and anoxia after about 10 days (e.g., October 2005, SCWA 2006). In contrast, mid-depth DO decreases more slowly, in spite of being below the pycnocline, and hypoxia is not observed within the two weeks of closure. If DO is the limiting factor, it may be that there is less time-aggregated loss of habitat with several short-term closures than there is with one persistent closure that sees a full transition to a freshwater lagoon. To properly assess this, one needs to understand rates of oxygen loss and gain, and the levels at which DO becomes critical to invertebrates or juvenile steelhead.

The patterns of water temperature are not expected to be limiting in either scenario, given that the stratification is too deep for solar-pond effects when stratified and that the cool coastal climate keeps surface temperatures cool throughout the summer.

Whether steelhead habitat is defined by salinity or DO, the existence of salinity pockets needs to be quantified (see above) and water quality tracked within these. Pockets near the mouth may be replenished by seawater following wave over-wash, although it is not clear how common these events are at the mouth of the Russian River.

In the previous section it was noted that summertime closed lagoons prior to human intervention were likely associated with estuarine waterlevels notably higher than allowed under the existing management structure. In addition to flooding of human assets, there is some concern about adverse water quality effects following breaching due to the flooding of lower Willow Creek. Analysis of oxygen depletion and BOD in the flooded Willow Creek is required to assess whether the 1992 event (Goodwin and Cuffe, 1993) is likely to be repeated if waterlevels are allowed to rise in summer. With annual estuarine flooding of the lower Willow Creek, this region may transition back to aquatic vegetation and the observed water quality impacts may change. This requires some attention.

3-4. Invertebrates.

The BO report expects a greater abundance of invertebrate food for juvenile steelhead in a freshwater lagoon during late summer than in an intermittently closed estuary. While this is a reasonable expectation, supported by reference to studies in comparable California estuaries, there are few references to the general literature on estuarine invertebrate communities and their habitat requirements. This literature should be reviewed (and there should be field study of invertebrate biomass in the Russian River prior to management action).

A general theme in the literature and in the BO report is that closure events, which lead to persistent stratification and low DO in sub-pycnocline, result in a decline of invertebrate communities. It appears to be the change in conditions that result in the decline, but it is the nature of the new pelagic environment and associated water quality that will determine the composition, diversity and biomass of the invertebrate community when it recovers. While population decline may be quick under toxic conditions (e.g., low DO), the transition and recovery of the invertebrate community is expected to take a few weeks – a typical time scale for invertebrate populations. As described in the previous section, the lack of invertebrate food that may persist for a few weeks during transition to a freshwater system (or longer if the physical transition is slow) should be compared with the effect of several short-term closures on invertebrate biomass. A key factor is the distribution of invertebrate biomass between deep benthic, shallow benthic, and pelagic environments as each environment experiences notably different DO conditions over time.

3-5. Steelhead habitat.

The BO report cites Smith (1990), Larson (1987), Zedonis (1992), and Bond (2006) to show that freshwater lagoons provide important rearing habitat for juvenile steelhead and that estuarine juveniles show increased growth and subsequent survival to spawning age. The observation of this phenomenon in other comparable Californian estuaries is a strong argument for the expectation of the same phenomenon in the Russian River estuary, if a freshwater lagoon is allowed to develop in the summer. Notwithstanding that a closed estuary with high waterlevel and low salinity is most likely to have developed during summer months prior to human effects, this is now a managed river-estuary system and one may question the relative habitat benefits of the existing intermittently closed estuary (if closure events are brief) versus the benefits of the persistently closed system envisaged for late summer.

To assess the habitat benefits one would want to know the primary factors that determine which habitat is used by juvenile steelhead. This should be based on a mechanistic understanding of the relationship of steelhead survival and growth to water temperature, salinity, dissolved oxygen, and invertebrate food availability. If these relationships can be independently determined then one can interpret the implications of time-space patterns of salinity, temperature, DO and invertebrate biomass in terms of steelhead juvenile habitat. Ultimately, this would yield an understanding of the time-varying carrying capacity of the estuary through the dry season, from open conditions at the end of the wet season in spring to open conditions again at the start of the subsequent wet season in fall.

4. RECOMMENDATIONS FOR IMPROVING SCIENCE-BASED CONFIDENCE

The BO report makes a scientifically credible argument that estuarine rearing habitat for juvenile steelhead will be significantly enhanced by reducing summer flow in the Russian River. The fuller argument is that the mouth of the estuary will remain closed after it first closes in the dry season and that the saline water in the estuary will be expelled over a period of weeks. This will yield a freshwater lagoon that supports abundant invertebrate biomass and precludes adverse water quality (low DO, high salinity, high temperature).

This review is not intended to have an opinion on whether this argument is correct or not. But the reviewer has been requested to make recommendations on how one can increase science-based confidence in this opinion. The following recommendations are in this context.

4-1. Recommended analyses that do not require new data.

Based on the above discussions, there are a number of desktop analyses that can be performed to better frame the issue and the proposed actions for enhancing steelhead habitat in the estuary. These studies involve analysis of existing data and should be well grounded in available theoretical understanding of specific mechanisms.

R1. Assess conditions (waves, tide, river flow) under which the estuary mouth will close based on an analysis of all available data. This analysis is well advanced through the studies of UCD student Dane Behrens (in collaboration with advisors Largier and Bombardelli). This is specifically important in years when the mouth may remain open well into summer due to the absence of a suitable wave event following the decline of river flow in spring.

R2. Quantify seepage flow rate Q_s through the sandbar through a careful water balance calculation that accounts for other terms like groundwater and evaporation. This analysis can provide an estimate of what river flow can be accommodated without risking breaching of the estuary mouth. Further, knowledge of Q_s will allow a credible estimate of how quickly saline waters will be expelled from the estuary under different estuarine waterlevel conditions.

R3. Evaluate the stability of an "overflow" mouth state at different flow rates through comparison with other Californian estuaries and reference to available published studies on perched lagoon systems and erodability of the sand berm.

R4. Determine how salinity-based stratification evolves following closure, based on an analysis of existing temperature and salinity data from the Russian River estuary and with reference to hydrodynamic understanding published in the literature. While the empirical analysis can fully describe the evolution of stratification over a week or two, the use of theory can provide a credible quantitative description of how stratification will evolve over time as the saline waters are expelled from the estuary. This analysis is the basis for vertical mixing rates, a primary determinant of DO levels in a stratified estuary.

R5. Determine how DO levels evolve following closure, based on an analysis of existing data from the Russian River estuary and with reference to published knowledge of factors controlling DO levels in estuaries in general. In particular, this analysis can provide information on the thickness of the near-bottom anoxic layer observed in short-term closures.

R6. Assess the type, distribution, and biomass of invertebrate populations that are suitable food for juvenile steelhead in summer. This involves a quantitative summary of available data from the Russian River estuary and a review of similar data from other bar-built estuaries in California and worldwide.

R7. Outline other changes expected in the Russian River estuary if it remains closed for a prolonged period in late summer. This analysis is not intended as an environmental impact assessment, but to pre-empt unanticipated consequences. There is concern about changing water properties in a low-flow closed-mouth scenario, including the prospect that elevated concentrations of contaminants may impact juvenile steelhead, other salmonids, invertebrate populations, ecosystem vitality, or public health.

4-2. Recommended analyses that require new data.

Further insight and quantitative information in support of management decisions can be obtained from focused field or lab studies. These would be short-term studies directed at understanding and quantifying key mechanisms.

R8. Field study of current velocities and mixing rates together with stratification to better quantify and predict stratification during closure events and over the transition to a freshwater lagoon.

R9. Field survey of invertebrate biomass and types under open mouth, closed mouth and freshwater lagoon systems – specifically quantifying (i) the decline and recovery of biomass following closure and transition, and (ii) the relative biomass in shallow benthic areas, deep benthic areas, and water column.

R10. Field study of juvenile steelhead habitat use in the Russian River estuary during summer, with analyses quantifying juvenile use of specific locations as well as specific water types (in terms of salinity, temperature and dissolved oxygen).

R11. Analysis of juvenile steelhead diet confirming their dependence on aquatic invertebrates and establishing diet preferences. This study should be concurrent with the survey of invertebrates, providing information on invertebrate availability at the time of the diet assessment.

4-3. Recommended analyses during flow experimentation.

R12. Ultimately, if the proposed action is to be implemented, it is recommended that a set of observations is obtained during an initial pilot year of operation. These data would be analyzed to verify that morphological, hydrological, and ecological responses are as expected. The results would lead to refinement of the management plan. Key observations would include the (i) water balance, (ii) stratification, (iii) water temperature, salinity and dissolved oxygen, (iv) invertebrate biomass, (v) juvenile steelhead movement, (vi) contaminant concentrations, and (vii) ecosystem vitality.

This pilot operation will also allow tuning of the water balance to better resolve flow rate through the sandbar and to obtain experience in adjusting river flow and pump withdrawal rates to maintain a steady, desirable waterlevel in the estuary. This water balance will be based on a model and the experience will allow for refining model parameter values. Further, the pilot year of operation can be used to explore the feasibility of maintaining a shallow but stable overflow channel at the mouth.

4-4. Recommended analyses as part of adaptive management.

R13. Once implemented, it is recommended that a set of physical/chemical data is monitored in real-time as inputs to water management decisions on a daily basis. This would include observations of berm height, estuary waterlevel, temperature, salinity and dissolved oxygen. This monitoring will increase confidence in management and also provide key information on interannual differences and the implications of anomalously dry or wet years for water management.

R14. It is also recommended that a set of ecological data is monitored for retrospective assessment of juvenile steelhead rearing success in the estuary. These data on invertebrates and juvenile steelhead will be combined with physical/chemical data to explain interannual variability, including climate change.

Both physical/chemical and ecological data may be used in an adaptive management approach, adjusting river flow rate to optimize the juvenile steelhead habitat within the context of multiple ecological and human uses of the estuary system.

5. CONCLUSIONS/RECOMMENDATIONS

The BO report makes a scientifically credible argument that estuarine rearing habitat for juvenile steelhead will be significantly enhanced by reducing summer flow in the Russian River. The fuller argument is that under low-flow conditions the mouth of the estuary will remain closed after it first closes in the dry season and that the saline water in the estuary will be expelled over a period of weeks. This will yield a freshwater lagoon that supports abundant invertebrate biomass and precludes adverse water quality (low DO, high salinity, high temperature).

Four fundamental questions were posed for the reviewer:

(1) Does the site specific data for the Russian River, referenced supporting literature, and analysis in the draft BO provide reasonable support for the conclusion that the regulated elevated inflows and systematic artificial breaching of the Russian River estuary collectively cause an adverse effect on rearing habitat for steelhead in the lower Russian River (i.e., in the estuary/potential lagoon system)? If not, what relevant scientific information should be considered?

The data, literature and analysis in the report provide adequate support for the assertion that the regulated elevated inflows and systematic artificial breaching of the Russian River estuary collectively cause an adverse effect on rearing habitat for steelhead in the estuary. However, additional data and literature are available and additional analysis of these (plus perhaps new data) is required to develop enough confidence to determine the remedies and to develop new management protocols that have a high likelihood of providing significantly improved rearing habitat for steelhead in the estuary/lagoon. The additional literature includes a broader collection of journal papers on estuarine mouth morphodynamics, estuarine stratification hydrodynamics, and estuarine invertebrate community dynamics (in context of breaching). Additional data include existing time series of waterlevel, mouth state, temperature, salinity, dissolved oxygen, river flow, offshore waves, and ocean tide. While some of these data have been referenced in the report, there are significant opportunities for analysis of these data that can increase confidence in the BO and potential remedies and revision of management protocols. This has been addressed in the recommendations.

(2) Were relevant published and unpublished studies on the relative productivity of freshwater lagoons and estuaries and the use of freshwater lagoons by steelhead and other salmonids missed? If so, what key studies were missed?

As noted above, there is a rich literature on estuarine invertebrate communities and presumably several that address bar-built estuaries that are intermittently open or closed. I am aware of studies in Australia and South Africa but have not conducted a literature search. I am less aware of the literature on the use of freshwater lagoons by salmonids, but expect that there are papers beyond those that have been cited (e.g., studies of lagoons in Oregon). However, the most pertinent studies are presumably those that address comparable Californian estuaries and these have been well cited.

(3) The draft BO states on page 172 that the "systematic breaching of the estuarine bar reduces the estuary's carrying capacity for juvenile steelhead". Is this a reasonable and adequately supported statement?

Yes, this statement is reasonable and adequately supported. However, there is a level of uncertainty that has not been quantified. This uncertainty becomes key in deciding what actions are required to improve the system.

(4) What uncertainties related to the estuarine analysis were not addressed that might affect the BO substantively?

In this review, five underlying expectations are identified – each with its own uncertainty. Appreciation of these multiple sources of uncertainty is not explicitly addressed, nor is the fact that uncertainty of the first three physics-dominated expectations can be reasonably reduced by (desktop) studies, as recommended. It seems that the greatest uncertainty is related to how the invertebrate abundance (or other juvenile steelhead food) will vary through the prolonged hypoxic phase and the subsequent freshwater lagoon phase in this specific ecosystem.

A set of recommendations is offered for increasing science-based confidence in the BO. Most importantly, a set of desktop, mechanism-based analyses can be conducted that will improve insight and allow quantification of the BO argument. These are strongly recommended. Further field studies may be merited following those analyses, although time and costs may argue against proceeding without these. If implemented, it is strongly recommended that a pilot phase be monitored closely and that ongoing monitoring is included in an adaptive management approach to managing water flows on the Russian River.

This review points out the interplay between regulation of maximum estuarine waterlevel in summer and the regulation of minimum river flow, introducing management options within the objective of maintaining a closed mouth during late summer. Secondly, this review introduces the option of an “overflow” mouth state, with the twin benefits of allowing greater river flow and also allowing late-season out-migration of juvenile salmonids without allowing seawater intrusion or pinniped predation in the estuary.

In conclusion, while stronger science support gives one more confidence in what to expect, these remain just expectations and one can only gain full confidence in this scenario by directly observing these responses in the Russian River estuary. This argues for a pilot study combined with detailed observations.

<u>APPENDIX A</u> – BIBLIOGRAPHY OF MATERIALS REVIEWED.

Behrens, D. K., F. A Bombardelli and J. L. Largier. 2008. Predicting inlet closure in an estuary using non-dimensional stability indices: the case of the Russian River. To be submitted to *Journal of Coastal Research*.

Behrens, D. K., F. A Bombardelli and J. L. Largier. 2008. Morphology of an unstable river mouth: the case of the Russian River. To be submitted to *Estuaries*.

Bond, M.H. 2006. *Importance of Estuarine Rearing to Central California Steelhead (Oncorhychus mykiss) Growth and Marine Survival.* MS Thesis. University of California Santa Cruz. 39 pp. + figures and tables.

Cannata, S.P. 1998. *Observations of Steelhead Trout (Oncorhychus mykiss), Coho Salmon (O. kisutch) and Water Quality of the Navarro River Estuary/Lagoon, May 1996 to December 1997*. Humboldt State University Foundation. 48 pp, + tables and figures.

Entrix. 2004. *Russian River Biological Assessment*. September 29, 2004.

Goodwin, P. and C. K. Cuffe. 1993. *Russian River Estuary Study 1992-93.* Report prepared for Sonoma County and California State Coastal Conservancy. 65pp + appendices.

Higgins, P. 1995. *Fisheries Elements of a Garcia River Estuary Enhancement Feasibility Study.* Mendocino County Resource Conservation District. 22pp + appendix.

Largier, J. L. and J. H. Slinger. 1991. Circulation in highly stratified southern African estuaries. *South African Journal of Aquatic Science* 17:103-115.

Largier, J. L., J. H. Slinger and S. Taljaard. 1992. The stratified hydrodynamics of the Palmiet - a prototypical bar-built estuary, p.135-153. In: Prandle (Ed.), *Dynamics and Exchanges in Estuaries and the Coastal Zone*. American Geophysical Union, Washington DC.

Largier, J. L. 1992. Tidal intrusion fronts. *Estuaries* 15:26-39.

Maahs, M., and S.P. Cannata. 1998. *The Albion River Estuary: Its History, Water Quality, and use by Salmonids, other Fish and Wildlife species.* Prepared for the Humboldt County Resource Conservation District and Coastal Land Trust.

Merritt Smith Consulting. 1997. *Biological and Water Quality Monitoring in the*

Russian River Estuary 1996.

Merritt Smith Consulting. 1998. *Biological and Water Quality Monitoring in the Russian River Estuary 1997.*

Merritt Smith Consulting. 1999. *Biological and Water Quality Monitoring in the Russian River Estuary 1998.*

Merritt Smith Consulting. 2000. *Biological and Water Quality Monitoring in the Russian River Estuary 1999.*

Philip Williams & Associates. 2004. *Crissy Field Marsh Expansion Study.*

Philip Williams & Associates. 2005. *Projecting the Future Evolution of Bolinas Lagoon.*

Prunuske Chatham Inc. 2004. *Review of the Flow Proposal in the Russian River Draft Biological Assessment.* Prepared for Sonoma County. 45pp.

SCWA website http://www.scwa.ca.gov/environment/russian_river_estuary.php

SCWA with Merritt Smith Consulting. 2001. *Biological and Water Quality Monitoring in the Russian River Estuary 2000.*

SCWA. 2006a. *Russian River Estuary Fish and Macro-Invertebrate Studies, 2005.* Sonoma County Water Agency, Santa Rosa, CA. 35 pp.

SCWA. 2006b. *Russian River Estuary Sandbar Breaching: 2005 Monitoring Report*. Sonoma County Water Agency, Santa Rosa, CA. 58 pp.

Slinger, J. H., S. Taljaard and J. L. Largier. 1995. Changes in estuarine water quality in response to a freshwater flow event, p. 74-81. In: K. R. Dyer (Ed.), *Changes in Fluxes in Estuaries: Implications from Science to Management*. Olsen & Olsen, Denmark.

Smith, J. 1990. *The Effects of Sandbar Formation and Inflows on Aquatic Habitat and Fish Utilization in Pescadero, San Gregorio, Wadell, and Pomponio Creek Estuary/Lagoon Systems, 1985-1989.* San Jose State University, San Jose, CA. 38 pp + tables and figures.

Zedonis, P. 1992. *The Biology of the Juvenile Steelhead (Oncorhynchus mykiss) in the Mattole River Estuary/Lagoon, California*. MS Thesis, Humboldt State University. 56pp.

APPENDIX B – COPY OF STATEMENT OF WORK

Statement of Work for Dr. John Largier

Assessment of the Estuarine Analysis for the Russian River Water Supply and Flood Control Biological Opinion

Background

The purpose of this independent review is to evaluate and comment on the use of the best available scientific and commercial information in the estuarine-related analysis of the draft (dated June 11, 2007) Biological Opinion (BO) for the Russian River Water Supply and Flood Control Project. It is hoped that this review will help ensure that the best available information is used in this biological opinion. The review will focus on the technical aspects of the estuarine-related portions of the NMFS draft biological opinion; the review will not determine if NMFS conclusions regarding the project's potential to adversely modify critical habitat or jeopardize the continued existence or recovery of listed salmonids are correct.

The Southern and Central Coastal sections of California have a Mediterranean climate that significantly affects physical and water quality dynamics of estuaries. A combination of ocean wave action and the absence of significant rainfall between late May and early November contribute to the formation of closed, freshwater lagoons at river mouths. Wave action builds up sandbars at river mouths; low summer inflow to the lagoons percolate through the bar, thus maintaining closed freshwater systems. Limited research indicates that, in this region where summer flows in headwaters are naturally very low, freshwater lagoons provide highly productive and important rearing habitats for steelhead (*Oncorhynchus mykiss*) and possibly Chinook salmon (*O. tshawytscha*).

The ongoing and proposed operations of the Russian River reservoirs cause sustained, unnaturally high flows to the estuary from approximately May through early November. During this period, the elevated flows can cause natural bar breaching at the river's mouth, with resulting water quality cycles that can be deleterious to juvenile salmonids. The elevated summer inflows also contribute to high water surface elevations that threaten to flood a few properties bordering the Russian River estuary. Project operators address the potential threat of property flooding by breaching bars that form at the river's mouth, thereby maintaining the estuary as an open system with nearly marine conditions in the middle and lower segments of the system.

In conducting Section 7 consultations, NMFS is obligated to use the best scientific and commercial data available to evaluate whether projects jeopardize the continued existence of species listed under the Endangered Species Act. However, for such analyses, NMFS is not obligated to independently develop new scientific data. NMFS draft BO for the Russian River Water Supply and Flood Control Project reviewed scientific literature concerned with the role of small estuaries and freshwater lagoons as rearing habitat for steelhead. Information on estuarine use and population dynamics of steelhead and other salmonids in Mediterranean climates is very limited; most is from unpublished manuscripts and graduate theses. Most published information on steelhead use of estuaries is based on populations from more northerly regions where year-round rainfall supports relatively high summer flows and rearing habitat in upland watersheds. NMFS draft BO directly addresses estuarine issues in three separate sections: the Baseline (Section V., pp 82-83, 92-94, 98, and 102), the Effects (Section VI.G), and the Integration and Synthesis (Sections VIII.A.2, and VIII. B.2).

Fundamental Questions for the CIE reviewers

- Does the site specific data for the Russian River, referenced supporting literature, and analysis in the draft BO provide reasonable support for the conclusion that the regulated elevated inflows and systematic artificial breaching of the Russian River estuary collectively cause an adverse effect on rearing habitat for steelhead in the lower Russian River (*i.e.*, in the estuary/potential lagoon system)? If not, what relevant scientific information should be considered?

- Were relevant published and unpublished studies on the relative productivity of freshwater lagoons and estuaries and the use of freshwater lagoons by steelhead and other salmonids missed? If so, what key studies were missed?

- The draft BO states on page 172 that the "systematic breaching of the estuarine bar reduces the estuary's carrying capacity for juvenile steelhead". Is this a reasonable and adequately supported statement?

- What uncertainties related to the estuarine analysis were not addressed that might affect the BO substantively?

General Requirements

The CIE shall provide three independent scientists for this review. Expertise is required in anadromous salmonid biology and ecology, hydrology, and the ecology of estuaries in Mediterranean climates (*i.e.,* estuarine systems that periodically form freshwater lagoons during the low flow season). No consensus opinion among the CIE reviewers is sought.

The activities required under this Statement of Work shall be conducted electronically, so no travel is needed.

CIE reviewers shall review the following document which is the focus of the questions listed above:

- Draft Biological Opinion for Water Supply, Flood Control Operations, and Channel Maintenance conducted by the U.S. Army Corps of Engineers and the Sonoma County Water Agency in the Russian River watershed. National Marine Fisheries Service. June 2007.

To aid the reviewers, we are providing copies of the following unpublished manuscripts cited in NMFS BO:

1. SCWA. 2006. Russian River estuary fish and macro-invertebrate studies, 2005. Sonoma County Water Agency, Santa Rosa, CA. 35 pp.

2. SCWA. 2006. Russian River estuary sandbar breaching 2005 monitoring report. Sonoma County Water Agency, Santa Rosa, CA. 58 pp.

3. Smith, J. 1990. The effects of the sandbar formation and inflows on aquatic habitat and fish utilization in Pescadero, San Gregorio, Wadell, and Pomponio Creek estuary/lagoon systems, 1985-1089. Department of Biological Sciences, San Jose State University, San Jose, CA. 38 pp + tables and figures.

4. Higgins, P. 1995. Fisheries elements of a Garcia River estuary enhancement feasibility study. Mendocino County Resource Conservation District. 22 pp + appendix.

5. Cannata, S.P. 1998. Observations of steelhead trout (*Oncorhychus mykiss*), coho salmon (*O. kisutch*) and water quality of the Navarro River estuary/lagoon May 1996 to December 1997. Humboldt State University Foundation. 48 pp, + tables and figures.

6. Maahs, M., and S.P. Cannata. 1998. The Albion River estuary, its history, water quality, and use by salmonids, other fish and wildlife species. Prepared for the Humboldt County Resource Conservation District and Coastal Land Trust.

7. Zedonis, P. 1992. The biology of the steelhead (*Oncorhychus mykiss*) in the Mattole River estuary/lagoon. Masters Thesis. California State University-Humboldt.

8. Bush, R.A. 2003. Juvenile steelhead and residence and growth patterns in a California coastal lagoon. Center for Integrated Watershed Science and Management, University of California, Davis.

9. Bond, M.H. 2006. Importance of estuarine rearing to central California steelhead (*Oncorhychus mykiss*) growth and marine survival. Masters Thesis. University of California Santa Cruz. 39 pp.

The above material will be provided by the NMFS Southwest Regional's (SWR) contact persons: Dick Butler Dick.Butler@noaa.gov and Bill Hearn William.Hearn@noaa.gov

Each reviewer's duties shall not exceed a maximum total of 10 days – approximately 5 days for report and literature review and 5 days to produce a written report of the findings. Each reviewer may conduct their analyses and writing duties from their primary work location. Each report is to be based on the individual reviewer's findings, and no consensus report shall be accepted.

The itemized tasks of each reviewer consist of the following.

1. Read the draft Russian River Biological Opinion with a focus on the estuarine component of the analysis.

2. Consider additional scientific information as necessary.

3. No later than February 15, 2007, each CIE reviewer shall submit their independent peer-review report addressing each task in this Statement of Work to Dr. David Die at ddie@rsmas.miami.edu and Mr. Manoj Shivlani at mshivlani@rsmas.miami.edu

Submission and Acceptance of CIE Reports

No later than February 29, 2007, the CIE shall provide via e-mail the final independent CIE reports and the CIE chair's summary report to the COTR William Michaels (William.Michaels@noaa.gov) at NOAA Fisheries. The COTR and alternate COTR Dr. Stephen K. Brown (Stephen.K.Brown@noaa.gov) will review the CIE reports to determine that the Term of Reference was met, notify the CIE program manager via e-mail regarding acceptance of the reports by December 30, 2007, and then distribute the reports to the SWR contact person.

ANNEX I: REPORT GENERATION AND PROCEDURAL ITEMS

1. The report shall be prefaced with an executive summary of comments and/or recommendations.

2. The main body of the report shall consist of a background, description of review activities, summary of analyses and comments, and conclusions/recommendations.

3. The report shall also include as separate appendices the bibliography of materials reviewed and a copy of the statement of work.

Please refer to the following website for additional information on report generation: http://www.rsmas.miami.edu/groups/cimas/report_Standard_Format.html