# Appendix D

# Modeling Analysis of Habitat Restoration

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
650 Capitol Mall, Suite 5-100
Sacramento, California 95814-4700

May 13, 2017

MEMORANDUM FOR: ARN: 151422-WCR2016-SA00204

FROM: Erin Strange, San Joaquin River Branch, California Central Valley Office, West Coast Region

REVIEWED BY: Maria Rea, Assistant Regional Administrator, California Central Valley Office, West Coast Region

SUBJECT: Technical memorandum regarding additional analysis of habitat restoration actions for enhancement of juvenile rearing habit and amelioration of reverse flows in the Delta for the California WaterFix Project (CWF).

Purpose of Analysis:

The purpose of this analysis is to determine: 1) the impact of fish routing and habitat restoration on the cohort replacement rate of winter-run Chinook salmon, and 2) how reverse flows in the Delta caused by proposed project can be ameliorated with Delta tidal habitat restoration.

Background:

Habitat restoration is proposed for two purposes: 1) to improve spawning and rearing habitat for listed salmonids; and 2) address potential undesirable hydrodynamic effects of NDD operations (e.g. reverse flows).

Upstream Habitat Restoration Actions. As a condition of the 2081(b) ITP, DFW is requiring DWR to improve spawning and rearing habitat for spring run chinook salmon (CHNSR), winter run chinook salmon (CHNWR) and steelhead, and contribute to establishment of additional populations of winter run, support adult spawning, egg incubation and juvenile production. The funding described above will be initially used specifically to establish a new population of CHNWR through introduction and reintroduction of fish into Sacramento River tributaries (which may include Battle Creek and/or upstream of Shasta Reservoir) and to support that population with associated habitat restoration and other measures prior to operation of the NDD

or within 12 years of order issuance[1]. Consistent with the 2081(b) ITP, the goal of this action is to establish a new CHNWR population in the Sacramento River watershed within the term of this permit that meets the low extinction risk criteria identified by the Central Valley Technical Recovery Team (CVTRT) (Lindley et al.2007). As a condition of the 2081(b) ITP, DWR will fully fund and implement reintroduction and restoration action effectiveness monitoring and extinction risk monitoring to ensure that the goal is met. Additionally, the 2081(b) ITP requires that funding commitments will be sufficient to support creation and enhancement of Sacramento River spawning and instream and/or off-channel rearing habitat and measurable expansion of salmonid habitat capacity. Consistent with the 2081(b) ITP, the goal of this effort is to contribute to the quantity, quality, and diversity of important rearing habitat along the Sacramento River corridor for CHNWR, CHNSR, and steelhead, and may include use of mitigation bank(s) as appropriate. Initially efforts will be focused on restoring 80 acres of spawning and rearing habitat in the upper Sacramento River above the Red Bluff Diversion Dam (RBDD). Restoration of rearing habitat in particular above RBDD is targeted at reducing density dependent reductions in CHNWR survival above RBDD. The committed annual funds may also be used to restore habitat in the middle Sacramento River (e.g., in Sutter Bypass). DWR will coordinate with CDFW, NMFS, FWS, Reclamation and other entities undertaking restoration and enhancement actions to identify the highest priority projects for funding annually. Restoration opportunities will align with species recovery needs and be guided by information in the Salmon Resiliency Strategy. This measure may be terminated with written approval from CDFW and NMFS upon demonstration that the measure has offset the population level effects of the CWF operations.

Delta Habitat Restoration. DWR and Reclamation commit to improve and expand the diversity, quantity, and quality of rearing and refuge habitat in the tidal portions of the Delta and Suisun Marsh, including conservation measures discussed below in 3.4.3.1.2.1 *Tidal Perennial Habitat Restoration*. As described in this section, the PA includes conservation measures to provide restoration of at least 1,800 acres of tidal habitat prior to operation of the NDD, consistent with the multi-species benefits that exist with restoration associated with the delta smelt conservation measures described below and other restoration efforts, that will contribute to improved growth, survival, and migratory success of juvenile CHNWR, CHNSR, and steelhead, including potential use of mitigation banks as deemed appropriate. Implementation of these measures will be funded out of the project budget related to construction costs and not through the additional funds as described above, and is in addition to the 9,000 acres of restoration currently being implemented through the previously described Existing Commitments.

It is expected that through the measures described above, additional tidal restoration will be provided to sufficiently address potential undesirable hydrodynamic effects of NDD operations (e.g. reverse flows). DWR and Reclamation commit to ongoing analytical efforts as part of the CWF AMP to accurately characterize the conditions in the near future when benefits of in-progress restoration projects (e.g., Cache Slough and Suisun Marsh) have begun to be realized. DWR and Reclamation also commit to providing the restoration type, location, and amount that, in combination with other changes to baseline, would be necessary to meet ESA and CESA

[1] As stated previously, according to the draft DFW's 2081(b) ITP, permit terms become operative at issuance of the SWRCB order approving the change of point of diversion for DWR and Reclamation, consistent with the requirements of the Delta Reform Act of 2009.

standards for any project-related effects on the frequency, duration, and magnitude of reverse flows caused by NDD operations. Restoration opportunities will align with species recovery needs and be guided by information in the Salmon Resiliency Strategy. Furthermore, DWR and Reclamation commit as part of the AMP to a monitoring program to assess the performance of these actions and modify the mitigation approach as necessary to offset the effects of the project as they are better understood.

Description of Analysis and Results:

**Reverse Flows**

Analyses were provided on April 26, 2017 in email from Garner Jones (DWR) – Draft write-up entitled "TIDAL HABITAT RESTORATION EFFECTS ON SACRAMENTO RIVER REVERSE FLOWS AT GEORGIANA SLOUGH":

There is concern regarding the potential for water export by the proposed north Delta diversions (NDD) to increase the incidence of reverse flows in the Sacramento River at Georgiana Slough, thereby increasing the potential for downstream-migrating juvenile salmonid entry into the interior Delta, where survival is significantly reduced (Perry et al. 2010, 2012; Singer et al. 2013). Although real-time operations would aim to minimize such effects by ramping down NDD operations when pulses of juvenile salmonids are migrating through the Delta, concern remains as to this potential effect. As illustrated in the public draft Bay Delta Conservation Plan (BDCP), tidal habitat restoration's redirection of tidal energy away from the Sacramento River–Georgiana Slough junction has the potential to more than offset NDD effects on reverse flow relative to a baseline, no action alternative that does not include either the NDD or tidal habitat restoration (DWR 2013: Appendix 5.C *Flow, Passage, Salinity, and Turbidity*, Section 5C.5.3.8 *Sacramento River Reverse Flows Entering Georgiana Slough*). This ability of tidal marsh restoration in the Cache Slough complex to influence the tidal conditions in the Sacramento River near Georgiana Slough was documented in the BDCP discussions as early as 2009 (BDCP Integration Team Technical Studies). Several hypothetical restoration scenarios were considered as part of initial BDCP discussions, which included around 6,750 acres, 13,000 acres, and 20,000 acres of restoration in the Cache Slough complex.

The draft BDCP modeling included around 25,000 acres of tidal habitat restoration in the Delta and Suisun Marsh by 2025, with around 13,000 acres in the Cache Slough complex. DSM2-HYDRO modeling illustrated that tidal habitat restoration results in less reverse flow for a given Sacramento River bypass flow downstream of the NDD (Figure 1). The three scenarios depicted in Figure 1 include EBC2 (which represented existing climate and sea level, with operational criteria the same as the CWF NAA scenario), EBC2_ELT (same operating criteria, climate, and sea level as the CWF NAA scenario), and ESO_ELT (similar to the CWF PA scenario, but with tidal habitat restoration). As described by DWR (2013: Appendix 5.C Flow, Passage, Salinity, and Turbidity, Section 5C.5.3.8 Sacramento River Reverse Flows Entering Georgiana Slough), smoothed relationships between mean monthly bypass flow and the percentage of each month with reverse flows were created for each of these scenarios using generalized additive models (GAM with 4 degrees of freedom; Figure 2).

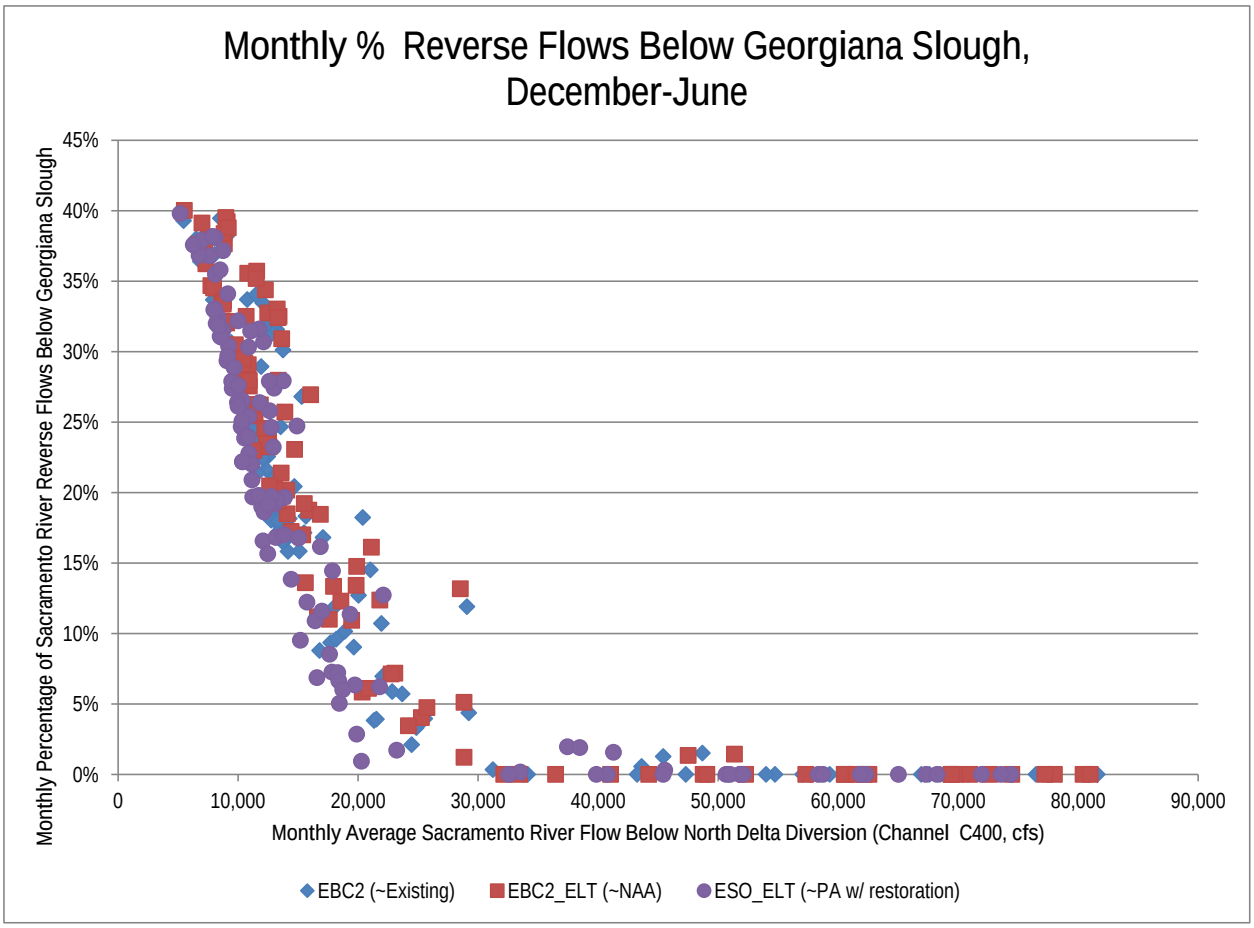


Figure 1. DSM2-HYDRO-Modeled Percentage of Each Month With Reverse Flows at Sacramento River Below Georgiana Slough (DSM2 Channel 423 at 1000 feet; SAC_37) Versus Mean Monthly Flow in the Sacramento River Below the North Delta Diversions (CALSIM Channel C-400), December–June 1976–1991

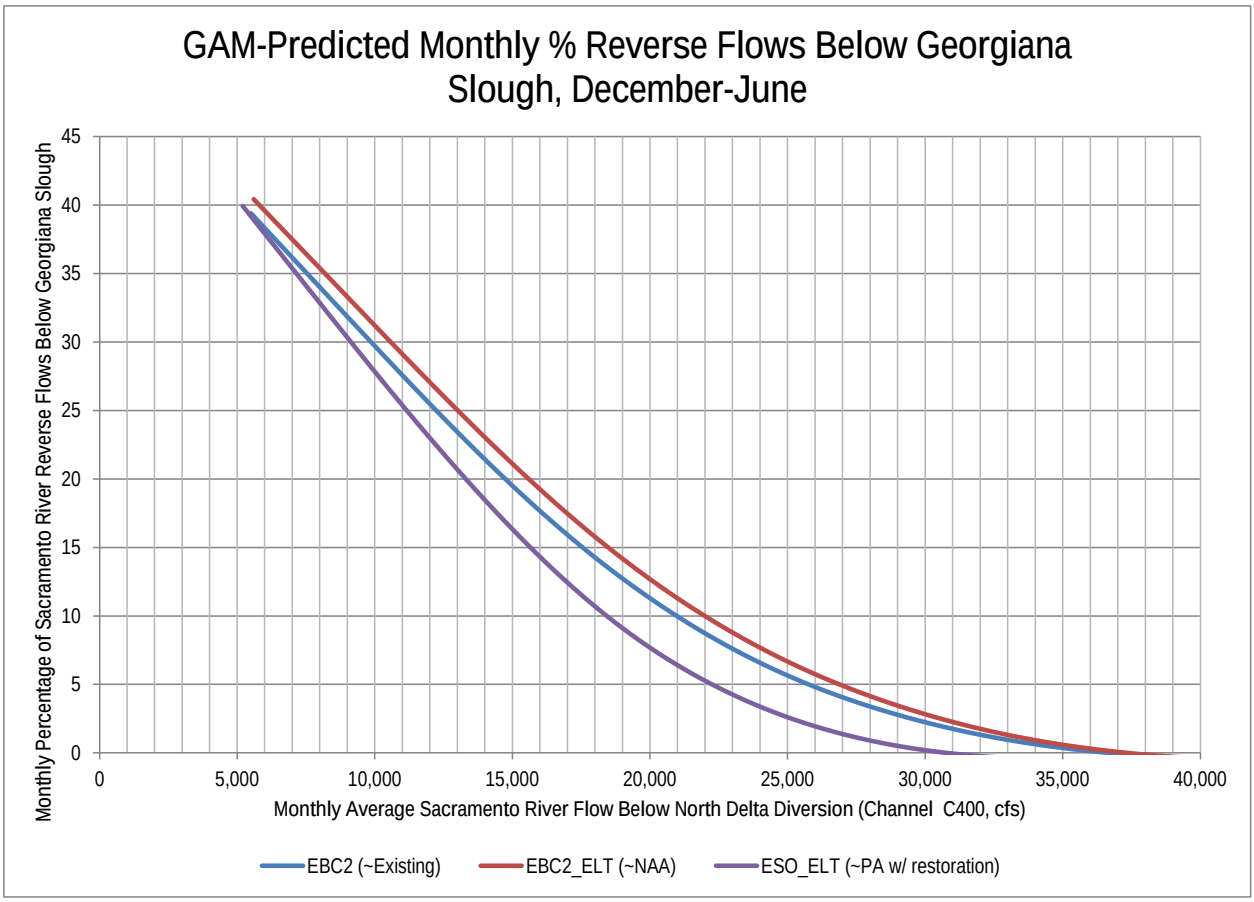


Figure 2. Generalized Additive Model Splines of DSM2-HYDRO-Modeled Percentage of Each Month With Reverse Flows at Sacramento River Below Georgiana Slough (DSM2 Channel 423 at 1000 feet; SAC_37) Versus Mean Monthly Flow in the Sacramento River Below the North Delta Diversions (CALSIM Channel C-400), December–June 1976–1991.

Using the GAM relationships illustrated in Figure 2, predictions of reverse flow percentage were created for 100-cfs bypass flow increments between ~5,500 cfs and 45,000 cfs. These were then related to mean monthly flow by water-year type for the CWF NAA, PP, and $PP_{LFS}$ scenarios (see Table 4.D-4 in Appendix 4.D *Comparison of Key Hydrological Variables for Proposed Project with Longfin Smelt Spring Outflow Criteria to No Action Alternative and Proposed Project Scenarios* of the CWF ITP application), rounded to the nearest 100 cfs. This shows that for the months of December–June, which are the main months of interest for juvenile outmigrating salmonids, inclusion of several thousand acres of tidal habitat restoration in the Cache Slough complex generally would offset effects of less bypass flow under the PP, particularly when Delta outflow criteria for longfin smelt are included ($PP_{LFS}$) (Table 1).

| Month | Year Type | Mean Flow (cfs) | | | Predicted % Reversal | | | Absolute % Difference | |
|---|---|---|---|---|---|---|---|---|---|
| | | NAA | PP | $PP_{LFS}$ | NAA | PP | $PP_{LFS}$ | PP - NAA | $PP_{LFS}$ - NAA |
| Dec | W | 36,300 | 33,100 | 33,200 | 0.2 | 0.0 | 0.0 | -0.2 | -0.2 |
| | AN | 24,700 | 22,500 | 22,500 | 7.0 | 4.7 | 4.7 | -2.2 | -2.2 |
| | BN | 15,800 | 14,200 | 14,200 | 19.6 | 18.0 | 18.0 | -1.6 | -1.6 |
| | D | 13,600 | 12,700 | 12,800 | 23.8 | 21.4 | 21.2 | -2.5 | -2.7 |
| | C | 11,200 | 10,300 | 10,300 | 28.7 | 27.1 | 27.1 | -1.6 | -1.6 |
| Jan | W | 49,300 | 42,900 | 43,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | AN | 38,600 | 33,000 | 33,000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | BN | 18,300 | 16,400 | 16,500 | 15.3 | 13.6 | 13.4 | -1.7 | -1.9 |
| | D | 17,200 | 15,600 | 15,600 | 17.1 | 15.1 | 15.1 | -2.0 | -2.0 |
| | C | 14,100 | 13,300 | 13,300 | 22.9 | 20.0 | 20.0 | -2.8 | -2.8 |
| Feb | W | 56,600 | 48,800 | 48,700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | AN | 46,700 | 40,000 | 40,100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | BN | 30,300 | 26,300 | 26,300 | 2.6 | 1.8 | 1.8 | -0.9 | -0.9 |
| | D | 23,400 | 20,100 | 20,100 | 8.3 | 7.5 | 7.5 | -0.8 | -0.8 |
| | C | 16,000 | 14,200 | 14,200 | 19.3 | 18.0 | 18.0 | -1.2 | -1.2 |
| Mar | W | 48,000 | 40,100 | 40,400 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | AN | 40,800 | 34,100 | 35,400 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | BN | 18,500 | 15,100 | 16,100 | 15.0 | 16.1 | 14.1 | 1.2 | -0.8 |
| | D | 21,300 | 17,300 | 17,900 | 10.9 | 11.9 | 10.9 | 1.0 | 0.0 |
| | C | 12,500 | 11,700 | 11,600 | 26.0 | 23.7 | 23.9 | -2.3 | -2.1 |
| Apr | W | 35,000 | 32,400 | 30,800 | 0.6 | 0.0 | 0.0 | -0.6 | -0.6 |
| | AN | 24,100 | 22,900 | 22,400 | 7.6 | 4.4 | 4.9 | -3.2 | -2.7 |
| | BN | 14,100 | 13,600 | 13,700 | 22.9 | 19.3 | 19.1 | -3.5 | -3.7 |
| | D | 14,900 | 14,300 | 14,200 | 21.3 | 17.8 | 18.0 | -3.5 | -3.3 |
| | C | 10,300 | 10,100 | 10,200 | 30.6 | 27.6 | 27.3 | -3.0 | -3.2 |
| May | W | 29,800 | 26,700 | 26,000 | 2.9 | 1.5 | 1.9 | -1.4 | -1.0 |
| | AN | 16,700 | 15,400 | 15,500 | 18.0 | 15.5 | 15.3 | -2.5 | -2.7 |
| | BN | 12,500 | 12,000 | 11,900 | 26.0 | 23.0 | 23.2 | -3.0 | -2.8 |
| | D | 11,600 | 11,400 | 11,300 | 27.9 | 24.4 | 24.7 | -3.5 | -3.2 |
| | C | 8,200 | 8,000 | 8,000 | 35.0 | 32.9 | 32.9 | -2.1 | -2.1 |
| Jun | W | 20,000 | 15,100 | 15,100 | 12.7 | 16.1 | 16.1 | 3.4 | 3.4 |
| | AN | 13,400 | 11,500 | 11,400 | 24.2 | 24.2 | 24.4 | 0.0 | 0.2 |
| | BN | 12,800 | 12,000 | 12,000 | 25.4 | 23.0 | 23.0 | -2.4 | -2.4 |
| | D | 12,600 | 11,500 | 11,900 | 25.8 | 24.2 | 23.2 | -1.7 | -2.6 |
| | C | 9,300 | 9,100 | 9,200 | 32.7 | 30.1 | 29.8 | -2.6 | -2.8 |

Red highlights indicate >0.5% more under PP or $PP_{LFS}$ than NAA

Green highlights indicate >0.5% less under PP or $PP_{LFS}$ than NAA

## Rearing Habitat Restoration

NMFS used the WRLCM to evaluate the proposed habitat restoration from the Revised PA along with some fish routing actions (Figure 2-184). Scenario #1 was developed as a test-run for the model to implement the various proposed actions and evaluate how the model treated those additions. Scenario #2 captures the habitat restoration being proposed as part of the PA, as well habitat restoration that is being recommitted to in the Revised PA that was originally part of the NMFS 2009 BiOp RPA and/or EcoRestore.

| Scenario | Benefit | Proposed Actions | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fish Routing | | | | | Habitat Restoration | | |
| | | Delta Cross Channel Gate Ops | Fremont Weir – Yolo Bypass | Georgiana Slough Barrier (non-physical) | Steamboat Slough Fish Guidance | Sutter Slough Fish Guidance | Upper Sac Convert to natural bank, Backwater/ Floodplain | Lower Sac Non-tidal wetland/ Floodplain | Delta Tidal Marsh |
| **1** | Low | NAA | 15% more fish migrants into Yolo | Entrainment reduced by a relative 50% | Increase entrainment by 15% | Increase entrainment by 15% | Increase habitat capacity by 80 acres | Increase habitat capacity by 80 acres | Increase habitat capacity by 80 acres |
| **2** | Med | NAA | 15% more fish migrants into Yolo | Entrainment reduced by a relative 50% | Increase entrainment by 15% | Increase entrainment by 15% | Increase habitat capacity by 80 acres | Increase habitat capacity by 9,000 acres | Increase habitat capacity by 11,000 acres |
| **Model Representation** | Current | PA | Proposed Fremont Weir | None | None | None | Existing habitat | Existing habitat | Existing habitat |
| | New | NAA | An additional percentage of fish enter Yolo | Reduce relative percentage of fish entering GS | Increase percentage of fish entering Steamboat Slough | Increase percentage of fish entering Sutter Slough | Add habitat | Add habitat | Add habitat |
| | Steps | DCC closure as NAA | Adjust LCM code | 1. Adjust Hydrofile 2. ePTM run 3. LCM | 1. Adjust Hydrofile 2. ePTM run 3. LCM | 1. Adjust Hydrofile 2.ePTM run 3. LCM | 1. Alter HEC-RAS geometry to estimate increased habitat capacity 2. LCM | 1. Alter HEC-RAS geometry to estimate increased habitat capacity 2. LCM | 1. Alter HEC-RAS geometry to estimate increased habitat capacity 2. LCM |

Figure 2-184. Habitat Restoration and Fish Routing Scenarios Evaluated with the Winter-run Life Cycle Model.

This analysis focused on the evaluation of change in cohort replacement rate between Scenario 2 and NAA as compared to the original analysis of the change in cohort replacement rate between the PA and NAA to demonstrate the population level benefits of the proposed habitat restoration and fish routing activities. The percent difference in mean cohort replacement rate under SA was approximately 1% better under all the scenarios when compared to the PA (Table 2-235 and Table 2-236). The restored habitat in the Lower River increased the proportion of fry rearing and subsequently smolting in this habitat; however, the Lower River smolts experienced through-delta survival rates that were affected by the north Delta diversions. The implementation of non-physical barriers at Georgiana Slough, Steamboat Slough, and Sacramento Slough under S2 did improve the survival rates of smolts originating in the Lower Sacramento River over the PA. These routing measures did not fully mitigate for the overall reduction in smolt survival due to operation of the North Delta Diversions under the PA, however.

Table 2-235. Percent Difference in Winter-run Chinook Salmon Cohort Replacement Rate Between Scenario Two (S2) and NAA.

| CWF Alternative (S2, NAA) Comparison | Percent Difference in mean CRR (S2-NAA /NAA ) | Percent Difference in median CRR (S2-NAA /NAA ) | Pr (NAA > S2) |
|---|---|---|---|
| Scenario 1 | -7.19% | -6.58% | 0.999 |
| Scenario 1A | -7.85% | -6.31% | 0.999 |
| Scenario 1B | -8.16% | -6.64% | 0.998 |
| Scenario 2 | -8.37% | -6.70% | 0.998 |
| Scenario 2A | -6.98% | -5.36% | 0.998 |
| Scenario 2B | -7.80% | -6.16% | 0.998 |

Table 2-236. Percent Difference in Winter-run Chinook Salmon Cohort Replacement Rate Between PA and NAA.

| CWF Alternative (PA, NAA) Comparison | Percent Difference in mean CRR (PA-NAA /NAA ) | Percent Difference in median CRR (PA-NAA /NAA ) | Pr (NAA > PA) |
|---|---|---|---|
| Scenario 1 | -8.72% | -7.72% | 0.997 |
| Scenario 1A | -8.51% | -7.53% | 0.998 |
| Scenario 1B | -8.92% | -7.92% | 0.998 |
| Scenario 2 | -9.18% | -7.94% | 0.998 |
| Scenario 2A | -7.75% | -6.56% | 0.998 |
| Scenario 2B | -8.59% | -7.37% | 0.998 |

Conclusions:

**Reverse Flows**

In the absence of specific information in the CWF Biological Assessment, the CWF Biological Opinion (Opinion) relies on the NDD bypass evaluation in the smolt entrainment model to evaluate the likelihood of reverse flows and proportion of daily reverse flows in the Sacramento River downstream of Georgiana Slough under the PA without extensive real-time operations adjustments. Unlimited pulse protections, which as described in the PA would be implemented through real-time operations at the NDD, cannot be modeled with the tools described here but are evaluated with a different level of analysis discussed in CWF Opinion Section 2.5.1.2.7.4 Delta Survival. In addition, in the June 2017 Revised PA, DWR committed to additional Delta habitat restoration that is expected to change the tidal prism so that the operational commitment of not exacerbating reverse flows in the north Delta can be met.

As illustrated in the public draft Bay Delta Conservation Plan (BDCP), tidal habitat restoration's redirection of tidal energy away from the Sacramento River–Georgiana Slough junction has the potential to more than offset NDD effects on reverse flow relative to a no action alternative (reflecting continuation of the environmental baseline) that does not include either the NDD or tidal habitat restoration (DWR 2013: Appendix 5.C Flow, Passage, Salinity, and Turbidity, Section 5C.5.3.8 Sacramento River Reverse Flows Entering Georgiana Slough). Several hypothetical restoration scenarios were considered as part of initial BDCP discussions, which included around 6,750 acres, 13,000 acres, and 20,000 acres of restoration in the Cache Slough complex (see Appendix G Habitat Restoration of this Opinion). The PA adds 1,800 acres of Delta tidal habitat restoration to the existing commitments for 9,000 acres of Delta tidal habitat restoration, which in total according to DSM2-HYDRO modeling will mute reverse flows to varying degrees depending on Sacramento River outflow (see Figures 1 and 2 in Appendix G Habitat Restoration of this Opinion).

In addition to the 1,800 acres, the PA states, " DWR and Reclamation also commit to providing the restoration type, location, and amount that, in combination with other changes to baseline, would be necessary to meet ESA and CESA standards for any project-related effects on the frequency, duration and magnitude of reverse flows caused by NDD operations…Furthermore, DWR and Reclamation commit as part of the AMP to a monitoring program to assess the performance of these actions and modify the mitigation approach as necessary to offset the effects of the project as they are better understood." Therefore, Reclamation and DWR are not only commiting to an additional 1,800 acres, but are also committing to a new program of Delta habitat restoration that will be driven by the PA objective of the project not exacerbating reverse flows in the North Delta/Lower Sacramento River area, and be based on science, monitoring and adaptive management.

NMFS expects that tidal habitat restoration (both the additional 1,800 acres and the new objective-driven program) in combination with reductions in NDD diversions due to real-time operation pulse protection actions will prevent the exacerbation of reverse flows in the north Delta. Therefore, the Calsim modeling for the PA represents a worst-case scenario analysis. The Calsim modeling for the PA does not account for the prevention of additional reverse flows in the north Delta that is expected with proposed NDD operations. Therefore, the analysis presented

here, which is based on the Calsim modeling, includes an increase in flow reversals and the subsequent impacts to migrating salmonids, but the increase is expected to be prevented or reduced to some degree under the PA.

**Habitat Restoration**

NMFS expected the results to show more improvement in the winter-run Chinook salmon cohort replacement rate under S2. This moderate improvement is likely due to the population dynamics of the winter-run Chinook salmon (one population at low abundance) and how the different aspects of the species life-cycle are modeled relative to the fishes habitat use. The proposed Delta habitat restoration did not improve the cohort replacement rate under this scenario because the current low abundance of the winter-run population is not limited by Delta rearing habitat. As the population abundance increases because of recovery action implementation (such as newly reintroduced populations in Battle Creek and upper Sacramento River – above Shasta Reservoir) the availability of additional tidal Delta rearing habitats will become more important for the species.