sturgeon population by influencing the timing, magnitude, and relative success of each spawning season. However, NMFS has insufficient information to make a conclusion with regard to whether there is an effect on juvenile green sturgeon migration travel time through the Delta relative to change in flow due to the PA.

2.5.1.2.7.1.3.5 Fall-Run Exposure and Risk

Fall run Chinook salmon have a wide emigration window and utilize different life history strategies at the juvenile stage. In wetter years, it is not uncommon to find fall run Chinook salmon fry in the Delta as early as December (Table 2-173). April is when the fall-run hatchery smolts are released at various locations upstream of and within the Delta, contributing to high abundance in the Delta in April for smolt-sized fish. The emigration window can last until August on rare occasions but generally extends from December through June (Table 2-173).

Table 2-173. Fall-run Sacramento and San Joaquin Basin Emigration from 1995 to 2008.

Monitoring Location	Data	Month											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Knights Landing	Mean Size (Fork length) Size Range	NA	NA	35 (34-36)	37 (37-38)	39 (38-40)	43 (37-52)	73 (60-80)	77 (73-81)	78 (72-83)	76	91	87
Sacramento Trawl	Mean Size (Fork length) Size Range	NA	NA	35 (34-36)	37 (35-40)	39 (37-41)	45 (39-53)	72 (69-78)	77 (71-81)	82 (75-90)	85 (78-94)	92 (85-102)	NA
Chipps Island Trawl	Mean Size (Fork length) Size Range	NA	NA	NA	38 (36-43)	39 (37-41)	56 (42-69)	78 (76-82)	81 (78-84)	85 (80-92)	89 (80-96)	NA	NA
Mossdale	Mean Size (Fork length) Size Range	NA	NA	NA	37 (36-38)	39 (36-47)	50 (38-65)	76 (65-80)	86 (78-91)	97 (92-102)	NA	NA	NA

KEY	Degree of rearing expected	High >20%	Medium 10-20%	Low 2-10%	Rare to None <2%

Note: Inter-annual proportion of population sampled at Midwater Trawl at Chipps Island, Midwater and Kodiak Trawls at Sherwood Harbor near Sacramento, conducted by The Delta Juvenile Fish Monitoring Program (DJFMP), Stockton, CA, USFWS.

Channel Velocity Differences in North Delta

The velocity analysis revealed that, in the north Delta, the median velocities are reduced under the PA throughout the fall-run Chinook salmon emigration period (December through June) (Table 2-173) and across all water year types (BA Table 5.4-9 in Appendix C of this Opinion). The reduced velocities in the North Delta suggest outmigrating fall-run smolts will experience longer travel time and, therefore, higher mortality during the entirety of their migration period for which velocity data are available.

Specifically, in the North Delta, results for December in below normal, above normal, and wet water year types show that median velocity for the Sacramento River downstream of the NDD, including Steamboat and Sutter Sloughs, are 5 to 15 percent lower for the PA (BA Table 5.4-9 in Appendix C of this Opinion). December is the start of the fall-run Chinook salmon fry sized fish (<70 mm) emigration and they are expected to be present in these wetter year types. USFWS monitoring detects a low proportion of interannual migrants during this month (Table 2-173).

During January and February, median velocities are consistently lower by five percent or more under the PA for the Sacramento River downstream of the NDD, including Steamboat and Sutter Slough (BA Table 5.4-9 in Appendix C of this Opinion), with the biggest changes occurring in January of wet and above normal years ranging from a 10% to 18% reduction in velocities. These could be months when fall-run Chinook salmon are rearing in the Delta. Sacramento Trawl detects a large proportion of fall run inter-annual fry sized migrants during January and February (Table 2-173).

The greatest velocity reductions for the December through May fall-run migratory period occur in March when velocities are reduced for the Sacramento River downstream of the NDD, including Steamboat and Sutter Sloughs, (BA Table 5.4-9 in Appendix C of this Opinion) by 10% or more in all water year types except critical years. Velocity reductions in the north Delta during March would occur when a large proportion of the fry sized population is rearing and migrating in the Delta (Table 2-173). This could cause adverse effects to habitat availability and increase predator encounters due to increased routing to or greater exposure in higher mortality habitats.

The magnitude of velocity reductions in April are not as large as in earlier months (most are under 5%); some of the larger velocity reductions for PA operations in April range from 5% to 10% (BA Table 5.4-9 in Appendix C of this Opinion). This would affect the majority of fall-run Chinook salmon smolts as most of the population is over 70 mm at this point in the year and hatcheries are releasing millions of smolts during April (Table 2-173).

During May, another peak month of fall-run Chinook salmon smolt migration (Table 2-173), velocity reductions are greater and more frequent than April but not as prevalent or extreme as the earlier migratory and rearing months of December through March (BA Table 5.4-9 in Appendix C of this Opinion). This would increase travel time affecting survival during a peak migratory month.

During June, reductions in velocities are increasing and range from 5 to 24% in the Sacramento River downstream of the NDD, including Steamboat and Sutter Sloughs (BA Table 5.4-9 in Appendix C of this Opinion). During June, the abundance of fall-run Chinook salmon smolts is decreasing in comparison to April and May smolt presence (Table 2-173). Velocity reductions in the north Delta during June would increase travel time and predation encounters for the tail end of fall-run Chinook salmon smolt emigration through the North Delta.

An analysis was done to look at changes in differences in the magnitude of negative velocities (flow reversing) between scenarios (BA Table 5.4-10 in Appendix C of this Opinion). This analysis recognizes that, in the tidal Delta, velocities are not always seaward and can become slack or negative during the day. This affects fish migration as fish may be advected back upstream during flood tide, hold in the water column or a side bank or exert more energy to continue seaward, all affecting travel time during active outmigration. As discussed in Section 2.5.1.2.7.1.2 NDD Bypass Flows and Smolt Entrainment Analysis, there is insufficient information to analyze the PA operational constraint regarding no increase in reverse flows.

In the north Delta, the velocity analysis indicated increased negative velocities under the PA during important fall-run Chinook salmon migratory months of February through May upstream and downstream of Georgiana Slough on the Sacramento River (BA Table 5.4-10 in Appendix C of this Opinion). Increased negative velocity can range up to 98% more during the month of March under the PA though most increases range between 7% to 30%. Increases in flow reversals would likely reduce the survival probability of outmigrating smolts by moving them back upstream, increasing their exposure to junctions that lead to migratory routes of lower survival, such as in Georgiana Slough.

The third part of this hydrodynamic analysis looked for differences in modeling results between NAA and PA in the proportion of time each day that velocity was negative in north Delta channels. In the north Delta, the modeling results show that proportion of day with reverse flows increases under the PA especially in Steamboat Slough and downstream of Georgiana Slough (BA Table 5.4-11 in Appendix C of this Opinion).

The velocity analysis indicates that the majority of fall-run Chinook salmon will experience conditions in the north Delta as a result of the PA that will increase travel time, reduce habitat, and potentially increase predator exposure resulting in adverse effects. These adverse effects are impactful for the fry-sized life stage (due to their increased vulnerability due to their small size) and for the late arriving fall-run smolts in June or July (who will experience overall poor migration and rearing conditions in the Delta). During the peak months of smolt presence in the Delta (April and May), changes in velocities are not as pronounced as in the shoulder months.

Channel Velocity Differences in Central Delta

In the central Delta at the DCC location, velocities were very similar between the NAA and PA scenarios in the December through May period. However, in June they became more positive in wet years and critical years, but more negative in above normal, below normal, and dry water year types. Based on the velocity analysis, travel time and predation risk for outmigrating fall-run Chinook salmon smolts in the central Delta are not expected to change under the PA for the period between December and May, but will increase in the month of June (BA Table 5.4-9 in Appendix C of this Opinion). The magnitude of negative water velocities did not change substantially from December through May. However, in June, the magnitude of negative velocities became more negative in all water year types except for critical water years. In wet years, the magnitude of negative water velocities became 7% more negative in the DCC channel, and was 3% more negative in above normal, below normal, and dry water year types (BA Table 5.4-10 in Appendix C of this Opinion). The proportion of the day in which water velocities were negative remained unchanged between December and May when the DCC gates were closed. In

June when the gates become operable again, the proportion of the day in which the flows were negative increased substantially in all water year types. In above normal years, the percentage increase is 100% (BA Table 5.4-11 in Appendix C of this Opinion). Fall-run Chinook salmon smolts will experience conditions in the Central Delta in June that will increase travel times leading to increased predation exposure, and increased exposure to advection into river junctions leading to waterways with lower survival rates, resulting in overall adverse effects. Negative velocities in Georgiana Slough were not examined in this analysis though it is an important migratory route that is examined in other models in this biological opinion. Specifically, the NDD bypass flows and smolt entrainment model assesses changes in proportion of smolts using Georgiana Slough, and the DPM and Perry Survival Model assesses differences in survival using this migratory route.

Channel Velocity Differences in South Delta

In the south Delta, the modeling indicates that flow velocities generally increase in the San Joaquin River between the location of the Head of Old River and the Port of Stockton at Channel Point where the confined river channel enters the much larger Stockton DWSC. Under the PA, the HOR gates are operated from January through June to enhance flows in this river reach and keep fish from entering the Old River channel. As modeled, there is little difference in flow velocity in December between the PA and NAA scenarios when the gates are not operated. From January through June, the increases in velocity range from 8% (June, wet water year type) to 54% (January, below normal water year type). During key emigration months in the San Joaquin River Basin for fall-run Chinook salmon parr and smolts entering the Delta (March through May), increases in flow velocity typically range from 30% to almost 50% under the PA compared to the NAA scenario (BA Table 5.4-9 in Appendix C of this Opinion). This will help fall run Chinook salmon smolts travel faster downstream from the HOR location to the Stockton DWSC. Shortened travel times are anticipated to decrease predation risks by shortening the temporal overlap with predators in this river reach.

The San Joaquin River flow velocity near the mouth of the Mokelumne River (Channel node 45) would also generally be higher under the PA compared to the NAA scenario. Flow velocities would be higher in almost all water year types from December through June. Most of these increases would be greater than 5%. Only in June of critical water year types would the PA and NAA scenarios have equal flow velocities. The increases in flow velocity, as modeled, range between 6% and 31% (BA Table 5.4-9 in Appendix C of this Opinion), and should aid the downstream movement of fall-run Chinook salmon smolts through the Stockton DWSC by reducing the temporal exposure to potential predators in this reach of the river. Shorter exposure to predators should enhance survival of fall-run Chinook salmon smolts by reducing the duration of predator-prey interactions.

Velocities in the Old River channel also increase under the PA scenario relative to the NAA scenario in most months and water year types, except for the months of April and May. Under the NAA scenario, median 15 minute velocities are typically negative in most water year types during the period between December and March, except for wet water year types when some positive velocities are observed in the modeling output. In Old River, downstream of the south Delta export facilities, the differences were related to less south Delta exports. However, in April and May, it was also apparent that in drier years, median velocity was less positive under the PA than the NAA. Although the PA criteria are consistent with the OMR flows and San Joaquin I/E ratio requirements in the current BiOp for the Long Term operations of the CVP and SWP

(NMFS 2009), and south Delta export pumping is almost always lower in April and May; the modeling assumption that the HOR gates are closed 50% of the time during the fall run Chinook salmon migration period combined with differing modeling assumptions for south Delta exports to fill San Luis Reservoir results in Old River channel velocities that were slightly lower under the PA scenario than the NAA (although both had positive median velocity). Channel velocity in Old River upstream of the south Delta export facilities was less positive under the PA than NAA, reflecting less south Delta exports under the PA (i.e., the export facilities exert some hydrodynamic influence by increasing velocity toward the facilities when pumping) and the operation of the HOR gate, which blocks flow from entering 50% of the time during the January–June period.

Fall-run Chinook salmon fry/parr sized fish in the Old River channel corridor would benefit from the more positive flow velocities downstream of the CVP and SWP facilities during the December through March period. These fish could come from anywhere in the Central Valley region. The more positive velocities indicate that there is less net flow towards the facilities since the channel dimensions remain the same. This is a result of anticipated reduced exports in the south Delta under the PA scenario. More positive velocities (even though they are still predominately negative) may mean that fall-run Chinook salmon within the Old River channel downstream of the facilities are advected towards the fish salvage facilities at a lower rate under the PA compared to the NAA scenario. In the Old River channel, upstream of the project facilities, the reduced median velocity is related to the operations of the HOR gate and the reduction in exports from the facilities under the PA scenario. Under the NAA, more flow is routed into the Old River channel at the HOR and under higher export moves at an increased velocity towards the facilities. This would provide an alternative route for emigrating fall-run Chinook salmon smolts from the San Joaquin River basin towards the ocean. However, once in the vicinity of the export facilities, few fish are able to pass the intakes and proceed downstream and are typically entrained into the facilities. Under the PA, the HOR gates are operated to reduce the routing of fall-run Chinook salmon into the Old River channel when emigrating fish are detected in regional monitoring efforts (i.e., Mossdale trawls). Nevertheless, some fish will enter the Old River channel when the gates are lowered during the January through June period or pass through the boat locks or fish ladder when they are in operation. These fish will have slower transit times through the Old River migratory route between the HOR location and the project facilities. Slower transit times related to reduced flow velocity are likely to enhance the risk of predation on fall-run Chinook salmon smolts in the channels that make up the Old River migratory route.

The magnitude of negative flow velocity was modeled to compare the changes between the PA and NAA scenarios (BA Table 5.4-10 in Appendix C of this Opinion). Considering only negative velocity estimates under the PA, the median negative velocity in the San Joaquin River downstream of Old River was greater (closer to zero) than under the NAA, with the relative difference decreasing as water years became drier. The muting of the negative velocities (flow velocity becoming more positive) is a reflection of the operation of the HOR gate, which redirects more flow down the San Joaquin River main channel. The greater percentage of river flow moving down the main channel will increasingly offset the influence of the tides in this river reach, and enhance downstream movement of fish. These effects occur in all water year types from January through June and should benefit emigrating fall-run Chinook salmon juveniles from the San Joaquin River basin. There was little difference between the PA and NAA scenarios farther downstream near the confluence with the Mokelumne River (Channel node 45), reflecting greater tidal influence on flow velocities relative to river inflow. Negative velocity estimates in Old River downstream of the south Delta export facilities under the PA were either less than or similar to those under the NAA scenario (defined as <5% difference in the medians), whereas in Old River upstream of the facilities, the negative velocities were greater (again reflecting less south Delta exports and the influence of the HOR gate, both of which would increase the influence of flood tides in this channel). More negative velocities are believed to be detrimental to downstream migration of fall-run Chinook salmon smolts by increasing travel times. As stated above, increased travel times will likely increase the smolts' exposure to predators and reduce survival in those channels.

The third part of the velocity analysis was proportion of day with negative velocities. In the south Delta, the analysis showed positive effects under the PA in the San Joaquin River downstream of the HOR and Old River downstream of the south Delta export facilities (BA Table 5.4-11 in Appendix C of this Opinion) in which a lower percentage of the day had negative flows. There were a couple of water years in January, February, and March when the PA reduced proportion of day with reverse flow by 6% to 16%. Conversely, for reasons already explained, the operations of the HOR gate increased the percentage of the day in which flows were negative upstream of the South delta export facilities from January through May. Emigrating fall-run Chinook salmon smolts should benefit with the reduction in the proportion of the day in which negative flows occur in the San Joaquin River downstream of the HOR gate location and in Old River downstream of the South Delta export facilities.

Effect of NDD bypass rules on fall-run migration (Perry et al. 2016 NDD bypass flows and smolt entrainment model)

As noted in the fall-run temporal distribution tables, the Delta migration period generally occurs between January and June with low presence occasionally in December and July (Table 2-173).

Under the PA NDD bypass rules, December and April fall under identical operations rules once initial pulse protection ends; beginning with Level 1 operation, and then increasing to Level 2 or Level 3 operations when flow criteria are met. Of the three main operations levels, Level 1 provides the most protection or least change in riverine flows from the NAA scenario. Under Level 1 operations, the increase in probability of a flow reversal remains under 30% and the increase in the proportion of the day with a flow reversal remains under 5%. Under Level 2, the probability of a flow reversal can be as high as 80% with a ~4-6% increase in the proportion of the day with a flow reversal; while under Level 3, the probability of a flow reversal is up to 100%, with the increase in the proportion of the day with a flow reversal up to 15% (Figure 2-120). Fall-run Chinook salmon will complete the fry life-stage during these months and a large portion of the smolt life-stage will be in the Delta during these months as well (Table 2-173).

May has a unique set of NDD bypass rules that is less protective than the diversion rules in December through April (Appendix A2 Table 3.3-2 of this Opinion). A large proportion of fall-run Chinook salmon smolts are expected to be in the Delta during this month (Table 2-173). They may experience slightly longer travel times than smolts traveling during earlier months given the same inflow at Freeport. This would be due to lower velocities that result from less restrictive diversions under the NDD bypass rules (BA Table 5.4-11 in Appendix C of this Opinion). Under the May Levels 1-3 bypass rules, the probability of a flow reversal ranges from 40% at Level 1 up to 100% at Level 3 and the proportion of the day with reverse flow ranges from 5% under Level 1 up to 16% during Level 3 when discharge at Freeport ranges from 10,000 cfs to 30,000 cfs (Figure 2-121).

June NDD bypass rules are less protective than the diversions rules in December through April and the diversion rules unique to May (Appendix A2 Table 3.3-2). A large portion of fall-run Chinook salmon smolts are likely to still be in the Delta or out-migrating through the Delta. This means the longer travel times experienced by smolts out migrating in June will likely be the highest adverse impact under the PA for the fall run smolt population. Under the June Levels 1-3 bypass rules, the probability of a flow reversal ranges from 50% at Level 1 up to 100% at Level 3 and the proportion of the day with reverse flow ranges from 5% under Level 1 up to 18% during Level 3 when discharge at Freeport ranges from 10,000 cfs to 30,000 cfs (Figure 2-122).

Based on the adverse effects Level 2 and Level 3 diversions have on riverine conditions that influence migration routing, travel time, and overall survival, fall-run would be less impacted under low level pumping and Level 1 operations. Under the NDD bypass rules and no other constraints to diversions, fall-run Chinook salmon smolts that are in the Delta during May and particularly June may have slightly longer travel times than smolts who migrate out earlier. This could result in higher mortality rates for the later migrating fall-run Chinook salmon smolts that are an important part of the species life history diversity.

Perry Survival Model – Travel Time

The Perry Survival Model helps to quantify the actual travel time that smolts will experience under the different Delta inflows between scenarios. Travel time through the Delta will be increased under the PA during the migration period for fall-run Chinook salmon. February, March, and June show the largest increase in travel time, which corresponds with the fall-run Chinook salmon fry life-stage presence in the Delta and the later arriving smolt outmigration in June. For example, travel time under the PA will increase from 0.33 days to 1.4 days during February and March for 50% of the years (Table 2-168). During 25% of the years, travel time will increase during February and March from 1.1 to 3 days under the PA (Table 2-168). During June, travel times will increase under the PA from 0.12 to 1.3 days during 50% of years (Table 2-168). During 25% of the years in June, travel time will increase from 1.3 to 3.5 days under the PA (Table 2-168). Travel times are also increased under the PA in key migratory months of April and May when the majority of fall run Chinook salmon smolts are expected to be in the Delta. Travel time differences in April and May are less than in the other fall run migration months. Travel time for 50% of years will increase under the PA in April from 0.02 days to 0.39 days and in May from 0.05 days to 0.47 days (Table 2-168). During 25% of years, travel time will increase under the PA from 0.39 days to 1.6 days and 0.47 days to 1.7 days in April and May, respectively (Table 2-168). During the other 25% of years, travel time differences under the PA will range from a slight increase of 0.02 days to a reduction of 0.73 days and an increase of 0.05 days to a reduction of 0.54 days during April and May, respectively (Table 2-168).

Since travel time will affect fall-run Chinook salmon survival in the Delta, a more thorough look at fall-run Chinook salmon survival under the different operating levels by month and water year type is included in the Perry Survival Model. The Perry Survival Model is best suited to determine overall effects to fall-run Chinook salmon due to PA operations in the north Delta. The Perry Survival Model encompasses the key stressors that affect overall migratory success in the Delta, travel time, route selection, and survival probabilities under Freeport inflows. While we identify the individual stressors, the effects of the PA on travel time are best evaluated holistically to determine an overall migratory success (survival) or failure (mortality).

Based on the travel time analysis in Section 2.5.1.2.7.1.3 Perry Survival Model (Travel Time Component), operations under the PA would increase travel times throughout the fall-run migratory period with the biggest increases in February, March, and June, which are important migratory months for fall-run Chinook salmon juvenile diversity in the Delta. Increases in travel times for fall-run Chinook salmon fry sized fish (<70 mm) could be expected particularly in the month of February and March. April is the main migratory month of fall-run Chinook salmon smolts and travel time differences between scenarios were modest for 75% of the years ranging from 0.39 days increase to 0.73 days decrease under the PA. The 25% of years with the greatest increase under the PA ranged up to 1.6 days (Table 2-168). Likewise, in May, travel time for 75% of years increased under the PA up to 1.7 days. Although the effect of increase in travel time for these key migratory months are not substantial, it is still an adverse effect of the PA. Additionally, when fall-run Chinook smolts are mostly present in the Delta during April and May, there was not a substantial benefit in south Delta velocities and sometimes in drier years there was an increase in entrainment risk at the south Delta facilities. NMFS therefore expects that reduction in flow as a result of the PA will increase travel time for the majority of outmigrating smolts. This will result in an adverse effect to a high proportion of rearing and outmigrating fall-run Chinook juveniles.

2.5.1.2.7.1.3.6 Late Fall-run Chinook Salmon Exposure and Risk

Late fall-run Chinook salmon occur in the Delta from July through January, with peak occurrence in December (Table 2-174).

Table 2-174. Late Fall-run Sacramento and San Joaquin Basin Emigration from 1995 to 2008.

Monitoring Location	Data	Month											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Sacramento Trawl (RM 55)	Mean Size (Fork length) Size Range	NA	108 (81-125)	117 (103-132)	153 (130-201)	NA	NA	NA	NA	NA	64 (58-67)	77 (72-81)	89 (80-103)
Chipps Island Trawl (RM 18)	Mean Size (Fork length) Size Range	NA	119 (106-129)	125 (112-147)	137 (122-176)	NA	NA	NA	NA	NA	NA	NA	90 (84-100)

KEY	Degree of rearing expected	High >20%	Medium 10-20%	Low 2-10%	Rare to None <2%

Note: Midwater Trawl at Chipps Island, Midwater and Kodiak Trawls at Sherwood Harbor near Sacramento, conducted by The Delta Juvenile Fish Monitoring Program (DJFMP), Stockton, CA, USFWS.

Channel Velocity Differences in North Delta

The Delta velocity analysis was conducted for the months of December through June, which overlaps with late fall-run Chinook salmon juvenile migration through the Delta in December and January. The analysis revealed that the median velocities in the north Delta on the Sacramento River are reduced under the PA throughout December and January across all water year types, with just a few exceptions (BA Table 5.4-9 in Appendix C of this Opinion). The reduction in median velocity under the PA downstream of the North Delta Diversion (site 418) in December ranges from 7% in dry water years up to 15% in wet water years; in January, the reduction ranges from 7% in critical water years up to 18% in above normal water years. The reduced velocities in the North Delta in December and January under the PA suggest outmigrating late fall-run smolts will experience longer travel time and, therefore, greater predation risk and higher mortality, relative to under the NAA.

An analysis was done to look at changes in differences in the magnitude of negative velocities (flow reversing) between the PA and the NAA (BA Table 5.4-10 in Appendix C of this Opinion). This analysis recognizes that velocities in the tidal Delta are not always seaward and can become slack or negative during flood tides. This affects fish migration as fish may be pushed back upstream during flood tide, hold in the water column or a side bank or exert more energy to continue seaward, all affecting travel time during active outmigration. As discussed in Section 2.5.1.2.7.1.2 NDD Bypass Flows and Smolt Entrainment Analysis, there is insufficient information to analyze the PA operational constraint regarding no increase in reverse flows.

In the north Delta, the velocity analysis indicated there was no consistent change or pattern in the negative velocities under the PA relative to the NAA in December and January (see locations 418, 421, and 423 in BA Table 5.4-10 in Appendix C of this Opinion). The PA increased negative velocity in some water years at some locations, and decreased negative velocity in other water years and locations, and in many location/water year combinations there was little to no difference between the alternatives. The PA increased negative velocity in the Sacramento River just upstream from Georgiana Slough by as much as 78% in January in above normal water years. Conversely, the PA decreased negative velocity just downstream of the proposed North Delta Diversion by 35% in January of critical water years.

The third part of this hydrodynamic analysis looked for differences in modeling results between the NAA and PA in the proportion of time each day that velocity was negative in north Delta channels. In the north Delta, the modeling results for the peak late fall-run Chinook salmon migration (December) show that the proportion of day with reverse flows generally increases under the PA at some locations and water year types and is no different than under the NAA in other locations and water year types (BA Table 5.4-11 in Appendix C of this Opinion). There are no locations and water years that the PA decreases the proportion of the day with reverse flows.

Overall, the three velocity analyses indicate that juvenile late fall-run Chinook salmon moving through the north Delta during the peak of the juvenile emigration period will experience an increase in travel time, likely resulting in increased predation risk and decreased survival relative to under the NAA.

Channel Velocity Differences in Central Delta

Based on the velocity analysis within the Delta Cross Channel, travel time and predation risk for emigrating late fall-run Chinook salmon smolts in the central Delta are not expected to increase under the PA during December and January (BA Table 5.4-9 in Appendix C of this Opinion). In fact, travel time under the PA is expected to decrease by 6% in December of above normal water years and decrease by 5% in January of below normal water years relative to under the NAA.

There was little to no change in the Delta Cross Channel between the PA and NAA in December and January across all water year types in the magnitude of negative water velocities (BA Table 5.4-10 in Appendix C of this Opinion) and in the proportion of the day in which water velocities were negative (BA Table 5.4-11 in Appendix C of this Opinion). Based on the water velocity analyses, late fall-run Chinook salmon juveniles are not expected to experience adverse effects related to water velocity in the Central Delta under the PA relative to the NAA. It is important to note that negative velocities in Georgiana Slough were not examined in this analysis though it is an important migratory route that is examined in other models in this biological opinion. Specifically, the NDD bypass flows and smolt entrainment model assesses changes in proportion of smolts using Georgiana Slough, and the DPM and Perry Survival Model assess differences in survival using this migratory route.

Channel Velocity Differences in South Delta

Late fall-run Chinook salmon originate from the Sacramento River basin or the Coleman National Fish Hatchery, and as such are relatively unlikely to occur in the south Delta, particularly at the most upstream locations in the south Delta. The velocity analyses indicate that PA flow velocities in the south Delta in December and January generally are the same or higher than flow velocities under the NAA (BA Table 5.4-9 in Appendix C of this Opinion). The increases in velocity would likely improve the survival of any late fall-run Chinook salmon smolts that may have moved into the south Delta. In January, flow velocity decrease in the Old River upstream of the south Delta export facilities, but it is unlikely that late fall-run Chinook salmon would occur that far upstream.

The San Joaquin River flow velocity near the mouth of the Mokelumne River (Channel node 45) would also generally be higher under the PA compared to the NAA scenario. Flow velocities would be higher in all water year types during December and January, with most of these increases being greater than 5%. The increases in velocity under the PA relative to the NAA would likely improve the survival of any late fall-run Chinook salmon smolts that may have moved into the south Delta in the vicinity of the mouth of the Mokelumne River.

Late fall-run Chinook salmon fry/parr sized fish in the Old River channel corridor downstream of the export facilities would benefit from more positive flow velocities December and January under the PA (BA Table 5.4-9 in Appendix C of this Opinion). The more positive velocities indicate that there is less net flow towards the facilities since the channel dimensions remain the same. This is a result of anticipated reduced exports in the south Delta under the PA scenario. More positive velocities (even though they are still predominately negative) may mean that late fall-run Chinook salmon within the Old River channel downstream of the facilities are pushed towards the fish salvage facilities at a lower rate under the PA compared to the NAA scenario.

The magnitude of negative flow velocity in the south Delta was modeled to compare the changes between the PA and NAA scenarios. Channel velocity under the PA in December and January in the San Joaquin River downstream of the head of Old River and near the mouth of the Mokelumne River, and in the Old River downstream of the export facilities was similar to or less negative than velocity under the NAA across all water years (BA Table 5.4-10 in Appendix C of this Opinion). In the San Joaquin River, downstream of the head of Old River in January, velocity under the PA became less negative than under the NAA by a range of 14% in critical water years to 21% in wet water years. The muting of the negative velocities (flow velocity becoming less negative) in the San Joaquin River is a reflection of the operation of the HOR gate, which redirects more flow down the San Joaquin River main channel. The greater percentage of river flow moving down the main channel would offset the influence of the tides in this river reach, and enhance downstream movement of fish. These effects should benefit emigrating late fall-run Chinook salmon juveniles by decreasing the likelihood that juveniles would become disoriented by reverse flows and move into the San Joaquin River, as well as decreasing seaward travel time for any juveniles that do make their way from their Sacramento River origins into the south Delta. More negative velocities are assumed to be detrimental to the downstream migration of late fall-run Chinook salmon juveniles by increasing travel times. As stated above, increased travel times for juveniles will likely increase their exposure to predators and reduce their survival.

The third part of the velocity analysis was proportion of day with negative velocities. In the south Delta in January, the analysis showed positive effects for multiple water year types under the PA in the San Joaquin River downstream of the HOR and Old River downstream of the south Delta export facilities (BA Table 5.4-11 in Appendix C of this Opinion) in which a lower percentage of the day had negative flows. Conversely, for reasons already explained, the operations of the HOR gate under the PA increased the percentage of the day in which flows were negative upstream of the South delta export facilities during January, relative to the NAA. However, given that late fall-run Chinook salmon originate from the Sacramento River basin, they are unlikely to occur in the Old River upstream of the south Delta export facilities. Emigrating late fall-run Chinook salmon juveniles should be unaffected or would benefit with the reduction in the proportion of the day in which negative flows occur in the San Joaquin River downstream of the HOR gate location and in Old River downstream of the south Delta export facilities.

Effect of NDD Bypass Rules on Late Rall-run Migration (Perry et al. 2016 NDD Bypass Flows and Smolt Entrainment Model)

As noted in the fall-run temporal distribution tables, the Delta migration period generally occurs between July and January, with peak presence in December (Table 2-174). Late fall-run Chinook salmon occurring in the Delta in December and January would be smolt-sized and, therefore, the Perry et al. 2016 NDD bypass flows and smolt entrainment model is applicable for late fall-run Chinook salmon in those months.

Under the PA NDD bypass rules, December through April fall under identical operations rules once initial pulse protection ends; beginning with Level 1 operation, and then increasing to Level 2 or Level 3 operations when flow criteria are met. Of the three main operations levels, Level 1 provides the most protection or least change in riverine flows from the NAA scenario. Under Level 1 operations, the increase in probability of a flow reversal remains under 30% and the increase in the proportion of the day with a flow reversal remains under 5%. Under Level 2, the increase probability of a flow reversal can be as high as 80% with a ~4-6% increase in the proportion of the day with a flow reversal; while under Level 3, the probability of a flow reversal is up to 100%, with the increase in the proportion of the day with a flow reversal up to 15% (Figure 2-120).

Based on the adverse effects Level F2 and Level 3 diversions have on riverine conditions that influence migration routing, travel time, and overall survival, late fall-run would be less impacted under low level pumping and Level 1 operations. Under the NDD bypass rules and no other constraints to diversions, late fall-run Chinook salmon smolts that are in the Delta during December and January may have slightly longer travel times under the PA than the NAA. This could result in higher mortality rates under the PA than under the NAA for the peak migration of late fall-run Chinook salmon smolts.

Perry Survival Model – Travel Time

The Perry Survival Model helps to quantify the actual travel time that smolts will experience under the different Delta inflows between scenarios. Travel time through the Delta will be increased under the PA during the migration period for late fall-run Chinook salmon. For example, during the peak month of late fall-run Chinook salmon smolt emigration (December), the median increase in travel time over all water year types is 0.29 days under the PA as compared to the NAA (Table 2-168). Travel time for late fall-run Chinook salmon juveniles across all water year types also is expected to increase under the PA relative to the NAA during October and November (Table 2-167) and January (Table 2-166). For 75% of years under the PA, travel time increases during October and November range from 0.2 days up to 4.6 days. The increased travel time from October through January is expected to result in decreased survival for the majority of outmigrating late fall-run Chinook salmon juveniles.

2.5.1.2.7.2 Outmigration Routing

Several studies of salmonid migration through the Sacramento-San Joaquin Delta show that the survival rate for salmonids is notably lower for fish that travel through the interior Delta than for those that migrate through the Sacramento River or Sutter and Steamboat Sloughs (Perry 2010; Newman 2003). These reductions are most likely due to higher predation rates in the interior Delta, longer migration times required to navigate the circuitous path of channels under lower distributary velocities, and risk of entrainment into the CVP/SWP (Perry et al. 2010; Perry et al. 2013; Newman 2003; Newman,and Brandes 2010; NMFS 2009). Because a proportion of Sacramento River basin salmonids are exposed to interior Delta migration routes, migratory route entrainment is considered a stressor that can affect individual fish survival and overall population abundance. Assessing survival and migratory patterns for salmonids in the Delta under the operations of the PA relies on examination of flows into and hydrodynamics of the Delta. Note we do not analyze the effects on salmonid outmigration routing from the revised NDD operations (e.g., unlimited pulse protection as described in Section 2.5.1.2.7.4 Delta Survival) because we do not have modeling information to inform the analysis of outmigration routing specifically.

The methods that are used to analyze how changes in hydrology or flows can affect migratory route entrainment are summarized in Table 2-175.