EFFECTS OF WATER PROJECT OPERATIONS ON JUVENILE SALMONID MIGRATION AND SURVIVAL IN THE SOUTH DELTA

Volume 1: Findings and Recommendations

Prepared for:
Collaborative Adaptive Management Team

Prepared by:
Salmonid Scoping Team

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SALMONID SCOPING TEAM

This report has been prepared through a collaborative process involving technical experts participating on the Collaborative Adaptive Management Team (CAMT) Salmonid Scoping Team (SST). SST participants contributing to the report include John Ferguson (Co-chair), Anchor QEA, LLC; Chuck Hanson (Co-chair), Hanson Environmental, Inc.; Mike Schiewe (Co-chair retired), Anchor QEA, LLC; Pat Brandes, U.S. Fish and Wildlife Service; Rebecca Buchanan, University of Washington; Barbara Byrne, National Marine Fisheries Service; Sheila Greene, Westlands Water District; Brett Harvey, California Department of Water Resources; Rene Henery, Trout Unlimited; Joshua Israel, U.S. Bureau of Reclamation; Daniel Kratville, California Department of Fish and Wildlife; Michael Harty, Kearns & West; Joe Miller, Anchor QEA, LLC; Meiling Roddam, National Marine Fisheries Service[1]; and Briana Seapy, Kearns & West.

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[1] Currently with State Water Resources Control Board

EXECUTIVE SUMMARY

Key information developed by the Salmonid Scoping Team (SST) and presented in Volumes 1 and 2 is summarized below under three categories: findings and gaps, areas of technical disagreement, and recommendations. The report presents results of a collaborative scientific compilation and review of information: 1) primarily related to the application of hydrodynamic simulation models used to assess local and regional changes in flow direction and water velocities in Delta channels that are affected by river inflow, water project exports, and tides; 2) juvenile salmonid migration behavior including migration rate and route selection based on tracking tagged juvenile Chinook salmon and steelhead in the Delta and scientific literature from other basins; and 3) the survival of juvenile Chinook salmon and steelhead as they migrate downstream through the lower San Joaquin River and central and south regions of the Delta. The assessment of information focused primarily on the effects of water project operations on Delta hydrodynamics and juvenile salmon and steelhead migration and survival in the lower San Joaquin River and Delta. Survival data for juvenile Chinook salmon were based on results of both coded-wire tag (CWT) and AT studies. Volume 2 presents responses to eight management questions posed by CAMT. It is important to note that the review was guided by a narrow scope assigned by CAMT that was focused on specific regions within the Delta, hydrodynamic drivers, and outcomes (Volume 1, Section 1.2).

Given the limited scope, some potentially important factors were not reviewed at all or in detail due to time or resource constraints; for example: 1) fry and juvenile rearing conditions upstream of the Delta that affect juvenile growth, health, condition, size at Delta entry, and survival; 2) a broader consideration of migration and survival on the Sacramento River and changes in hydrodynamic conditions in the north Delta; 3) a broader suite of factors thought to contribute to stress and mortality within the Delta; and 4) a broader suite of potential data gaps, findings, and recommendations for actions to benefit salmonids upstream and within the Delta. These factors were considered to be outside the limited scope of this review. The SST believes that expanding the assessment of factors affecting juvenile salmonid migration behavior and survival through the Delta and any associated research will be critical to advancing our understanding of how to improve survival and salmonid population abundance.

KEY FINDINGS AND GAPS

The key findings reflect information that emerged from, or was supported by, the literature review and analysis undertaken by the SST in the course of preparing Volumes 1 and 2. Key findings were typically characterized as having a medium or high basis of knowledge and were judged by the SST as being critical to our understanding of salmon and steelhead survival in the Delta, in the context of hydrodynamic conditions and export operations. Key data gaps reflect areas within the scope of the SST's review where the basis of knowledge was typically low or minimal. The SST placed an emphasis on gaps that, if filled, would likely improve our understanding and inform our ability to more effectively manage water project operations and hydrodynamic conditions for improved salmonid survival. The methodology used to rate basis of knowledge is described in Section 2.4.

The findings and gaps below refer to juvenile Chinook salmon and steelhead migrating through the Delta (i.e., not rearing). For through-Delta survival, San Joaquin River-origin Chinook salmon (fall-run) are discussed separately from Sacramento River-origin Chinook salmon (fall-, late-fall, spring-, and winter-run) because they experience different geography and environmental conditions (including hydrology), and steelhead are discussed separately from Chinook salmon.

It is important to emphasize that while gaps exist, results of previous survival and hydrodynamic model studies have yielded important information on geographic and temporal trends in survival and how physical conditions in the Delta may change with inflow, tides, and exports. This information constitutes a substantial body of scientific information to build upon when addressing fish and water management priorities by refining and expanding the experimental design and statistical analyses of future salmonid survival studies.

THROUGH-DELTA SURVIVAL

Through-Delta survival has been consistently low for San Joaquin River Chinook salmon, and more variable for Sacramento River Chinook salmon; survival data are limited for steelhead.

SAN JOAQUIN RIVER FALL-RUN CHINOOK SALMON

Findings

- Survival has been low (less than 0.2 [i.e., less than 20%] since 2002). For example, through-Delta survival has been less than or equal to 0.05 for 14 of 22 estimates, and less than or equal to 0.10 for 20 of 22 estimates, since 2002 (Appendix E, Figure E.2-3). Prior to 2002, juvenile Chinook salmon survival rates were typically higher in high flow years (1995, 1997, 1998, and 1999).
- Since 2002, through-Delta survival has been low (less than 0.2) even in higher flow years (2006, 2011) (Appendix E, Figure E.2-3), which is not consistent with results of earlier survival studies showing evidence of increased juvenile survival as Delta inflows increased during the migration period.
- In the South Delta, survival has been low in all routes since 2008 (Appendix E, Figure E.4-3), which is not consistent with results of the majority of earlier CWT survival studies that indicated higher survival for those migrating juvenile salmon that remained in the San Joaquin River at the head of Old River when compared to those that entered Old River at that location.
- Survival from the export facilities to Chipps Island via salvage and trucking was higher from the Central Valley Project (CVP) than the State Water Project (SWP), with a primary difference being the Clifton Court Forebay (CCF) in the SWP route (Appendix E, Figure E.4-7, Table E.4-3). Although validation of the assumption of lower pre-screen losses at the CVP

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intake compared to the SWP intake is needed, these results support a recommendation for preferential export operations using the CVP intake to benefit salmonids.

- The survival rate per kilometer from the CVP to Chipps Island via salvage was sometimes higher than the survival rate through the lower San Joaquin River reaches, but was low in absolute terms.

Gaps in Information

- Many drivers for low through-Delta survival have been hypothesized, but the role of each has not been quantified. Hypothesized factors contributing to the observed low Delta survival include increased abundance and increased metabolic rate of predatory fish such as striped bass and largemouth bass in the Delta, water project operations affecting the magnitude and timing of flow resulting in increased juvenile salmonid predation mortality, changes in Delta habitat including expansion of non-native submerged aquatic vegetation, increased water clarity, potential exposure to contaminants, and other factors. The potential contribution of these factors to salmonid mortality supports a stronger focus on investigating the mechanisms underlying salmonid mortality in different regions of the Delta and their link to water project operations (see Section 3; Appendix E, Figure E.1-1, Table E.1-1).
- Collection and analysis of data on migration and survival of acoustic-tagged Chinook salmon released in the San Joaquin River is ongoing; survival estimates have been calculated through 2012. Additional data through 2016 will be compiled and analyzed to investigate various hypotheses over observed conditions such as potential relationships between flows and export rates and survival, as well as route selection and migration rate within various regions of the lower river and Delta. Other analyses can also be done and support our recommendation to continue studies and do additional data analyses and assessment. However, because these studies were observational in nature, and were not designed to test these hypotheses, the findings from such analyses will be limited and will not obviate the need for future investigations.

SACRAMENTO CHINOOK SALMON

Findings

- Survival among release groups has been variable across years and among populations. For example, in 2013 and 2014, through-Delta survival was estimated at 0.32 to 0.35 for hatchery winter-run Chinook salmon, 0.00 to 0.30 for hatchery spring-run Chinook salmon, and 0.00 for hatchery fall-run Chinook (based on data from only one release group in 2014), whereas between 2006 and 2010, late-fall-run Chinook had through-Delta survival estimates ranging from 0.17 to 0.64 (Appendix E, Section E.2.1, Table E.2-2).

Gaps in Information

- Data for some populations (e.g., winter-run, spring-run) are more limited than for other populations (e.g., late-fall-run). The majority of experimental survival studies conducted to date have been performed using hatchery-produced fall-run and late-fall-run Chinook salmon. Acoustic survival studies using hatchery-produced winter-run Chinook salmon have been initiated only in the last four years. Little information is available on survival of wild

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salmonids or on the applicability of hatchery-produced salmonids as a representative surrogate for wild stocks. Little information is currently available on the primary drivers for differences in survival between populations; however, more is being learned about the role of environmental conditions on survival, the role of route selection (e.g., mainstem versus interior Delta routes) and migration timing and behavior on survival, and other factors affecting survival of different stocks in the Sacramento River and Delta (Appendix E, Section E.2.1, Table E.2-1, Table E.2-2).

STEELHEAD

Findings

- Based on data from 2011 and 2012, survival of acoustic-tagged juvenile steelhead migrating from the San Joaquin River (0.32 to 0.54) has been greater than that of fall-run Chinook salmon from the same years (0.02 to 0.03) (Appendix E, Section E.2.1, Table E.2-3).
- Based on data from 2009 and 2010, survival of acoustic-tagged juvenile steelhead migrating from the Sacramento River (0.47 to 0.58) has been comparable to estimates of Sacramento River late-fall-run Chinook salmon survival from the same years (0.34 to 0.64) (Appendix E, Section E.2.1, Table E.2-2).

Gaps in Information

- For both San Joaquin River and Sacramento River steelhead, relatively few data are available on survival through the Delta compared to Chinook salmon (collection and analysis of San Joaquin River steelhead data is ongoing; survival estimates have been calculated for 2011 through 2012, and will be available for 2013 through 2016). Survival estimates for juvenile steelhead migrating downstream in the Sacramento River are available for several years but do not represent a wide range of environmental conditions.

FISH SIZE

Multiple lines of evidence indicate smaller fish respond to conditions differently and usually experience lower survival than larger fish.

Findings

- Studies of juvenile fishes undertaken to develop an estimate of handling and trucking mortality found that for Chinook salmon, mortality during holding and trucking was greater (2% mortality) for juvenile Chinook salmon less than 100 millimeters (mm) than for salmon greater than 100 mm (0% mortality; Appendix E, Section E.3.2.1).
- Based on CWT fall-run Chinook salmon released in the Delta, fish size was found to be a stronger indicator of ocean recovery rates than were hydrologic variables (inflow, exports), based on analyses by Zeug and Cavallo (2013) (Appendix E, Section E.6.2.1).
- In the two years with survival data for both Chinook salmon and steelhead from the San Joaquin River, the steelhead were both larger than the Chinook salmon and had higher survival; it is unclear the extent to which fish size was the primary driver of the differences in

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survival versus other variables (e.g., species) (Appendix E, Section E.2.1, Figures E.2-3 and E.2-4, Table E.2-3).

- AT studies in the Sacramento River have found higher through-Delta survival for larger fish (Appendix E, Section E.9.2.1). Perry (2010) found a significant relationship between acoustic-tagged late-fall-run Chinook salmon and survival in the Sacramento River mainstem and Sutter and Steamboat sloughs. Newman (2003) found a positive relationship between fish size and through-Delta survival for CWT fall-run Chinook salmon migrating from the Sacramento River.
- Louver efficiency experiments show a non-monotonic (i.e., not strictly increasing or strictly decreasing) relationship between Chinook salmon size and efficiency (Appendix E, Section E.3.2.1).
- Shorter through-Delta travel times of San Joaquin River fall-run Chinook salmon were observed with increasing smolt size based on CWT fish (Appendix D, Section D.4); however, despite Chinook salmon being smaller than steelhead, migration rates (e.g., kilometers per day) of acoustic-tagged Chinook salmon released into the San Joaquin River in 2011 and 2012 were approximately twice that of steelhead (Appendix D, Section D.5.2). Average travel time between Durham Ferry and Chipps Island for steelhead in 2011 (276.7 mm fork length [FL]) was 11.08 days (SE = 0.12 days) while travel time for juvenile fall-run Chinook salmon (110.8 mm FL) was 3.02 days (SE = 0.27 days). In 2012 steelhead (233.6 mm FL), travel time was 9.41 days (SE = 0.25 days) compared to juvenile salmon (112.8 mm FL) travel time of 5.75 days (SE = 0.41 days).

Gaps in Information

- Existing tagging data do not represent the full range of sizes of wild fish because of tag burden concerns (i.e., tags are too large for smaller fish).
- The survival effect of differences in salmon and steelhead size for fish reared in the hatcheries compared to wild fish is uncertain.
- Our scope focused primarily on migrating juvenile salmonids, and we did not review information on how rearing fry or parr respond to hydrodynamic factors such as water velocity (Appendix D, Section D.4).

PROJECT EFFECTS

Water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities, but direct mortality does not account for the majority of the mortality experienced in the Delta; the mechanism and magnitude of indirect effects of water project operations on Delta mortality outside the facilities is uncertain.

Findings

- Direct mortality (at the facilities) is a combination of pre-screen and within-facility mortality (including mortality during salvage and transport), and entrainment into the pumps and water conveyance canals (Appendix E, Section E.3.2.1).

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- There is a large amount of indirect evidence of predation within the facilities including pre-screen losses in CCF, within the salvage facilities, and at release sites in the Delta (Appendix E, Section E.3.2.1). Predatory fish have been observed near and within the water project facilities, and juvenile salmon and steelhead have been collected from predator stomach samples. Additional indirect evidence includes results of mark-recapture experimental studies within CCF for both salmon and steelhead, observations of predator movement and behavior from AT studies, and observations of stationary ATs in and near the facilities thought to have been defecated by predatory fish. Indirect evidence of predation mortality associated with water project facilities and elsewhere in the Delta channels supports recommendations for reducing predation; however, such reductions should be paired with actions to improve survival in the Delta upstream of the facilities, to yield substantial increases in survival through the Delta.
- Despite implementing actions within the reasonable and prudent alternative (RPA) intended to reduce through-Delta mortality, through-Delta survival remains low (Appendix E, Section E.2, Figure E.2-3, Tables E.2-2 and E.2-3).
- Hydrodynamic monitoring and simulation modeling indicate that exports have the greatest effect on flow and velocity in the region of the Delta nearest the export facilities (Appendix B, Section B.5).
- Results of studies show that route selection is generally proportional to the flow split at channel junctions, and the effect of exports on route selection is strongest at the junction leading directly to the export facilities (i.e., head of Old River). Results of juvenile Chinook salmon survival studies using CWT and more recently (2008, 2010, 2011, and 2012) ATs have not shown a strong or consistent relationship with SWP and CVP export rates. Steelhead data are limited to only 2011 and 2012; additional data through 2016 are being analyzed for both salmon and steelhead. Survival rates for juvenile salmon since 2002 have been consistently low independent of variation in both export rates and Delta inflows.

Gaps in Information

- Additional analyses are needed to investigate the expected change in salmonid route selection and subsequent survival from changes in export rates (Appendix D, Section D.8).
- The evidence of a relationship between exports and through-Delta survival is inconclusive; the key findings presented in this table are supported by medium or high basis of knowledge, but our basis of knowledge on the relationship between exports and through-Delta survival is low (Appendix E, Section E.6.2.1). Since 2002, juvenile fall-run Chinook salmon survival in the south Delta has been consistently low despite restriction of export rates. Survival rates for acoustic-tagged juvenile steelhead are currently available only for two years (2011 and 2012), which are insufficient to support an analysis of the potential relationship between export rate and survival. Analysis of additional AT data for 2013 through 2016 will help further assess potential relationships for both salmon and steelhead.

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- Estimates of entrainment mortality at the export facilities from salvage counts depend on pre-screen mortality, but data on the magnitude and variability of pre-screen mortality are unavailable at the CVP (Appendix E, Section E.3.2.1).
- There is uncertainty in the spatial and temporal variability in predation pressure and how predation pressure responds to changes in water project operations and associated habitat changes (Appendix E, Sections E.3.2, E.3.3, E.4.2.5, and E.4.3). Based on current AT technology, it is difficult to determine when, where, and if a juvenile salmonid has been preyed on within a reach of the Delta. How water project operations affect Delta flows and velocities, physical structures, and habitat conditions that in turn affect both predators and prey warrants further investigation.
- The contribution of water project operations to the total mortality of juvenile salmonids has not been quantified. Many of the mechanisms through which changes in Delta hydrodynamics and other factors related to water project operations may contribute to salmonid mortality (e.g., change in vulnerability to predation in Delta channels or change in migration routing as a result of water project operations) are uncertain.
- Estimates of direct mortality (e.g., mortality resulting from pre-screen losses and losses at the louver and salvage facilities, which are directly related to water project export operations) have been developed from CWT data by several authors and show, in general, that the magnitude of direct loss (e.g., percentage of a marked release group observed in fish salvage) is typically low for juvenile Chinook salmon (typically less than approximately 1%). However, such estimates do not include export-induced mortality prior to entering the facilities that is indirectly related to water project operations (e.g., mortality resulting from project related changes in habitat). Estimates of direct facility mortality as a proportion of total migration mortality have been as high as 5.5% for winter-run Chinook salmon and 17.5% for Chinook salmon released in the San Joaquin River (Zeug and Cavallo 2014).
- It is unknown whether equivocal findings regarding the existence and nature of a relationship between exports and through-Delta survival is due to the lack of a relationship, the concurrent and confounding influence of other variables, or the effect of low overall survival in recent years. These data gaps support a recommendation for further analysis of available data, as well as additional investigations to test hypotheses regarding export effects on migration and survival of Sacramento and San Joaquin River origin salmonids migrating through the Delta.

PHYSICAL CONDITIONS

The Delta is a complex and dynamic environment, and the relative influence of tides, inflow, and exports on hydrodynamic conditions (flow and velocity) varies temporally and spatially throughout the Delta. Project operations affect physical conditions in the Delta through various ways including Delta inflows, exports, and gate and barrier operations.

Findings

- The major rivers in the South Delta (San Joaquin, Old, and Middle) transition from a riverine environment to a tidally dominated environment in the Delta (Appendix B, Figure B.1-2).
- The hydrodynamic effect of increases in Delta inflow on flow and velocity in the South Delta is greatest at the upstream reaches of the major rivers, diminishes with distance downstream through the Delta or away from the mainstem rivers (i.e., into the interior Delta), and is affected by barriers, tidal phase, and exports (Appendix B, Figures B.5-1 through B.5-7 and B.5-13 through B.5-17).
- The hydrodynamic effect of exports on flow and velocity in the South Delta is strongest in Old River at the export facilities, in Middle River at Victoria Canal and the downstream end of Railroad Cut, and at Columbia Cut, and is affected by tidal phase, Delta inflow, and barriers (Appendix B, Figures B.5-1 through B.5-8 and B.5-13 through B.5-17).
- The effect of tides decreases with distance up mainstem rivers, and the tidally dominated region varies with Delta inflow, exports, and tidal phase (Appendix B, Figures B.5-1 through B.5-7).
- Hydrodynamic models were developed for water project planning and have typically been used for long time scales (e.g., daily) and large geographic areas (e.g., San Joaquin River flow routing).
- The application of current hydrodynamic simulation models to predictions of flow and velocity at South Delta channel junctions when encountered by migrating salmonids at specific times (i.e., on short time scales and small geographic areas) may not be reliable (Appendix B, Section B.3; Appendix C, Pages C-14 through C-163).
- The Delta Simulation Model 2 (DSM2) may be useful for assessing how exports from the South Delta, river inflows, barriers, and tides can influence the magnitude, duration, and direction of water velocities and flows within channels, depending on its accuracy relative to validation for specific areas and time scales. However, 15-minute velocities and flows estimated from DSM2 have been found to vary substantially from measured conditions and timing related to tidal conditions (Appendix C, Pages C-14 through C-231) and were not found to be accurate for assessing fish fates and behaviors at specific times and locations which would require direct measurement of flows in the field, or the application of simulation models depending on the temporal and spatial resolution needed to support analyses of specific hypotheses or management questions.
- Model validation analysis conducted for this report concluded that: 1) some locations of the South Delta validate better than others; 2) validation quality at Turner Cut varied over a period of several years; 3) validation at high inflows was poorer than at lower inflows; 4) validation was better at the daily average time step compared to the 15-minute instantaneous time step; and 5) validation using RMA 2-D was better than DSM2 on average (Appendix B, Sections B.3.1.5 and B.3.1.6; Appendix C, Pages C-14 through C-163).

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- The application of hydrodynamic models to fish behavior requires calibration and validation at appropriate temporal and spatial scales (Appendix B, Section B.3; Appendix C, Pages C-14 through C-163).
- Results of limited analysis of AT data indicate that juvenile Chinook salmon migration rate slowed in areas of the Delta with bi-directional tidal velocity compared to upstream riverine reaches with uni-directional flows (Appendix D, Section D.6). No analyses were found on a potential relationship between water project exports and juvenile salmonid migration rates within the Delta, although data are available from recent AT studies that could be used to test hypotheses related to effects of riverine flow and export rates on reach-specific migration rates.

Gaps in Information

- Model calibration and validation can be limited by insufficient data on factors such as: 1) Delta Consumptive Use; 2) South Delta bathymetry; 3) Clifton Court inflow; and 4) monitoring station calibration.
- Further model refinements and validation are needed at temporal and spatial scales appropriate for use in analysis of salmonid migration.
- The magnitude of change in flow, water velocity, or water quality needed to elicit a behavioral or survival response by migrating juvenile salmonids has not been determined.
- The specific behavioral mechanisms underlying the slowing of migration rates in tidally influenced areas are uncertain. Selective tidal surfing behavior has been hypothesized as a mechanism supporting juvenile salmonid migration through the tidal region of the Delta, but requires further analysis and investigation (Appendix D, Section D.6).

MANAGEMENT ACTIONS

- **Gates and barriers influence fish routing away from specific migration corridors.**
- **The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.**
- **The extent to which management actions such as reduced negative Old and Middle River (OMR) reverse flows, ratio of San Joaquin River inflow to exports (I:E), and ratio of exports to Delta inflow (E:I) affect through-Delta survival is uncertain.**

FINDINGS

General

- Spatial variability in the relative influence of Delta inflow and exports on hydrodynamic conditions means that high inflow or I:E, and low exports or E:I, may differentially affect fish routing and survival in different Delta regions (Appendix B, Section B.5; Appendix E, Sections E.6 and E.2.3).

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- Uncertainty in the relationships between I:E, E:I, and OMR reverse flows and through-Delta survival may be caused by the concurrent and confounding influence of correlated variables, overall low survival, and low power to detect differences (Appendix E, Section E.2.3).
- Juvenile salmonid migration rates tend to be higher in the riverine reaches and lower in the tidal reaches (Appendix D, Sections D.3. and D.6; Appendix E, Section E.5, Figure E.5-1).

San Joaquin River

- Barriers: A barrier at the head of Old River reduces steelhead and Chinook salmon entrainment into the heads of OMR migration corridors. Historically, through-Delta survival of CWT juvenile fall-run Chinook salmon was estimated to be higher for those salmon using the San Joaquin River migration corridor, indicating, on average, a survival benefit associated with the spring installation of the Head of Old River Barrier (HORB); however, data from recent (2010 through 2012) AT studies have shown that survival has been equally low through all routes for Chinook salmon (Appendix D, Section D.11; Appendix E, Section E.4.2.1). The mechanisms affecting changes in juvenile survival among south Delta migration routes and factors that may have changed that earlier relationship in recent years remain uncertain and warrant further investigation.
- Inflow: Higher Delta inflow from the San Joaquin River is associated with increased survival in the San Joaquin River to Jersey Point when the HORB is in place; however, under low-flow conditions survival can be low even with the barrier in place (Appendix E, Section E.8, Figure E.8-2).
- Inflow: Higher San Joaquin River flow is associated with higher Chinook salmon survival to the Turner Cut junction but the effect does not always result in higher through-Delta survival because of mortality in downstream reaches (Appendix E, Section E.8, Figure E.8-1).
- I:E: The relationship between Delta survival of San Joaquin River Chinook salmon and I:E is variable but generally positive for lower I:E values (e.g., I:E less than 3) (Appendix E, Section E.11, Figure E.11-1). Results of these studies are confounded by the use of flow ratios since the same I:E ratio can represent different absolute flow and export rates. These results are further confounded by installation and operations of various South Delta barriers. Data are available from only two years of AT studies using steelhead (Appendix E, Section E.11-4).
- Exports: There was a weak positive association between the through-Delta survival of San Joaquin Chinook salmon and combined exports using the CWT data set, but comparisons are complicated by the correlation between exports and San Joaquin River inflow (Appendix E, Section E.6.2.1).

Sacramento River

- Gates: Closure of the Delta Cross Channel (DCC) gates can increase through-Delta survival by reducing the risk of juvenile salmonids migrating into the interior Delta from the Sacramento

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River; however, on flood tides at low flows, similar numbers of salmon can be diverted into the interior Delta through Georgiana Slough alone (Appendix D, Section D.12).

- Inflow: Increased Delta inflow from the Sacramento River is associated with increased through-Delta survival for Chinook salmon migrating from the Sacramento River (Appendix E, Section E.9.2.1).
- E:I: Statistical analyses suggest a weak but generally negative effect of increased E:I on survival of Sacramento River fall-run Chinook salmon, but not for late-fall-run Chinook salmon (Appendix E, Section E.10). Survival data are not available to assess potential relationships between E:I and survival for winter-run or spring-run Chinook salmon or steelhead. Uncertainty in the relationship between E:I and survival may be caused by the confounding influence of correlated variables and low power to detect differences (Appendix E, Section E.2.3).

GAPS IN INFORMATION

General

- The effects of OMR reverse flows on salmonid survival and route selection in the Delta (outside of the facilities) have had limited analysis. Data are available from the AT migration and survival studies, as well as earlier CWT data, that might be used in analyses of potential relationships between OMR reverse flows and juvenile salmonid survival. Relationships between OMR reverse flows and migration route and migration rate, as well as reach-specific and regional survival, could be tested using AT data from both Chinook salmon and steelhead.
- The relationships between water project operations and survival on various spatial and temporal scales are poorly understood. The detailed information generated from the recent salmon and steelhead AT studies, in combination with refinements in the application of hydrodynamic simulation models to fishery analyses in the Delta, offers the opportunity to conduct additional analyses at a finer spatial and temporal resolution than before; however, more data will be needed to understand patterns over a variety of conditions.

San Joaquin River

- Results of early CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River downstream of Old River, and into Old River, showed evidence of higher survival to Jersey Point for those fish that migrated downstream in the San Joaquin River mainstem compared to fish migrating through Old River. Results of limited AT data from 2010 to 2012 showed evidence of equally low survival independent of route selection at the head of Old River. Reach-specific survival estimates with the HORB in place are available only for one year (2012) for both fall-run Chinook salmon and steelhead, although more recent data from 2014 to 2016 (all with the HORB in place for Chinook salmon and some of the steelhead releases) have yet to be analyzed. Further analysis of the available AT data and additional experimental studies to examine the mechanisms affecting juvenile

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- **Gates and barriers influence fish routing away from specific migration corridors.**
- **The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.**
- **The extent to which management actions such as reduced negative Old and Middle River (OMR) reverse flows, ratio of San Joaquin River inflow to exports (I:E), and ratio of exports to Delta inflow (E:I) affect through-Delta survival is uncertain.**

salmon and steelhead survival for those fish migrating downstream in the San Joaquin River mainstem and those entering Old River are needed to assess the potential biological benefits of influencing migration route selection through installation of the HORB in South Delta channels.

- Because few observations of salmon migration survival are available for higher I:E values (e.g., I:E greater than 5), higher San Joaquin River inflow levels (e.g., Vernalis inflow greater than 10,000 cubic feet per second [cfs]), and higher export levels (e.g., combined export rate greater than 5,000 cfs), the variability in survival under these higher levels of I:E, inflow, and exports is not well-characterized (Appendix E, Sections E.2.3 and E.11).
- Exports: Data on potential relationships between San Joaquin River inflow and exports on migration and survival of acoustically tagged juvenile salmon and steelhead are limited to just a few years and environmental conditions; therefore, firm conclusions cannot be made from the AT data sets for San Joaquin Chinook salmon or steelhead (Appendix E, Section E.6.2.1).

CONSTRAINTS ON UNDERSTANDING

Current understanding of juvenile salmon and steelhead survival in the Delta is constrained by a variety of factors (as listed below).

Findings

- The nature of the I:E and E:I metrics as ratios makes it challenging to test their effects, since different sets of physical conditions may be represented with the same I:E or E:I value (e.g., both high and low inflow conditions may be associated with the same I:E value, depending on exports).
- Determining the effectiveness of management operations such as I:E, E:I, and OMR reverse flow restrictions is difficult when all observations are in the presence of those restrictions (i.e., there is no control condition to compare to the experimental condition) (Appendix E, Section E.13). Development of future experimental designs would need to consider increased operational flexibility and/or alternative approaches to the experimental design to test a range of prescribed water project operational conditions.
- There has been low variability and little replication in conditions during recent tagging studies, in particular San Joaquin River inflow and exports. Most observations of smolt survival have been at low levels of both inflow and exports, in part as a result of recent drought conditions. Furthermore, it is not possible to test the effects of changes in conditions in the absence of variability in those conditions (Appendix E, Section E.2.3). Developing the future experimental design for salmonid monitoring would need to consider prescribing flow and export conditions extending over a wide enough range to detect biological responses if such relationships exist.

CONSTRAINTS ON UNDERSTANDING

Current understanding of juvenile salmon and steelhead survival in the Delta is constrained by a variety of factors (as listed below).

- Low overall survival makes it difficult to detect changes in survival, both in general and in response to changes in management operations (Appendix E, Section E.13).
- Hydrodynamic models are developed and calibrated for specific locations, time periods and time scales, and study questions; application of simulation models for other uses (e.g., using the reviewed models in the South Delta or on the scale of fish response) is dependent, in part, on the specific hypotheses and management questions being evaluated and the resolution and accuracy needed in model predictions to support the analysis (Appendix B, Section B.3).
- Disparity between current hydrodynamic models and measurements of hydrodynamics data (flow and velocity) at key locations in the Delta (e.g., Turner Cut, Frank's Tract) limits our ability to detect patterns between changes in velocities and flows and changes in salmon survival and behavior from AT observations (Appendix C, Figures 18 through 20 and 24 through 29). Further model calibration and validation and refinements to model parameters is expected to advance the application of these models in support of fishery analyses.
- Salmon likely respond to changes in water velocities rather than to changes in flow, but hydrodynamic modeling results show larger disparities between modeled and measured conditions for velocity than for flow (Appendix C, Pages C-14 through C-163).

Gaps in Information

- Understanding the effects of water project operations on route selection and through-Delta survival of juvenile salmonids may require additional statistical analysis of route-specific survival, hydrodynamics, habitat complexity, and environmental variability. Completing the analysis of AT data through 2016 will provide the foundation for more statistical analyses using multivariate approaches involving a number of physical and biological covariates for hypothesis testing.
- Modeling of the potential biological response of particular water project operation actions has not been done (hypothetical examples of measurable objectives include: reduce migration into the Interior Delta through Turner Cut by 50%, increase juvenile survival in the South Delta to an average of 30%), which limits our ability to make short-term action recommendations that are predicted to achieve a specific biological objective and to evaluate the performance of the action in achieving the desired effect.
- Further analysis is needed to assess which hydrodynamic models best represent observed hydrodynamic or water quality changes caused by water operation decisions or other management actions, on the scale of fish perception and response; the calibration and validation of the appropriate spatial and temporal scales for biological application needs additional refinement.
- Several potential problems (gaps) have been identified in the literature relative to hydrodynamic model calibration in the South Delta, including representation of the CCF operations, South Delta bathymetry data, Delta Island Consumptive Use data, high inflow conditions, and challenges associated with estimating Delta outflow. Further refinement of hydrodynamic simulation models and their application to assessing salmonid migration and survival will improve the technical foundation for evaluation of the performance of management actions.

TECHNICAL DISAGREEMENTS

SST members agree with the key findings and gaps presented in the tables above. Technical disagreements about the characterization of information are identified in Volumes 1 and 2 and are summarized below.

Volume 1

- There was not consensus in the SST regarding the definition and application of the basis of knowledge. The basis of knowledge review rated peer-reviewed publications higher than agency or contract reports. While the assumption was made that peer-reviewed articles have more robust information, it was noted that agency reports and peer-reviewed articles can have varying degrees of robustness, the assumption is not likely true for all peer reviewed articles, and agency reports can also be peer reviewed. Furthermore, agency reports may provide better and more specific information relative to the questions we are asking and this is not reflected in the basis of knowledge definition or applications. At least one SST member felt that similar results from multiple agency reports should be rated higher than a medium basis of knowledge. Despite differences in the interpretation of weighting to be given to various sources of information among the SST, the body of scientific information available, including agency reports, peer-reviewed journal publications, discussions with technical experts, and data analyses prepared by the SST as part of preparing the gap analysis, were all used in developing findings and recommendations presented in this report.
- There was a disagreement within the SST about whether the analysis of ocean recovery rates of CWT fish (i.e., the Zeug and Cavallo [2013] analysis) is informative for Delta survival because ocean recovery rates combine Delta survival with ocean survival and incorporate assumptions about fishing effort between years. Some SST members believe that the joint probability of Delta survival and ocean survival is pertinent, although not conclusive, to Delta survival (Appendix E, Section E.6.2).
- There was disagreement within the SST about whether there is a relationship between exports and the relative survival associated with the Interior Delta route compared to the Sacramento River mainstem route, based on modeling by Newman and Brandes (2010). Some SST members believe that, despite the indeterminacy in model selection, a potential effect of exports was demonstrated (Appendix E, Section E.6.2.1). The disagreement was based, in part, on model selection that identified that relative Interior Delta survival was similarly predicted with models that did not include exports, based on the low samples sizes available.
- There was a disagreement within the SST about providing short-term recommendations for actions to improve salmonid survival at this time, noting that no modeling or analysis has been conducted to assess potential benefits to salmon or steelhead from these actions and that a more systematic process of evaluation of alternatives and priorities should precede any recommendations for actions. Some on the SST felt that the prolonged low levels of juvenile salmon survival in the South Delta warrant immediate action.

Volume 2

- There was a disagreement within the SST over whether the data provided in Volume 2 support the conclusion that improved protection of Sacramento River salmonid populations would result if the onset date of OMR reverse flow management were triggered by detection of migrants at monitoring stations located on the Sacramento River upstream of distributary junctions leading toward the San Joaquin River. Results of salmonid monitoring in the Sacramento River and San Joaquin River have shown that the seasonal timing of Delta entry for juvenile Endangered Species Act (ESA)-listed salmonids varies among years. The January 1 onset of OMR flow management coincides with the presence of winter-run Chinook salmon in most years, spring-run Chinook salmon in many years, and steelhead in some years. Some SST members conclude that although not capturing all of the seasonal variation in juvenile movement, the January 1 trigger date provides a general approximation of the migration timing during the winter months, and, based on its simplicity for triggering management actions, has utility (Management Question 3).
- In Volume 2, there is a statement that limiting OMR reverse flow to -5,000 cfs is effective at preventing increased routing into the Interior Delta, presumably resulting in increased survival. There was a disagreement over whether the data provided in Volumes 1 or 2 supported such a statement. Some felt the discussion and conclusion was based primarily on conceptual model predictions and reasoning, not on factual analysis (Management Question 3).
- There was a disagreement within the SST about the statement that short-term restrictions of exports resulting in OMR reverse flows more positive than the -5,000 cfs may do little to improve through-Delta survival for Chinook salmon due to low overall survival. The disagreement was that, since we have no evidence of the effects of OMR reverse flow restrictions on survival, we have no evidence that the continued OMR reverse flow restrictions will affect survival (Management Question 4).
- There was a disagreement within the SST about presenting the hypothesis that the influence of exports on habitat may have a stronger effect on survival than that of short-term hydrodynamic changes related to exports, since the argument is based on reasoning and not data analysis (Management Question 4).
- There was a disagreement within the SST about whether Passive Integrated Transponder (PIT) tags, which have been used extensively in salmonid studies in river systems such as the Columbia River, could expand the available evaluation methodologies; some members believe that, as a result of difficulties in PIT tag detection in larger channels (the PIT tag needs to be in close proximity to the detector to be read), the technology will not provide any better information than is currently available through existing methodologies. Therefore, there was disagreement over whether to recommend that PIT tag technologies be applied to the Delta to facilitate monitoring of biological metrics. The selection and application of specific technologies in future investigations will need to be based, in part, on the nature of the investigation, specific data needs, detection ability, and other factors (Management Question 6).

- There were no areas of formal scientific disagreement among SST members regarding the use of surrogates; however, there is disagreement among scientists in general about the usefulness of performing surrogacy comparisons in situations where only some of the pertinent types of surrogacy can be evaluated. Seven common positions on the use of surrogates are identified (Management Question 8).

RECOMMENDATIONS

The SST has identified the following recommendations for the CAMT to consider. The recommendations provide guidance on how future investigation and research efforts could be focused to build on the existing knowledge base and address key data gaps. They were developed to advance our understanding of the role of factors influencing salmonid survival through the Delta, the role of Delta conditions in salmonid fitness at the individual and population level, and opportunities to improve salmonid population abundance and status through changes to Delta conditions and water project operations.

The recommendations are informed by several overarching observations, as follows:

- The Delta is a very complicated environment in which to study and measure juvenile salmonid survival.
- While much information has been gained using the current approach, numerous key questions remain unresolved and will require new analyses and experimental approaches.
- The Delta should be perceived not as a singular region, but a suite of regions defined by different physical forcing factors. The regions are areas dominated by natural and water project inflow (upper San Joaquin River mainstem), tidal conditions (lower San Joaquin River mainstem and Delta), and exports (South Delta). Results of South Delta survival studies using juvenile Chinook salmon have shown consistently low survival over the past decade. Resolving the low observed juvenile salmonid survival may require different approaches for each region that would be integrated into a single program.
- Resolving the low survival should shift from questions developed by researchers to ones that simultaneously integrate three components: science (what can be tested), management (what needs to be tested), and operations (what can be put into place for testing). This shift in approach would support both observational studies and needed controlled experiments.
- Answering key survival and water project operation questions in the Delta is challenging, and future decisions will have to be made in the face of scientific uncertainty. Therefore, decision-support tools also need to be developed that help characterize risk and uncertainty for managers.

Continue Existing Survival Studies, Monitoring, and Analysis of Data

Discussion: The purpose of this recommendation is to continue and complete the existing analyses of route entrainment, reach survival, predation investigations, and salvage that are under way. Ongoing studies might be adapted as a long-term monitoring and adaptive management plan is developed and implemented. They are needed to provide a foundation for an expanded research program, generate information, and inform near-term management decisions, and complete ongoing research studies to maintain time series information.

Schedule: Ongoing
Management Application: Current studies provide information about through-Delta survival of Chinook salmon and steelhead, and some estimates of reach-specific survival and junction-specific routing under potentially different (but usually not controlled) inflow and export conditions. Continuing to estimate through-Delta survival will provide continuity for time series data needed to assess current status, interannual variability, and long-term trends. Ongoing research on predation is critical to identifying relationships between predator and juvenile behavior, and predator concentrations.

Investigate Short-Term Actions To Improve Salvage Facility Operations

Discussion: The purpose of this recommendation is to determine whether current operations and salvage facilities at the SWP and CVP could be improved to reduce losses to listed and non-listed salmonids entrained into the facilities. The SST understands that a great deal of effort has been directed toward improving the facilities, and facility experts would need to be involved in any future discussions. Suggestions for actions to reduce direct facility mortality based on findings in Appendix E, Section E.3.2.2 include:

- Control predator populations in CCF and behind the CVP trash racks.
- Control secondary louver efficiency by control of bypass water velocities.
- Keep primary and secondary louvers free from debris, but also reduce time when they are inoperable for cleaning.
- Improve salmon passage within the CVP, and decrease predator passage within the CVP.
- Consider alternate truck release locations of salvaged fish to prevent large predator assemblages.
- Verify the assumption that pre-screen losses at the CVP intake are 15% and substantially lower than losses at the SWP.
- Test using the CVP for export instead of the SWP to reduce losses of salmonids in CCF.

Additional suggestions include:

- Test how different CCF radial gate openings affect water inlet velocities and fish entrainment; determine whether water velocity thresholds for entrainment at the gate entrances can be identified based on literature reviews, model studies, and empirical testing; and, if new operations are identified, evaluate whether survival is increased.
- Evaluate filling the scour hole inside the CCF radial gates to reduce predator habitat and predation.
- Review the fish facilities design criteria and compare them to current state and federal design criteria; adjust facility operations or modify facilities to meet the current state and federal criteria if possible. For example, install flow control structures behind CVP louvers to improve efficiency during low export volume operations.
- Review past studies and evaluate whether new fish truck transport release operations, such as the use of net pens and barges, would be effective in reducing post-release mortality.

Schedule: Ongoing

Management Application: The goal of these actions is to reduce the proportion of fish entrained into water project facilities, reduce losses to fish that are entrained within the facilities, and enhance the survival of fish salvaged by improving truck transport and release operations. To the extent possible, responses (e.g., entrainment, mortality) should be measured before and after any modification is implemented to document the effectiveness of the modification.

Develop a Long-term Monitoring, Research, and Adaptive Management Plan

Discussion: A long-term monitoring, research, and adaptive management plan with stable and reliable funding for implementation is needed to fully assess the effects of water project operations and other Delta management actions. It is envisioned that this plan would need to be implemented for a period of at least 15 years. It should be based on monitoring, modeling, and direct manipulation of factors of interest. It will require a policy commitment to a range of management actions to be tested, agreement among managers and scientists of the level of precision needed to determine study success, and agreement that operations needed for the experimental conditions being tested can be achieved. The plan should augment and expand the scope of current studies in terms of the breadth, depth and number of analyses, monitoring studies, and experiments conducted.

The SST believes that studies that focus on causal mechanisms at appropriate time and space scales are an important approach, especially regarding understanding how fish behavior responds to local conditions.

Development of a long-term plan as envisioned here would require a number of discussions among research scientists and managers and may require a multi-pronged focus on water project operations, Delta habitat conditions, predation, and other stressors thought to contribute to the low survival observed over the past decade. Although there are a number of potential approaches to developing the long-term plan, one approach to consider would be an integrated (physical and biological) approach to monitoring and modeling, and the manipulation of treatment conditions (e.g., flow, exports, I:E ratios) within certain reaches and over specific time scales. Integration across technical disciplines (biologists, hydrodynamics experts, physical and biological modelers, and biometricians) and methods (fish tagging and modeling) would continue and expand. The plan would incorporate new information in an adaptive manner, where information gathered at one stage of the process is incorporated into the following action (i.e., data gathering or analysis, model development, or system manipulation), and the action is then adjusted based on the new information. Consideration should also be given to integrating the long-term plan with other smelt, salmon, and water management programs in the Delta and Central Valley.

Schedule: 3 to 5 years

Management Application: The long-term monitoring, research, and adaptive management plan would be used to assess the RPA actions and underlying mechanisms related to the influence of water project operations on salmonid population viability. Results of monitoring would also be applied to better understand the importance of other potential limiting factors on migration and survival of juvenile salmonids in the Delta. It would also be used to inform a broader suite of actions intended to improve juvenile salmon survival in the Delta and population productivity.

Implement the Long-term Monitoring, Research, and Adaptive Management Plan

Discussion: Implementing the long-term plan will involve conducting the analyses, monitoring, and research identified during plan development (and thereafter) to evaluate key questions and hypotheses in a methodical manner, adaptively applying the information to management actions, and developing decision-support tools for managers that help characterize uncertainty and risk. Plan implementation should emphasize timely synthesis of research and monitoring, and publishing in peer-reviewed journals. Implementing the long-term plan is needed to develop the information necessary to assess how existing water project operations directly and indirectly affect the survival of listed and non-listed salmonids in the Delta. In addition, a statistically robust, long-term program designed to investigate the underlying mechanisms affecting salmonid survival will improve the scientific basis for identifying new water project operations. It is envisioned that this plan would need to be implemented for a period of at least 15 years.

Schedule: 15+ years

Management Application: Implementation of the long-term monitoring, research, and adaptive management plan will allow water project operations to be assessed. It will reduce uncertainty, potentially identify the incremental role water projects operations have on salmonid survival through the Delta, and potentially lead to adjustments to water project operations that improve survival beyond the current levels. Information gained through implementing the long-term plan could be integrated with, and incorporated into, decision support tools used to better manage the system. It is envisioned that the long-term plan will be integrated with other major monitoring programs in the Central Valley.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABBREVIATION	DEFINITION
1-D	one-dimensional, typically applied to hydrodynamic simulation models
2-D	two-dimensional, typically applied to hydrodynamic simulation models
3-D	three-dimensional, typically applied to hydrodynamic simulation models
ADCP	Acoustic Doppler Current Profiler
AT	acoustic tag
BAFF	Bio-Acoustic Fish Fence
BBID	Byron Bethany Irrigation District
BiOp	NMFS 2009 Biological and Conference Opinion for the Long-Term Operations of the Central Valley Project and State Water Project
CAMT	Collaborative Adaptive Management Team
CCF	Clifton Court Forebay
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CRR	cohort replacement rates
CVP	Central Valley Project
CWT	coded-wire tag
DCC	Delta Cross Channel
Delta	Sacramento-San Joaquin River Delta
DLO	Driver-Linkage-Outcome
DRR	differential recovery rates
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
E:I	ratio of exports to inflow
ESA	Endangered Species Act
FL	fork length
ft/sec	feet per second
HORB	Head of Old River Barrier
I:E	ratio of inflow to exports
IOS	Interactive Object-oriented Salmon Simulation model
JPE	juvenile production estimate
MWD	Metropolitan Water District
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
OBAN	Oncorhynchus Bayesian Analysis model
OMR	Old and Middle River

LIST OF ACRONYMS AND ABBREVIATIONS

ABBREVIATION	DEFINITION
PIT	Passive Integrated Transponder
PVA	population viability analyses
RMA	Resource Management Associates
RPA	reasonable and prudent alternative
SalSIM	San Joaquin Salmon Life Cycle Model
SAR	smolt to adult ratios
SDWSC	Stockton Deepwater Ship Canal
SST	Salmonid Scoping Team
SWC	State Water Contractors
SWP	State Water Project
SWRCB	State Water Resources Control Board
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
VAMP	Vernalis Adaptive Management Plan
WWD	Westlands Water District

1.0 INTRODUCTION

This report provides a synthesis of technical information regarding juvenile salmonid migration and survival in the Sacramento-San Joaquin River Delta (Delta) specifically related to operations of the State Water Project (SWP) and Central Valley Project (CVP) (Figure 1-1). For purposes of this report the Interior Delta has been defined as waters in the Delta that are outside the mainstems of the Sacramento River and San Joaquin River. We define South Delta as the San Joaquin River and channels west and south of the San Joaquin River. The report provides a review of available information, identifies gaps in existing knowledge, and provides recommendations for future actions. Volume 2 of the report addresses eight specific management questions identified by the Collaborative Adaptive Management Team (CAMT). Background information on the Delta and water project operations is presented in Appendix A. Detailed information on Delta hydrodynamics and hydrodynamic simulation models, salmonid migration behavior and survival is presented in Appendices B through E.

1.1 PURPOSE

Information provided in this report is intended to inform policy and management decisions, including future California Environmental Quality Act (CEQA)/National Environmental Policy Act (NEPA) analyses, biological assessments, and biological opinions related to water project operations in the South Delta. The report is also intended to provide CAMT and others with a technical basis for prioritizing future investigations of salmonid behavior and survival in the Delta.

1.2 SCOPE

Several factors have been hypothesized to influence the survival rates and dynamics of Central Valley Chinook salmon and steelhead populations. Some factors are directly related to water project operations such as entrainment at the salvage facilities. Some factors are indirectly related to water operations such as changes in migration route or migration rate in response to changes in water velocity or flow that result in an increased risk of predation. Other factors are completely independent of water project operations.

The scope of this investigation, as determined by CAMT, was to focus narrowly on the effects of SWP and CVP operations on salmonid migration and survival in the Delta. Water project operations considered include inflow into the Delta, exports from the Delta, temporary agricultural barriers, Delta Cross Channel (DCC) gate operations, and Head of Old River Barrier (HORB).

The primary geographic focus was on the Sacramento-San Joaquin Delta south of the San Joaquin River. The geographic scope also included those pathways and export-related facilities that provide access for Sacramento River salmonids into the Central and South Delta, primarily the DCC and Georgiana Slough.

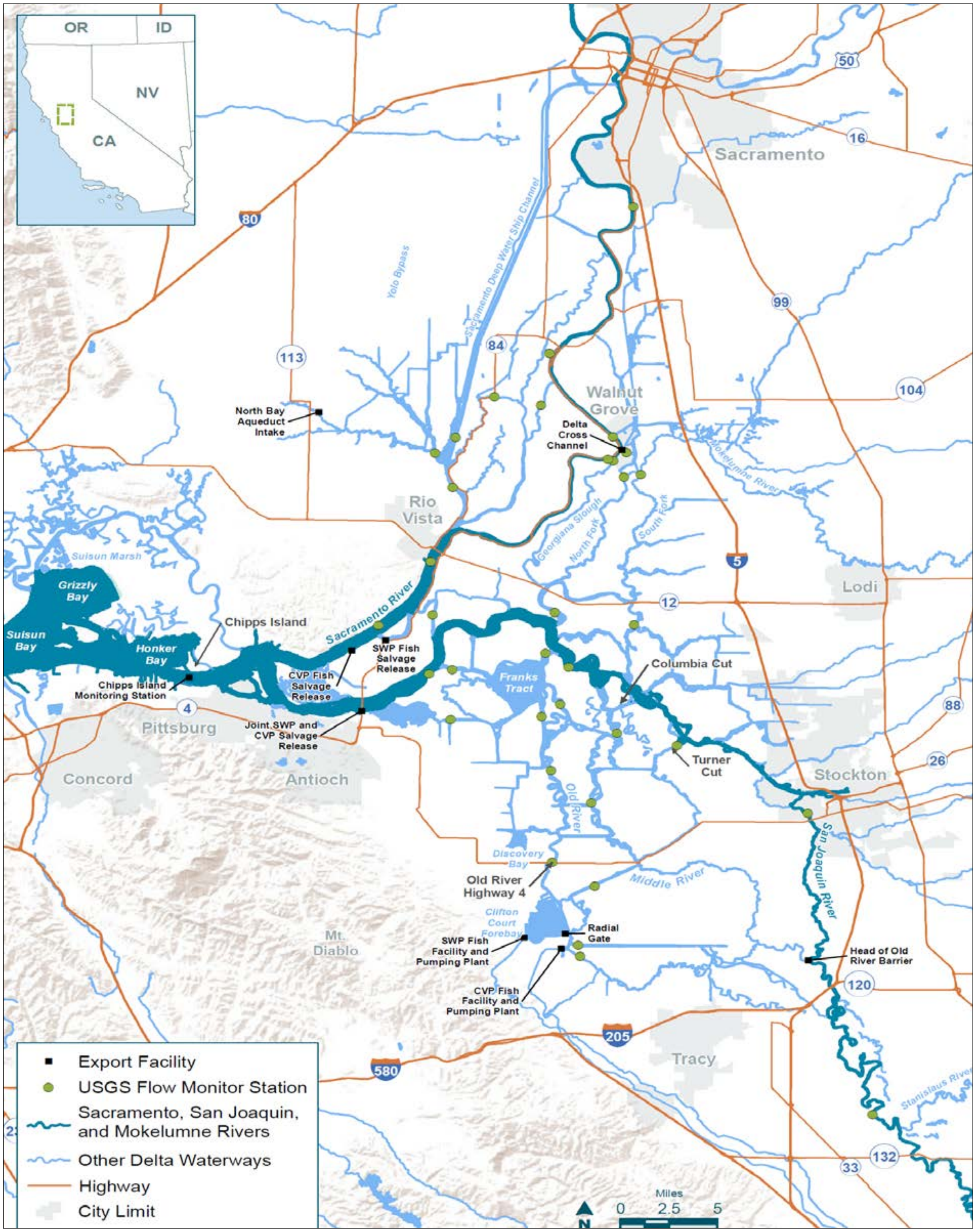


Figure 1-1. Map of the Sacramento-San Joaquin River Delta

Many factors affecting salmonid survival are outside of the scope of this analysis. The fact that these factors are not included in the analysis should not be interpreted to mean that they are not vitally important to salmonid survival, spatial distribution, productivity or abundance. Nor should this fact be interpreted to mean that the effect of these factors on survival may not be influenced by water project operations. The Salmonid Scoping Team (SST) endorses and recommends that further consideration be given to these other project- and non-project-related factors that affect salmonid population viability.

For example, it has been hypothesized that a substantial proportion of the juvenile mortality in the Delta is the result of predation, especially inside and near the water project facilities (Clark et al. 2009), but mechanistic linkages between water project operations and conditions supporting high predation in other areas of the Delta are largely unknown. In addition, there are potential linkages between water project operations (e.g., barrier installations) and outcomes such as habitat quality, growth, and life history diversity. Similarly, factors such as riverine and Delta inflows, and habitat quality and habitat availability on the size, timing, distribution and physical condition of juvenile salmon and steelhead entering the Delta have the potential to influence the likelihood of outcomes related to potential effects of water project operation related drivers on migration behavior or survival. Water project operations resulting in changes in velocity or flow direction could affect habitat conditions in the Delta, resulting in increased mortality in some migration pathways and/or reduced growth, which could result in reduced survival of juvenile salmon at ocean entry.

The potential effects of water project operations in the Delta on reduced growth or altered migration timing that influence subsequent survival of juveniles (e.g., in the ocean) and overall population life history diversity are not evaluated here. The broad conceptual model predicts that water project operations could affect migration timing, migration rates and route selection, and locations of rearing salmonids and habitat use in the tributaries influenced by SWP and CVP operations such as the Feather, American, Sacramento, and Stanislaus rivers and Delta. Operations have the potential to constrain life history diversity as a result of altering instream flows, export operations, and other habitat conditions by favoring one type of life history attribute over others. Over time, this can represent a selective pressure that reduces diversity within a population. The cumulative effect of water project operations on juvenile salmonid mortality in and beyond the Delta, in relation to other stressors, is a major gap in our knowledge.

2.0 METHODS AND APPROACH

The SST started with a broad conceptual model developed by the South Delta Salmon Research Collaborative Effort (Figure 2-1). The initial conceptual model was refined using a Driver-Linkage-Outcome (DLO) structure (DiGennaro et al. 2012) to more explicitly identify potential linkages between project operations, salmonid migration behavior, and survival (Figure 2-2; Table 2-1 through Table 2-3).

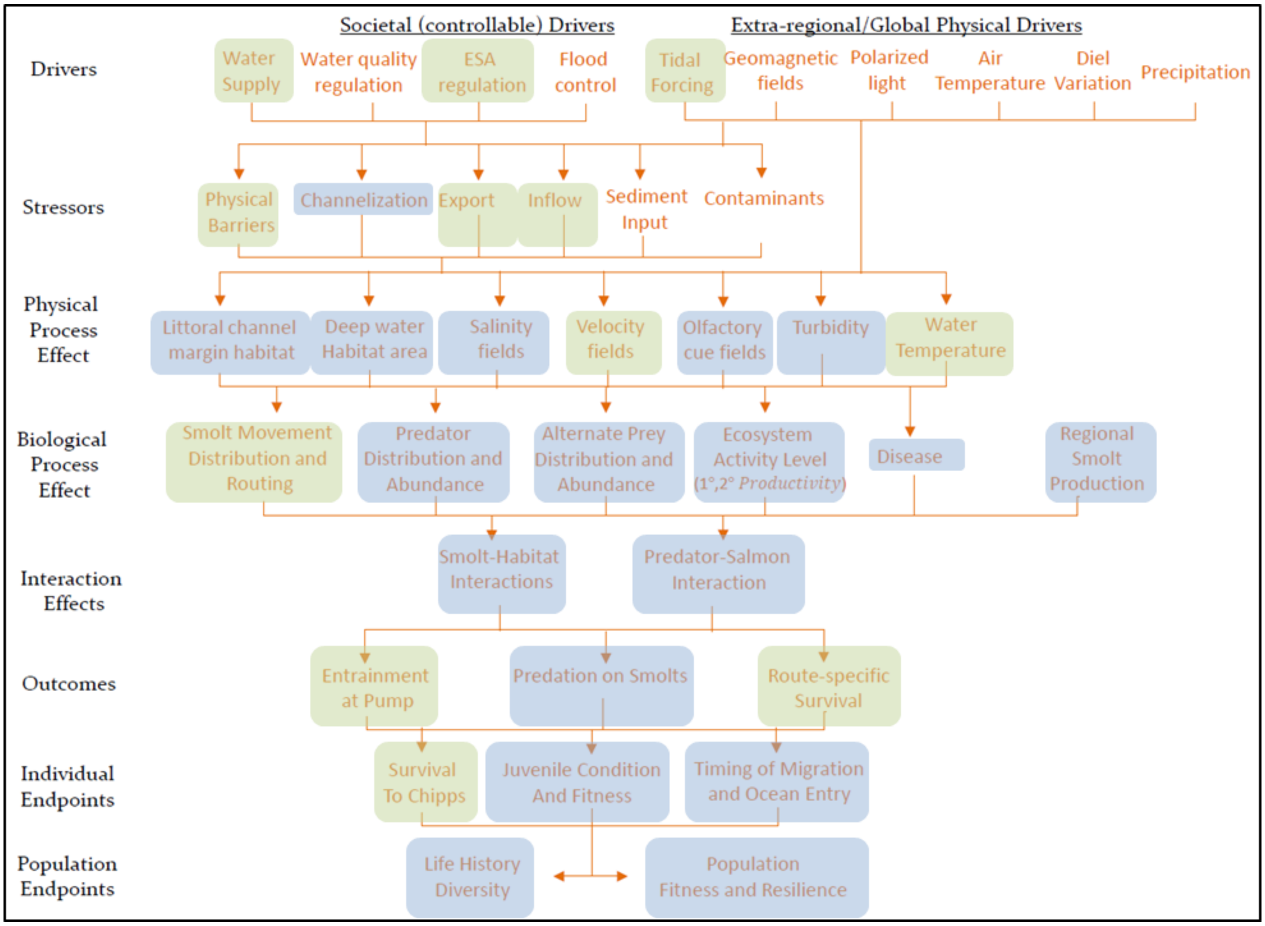


Figure 2-1. Conceptual Model from the South Delta Salmonid Research Collaborative Effort Describing Factors Affecting Survival of Juvenile Salmonids in the South Delta

Notes: Green highlights indicate model components included within the narrower scope of the SST report. Blue highlights indicate model components also potentially relevant to export effects and recommended by the SST for inclusion in an expanded research program.

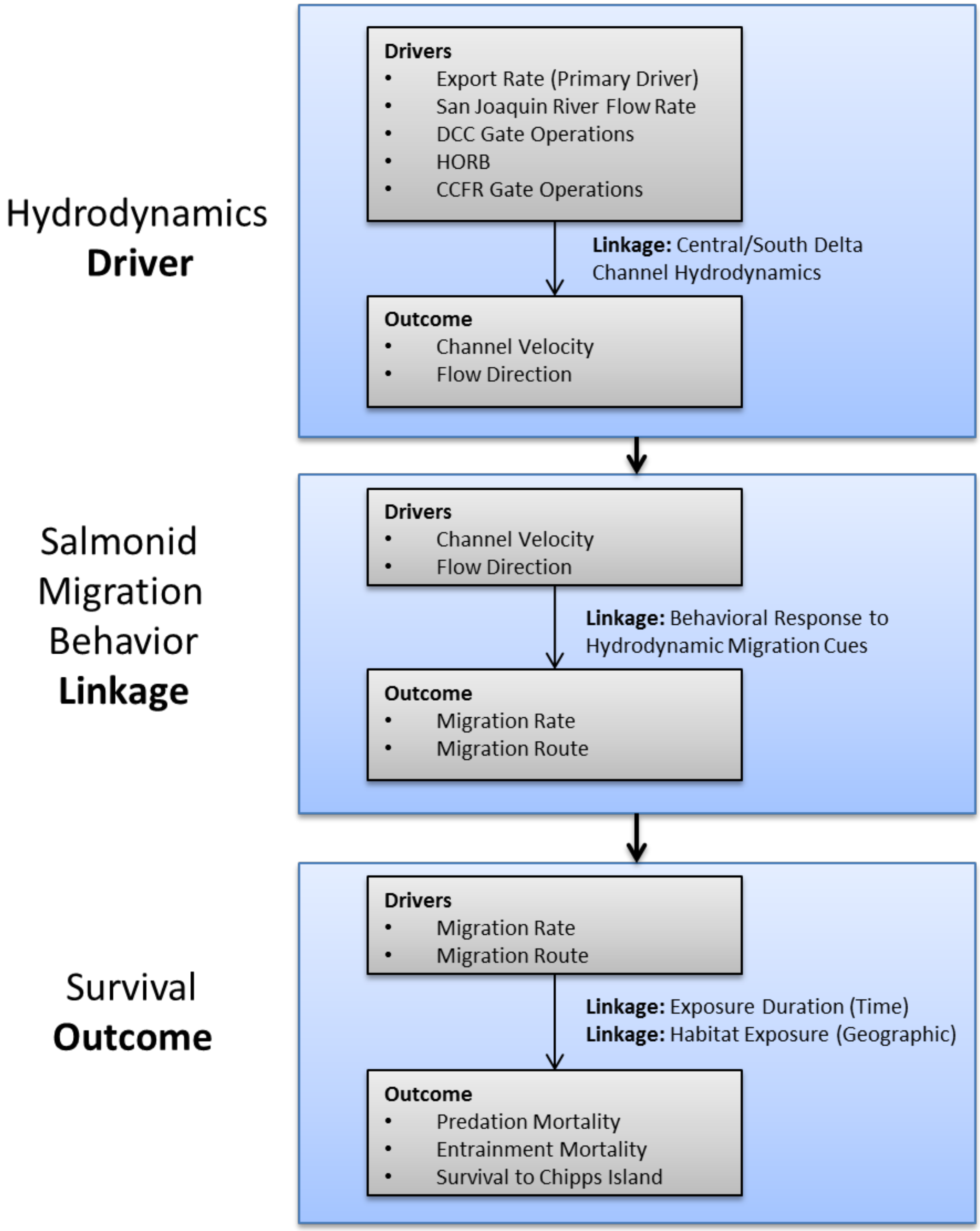


Figure 2-2. Prioritized Focal Areas and Framework Considered by SST to Evaluate Water Project Operations

Table 2-1. Hydrodynamics DLO Components for Analysis

Drivers	Linkages	Outcomes
• Exports • River inflow (Sacramento and San Joaquin) • Tide • Channel morphology	• Proximity to exports • Channel configuration/barrier deployment • Clifton Court Forebay (CCF) operation radial gate operations (e.g., opening to fill CCF and then closing to isolate the pumping plant operations from the Delta)	• Instantaneous velocities or flows • Net daily flow • Sub-daily velocity • *Percent positive flow* • *Water temperature* • *Salinity* • *Residence time* • *Source/origin of water*

Note: Red italicized text indicates DLOs that were not included in the analysis.

Table 2-2. Behavior DLO Components for Analysis

Drivers	Linkages	Outcomes
• Instantaneous flow/velocity (channels) • Instantaneous flow/velocity (junctions) • *Water quality (e.g., temperature, dissolved oxygen, salinity, turbidity, contaminants* • *Hydraulic residence time* • Spatial/temporal heterogeneity of hydrodynamic/water quality drivers • *Small-scale hydrodynamics as affected by structures/bathymetry*	• Physiological and behavioral responses to hydrodynamic or water quality conditions, gradients, or variability, such as: – *Rearing* – *Active swimming* – Lateral distribution in the channel – Passive displacement – Diel movements – *Energy expenditure* – *Selective tidal stream transport*	• Individual outcomes: – Migration rate – Migration route – Migration timing – *Timing of Delta entry* – *Delta residence time* – *Rearing location* • Population outcomes: – Population-scale outcomes depend on the spatial/temporal heterogeneity of individual outcomes

Note: Red italicized text indicates DLOs that were not included in the analysis.

Table 2-3. Salmonid Survival DLO Components for Analysis

Drivers	Linkages	Outcomes
• Migration route selection • Migration rate	• Exposure to variables (e.g., habitat and predators) that affect differential survival between routes or between years for the same route • Duration of exposure to route-specific conditions that affect survival	• Mortality

Evaluation criteria (Table 2-4), modified from the DRERIP Scientific Evaluation Process (DiGennaro et al. 2012), were developed and used to characterize the basis of knowledge supporting observed relationships in the available data. Where insufficient or contradictory information existed, the issue was identified as a gap and subsequently given consideration for potential future investigation.

Table 2-4. Criterion for Assessing the Basis of Knowledge

The basis of knowledge is an objective assessment of the evidence the SST reviewed about the relationship described in the conceptual model.	
High	1. Understanding is based on peer-reviewed studies within the system and scientific reasoning accepted by most members of the SST.
Medium	2. Understanding is based on peer reviewed studies from outside the system and corroborated by non-peer-reviewed studies within the system. 3. If evidence is from a single study, regardless of publication, then understanding is medium. 4. Understanding is based on multiple non peer reviewed agency reports.
Low	5. Understanding is based on one non-peer-reviewed research report within the system or elsewhere. 6. If evidence from multiple reports is inconsistent, then understanding is low.
Minimal	7. Understanding is lacking with the scientific basis being unknown or not widely accepted by the SST.

2.1 CONCEPTUAL MODEL

A simplified DLO conceptual model was developed to illustrate current understanding of how drivers (water project operations), relate to linkages (hydrodynamics and salmon migration behavior [migration rates and route selection]) and outcomes (Delta survival). The model is shown graphically in Figure 2-2 and summarized below:

1. Water project operations, including exports, in-Delta barriers, and water project effects on Delta inflow, affect hydrodynamics in some parts of the Delta.
2. Changes in water velocities, residence time, source, and flow direction affect juvenile salmonid behavior, including migration rate and route selection.
3. Selection of different routes through the Delta and migrating at different rates (speeds) through the Delta affect survival. Water project operations also potentially influence factors responsible for differential survival among different routes. Water project effects may be direct (e.g., entrainment into the export facilities) or ecologically indirect (e.g., predator densities and distribution, alternative prey production, habitat conditions).

Due to the limited scope of the analysis (see Section 1.2) the DLOs included reflect a subset of the array of factors that affect juvenile salmonid migration behavior and survival within the Delta, as shown in Figure 2-1. The SST acknowledges that there may be additional relationships related to the potential impacts of water exports and non-project-related factors on salmon populations that are outside the scope of this analysis or were not included in this assessment as a result of limitations in available data or time for analysis.

2.2 COMPILATION AND ASSESSMENT OF INFORMATION

The SST compiled a reference library of more than 350 technical reports and scientific papers related to water project effects on Delta hydrodynamics, salmonid migration and salmonid survival. The report includes consideration of peer reviewed scientific publications, technical reports (grey literature), and unpublished data from acoustic tag (AT) survival and migration studies (e.g., six-year steelhead and Chinook salmon studies in the South Delta) and hydrodynamic models (e.g., Delta Simulation Model 2 [DSM2], RMA2). Information such as personal communications and symposia presentations has also been included but given less weight.

2.3 PREDICTED (HYPOTHESIZED) RELATIONSHIPS

The conceptual models shown in Tables 2-1, 2-2, and 2-3 were used to develop predicted (hypothesized) relationships and outcomes. These relationships were then examined based on available quantitative (statistical analyses and modeling) and qualitative study results, including observed patterns and trends in the available data that may not be statistically significant but suggest potential responses. Consideration was given to factors such as variability in study results, the range of conditions tested, elements of the experimental design such as sample size, tagging and monitoring methods, replication, stability of experimental test conditions, and consistency of results with other studies.
Available information was characterized as:

1. Consistent and supportive of the relationship predicted based on the conceptual model
2. Not consistent or not supportive of the predicted relationships, suggesting that alternative hypotheses and relationships should be considered
3. Inconsistent or inadequate to support or refute a predicted relationship

Relationships that were characterized as inconsistent or inadequate (No. 3 above) were identified as gaps in information that could be addressed in the future.

The conceptual models can also be used to identify testable hypotheses and predictions to be assessed using data or information in the scientific literature and further analysis of existing studies. The following are examples of testable hypotheses.

Null Hypothesis	Alternative Hypothesis based on Conceptual Model
Migration route selection is independent of project operations	Project operations result in changes to water velocity and flows in Delta channels that affect route selection; specifically, increased exports result in increased selection of Interior Delta routes
Survival within the Delta is independent of project operations (direct and indirect losses; ratio of exports to inflow [E:I]; ratio of inflow to export [I:E]; Old and Middle River [OMR] reverse flows; export rate)	Project operations result in changes to water velocity and flows in Delta channels that affect direct and indirect mortality
Survival within the Delta is independent of migration route selection	Survival varies among alternative migration routes; survival is reduced within Interior Delta channels when compared to the San Joaquin River mainstem

The analysis also identified study results and interpretations where there was general agreement within the SST regarding data interpretation, and where there were disagreements within the SST. Gaps in scientific understanding related to water project effects on Delta hydrodynamics, salmonid migration behavior, and survival, as well as scientific disagreements, are summarized below with additional information included in Appendices A through E.

2.4 BASIS OF KNOWLEDGE

The basis of knowledge for observed relationships was determined using criterion adapted from the DRERIP (DiGennaro et al. 2012) process, as shown in Table 2-4. The basis of knowledge is intended to provide a standardized, objective means for characterizing the level of understanding regarding a given relationship or conclusion where understanding is defined as follows:

> ***Understanding:*** *A description of the known, established, and/or generally agreed upon scientific understanding of the nature of a driver, linkage or outcome. Understanding may be limited due to lack of knowledge and information or due to disagreements in the interpretation of existing data and information; or because the basis for assessing the understanding of a linkage or outcome is based on studies done elsewhere and/or on different organisms, or conflicting results have been reported. Understanding should reflect the degree to which the model that is used to represent the system does, in fact, represent the system.*

There was not consensus in the SST regarding the definition and application of the basis of knowledge criteria. The criteria listed in Table 2-4 categorize peer-reviewed publications higher than agency or contract reports. Peer-reviewed journal articles are considered an objective and rigorous source of information because: 1) they are independently reviewed and meet scientific standards prior to being published; 2) the selection of peer reviewers is not under the control of the author; 3) the author must respond to all peer review comments; 4) author responses must meet the satisfaction of an independent editor; and 5) peer-reviewed journals have a mechanism for reader comments and dissenting opinions with author responses to be published and affiliated with the original journal article. While many agency reports are peer reviewed, the selection of reviewers and the response to reviewer comments are typically controlled by the author(s) or contracting agency, and there is no consistent or dependable manner to assess the rigor of peer review for individual agency reports. Therefore, when an agency report was the primary source of information without the corroboration of an independently peer-reviewed publication, a "low" Basis of Knowledge rating was assigned. However, agency reports may provide better and more specific information relative to the questions the SST addressed. For this reason, at least one SST member felt that results from multiple agency reports should be rated higher than a medium basis of knowledge.

3.0 RESULTS AND DISCUSSION

Results of the SST review and analyses are summarized below for seventeen topic areas related to salmonid migration and survival in the Delta. For each topic area, conceptual model predictions are provided followed by a summary of existing analyses and a summary of findings. Where significant scientific disagreements exist, they are listed. Additional information is presented in Appendices B (hydrodynamics), C (simulation model validation), D (migration behavior), and E (survival).

3.1 EFFECTS OF PROJECT OPERATIONS ON DELTA HYDRODYNAMICS

Hydrodynamic conditions, including the flow distribution, flow direction, and water velocities in Delta channels, are influenced by a variety of factors including tides, freshwater inflows, channel geometry and channel-bed characteristics, water diversions, and operation of barriers and gates. Under periods of low inflow, the system is strongly tidal with reversing flows. As inflows increase, channels become more riverine, and tidal-induced flow reversals in Delta channels are reduced. Exports can influence the direction and velocity of flow in the South Delta, with high exports causing more negative flows in OMR. DCC operations affect the balance of flow between the western and eastern/southern areas of the Delta. Opening the DCC allows flow to transfer from the Sacramento River into the Mokelumne River and then into the lower San Joaquin River and Interior Delta (DeGeorge 2013).

Flow patterns in the South Delta tend to be more complex than the north Delta due to the influence of CCF radial gate operations and exports on OMR hydrodynamics, more complex interconnected channels, the presence of South Delta temporary barriers, lower inflow from the San Joaquin River, and greater tidal excursion along the mainstem of the San Joaquin River. Flow splits at critical junctions may be affected by the conveyance characteristics of the connecting channels, tidal phasing, and installation and operation of barriers and gates (DWR 2011a, 2011b, 2015a). Bathymetry and channel and levee characteristics maintained for water conveyance also affect habitat features in both the north and South Delta.

3.1.1 Conceptual Model Predictions

Relationships between water project operations and Delta hydrodynamics are hypothesized to vary depending on a variety of factors that include:

- Water velocities in South Delta channels would change in response to exports; the magnitude of velocity change varies depending on the magnitude of export rates, tidal condition, distance from the export facilities, Delta inflow, and channel location and configuration.
- Flow direction in South Delta channels would change in response to exports; the change in flow direction varies depending on the magnitude of export rates, tidal condition, distance from the export facilities, Delta inflow, and channel location and configuration.
- Installation and operation of temporary barriers and the DCC and CCF radial gates alter the water velocities, water surface elevation (stage), and flow direction in adjacent Delta channels; these changes are greatest in the immediate vicinity of the structure and diminish with distance away from the barrier.

3.1.2 Analysis

Actual hydrodynamic measurements and predictions based on hydrodynamic simulation modeling (Appendices B and C) were used to test the hypothetical linkages between SWP and CVP exports (driver), linkages (change in channel flow), and outcomes (change in water velocity and flow direction at various geographic locations). To assess the limitations of this approach, the analysis included: 1) consideration of various simulation model frameworks and performance (validation) of model predictions of water velocities and flows compared to measured conditions at various time scales and locations within the Delta; and 2) results of simulation model predictions of changes in water velocity and flow at various locations as a function of river inflow and SWP and CVP export operations. The basis of knowledge is considered to be low because information on the relationships between water project operations and South Delta hydrodynamics among different migration routes and drivers such as exports, barriers or Clifton Court radial gate operations, and migration route velocity is based primarily on non-peer-reviewed agency reports, and because of limitations of the models and lack of calibration and validation in the south Delta channels as presented in this report (see Appendices B and C).

Existing Understanding of the Effects of Water Project Operations on Delta Hydrodynamics

DSM2 simulation modeling results were used to assess the potential impact of water project operations on Delta hydrodynamics. Results of the hydrodynamic simulations show the relative influence of tides, river inflows, and exports on hydrodynamic conditions of flow direction, magnitude, and average cross-sectional velocity within the Delta DSM2 channel reaches given the daily tidal dynamics. Results also suggest that the effect of exports is greatest in Old River immediately downstream of the export facilities and diminishes with distance downstream of the facilities. Changes in velocities are also shown upstream and downstream of the facilities in the model runs with flows and velocities increasing in reaches upstream of the export facilities, and decreasing downstream of the facilities. Based on the DSM2 modeling, exports have little to no effect on flow and velocities in other areas of the Delta such as the San Joaquin River mainstem, north Delta, and Sacramento River.

Results of DSM2 modeling showed tides are a significant factor affecting hydrodynamics in the Delta (Figure 3-1), with Delta inflow and exports affecting the geographic area and magnitude of tidal influence. Using DSM2 model scenarios from Kimmerer and Nobriga (2008), minimum and maximum flows range from +150,000 to -155,000 cubic feet per second (cfs) in the western Delta at Chipps Island, from +29,000 to -29,000 cfs in the lower San Joaquin River at the mouth of Middle River and from +2,500 to -2,900 cfs in the San Joaquin River between Upper and Lower Roberts Island (Figure 3-1; Cavallo et al. 2013). Using the same model scenarios, minimum and maximum velocities ranged from + 1.9 to -1.8 feet per second (ft/sec) in the western Delta near Jersey Point; from to +1.3 to -1.2 ft/sec in the lower San Joaquin River at the mouth of Middle River; and from +1.4 to -1.8 ft/sec between Middle and Lower Roberts Island.

A series of DSM2 one-dimensional (1-D) simulation model runs was performed to characterize the effects of SWP and CVP exports (2,000, 6,000, and 10,000 cfs) and inflows (12,000, 21,000, and 38,000 cfs) on average daily flows and instantaneous velocities within Delta DSM2 channel reaches. Results of the simulations showed:

- In the San Joaquin River mainstem, increasing exports from 2,000 to 10,000 cfs resulted in a change in instantaneous tidal minimum velocity ranging from +0.05 ft/sec just upstream of the head of Old River to -0.21 ft/sec just downstream of False River.
- In Old River, increasing exports from 2,000 to 10,000 cfs resulted in a change in instanteous tidal minimum velocity ranging from +0.54 ft/sec downstream of Paradise Cut to -1.19 ft/sec downstream of Clifton Court intake.
- In Middle River, increasing exports from 2,000 to 10,000 cfs resulted in a change in instantaneous tidal minimum velocity ranging from -0.09 ft/sec just upstream of Victoria Canal to -0.53 ft/sec just downstream of Victoria Canal.

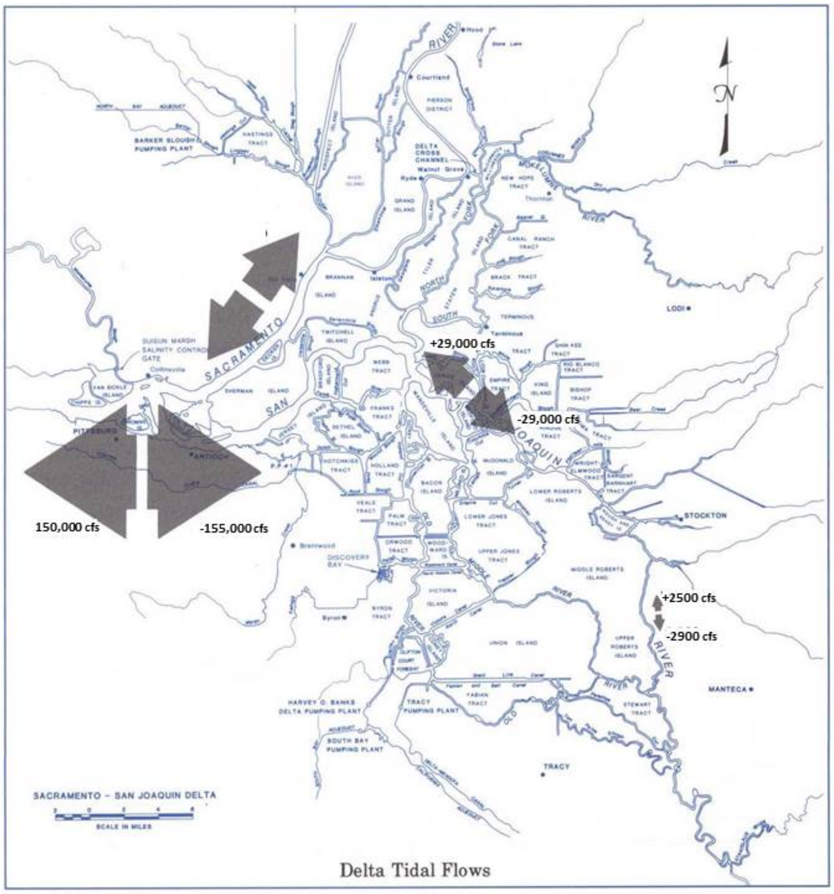


Figure 3-1. Modeled Maximum Flows at Four Locations in the Sacramento-San Joaquin Delta Using DSM2 at Low Delta Inflows of 12,000 cfs (1,495 cfs San Joaquin River Inflow and 10,595 cfs Sacramento River Inflow), High Exports of 10,000 cfs, and Head of Old River Out

Sources: Graphic from DWR (1995) Delta Atlas; model results from DSM2 scenarios from Kimmerer and Nobriga (2008).

The DSM2 model simulations were used based on average daily flow to assess the magnitude of change throughout the South Delta in response to export rates of 2,000 and 10,000 cfs. The changes in average daily flow within Delta channels as a function of three levels of Delta inflow and three levels of SWP and CVP exports are expressed as color contours representing a "heat" map of average daily flow shown in Figure 3-2. Results of these average daily flow estimates show that, particularly under low inflow conditions, the effect of increasing exports is to increase the magnitude of reverse flows in the South Delta DSM2 channel reaches. Increasing exports resulted in the greatest flow changes within Delta DSM2 channel reaches south of the San Joaquin River mainstem. The effect of increasing Delta inflow was generally a reduction in the average daily effects of exports on South Delta hydrodynamic conditions.

To further investigate the potential effects of water project operations on hydrodynamic conditions in the San Joaquin River mainstem in the South Delta and at Georgiana Slough in the North Delta, results of the 1-D DSM2 simulation model were analyzed at specific river junctions by Cavallo et al. (2013) using flow predictions at a 15-minute time step over a 24-hour period. Results show that flows are affected by river flow, exports, and tidal conditions in the San Joaquin River mainstem at the head of Old River, but downstream in the San Joaquin River mainstem, SWP and CVP exports and Delta inflow rate have much less effect and tides dominate more. At Georgiana Slough in the North Delta, Delta inflow and tides dominate and exports have little to no effect (see Appendices B and C for additional detail regarding Delta hydrodynamic simulation models). A similar junction assessment was conducted by the SST with the same model output set for velocity with similar results (Appendix B, Sections B.5.3 and B.5.4).

As river inflow increases, tidal effects on flow decrease in the upstream areas of the South Delta routes and at Georgiana Slough. As river flow decreases, the effect of tides on flow direction and velocity increase. The flows and velocities in the immediate vicinity of the north and South Delta channel junctions are complex in terms of local turbulence and the location of the hydraulic streakline in the mainstem river channel (Appendix B, Section B.4 and Figures B.4-1 and B.4-2).

In addition to modeling the effects of inflow and exports on flow magnitude and direction at various DSM2 junctions, the 15-minute DSM2 predictions for changes in water velocity were also examined. Due to limited resources to obtain the 15-minute output, we selected fewer scenario options. The model scenarios were limited to low Sacramento and San Joaquin River inflow (12,000 cfs) and low export (2,000 cfs), high inflow (38,000 cfs) and low export (2,000 cfs), and high inflow (38,000 cfs) and high export (10,000 cfs). The low inflow and high export scenario was not recommended for modeling because it was not realistic from an operations perspective. The HORB and South Delta Temporary Barriers were not installed in the model for these analyses.

With the availability of 15-minute model output, we were able to see the complexity of the hydrodynamics in the South Delta channels reflecting the variation in velocity conditions that a juvenile salmonid would encounter while migrating through the South Delta. Figure 3-3 is an illustration of the 15-minute instantaneous velocities over a complete tidal cycle for each of the DSM2 channel reaches in each route.

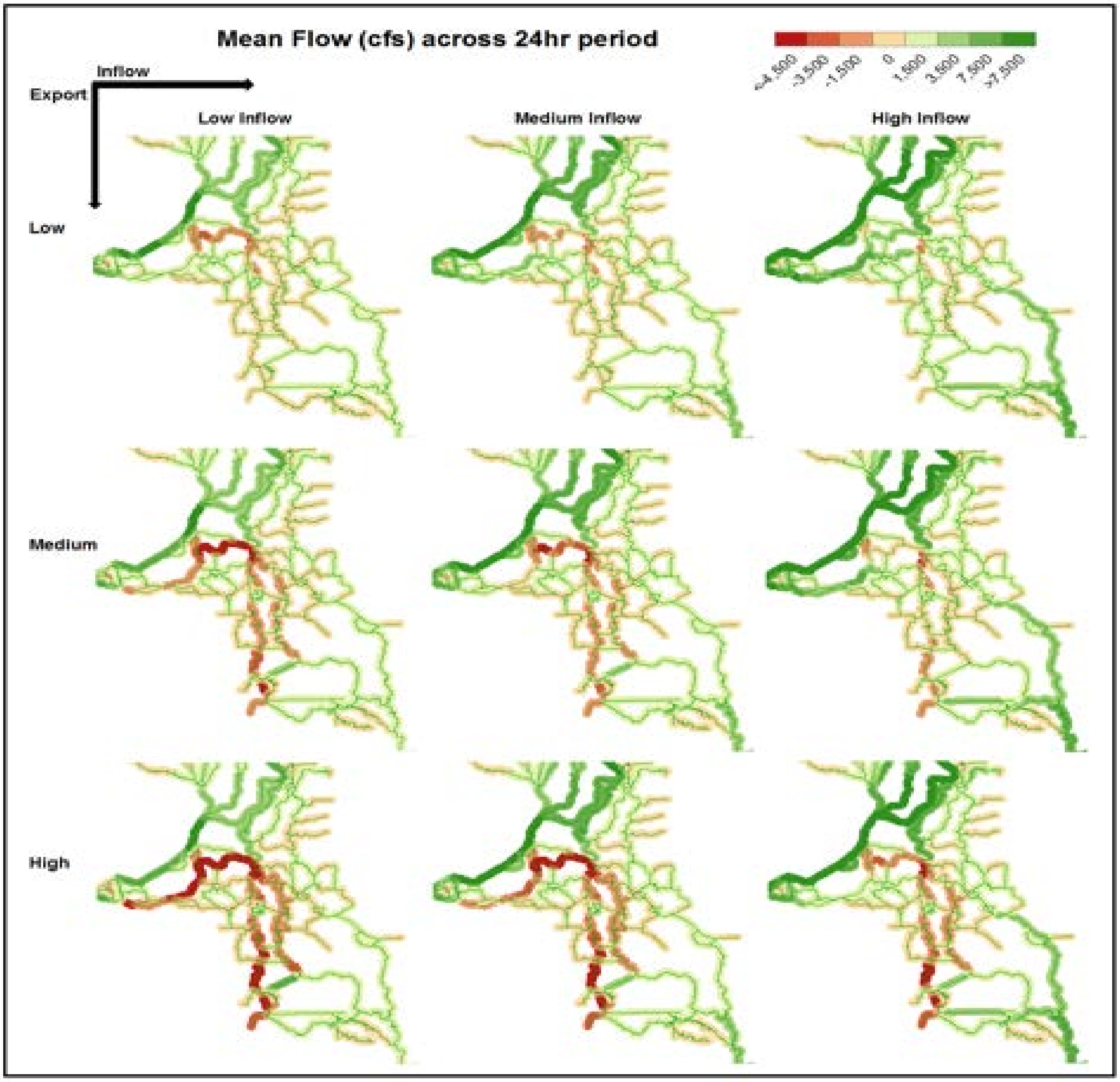


Figure 3-2. Daily Average Flow at Each DSM2 Channel at Three Export Rates and Three Delta Inflow Rates

Note: The export rates were 2,000, 6,000, and 10,000 cfs, and the Delta inflow rates were 12,000, 21,000, and 38,000 cfs.

In DSM2, the waterways are segmented into distinct channel reaches and given numbers. San Joaquin River route is made up of channel reaches 7 through 50. Old River route is made up of channel reaches 54 through 124. Middle River route is made up of channel reaches 125 through 163. The multiple lines in each graph in Figure 3-2 are the individual DSM2 channel reaches and the x axis represents time (approximately 25 hours). The tide phase reaches the upstream DSM2 channel reaches several hours later than the downstream reaches within a route, there are groups of DSM2 channel reaches that are similar in terms of amplitude and tide phase timing, compared to other groups. The hydrodynamic and geometric complexity of these South Delta channels and the interactions between San Joaquin River inflow, exports, and tides contribute to the environmental conditions and migration cues encountered during downstream passage by juvenile salmonids.

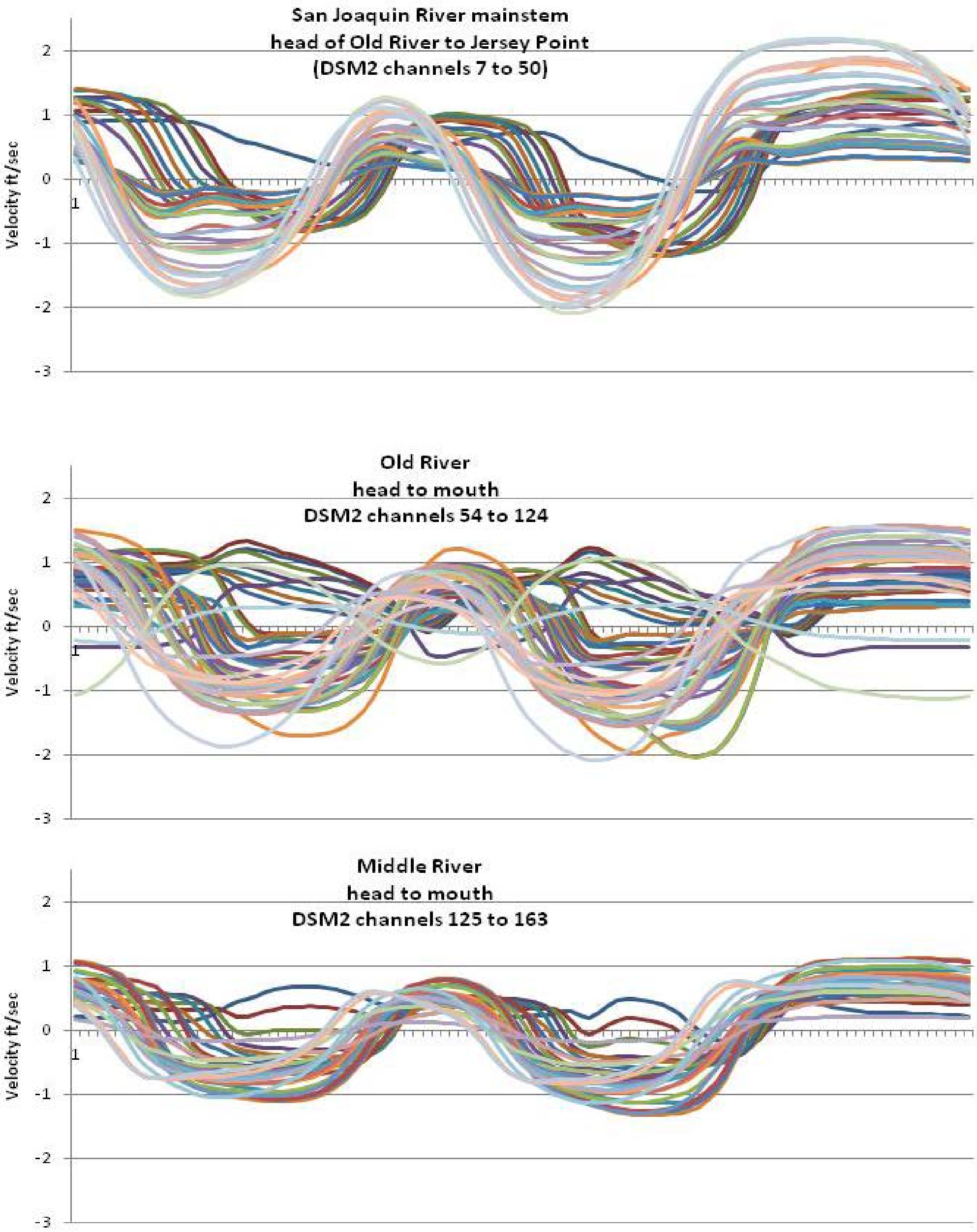


Figure 3-3. DSM2 Modeled Instantaneous 15-Minute Interval Velocity Versus Time Over One Tidal Cycle (~25 hours) in DSM2 Channel Reaches in Three Routes of the South Delta

Notes: The DSM2 channel reaches are reaches of the river as defined in the DSM2 model grid. The routes are the San Joaquin River mainstem, Old River, and Middle River. Each line represents one DSM2 channel reach within the route at the low inflow/low export model scenario. The x axis represents the time period modeled from 0 (origin) to approximately 25 hours.

Figure 3-4 and Figure 3-5 illustrate water velocity profiles for the San Joaquin River, Old River, and Middle River routes under two export and two inflow conditions showing the tidally averaged, maximum, and minimum 15-minute instantaneous velocities. Results of these analyses show that water velocities in the South Delta channels are primarily positive during the ebb tide stage (flowing downstream) in contrast to primarily negative during the flood tide stage (flowing upstream) in all three routes. These changes in velocity patterns as a function of tide are expected as the South Delta flows reverse direction between ebb and flood tide stage, which adds further to the hydrodynamic complexity encountered by juvenile salmonids migrating downstream through these South Delta routes. The reverse velocity pattern in the three South Delta routes shown in Figure 3-4 (left panel) occurred downstream of: 1) Stockton in the San Joaquin River mainstem; 2) Grant Line Canal in Old River; and 3) Tracy Boulevard in Middle River under both the low and high river inflow conditions. Tidal effects had a substantially greater influence on water velocities than differences between high and low exports under high inflow conditions in the San Joaquin River mainstem, but in Old River, export effects increased to about 35% of the tidal effect near the SWP and CVP facilities (Figure 3-4, right panel). Additional analysis of 15-minute velocity results are presented in Appendix B.

Results of the simulation analysis at the junction of San Joaquin River and head of Old River (Figure 3-6) showed little difference in water velocities upstream, downstream, and within Old River (three DSM2 channel reaches) associated with differences between the low and high export condition (at high inflow). Differences in velocities as a function of low and high river flow (at low exports) were apparent at all three locations with greater cyclic tidal variation in velocities under the low river flow condition. Increased river flow resulted in consistently high velocities at the head of Old River junction at all three of the DSM2 channel reaches included in the model analysis.

At the junction of the San Joaquin River and Turner Cut (Figure 3-7), the greatest influence on water velocities was associated with tidal phase (cyclic tidal signal) with river flow and exports having little effect on water velocities. These results show the greater influence of tides at locations further downstream in the Delta as well as the diminished effect of river flow on water velocities at the Turner Cut junction. Water velocity at Turner Cut junction DSM2 channel reaches was virtually independent of variation between low (2,000 cfs) and high (10,000 cfs) export levels in these simulation analyses.

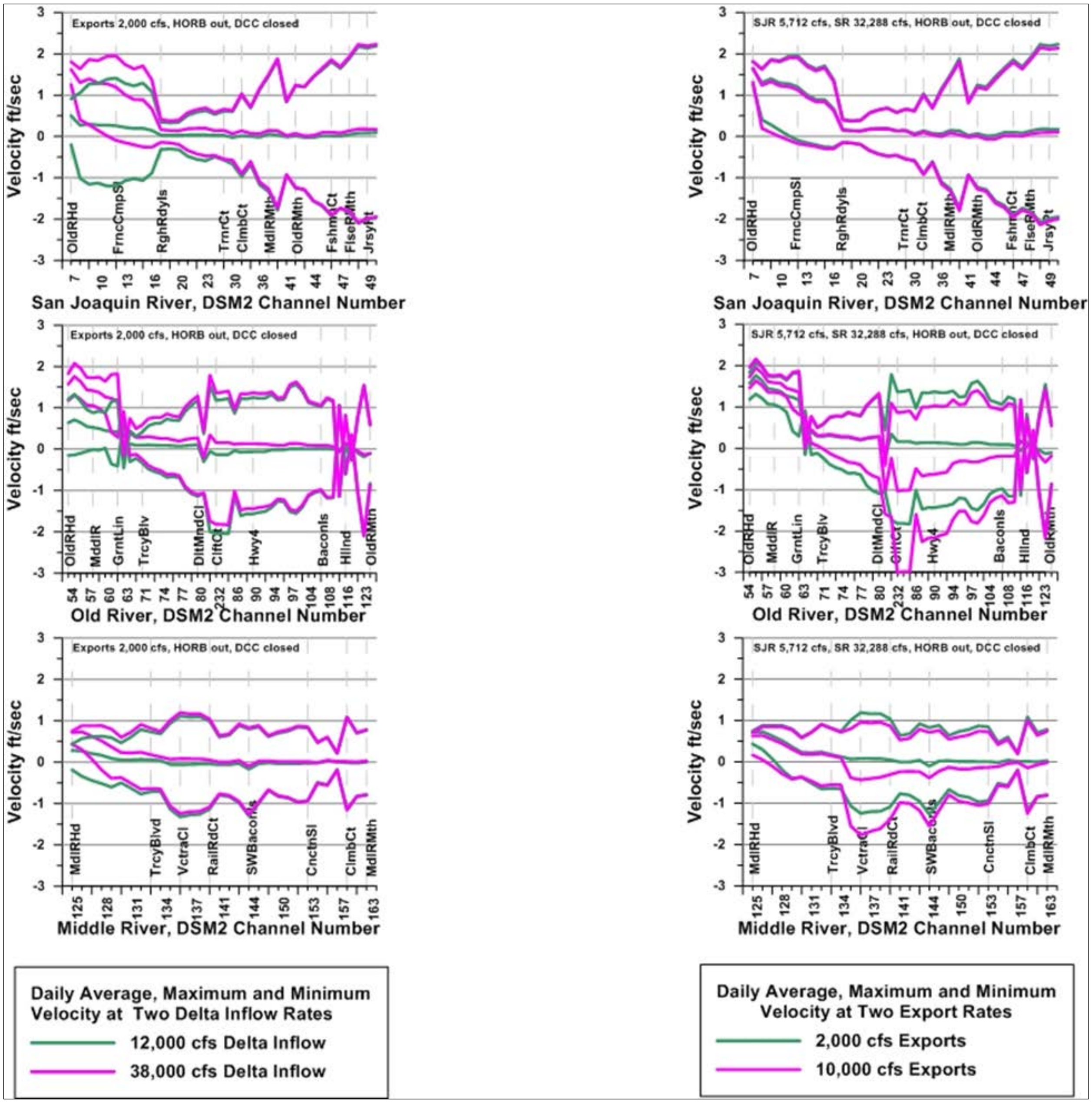


Figure 3-4. DSM2 modeled average daily velocity and instantaneous maximum velocity associated in each channel reach, in each of two routes in the South Delta. The two model scenarios were, left panels: low exports at low and high inflows, and right panels: high inflows at low and high exports. We limited the export scenarios to low exports and the inflow scenario to high inflows because high exports are not permitted at low inflows. In each graph, the upper set of lines represents the maximum velocities for the scenario, the middle set of lines represents the daily average velocities for the scenario, and the lower set of lines represents the minimum velocities for the scenario. The minimum and maximum velocities are associated with the flood and ebb tides, respectively.

Note: The three routes are San Joaquin River mainstem, Old River, and Middle River. The x axis is the serial DSM2 model channel number.

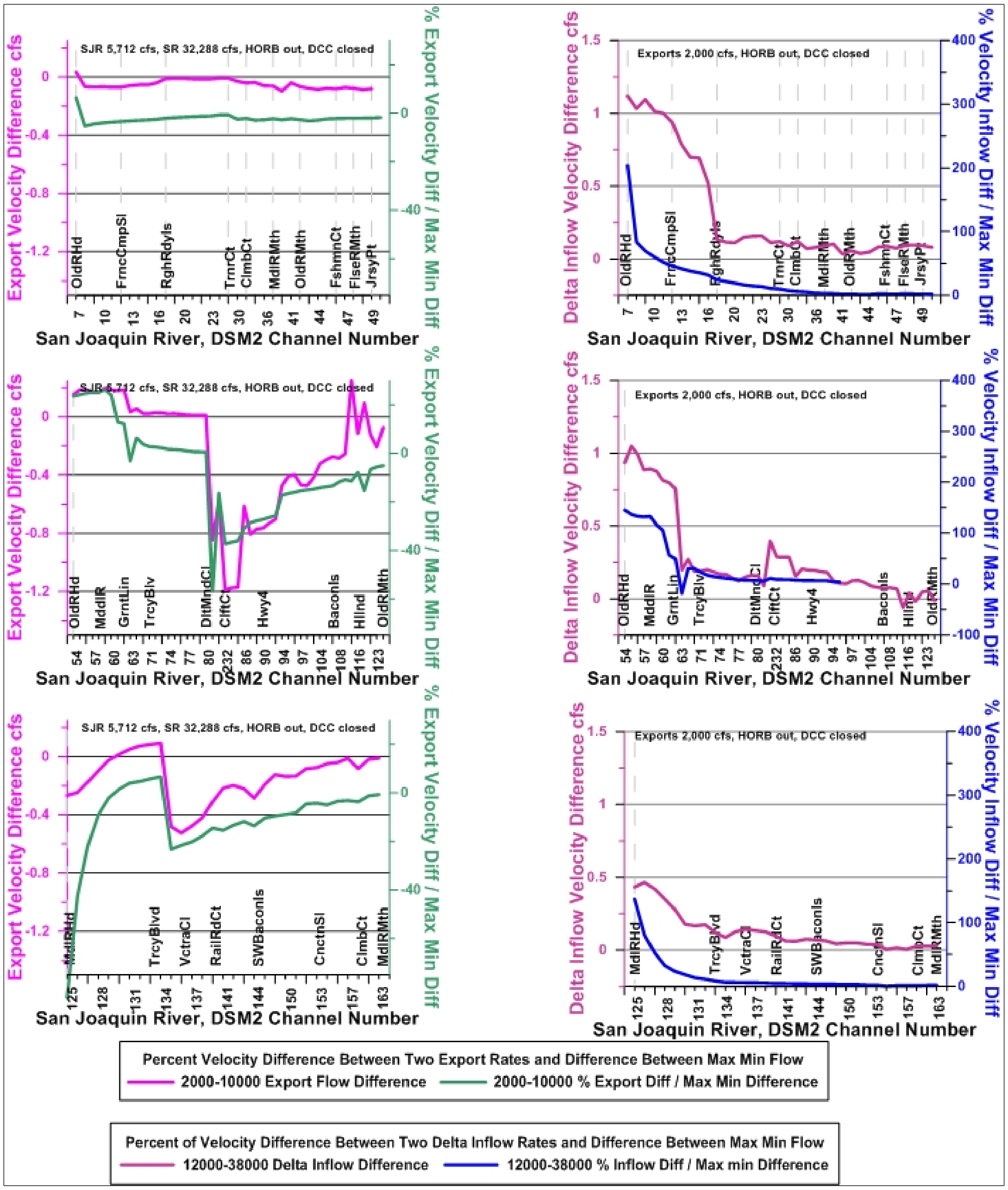


Figure 3-5. Effect of Export Rate and Delta Inflow on Tidal Velocity in the Lower San Joaquin River

Notes: All left panels represent the high inflow scenario, the difference in average tidal velocity between low and high export rate (left y axis), and the difference in daily average velocity between low and high export rate divided by the difference between instantaneous maximum and minimum velocity at the low export rate (right y axis) without the HORB. The right panels represent the difference in daily average velocity between low and high inflow rate (left y axis) and the difference in daily average velocity between low and high inflow rate divided by the difference between daily maximum and minimum velocity at the low at the low inflow rate without the HORB. All right panels represent the low export scenario. The three routes are San Joaquin River mainstem, Old River, and Middle River. The x axis is serial DSM2 channel number.

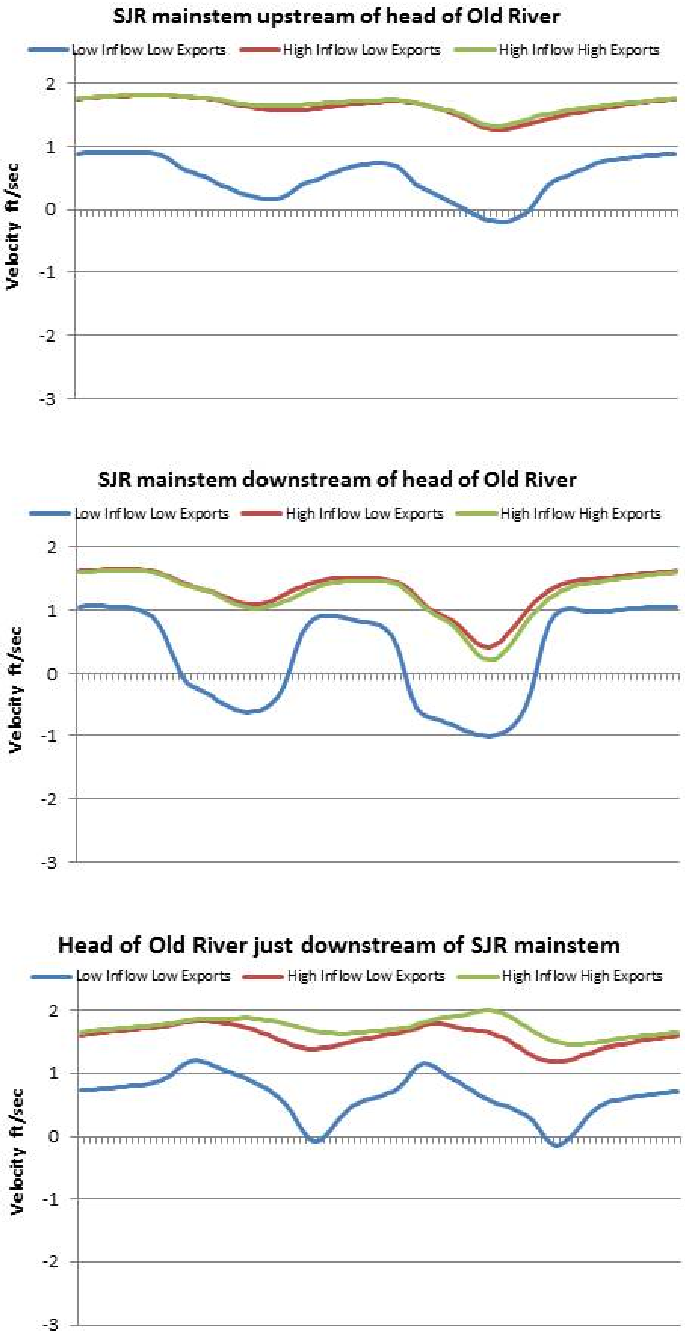
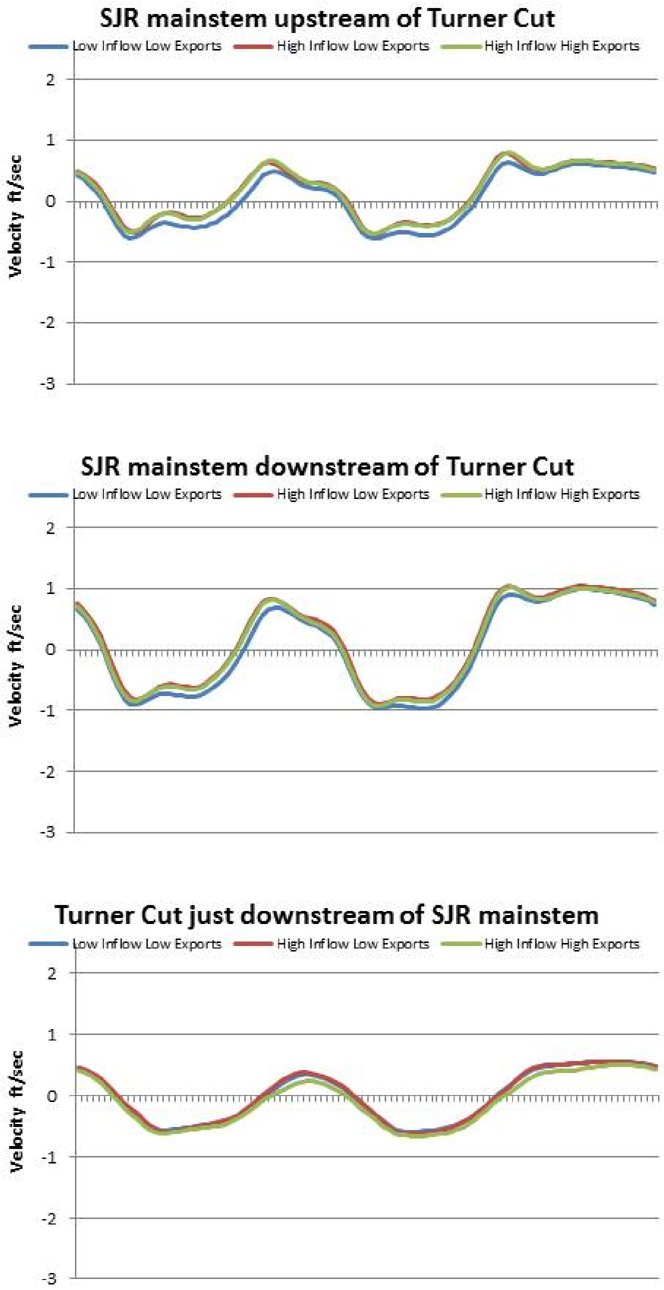


Figure 3-6. DSM2 Modeled Instantaneous 15-Minute Velocity Versus Time Over a Complete Tidal Cycle (~25 Hours) at the Junction of the San Joaquin and Head of Old River

Notes: There are three DSM2 channel reaches at the junction (three panels). Within each panel, there are three scenarios: low inflow/low export, high inflow/low export, and high inflow/high export.


SJR mainstem upstream of Turner Cut

SJR mainstem downstream of Turner Cut

Turner Cut just downstream of SJR mainstem

Figure 3-7. DSM2 Modeled Instantaneous 15-Minute Velocity Versus Time Over a Complete Tidal Cycle (~25 Hours) at the Junction of the San Joaquin and Turner Cut

Notes: There are three DSM2 channel reaches at the junction (three panels). Within each panel, there are three scenarios: low inflow/low export, high inflow/low export, and high inflow/high export.

Results of simulation modeling further downstream in the Delta at the mouth of Old River (Figure 3-8) showed an even stronger tidal signal (cyclic pattern in velocities) with positive (downstream) velocities on the ebb tide cycle and negative (upstream) velocities on the flood tide cycle at all three DSM2 channel reaches under all three scenarios. At the mouth of Old River there was virtually no variation in water velocities in response to either high or low river flow or high or low export rates.

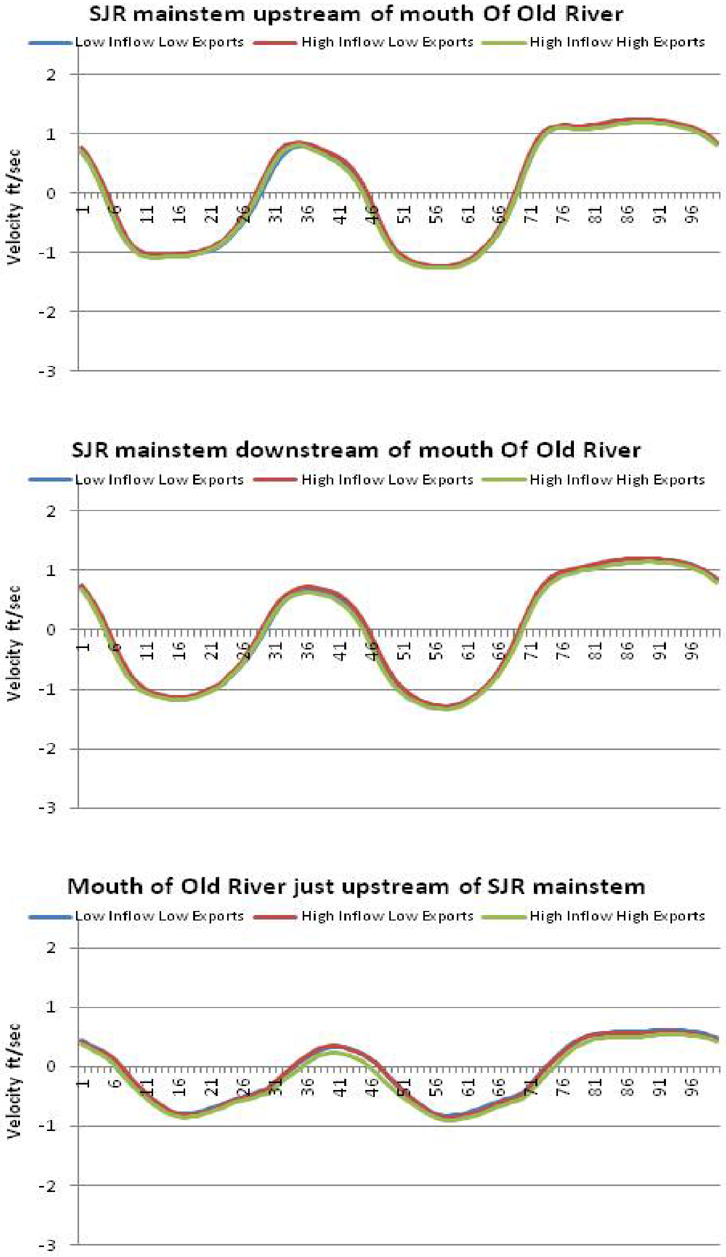


Figure 3-8. DSM2 Modeled Instantaneous 15-Minute Velocity Versus Time Over a Complete Tidal Cycle (~25 Hours) in Three Channels at the Junction of the San Joaquin River Mainstem and the Mouth of Old River

Notes: There are three DSM2 channel reaches at the junction (three panels). Within each panel, there are three scenarios: low inflow/low export, high inflow/low export, and high inflow/high export.

3.1.3 Summary of Findings

The application of hydrodynamic simulation models has proven to be a useful analytic and planning tool when applied at an average daily time step but has not yet achieved sufficient resolution for use in predicting hydrodynamic conditions experienced by a juvenile salmonid at the specific time and location when it encounters a complex channel junction in the South or Central Delta. Hydrologic simulations provide a means for evaluating local and regional changes in Delta hydrodynamic conditions associated with alternative water project management; however, the Delta channels and channel junctions are characterized by complex and dynamic conditions that complicate the development and interpretation of modeling results.

The 1-D DSM2 model, in particular, provides a tool for assessing changes in Delta hydrodynamic conditions that has been used extensively for water supply planning. Validation tests indicate that DSM2 is more accurate for predicting average daily metrics than 15-minute time step metrics (Appendices B and C). The model validates well at some locations with weaker agreement between observed and predicted flow and velocity at other locations. Factors such as simplifying assumptions for Delta consumptive water use, channel bathymetry, and complex geometry and dynamic tidal conditions contribute to variability in model validation. More complex 2-D or 3-D simulation models may be needed in some analyses to represent more complex hydrodynamic conditions on a finer time scale experienced by juvenile salmonids migrating through the Delta (Appendices B and C).

Selection of the appropriate simulation modeling tool should be based on the specific goals and objectives of an analysis, the level of resolution needed in model results, the complexities of the areas being modeled in terms of dynamic tidal and flow conditions, and channel geometry. The selected modeling tool should be calibrated and independently validated at a temporal and spatial scale appropriate for the desired analysis.

The effect of river flow is greatest in upstream riverine reaches and the effect of tides increases at downstream Delta locations. The effects of SWP and CVP exports on hydrodynamics is greatest in channels located in close proximity to the export facilities and decreases as a function of distance both upstream and downstream of the facilities.

3.1.4 Areas of Disagreement

The existing hydrodynamic models may not be useful for assessing how exports from the South Delta, river inflows, and tides may influence the magnitude, duration, and direction of water velocities within selected channels and channel junctions in the Delta at the spatial and temporal scales needed for biological studies, such as the analyses of salmon migration behavior and survival. Further model validation and refinement is needed before analysis of salmonid migration behavior and survival in response to changes in channel hydrodynamics can be conducted with confidence. Further, there is also currently no broad scientific agreement on threshold changes in flows or velocities that influence salmonid migration behavior or survival within a channel or at a channel junction. Some of the SST members felt that any change in velocity or flow resulting from water project operations could be biologically significant, while others felt that only changes above some threshold that has yet to be defined should be considered to have potential biological significance. For example, would a change in velocity at a specific location in the Delta as a result of a change in exports of 0.01 ft/sec, 0.1 ft/sec, or 1.0 ft/sec be expected to affect route selection, migration rate, or survival?

3.2 EFFECTS OF HYDRODYNAMICS ON MIGRATION RATE

Anderson et al. (2015) and others have hypothesized that the survival of juvenile salmonids migrating through the Delta varies as a function of their downstream migration rate and duration of residence in the Delta. The hypothesis assumes that the longer juvenile salmonids remain in the Delta, the greater their risk of mortality as a result of predation, entrainment into unscreened water diversions, exposure to adverse water quality conditions, and other factors. Water project operations during the juvenile migration period have the potential to affect migration rate by altering river flows through reservoir operations and releases, altering flow patterns or water velocities in the Delta through SWP and CVP exports, or installing temporary barriers.

3.2.1 Conceptual Model Predictions

The conceptual model predicts the following:

- The downstream migration rate of Chinook salmon and steelhead smolts will increase as river flow into the Delta increases.
- The downstream migration rate of juvenile salmonids will increase as water velocities increase in tributary rivers to the Delta.
- Migration rates of juvenile salmonids will be reduced in response to South Delta reverse flows as a result of increased SWP and CVP export rates (e.g., OMR reverse flows).
- Migration rates of juvenile salmonids will decrease as a result of bi-directional tidal flows and reduced downstream velocity in the Delta.

3.2.2 Analysis

Several salmonid migration studies conducted in the Pacific Northwest have shown evidence of a relationship between river flows and migration rates of juvenile salmon and steelhead. Raymond (1979) observed a decrease in migration rate of juvenile Chinook salmon and steelhead with decreasing flows associated with dams on the Snake River. Zabel et al. (1998) found a strong positive relationship between flow and migration rate of juvenile Chinook salmon on a seasonal basis in the Snake River. Smith et al. (2002) found a strong and consistent negative relationship between flow and travel time through reaches in the Snake River.

Results of survival and migration studies in the Sacramento and San Joaquin rivers and Delta, however, suggest that the relationships between river flow and migration rates of salmonids through the Delta are more complex than in the Pacific Northwest. Williams (2006) characterized flow as a proximate factor that influences migration rate of juvenile Chinook salmon through the Delta but was not able to provide information from available coded-wire tag (CWT) studies on the relationship between migration rate and flow for riverine versus tidal regions of the estuary. Hankin et al. (2010) concluded that the Vernalis Adaptive Management Plan (VAMP) study results support the idea that "increased inflows to estuaries and increased down-estuary net current velocities decrease juvenile salmon travel time through the system and increase survival." However, results of the VAMP CWT studies combine migration rates that include both riverine and tidal reaches. With the more recent application of AT technology, more precise estimates of migration rates and potential relationships with river flow have been developed. Michel et al. (2012), for example, found that water velocity and river flow were positively correlated with movement rate for juvenile late-fall-run Chinook salmon released in the Sacramento River in January, and that the fastest movement rates were observed in the upper reaches of the Sacramento River where riverine conditions were dominant. Migration rates have been observed to decrease when juvenile salmonids enter the tidally dominated regions of the Delta where flows are bi-directional and the effect of river flow on water velocities is diminished.

A limited number of analyses were found that examined the potential relationship between SWP and CVP export operations, changes in channel velocities in the Delta, or the magnitude of OMR reverse flows and juvenile salmonid migration rates through the Delta. There is a growing body of scientific information from the six-year steelhead survival study, the associated juvenile salmon survival studies, AT monitoring of juvenile winter-run and fall-run Chinook salmon on the Sacramento River, the VAMP AT studies and others that can be analyzed to investigate relationships between migration rate and reach-specific and regional survival, as well as between water project operations and migration rates within the Delta. Analyses of the relationship between fish size, migration rate, and survival in South Delta channels, as well as migration rate through specific migration routes and associated survival, require further analysis.

3.2.3 Summary of Findings

Limited information from AT studies suggests a relationship exists between river flow, water velocities, and migration rate of juvenile salmonids in riverine reaches of the Delta but not within the tidally dominated regions of the estuary. Despite data being available from a number of recent studies, very little information exists on the potential relationships between water project operations and juvenile salmonid migration rates, reach-specific and regional survival, or how changes in water velocities and flow direction in the riverine versus tidally dominated regions of the Delta influence migration or survival.

Uncertainty remains regarding the following:

- How migration rates vary through specific reaches in response to variation in water project operations and inflow
- How the relationship between migration rate depends on covariates such as temperature, flow, or water velocity that vary within and among years
- The trade-offs between faster migration rates as a possible predator avoidance mechanism within the Delta, and slower migration rate as a growth opportunity that may reduce predation in estuarine and ocean environments

Outside of the north Delta, it is not currently possible to predict how specific changes in flow and velocity impact migration rates. AT studies have not shown strong relationships between exports and migration rate under the conditions tested, but few analyses have focused on the relationship between exports and migration rate. Also, exports, velocities, and flows may be linked at some locations such that determining relative effects among these variables will be difficult.

3.3 EFFECT OF HYDRODYNAMICS ON MIGRATION ROUTE

The Delta is a complex interconnected network of channels representing the estuarine transition between the upstream tributary rivers and the downstream bays and coastal waters. Juvenile salmonids migrating downstream into and through the Delta encounter a number of channel junctions that, depending on behavioral selection, determine the migratory pathway through the Delta. A number of factors are thought to affect the behavioral response of juvenile salmonids at a junction including the following:

- Magnitude of river flow
- Channel velocity
- Influence of tidal action on both flow direction and velocity
- Configuration of the channel junction
- Location of the juvenile salmonids in the channel cross-section with respect to the channel junction
- Physical barriers such as the HORB

It has been hypothesized that habitat conditions and the duration of juvenile residence in the channels vary, and that exposure to sources of mortality varies among pathways. The flow patterns, including water velocities and flow splits at these channel junctions, are among the factors that potentially affect route selection.

3.3.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Route selection at channel junctions is expected to be a function of tidal velocity, flow direction, and junction geometry resulting in route selection proportional to flow splits.
- Route selection at channel junctions varies in response to effects of tides, Delta inflow, exports, and barrier operations that affect channel velocities and flow splits.
- Route selection is expected to be affected by exports proportionally to the incremental effect of exports on water velocity and flow within a channel or at a channel junction.
- Export effects on route selection are greatest in the immediate vicinity of the export facilities and diminish as a function of distance away from the facilities.

3.3.2 Analysis

Cavallo et al. (2015) compiled data on juvenile Chinook salmon migration behavior from AT studies at six junctions in the Delta including the head of Old River, Georgiana Slough, DCC, Sutter Slough, Steamboat Slough, and Turner Cut. Flow estimates (river inflow, export rates, proportion of flow entering the distributary, ratio of velocities in the main channel to that in the distributary, and proportion of time over a day that flow was entering the distributary) over a 24-hour period corresponding to the day of arrival of tagged salmon at each junction were estimated using the 1-D DSM2. The proportion of juvenile salmon (both fall-run and late-fall-run Chinook salmon) migrating into each channel junction from 41 release groups was used as the basis for route selection. A best-fit linear model was used to describe the relationship between hydrodynamic metrics and route selection. The proportion of flow entering a distributary was selected as the best model predictor accounting for 70% of the observed variance in route selection ($R2 = 0.70$; $P < 0.001$). The regression model was then used to predict route selection at nine junctions over a range of river inflow and export conditions represented in the hydrodynamic simulations.

Results of the model analysis showed that more fish entered junctions with strong riverine influence like head of Old River and Georgiana Slough. There were fewer fish entering the single distributary (i.e., Turner Cut) in the tidally dominated regions of the Delta where both inflow and diversions had only small effects on predicted route selection. The hydrodynamics at such distributaries in tidally driven regions were dominated by tidal flow resulting in substantial periods each day when flows were not entering the distributary. Geometry of the junction and channels, and tidal conditions at the time the fish enters the junction, were identified as factors affecting route selection, but the data used to develop the model had very little information derived from tidal junctions (only Turner Cut in some instances). The effect of exports was greatest at the junction directly connected to channels leading to the export facilities (i.e., head of Old River) and diminished with distance from the export facilities.

Results of these analyses are generally consistent with the qualitative predictions from the conceptual model and prior studies (Kemp et al. 2005; Perry 2010) that route selection is generally proportional to the flow split at channel junctions and that the effect of exports on flow velocities and route selection diminishes with distance away from the facilities.

In 2012, a steelhead migration and survival study was designed and implemented in an effort to learn more about the effects of OMR reverse flows on survival through the Delta (Delaney et al. 2014). Yearling steelhead from the Mokelumne River hatchery were acoustic-tagged and released into the San Joaquin River in the vicinity of Stockton. Tag detectors were deployed in various channels and channel junctions located throughout the Central and South Delta. Unfortunately, tag detectors were not placed such that the probability of detection at all individual receivers could be determined. AT monitoring for the study show that juvenile steelhead migrates downstream through a variety of pathways and exhibit a wide range of behavioral responses to channel junctions under various export and hydrodynamic conditions (Delaney et al. 2014). The study showed that there was a higher probability of steelhead tags, located at the west end of Railroad Cut in Old River (about ten miles from the export facilities), to move south towards the export facilities as OMR reverse flows became more negative (Delaney et al. 2014).

Prior CWT studies have suggested that reducing the proportion of juvenile salmon that entered Old River would increase through-Delta survival, because survival had been shown to be, on average, greater in the San Joaquin River relative to that in Old River (Brandes and McLain 2001; SJRGA 2007). Several AT studies have been conducted within the southern part of the Delta over the past ten years to estimate reach and route-specific survival of Chinook salmon and steelhead (SJRGA 2013; Buchanan et al. 2013; Appendix E, Section E.4). Other studies assessed the benefits of a non-physical barrier, relative to increasing the proportion of fish entering the San Joaquin River at the head of Old River junction in 2009 and 2010 (Bowen et al. 2009; Bowen and Bark 2010). Results of the non-physical HORB studies conducted by Bowen et al. (2009), Bowen and Bark (2012), and the California Department of Water Resources (DWR 2015a) provided information on the potential behavioral response of juvenile migrating salmonids to the non-physical HORB; however, detailed information on water velocities, flow direction, and exports were not included as part of the analysis.

In 2011, the effects of CVP and SWP exports on route entrainment into the head of Old River on Chinook salmon (SJRGA 2013) and steelhead (Buchanan 2013) were evaluated. Variables included flow proportion, flow magnitude, velocity, and river stage. Similar analyses were conducted for the 2009 and 2010 Chinook salmon releases (SJRGA 2013). In 2009, there was a significant relationship between CVP exports and route selection at the head of Old River, when CVP export rate was the only factor considered, but when flow or velocity were accounted for in the model, the additional effect of CVP exports was not significant. In 2011, Chinook salmon route selection at the head of Old River was significantly related to flow and velocity in the San Joaquin River just downstream of the head of Old River (i.e., at San Joaquin Lathrop). Exports were considered but were not found to be significant. In 2011, no factors were significantly associated with route selection at the head of Old River for steelhead.

3.3.3 Summary of Findings

Results of hydrodynamic simulation modeling show that the proportion of flow splits at channel junctions such as Turner Cut and Columbia Cut is dominated by river inflow and tidal conditions with a substantially lower influence from exports. These results are consistent with those presented by Cavallo et al. (2015) noting that it would be very difficult to influence route selection along the lower San Joaquin River by managing SWP and CVP export rates. As an alternative to trying to affect route selection by juvenile salmonids at these junctions along the San Joaquin River, DWR (2015b) investigated engineering solutions such as the installation of non-physical barriers in an effort to reduce route selection into Old River.

Results of fine-resolution acoustic and hydrodynamic monitoring in the Sacramento River at Georgiana Slough demonstrate the ability to predict route selection of juvenile salmonids based on the location of the fish in the channel cross-section and the hydraulic streaklines showing the proportion of the river flow entering the slough (DWR 2012). Studies that integrate salmonid migration behavior and hydrodynamics at channel junctions have not been conducted in the South Delta.

Based on the review of information, the SST concluded that:

- Juvenile salmonids encountering a channel junction typically select a migration route in proportion to the flow split, although other factors also appear to affect migration route selection (location in the channel cross-section, streakline location, and channel geometry).
- Fine-resolution AT monitoring, in combination with local hydrodynamic monitoring of flow direction and velocity, has proven beneficial in evaluating the behavioral response of juvenile salmonids encountering channel junctions along the Sacramento River at Georgiana Slough and the DCC.
- The behavioral response of juvenile salmonids encountering channel junctions along the San Joaquin River in the Delta (both channel configurations and hydrodynamics) has not been studied adequately.
- The general predictions from the conceptual model are supported by results of recent studies and analyses, although model refinements and additional monitoring and modeling should be performed to add specificity to the predictions.

3.4 EFFECTS OF TEMPORARY BARRIERS ON MIGRATION RATE AND ROUTE

During spring and summer months, DWR installs a series of temporary riprap barriers at strategic locations in the South Delta (Appendix A, Section A.1.1) for the purpose of stabilizing and increasing water surface elevations in South Delta channels to facilitate agricultural irrigation and to mitigate for effects of SWP export operations on water levels. In addition, a temporary barrier has occasionally been installed at the head of Old River during the spring to reduce the movement of juvenile salmonids into Old River in an effort to reduce exposure to the SWP and CVP export facilities and improve survival. The temporary rock barrier has also been installed at the head of Old River in the fall to improve flows and dissolved oxygen concentrations in the lower San Joaquin River to benefit upstream migrating adult fall-run Chinook salmon.

3.4.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Survival of juvenile salmonids to Chipps Island is expected to be higher in routes that avoid the Interior Delta; thus, overall survival to Chipps Island is anticipated to be higher in the presence of barriers and gates that block access to the Interior Delta routes (e.g., at the head of Old River).
- Installation of temporary barriers in the South Delta results in local changes in flows and water velocities that affect salmonid route selection and migration rates.
- Survival in localized areas where temporary barriers are installed is expected to be lower when the barriers are in because of the attraction of predators to the barrier sites.
- Barriers that result in delays in migration out of the Delta are expected to result in reduced survival.

3.4.2 Analysis

The effect of the temporary agricultural barriers in Old River near Tracy, Middle River, and Grant Line Canal (Appendix A, Section A.1.1) on juvenile salmon migration rate and survival was evaluated in 2011 (SJRGA 2013). Survival and travel times through the Delta were compared before and after the initiation of barrier installation. Total survival through the Delta to Chipps Island, as well as survival through the Old River route to Chipps Island, was higher for smolts passing Mossdale after the installation began for the OMR agricultural barriers. Travel time to CCF was also shorter after installation of the OMR barriers began (SJRGA 2013). At the Grant Line Canal barrier, more fish selected Old River and fewer fish successfully passed the barrier after installation began (passage success = 0.9972 before versus 0.9732 after, P = 0.04; SJRGA 2013).

Results from the 2011 study are somewhat paradoxical (e.g., shorter travel time and higher survival through the Old River route after barrier installation); however, because of temporal changes in conditions through the study season, effects of barriers on survival and travel time were confounded by other temporally varying conditions (e.g., flow, exports, water temperature). In particular, installation of all three barriers began near the time of increases in combined export rates (approximately June 1) from less than 4,000 cfs to greater than 8,000 cfs. Also, comparisons were made relative to the initiation of barrier installation, which lasted from one to four weeks, depending on the barrier. Fish had relatively unimpeded passage during the early parts of installation. Most tagged fish had passed through the region before the barriers were installed.

As part of the South Delta Temporary Barriers Project evaluation (DWR 2011a, 2011b), the 1-D DSM2 open channel, unsteady flow, hydrologic simulation model was used to estimate changes in average daily flow in various Delta channels with and without the temporary barriers, extending over a network from the I Street bridge in Sacramento to Vernalis on the San Joaquin River and west to Martinez. The model was used each year to represent actual hydrologic boundary conditions during the period that the barriers are installed.

Results of the DSM2 simulations showed that installation of the temporary barriers significantly altered stage and flows in the South Delta (DWR 2011a, 2011b). The effects of barrier installation were typically localized to the channels in the immediate vicinity of each barrier and diminished with distance upstream and downstream. For example, installation of the Middle River barrier in 2008 raised water elevation at the barrier approximately 0.5 feet, but the effect was limited, spatially, to the Middle River channel. Installation of the Grant Line Canal barrier was found in 2008 to raise water levels in the canal by approximately 1.5 feet as well as raising water levels in Middle River by approximately 1 foot and in Old River by approximately 0.5 feet (DWR 2011a). The barriers were also found to diminish tidal variation in flows, with the effect most pronounced in OMR when the Grant Line barrier was installed.

The HORB is installed during the spring salmonid migration period to improve juvenile fall-run Chinook salmon survival on the San Joaquin River based on results of CWT survival studies conducted by the U.S. Fish and Wildlife Service (USFWS) (DWR 2015a; SJRGA 2007). The temporary rock barrier keeps juvenile salmon in the San Joaquin River mainstem where survival is thought to be higher than for those fish that migrate into Old River, reduces the movement of juvenile salmonids into the South Delta through Old River, and reduces exposure to potential entrainment into the SWP and CVP export facilities. SJRGA (2007) provides information on the survival relationships for CWT juvenile Chinook salmon when the HORB is installed and when it is not. Results of early CWT studies generally showed a pattern of increased juvenile survival when fish did not migrate into Old River; however, results of more recent AT studies using both juvenile Chinook salmon and steelhead have not shown a consistent pattern of increased survival for those fish that remain in the San Joaquin River mainstem (see Section 3.7).

Results of DSM2 simulation modeling show that installation of the HORB significantly reduces the flow of water that entered Old River and Grant Line Canal (DWR 2011a, 2011b) from the lower San Joaquin River. The HORB increases flows in the mainstem of the San Joaquin River, decreases flow in Old River between the HORB and Grant Line Canal, and decreases minimum velocity in Middle River between the HORB and Tracy Boulevard. The HORB creates a physical barrier to juvenile salmonid migration from the San Joaquin River into Old River, although culverts through the barrier provide limited opportunities for salmonid migration through the barrier.

3.4.3 Summary of Findings

Results from CWT studies from 1985 to 1990 indicate installation of the HORB resulted in increased juvenile salmon survival, but acoustic telemetry data from 2010 to 2012 have generally not been consistent with that hypothesis. In most years, there was no significant difference between survival in the two routes, based on AT data, and survival has been very low in both routes. Survival of fall-run Chinook salmon from AT data was higher in the San Joaquin River route for one release group (in 2010), and higher in the Old River route for four release groups (2010 and 2011).

Although the SST did not conduct a comprehensive review of the existing study plans and data regarding the effect of various agricultural barriers on migration rate and route, the SST feels there are gaps in our knowledge of how fish behavior is affected by the barriers. The SST notes that because these barriers are usually constructed in mid-April or later, the presence of the barriers overlaps with the migration timing of Central Valley steelhead (from either basin, but particularly the San Joaquin River basin for both geographic and migration-timing reasons) and spring-run Chinook salmon that enter the South Delta. In years when the HORB is not installed or water levels are less of a concern, construction of these barriers may not occur until late May or later, by which time most listed salmonids have exited the Delta. The incremental contribution of the South Delta barriers to overall salmon and steelhead survival to Chipps Island over a range of hydrologic conditions remains unknown.

3.5 DELTA CROSS CHANNEL AND GEORGIANA SLOUGH MIGRATION ROUTE

The DCC radial gates are located on the Sacramento River upstream of Walnut Grove (Appendix A, Section A.1.1) and regulate the movement of water from the Sacramento River through a constructed channel into the Interior Delta and subsequently into the South Delta where it can be exported at the SWP and CVP facilities. Under State Water Resources Control Board (SWRCB) D-1641, the DCC is required to be closed during the late winter and spring to avoid the movement of juvenile salmonids through the DCC into the Interior Delta where survival studies have shown higher mortality. Georgiana Slough is a natural channel located immediately downstream of Walnut Grove (Appendix A, Section A.1.1) that also provides a pathway for juvenile salmonids to migrate into the Interior Delta. Flow in the Sacramento River in the vicinity to these two junctions is uni-directional (downstream during periods of high river flow) and bi-directional (flowing both upstream and downstream) in response to tidal conditions when river flow is reduced.

3.5.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Salmonids that enter the Interior Delta through the DCC or Georgiana Slough have lower survival when compared to salmonids migrating in the Sacramento River mainstem.
- The probability of juvenile salmonids migrating into the DCC or Georgiana Slough varies in response to local hydrodynamic conditions.
- Understanding the linkage between local hydrodynamics at the DCC and Georgiana Slough and salmonid migratory behavior can be applied to studies on migration route selection in the South Delta.

3.5.2 Analysis

In 2009, studies were conducted using ATs to investigate how survival through the Delta varied with DCC gate operations (Perry and Skalski 2009). These studies documented route selection and reach-specific survival for tagged late-fall-run salmon migrating from Sacramento to Chipps Island and migrating through three main migration routes: Sutter and Steamboat sloughs, the Sacramento River mainstem, and Georgiana Slough (Perry 2010; Perry et al. 2010, 2015). Results of these studies show that DCC gate closures can decrease the number of fish entering the Interior Delta through the DCC. However, under low Sacramento River flows and bi-directional tidal flow, just as many tagged fish entered the Interior Delta through Georgiana Slough alone, as when the DCC gates are open (Perry 2010). Many tagged fish moved upstream into Georgiana Slough on flood tides.

Studies conducted in the early 1990s on the effectiveness of a non-physical (sound) barrier at Georgiana Slough showed similar results (Hanson and SLDMWA 1996). Under low river flow conditions and flood tidal stage, flow in the Sacramento River reversed direction with water moving upstream and into Georgiana Slough. Juvenile Chinook salmon released into the Sacramento River downstream of the confluence with Georgiana Slough were collected in Georgiana Slough.

During 2010 and 2011, detailed fine-grain 3-D AT monitoring was conducted in the Sacramento River as part of the Georgiana Slough non-physical barrier research investigation

(DWR 2012, 2015b; Perry et al. 2015). High-resolution 3-D AT detection provided detailed information on the precise location and migratory pathway for each of the ATs. In addition, Acoustic Doppler Current Profilers (ADCPs) were deployed within the study reach to continuously measure water velocity profiles in the Sacramento River immediately adjacent to the confluence with Georgiana Slough.

Results of these studies demonstrate that the lateral location of juveniles within the Sacramento River is one of the factors influencing the probability that a fish will subsequently migrate into Georgiana Slough. Hydraulic streaklines suggest that juvenile salmonids migrating on the western side of the Sacramento River (farthest away from the confluence with Georgiana Slough) have a significantly lower probability of migrating into the slough compared to juveniles on the eastern side of the Sacramento River, which is subject to the hydrodynamic influence of the Georgiana Slough confluence. Fish movement into Georgiana Slough was also related to river flow and tidal conditions.

The National Marine Fisheries Service (NMFS) 2009 Biological and Conference Opinion for the Long-Term Operations of the Central Valley Project and State Water Project (BiOp) included a reasonable and prudent alternative (RPA) requiring DWR and U.S. Bureau of Reclamation (USBR) to consider engineering solutions to reduce the diversion of juvenile salmonids from the Sacramento River into the Interior and South Delta (BiOp Action IV.1.3). In response to this requirement, DWR has prepared an assessment of potential engineering approaches to improving juvenile salmon survival at various channel junctions in the Delta (DWR 2015b).

After evaluating results of experimental tests using various alternative non-physical barrier technologies, DWR implemented the Georgiana Slough Non-Physical Barrier Study in 2011 and 2012 to test the effectiveness of using a non-physical barrier, referred to as a behavioral Bio-Acoustic Fish Fence (BAFF). The BAFF combines three stimuli expected to deter juvenile Chinook salmon and steelhead from entering Georgiana Slough: sound, high-intensity modulated light (previously known as stroboscopic light), and a bubble curtain. In 2014, a floating fish fence was tested as a potential method of guiding juvenile salmonids away from Georgiana Slough into an area of the Sacramento River where flows would guide the fish downstream. As part of the studies, hydrodynamics and velocity were measured using ADCPs simultaneously to fine-scale fish movements. Results of velocity monitoring using ADCPs were used in local hydrodynamic simulation models to predict flow and velocity encountered by juvenile salmonids migrating through the test area.

3.5.3 Summary of Findings

The effects of DCC gate operations are well studied and understood, although several information gaps have been identified. Interest has been expressed in further examining potential alternative radial gate operations including gate closures in the fall to reduce adult fall-run Chinook salmon from straying from the Mokelumne River into the American River that would also allow some water flow into the Interior Delta to benefit water quality and other uses.

Although there have been several non-physical barrier studies conducted, conditions of low Sacramento River flow and strong tidal flow reversals have not been evaluated. The application of high-resolution ATs in combination with detailed site-specific hydrodynamic monitoring (ADCP velocity and flow monitoring) and simulation modeling has proven to be an effective approach to assessing the interaction between local hydrodynamics and salmonid route selection at Georgiana Slough and the DCC, but has not been applied to migration or survival studies in the South Delta.

A variety of site-specific conditions, including the location of the migrating salmonids within the channel cross-section, channel configuration, flow, and velocity patterns have been identified as affecting route selection.

3.6 JUVENILE SALMONID SURVIVAL IN THE SOUTH DELTA

Over the past several decades, there have been a number of experimental survival studies conducted in the South Delta using juvenile Chinook salmon (Brandes and McLain 2001; SJRGA 2007, 2013; Buchanan et al. 2013; Appendix E, Section E.2). Past studies were performed using CWT juveniles released during the spring at various locations in the lower San Joaquin River and recaptured at Antioch and Chipps Island. More recent studies have used acoustic-tagged juvenile salmon and steelhead. Results of these studies are discussed in detail in Appendix E and summarized below.

3.6.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Survival of juvenile salmonids varies among years with greatest survival during wet years and reduced survival in dry years.
- Survival of larger yearling steelhead is expected to be greater than that for smaller Chinook salmon smolts.

3.6.2 Analysis

Since 1998, survival studies conducted with both CWT and acoustic-tagged juvenile Chinook salmon have documented a substantial decline in survival in the lower San Joaquin River (Figure 3-9). Survival through the Delta tends to be lower than survival through comparable distances and environments for different populations (i.e., larger fish) or in different systems (Perry et al. 2010; Buchanan et al. 2013; Michel et al. 2015). Multivariate statistical analyses of the existing survival and migration data have been initiated but are not complete.

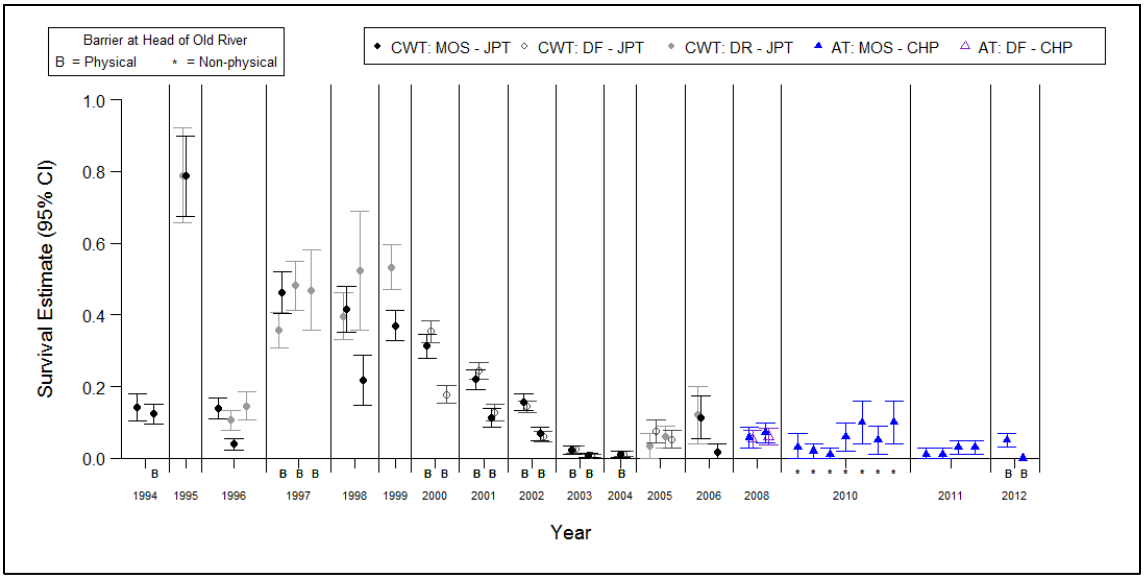


Figure 3-9. Estimated Survival of Fall-run Juvenile Chinook Salmon from Mossdale, Durham Ferry, or Dos Reis to Either Jersey Point (CWT) or Chipps Island (AT)

Note: Intervals are 95% confidence intervals, truncated to 0 if necessary.
Sources: SJRGA 2013; Buchanan et al. 2015

Results of survival studies have shown:

- Survival of acoustic-tagged fall-run Chinook salmon migrating through the Delta (to Jersey Point or Chipps Island) has been approximately 5% or less in recent years (Figure 3-9). Since 2002, survival from Mossdale to Jersey Point or Chipps Island has been less than 5% for 14 of 22 estimates, and less than 10% for 20 of 22 estimates (Appendix E, Section E.2.1.1).
- Survival to Chipps Island via export facilities is higher for the CVP than for the SWP.
- The survival rate per kilometer from the CVP to Chipps Island via salvage was sometimes higher than the survival rate through the lower San Joaquin River reaches.
- Sacramento River Chinook salmon and steelhead survival has been variable across years and among populations. For example, in 2013 and 2014, through-Delta survival was estimated at 32% and 35% for winter-run Chinook salmon, 0% to 30% for spring-run Chinook salmon, and 0% for fall-run Chinook salmon (data only for 2014), whereas between 2006 and 2010, late-fall-run Chinook salmon had through-Delta survival estimates ranging from 17% to 64%. Based on two years of data, survival of juvenile steelhead migrating from the Sacramento River (47 to 58%) has been comparable to estimates of Sacramento River late-fall-run Chinook salmon survival from the same years (34% to 64%).
- Based on data from 2011 and 2012, survival of acoustic-tagged juvenile steelhead migrating from the San Joaquin River (0.32 to 0.54) has been greater than that of fall-run Chinook salmon from the same years (0.02 to 0.03) (Appendix E, Section E.2.1, Table E.2-3).

The incremental contribution and relationships between water project operations, predation, and other stressors on the high levels of juvenile salmonid mortality observed in the South Delta is largely unknown. Results of acoustic tagging studies are beginning to provide information on reach-specific mortality; however, the underlying cause of the high mortality is uncertain.

3.6.3 Summary of Findings

Based on results of available information the SST concluded that:

- Survival of juvenile steelhead migrating through the San Joaquin River and Delta is greater than that for juvenile Chinook salmon. This finding is consistent with the conceptual model prediction that larger juveniles have greater survival, but this is based on only two years of steelhead survival data.
- Juvenile Chinook salmon survival did not increase in 2011 in response to wet hydrologic conditions when compared to dry conditions in 2012, which is not consistent with the conceptual model prediction.
- Survival of juvenile Chinook salmon has shown a declining trend with survival over the past decade, typically 5% or less for those fish migrating through the lower San Joaquin River and Delta, independent of hydrologic conditions.
- Survival of juvenile salmonids is generally greater in the Sacramento River than in the San Joaquin River, but varies with population and year.

3.7 SURVIVAL AS A FUNCTION OF ROUTE SELECTION

3.7.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Route selection is a major factor in determining the probability of survival.
- Fish that migrate through Old River at its distribution point from the San Joaquin River are likely to have a lower probability of survival than those that use the San Joaquin River mainstem.
- Fish that enter the Interior Delta from distribution points farther downstream on the San Joaquin River (e.g., Turner Cut or Columbia Cut) or via Georgiana Slough are expected to have lower survival through the Delta than fish that remain on the mainstem river, whether they are migrating from the San Joaquin River or from the Sacramento River.
- Survival rates (per kilometer) are expected to vary within the Delta because of differences in habitat and predation pressure.
- Route selection is expected to be affected by the incremental effect of exports on water velocity and flow within a channel or at channel junctions.
- Export effects on route selection are expected to be greatest in the immediate vicinity of the export facilities and diminish as a function of distance away from the facilities.

3.7.2 Analysis

Two primary routes through the South Delta were examined: Old River and San Joaquin River (Figure 3-10 and Figure 3-11). Migration through the CVP and SWP fish salvage facilities is a component of both routes because fish can enter the South Delta at Turner Cut or downstream. The primary differences in the routes are the upstream reaches.

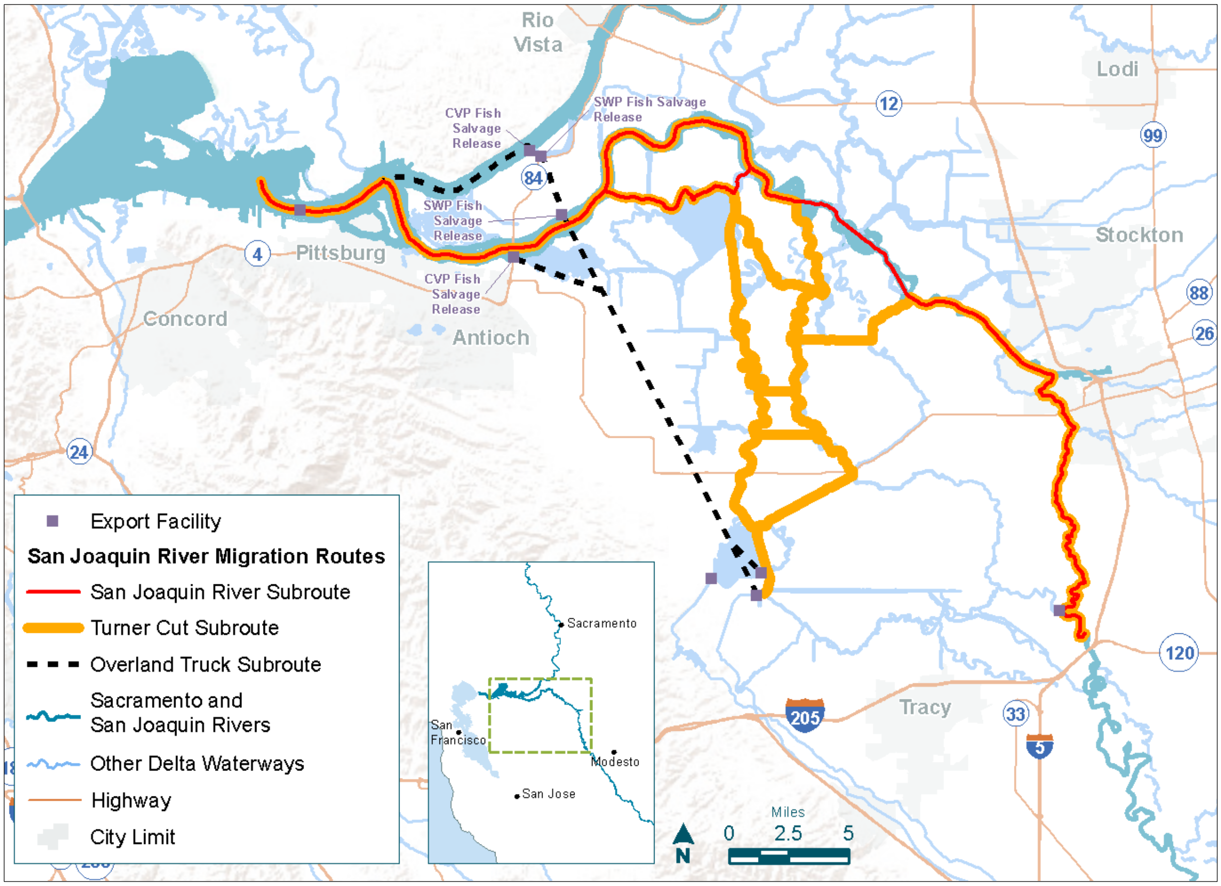


Figure 3-10. Migration Routes to Chipps Island for Fish that Remain in the San Joaquin River at the Head of Old River ("San Joaquin River Route")

Notes: The migration route of salvaged fish is shown as a dashed line. The San Joaquin River mainstem subroute is shaded in red, and the Turner Cut subroute through the Interior Delta is shaded in orange.

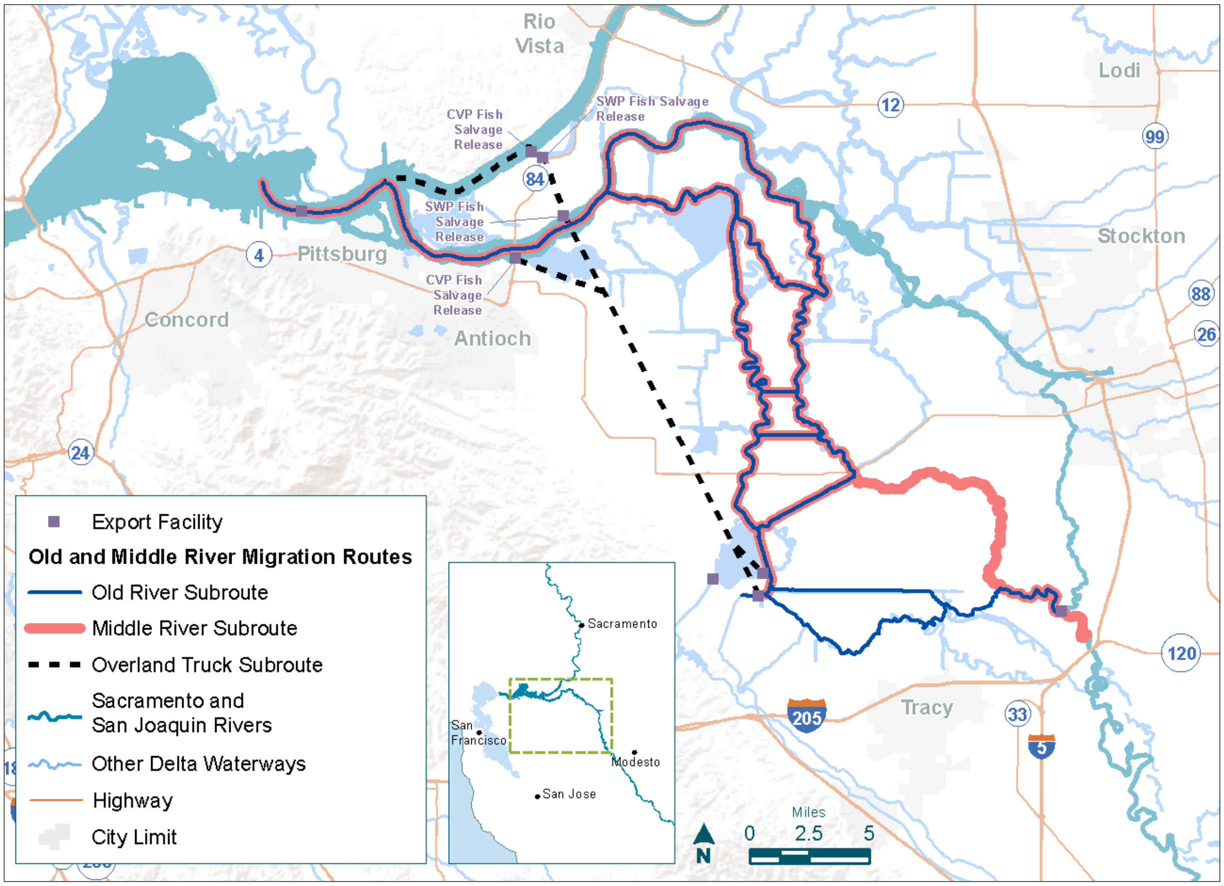


Figure 3-11. Migration Routes to Chipps Island for Fish that Enter Old River at the Head of Old River ("Old River Route")

Notes: The migration route of salvaged fish is shown as a dashed line. The Old River subroute is shaded blue, and the Middle River subroute is shaded pink.

Migrating salmonids can enter the South Delta from the San Joaquin River via the head of Old River, Turner Cut, Columbia Cut, OMR, and False River. We did not examine junctions other than Old River and Turner Cut because there are no data on their use, but we recognize that they may be important entrances to the South Delta.

We first examined broad-scale, route-specific survival, then focused on reach-specific information to better understand patterns of survival at a smaller spatial scale.

Route Survival from the Head of Old River

At the head of Old River, fish either enter Old River and move into the South Delta or fish remain in the San Joaquin River. In many years, a temporary physical barrier (HORB) has been installed at the head of Old River to reduce the number of migrating salmon entering the Interior Delta at that junction. In 2009 and 2010, an experimental non-physical barrier (bioacoustic fish fence) was tested in place of the physical barrier (DWR 2015a). In 2012, the physical barrier was installed.

The following summarizes results of survival studies in relation to the installation of the HORB:

- From 1985 to 1990, the HORB was not installed. The fall-run Chinook salmon survival index to Chipps Island was greater for fish released in the San Joaquin River than for those released in Old River for all but one release group (Appendix E, Section E.12; Brandes and McLain 2001).
- In 2008 the HORB was not installed and AT Chinook salmon that remained in the San Joaquin River at the head of Old River had higher survival than fish that entered Old River. However, fish mortality was confounded with a high rate of premature tag failure (Holbrook et al. 2009) and there was no predator filter applied to AT data that year.
- In 2010, a bio-acoustic fish barrier was installed and the relative survival of Chinook salmon in the San Joaquin River route versus the Old River route varied throughout the study: only the first release group had significantly higher survival in the San Joaquin River. When the data were pooled across all releases, fish that took the Old River route had higher survival (SJRGA 2011).
- In 2011, no barrier was installed and survival of Chinook salmon to Chipps Island was consistently low, but was higher for two groups of tagged fish (out of five) that entered Old River during higher exports ($P < 0.05$) than for those that remained in the San Joaquin River (SJRGA 2013).
- In 2012, the Old River physical barrier was installed and survival was higher in the San Joaquin River route than in the Old River route for steelhead, but there was no difference by route for Chinook salmon (Buchanan 2015; Buchanan et al. 2015).

Reach Survival

Survival rates at the reach scale for Chinook salmon and steelhead in the San Joaquin River and Old River were examined to see how specific reaches contribute to route-specific survival. The examination used reaches and sub-reaches that generally corresponded with landmarks from previous studies and important junction locations within the South Delta as shown in Table 3-1 and Figure 3-12.

Table 3-1. Heat Map Depicting Survival Rates (S(1/km)) Through San Joaquin River Reaches to Chipps Island

Reach Name (km)	Survival estimate per km ($S^{(1/km)}$)						
	Chinook Salmon					Steelhead	
	2008	2009	2010	2011	2012	2011	2012
Durham Ferry (Release) to Banta Carbona (11)			0.999	0.994	0.975	0.962	0.967
Banta Carbona to Mossdale (10/9)			0.995	0.993	0.953	0.982	0.978
Mossdale to Head of Old River (4/5)	0.967	0.954	0.981	0.997	0.987	0.985	0.995
Lathrop to San Joaquin River at Garwood Bridge (18/15)	0.986	0.971	0.989	0.993	0.980	0.995	0.997
Garwood Bridge to SDWSC (3)	0.955	0.921	0.983	0.980	0.936	0.993	0.990

Reach Name (km)	Survival estimate per km ($S^{(1/km)}$)						
	Chinook Salmon					Steelhead	
	2008	2009	2010	2011	2012	2011	2012
SDWSC to Turner Cut Junction (15)	0.958	0.852	0.942	0.965	0.947	0.997	0.994
MacDonald Island to Medford Island (5)			0.863	0.833	0.852	0.942	0.923
Turner Cut to Jersey Point (includes Interior Delta route but not San Joaquin River) (28)	0			0	0	0.958	0.934
Medford Island to Jersey Point (21)				0.881	0.964	0.992	0.987
Jersey Point to Chipps Island (22)	0.981			0.983	0.971	0.997	0.989

Notes: SDWSC = Stockton Deepwater Ship Canal. Red boxes indicate lowest survival rate (less than 0.90 per km) and lighter boxes indicate higher survival rate (white: greater than or equal to 0.99 per km). Missing values reflect too few fish present in the reach to estimate survival, or the study was not designed to estimate parameter.

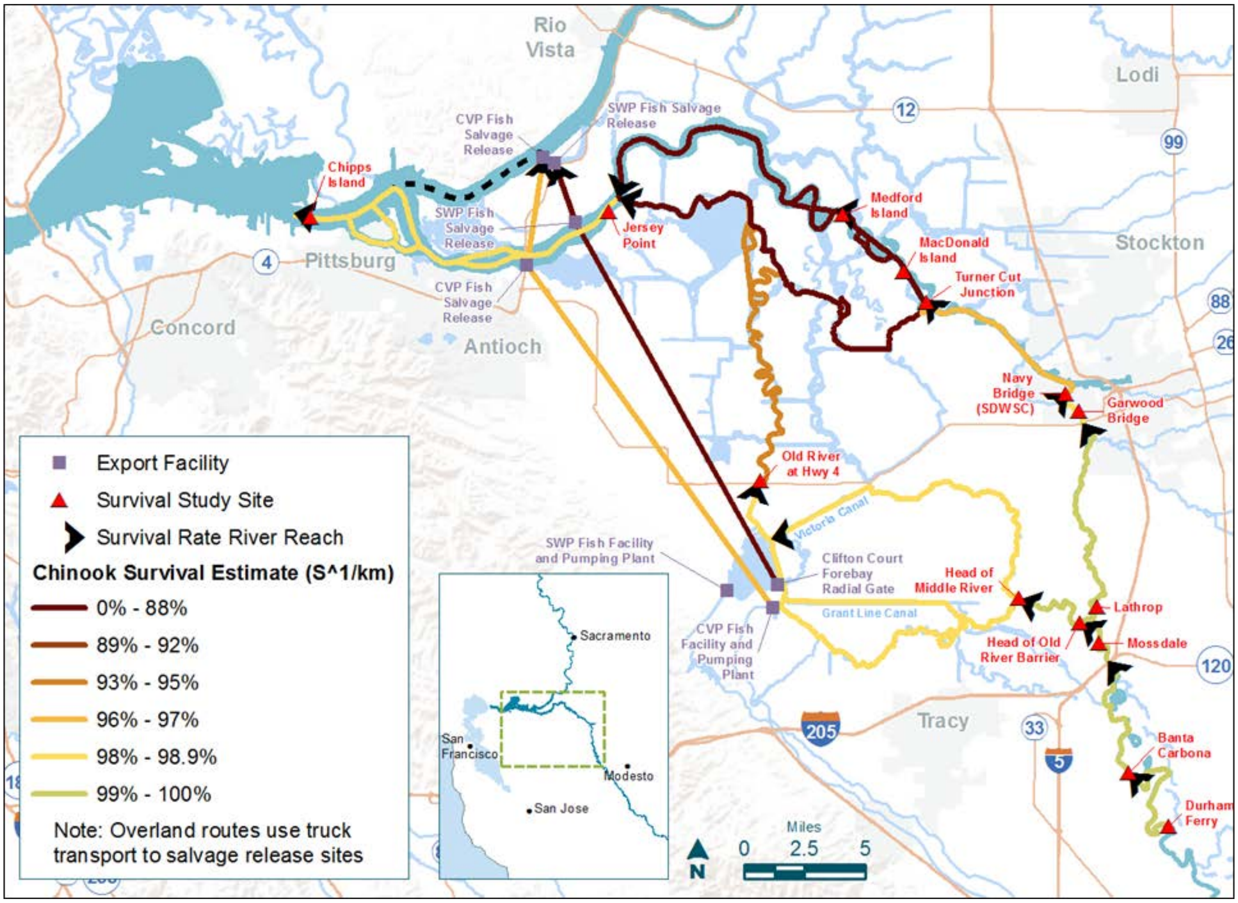


Figure 3-12. Geographical Illustration of Heat Map Survival Rate (per km) Estimates for 2011 Chinook Salmon

Note: See Table 3-1 and Table 3-2 for complete results from all years and species.

Turner Cut to Chipps Island

Survival of fish on the San Joaquin River mainstem between Turner Cut and Chipps Island is among the lowest for both Chinook salmon and steelhead (Figure 3-12). Migrating into Turner Cut resulted in even poorer survival to Chipps Island (Table 3-1; Figure 3-12). Results in 2010, 2011, and 2012 indicate that none of the 13%, 21%, or 11% of the Chinook salmon, respectively, estimated to have migrated into Turner Cut survived to Chipps Island (although some tags identified as predators were detected at Chipps Island) (SJRGA 2011, 2013; Buchanan et al. 2015). In contrast, the probability of surviving from the Turner Cut junction to Chipps Island for Chinook salmon that remained in the San Joaquin River at Turner Cut was estimated at 0.14, 0.02, and 0.14 for these three years, respectively (Appendix E, Section E.4.2.2; SJRGA 2011, 2013; Buchanan et al. 2015).

The acoustic telemetry study of juvenile steelhead that was part of the 2012 stipulation study (Delaney et al. 2014) also found that survival to Chipps Island was lower for steelhead that entered Turner Cut than for steelhead that remained in the San Joaquin River. Results from the first two years of the six-year study of acoustic-tagged steelhead (2011 to 2012) estimated the probability of surviving from the Turner Cut junction to Chipps Island as 0.43 and 0.18 for fish that entered Turner Cut, compared to 0.78 and 0.49 for fish that remained in the San Joaquin River (Buchanan 2013, 2014). This suggests that staying in the San Joaquin River at Turner Cut was beneficial for steelhead, as well as Chinook salmon.

Salmon Survival Through Old River

For survival reaches along the Old River migration route (Figure 3-12), survival rates per kilometer were often higher in the Old River to Middle River and Middle River to Highway 4 reaches, but there was considerable variability between years (Table 3-2). Survival rates for reaches leading to or bypassing the fish facilities (but not passing through the facilities) were generally comparable to those observed in the San Joaquin River for both Chinook salmon and steelhead.

Survival estimates are missing for some reaches and Chinook salmon release groups, either because the receivers were not in place to allow for survival estimation in the reach (e.g., survival to Jersey Point or Chipps Island in 2009; Table 3-1 and Table 3-2) or because too few fish were observed in the region to estimate survival (i.e., from the Highway 4 sites in 2012, when a physical barrier was installed at the head of Old River; Table 3-2).

The survival rates for fish passing into CCF were consistently low relative to other reaches for Chinook salmon and steelhead. The lowest observed survival rates for Chinook salmon, among all reaches in both the Old River route and the San Joaquin River route occurred in reaches that included the SWP and CVP fish facilities (including the Turner Cut route). Nevertheless, survival from the CVP to Chipps Island (via salvage) was sometimes higher than survival through the lower San Joaquin River reaches (Table 3-1 and Table 3-2).

Table 3-2. Heat Map Depicting Survival Rates (S(1/km)) Through Old River Reaches to Chipps Island

	Survival estimate per km ($S^{(1/km)}$)						
	Chinook					Steelhead	
Reach Name/(km)	2008	2009	2010	2011	2012	2011	2012
Old River (head) to Middle River Head (6)		0.953	0.983	0.997	0.981	0.990	0.977
Middle River Head to CVP/CCF/HWY 4 (20/21)		0.912	0.997	0.981		0.994	0.977
Old River near HWY 4 to Jersey Point (60)			0.926	0.936		0.992	0.958
CVP tank to Chipps Island (15/19)	0.845		0.972	0.969		0.988	0.973
CCF Radial Gates (interior) to Chipps Island (21/24)	0.904		0	0.83		0.979	0.924

Notes: Red boxes indicate lowest survival rate (less than 0.90 per km) and lighter boxes indicate higher survival rate (white: greater than or equal to 0.99 per km). Missing values reflect too few fish present in the reach to estimate survival, or the study was not designed to estimate parameter.

3.7.3 Summary of Findings

Results from CWT studies from 1985 through 1990 are consistent with the conceptual model predictions that through-Delta survival is higher for fish that avoid the Interior Delta, but AT data from 2010 through 2012 have generally not been. In most years, there was no significant difference between Chinook salmon survival in the two primary routes (San Joaquin River and Old River), based on AT data, and survival has been very low in both routes.

The routes that include the water export facilities tend to have the lowest survival through the Delta, including the route from Turner Cut through the Interior Delta. However, survival from the CVP to Chipps Island via salvage was sometimes higher than survival through the lower San Joaquin River reaches. Approaching the CVP appears to have high risk of predation, but successful passage to and through the salvage system enables the fish to avoid migrating through the rest of the South Delta.

Survival from the Turner Cut junction to Chipps Island has consistently been higher for fish that remain in the San Joaquin River at that junction than for fish that enter Turner Cut, for both Chinook salmon and steelhead.

Survival tends to be higher in the upstream reaches and in the San Joaquin River mainstem compared to the Interior Delta, although survival through the lower San Joaquin River reaches appears comparable to survival through Interior Delta reaches.

The linkages relating survival to migration route are not well understood. Although it is hypothesized that mortality is primarily due to predation, there is little direct information on predation rates, predator communities, and habitat characteristics that might affect predation rates throughout the South Delta.

3.8 SURVIVAL AS A FUNCTION OF MIGRATION RATE

Two differing conceptual models hypothesize how migration rate may influence juvenile salmonid survival: 1) a slow migration rate may lower survival by prolonging exposure to mortality risks such as predation and entrainment in the water project export facilities or other unscreened diversions; or 2) a slow migration rate may increase survival by increasing exposure to favorable rearing conditions in the Delta resulting in larger, healthier juveniles.

3.8.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Juvenile salmonids with slower migration rate will have lower survival probabilities through the Delta.
- Juvenile salmonid migration rate is expected to be higher and more strongly related to water velocities in the riverine reaches of the Delta and slower in the tidal reaches.
- Migration rate is expected to vary among juvenile lifestages with migration rates increasing as a function of increasing fish length.
- Based on differences in size and maturity, migration rates for yearling steelhead that migrate, and do not residualize, are expected to be faster than for Chinook salmon smolts.
- Extended exposure to higher water temperatures may reduce fitness because of increased disease or increased predation rate because of heightened metabolic rate of the predators.
- Independent of temperature, prolonged exposure to regions with higher predation risk are expected to increase the probability of mortality.
- Extended exposure to the entrances to the water export facilities are expected to increase entrainment risk, but may or may not also increase the probability of being salvaged and trucked around the rest of the Delta.

3.8.2 Analysis

The XT model predicts that survival of prey (salmonids) will be proportional to migration rate in tidal reaches, as prey slow down relative to predators (Anderson et al. 2005). Several publications are available on the relationship between migration rate and survival in the Delta. It has been observed in the north Delta that slower migration rates are correlated with increased mortality of juvenile Chinook salmon (e.g., Perry et al. 2010). Cavallo et al. (2012) observed in an experimental study that large increases in flow were followed by increased migration rates and higher survival for juvenile Chinook salmon in the lower Mokelumne River, but the survival effect was not consistent across reaches.

The majority of information pertaining to the South Delta comes from CWT and AT studies (Holbrook et al. 2009; SJGRA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2013, 2015). We examined migration rates and survival in the San Joaquin River and Old River for the same reaches described in Section 3.7. We also explored observed patterns in travel time and survival from Mossdale to Chipps Island and Jersey Point, using data from CWT studies from 1996 through 2006 (Newman 2008).

Migration rate (kilometers per day) in the San Joaquin River tended to be faster for both Chinook salmon and steelhead in the upstream reaches (Lathrop to SDWSC and Old River to the head of Middle River) compared to downstream reaches. The predominantly tidal reach between the upstream entrance of the SDWSC and the Turner Cut junction tended to have slower rates of travel. The reach from the CCF gates to Chipps Island (via salvage at SWP) had the slowest travel rates for steelhead.

Analysis conducted by the SST used simple linear regression to compare survival estimates of CWT fall-run Chinook salmon from the Mossdale area of the San Joaquin River to Jersey Point with travel time. The survival data are actually differential recovery rates (DRR) of CWT fish released in 1996 through 2006 upstream in the San Joaquin River (i.e., Mossdale, Durham Ferry, or Dos Reis) relative to those released at Jersey Point, and recovered in the Chipps Island trawl or in ocean fisheries (Newman 2008). Travel time was calculated as a weighted average of observed delay from release to recapture, for all individuals recaptured from a release group; Dos Reis release groups and ocean recoveries were omitted from the travel time calculations. Comparison of the DRR to average travel time showed no significant relationship between travel time and survival for these CWT data (P = 0.52; r = 0.17; Figure 3-13).

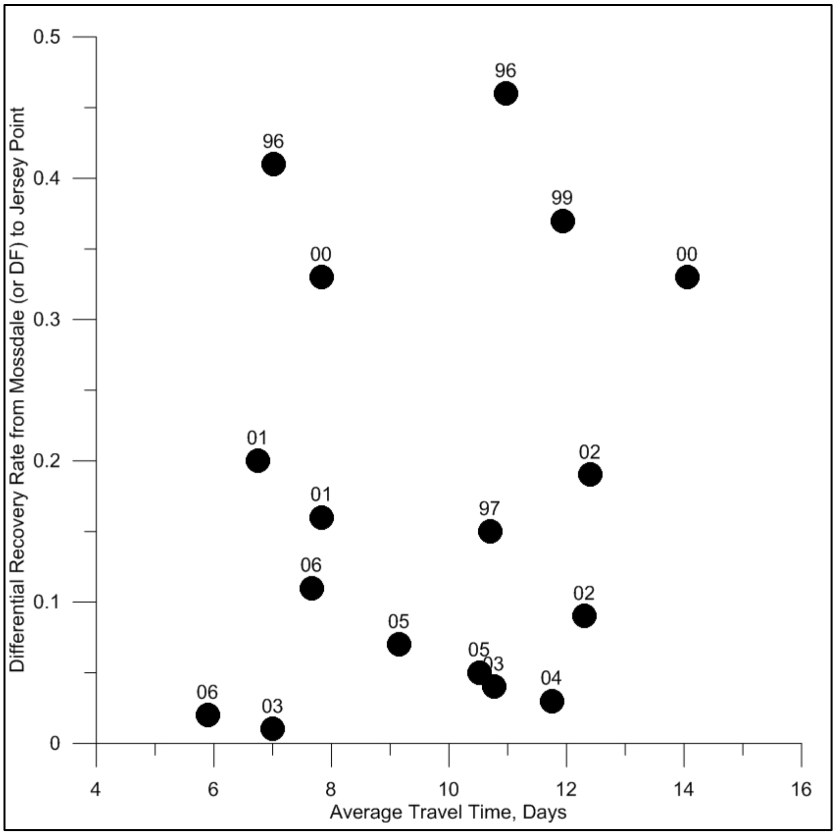


Figure 3-13. Average Travel Time of Specific Releases of Fall Chinook Salmon Versus an Estimate of Survival Based on a Ratio of Recovery Fractions for Upstream Releases to Downstream Releases at Jersey Point for the Mossdale to Jersey Point Reach

Note: Data plotted by Sheila Greene (Westlands Water District).

Results of the survival and migration studies conducted on the Sacramento River (Michel et al. 2015) showed evidence of a weak relationship between migration rate and survival for AT late-fall-run Chinook salmon produced in the Coleman hatchery and released into the upper Sacramento River at Battle Creek or Jelly's Ferry and monitored downstream to the Golden Gate as shown below:

Year	Overall % Survival	Mean Successful Migration Movement Rate (km/day)
2007	2.8	23.5 (+/- 3.6)
2008	3.8	17.5 (+/- 1.5)
2009	5.9	17.5 (+/- 1.1)
2010	3.4	21.9 (+/- 2.1)
2011	15.7	36.0 (+/- 3.0)

3.8.3 Summary of Findings

A positive association between migration rate and survival was observed in AT data for various regions of the Delta: north Delta (Perry et al. 2010) and lower Mokelumne River (Cavallo et al. 2012). Preliminary SST analysis of South Delta data observed this pattern in some reaches in the San Joaquin River (Lathrop to SDWSC) and SDWSC to Turner Cut (for steelhead only), and in the Old River between the heads of Old and Middle rivers. However, the migration rate-survival relationship was not consistent in all reaches, years, and data sources. The expected positive relationship between migration rate (kilometers per day) and survival was not observed from SDWSC to the Turner Cut junction for AT Chinook salmon. CWT Chinook salmon data from San Joaquin River releases showed no relationship between DRR (i.e., survival index) and travel time from upstream San Joaquin River sites to Chipps Island (Figure 3-13).

Although there are several years of data on survival and migration rate in some reaches of the San Joaquin River, we do not yet have a general understanding of the relationship between migration rate and survival in all regions of the Delta.

3.9 SURVIVAL AS A FUNCTION OF EXPORT RATE

Increased export rates have been hypothesized to draw more fish into the South Delta and into the water export facilities, decreasing survival through the Delta to Chipps Island. The effects of exports on juvenile salmonid survival may be direct effects (e.g., losses at the export facilities) or indirect effects (e.g., losses that occur in the Delta that are affected in some way by water project operations such as changes in Delta hydrodynamics that result in mortality through mechanisms such as predation or entrainment at unscreened water diversions).

3.9.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Direct mortality is a function of export rates.
- Pre-screen loss is higher at the SWP than at the CVP because fish must navigate CCF outside the SWP.
- Pre-screen loss is higher for Chinook salmon than for steelhead because Chinook salmon are smaller.
- Louver efficiency is higher at higher export levels.
- Salvage can be used as a surrogate for entrainment rates.
- The rate of indirect mortality in the Delta will increase as export rates increase.

3.9.2 Analysis

A central issue confounding the ability to identify and isolate the influence of export and inflow on juvenile survival is the correlation of inflow and export rates across the range of conditions tested during acoustic telemetry and CWT survival studies. Mean values of San Joaquin River inflow at Vernalis during the VAMP management periods from 2000 through 2011 ranged from 2,280 cfs in 2009 to greater than 20,000 cfs in 2006; average observed export rates from the same periods ranged from 1,330 cfs to 5,750 cfs (Figure 3-14). Correlation between inflow and exports was r = 0.60 throughout the VAMP study; however, without the first observation from 2006, correlation was considerably higher (r = 0.98) (Figure 3-14). Newman (2008) also reported that "exports and flows were highly positively correlated" (r = 0.88) in his analysis of VAMP and pre-VAMP CWT data. Inflow is also partially confounded with the status of the HORB because the barrier cannot be installed when flows are greater than 5,000 cfs or operated when flows are greater than 7,000 cfs.

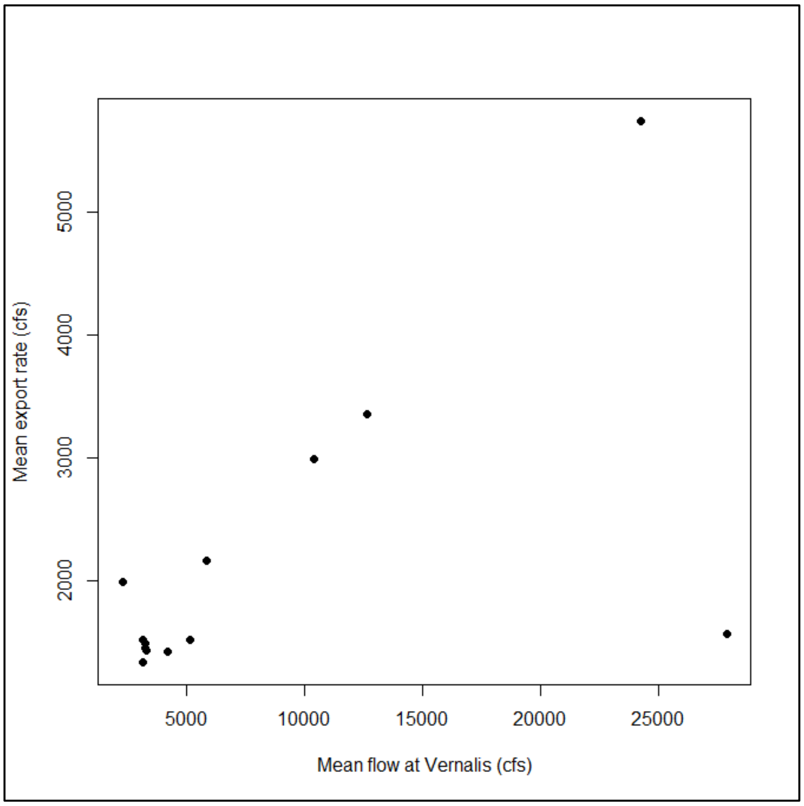


Figure 3-14. Observed Mean Inflow and Exports During VAMP Period, 2000 Through 2011

Note: Reproduced from SJRGA (2013).

The high correlation between covariates confounds estimation of the effects of the individual covariates. Single-variable analyses can identify observed relationships between individual covariates and survival, but will not be able to determine which covariates actually drive survival or account for multicollinearity. A multi-covariate analysis may be more appropriate to determine the relative effects of inflow, exports, and the barrier on survival, but will still be hindered by the degree of correlation among the covariates. Separating the effects of inflow and exports on survival is further complicated by the practice of increasing upstream reservoir releases to provide water for anticipated increased export rates.

A large number of survival studies have been conducted using CWT and more recent ATs to assess the potential relationships between SWP and CVP export operations and the migration and survival of juvenile Chinook salmon and steelhead (Brandes and McLain 2001; Baker and Morhardt 2001; Newman 2008; Newman and Brandes 2010; Perry et al. 2010, 2012; Perry 2010; Delaney et al. 2014; Zeug and Cavallo 2013, 2014; SJRGA 2007, 2013; Buchanan et al. 2013; Appendix E, Section E.6.2). Most of the available data on the survival of fish in the San Joaquin River relative to export levels were collected in the lower portion of the export range. More than 80% of the tests were conducted when exports were less than 4,000 cfs.

Many of the current management metrics for regulating export rates are based on a ratio between Delta inflow and exports such as the Delta E:I or San Joaquin River I:E. When these regulatory measures are in place, there is a high correlation between flows and exports. Therefore, distinguishing between the effects of exports and inflow on juvenile survival through correlation is difficult. No causal conclusions can be made from observational data and correlation analysis. The association between exports and survival has not been analyzed using rigorous statistical methods. These data are being processed and formal statistical analysis has been initiated.

The SST evaluated available CWT and AT data using visual inspection of scatterplots. Scatterplots are used to observe broad patterns in the data, but are not conclusive. The preliminary graphical analysis provided by the SST is meant to suggest possible relationships based on existing data, but is not meant to provide final conclusions on the existence and type of relationships between survival and inflows or exports.

Chinook Salmon

For Sacramento River late-fall-run Chinook salmon, Newman and Brandes (2010) reported evidence of a negative relationship between exports and the relative survival of Chinook salmon released in the Interior Delta compared to those released in the Sacramento River mainstem. However, they also reported equal support for a model that replaced exports with E:I, and nearly equal support for a simpler model that excluded exports entirely. They suggest that the indeterminacy of the modeling results may have resulted from a low signal-to-noise ratio in the data. In particular, there was a large amount of variability in the relative survival estimates that was unexplained by exports.

Newman (2003) reported a negative effect of exports on survival of Sacramento River fall-run Chinook salmon through the Delta, as well as significant effects of flow, salinity, temperature, tide, turbidity, and position of the DCC gate. Perry (2010) modeled survival of

AT late-fall-run Chinook salmon migrating through various routes in the Sacramento River as a function of flow, exports, and fish length, and found no effect of exports on survival in Interior Delta routes; he did not explore the possible effect of exports on survival in mainstem routes.

Simple single-variable graphical analyses using both CWT and AT data from San Joaquin River Chinook salmon also show equivocal patterns in survival and exports (Figure 3-15). Based on the CWT data, survival to Jersey Point appears to increase as exports increase for exports less than approximately 4,000 cfs, despite considerable variability not explained by export rate (Figure 3-15). However, this pattern does not appear to hold for the AT data, and is complicated by an unbalanced study design of export levels (i.e., many low export observations and few high) and the correlation between flow and exports. Unlike the CWT data, there does not appear to be a positive relationship between exports and survival using only AT data. Whether this is due to changes in study methodology or to changes in the system over time is not known (most CWT studies predate AT studies). Using either CWT or AT data alone or combined, there is considerable variation in survival estimates from Mossdale to Jersey Point for export levels less than 4,000 cfs, whereas the survival estimates for higher export levels are consistently low (upper left plot in Figure 3-15).

Similar patterns are observed for survival from Mossdale to Chipps Island from AT data (top right plot in Figure 3-15). This pattern is consistent with a factor-ceiling relationship, in which high levels of exports restrict the range of survival values, but low levels of exports impose no such restriction, and other factors control survival at low levels of exports. However, although the data suggest such a relationship may be possible based on a visual inspection of the scatterplots, it is important to note that there are only two survival observations for export levels greater than 4,000 cfs, and the low survival estimates observed for these two export levels are well within the range of observations at lower export levels.

Although it is possible that both the observed survival estimates for high export levels (i.e., greater than 4,000 cfs) were low because high export rates impose a low maximum survival, it is also possible that the limited range of the observed survival estimates was due to chance.

To explore that possibility, we ran simulations by randomly selecting two observations, without replacement, from the pool of estimated survival probabilities from low export levels (less than 4,000 cfs), and computed the frequency of observing only estimates less than the maximum observed for the higher export levels (i.e., less than or equal to 0.07). The event of observing only survival estimates less than or equal to 0.07 occurred in only 10% of 100,000 simulations, indicating a low probability of observing two such low estimates only by chance. This exercise supports the hypothesis that a high export rate imposes a maximum on through-Delta survival, although there remains uncertainty about the value of the maximum survival possible.

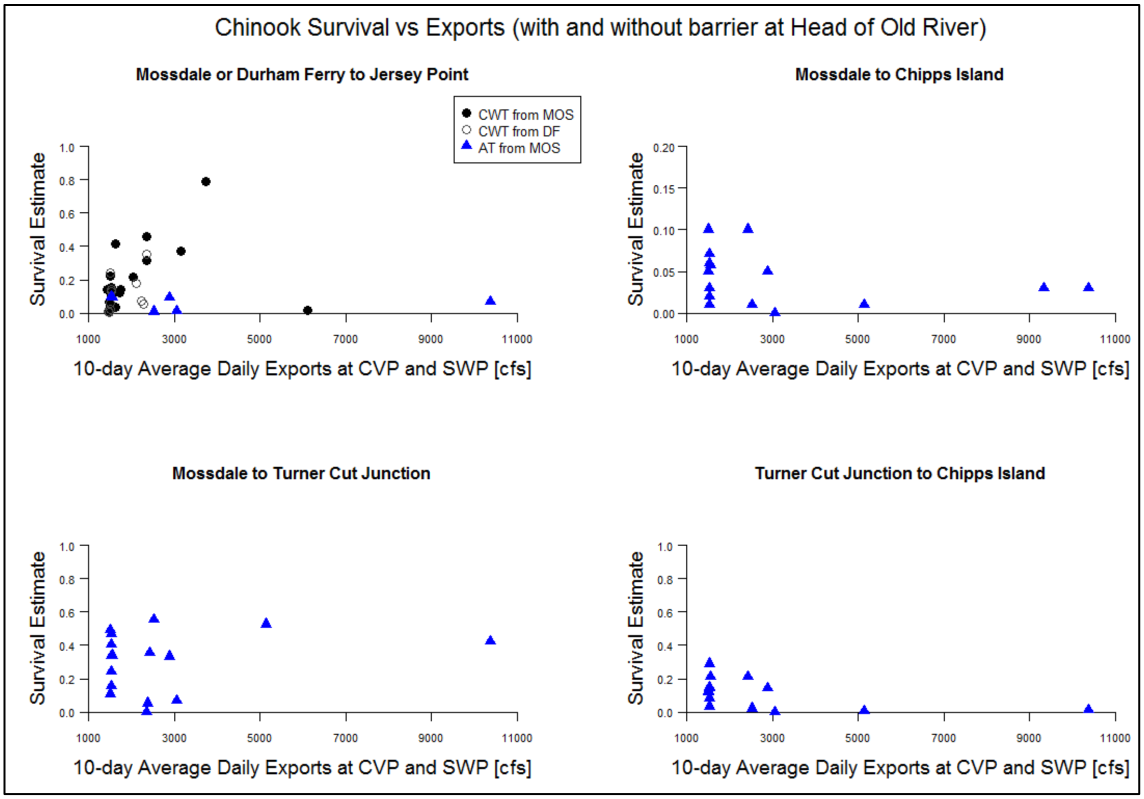


Figure 3-15. Estimated Survival of Fall-Run Chinook Salmon Versus the 10-Day Average of Daily Exports at CVP and SWP, Under all Barrier Conditions at the Head of Old River

Notes: Export rates are measured from the final day of release at Durham Ferry or Mossdale, downloaded from www.water.ca.gov/dayflow/. Before 2002, SWP omits Byron Bethany Irrigation District (BBID) intake; in 2002, SWP = Banks Pumping Plant flow; after 2002, SWP includes BBID. Survival from Mossdale or Durham Ferry to Jersey Point and Chipps Island includes all routes.

There is some indication that survival from Turner Cut to Chipps Island may decrease with increasing exports (Figure 3-15), but there is considerable variation in survival estimates at the lowest export level (1,500 cfs). Again, this is consistent with a factor-ceiling relationship in which the export rate restricts the maximum survival possible while other variables control the mean survival. However, as on other spatial scales, there are only two observations at exports greater than 5,000 cfs. Further analysis is warranted that accounts for barrier status at the head of Old River and intra-annual variation. Additional years of data are likely to be required to clarify any relationship between exports and survival.

During the VAMP study (2000 through 2011), low export rates were maintained during the spring outmigration period, resulting in low velocities at the primary louvers at the CVP Tracy Fish Collection Facility, which do not maintain high facility efficiencies. To compensate, the CVP attempted to increase the primary bypass ratio during these times, which resulted in increased secondary channel velocities, and higher recovery rates of Chinook salmon (USBR 2008). Gingras (1997) found higher survival for Chinook salmon in CCF when exports were higher. Nevertheless, visual inspection of simple scatterplots of estimated facility survival, from entrance at the CVP trash racks or CCF radial gates to Chipps Island, plotted against export rates show no well-defined trend, based on AT data from the VAMP study and the 2012 Chinook salmon tagging study in the South Delta (Figure 3-16). For survival from the CVP trash racks to Chipps Island, both the highest and lowest survival estimates were observed for the lowest levels of exports, whether restricted to CVP exports or to combined CVP and SWP exports (top row, Figure 3-16). This suggests that at very low export levels, a combination of factors that are not directly related to exports determine survival through the CVP. For average CVP export rates greater than 2,000 cfs (or combined exports greater than 5,000 cfs), survival from the CVP trash rack to Chipps Island was between 0.10 and 0.25, suggesting that export rates in this range may impose a restriction on the survival probabilities possible, but there does not appear to be a relationship between export rate and average survival probability (Figure 3-16). It is possible that a related factor determines survival at these export rates. Additional observations in this range (e.g., CVP greater than 2,000 cfs) may provide more insight into the relationship between exports and survival through the CVP facility. For survival through CCF to Chipps Island, survival was at or near 0 for all observations, except for one of the highest export levels (Figure 3-16). No survival estimates are available from the SWP trash racks to Chipps Island because acoustic telemetry receivers were not placed at the SWP trash racks.

On a population level, Zeug and Cavallo (2014) explored the factors affecting salvage of juvenile Chinook salmon at the CVP and SWP, and found that increased export rate was associated with increased salvage rates at both facilities for Chinook salmon from both San Joaquin River releases and Sacramento River releases. By estimating entrainment and direct mortality at the facilities from the salvage numbers, they concluded that increased exports result in increased facility mortality (including pre-screen loss, entrainment loss, and within-facility loss). Kimmerer (2008) came to similar conclusions for winter-run Chinook salmon, and found that the estimated proportion of winter-run juveniles exiting the Delta that were salvaged increased with increased export flows. The proportion of total loss in the Delta due to exports varied depending on pre-screen survival (i.e., survival from pre-screen loss and canal entrainment loss) (Kimmerer 2008; Zeug and Cavallo 2014). Zeug and Cavallo (2014) also noted that relating water diversions to the proportion of population loss due to entrainment is complicated by having few observations at higher export rates (i.e., only three observations of San Joaquin River entrainment loss for exports greater than 4,000 cfs).

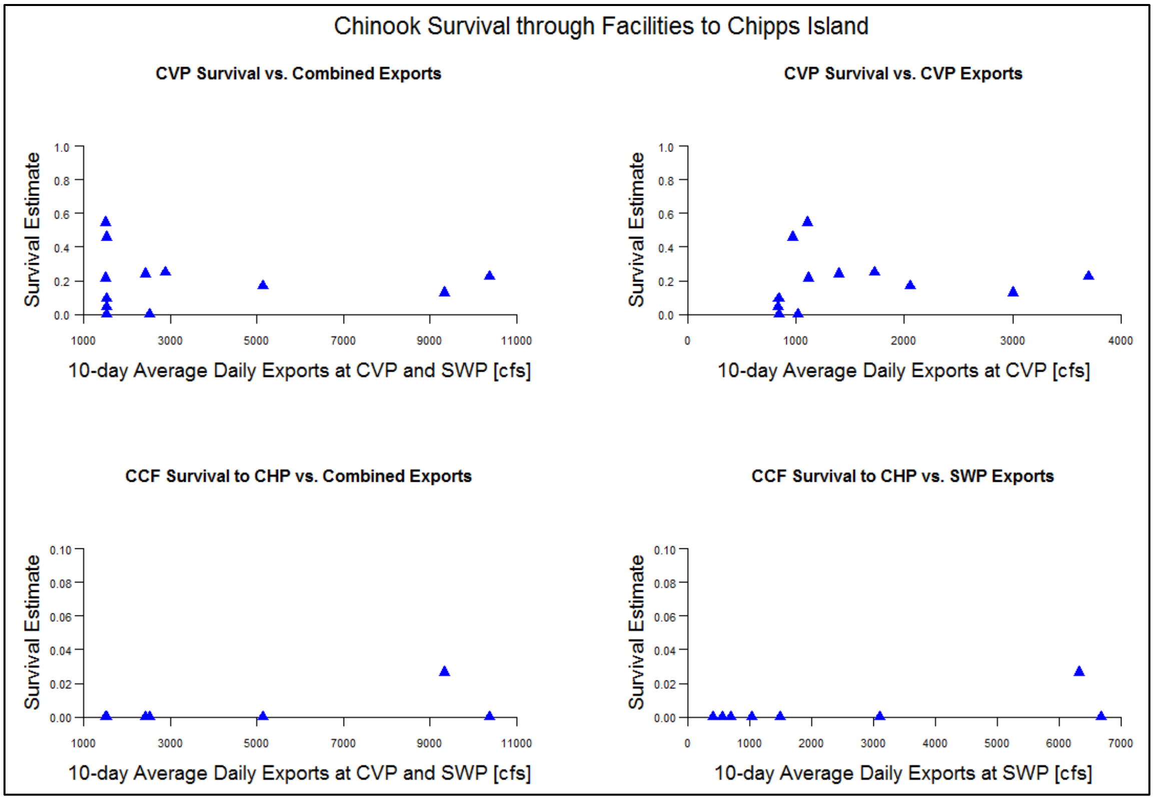


Figure 3-16. Estimated Survival of Fall-Run Chinook Salmon Based on Data from 2008 and 2010-2012 AT Studies, Versus the 10-Day Average of Daily Exports at CVP and SWP

Notes: Survival is from trash racks for CVP, and from radial gates at entrance to CCF for SWP. Survival from CCF to Chipps Island is through the SWP. Export rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rate at SWP includes BBID diversions.

San Joaquin River Steelhead (Indirect Losses)

No published analysis of steelhead survival through the South Delta is available in the peer-reviewed literature. Visual inspection of the two years of survival estimates of acoustic-tagged steelhead through the South Delta (i.e., from Mossdale to Jersey Point or Chipps Island) shows an indeterminate relationship between combined export rates and survival (Figure 3-17). Survival from Mossdale to Chipps Island is slightly higher for higher levels of exports (greater than 3,500 cfs), but also higher for the lowest levels of exports observed during the two study years (2011 and 2012).

There was little variability in export levels during the study periods compared to the variability observed during the multi-decade Chinook salmon studies (Figure 3-17). When only evaluating survival on the San Joaquin River route from Mossdale to the Turner Cut junction, there was no indication of a relationship between exports and survival (Figure 3-17). From the Turner Cut junction to Chipps Island, and including routes from the Turner Cut junction through the salvage facilities, survival decreases as exports increase from approximately 2,500 cfs to 3,000 cfs, but is higher for export rates greater than 3,500 cfs (Figure 3-17). It is not known from only two years of data if the non-linear relationship observed is representative of all conditions, or if the variability in the survival estimates primarily reflects other variables such as inflow, status of the HORB, fish condition, or other factors, or simply interannual and seasonal variability. Based on visual inspection of Figure 3-17, there is no suggestion of a factor-ceiling relationship between exports and survival on any spatial scale. Additional AT data and analysis are needed including both higher and lower export levels.

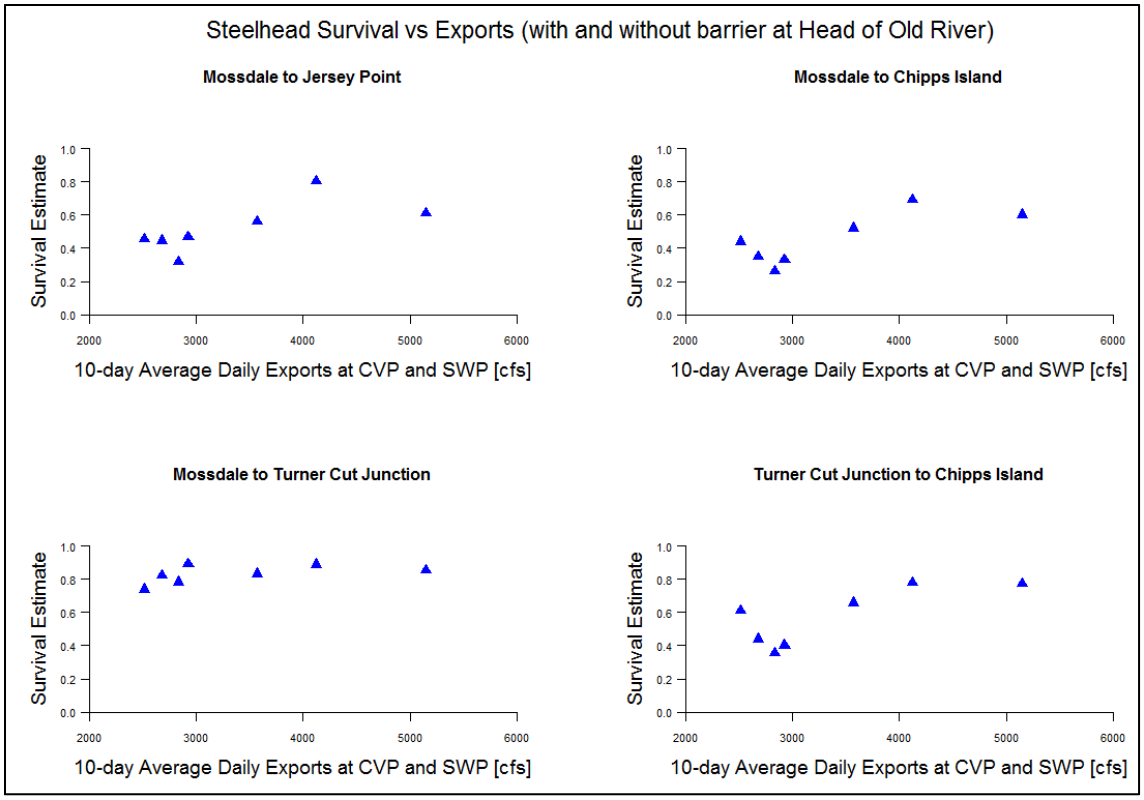


Figure 3-17. Estimated Survival of Steelhead Based on Data from 2011 and 2012 AT Studies, Versus the 10-Day Average of Daily Exports at CVP and SWP, Regardless of Barrier Status at the Head of Old River

Notes: Export rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rate at SWP includes BBID intake. Survival from Mossdale to Jersey Point and Chipps Island includes all routes.

Survival of steelhead through the export facilities may be related to export rates. There is a higher probability of acoustic-tagged steelhead entering the CVP facility when flows through the CVP were higher (Karp et al. 2014). Scatterplots of estimated facility survival to Chipps Island from entrance at the CVP trash racks or CCF radial gates plotted against export rates for acoustic-tagged steelhead show a positive association between the CVP export rate (less than or equal to 4,000 cfs) and survival through the CVP to Chipps Island (Figure 3-18). Broadly speaking, there is a similar pattern for the SWP. A wide range of survival estimates is observed for low export rates while the few observations at higher export rates have relatively high survival (0.75 to 0.86) with little variation (Figure 3-18, bottom row).

However, there are insufficient data to adequately characterize a relationship, because there are only three observations at combined export rates greater than 4,000 cfs and because two years of observations are insufficient to reflect interannual variability. No survival estimates are available from the SWP trash racks to Chipps Island because acoustic telemetry receivers were not located at the SWP facility.

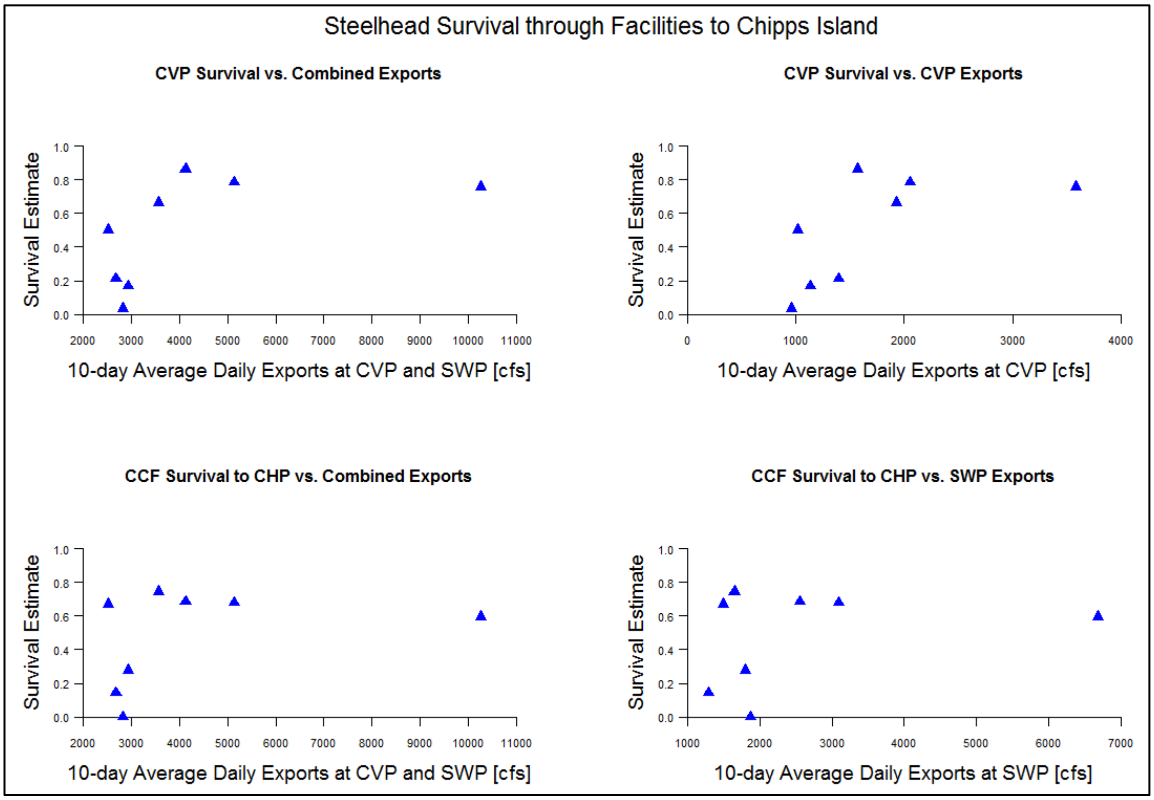


Figure 3-18. Estimated Survival of Steelhead Based on Data from 2011 and 2012 AT Studies, Versus the 10-Day Average of Daily Exports at CVP and SWP

Notes: Survival is from trash racks for CVP, and from radial gates at entrance to CCF for SWP. Survival from CCF to Chipps Island is through the SWP. Export rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rate at SWP includes BBID diversions.

Direct Losses

Water project operations include CCF, export facilities (CVP and SWP), and intake canals leading to the facilities (Figure 3-19). Salvage facilities are located on the intake canals for the Tracy Fish Collection Facility (CVP) and John F. Skinner Delta Fish Protection Facility (SWP). These facilities are similar in design, using a primary louver system to direct fish out of the intake canals (primary channel) and into secondary channels. A secondary louver system or fish screen on the secondary channels directs fish into holding tanks, where fish are concentrated. At regular intervals throughout the day and night or as needed, fish in holding tanks are transferred to transport trucks and hauled to release sites on the lower Sacramento and San Joaquin rivers (Figure 1-1), and released through a pipe.

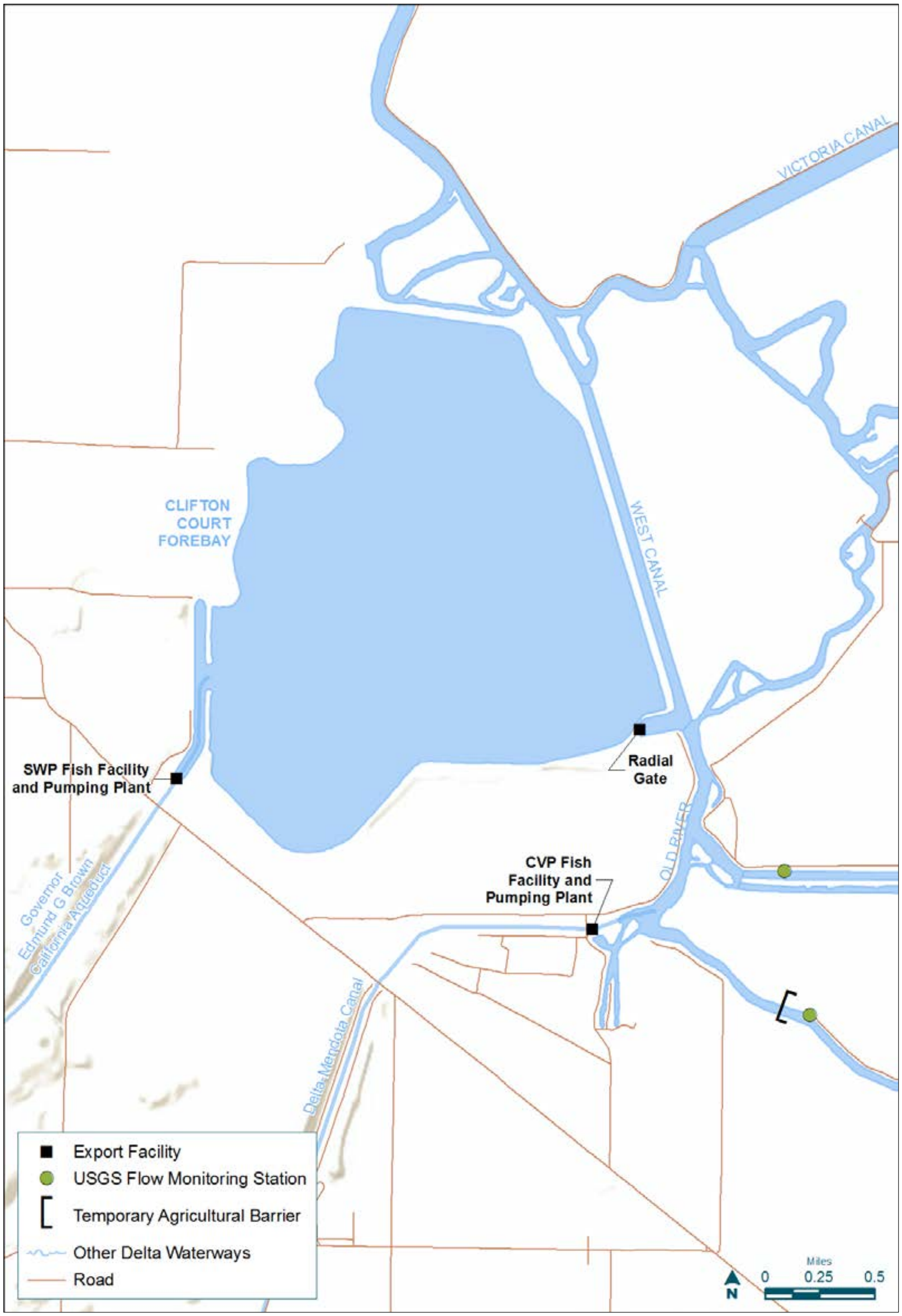


Figure 3-19. Location of CVP and SWP Fish Salvage Facilities Relative to CCF

The SWP and CVP salvage facilities differ in that the SWP facility is preceded by a large forebay (i.e., CCF) where water is collected and stored during high tides to maintain adequate water elevations for pumping. Although this forebay allows more flexibility for the timing of pumping relative to tidal stage, Chinook salmon and steelhead suffer higher mortality rates in CCF compared to the salvage facilities at either the CVP or SWP (i.e., from the trash racks at the entrance of the facilities through release after salvage). A multi-channel primary intake at the SWP salvage facility allows greater control over intake velocities and therefore more effective fish salvage than available at the CVP.

One of the challenges of evaluating impacts at the salvage facilities is correctly identifying fish (e.g., race, tributary of origin) that enter the facilities relative to those that enter and leave the Delta. For many years, genetic tissue sampling for winter-run salmon has occurred at the fish facilities, and has occurred for the spring-run more recently (Banks et al. 2014; Harvey et al. 2014). Genetic sampling of winter- and spring-run Chinook salmon has also occurred for 3 years for fish entering the Delta at Sacramento (2009, 2010, and 2011) and is also being conducted in 2016. Genetic tissue has not been consistently sampled from juvenile salmon entering, in, and leaving the Delta. Additional analyses of these samples could provide an opportunity to better enumerate the proportional loss of winter-run and spring-run salmon entering the fish facilities. Tissue sampling for salmon that enter and leave the Delta would help put the genetic information obtained at the fish facilities in perspective and would improve abundance estimates. Efforts are also being conducted in 2016 to obtain improved estimates of Sacramento trawl capture efficiency using captures of both AT and CWT juvenile winter-run Chinook salmon. The improved capture efficiency estimates, in combination with results of the 2016 genetics testing, will allow more accurate estimates of the numbers of juvenile winter-run Chinook salmon migrating into and surviving in the Delta.

No reliable estimates are available of the proportion of the juvenile steelhead population salvaged at the facilities for either the Sacramento River or San Joaquin River populations. NMFS has used a proportional loss approach to define the incidental take limit for direct export losses of juvenile winter-run Chinook salmon as 2% of the estimated number of juvenile winter-run entering the Delta from the Sacramento River based on the juvenile production estimate (JPE) calculated each year. Using a proportional approach, the losses at the export facilities are adjusted each year to account for variation in the annual production of juvenile winter-run Chinook salmon. A similar approach is used to estimate the proportion of juvenile spring-run Chinook salmon lost based on recapture of tagged surrogates at the salvage facilities.

Kimmerer (2008) evaluated the proportional losses of Chinook salmon resulting from direct project operations based on an analysis of CWT juvenile salmon released into the upper Sacramento River and subsequently recaptured in the fish salvage operations or in the USFWS Chipps Island trawls. Assuming a pre-screen loss in CCF of 80%, the mean salvage related loss was 10% at the highest levels of exports analyzed by Kimmerer (2008). This approach is consistent with results of experimental pre-screen loss studies reported by Kano (1990), Gingras and McGee (1997), and Clark et al. (2009). Zeug and Cavallo (2014) expanded the numbers of CWT salmon observed at the SWP and CVP fish salvage facilities to account for louver efficiency and pre-screen losses in order to develop estimates of total expanded loss for each CWT group as a percentage of the number of fish released. Results showed that the average total loss, expanded for louver efficiency and pre-screen losses, were 0.84% for late-fall-run, 0.2% for winter-run, and 0.03% for fall-run Chinook salmon released into the Sacramento River. The proportion of salvaged fall-run Chinook salmon released into the San Joaquin River was higher, as would be expected given the proximity of the river to the South Delta export facilities, with a mean total loss estimated to be 1.4%.

Zeug and Cavallo (2014) used a statistical modeling approach to assess factors related to entrainment into the SWP and CVP export facilities. Exports and other environmental variables used in the analysis were averaged over a seven-day period prior to the median capture date in the Chipps Island trawl based on results of AT monitoring indicating the average duration of salmonid migration through the Delta was 6.4 days (Michel et al. 2012). Separate statistical models were developed for the SWP and CVP export facilities. Results were expanded to estimate the proportion of the juvenile population at risk of loss. The model predicted a significant increase in salvage as diversion rate increased. There was a significant negative relationship between flow and salvage and a positive relationship between distance from release to export facilities and salvage at the CVP.

Efforts have been made to minimize direct mortality, including fish guidance away from pumps and into salvage facilities, and pumping schedules designed to limit the attraction of migrating fish to the facilities. Assessing the effects of these actions is hampered by several considerations. First, there is little direct data on fish mortality from entrainment, pre-screen mortality (at the CVP), or within-facility mortality. Instead, estimates of loss are computed based on salvage counts or salvage rates, and assumed parameters that represent pre-screen or within-facility mortality, some but not all of which are based on historical tagging studies; thus, loss estimates are constrained to increase as the effectiveness increases of an impact-reduction action that can promote migration survival (i.e., salvage). The quality of the assumed relationship between salvage and loss may vary between and within water years and salmon runs, making it difficult to monitor effects of management decisions on direct mortality with accuracy and precision. Second, there is considerable uncertainty about the population-level effects of direct mortality (i.e., the proportion of the migrating population that actually enters and is lost at the facilities). Third, all of the spatially precise acoustic telemetry data and much of the CWT data come from the period when export facilities have been operated to limit negative impacts on migrating salmon populations. This means there is relatively little variability in export rates during the salmon outmigration, and thus little opportunity to detect a survival relationship with export rate. It is notable that even during the period of export operations reductions designed to improve salmon survival, salmon survival has remained low through the Delta (especially for fall-run Chinook salmon).

Results of Chinook salmon CWT survival studies show that the percentage of an experimental release group that is recovered in SWP and CVP fish salvage operations is low (typically less than 1%) but these estimates do not account for mortality within the rivers and Delta prior to encountering the export facilities. Zeug and Cavallo (2014) provide an analysis of 749 CWT releases totaling more than 28 million juvenile Chinook salmon into the Sacramento River and found that on average 0.068% were recovered in SWP and CVP salvage operations. Late-fall-run Chinook salmon were recovered at a rate of 0.2%, winter-run at a rate of 0.05%, and fall-run at a rate of 0.01%. Results of the CWT analysis for juvenile fall-run Chinook salmon released into the San Joaquin River showed 0.6% of fish in 313 releases totaling more than 7 million fish were recovered in salvage operations (Zeug and Cavallo 2014). When Zeug and Cavallo (2014) estimated the proportional loss of the overall migration mortality accounted for by the CVP and SWP exports, they found it ranged from less than 1% to 17.5%, depending on race, export levels, and where the fish were released.

<u>Clifton Court Forebay Gate Operations</u>

The conceptual model predicts the following:

- Increased flow and water velocities resulting from opening the CCF radial gates result in increased salmonid entrainment into CCF and increased salvage.
- Increased water velocities and turbulence within CCF downstream of the radial gates result in increased vulnerability to pre-screen losses as a result of predation.

The 2,200-acre CCF is operated as a regulating reservoir within the tidal region of the South Delta for SWP water export operations (Clark et al. 2009). Water is diverted from Old River and West Canal into the CCF intake through five radial gates (each 20 by 20 feet). Diversion (gate opening) is timed to occur as the flooding tide reaches the CCF intake and through the early part of the ebb tidal cycle. The frequency that the radial gates are opened to flood CCF depends on the SWP export rate, the volume of water storage in CCF, and tidal conditions. When the difference in water surface elevation between Old River and CCF is greatest, water velocities through Clifton Court Canal typically exceed 15 ft/sec at flow rates typically ranging between 10,000 and 15,000 cfs (Clark et al. 2009). After CCF has been filled, the radial gates are closed and water exports are made from storage within CCF.

When CCF gates are initially opened, water velocities and flow entering CCF is high and juvenile salmonids in the immediate area of the gates would be vulnerable to entrainment into CCF and the salvage facility. Juvenile salmonids would continue to be vulnerable to entry into CCF as long as the radial gates remain open. Gingras and McGee (1997) also observed striped bass moving into and out of CCF while the radial gates were open. When the gates are closed, salmonids are not vulnerable to entrainment into the SWP. In contrast, hydrodynamics in Old River and West Canal are continuously affected by CVP export rates but at a substantially lower rate than occurs when the CCF gates are opened. The hydrodynamic simulation models that are currently in use do not use actual measured flow or velocity entering CCF but rather rely on estimates of flow predicted by differential storage or stage. Further, analyses of relationships between export rates and salmonid salvage at the SWP and CVP facilities and survival through the Delta have relied on average export rates for both facilities, typically over a period of one to two weeks as if CCF did not exist.

Pre-Screen and Facility Losses

Pre-screen loss occurs on the facility side of the trash racks at the CVP and downstream of the radial gates at the entrance to CCF and is assumed to be caused by a large predator population adjacent to and within the salvage facilities. The seasonal and interannual variability of the pre-screen loss is unknown. The evidence of loss due to predation comes from a variety of sources, as follows:

- There is indirect evidence from outside of the Delta that illustrates that salmonid predators aggregate at areas where migrating smolts are concentrated (Rieman et al. 1991; Ward et al. 1995; Sabal 2014). Within the Delta, Brown et al. (1996) observed that predators are abundant near intakes, screens, and louvers at the CVP and SWP facilities.
- During a one-month beach-seining effort in 1992, more than 80% of the fish sampled from CCF were striped bass that were large enough to prey on juvenile Chinook salmon (Brown et al. 1996).
- Gingras and McGee (1997) observed large numbers of predator-sized striped bass move back and forth through the CCF radial gates on very short timescales.
- Estimates of pre-screen mortality at the SWP ranged from 63% to 99% for a series of tagged Chinook salmon releases between 1976 and 1993 (Gingras 1997).
- Studies conducted with tagged steelhead estimated pre-screen mortality between 78% and 82% (Clark et al. 2009). These pre-screen mortality rates were considerably higher than those estimated for steelhead once they had entered the SWP John F. Skinner Delta Fish Protection Facility salvage facility (26%; Clark et al. 2009).

In the 2010 VAMP study, a large number of detections at the CCF radial gates of ATs originally inserted into juvenile fall-run Chinook salmon were classified as predator detections based on assumed behavioral differences between Chinook salmon and predators such as striped bass. When detections classified as coming from predators were included in survival analysis, the estimated probability of passing through the CCF entrance channel to the interior CCF was 0.74 (SE = 0.04); without those "predator-type detections," the estimated probability of entering CCF was reduced to approximately 0.28 to 0.36 (SE = 0.05), depending on the status of gate opening upon arrival in the entrance channel. In both cases, estimated survival from the radial gates to Chipps Island was very low: 0 without the predator-type detections, and 0.01 with the predator-type detections (SJRGA 2011).

The pre-screen loss at the CVP intake (upstream of the trash rack) is based on an unsupported assumption of 15% constant loss for juvenile salmonids. No quantitative studies have been conducted to determine the actual pre-screen loss at the CVP intake for either juvenile Chinook salmon or steelhead; available estimates do not distinguish between pre-screen loss and failure to be guided by the primary louvers.

The CVP Tracy Fish Collection Facility salvage facilities also provide favorable habitat for predatory fish, primarily striped bass. Striped bass reside around and inside the bypass channels of the salvage facility in higher densities than typically observed in natural settings. These predatory fish take advantage of low velocity holding areas provided by facility structures to prey on smaller fish drawn into the facility, including juvenile salmonids (Liston et al. 1994; Vogel 2010; Sutphin et al. 2014). Mobile monitoring in 2010 suggested predation was still an issue in front of the CVP trash racks, with a total of 37 ATs detected near this location, although it is unknown if more tags were deposited elsewhere (SJRGA 2011).

Salvage

Salvage rates and the survival of salvaged salmon and steelhead have been estimated, but there is considerable uncertainty about the number and proportion of salmonid migrants that are salvaged annually, and the population-level effect of salvage operations. From recent AT studies in the South Delta, it appears that most of the juvenile Chinook salmon and steelhead mortality within the Old River migration route occurred after the fish entered CCF or the CVP or migrated past Highway 4 on Old River:

- For juvenile Chinook salmon in 2010 and 2011 (but not 2012) (SJRGA 2011, 2013; Buchanan et al. 2015)
- For juvenile steelhead in 2011 and 2012 (Buchanan 2013, 2015; Buchanan et al. 2015)

In each of these cases, survival from Mossdale to the export facilities or Highway 4 (annual average = 0.66 to 0.77 for Chinook, 0.55 to 0.78 for steelhead) was considerably higher than total survival from Mossdale to Chipps Island through the Old River route (annual average = 0.04 to 0.07 for Chinook, 0.07 to 0.52 for steelhead). Furthermore, approximately three times as many Chinook salmon, and three to nine times as many steelhead, entered the facilities as arrived at Highway 4 (annual averages). This observation, combined with low survival from the facility entrances or Highway 4 to Chipps Island, suggests that the greatest proportion of mortality in the Old River route in these studies occurred after juvenile salmonids either passed through the CVP trash racks or entered CCF.

In acoustic telemetry studies, among the fish that went to the facilities, similar proportions of Chinook salmon went to the CVP as to CCF in 2010 and 2011 (SJRGA 2011, 2013). Nevertheless, for Chinook salmon in 2010 and 2011, estimated transition probabilities from the CVP trash rack to Chipps Island were higher than from CCF to Chipps Island, indicating higher mortality due to some combination of pre-screen loss, entrainment loss, and facility loss at CCF and SWP than at the CVP (SJRGA 2011, 2013). In 2012 when the HORB was in place, very few Chinook salmon were observed entering the Old River route, none were detected at CCF, and only one at the CVP (which was later detected at Chipps Island)

(Buchanan et al. 2015). In contrast, more steelhead went to CCF than to the CVP in both 2011 and 2012, and no more than 10% of the tagged steelhead detected at Chipps Island came via the CVP in these years (Buchanan 2013, 2015).

Despite the high mortality observed through the salvage facilities in these studies, the route through the CVP salvage, holding tank, and truck transport often represented the majority of the tagged Chinook salmon observed at Chipps Island from San Joaquin River acoustic telemetry studies. In 2010 and 2011, over 60% of the tagged salmon detected at Chipps Island came through the salvage facilities and truck transport at CVP (SJRGA 2011, 2013). In 2010, 19 of the 20 acoustic-tagged juvenile Chinook salmon that survived to Chipps Island via the Old River route, and 29 tagged salmon that survived to Chipps Island via all routes combined, came by way of the CVP (Buchanan et al. 2013), suggesting that survival through the CVP was higher than through all alternative routes.

3.9.3 Summary of Findings

The conceptual model predicted that increased export rates would result in decreased survival through the Delta to Chipps Island. Findings from CWT and AT data for Chinook salmon have been inconsistent and data for steelhead are limited. Findings include:

- A negative relationship between export rate and through-Delta survival was found for Sacramento River fall-run Chinook salmon from CWT data (Newman 2003), although more recent AT data from late-fall-run Chinook salmon showed no relationship (Perry 2010).
- The relative success of the Interior Delta route compared to the Sacramento River mainstem route to Chipps Island was negatively related to export rate, but a model that omitted export rate accounted for the variability in the data equally well as the export models (Newman and Brandes 2010).
- CWT data from San Joaquin River fall-run Chinook salmon provide moderate evidence of a positive relationship between through-Delta survival and export rates, but may be due to the high correlation between exports and San Joaquin River inflow (Newman 2008; SJRGA 2007).
- AT data from San Joaquin River fall-run Chinook salmon provide moderate evidence that high export rates are associated with low through-Delta survival, but there are few observations at high export rates, and considerable variability in survival estimates at low export rates.
- Comparison of CWT ocean recovery rates with measures of Delta hydrodynamics, including export rates, found no evidence of a relationship but reflect both Delta and ocean survival (Zeug and Cavallo 2013).
- Only two years of steelhead AT data have been analyzed, and they depict an indeterminate relationship between export rates and through-Delta survival.
- CWT and AT survival studies have been conducted using Central Valley Chinook salmon for over four decades with survival studies using steelhead being conducted

using ATs over the past six years. The majority of these experimental studies focus on survival within the tributary rivers and Delta and have not been used to quantify the incremental effect of water-project-related impacts (lethal and sublethal) on the overall population dynamics, abundance, or resilience of the species.

- Direct mortality of juvenile Chinook salmon due to export operations (e.g., pre-screen losses, entrainment, and salvage) appears to be low based on results of CWT recoveries analyzed by Zeug and Cavallo (2014).
- The incremental contribution of export operations and associated changes in flows and velocities in the Delta to indirect mortality (i.e., water project operations-related mortality that occurs outside the facilities and CCF) has not been quantified.
- At present, we do not adequately understand how survival varies in response to export rates. Limited information is available on the following:
    - Influence of export rates on the relative survival in different routes through the Delta for San Joaquin River salmonids
    - Interannual and within-season variability in survival at high export rates on various spatial scales

3.10 SURVIVAL AS A FUNCTION OF DELTA INFLOW

Delta inflow has been hypothesized as an important factor affecting juvenile downstream migration through the rivers and Delta. As shown in Section 3.1 and Appendix B Section B.5 and Figure B.5-8, inflow to the Delta has a larger effect on hydrodynamic conditions upstream in the more riverine reaches of the tributary rivers and a diminishing effect further downstream as tidal influence becomes a stronger factor affecting Delta hydrodynamics.

3.10.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Increased Sacramento River inflow is associated with increased survival to Chipps Island for Chinook salmon and steelhead migrating from the Sacramento River.
- A positive relationship exists between San Joaquin River inflow and through-Delta survival for both salmon and steelhead.
- A stronger relationship between San Joaquin River inflow and survival exists in upstream regions of the San Joaquin River and Interior Delta compared to downstream regions where tidal conditions become more dominant.

3.10.2 Analysis

There have been a large number of CWT and more recently AT studies designed to examine the relationships between Delta inflow from the Sacramento and San Joaquin rivers and survival of juvenile salmonids migrating through the Delta to Chipps Island (SJRGA 2007, 2013; Buchanan et al. 2013; Appendix E). However, Delta inflow is highly correlated with export rates and distinguishing between effects of exports and inflow is difficult (see Section 3.9; Appendix E, Section E.2.3). To date, results of most of these survival studies have been limited to examining correlations between Delta inflow during the period that an experimental group of tagged salmonids are migrating downstream and their estimated survival at Chipps Island. For CWT fish there is no ability to assess the migration route or reach-specific survival.

Survival as a Function of Sacramento River Inflow

The relationship between Sacramento River inflow and survival through the Delta for Chinook salmon has been explored separately by Newman (2003) and Newman and Rice (2002) using CWT data from fall-run Chinook salmon, and Perry (2010) using AT data for late-fall-run Chinook salmon. Newman and Rice (2002) report a slight positive effect of Sacramento River flow on survival, but caution that the flow effect was confounded by salinity. Newman (2003) modelled survival of fall-run Chinook salmon using Sacramento River discharge measured at Freeport and found a positive effect of flow on survival, along with significant effects of exports, tide, temperature, salinity, turbidity, and position of the DCC gate. Perry (2010) modeled survival of late-fall-run Chinook salmon using Sacramento River discharge just downstream of Georgiana Slough. He found a positive relationship between Sacramento River discharge below Georgiana Slough and survival in both the Sacramento River mainstem and Sutter and Steamboat sloughs for late-fall-run Chinook salmon, as well as between fish length and survival.

Kimmerer (2008) and Zeug and Cavallo (2014) investigated the effect of Sacramento River inflow on salvage rates for CWT hatchery Chinook salmon. Kimmerer (2008) found no relationship between proportional salvage or total salvage and Sacramento River flow for winter-run Chinook salmon. Zeug and Cavallo (2014) reported that the probability of collecting any fish in salvage was negatively associated with Sacramento River inflow for both the CVP and SWP, and the number of salmon salvaged was also negatively associated with inflow for CVP salvage of winter-run, late-fall-run, and fall-run Chinook salmon. Assuming that salvage and entrainment vary together, this suggests that entrainment loss is also negatively associated with Sacramento River inflow.

Results of AT survival studies for late-fall-run Chinook salmon on the Sacramento River (Michel et al. 2015) over four low-flow years (2007 through 2010) and one high-flow year (2011) showed overall survival ranged from 2.8 to 5.9% under low-flow conditions but increased to 15.7% under high-flow conditions in 2011. The observed increase in survival in 2011 under high-flow conditions was consistent with the trend predicted by the conceptual model.

Survival as a Function of San Joaquin River Inflow

The presence of the physical rock barrier at the head of Old River depends partly on San Joaquin River inflow. The rock barrier cannot be installed at flows greater than 5,000 cfs, and cannot be operated (e.g., without wash-out) at flows greater than 7,000 cfs. Because the barrier restricts route selection at the head of Old River, and may affect downstream survival due to flow effects and predator distribution (DWR 2015a), this restriction means that any effect of San Joaquin River inflow on survival may depend on the status of the barrier (SJRGA 2007). In addition, the effect of inflow is expected to be stronger in the upstream reaches of the San Joaquin River because tides override the influence of San Joaquin River inflow on hydrodynamics further downstream in the Delta (see Section 3.1).

Zeug and Cavallo (2014) investigated the effect of San Joaquin River inflow on entrainment of San Joaquin River fall-run Chinook salmon in the CVP and SWP, based on CWT release sizes and salvage numbers. They found no effect of flow on entrainment at the SWP. At the CVP, they found a positive association between flow and the probability of observing fish in salvage (Zeug and Cavallo 2014). This finding is counter to the conceptual model's prediction, but may partially reflect a positive correlation between exports and inflow during CWT studies.

Chinook Salmon

The 2006 VAMP report (SJRGA 2007) reported results showing a stronger relationship between CWT salmon through-Delta survival and San Joaquin River inflow when the HORB was installed compared to when the HORB was not installed. A relationship has also been reported between adult fall-run Chinook salmon escapement to San Joaquin River tributaries and spring flow in the San Joaquin River two and a half years earlier when juveniles were migrating downstream; however, the strength of the flow-escapement relationship is based on years when river flow was extremely high (flood conditions; SJRGA 2007). Newman (2008) found a significant effect of San Joaquin River inflow at Vernalis in predicting fall-run Chinook salmon survival to Jersey Point, with higher inflows associated with higher survival estimates, based on CWT data. However, because the HORB cannot be installed when San Joaquin River flows are high (greater than approximately 5,000 cfs), the effect of inflow is confounded with the effect of the barrier. Newman (2008) recommended further exploration. Zeug and Cavallo (2013) found no support for a hydrologic model (including both exports and inflow) of an index of joint Delta survival and ocean survival using ocean recovery rates, but caution that variability in ocean survival may swamp the signal of any relationship between Delta inflow and Delta survival.

These modest relationships between CWT salmon survival and Delta inflow are not consistent or robust. For example, 2006 and 2011 were high-flow years and 2012 was a low-flow year, but survival estimates to Chipps Island in the high-flow year (2011) were similar to those in the low-flow year (2012) (Figure 3-9). The HORB was absent in 2011 because of the high flows and most acoustic-tagged Chinook salmon (60%) reaching the head of Old River continued migrating down the San Joaquin River, while approximately 40% entered Old River at that junction; survival to Chipps Island was low in both routes (less than or equal to 0.04) (SJRGA 2013). The barrier was in place during the low-flow year of 2012, and most tagged Chinook salmon remained in the San Joaquin River, but survival was very low (Figure 3-9). This pattern is consistent with an interaction between an inflow effect and a barrier effect, in which the effect of inflow depends on the barrier. However, distinguishing between an inflow effect and a barrier effect, and describing any interaction between them, is complicated because the HORB cannot be operated or installed during high-flow conditions. Thus, any barrier-inflow interaction effect must be interpreted only for inflow less than 7,000 cfs (the highest inflow for which the barrier may be operated).

The relationships between survival of CWT and acoustic-tagged Chinook salmon and average 10-day San Joaquin River flow at Vernalis are shown in Figure 3-20 for all years, regardless of status of the HORB. Results for survival between Mossdale or Durham Ferry and Jersey Point were characterized by high variability, especially at river flows greater than 10,000 cfs. Results of AT survival studies (upper right panel) showed no clear pattern between survival and river flow. A relatively strong positive relationship between inflow and survival appears to exist for the reach between Mossdale and Turner Cut, whereas there appears to be a negative relationship between flow at Vernalis and survival from Turner Cut to Chipps Island. However, these results are based on only visual inspection of data from only four to five years, depending on the reach. With a physical barrier in place, there are only two survival estimates available on this spatial scale, which is too few observations to characterize the variability in reach-specific survival. Thus, it is not currently possible to determine the relationship between Vernalis inflow, the barrier, and survival in different regions of the Delta. There is a lack of data on reach-specific survival in the presence of a physical barrier as well as reach-specific survival at high inflow levels.

<u>Steelhead</u>

Visual inspection of the few steelhead data available shows an overall increase in survival from Mossdale to Jersey Point or Chipps Island as San Joaquin River inflow increases (Figure 3-21). The increase is noticeable on the reach scale from the Turner Cut junction to Chipps Island, but not from Mossdale to Turner Cut. Of the two years of steelhead data, 2011 was a high-flow year in which the HORB was absent, and 2012 was a low-flow year in which the rock barrier was installed and operating. Survival to the Turner Cut junction was similar in both years (Figure 3-21). Overall, survival to Chipps Island was slightly lower in 2012.

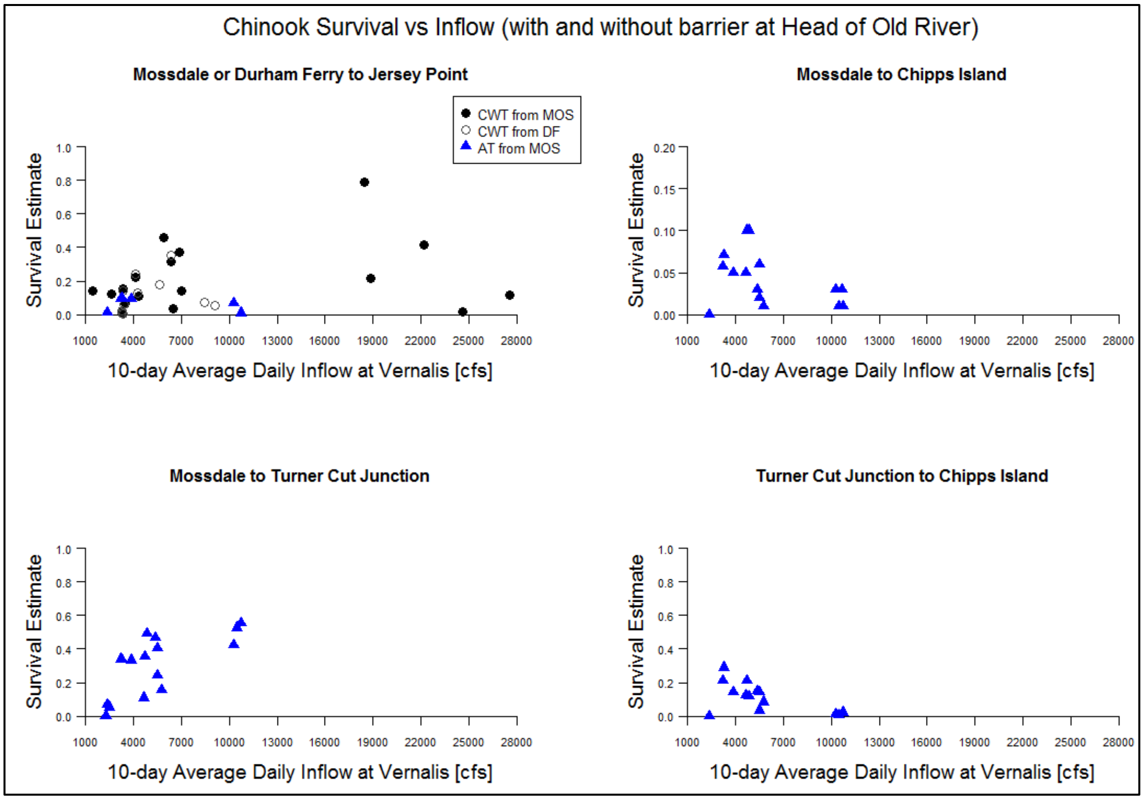


Figure 3-20. Estimated Survival of Fall-Run Chinook Salmon Versus the 10-Day Average of Daily Average Inflow at Vernalis, for All Barrier Status Conditions at the Head of Old River

Notes: Inflow data are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Survival from Mossdale to Jersey Point and Chipps Island includes all routes.

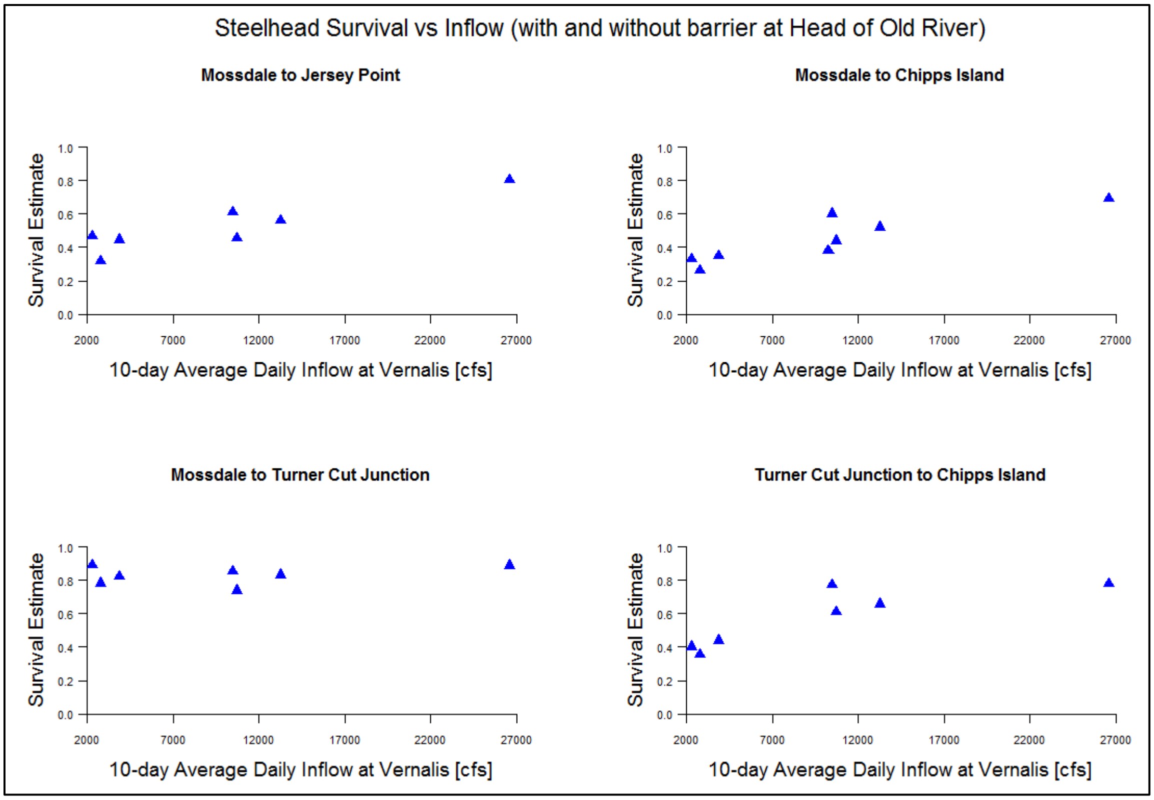


Figure 3-21. Estimated Survival of Steelhead Based on Data from 2011 and 2012 AT Studies, Versus the 10-Day Average of Daily Exports at CVP and SWP, Regardless of Barrier Status at the Head of Old River

Notes: Inflow data are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Survival from Mossdale to Jersey Point and Chipps Island includes all routes.

The spatial pattern observed for steelhead is in contrast to the pattern observed for fall-run Chinook salmon, where a positive relationship between inflow and survival was observed from Mossdale to the Turner Cut junction, but a possible negative relationship was observed from the Turner Cut junction to Chipps Island. One difference between Chinook salmon and steelhead from the acoustic telemetry studies is that steelhead have been observed successfully reaching Chipps Island after entering the South Delta at Turner Cut, whereas no Chinook salmon that have entered Turner Cut have been observed at Chipps Island (Table 3-2; Appendix E, Section E.4.2).

3.10.3 Summary of Findings

The concept of higher survival associated with higher inflow is supported by tagging studies of juvenile salmonids on some spatial scales but not on others. Inflow appears to affect survival more in the upstream reaches where the environment is more riverine, and less in the downstream reaches that are more tidal (see Section 3.1).

Although inflow is a factor in juvenile salmonid migration survival through the Delta, it is not the only factor influencing survival, and it is unlikely that survival can be controlled through inflow alone. The low Chinook salmon survival in 2006 and 2011, both high-flow years, contributes substantially to the uncertainty in the flow-survival relationship.

3.11 SURVIVAL AS A FUNCTION OF THE SAN JOAQUIN INFLOW:EXPORT RATIO

The BiOp (NMFS 2009) included a requirement (RPA IV.2.1) that limits SWP and CVP export rates during April and May to a fraction of the San Joaquin River flow at Vernalis. The I:E varies among years in response to hydrologic conditions up to a ratio of 4:1. The ratio is intended to reduce the potential effects of SWP and CVP exports on downstream migrating juvenile steelhead that emigrate from the San Joaquin River tributaries and pass through the Delta during April and May.

3.11.1 Conceptual Model Predictions

The conceptual model predicts that:

- Delta survival increases with I:E, and the relationship may depend on the status of the HORB.
- The relationship between I:E and survival may vary in different regions of the Delta.

3.11.2 Analysis

The Bureau of Reclamation has conducted experimental survival studies using hatchery-produced yearling steelhead since 2011 (six-year steelhead survival study). Results have undergone preliminary analyses for 2011 and 2012, and are in the process of being analyzed for 2013 through 2016. Additional data are also available from experimental survival studies conducted using CWT juvenile fall-run Chinook salmon (e.g., SJRGA 2007) and more recently using acoustic-tagged juvenile Chinook salmon (SJRGA 2011, 2013; Buchanan et al. 2013, 2015).

For most of the available survival estimates of through-Delta survival, the I:E ratio was less than 5. The ratios tested for fish released into the San Joaquin River ranged from 0.99 to 17.9. Results from CWT studies and preliminary results from acoustic telemetry studies have shown a limited positive relationship between I:E ratio and survival of San Joaquin fall-run Chinook. The 2006 VAMP report compared a CWT survival index (Durham Ferry or Mossdale to Jersey Point) to the San Joaquin River I:E for San Joaquin River Chinook salmon, and found a significant positive association when the HORB was in place (slope = 0.22, $P < 0.05$), and no significant relationship when the barrier was not in place (SJRGA 2007).

The available estimates of survival through the Delta, from either CWT or AT data, were plotted against the 10-day average I:E (Appendix E, Section E.11.2). The correlation between inflow and exports observed in these data complicates predictions of survival versus I:E. Visual inspection of scatterplots of the available survival estimates through the Delta to Jersey Point show that most estimates are for 10-day average I:E less than 5. Aside from the status of the HORB, there is considerable variability in survival for I:E les than 5. However, the maximum observed survival estimate to Jersey Point increased to 0.46 as I:E increased from 1 to 3, while only low survival estimates (range = 0.01 – 0.14) were observed for I:E of approximately 4. The highest survival estimate to Jersey Point (0.79), from Chinook salmon CWT data in 1995, was observed for I:E = 5.0; lower estimates were observed for I:E = 9.4 and approximately 16 to 18, but these estimates were nevertheless higher than many of the survival estimates for I:E less than 5. All estimates for I:E greater than 4.5 were from CWT studies.

In general, estimated survival to Jersey Point tended to increase with I:E when the HORB was installed, but no estimates for I:E greater than 3 were observed with the barrier. For survival to Jersey Point, a similar pattern in survival estimates was observed for I:E as for inflow for I:E less than 5: a general increase in the maximum observed survival estimate, and considerable variability about the mean survival estimate below this maximum.

Zeug and Cavallo (2014) compared salvage models for CWT Chinook salmon using inflow and water diversion rates (exports) as separate factors to models using the ratio of exports to inflow, and found that the ratio (I:E) did not account for the variability in salvage rates, as well as including inflow and exports separately. The available AT survival estimates from San Joaquin River Chinook salmon from the CVP trash racks to Chipps Island for acoustic-tagged Chinook salmon demonstrate considerable variability relative to I:E. Most exhibit very low survival estimates for I:E greater than 3, but the highest survival estimates also occurred for I:E greater than 3.

3.11.3 Summary of Findings

Findings show a complicated relationship with considerable variability, based mostly on provisional visual inspection of scatterplots:

- CWT Chinook salmon data show increased through-Delta survival for higher levels of I:E, up to approximately I:E = 3, in the presence of a physical barrier at the head of Old River, but no relationship in the absence of the barrier (SJRGA 2007).
- AT Chinook salmon data show a similar pattern for I:E less than 3, but mostly in the absence of a physical barrier at the head of Old River.
- Both CWT and AT Chinook salmon data show more variability, but mostly lower, through-Delta survival estimates for I:E between 3 and 5, all in the absence of a physical barrier at the head of Old River.
- Few observations from tagging data are available for I:E greater than 5, and all are from CWT data.

- Comparison of adult Chinook salmon escapement to the San Joaquin River basin between 1951 and 2003 with San Joaquin River I:E two and a half years before adult return showed a positive association (years 1951 through 2003; SJGRA 2007; updated by the SST through 2012); I:E values ranged up to greater than 300 during this time period, although most observations were less than 10.

3.12 SURVIVAL AS A FUNCTION OF THE DELTA EXPORT:INFLOW RATIO

The Delta E:I is a regulatory requirement in the SWRCB Water Quality Control Plan D-1641. The ratio of SWP and CVP export rates to total Delta inflow during the winter and spring is limited to 35%, while the E:I ratio during the remainder of the year is limited to 65%.

3.12.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Exports are expected to have a negative effect on survival, and inflow a positive effect on survival.
- As the ratio of exports to inflow increases, survival is expected to decrease.
- Direct mortality in the facilities affects only fish that enter the South Delta, so the relative survival in the South Delta route to survival in the Sacramento River mainstem and San Joaquin River route is expected to also decrease as E:I increases.

3.12.2 Analysis

Newman and Rice (2002) found that increases in the ratio of exports to Sacramento River inflow were associated with lower survival of Sacramento River fall-run Chinook salmon through the lower Sacramento River and Delta, but the effect was small and not statistically significant. For late-fall-run Chinook salmon released into the northern Interior Delta (i.e., Georgiana Slough), Newman and Brandes (2010) reported nearly equal support for three models of the relative survival of Interior Delta releases to Sacramento River mainstem releases that used either the ratio of exports to Sacramento River inflow, exports alone, or no exports. Zeug and Cavallo (2014) found that the E:I explained less variation in salvage rates of hatchery CWT fish from the Sacramento River than using measures of exports (E) and inflow (I) separately.

Cunningham et al. (2015) used data on salmon stock abundance (adult escapement and juvenile run estimates) to calibrate a lifecycle model for Sacramento River Chinook salmon, and concluded that juvenile outmigration survival through the Delta depended on the E:I for fall-run Chinook salmon, but not for the spring-run or winter-run Chinook salmon. For the fall-run Chinook salmon, Delta survival was estimated to decrease as the E:I increased (Cunningham et al. 2015).

3.12.3 Summary of Findings

Findings have generally shown a negative relationship between E:I and survival for Sacramento River Chinook salmon, but evidence is sometimes weak or the relationship is non-statistically significant:

- E:I has a small, non-statistically significant negative effect on survival of fall-run Chinook salmon (Newman and Rice 2002).
- Models using E:I to account for variation in CWT recovery data had approximately the same, or less, support from the data as models that used either exports alone or no measure of exports for late-fall-run Chinook salmon (Newman and Brandes 2010), and less support from the data as models that used exports and inflow separately for fall-run, late-fall-run, and winter-run Chinook salmon (Zeug and Cavallo 2014).
- A stage-structured lifecycle model found a negative effect of E:I on survival through the Delta for fall-run Chinook salmon but not for spring- or winter-run salmon (Cunningham et al. 2015).

3.13 MIGRATION AND SURVIVAL AS A FUNCTION OF OLD AND MIDDLE RIVER FLOWS

SWP and CVP exports can result in reverse flows occurring in OMR, depending on other Delta hydrologic conditions such as inflow from the San Joaquin River. Although flows in OMR reverse naturally in response to flood tide conditions, the addition of SWP and CVP export effects results in a greater magnitude and longer duration of reverse flow conditions than would occur in response to tidal conditions only. OMR reverse flows are identified as an important factor affecting juvenile salmonid migration through the Delta in the BiOp (NMFS 2009).

3.13.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Increased negative OMR reverse flow is expected to draw fish from the Sacramento River or lower San Joaquin River into the South Delta and toward the export facilities, and to prevent fish that have entered the South Delta from navigating northward through Delta channels to exit the Delta.
- Increased negative OMR reverse flow is expected to decrease through-Delta survival of Sacramento River and San Joaquin River salmon and steelhead.
- For San Joaquin River fish that have already entered the South Delta at the head of Old River, increased OMR reverse flows may result in faster entry to salvage facilities at the CVP and SWP, and so may be associated with higher survival from the head of Old River to Chipps Island via the salvage route.

3.13.2 Analysis

A recent study with juvenile steelhead was undertaken to assess the relationship between OMR flows and behavior and survival in the San Joaquin River mainstem and South Delta (Delaney et al. 2014). Results of this study may apply to Sacramento River origin salmonids that reach the San Joaquin River mainstem and South Delta, but studies to assess how OMR flows affect salmonid migration rate and route selection in the region north of the San Joaquin River mainstem have not been done. The SST feels there is a gap in our understanding of how OMR flows, specifically, impact the migration rate and routing and survival of juvenile salmonids in the Delta. However, the SST did not specifically evaluate effects of OMR flows on survival.

3.13.3 Summary of Findings

The relationship between hydrodynamic conditions in OMR and the mechanisms underlying route selection by juvenile Chinook salmon and steelhead are poorly understood. The majority of information on the effects of OMR reverse flows and salmonid behavior has been derived from relationships between salmonid salvage at the SWP and CVP and the magnitude of reverse flows occurring when these fish were migrating through the Delta. Salmonid survival rates in the South Delta are so low that any protection afforded by an OMR reverse flow restriction of -5,000 cfs will be small until background survival rates improve. Most AT survival and migration studies have focused on through-Delta survival rather than reach-specific survival in the OMR corridor, and no statistical analysis of the association between OMR reverse flows and either through-Delta survival or reach-specific survival has been performed.

3.14 USE OF SURROGATES

Conducting CWT survival studies requires a large number of juvenile salmonids to support a mark-recapture experimental design (typical group sample sizes range from 25,000 to 100,000 fish each). AT survival and migration studies require smaller sample sizes (typically 500 to 5,000 fish). To date, juvenile Chinook salmon and steelhead used in these studies have almost exclusively been obtained from Central Valley fish hatcheries. The validity of the use of hatchery stocks as a surrogate for wild salmonids is a key management question (see Volume 2, Management Question 8).

3.14.1 Conceptual Model Predictions

The conceptual model predicts that migration behavior and survival of juvenile salmonids produced in hatcheries and tagged is representative of migration of wild salmonids.

3.14.2 Analysis

Virtually all of the Chinook salmon and steelhead survival studies conducted in the Central Valley have used hatchery-origin juvenile salmonids as a surrogate for wild populations. Although limited comparative studies have been initiated to test the underlying assumption that the migration behavior and survival of hatchery reared juvenile salmonids is representative of wild stocks, and that one race of Chinook salmon is representative of other races, there are currently only limited data to validate the use of surrogates in experimental survival studies. Michel et al. (2012) conducted a set of comparative survival studies in the Sacramento River using wild and hatchery-produced salmon and found, in general, that survival rates were similar for the two test groups, although the variation in survival within a reach was greater for wild produced salmon when compared to hatchery salmon.

In the short term, hatchery-origin fish may be the only readily accessible source of study fish for large-scale survival studies. Therefore, there will likely be a long-term need for data to further address the use of hatchery salmonids in survival studies as being representative of their natural-origin unmarked counterparts. At present, there are insufficient data to build a reliable, accurate correction factor for translating the survival of surrogate populations to other natural-origin salmonids in the Delta. However, some recent releases of acoustic-tagged, wild, juvenile winter-run Chinook salmon offer an opportunity to conduct a comparison with acoustic-tagged, hatchery juvenile winter-run Chinook salmon. Also, naturally produced fall-run Chinook salmon juveniles from the Sacramento River could be collected and tagged in comparative studies with hatchery-produced juvenile fall-run Chinook salmon. Adequate sample sizes and number of replicates needed for robust comparisons would be a requirement of these comparisons.

3.14.3 Summary of Findings

Limited comparative studies of migration behavior and survival for hatchery and wild salmonids have begun, but require expansion to assess relationships for both the Sacramento and San Joaquin river systems and for various races of Chinook salmon in addition to steelhead. There is currently insufficient information from comparative migration and survival studies to assess how representative hatchery-produced salmonids are as surrogates for wild stocks.

For the development of the Best Available Science in Endangered Species Act (ESA) applications, the direct use of target species rather than surrogates should be considered as the first (and best) option to answer test questions related to behavior and survival; however, often this is not possible or allowed. In these situations, the use of surrogates should be accompanied by a description of the evidence that supports their use. This issue is addressed comprehensively by Murphy and Weiland (2014). The evidence should be described explicitly in the development of assumptions associated with the specific study design or evaluation. In situations where it is unclear that a surrogate species is representative of a target species or population, the relationship between the two should be further evaluated to determine the efficacy of using surrogates, or the uncertainty characterized in the study proposal and final reports for managers.

3.15 EFFECTS OF PROJECT OPERATIONS ON WATER QUALITY GRADIENTS AND BEHAVIOR (MIGRATION CUES)

Water quality gradients, such as salinity, may be one of the cues used by juveniles for downstream migration. To the extent that water project operations alter these migration cues, juvenile salmonids may enter false pathways or be delayed in passing through the Delta and therefore may be more vulnerable to sources of mortality.

3.15.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Water quality gradients provide an important migratory cue for juvenile salmonids affecting route selection.
- Water project operations affect Delta hydrodynamics and water quality gradients resulting in false migration cues and pathways contributing to migration delays and reduced juvenile survival.

3.15.2 Analysis

Salmonids are known to use olfactory cues and potentially other water quality gradients to help guide migration throughout their lifecycle (Hasler and Wisby 1951; Dittman and Quinn 1996). A variety of potential water quality gradients that may affect salmonid migration through the Delta exist such as salinity, water temperature, and turbidity gradients.

Water project operations such as opening or closing the DCC radial gates, installation of agricultural barriers, reservoir releases, and South Delta export operations alter the geographic distribution and concentrations of various water quality constituents that potentially affect migration rates or routes for salmonids in the Delta. For example, releases from upstream project reservoirs, in combination with changes in Delta exports, influence the magnitude of Delta outflow and the associated salinity gradients in the western Delta and Suisun Bay.

Water project operations, particularly upstream reservoir releases for export in the South Delta, may affect water temperature with the greatest effects occurring in upstream tributaries and diminishing downstream in the Delta. The extent of the influence has been identified as a knowledge gap and is presently under investigation (K. Gleichauf, Stanford University, personal communication). Water temperature may affect the migration of juveniles by influencing growth, smolt transformation, saltwater survival, and disease (Adams et al. 1975; Holt et al. 1975; Wurtsbaugh and Davis 1977; Hughes et al. 1978; Boles 1988; Cech and Myrick 1999; McCullough 1999; Benjamin et al. 2013).

Chinook salmon can smolt at temperatures ranging from 6 to 20°C; however, salmon that smolt at higher temperatures (greater than 16°C) tend to display impaired smoltification patterns and reduced saltwater survival, while juvenile salmon that rear in the 10 to 17.5°C temperature range are optimally prepared for saltwater survival (Myrick and Cech 2005). Steelhead successfully undergo parr-smolt transformation at temperatures between 6.5 and 11.3°C, and show little seawater adaptation at temperatures above 15°C (Adams et al. 1975). Cooler temperatures (less than 10°C) tend to increase their seawater adaptation. Cooler temperatures also reduce their risk of predation and disease, both of which are increased at higher temperatures (Myrick and Cech 2005), which could affect migration rates and survival.

The effects of temperature on the migration of juvenile salmonids may in turn have effects on overall juvenile life history strategies. For example, in the Columbia and Snake rivers, migration timing in Chinook salmon and steelhead was strongly and inversely correlated with flow and significantly influenced by temperature, as well as date of ocean entry and prior travel time (Berggren and Filardo 1993). In the Stanislaus River, smolt migrant size was found to be negatively associated with temperature and positively associated with discharge (Zeug et al. 2014). The velocity at which a change in swimming behavior is detected in Chinook salmon smolts (response velocity) has also been shown to increase with increasing water temperature (Enders et al. 2009).

3.15.3 Summary of Findings

A substantial body of information is available on the relationships between exposure of salmonids to concentrations of various water quality constituents on spawning, egg incubation, juvenile rearing in tributaries, and smolting, but there is a paucity of information on the relationships between various water quality gradients and constituents as migration cues for juveniles within the estuary. Studies have not been conducted to investigate water quality gradients and migration rate, route selection, or survival within the Delta. Although review of the effects of water quality gradients on juvenile salmonid migration and survival was not the focus of this study, the SST recommends that further consideration be given to the effects of water quality in the Delta on salmonid migration and survival.

3.16 LIFE HISTORY STAGES AND STRATEGIES

Chinook salmon and steelhead inhabiting the Central Valley rivers express a wide range of life history characteristics. Adult migration timing varies among Chinook salmon runs, juvenile rearing may involve a rapid downstream dispersal as fry soon after juveniles emerge from redds, upstream rearing for a period of months in natal and non-natal habitats prior to migrating downstream to the ocean as young-of-the-year smolts, and rearing in upstream areas for an extended period migrating downstream at age one or two. The diversity of life history characteristics is thought, in part, to be an adaptation to variable environmental conditions such as inter- and intra-annual variation in precipitation and runoff, as well as to extend the period of ocean entry to improve juvenile survival.

3.16.1 Conceptual Model Predictions

The conceptual model predicts the following:

- Diversity in life history expression for juvenile salmonids (variable rearing strategies in the rivers and Delta, variable migration timing, variable size at migration) contribute to increased population-level survival.
- Water project operations, including river flows, seasonal gate and barrier operations, and Delta export operations have the potential to constrain and reduce life history diversity and survival.

3.16.2 Analysis

A characteristic of healthy and robust salmonid populations is that they display a broad diversity of life history attributes (McElhany et al. 2000). Chinook salmon express a wide range of juvenile life history patterns in which some juveniles migrate downstream soon after emergence as fry to rear in the lower river reaches and Delta before emigrating to coastal waters (fall-, spring-, and winter-run Chinook salmon), while others rear in upstream habitats for an extended period, migrating downstream as fully developed smolts, or for some runs, as yearlings (steelhead, late-fall-run, fall-run, winter-run, and spring-run Chinook salmon). The wide diversity in juvenile life history tactics is thought to convey an evolutionary advantage to the populations by a wide geographic dispersal adapted to variable environmental conditions in juvenile rearing habitat and at the time of ocean entry (Goertler 2014; Beechie et al. 2006; Greene et al. 2010; Schroeder et al. 2015).

There have been significant analytical advances in recent years in the ability to use isotope ratios from otolith micro-chemistry to determine the natal stream, hatchery versus wild origin, and juvenile life history contributing to observed adults returning to a river to spawn (Barnett-Johnson et al. 2008; Sturrock et al. 2015; Weber et al. 2002). Results of recent analyses based on otolith micro-chemistry have shown evidence that salmon that migrate downstream as fry in wet years contributed a substantially greater proportion (greater than 20%) to subsequent adult returns to Central Valley rivers than in dry years (Sturrock et al. 2015).

The Delta serves both as rearing habitat for fry and as a migration corridor for smolts and yearlings. Acoustic telemetry studies to date have focused on larger, migrating salmonids that can accommodate an AT. Limited studies using half CWT were conducted in the past to assess survival of Chinook salmon fry (fish less than approximately 60 millimeters [mm]) in the Delta. Results of these early fry survival studies have not been used in assessing alternative management strategies for salmonids in the Delta or for assessing the relationships between water project operations and fry survival or contribution to the ocean fishery or spawning escapement. These attributes include, but are not limited to, seasonal diversity in migration timing and geographic diversity in rearing strategies and habitat use in the upstream tributaries and Delta.

3.16.3 Summary of Findings

Life history diversity has been identified as an important attribute of healthy and robust salmonid populations. No survival studies or analyses were identified that specifically examined the relationships between water project operations and life history diversity of Central Valley salmonids. Limited studies have been conducted to examine fry survival in the Delta, but results of these early studies may not reflect current environmental conditions in the Delta or current water project operations. Although review of the effects of water project operations on salmonid life history diversity was not the focus of this study, the SST recommends that further consideration be given to the effects of water project operations and facilities in the Delta on salmonid life history diversity.

3.17 COHORT AND POPULATION DYNAMICS AND OUTCOMES

3.17.1 Conceptual Model Predictions

The conceptual model predicts that water project operations have the potential to reduce salmonid survival in the Delta and adversely impact subsequent adult abundance in the ocean and escapement to Central Valley rivers (population-level affects).

3.17.2 Analysis

To date, survival studies conducted in the Central Valley rivers and Delta have focused on estimating survival of juvenile salmon and steelhead from an upstream release site such as Durham Ferry to a downstream detection site such as Chipps Island or the Golden Gate. In addition, only limited analyses have been conducted to assess survival of CWT marked salmon from each of the release groups in the ocean, other than as a comparison of survival estimated for juveniles based on trawling at Antioch and Chipps Island with survival estimated from commercial and recreational fishery recaptures of CWT salmon in the ocean and spawner escapement, as well as the CWT analyses reported by Zeug and Cavallo (2014).

Studies or tools that incorporate information from throughout the salmonid lifecycle (e.g., temporal and spatial distribution of cohorts, ocean survival) would help put the juvenile survival results into a broader population-level context. Information on the population-level consequences of various sources of juvenile mortality is limited, and the relationship of those sources to water project operations is unknown.

Analytical tools are available, and have been used to a limited extent, to assess how factors in the Delta ultimately affect adult abundance (e.g., Interactive Object-oriented Salmon Simulation [IOS] model) (Cavallo et al. 2011; Zeug et al. 2012), Oncorhynchus Bayesian Analysis (OBAN) model (Hendrix 2008), and the San Joaquin Salmon Life Cycle Model (SalSIM; CDFW 2005; Marston 2012). In addition, NMFS has developed a lifecycle model for winter-run Chinook salmon (Hendrix et al. 2014) and is currently developing additional lifecycle models that address other salmon runs on both the Sacramento and San Joaquin rivers. Lifecycle models for each race of Chinook salmon could be used to assess which management actions in the Delta and upstream could be implemented to meet or make progress towards species recovery. In addition, the lifecycle models could incorporate information from population viability analyses (PVAs), cohort replacement rates (CRRs), smolt to adult ratios (SARs), and other output metrics that would be useful to managers in tracking the status of various management actions and as a decision-making tool to provide a structured framework for prioritizing research and actions, and evaluating performance of actions in achieving survival and abundance targets (see Volume 2, Management Question 6). Once these additional lifecycle models have been calibrated, validated, and peer reviewed, it is expected the suite of analytical tools available will prove valuable in investigating the effects of project-related entrainment and other sources of mortality on the population dynamics of Central Valley Chinook salmon. These models are also expected to provide a stronger analytical framework for identifying hypothesized mechanisms affecting juvenile survival and future research priorities, and serve as a basis for identifying testable hypotheses and appropriate experimental designs for future experiments, monitoring, manipulation, and data analyses. To date, efforts devoted to lifecycle modeling have been limited to Chinook salmon; no steelhead lifecycle model has been developed for the Central Valley.

3.17.3 Summary of Findings

Lifecycle models are needed that reflect species-specific life history characteristics within the Sacramento and San Joaquin river systems. Mechanistic lifecycle models could be used to identify the change in Delta survival necessary to support population persistence or recovery. They can also be used in assessing the relative contribution of water project operations and other potential factors affecting the habitat conditions, migratory behavior, and survival of juvenile salmonids in the Delta. These models could also be used as an analytic tool for identifying hypotheses and potential mechanisms and linkages that are priorities for future research. NMFS and others have developed, or are currently developing, salmon lifecycle models that can be applied to Central Valley salmon stocks; however, the application of these models in the past for use as a technical basis for comparing alternative management strategies, assessing the relative contribution of different sources of potential mortality within the Delta, comparing potential benefits between water project operational management, habitat enhancements, and management targeted on non-project stressors has been limited.

Lifecycle models have been developed for Chinook salmon on both the Sacramento and San Joaquin rivers; no steelhead lifecycle model is available for the Central Valley, although models have been developed to address residency versus anadromy (Satterthwaite et al. 2009).

3.18 DISCUSSION AND SUMMARY OF KEY FINDINGS

3.18.1 Discussion

There appears to be little relationship between SWP and CVP exports and survival of San Joaquin River fall-run Chinook salmon through the Delta for export rates less than 4,000 cfs. There is moderate evidence that survival is low for export rates greater than 4,000 cfs, but there are only two observations for this higher range of export rates, and the variability in survival estimates at lower export levels suggests that two observations are too few to adequately represent the possible distribution of survival for the higher range. If we want to be sure that survival is low at high export levels, then more observations must be taken at high export levels. On the other hand, if those high export levels are far outside the range of levels being considered by managers, then taking more data to characterize the survival response at those levels is of limited use.

We have investigated the relationship between water project operations and survival of juvenile salmonids migrating through the Delta. We explored several mechanisms by which water project operations may affect survival, namely direct mortality at the facilities, migration route, and migration rate. We also examined patterns in survival, inflow, and export data for evidence of correlative relationships independent of migration route and rate. We used our conceptual model to predict relationships that we expected to see in the data and, where feasible, incorporated findings from the ecological literature or other systems into our review. Nevertheless, assessment of the support for a conceptual model of how a particular system works necessarily requires examining data from that actual system, and so a statistical assessment of data from the Delta was required. We used existing statistical assessments from published journal articles and agency reports, and briefly discussed preliminary and informal statistical assessment of data newly compiled by the SST for this report.

The following limitations of a statistical approach are well known: 1) correlation does not mean causation; and 2) variability in the true relationships may mask those relationships on certain spatial or temporal scales. The variability in relationships and the large number of possibly confounding factors have ramifications for data interpretation. Even if the hypothesized relationship exists, statistically significant results may not be attainable on all spatial and temporal scales, or may require many years of data over a wide range of conditions. This type of situation is observable in comparisons of through-Delta survival in different migration routes: survival was higher in the San Joaquin River route than in the Old River route in some years, but not in other years. Additional data under a range of inflow and barrier conditions may help clarify the relationship between migration route and survival, although it is likely that more years will be required if survival remains low in both routes. In some cases, however, conclusions can be made even in light of variability. For example, it appears safe to conclude that fish should stay out of Turner Cut when migrating down the San Joaquin River.

For planning future studies, a power analysis can be helpful to determine how many observations will be necessary to detect a relationship if it exists; however, a power analysis requires precise definition of the relationship to be detected (e.g., effect size) and the level of acceptable error (significance). A study will be most useful if managers and researchers agree on these objectives during the planning stage, rather than after the data have been collected. In particular, performing a power analysis after a study is complete to assess why no statistically significant result was found is inappropriate and will give invalid results; confidence intervals of estimated effect sizes are recommended as an alternative to hypothesis tests (e.g., Levine and Ensom 2001).

The Delta is a complex system, and the available data demonstrate the difficulty of coming to firm conclusions about relationships between drivers and outcomes in such a system. Relationships are likely to be complicated by high variability, interactions with other factors, multicollinearity between explanatory variables, and possibly non-linear characteristics. These issues, combined with the very low survival observed in recent years, make it difficult to identify and characterize any relationship that may exist, such as between export rates or route selection and survival. Tagging studies that may clarify the existence or nature of such a relationship will require several features including larger sample size, many replicates over multiple years, and observations at widely varying levels of explanatory variables. Sample size (i.e., size of release group) must be large enough that sufficient fish survive to downstream reaches to both estimate survival and capture the uncertainty of the estimate; the many different migration route options available to fish in the Delta mean that even larger sample sizes will be necessary to estimate survival in the downstream reaches of the less popular routes. However, it is important to note that using a few large release groups will not be sufficient to characterize a relationship; many observations are required, rather than a few (albeit precise) observations. The high variability observed in the system means that any single estimate will be insufficient to characterize the survival response at a particular level of the explanatory variable (e.g., exports); thus, multiple years of data will be required, covering the range of conditions that may be expected to be encountered. In a highly managed system in which extreme conditions are rare, it may take many years to collect data from enough conditions to detect a relationship with desired precision and level of significance. During that time, the system may undergo a regime change or the population may be extirpated.

An alternative is to artificially create extreme conditions in order to detect a relationship (Schindler and Hilborn 2015). However, low survival and interacting factors mean that those artificial extreme conditions would need to be created multiple times to characterize the variability of the response (e.g., survival). A power analysis can be used to guide study planning by informing the number of observations and sample size necessary. However, a power analysis is implemented to address a precisely defined question such as how many observations are necessary to detect an effect of size X with an error rate of Y and significance level of Z, assuming a particular relationship exists and that the variability of the relationship is known. Thus, to be most useful, a study should be designed with thoughtful input from managers on what question (quantitatively defined) they want answered, as well as researcher a priori understanding of the system. Studies may be designed to answer multiple questions, but a separate power analysis will be necessary for each objective.

Long-term, large-scale studies are challenging to fund and implement, and risk regime change during the duration of the study. Very low survival with resulting low, effective sample sizes in downstream reaches, and high levels of uncertainty in results, complicate matters further. A complement to large region-wide survival studies is a study that targets survival in a particular region such as Frank’s Tract or lower Old River. Although survival in these regions should be estimable from a region-wide study (if appropriate receiver locations are used), low survival is likely to preclude attaining reliable results in all years. Careful use of supplemental releases closer to the downstream reaches of special interest, in addition to upstream releases at historical release sites, has the benefit of providing adequate data to estimate survival in reaches that are poorly understood while continuing the useful time series of upstream or region-wide survival. Similar types of modifications to existing or historical studies may be feasible to address knowledge gaps in the conceptual model.

Warnings against using correlation to conclude causation are ubiquitous in the scientific literature, and appear occasionally in the more restricted world of fisheries literature, as well. Yet management decisions must be made before the question of causation is finally decided. Hilborn (2016) presents examples of cases in which even strong correlation was mistakenly taken as evidence of causation and later found to be faulty. He suggests that a useful alternative to using correlation as evidence of causation is to use multiple working hypotheses and for managers to identify policies that are “robust to the range of alternative hypotheses” (Schindler and Hilborn 2015; Hilborn 2016). A formal risk analysis may be useful to compare competing management decisions under an expanded suite of hypotheses.

With that advice in mind, it behooves us to consider a range of hypotheses. One hypothesis, which underlies the scope of this analysis, is that the water export operations determine survival of juvenile salmonids migrating through the Delta via short-term effects on routing and migration rate. If true, then survival of salmon passing through the Delta can be manipulated via adjustments to water project operations, including export rates, upstream reservoir releases, and gates and barriers within the Delta. The following are alternative hypotheses: 1) Delta survival is primarily a function of water temperature; and 2) Delta survival is primarily a function of predation pressure that itself depends on the size and composition of the predatory fish community. Additionally, water project operations may be affecting survival via long-term effects, or short-term effects not expressly considered in this report, including:

- Effects on the population of invertebrates, phytoplankton, and zooplankton, which in turn affect trophic resources, ecosystem productivity, and water equality (Jassby and Powell 1994; Jassby et al. 2002; Grimaldo et al. 2009)
- Effects on river channel geometry and riparian vegetation, and the extent of these effects on salmonid survival via changes in cover, refugia, and water temperature (Tabor and Wurtsbaugh 1991)
- Effects on water temperature, turbidity gradients, and water quality gradients in various regions of the Delta, via effects of river flow and water velocity
- Effects of actions that support water project operations (e.g., levee maintenance, installation of riprap on shorelines) on the Delta ecosystem, and the resulting effects on juvenile salmonid survival

The potential effects of some of the water project operations listed above are not detectable from short-term survival studies and comparisons to export or inflow rates.

If one or more of these alternative hypotheses is true, either in place of or in combination with our investigated hypothesis of short-term effects via migration routing and migration rate, yet management actions focus only on the short-term hypothesis, then it is unlikely that short-term modifications will be sufficient to return salmon survival through the Delta to desired levels. Adaptive management that allows for multiple hypotheses and focuses on desirable outcomes is more likely to be successful than policies that rely on a single hypothesis for which even the correlative analyses provide inconsistent evidence.

3.18.2 Summary of Key Findings and Gaps

Key findings and gaps are summarized in Table 3-3. These are the same findings and gaps presented in the Executive Summary. The key findings reflect information that emerged or was supported by the process of literature review and analysis undertaken by the SST. Key findings are typically characterized as having a medium or high basis of knowledge, and were judged by the SST as critical to our understanding of salmon and steelhead survival in the Delta in the context of hydrodynamic conditions and export operations. Key data gaps highlight areas within the research scope identified by the SST where our basis of knowledge is typically low or minimal with a particular emphasis on gaps that, if filled, would likely improve our understanding of the relationship between salmonid survival in the Delta and hydrodynamic conditions and exports, and/or inform our ability to more effectively manage Delta operation and hydrodynamics for improved salmonid survival. The methodology used to rate basis of knowledge is described in Section 2.4.

The findings below refer to juvenile Chinook salmon and steelhead migrating through the Delta (i.e., not rearing). For through-Delta survival, San Joaquin River-origin Chinook salmon (fall-run) are discussed separately from Sacramento River-origin Chinook salmon (fall-, late-fall-, spring-, and winter-run) because they experience different geography and environmental conditions (including hydrology), and steelhead are discussed separately from Chinook salmon.

Table 3-3. Summary of Key Findings

THROUGH-DELTA SURVIVAL

Through-Delta survival has been consistently low for San Joaquin River Chinook salmon, and more variable for Sacramento River Chinook salmon; survival data are limited for steelhead.

SAN JOAQUIN RIVER FALL-RUN CHINOOK SALMON

Findings

- Survival has been low (less than 0.2 [i.e., less than 20%] since 2002). For example, through-Delta survival has been less than or equal to 0.05 for 14 of 22 estimates, and less than or equal to 0.10 for 20 of 22 estimates, since 2002 (Appendix E, Figure E.2-3). Prior to 2002, juvenile Chinook salmon survival rates were typically higher in high flow years (1995, 1997, 1998, and 1999).
- Since 2002, through-Delta survival has been low (less than 0.2) even in higher flow years (2006, 2011) (Appendix E, Figure E.2-3), which is not consistent with results of earlier survival studies showing evidence of increased juvenile survival as Delta inflows increased during the migration period.
- In the South Delta, survival has been low in all routes since 2008 (Appendix E, Figure E.4-3), which is not consistent with results of the majority of earlier CWT survival studies that indicated higher survival for those migrating juvenile salmon that remained in the San Joaquin River at the head of Old River when compared to those that entered Old River at that location.
- Survival from the export facilities to Chipps Island via salvage and trucking was higher from the CVP than the SWP, with a primary difference being CCF in the SWP route (Appendix E, Figure E.4-7, Table E.4-3). Although validation of the assumption of lower pre-screen losses at the CVP intake compared to the SWP intake is needed, these results support a recommendation for preferential export operations using the CVP intake to benefit salmonids.
- The survival rate per kilometer from the CVP to Chipps Island via salvage was sometimes higher than the survival rate through the lower San Joaquin River reaches, but was low in absolute terms.

Gaps in Information

- Many drivers for low through-Delta survival have been hypothesized, but the role of each has not been quantified. Hypothesized factors contributing to the observed low Delta survival include increased abundance and increased metabolic rate of predatory fish such as striped bass

THROUGH-DELTA SURVIVAL

Through-Delta survival has been consistently low for San Joaquin River Chinook salmon, and more variable for Sacramento River Chinook salmon; survival data are limited for steelhead.

and largemouth bass in the Delta, water project operations affecting the magnitude and timing of flow resulting in increased juvenile salmonid predation mortality, changes in Delta habitat including expansion of non-native submerged aquatic vegetation, increased water clarity, potential exposure to contaminants, and other factors. The potential contribution of these factors to salmonid mortality supports a stronger focus on investigating the mechanisms underlying salmonid mortality in different regions of the Delta and their link to water project operations (see Section 3; Appendix E, Figure E.1-1, Table E.1-1).

- Collection and analysis of data on migration and survival of acoustic-tagged Chinook salmon released in the San Joaquin River is ongoing; survival estimates have been calculated through 2012. Additional data through 2016 will be compiled and analyzed to investigate various hypotheses over observed conditions such as potential relationships between flows and export rates and survival, as well as route selection and migration rate within various regions of the lower river and Delta. Other analyses can also be done and support our recommendation to continue studies and do additional data analyses and assessment. However, because these studies were observational in nature, and were not designed to test these hypotheses, the findings from such analyses will be limited and will not obviate the need for future investigations.

SACRAMENTO CHINOOK SALMON

Findings

- Survival among release groups has been variable across years and among populations. For example, in 2013 and 2014, through-Delta survival was estimated at 0.32 to 0.35 for hatchery winter-run Chinook salmon, 0.00 to 0.30 for hatchery spring-run Chinook salmon, and 0.00 for hatchery fall-run Chinook salmon (based on data from only one release group in 2014), whereas between 2006 and 2010, late-fall-run Chinook salmon had through-Delta survival estimates ranging from 0.17 to 0.64 (Appendix E, Section E.2.1, Table E.2-2).

Gaps in Information

- Data for some populations (e.g., winter-run, spring-run) are more limited than for other populations (e.g., late-fall-run). The majority of experimental survival studies conducted to date have been performed using hatchery-produced fall-run and late-fall-run Chinook salmon. Acoustic survival studies using hatchery-produced winter-run Chinook salmon have been initiated only in the last four years. Little information is available on survival of wild salmonids or on the applicability of hatchery-produced salmonids as a representative surrogate for wild stocks. Little information is currently available on the primary drivers for differences in survival between populations; however, more is being learned about the role of environmental conditions on survival, the role of route selection (e.g., mainstem versus interior Delta routes) and migration timing and behavior on survival, and other factors affecting survival of different stocks in the Sacramento River and Delta (Appendix E, Section E.2.1, Tables E.2-1 and E.2-2).

STEELHEAD

Findings

THROUGH-DELTA SURVIVAL

Through-Delta survival has been consistently low for San Joaquin River Chinook salmon, and more variable for Sacramento River Chinook salmon; survival data are limited for steelhead.

- Based on data from 2011 and 2012, survival of acoustic-tagged juvenile steelhead migrating from the San Joaquin River (0.32 to 0.54) has been greater than that of fall-run Chinook salmon from the same years (0.02 to 0.03) (Appendix E, Section E.2.1, Table E.2-3).
- Based on data from 2009 and 2010, survival of acoustic-tagged juvenile steelhead migrating from the Sacramento River (0.47 to 0.58) has been comparable to estimates of Sacramento River late-fall-run Chinook salmon survival from the same years (0.34 to 0.64) (Appendix E, Section E.2.1, Table E.2-2).

Gaps in Information

- For both San Joaquin River and Sacramento River steelhead, relatively few data are available on survival through the Delta compared to Chinook salmon (collection and analysis of San Joaquin River steelhead data is ongoing; survival estimates have been calculated for 2011 through 2012, and will be available for 2013 through 2016). Survival estimates for juvenile steelhead migrating downstream in the Sacramento River are available for several years but do not represent a wide range of environmental conditions.

FISH SIZE

Multiple lines of evidence indicate smaller fish respond to conditions differently and usually experience lower survival than larger fish.

Findings

- Studies of juvenile fishes undertaken to develop an estimate of handling and trucking mortality found that for Chinook salmon, mortality during holding and trucking was greater (2% mortality) for juvenile Chinook salmon less than 100 mm than for salmon greater than 100 mm (0% mortality; Appendix E, Section E.3.2.1).
- Based on CWT fall-run Chinook salmon released in the Delta, fish size was found to be a stronger indicator of ocean recovery rates than were hydrologic variables (inflow, exports), based on analyses by Zeug and Cavallo (2013) (Appendix E, Section E.6.2.1).
- In the two years with survival data for both Chinook salmon and steelhead from the San Joaquin River, the steelhead were both larger than the Chinook salmon and had higher survival; it is unclear the extent to which fish size was the primary driver of the differences in survival versus other variables (e.g., species) (Appendix E, Section E.2.1, Figures E.2-3 and E.2-4, Table E.2-3).
- AT studies in the Sacramento River have found higher through-Delta survival for larger fish (Appendix E, Section E.9.2.1). Perry (2010) found a significant relationship between acoustic-tagged late-fall-run Chinook salmon and survival in the Sacramento River mainstem and Sutter and Steamboat sloughs. Newman (2003) found a positive relationship between fish size and through-Delta survival for CWT fall-run Chinook salmon migrating from the Sacramento River.

FISH SIZE

Multiple lines of evidence indicate smaller fish respond to conditions differently and usually experience lower survival than larger fish.

- Louver efficiency experiments show a non-monotonic (i.e., not strictly increasing or strictly decreasing) relationship between Chinook salmon size and efficiency (Appendix E, Section E.3.2.1).
- Shorter through-Delta travel times of San Joaquin River fall-run Chinook salmon were observed with increasing smolt size based on CWT fish (Appendix D, Section D.4); however, despite Chinook salmon being smaller than steelhead, migration rates (e.g., kilometers per day) of acoustic-tagged Chinook salmon released into the San Joaquin River in 2011 and 2012 were approximately twice that of steelhead (Appendix D, Section D.5.2). Average travel time between Durham Ferry and Chipps Island for steelhead in 2011 (276.7 mm fork length [FL]) was 11.08 days (SE = 0.12 days) while travel time for juvenile fall-run Chinook salmon (110.8 mm FL) was 3.02 days (SE = 0.27 days). In 2012 steelhead (233.6 mm FL) travel time was 9.41 days (SE = 0.25 days) compared to juvenile salmon (112.8 mm FL) travel time of 5.75 days (SE = 0.41 days).

Gaps in Information

- Existing tagging data do not represent the full range of sizes of wild fish because of tag burden concerns (i.e., tags are too large for smaller fish).
- The survival effect of differences in salmon and steelhead size for fish reared in the hatcheries compared to wild fish is uncertain.
- Our scope focused primarily on migrating juvenile salmonids, and we did not review information on how rearing fry or parr respond to hydrodynamic factors such as water velocity (Appendix D, Section D.4).

PROJECT EFFECTS

Water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities, but direct mortality does not account for the majority of the mortality experienced in the Delta; the mechanism and magnitude of indirect effects of water project operations on Delta mortality outside the facilities is uncertain.

Findings

- Direct mortality (at the facilities) is a combination of pre-screen and within-facility mortality (including mortality during salvage and transport), and entrainment into the pumps and water conveyance canals (Appendix E, Section E.3.2.1).
- There is a large amount of indirect evidence of predation within the facilities including pre-screen losses in CCF, within the salvage facilities, and at release sites in the Delta (Appendix E, Section E.3.2.1). Predatory fish have been observed near and within the water project facilities, and juvenile salmon and steelhead have been collected from predator stomach samples. Additional indirect evidence includes results of mark-recapture experimental studies within CCF for both salmon and steelhead, observations of predator movement and behavior from AT studies, and observations of stationary ATs in and near the facilities thought to have been defecated by predatory fish. Indirect evidence of predation mortality associated with

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water project facilities and elsewhere in the Delta channels supports recommendations for reducing predation; however, such reductions should be paired with actions to improve survival in the Delta upstream of the facilities, to yield substantial increases in survival through the Delta.

- Despite implementing RPAs intended to reduce mortality at the export facilities, through-Delta survival remains low (Appendix E, Section E.2, Figure E.2-3, Tables E.2-2 and E.2-3).
- Hydrodynamic monitoring and simulation modeling indicate that exports have the greatest effect on flow and velocity in the region of the Delta nearest the export facilities (Appendix B).
- Results of studies show that route selection is generally proportional to the flow split at channel junctions, and the effect of exports on route selection is strongest at the junction leading directly to the export facilities (i.e., head of Old River). Results of juvenile Chinook salmon survival studies using CWT and more recently (2008, 2010, 2011, and 2012) ATs have not shown a strong or consistent relationship with SWP and CVP export rates. Steelhead data are limited to only 2011 and 2012; additional data through 2016 are being analyzed for both salmon and steelhead. Survival rates for juvenile salmon since 2002 have been consistently low independent of variation in both export rates and Delta inflows.

<u>Gaps in Information</u>

- Additional analyses are needed to investigate the expected change in salmonid route selection and subsequent survival from changes in export rates (Appendix D, Section D.8).
- The evidence of a relationship between exports and through-Delta survival is inconclusive; the key findings presented in this table are supported by medium or high basis of knowledge, but our basis of knowledge on the relationship between exports and through-Delta survival is low (Appendix E, Section E.6.2.1). Since 2002, juvenile fall-run Chinook salmon survival in the south Delta has been consistently low despite restriction of export rates. Survival rates for acoustic-tagged juvenile steelhead are currently available only for two years (2011 and 2012), which are insufficient to support an analysis of the potential relationship between export rate and survival. Analysis of additional AT data for 2013 through 2016 will help further assess potential relationships for both salmon and steelhead.
- Estimates of entrainment mortality at the export facilities from salvage counts depend on pre-screen mortality, but data on the magnitude and variability of pre-screen mortality are unavailable at the CVP (Appendix E, Section E.3.2.1).
- There is uncertainty in the spatial and temporal variability in predation pressure and how predation pressure responds to changes in water project operations and associated habitat changes (Appendix E, Sections E.3.2, E.3.3, E.4.2.5, and E.4.3). Based on current AT technology, it is difficult to determine when, where, and if a juvenile salmonid has been preyed on within a reach of the Delta. How water project operations affect Delta flows and velocities, physical structures, and habitat conditions that in turn affect both predators and prey warrants further investigation.

PROJECT EFFECTS

Water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities, but direct mortality does not account for the majority of the mortality experienced in the Delta; the mechanism and magnitude of indirect effects of water project operations on Delta mortality outside the facilities is uncertain.

- The contribution of water project operations to the total mortality of juvenile salmonids has not been quantified. Many of the mechanisms through which changes in Delta hydrodynamics and other factors related to water project operations may contribute to salmonid mortality (e.g., change in vulnerability to predation in Delta channels or change in migration routing as a result of water project operations) are uncertain.
- Estimates of direct mortality (e.g., mortality resulting from pre-screen losses and losses at the louver and salvage facilities, which are directly related to water project export operations) have been developed from CWT data by several authors and show, in general, that the magnitude of direct loss (e.g., percentage of a marked release group observed in fish salvage) is typically low for juvenile Chinook salmon (typically less than approximately 1%). However, such estimates do not include export-induced mortality prior to entering the facilities that is indirectly related to water project operations (e.g., mortality resulting from project related changes in habitat). Estimates of direct facility mortality as a proportion of total migration mortality have been as high as 5.5% for winter-run Chinook salmon and 17.5% for Chinook salmon released in the San Joaquin River (Zeug and Cavallo 2014).
- It is unknown whether equivocal findings regarding the existence and nature of a relationship between exports and through-Delta survival is due to the lack of a relationship, the concurrent and confounding influence of other variables, or the effect of low overall survival in recent years. These data gaps support a recommendation for further analysis of available data, as well as additional investigations to test hypotheses regarding export effects on migration and survival of Sacramento and San Joaquin River origin salmonids migrating through the Delta.

PHYSICAL CONDITIONS

The Delta is a complex and dynamic environment, and the relative influence of tides, inflow, and exports on hydrodynamic conditions (flow and velocity) varies temporally and spatially throughout the Delta. Project operations affect physical conditions in the Delta through various ways including Delta inflows, exports, and gate and barrier operations.

Findings

- The major rivers in the South Delta (San Joaquin, Old, and Middle) transition from a riverine environment to a tidally dominated environment in the Delta (Appendix B, Figure B.1-2).
- The hydrodynamic effect of increases in Delta inflow on flow and velocity in the South Delta is greatest at the upstream reaches of the major rivers, diminishes with distance downstream through the Delta or away from the mainstem rivers (i.e., into the interior Delta), and is affected by barriers, tidal phase, and exports (Appendix B, Figures B.5-1 through B.5-7 and B.5-13 through B.5-17).

PHYSICAL CONDITIONS

The Delta is a complex and dynamic environment, and the relative influence of tides, inflow, and exports on hydrodynamic conditions (flow and velocity) varies temporally and spatially throughout the Delta. Project operations affect physical conditions in the Delta through various ways including Delta inflows, exports, and gate and barrier operations.

- The hydrodynamic effect of exports on flow and velocity in the South Delta is strongest in Old River at the export facilities, in Middle River at Victoria Canal and the downstream end of Railroad Cut, and at Columbia Cut, and is affected by tidal phase, Delta inflow, and barriers (Appendix B, Figures B.5-1 through B.5-8 and B.5-13 through B.5-17).
- The effect of tides decreases with distance up mainstem rivers, and the tidally dominated region varies with Delta inflow, exports, and tidal phase (Appendix B, Figures B.5-1 through B.5-7).
- Hydrodynamic models were developed for water project planning and have typically been used for long time scales (e.g., daily) and large geographic areas (e.g., San Joaquin River flow routing).
- The application of current hydrodynamic simulation models to predictions of flow and velocity at South Delta channel junctions when encountered by migrating salmonids at specific times (i.e., on short time scales and small geographic areas) may not be reliable (Appendix B, Section B.3; Appendix C, Pages C-14 through C-163).
- DSM2 may be useful for assessing how exports from the South Delta, river inflows, barriers, and tides can influence the magnitude, duration, and direction of water velocities and flows within channels, depending on its accuracy relative to validation for specific areas and time scales. However, 15-minute velocities and flows estimated from DSM2 have been found to vary substantially from measured conditions and timing related to tidal conditions (Appendix C, Pages C-14 through C-231) and were not found to be accurate for assessing fish fates and behaviors at specific times and locations which would require direct measurement of flows in the field, or the application of simulation models depending on the temporal and spatial resolution needed to support analyses of specific hypotheses or management questions.
- Model validation analysis conducted for this report concluded that: 1) some locations of the South Delta validate better than others; 2) validation quality at Turner Cut varied over a period of several years; 3) validation at high inflows was poorer than at lower inflows; 4) validation was better at the daily average time step compared to the 15-minute instantaneous time step; and 5) validation using RMA 2-D was better than DSM2 on average (Appendix B, Sections B.3.1.5 and B.3.1.6; Appendix C, Pages C-14 through C-163).
- The application of hydrodynamic models to fish behavior requires calibration and validation at appropriate temporal and spatial scales (Appendix B, Section B.3; Appendix C, Pages C-14 through C-163).
- Results of limited analysis of AT data indicate that juvenile Chinook salmon migration rate slowed in areas of the Delta with bi-directional tidal velocity compared to upstream riverine reaches with uni-directional flows (Appendix D, Section D.6). No analyses were found on a potential relationship between water project exports and juvenile salmonid migration rates within the Delta, although data are available from recent AT studies that could be used to test hypotheses related to effects of riverine flow and export rates on reach-specific migration rates.

PHYSICAL CONDITIONS

The Delta is a complex and dynamic environment, and the relative influence of tides, inflow, and exports on hydrodynamic conditions (flow and velocity) varies temporally and spatially throughout the Delta. Project operations affect physical conditions in the Delta through various ways including Delta inflows, exports, and gate and barrier operations.

Gaps in Information

- Model calibration and validation can be limited by insufficient data on factors such as: 1) Delta Consumptive Use; 2) South Delta bathymetry; 3) Clifton Court inflow; and 4) monitoring station calibration.
- Further model refinements and validation are needed at temporal and spatial scales appropriate for use in analysis of salmonid migration.
- The magnitude of change in flow, water velocity, or water quality needed to elicit a behavioral or survival response by migrating juvenile salmonids has not been determined.
- The specific behavioral mechanisms underlying the slowing of migration rates in tidally influenced areas are uncertain. Selective tidal surfing behavior has been hypothesized as a mechanism supporting juvenile salmonid migration through the tidal region of the Delta, but requires further analysis and investigation (Appendix D, Section D.6).

MANAGEMENT ACTIONS

- **Gates and barriers influence fish routing away from specific migration corridors.**
- **The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.**
- **The extent to which management actions such as reduced negative Old and Middle River (OMR) reverse flows, ratio of San Joaquin River inflow to exports (I:E), and ratio of exports to Delta inflow (E:I) affect through-Delta survival is uncertain.**

FINDINGS

General

- Spatial variability in the relative influence of Delta inflow and exports on hydrodynamic conditions means that high inflow or I:E, and low exports or E:I, may differentially affect fish routing and survival in different Delta regions (Appendix B, Section B.5; Appendix E, Sections E.6 and E.2.3).
- Uncertainty in the relationships between I:E, E:I, and OMR reverse flows and through-Delta survival may be caused by the concurrent and confounding influence of correlated variables, overall low survival, and low power to detect differences (Appendix E, Section E.2.3).

- Juvenile salmonid migration rates tend to be higher in the riverine reaches and lower in the tidal reaches (Appendix D, Sections D.3. and D.6; Appendix E, Section E.5, Figure E.5-1).

San Joaquin River

- Barriers: A barrier at the head of Old River reduces steelhead and Chinook salmon entrainment into the heads of OMR migration corridors. Historically, through-Delta survival of CWT juvenile fall-run Chinook salmon was estimated to be higher for those salmon using the San

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- **The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.**
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Joaquin River migration corridor, indicating, on average, a survival benefit associated with the spring installation of the HORB; however, data from recent (2010 through 2012) AT studies have shown that survival has been equally low through all routes for Chinook salmon (Appendix D, Section D.11; Appendix E, Section E.4.2.1). The mechanisms affecting changes in juvenile survival among south Delta migration routes and factors that may have changed that earlier relationship in recent years remain uncertain and warrant further investigation.

- Inflow: Higher Delta inflow from the San Joaquin River is associated with increased survival in the San Joaquin River to Jersey Point when the HORB is in place; however, under low-flow conditions survival can be low even with the barrier in place (Appendix E, Section E.8, Figure E.8-2).
- Inflow: Higher San Joaquin River flow is associated with higher Chinook salmon survival to the Turner Cut junction but the effect does not always result in higher through-Delta survival because of mortality in downstream reaches (Appendix E, Section E.8, Figure E.8-1).
- I:E: The relationship between Delta survival of San Joaquin River Chinook salmon and I:E is variable but generally positive for lower I:E values (e.g., I:E < 3) (Appendix E, Section E.11, Figure E.11-1). Results of these studies are confounded by the use of flow ratios since the same I:E ratio can represent different absolute flow and export rates. These results are further confounded by installation and operations of various South Delta barriers. Data are available from only two years of AT studies using steelhead (Appendix E, Section E.11-4).
- Exports: There was a weak positive association between the through-Delta survival of San Joaquin Chinook salmon and combined exports using the CWT data set, but comparisons are complicated by the correlation between exports and San Joaquin River inflow (Appendix E, Section E.6.2.1).

Sacramento River

- Gates: Closure of the DCC gates can increase through-Delta survival by reducing the risk of juvenile salmonids migrating into the interior Delta from the Sacramento River; however, on flood tides at low flows, similar numbers of salmon can be diverted into the interior Delta through Georgiana Slough alone (Appendix D, Section D.12).
- Inflow: Increased Delta inflow from the Sacramento River is associated with increased through-Delta survival for Chinook salmon migrating from the Sacramento River (Appendix E, Section E.9.2.1).
- E:I: Statistical analyses suggest a weak but generally negative effect of increased E:I on survival of Sacramento River fall-run Chinook salmon, but not for late-fall-run Chinook salmon (Appendix E, Section E.10). Survival data are not available to assess potential relationships between E:I and survival for winter-run or spring-run Chinook salmon or steelhead. Uncertainty in the relationship between E:I and survival may be caused by the confounding

MANAGEMENT ACTIONS

- **Gates and barriers influence fish routing away from specific migration corridors.**
- **The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.**
- **The extent to which management actions such as reduced negative Old and Middle River (OMR) reverse flows, ratio of San Joaquin River inflow to exports (I:E), and ratio of exports to Delta inflow (E:I) affect through-Delta survival is uncertain.**

influence of correlated variables and low power to detect differences (Appendix E, Section E.2.3).

GAPS IN INFORMATION

General

- The effects of OMR reverse flows on salmonid survival and route selection in the Delta (outside of the facilities) have had limited analysis. Data are available from the AT migration and survival studies, as well as earlier CWT data, that might be used in analyses of potential relationships between OMR reverse flows and juvenile salmonid survival. Relationships between OMR reverse flows and migration route and migration rate, as well as reach-specific and regional survival, could be tested using acoustic tag data from both Chinook salmon and steelhead.
- The relationships between water project operations and survival on various spatial and temporal scales are poorly understood. The detailed information generated from the recent salmon and steelhead AT, in combination with refinements in the application of hydrodynamic simulation models to fishery analyses in the Delta, offers the opportunity to conduct additional analyses at a finer spatial and temporal resolution than before; however, more data will be needed to understand patterns over a variety of conditions.

San Joaquin River

- Results of early CWT survival studies conducted using juvenile fall-run Chinook salmon released into the lower San Joaquin River downstream of Old River, and into Old River, showed evidence of higher survival to Jersey Point for those fish that migrated downstream in the San Joaquin River mainstem compared to fish migrating through Old River. Results of limited AT data from 2010 to 2012 showed evidence of equally low survival independent of route selection at the head of Old River. Reach-specific survival estimates with the HORB in place are available only for one year (2012) for both fall-run Chinook salmon and steelhead, although more recent data from 2014 to 2016 (all with the HORB in place for Chinook salmon and some of the steelhead releases) have yet to be analyzed. Further analysis of the available AT data and additional experimental studies to examine the mechanisms affecting juvenile salmon and steelhead survival for those fish migrating downstream in the San Joaquin River mainstem and those entering Old River are needed to assess the potential biological benefits of influencing migration route selection through installation of the HORB in South Delta channels.
- Because few observations of salmon migration survival are available for higher I:E values (e.g., I:E > 5), higher San Joaquin River inflow levels (e.g., Vernalis inflow > 10,000 cfs), and higher export levels (e.g., combined export rate > 5,000 cfs), the variability in survival under these higher levels of I:E, inflow, and exports is not well-characterized (Appendix E, Sections E.2.3 and E.11).

MANAGEMENT ACTIONS

- Gates and barriers influence fish routing away from specific migration corridors.
- The relationship between San Joaquin River inflow and survival is variable, and depends on barrier status and region of the Delta.
- The extent to which management actions such as reduced negative Old and Middle River (OMR) reverse flows, ratio of San Joaquin River inflow to exports (I:E), and ratio of exports to Delta inflow (E:I) affect through-Delta survival is uncertain.

- Exports: Data on potential relationships between San Joaquin River inflow and exports on migration and survival of acoustically tagged juvenile salmon and steelhead are limited to just a few years and environmental conditions; therefore, firm conclusions cannot be made from the AT data sets for San Joaquin Chinook salmon or steelhead (Appendix E, Section E.6.2.1).

CONSTRAINTS ON UNDERSTANDING

Current understanding of juvenile salmon and steelhead survival in the Delta is constrained by a variety of factors (as listed below).

Findings

- The nature of the I:E and E:I metrics as ratios makes it challenging to test their effects, since different sets of physical conditions may be represented with the same I:E or E:I value (e.g., both high and low inflow conditions may be associated with the same I:E value, depending on exports).
- Determining the effectiveness of management operations such as I:E, E:I, and OMR reverse flow restrictions is difficult when all observations are in the presence of those restrictions (i.e., there is no control condition to compare to the experimental condition) (Appendix E, Section E.13). Development of future experimental designs would need to consider increased operational flexibility and/or alternative approaches to the experimental design to test a range of prescribed water project operational conditions.
- There has been low variability and little replication in conditions during recent tagging studies, in particular San Joaquin River inflow and exports. Most observations of smolt survival have been at low levels of both inflow and exports, in part as a result of recent drought conditions. Furthermore, it is not possible to test the effects of changes in conditions in the absence of variability in those conditions (Appendix E, Section E.2.3). Developing the future experimental design for salmonid monitoring would need to consider prescribing flow and export conditions extending over a wide enough range to detect biological responses if such relationships exist.
- Low overall survival makes it difficult to detect changes in survival, both in general and in response to changes in management operations (Appendix E, Section E.13).
- Hydrodynamic models are developed and calibrated for specific locations, time periods and time scales, and study questions; application of simulation models for other uses (e.g., using the reviewed models in the South Delta or on the scale of fish response) is dependent, in part, on the specific hypotheses and management questions being evaluated and the resolution and accuracy needed in model predictions to support the analysis (Appendix B, Section B.3).
- Disparity between current hydrodynamic models and measurements of hydrodynamics data (flow and velocity) at key locations in the Delta (e.g., Turner Cut, Frank's Tract) limits our ability to detect patterns between changes in velocities and flows and changes in salmon

CONSTRAINTS ON UNDERSTANDING

Current understanding of juvenile salmon and steelhead survival in the Delta is constrained by a variety of factors (as listed below).

survival and behavior from AT observations (Appendix C, Figures 18 through 20 and 24 through 29). Further model calibration and validation and refinements to model parameters is expected to advance the application of these models in support of fishery analyses; and

- Salmon likely respond to changes in water velocities rather than to changes in flow, but hydrodynamic modeling results show larger disparities between modeled and measured conditions for velocity than for flow (Appendix C, Pages C-14 through C-163).

<u>Gaps in Information</u>

- Understanding the effects of water project operations on route selection and through-Delta survival of juvenile salmonids may require additional statistical analysis of route-specific survival, hydrodynamics, habitat complexity, and environmental variability. Completing the analysis of AT data through 2016 will provide the foundation for more statistical analyses using multivariate approaches involving a number of physical and biological covariates for hypothesis testing.
- Modeling of the potential biological response of particular water project operation actions has not been done (hypothetical examples of measurable objectives include: reduce migration into the Interior Delta through Turner Cut by 50%, increase juvenile survival in the South Delta to an average of 30%, etc.), which limits our ability to make short-term action recommendations that are predicted to achieve a specific biological objective and to evaluate the performance of the action in achieving the desired effect.
- Further analysis is needed to assess which hydrodynamic models best represent observed hydrodynamic or water quality changes caused by water operation decisions or other management actions, on the scale of fish perception and response; the calibration and validation of the appropriate spatial and temporal scales for biological application needs additional refinement.
- Several potential problems (gaps) have been identified in the literature relative to hydrodynamic model calibration in the South Delta, including representation of the CCF operations, South Delta bathymetry data, Delta Island Consumptive Use data, high inflow conditions, and challenges associated with estimating Delta outflow. Further refinement of hydrodynamic simulation models and their application to assessing salmonid migration and survival will improve the technical foundation for evaluation of the performance of management actions.

3.19 TECHNICAL DISAGREEMENTS

SST members agree with the key findings and gaps presented in the tables above. Technical disagreements about the characterization of information are identified in Volumes 1 and 2 and are summarized below.

3.19.1 Volume 1

- There was not consensus in the SST regarding the definition and application of the basis of knowledge. The basis of knowledge review rated peer-reviewed publications higher than agency or contract reports. While the assumption was made that peer-reviewed articles have more robust information, it was noted that agency reports and peer-reviewed articles can have varying degrees of robustness, the assumption is not likely true for all peer reviewed articles, and agency reports can also be peer reviewed. Furthermore, agency reports may provide better and more specific information relative to the questions we are asking and this is not reflected in the basis of knowledge definition or applications. At least one SST member felt that similar results from multiple agency reports should be rated higher than a medium basis of knowledge. Despite differences in the interpretation of weighting to be given to various sources of information among the SST, the body of scientific information available, including agency reports, peer-reviewed journal publications, discussions with technical experts, and data analyses prepared by the SST as part of preparing the gap analysis, were all used in developing findings and recommendations presented in this report.
- There was a disagreement within the SST about whether the analysis of ocean recovery rates of CWT fish (i.e., the Zeug and Cavallo [2013] analysis) is informative for Delta survival because ocean recovery rates combine Delta survival with ocean survival and incorporate assumptions about fishing effort between years. Some SST members believe that the joint probability of Delta survival and ocean survival is pertinent, although not conclusive, to Delta survival (Appendix E, Section E.6.2).
- There was disagreement within the SST about whether there is a relationship between exports and the relative survival associated with the Interior Delta route compared to the Sacramento River mainstem route, based on modeling by Newman and Brandes (2010). Some SST members believe that, despite the indeterminacy in model selection, a potential effect of exports was demonstrated (Appendix E, Section E.6.2.1). The disagreement was based, in part, on model selection that identified that relative Interior Delta survival was similarly predicted with models that did not include exports, based on the low samples sizes available.
- There was a disagreement within the SST about providing short-term recommendations for actions to improve salmonid survival at this time, nothing that no modeling or analysis has been conducted to assess potential benefits to salmon or steelhead from these actions and that a more systematic process of evaluation of alternatives and priorities should precede any recommendations for actions. Some on the SST felt that the prolonged low levels of juvenile salmon survival in the South Delta warrant immediate action

3.19.2 Volume 2

- There was a disagreement within the SST over whether the data provided in Volume 2 support the conclusion that improved protection of Sacramento River salmonid populations would result if the onset date of OMR reverse flow management were triggered by detection of migrants at monitoring stations located on the Sacramento River upstream of distributary junctions leading toward the San Joaquin River. Results of salmonid monitoring in the Sacramento River and San Joaquin River have shown that the seasonal timing of Delta entry for juvenile Endangered Species Act (ESA)-listed salmonids varies among years. The January 1 onset of OMR flow management coincides with the presence of winter-run Chinook salmon in most years, spring-run Chinook salmon in many years, and steelhead in some years. Some SST members conclude that although not capturing all of the seasonal variation in juvenile movement, the January 1 trigger date provides a general approximation of the migration timing during the winter months, and, based on its simplicity for triggering management actions, has utility (Management Question 3).
- In Volume 2, there is a statement that limiting OMR reverse flow to -5,000 cfs is effective at preventing increased routing into the Interior Delta, presumably resulting in increased survival. There was a disagreement over whether the data provided in Volumes 1 or 2 supported such a statement. Some felt the discussion and conclusion was based primarily on conceptual model predictions and reasoning, not on factual analysis (Management Question 3).
- There was a disagreement within the SST about the statement that short-term restrictions of exports resulting in OMR reverse flows more positive than the -5,000 cfs may do little to improve through-Delta survival for Chinook salmon due to low overall survival. The disagreement was that, since we have no evidence of the effects of OMR reverse flow restrictions on survival, we have no evidence that the continued OMR reverse flow restrictions will affect survival (Management Question 4).
- There was a disagreement within the SST about presenting the hypothesis that the influence of exports on habitat may have a stronger effect on survival than that of short-term hydrodynamic changes related to exports, since the argument is based on reasoning and not data analysis (Management Question 4).
- There was a disagreement within the SST about whether Passive Integrated Transponder (PIT) tags, which have been used extensively in salmonid studies in river systems such as the Columbia River, could expand the available evaluation methodologies; some members believe that, as a result of difficulties in PIT tag detection in larger channels (the PIT tag needs to be in close proximity to the detector to be read), the technology will not provide any better information than is currently available through existing methodologies. Therefore, there was disagreement over whether to recommend that PIT tag technologies be applied to the Delta to facilitate monitoring of biological metrics. The selection and application of specific technologies in future investigations will need to be based, in part,

on the nature of the investigation, specific data needs, detection ability, and other factors (Management Question 6).

- There were no areas of formal scientific disagreement among SST members regarding the use of surrogates; however, there is disagreement among scientists in general about the usefulness of performing surrogacy comparisons in situations where only some of the pertinent types of surrogacy can be evaluated. Seven common positions on the use of surrogates are identified (Management Question 8).

4.0 RECOMMENDATIONS FOR NEXT STEPS

The SST has identified the following recommendations for CAMT to consider. The recommendations provide guidance on how future investigation and research efforts could be focused to build on the existing knowledge base and address key data gaps. They were developed to advance our understanding of the role of factors influencing salmonid survival through the Delta, the role of Delta conditions in salmonid fitness at the individual and population level, and opportunities to improve salmonid population abundance and status through changes to Delta conditions and water project operations.

The recommendations are informed by the following overarching observations:

- The Delta is a very complicated environment in which to study and measure juvenile salmonid survival.
- While much information has been gained using the current approach, numerous key questions remain unresolved and will require new analyses and experimental approaches.
- The Delta should be perceived not as a singular region, but a suite of regions defined by different physical forcing factors. The regions are areas dominated by natural and water project inflow (upper San Joaquin River mainstem), tidal conditions (lower San Joaquin River mainstem and Delta), and exports (South Delta). Results of South Delta survival studies using juvenile Chinook salmon have shown consistently low survival over the past decade. Resolving the low observed juvenile salmonid survival may require different approaches for each region that would be integrated into a single program.
- Resolving the low survival should shift from questions developed by researchers to ones that simultaneously integrate three components: science (what can be tested), management (what needs to be tested), and operations (what can be put into place for testing). This shift in approach would support both observational studies and needed controlled experiments.
- Answering key survival and water project operation questions in the Delta is challenging, and future decisions will have to be made in the face of scientific uncertainty. Therefore, decision-support tools also need to be developed that help characterize risk and uncertainty for managers.

4.1 CONTINUE EXISTING SURVIVAL STUDIES, MONITORING, AND ANALYSIS OF DATA

Discussion: The purpose of this recommendation is to continue and complete the existing analyses of route entrainment, reach survival, predation investigations, and salvage that are under way. Ongoing studies might be adapted as a long-term monitoring and adaptive management plan is developed and implemented. They are needed to provide a foundation for an expanded research program, generate information, and inform near-term management decisions, and complete ongoing research studies to maintain time series information.

Schedule: Ongoing

Management Application: Current studies provide information about through-Delta survival of Chinook salmon and steelhead, and some estimates of reach-specific survival and junction-specific routing under potentially different (but usually not controlled) inflow and export conditions. Continuing to estimate through-Delta survival will provide continuity for time series data needed to assess current status, interannual variability, and long-term trends. Ongoing research on predation is critical to identifying relationships between predator and juvenile behavior, and predator concentrations.

4.2 INVESTIGATE SHORT-TERM ACTIONS TO IMPROVE SALVAGE FACILITY OPERATIONS

Discussion: The purpose of this recommendation is to determine whether current operations and salvage facilities at the SWP and CVP could be improved to reduce losses to listed and non-listed salmonids entrained into the facilities. The SST understands that a great deal of effort has been directed toward improving the facilities, and facility experts would need to be involved in any future discussions. Suggestions for actions to reduce direct facility mortality based on findings in Appendix E, Section E.3.2.2 include:

- Control predator populations in CCF and behind the CVP trash racks.
- Control secondary louver efficiency by control of bypass water velocities.
- Keep primary and secondary louvers free from debris, but also reduce time when they are inoperable for cleaning.
- Improve salmon passage within the CVP, and decrease predator passage within the CVP.
- Consider alternate truck release locations of salvaged fish to prevent large predator assemblages.
- Verify the assumption that pre-screen losses at the CVP intake are 15% and substantially lower than losses at the SWP.
- Test using the CVP for export instead of the SWP to reduce losses of salmonids in CFF.

Additional suggestions include:

- Test how different CCF radial gate openings affect water inlet velocities and fish entrainment; determine whether water velocity thresholds for entrainment at the gate entrances can be identified based on literature reviews, model studies, and empirical testing; and, if new operations are identified, evaluate whether survival is increased.
- Evaluate filling the scour hole inside the CCF radial gates to reduce predator habitat and predation.
- Review the fish facilities design criteria and compare them to current state and federal design criteria; adjust facility operations or modify facilities to meet the current state and federal criteria if possible. For example, install flow control structures behind CVP louvers to improve efficiency during low export volume operations.
- Review past studies and evaluate whether new fish truck transport release operations, such as the use of net pens and barges, would be effective in reducing post-release mortality.

Schedule: Ongoing

Management Application: The goal of these actions is to reduce the proportion of fish entrained into water project facilities, reduce losses to fish that are entrained within the facilities, and enhance the survival of fish salvaged by improving truck transport and release operations. To the extent possible, responses (e.g., entrainment, mortality) should be measured before and after any modification is implemented to document the effectiveness of the modification.

4.3 DEVELOP A LONG-TERM MONITORING, RESEARCH, AND ADAPTIVE MANAGEMENT PLAN

Discussion: A long-term monitoring, research, and adaptive management plan with stable and reliable funding for implementation is needed to fully assess the effects of water project operations and other Delta management actions. It is envisioned that this plan would need to be implemented for a period of at least 15 years. It should be based on monitoring, modeling, and direct manipulation of factors of interest. It will require a policy commitment to a range of management actions to be tested, agreement among managers and scientists of the level of precision needed to determine study success, and agreement that operations needed for the experimental conditions being tested can be achieved. The plan should augment and expand the scope of current studies in terms of the breadth, depth and number of analyses, monitoring studies, and experiments conducted.

The SST believes that studies that focus on causal mechanisms at appropriate time and space scales are an important approach, especially regarding understanding how fish behavior responds to local conditions.

Development of a long-term plan as envisioned here would require a number of discussions among research scientists and managers and may require a multi-pronged focus on water project operations, Delta habitat conditions, predation, and other stressors thought to contribute to the low survival observed over the past decade. Although there are a number of potential approaches to developing the long-term plan, one approach to consider would be an integrated (physical and biological) approach to monitoring and modeling, and the manipulation of treatment conditions (e.g., flow, exports, I:E ratios) within certain reaches and over specific time scales. Integration across technical disciplines (biologists, hydrodynamics experts, physical and biological modelers, and biometricians) and methods (fish tagging and modeling) would continue and expand. The plan would incorporate new information in an adaptive manner, where information gathered at one stage of the process is incorporated into the following action (i.e., data gathering or analysis, model development, or system manipulation), and the action is then adjusted based on the new information. Consideration should also be given to integrating the long-term plan with other smelt, salmon, and water management programs in the Delta and Central Valley.

Schedule: 3 to 5 years

Management Application: The long-term monitoring, research, and adaptive management plan would be used to assess the RPA actions and underlying mechanisms related to the influence of water project operations on salmonid population viability. Results of monitoring would also be applied to better understand the importance of other potential limiting factors on migration and survival of juvenile salmonids in the Delta. It would also be used to inform a broader suite of actions intended to improve juvenile salmon survival in the Delta and population productivity.

4.4 IMPLEMENT THE LONG-TERM MONITORING, RESEARCH, AND ADAPTIVE MANAGEMENT PLAN

Discussion: Implementing the long-term plan will involve conducting the analyses, monitoring, and research identified during plan development (and thereafter) to evaluate key questions and hypotheses in a methodical manner, adaptively applying the information to management actions, and developing decision-support tools for managers that help characterize uncertainty and risk. Plan implementation should emphasize timely synthesis of research and monitoring, and publishing in peer-reviewed journals. Implementing the long-term plan is needed to develop the information necessary to assess how existing water project operations directly and indirectly affect the survival of listed and non-listed salmonids in the Delta. In addition, a statistically robust, long-term program designed to investigate the underlying mechanisms affecting salmonid survival will improve the scientific basis for identifying new water project operations. It is envisioned that this plan would need to be implemented for a period of at least 15 years.

Schedule: 15+ years

Management Application: Implementation of the long-term monitoring, research, and adaptive management plan will allow water project operations to be assessed. It will reduce uncertainty, potentially identify the incremental role water projects operations have on salmonid survival through the Delta, and potentially lead to adjustments to water project operations that improve survival beyond the current levels. Information gained through implementing the long-term plan could be integrated with, and incorporated into, decision support tools used to better manage the system. It is envisioned that the long-term plan will be integrated with other major monitoring programs in the Central Valley.

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