Appendix E
Effects of Migration Behavior and Project Facilities on Juvenile Salmonid Survival

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E.1 INTRODUCTION

The conceptual model relates water project operations to salmonid survival in the Delta in two primary ways: direct mortality caused by entrainment in or approach to the water export facilities, and an indirect effect of water project operations via influences on hydrodynamics in the Delta, which influences fish behavior, which in turn influences survival. The effect of water project operations on Delta hydrodynamics and the effect of changes in hydrodynamics on fish behavior are addressed in Appendices B and D, respectively. In this section, we address what is known about direct mortality from the water export facilities, how survival through the Delta may be related to fish behavior during migration, and how survival may be associated with water project operations overall.

For the purpose of this analysis, fish behavior is classified as the migration route selected and migration rate (Figure E.1-1). The conceptual model hypothesizes that fish that use the Interior Delta or pass through or near the water export facilities have lower survival than fish that remain in the mainstems of the San Joaquin River or Sacramento River. Migration route may influence survival by exposing migrating juvenile salmonids to regions that differ in factors such as predation pressure, entrainment risk into the State Water Project (SWP) or Central Valley Project (CVP) export facilities and other water diversions, water quality, and growth potential (Figure E.1-1). Regions of higher predation pressure or entrainment risk are hypothesized to decrease overall survival through the Delta, while using regions of higher growth potential may increase post-Delta survival if juvenile salmonids rear substantially during their migration through the Delta. Our scope of analysis was restricted to migration survival through the Delta, so the impact of using regions of higher growth potential on post-Delta survival is not investigated here. The conceptual model hypothesizes that migration rate may influence survival in one of two ways: a slow migration rate may lower survival by prolonging exposure to mortality risks such as predation or entrainment in the water export facilities, or it may increase survival by increasing exposure to favorable growing conditions (Figure E.1-1, Table E.1-1). The latter possibility is expected to affect primarily post-Delta survival, so this hypothesis is not investigated here. It is possible that other factors may link water export operations to survival in the Delta, in addition to migration route and migration rate (e.g., Table E.1-1). However, additional factors are either outside the scope of this gap analysis or there was insufficient time to evaluate them.

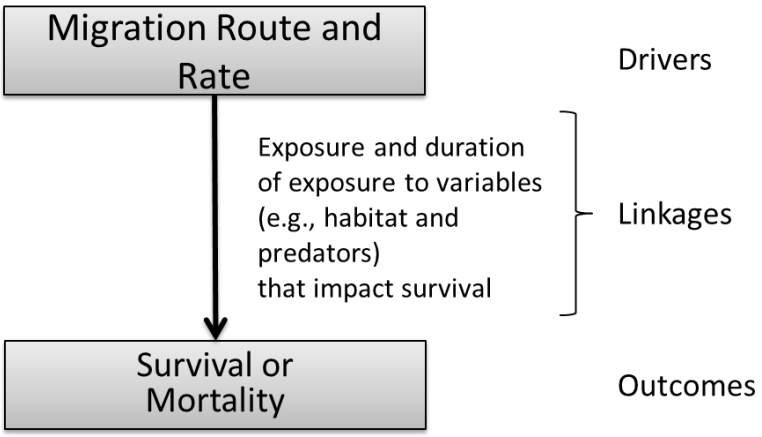

Figure E.1-1. Conceptual Model Depicting General Relationships Between Drivers, Linkages, and Outcomes Related to Survival That Were Evaluated By the Survival Sub-team

Table E.1-1. Drivers, Linkages, and Outcomes Considered Within Appendix E

Drivers	Linkages	Outcomes
• Juvenile migration route • Juvenile migration rate • *Migration timing* • *Timing of Delta entry* • *Delta residence time* • *Rearing location* • *Population scale outcomes depend on the spatial/temporal heterogeneity of individual outcomes*	• 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 • *Parr-smolt transformation* • *Juvenile condition and fitness* • *Spatial and temporal heterogeneity in size/timing of migration relationships*	• Mortality • *Survival at ocean entry* • *Survival while in ocean* • *Population fitness and resilience* • *Life history diversity*

Note: Black text identifies focal components analyzed in the report and red italicized text indicates components considered significant but not addressed or addressed only to a limited extent in this report because of time, resource, or scope constraints.

In this appendix, we present data and findings that pertain to the conceptual model components that relate Delta survival to migration route and rate and to direct mortality from the facilities. We address survival rate per kilometer in different regions of the South Delta (i.e., south and west of the San Joaquin River, including the San Joaquin River mainstem), the total through-Delta survival in different routes through the Delta, and survival in and around the water export facilities. We also examine findings that compare survival rate per kilometer to migration rate (i.e., travel time per kilometer), and compare

findings from different regions throughout the Delta. We compare the findings to the predictions from the conceptual model.

In addition to focusing on how survival relates to migration route and rate in our conceptual model, we also address the larger question of how survival may relate directly to water export operations in terms of exports, inflow, the ratio of San Joaquin River inflow to exports (I:E), and the ratio of exports to total Delta inflow (E:I); barriers and flow in Old and Middle rivers (OMR) are addressed briefly but are not explored in depth. These analyses explore whether there is a relationship between these measures of water export operations and survival without limiting such a relationship to the conceptual model linkages of migration route, migration rate, and direct mortality, and accommodate the possibility that other linkages between water export operations and survival may exist. These analyses focus on survival in the South Delta on several spatial scales, under the realization that survival may respond to different factors in different regions of the Delta.

This appendix is organized as follows. We first describe the type of information that is available for assessing the survival components of the conceptual model, and both the potential and the limitations of the information available. We then provide an overview of the survival data available and the hydrological conditions (namely Delta exports and inflow) associated with the survival data. The bulk of this appendix consists of detailed discussions of what the available data show regarding survival relative to migration route and rate and measures of water export operations, and how these findings compare to the conceptual model. We end with a discussion of the findings and conclusions, including suggestions for future data and analyses that may fill gaps in our understandings of the system.

The types of information available for assessing the survival components of the conceptual model consist of published, peer-reviewed journal articles; publicly available but unpublished technical reports of survival analyses; and new compilations (produced by the Salmonid Scoping Team [SST] for this report) of survival and hydrological data. The survival data used for the new compilations come from previously published analyses and articles or reports of individual survival studies, of which some reports are publicly available and others are still in draft form or available only via personal communication. Although some of the data being compiled are taken from peer-reviewed publications, some are taken from agency reports of the studies underlying peer-reviewed publications because the publication focused on a different aspect of the study (e.g., different spatial scale). Analysis of these new data compilations is not peer-reviewed at this time because it has been performed directly for this report. Thus, while considerable attention is given to these new data compilations in this report to present the current support, or lack thereof, for the survival components of the conceptual model, we place more weight on the peer-reviewed results than on these new, non-peer-reviewed analyses. However, some members of the SST feel that some agency reports should receiver higher weight, despite not being peer-reviewed for journal publication.

There are several types of analysis that may be considered for the compiled survival data presented here, depending on the specific linkage or level of the conceptual model being assessed. Commonly used methods include regression and correlation analysis. Mean regression may be appropriate to explore a hypothesized relationship between the average survival and an independent variable or driver, such as export rates. In particular, regression assumes that the independent variable is set at known values without error, as is typical in experimental rather than observational studies. However, by conditioning on the observed values of the independent variable, regression techniques may be appropriate even in cases of observational rather than experimental data. Quantile regression and factor-ceiling analysis are similar to regression of the mean but model a specified quantile (e.g., maximum) of the response distribution as a function of the independent variable, rather than the mean response. For example, factor-ceiling analysis seeks a limiting relationship between the independent variable and the response (survival), such that the value of the independent variable imposes a limit on the range of the distribution of the response (typically the maximum), but not the mean of that distribution. Correlation analysis explores associations between two variables that are both varying, rather than assuming that one variable is observed at known levels and drives the distribution (e.g., mean or maximum) of the other variable; correlation analysis is often considered to be more appropriate than regression in ecological studies where most data are observational rather than experimental. Path analysis is a form of correlation analysis that can be helpful in identifying causal relationships, but it is most useful in relatively simple systems with few variables, rather than a complex ecosystem such as the Delta.

Both time constraints and data constraints limit our analysis of the newly compiled survival data presented in this section. The fact that these analytical methods have not previously been implemented with these data is a gap in assessment of our conceptual model; additionally, the effort needed to perform these analyses exceeds the time available for this report. Some of these analyses are in the process of being implemented outside of the SST process, as is analysis of more recent acoustic tag (AT) data (i.e., 2013, 2014, and 2015 data for both Chinook salmon and steelhead), but have not yet been completed. Perhaps more importantly, many of the data presentations included in this appendix demonstrate that there is too little variability in the observed value of the explanatory variable (e.g., export levels) to perform conclusive analysis using available data. Instead of providing quantitative analytical results, we provide qualitative discussion of the observed patterns in the data based on visual examination of scatterplots, using the various analytical concepts described above to focus discussion. We use these qualitative observations to provide preliminary support (or lack thereof) for various conceptual model components, and to suggest what additional data or analyses would be useful in making more definitive conclusions.

E.2 OVERVIEW OF THE DATA AVAILABLE

Several types of data are used in this appendix, including data on survival probability, migration route, and travel time through the Delta for juvenile Chinook salmon and steelhead, and data on water export operations. We also describe results of statistical models that relate ocean recovery rates and adult escapement to conditions during Delta outmigration (assumed to be two and a half years before adult return). We first present an overview of the data on migrating salmonids, and then an overview of the data used on water export operations. We also describe the data used to compare juvenile salmonid survival to water export operations directly.

E.2.1 DATA ON SALMONID SURVIVAL, ROUTE USE, AND MIGRATION RATE

Much of the information used to develop this section of the report is based on survival estimates derived from two different study methodologies. This subsection provides a summary of salmonid survival studies in the Delta. Most of the information on survival in the South Delta (west and south of the San Joaquin River, and including the San Joaquin River) is based on the results of coded wire tag (CWT) and AT studies of juvenile fall-run Chinook salmon from the San Joaquin River basin. Results of two years of AT studies for steelhead are also used. Survival in and through the Delta for smaller life stages (e.g., fry) of the late-fall, winter, spring, and fall runs of Chinook salmon has not been estimated using AT because the tags are still too large to implant in fry-sized fish (less than 70 millimeters [mm]). Spatially detailed survival and migration data within the South Delta are not available for populations from the northern Delta because of the relatively small numbers of acoustically tagged fish released upstream that survive to enter the South Delta. In addition, during previous AT studies, receiver arrays were not in place to estimate survival within certain areas of the interior and South Delta (Perry et al 2012; Michel et al. 2013).

All juvenile Chinook salmon and steelhead from the Central Valley must move through the Delta to reach the ocean (Figure E.2-1). Juvenile salmon of all runs occur throughout the Delta, although at slightly different times of the year, at different sizes, and with significant overlap (Fisher 1994; Yoshiyama et al. 1998; Pyper et al. 2013). The movement of Sacramento River water to the South Delta for supplying the export pumps, and the tidal mixing in the Delta, are expected to contribute to the mixing of juvenile salmon runs in the Delta. Table E.2-1 summarizes the availability of salmonid survival data for each of the salmonid runs in the Delta.

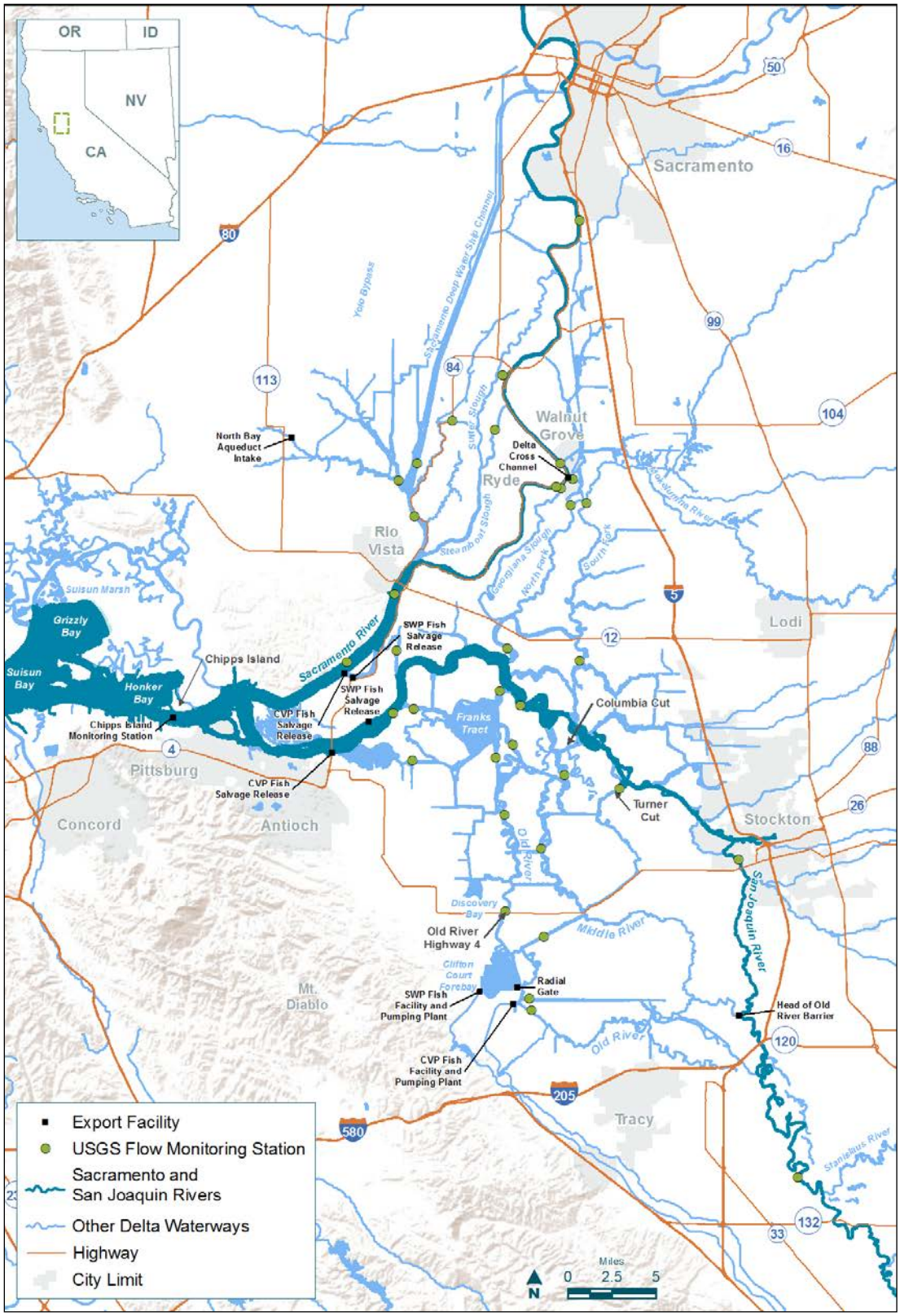

Figure E.2-1. Map of Sacramento-San Joaquin River Delta

Table E.2-1. Availability of Survival Study Information for Salmonids in the Delta

Life Stage	Tag	Region	Listed Populations			Non-listed Populations	
			Sac. R. Winter-run Chinook	CV Spring-run Chinook	CV Winter-run Steelhead (SR or SJ)	Fall-run Chinook (SR or SJ)	Late-fall-run Chinook
Fry (less than 70 mm)	CWT*	To and through Delta	Yes (H)	Yes (W)	Yes (H)	Yes (H, W)	No
		To Delta**	No	No	No	No	No
		Through Delta**	No	No	No	No	No
		Within Delta	No	No	No	Yes (H)	No
	AT	All	No	No	No	No	No
Smolt (≥ 70 mm)	CWT*	To and through Delta	Yes (H)	Yes (H, W)	Yes (H)	Yes (H)	Yes (H)
		To Delta**	No	No	No	No	No
		Through** Delta	No	No	No	Yes: North Delta (H) South Delta (H)	Yes: North Delta (H) Mokelumne (H)
		Within Delta	No	No	Yes (H)	Yes (H)	Yes (H)
	AT	To and through Delta	Yes (H)	Yes (H, W)	Yes: SR (H, W)	Yes: SR (H)	Yes: SR (H)
		To Delta	Yes (H)	Yes (H, W)	Yes: SR (H, W)	Yes: SR (H) SJR (H)	Yes: SR (H)
		Through Delta	Yes (H)	Yes (H, W)	Yes: SR (H, W) SJR (H)	Yes: SR (H) SJR (H)	Yes: SR (H)
		Within Delta	Yes	Yes	Yes: SR (H, W) SJR (H)	Yes: SR (H) SJR (H)	Yes (H)

*Notes: * = Survival indices are available from some of the CWT studies, while others provide absolute survival estimates. ** = It is possible to estimate survival indices or estimates to or through the Delta from existing data, but it has yet to been done. Better estimates of sampling efficiency at Sacramento and Chipps Island would yield improved survival estimates. H = hatchery; W = wild; SR = Sacramento River; SJR = San Joaquin River; To Delta = survival from river to Delta; Within Delta = survival and/or route selection in portion of Delta; Through Delta = total survival from Delta entry to Delta exit.*

Various statistical models have been fit to the CWT smolt survival data to identify the potential relative influence of several factors on survival through the Sacramento River Delta (Newman and Rice 2002; Newman 2003, 2008; K. Newman, personal communication). Factors identified as being important in the Delta for Sacramento River basin fall-run smolts included salinity, flow, Delta Cross Channel (DCC) gate position (both for Mokelumne and Sacramento River basin fish, although with opposite responses), release temperature, release location, and size of fish (Newman and Rice 2002; Newman 2003). Other factors increased or decreased in importance (i.e., exports or export/inflow ratio, tides) depending on which modeling framework was used (Newman and Rice 2002; Newman 2003). These results are discussed in more detail in the following sections.

Juvenile salmon and steelhead survival studies using ATs have been conducted throughout the Sacramento basin for fall-, spring-, and winter-run smolts or yearling-sized late-fall-run Chinook salmon and winter-run steelhead. Survival was estimated either to the Delta, to

Chipps Island or Benicia, or to the Golden Gate Bridge. Survival estimates for Sacramento River releases are summarized in Table E.2-2.

Table E.2-2. Estimates of Survival to the Delta, Through the Delta, and Through the Bay for Acoustic-tagged Winter-, Spring-, Fall-, and Late-fall-run Chinook Salmon and Steelhead from the Sacramento River Basin of the Central Valley[1]

Run	Origin	Year	Life-stage	Release Site/ Number Released	Total Survival to Delta	Survival through the Delta (Freeport to Benicia or Chipps Island) (SE)	Survival from Benicia to GG	Source
Winter	Livingston Stone Hatchery	2013	Smolt	Caldwell Park/148	0.15	0.32 (0.10)	1.00 (low confidence in estimate)	A. Ammann, personal communication
		2014	Smolt	Caldwell Park/358	0.36	0.35 (0.04)	0.32	A. Ammann, personal communication
Spring	Feather River	2013	Smolt	Feather River/300	0.08	0.30	1.00 (low confidence in estimate)	A. Ammann, personal communication
		2014	Smolt	Feather River/300	0.04	0.00		A. Ammann, personal communication
		2014	Smolt	Sacramento/200		0.00		A. Ammann, personal communication
Fall/Spring	Mill Creek-Wild	2013		Mill Creek/59	0.10	0.17	1.00 (Low confidence in estimate	A. Ammann, personal communication
		2014		Mill Creek/36	0.00			A. Ammann, personal communication
Spring/Fall	Battle Creek Wild	2014	Smolt	Battle Creek /76	0.00			A. Ammann, personal communication
Fall	Coleman NFH	2013	Smolt	Sacramento/200		0.00		A. Ammann, personal communication
Late-fall	Coleman NFH	Dec 2006	Yearlings	Sacramento/64		0.351		Perry et al. 2013
		Jan 2007	Yearlings	Sacramento/80		0.543		Perry et al. 2013
		Dec 2007	Yearlings	Sacramento/208		0.174		Perry et al. 2013
		Jan 2008	Yearlings	Sacramento/211		0.195		Perry et al. 2013
		Dec 2008	Yearlings	Sacramento/192; GS/100		0.368		Perry et al. 2013

[1] Missing estimates reflect insufficient data to estimate survival or study design that did not provide survival estimate on given scale.

Run	Origin	Year	Life-stage	Release Site/ Number Released	Total Survival to Delta	Survival through the Delta (Freeport to Benicia or Chipps Island) (SE)	Survival from Benicia to GG	Source
		Jan 2009	Yearlings	Sacramento/192; GS/100		0.339		Perry et al. 2013
		Dec 2009	Yearlings	18 km upstream of Sac 167; GS 72		0.464		Perry et al. 2012
		Dec 2009	Yearlings	18 km upstream of Sac/168; GS 72		0.374		Perry et al. 2012
		Feb/Mar 2009	Yearlings	18 km upstream of Sac/ 249		0.64	0.35	G. Singer, personal communication
		Jan/Feb 2010	Yearlings	18 km upstream of Sac/ 248		0.52	0.58	G. Singer, personal communication
Steelhead	Coleman NFH	Feb/Mar 2009		18km upstream Sac/250		0.58	0.44	G. Singer, personal communication
		Jan/Feb 2010		18km upstream Sac/250		0.47	0.64	G. Singer, personal communication

E.2.1.1 San Joaquin River Releases

Survival of juvenile fall-run Chinook salmon migrating from the San Joaquin River has been measured for over two decades. From 1994 through 2006, CWTs were used with a paired release study design of hatchery juvenile Chinook salmon, from either Feather River or Merced River hatchery, to estimate survival from Durham Ferry, Mossdale, or Dos Reis to Jersey Point (Figure E.2-2). For each survival estimate, CWT fish were released at Durham Ferry, Mossdale, or Dos Reis, and a separate group of CWT fish was released at Jersey Point. The relative recovery rate in the Chipps Island trawl and/or ocean fishery was interpreted as the probability of survival between the upstream release site (Durham Ferry, Mossdale, or Dos Reis) and Jersey Point (Newman 2008). Recoveries in the Antioch trawl were also used when available (Brandes and McLain 2001; SJRGA 2013; Newman 2008).

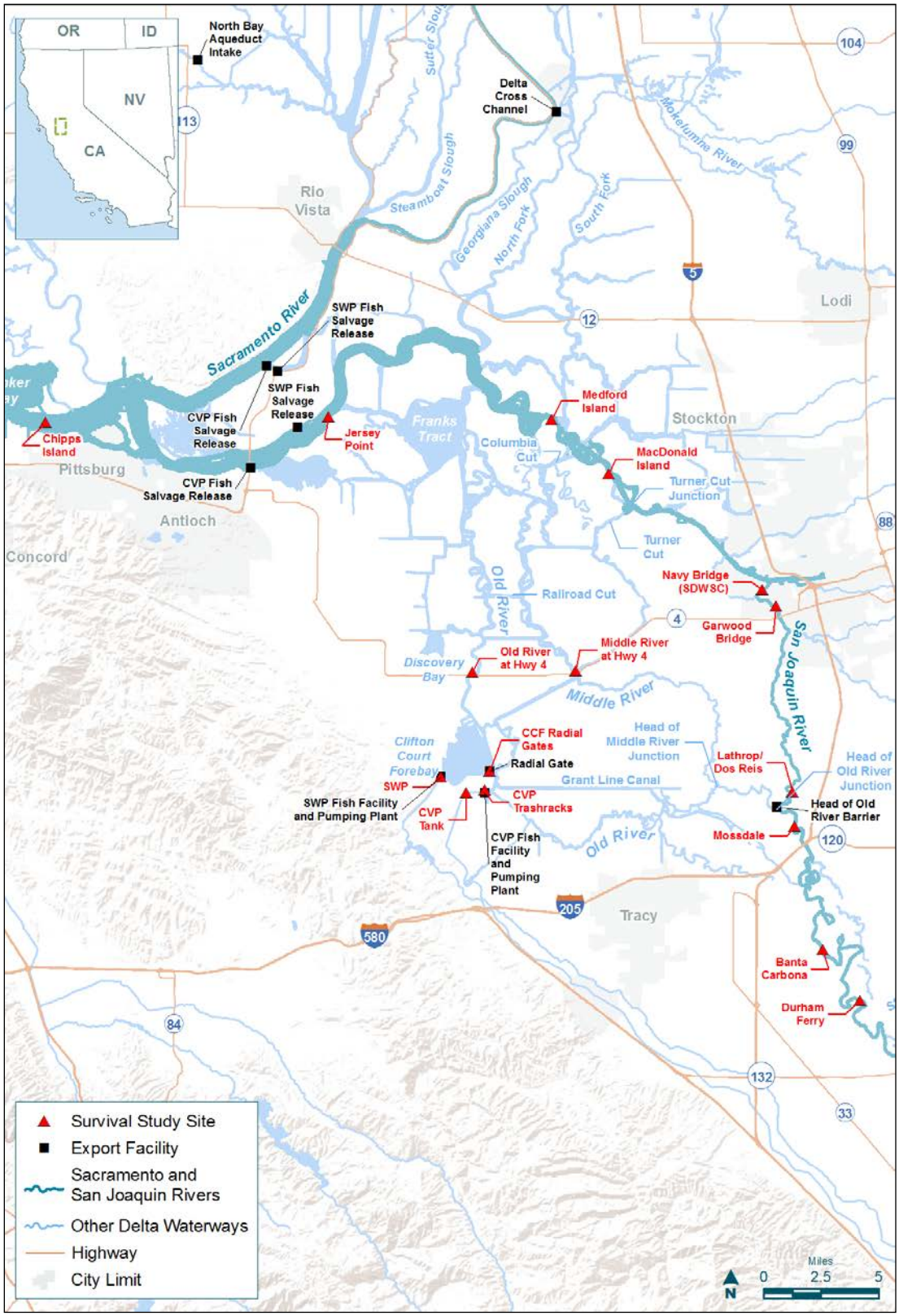

Figure E.2-2. South Delta Sites from CWT and AT Survival Studies

Starting in 2008, acoustic telemetry tags were used to estimate survival of Merced River hatchery fall-run Chinook salmon between Mossdale and Jersey Point or Chipps Island, or part way through the Delta as part of the Vernalis Adaptive Management Plan (VAMP) studies (SJRGA 2009, 2010, 2011, 2013; Holbrook et al. 2009, 2013; Buchanan et al. 2013). Since 2011, acoustic telemetry studies of fall-run Chinook salmon (SJRGA 2013; Buchanan et al. 2015) have been coordinated with concurrent studies of acoustic-tagged steelhead in the San Joaquin River Delta (i.e., 6-year study; Buchanan 2013, 2014). Acoustic telemetry also provided estimates of survival on smaller spatial scales (e.g., Mossdale to Stockton or Turner Cut) (Figure E.2-2).

Survival estimates from acoustic telemetry tags are not available for years when the full study was not performed (e.g., 2007 when a pilot study was performed) or when acoustic receivers were not located at either Jersey Point (2009 and 2010) or Chipps Island (e.g., 2009). The 2008 study was hampered by premature tag failure, and so survival estimates from 2008 reflect the joint probability of fish survival and tag survival, and are likely to represent the faster moving fish, which were more likely to be detected before their tags failed. Detections thought to have come from predators were removed in the 2009 to 2012 studies, but not from the 2008 study. In some years, a physical barrier was installed at the head of Old River. In other years, either no barrier was installed during the studies (i.e., 1995 to 1996, 1998 to 1999, 2005 to 2006, 2008, 2011) or an experimental non-physical barrier was installed for the entire study and was activated during passage of approximately half the study fish (i.e., 2009, 2010). The installation of the physical barrier is partially dependent on flows; flows greater than 5,000 cubic feet per second (cfs) prevent installation of the present configuration of the physical barrier, and flows greater than 7,000 cfs prevent operation of the barrier if it is installed. The number of culverts in the physical barrier has ranged from none (1994) to eight (2012); culverts allow some flow into Old River to supply irrigation water to the South Delta.

Over the years with survival estimates, survival of San Joaquin River fall-run Chinook salmon from Mossdale to either Jersey Point (CWT) or Chipps Island (AT) has ranged from a high of 0.79 to Jersey Point in 1995 (high flows and no barrier at the head of Old River; SJRGA 2013) to a low of 0.01 to Jersey Point in 2003 (low flows and a physical barrier; SJRGA 2013) and 0.00 to Chipps Island for the second release in 2012 (very low flows and a physical barrier; Buchanan et al. 2015) (Figure E.2-3). Survival to Chipps Island from AT fall-run Chinook salmon has been estimated at ≤ 0.1 for all years with estimates (Table E.2-3). Although the AT estimates represent survival all the way to Chipps Island, which is approximately 25 kilometers (km) downstream of Jersey Point, estimates to Chipps Island in 2010 to 2012 were comparable in value to estimates of survival to Jersey Point in 2002 to 2006 (Figure E.2-3). Survival from Dos Reis to Jersey Point was often slightly higher than from Mossdale. Survival from Durham Ferry to Jersey Point was similar in value to survival from Mossdale for most years (Figure E.2-3). It should be noted that test

fish used for AT tagging were larger than those used in the CWT studies (105 mm versus 80 to 90 mm) to meet the recommended AT weight to body weight of no greater than 5%.

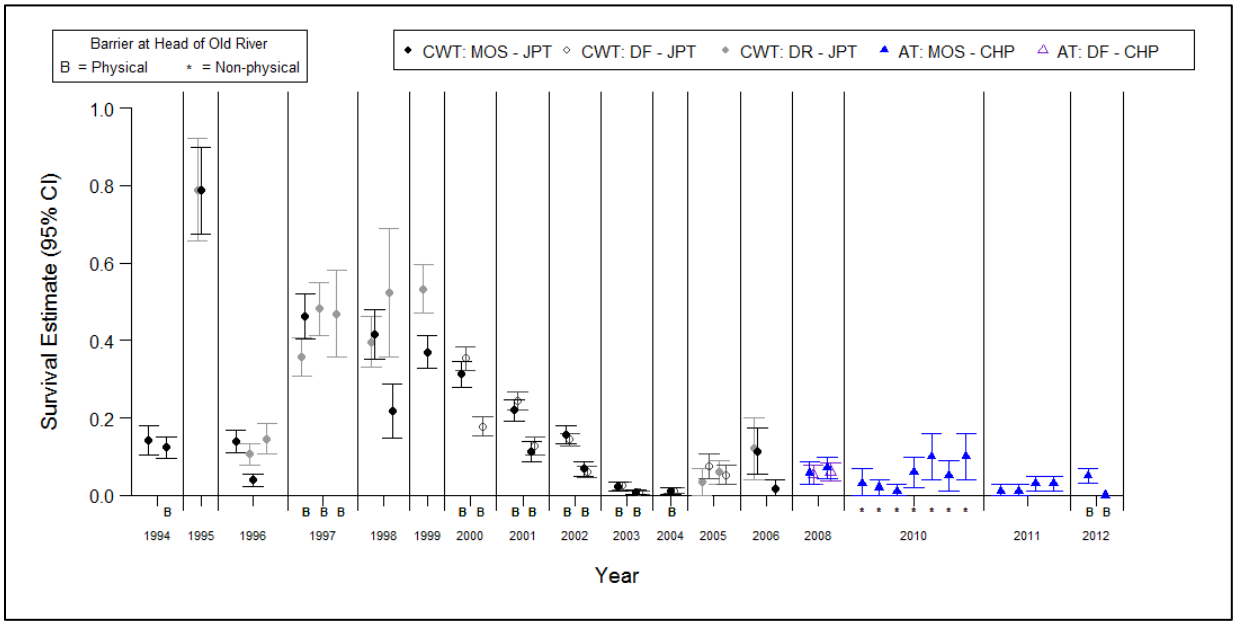

Figure E.2-3. Estimated Survival of Fall-run Juvenile Chinook Salmon from Mossdale (MOS), Durham Ferry (DF), or Dos Reis (DR) to Either Jersey Point (JPT; CWT) or Chipps Island (CHP; AT); Intervals are 95% Confidence Intervals, Truncated to 0 if Necessary

Sources: SJRGA 2013; Buchanan et al. 2015

Table E.2-3. Average Estimates of Survival Through the Delta (Mossdale to Chipps Island) for Acoustic-Tagged Chinook Salmon and Steelhead Released at Durham Ferry in the San Joaquin River

Species	Year	Number of Release Groups	Total Survival through Delta (SE)	Source
Chinook	2008[1]	2	0.06 (0.01)	Holbrook et al. 2009
	2009	(NA)	NA	SJRGA 2010
	2010	7	0.05 (0.01)	SJRGA 2011
	2011	4	0.02 (less than 0.01)	SJRGA 2013
	2012	2	0.03 (0.01)	Buchanan et al. 2015
Steelhead	2011	5	0.54 (0.01)	Buchanan 2013
	2012	3	0.32 (0.02)	Buchanan 2014

Notes: 1 = The survival estimates through the Delta for 2008 are minimum estimates, unadjusted for premature tag failure. No predator filter was used to remove likely predator detections in analysis of the 2008 data.

Survival of San Joaquin River Chinook salmon through the Delta is less than 0.2 for the majority (70%) of the estimates available since 1994 (Figure E.2-3). Even without the higher survival estimate of 0.79 to Jersey Point in 1995, there appears to have been a general trend of decreasing survival since 1998 (Figure E.2-3). 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) estimated late-fall-run Chinook salmon survival from the Sacramento River through the Delta at 0.35 to 0.54 in winter 2007, for fish of about 140 mm fork length (FL), using similar study design, tagging, and analysis methods as the AT results reported here for the San Joaquin River in 2008 and 2010 to 2012. However, these individuals of the late-fall population move through a different part of the system and have the option of avoiding the South Delta entirely; additionally, they migrate during a different part of the year (i.e., they were released in December and January instead of April and May), and do not migrate during the striped bass spawning migration.

Chinook salmon smolts in other systems on the western coast of North America (e.g., Columbia River, Fraser River) also have higher survival rates through river estuaries, although they may be larger fish (Buchanan et al. 2013). For example, Chinook salmon smolts from the Thompson-Fraser River in 2004 had a survival rate of 0.989 per kilometer through more than 330 river kilometers (rkm) to the mouth of the Fraser River; this corresponds to a survival probability of 0.37 over a distance of 89 rkm, which is approximately the distance from Mossdale to Chipps Island (Welch et al. 2008; Buchanan et al. 2013). For comparison, estimated survival of fall-run Chinook from Mossdale to Jersey Point in 2004 was 0.011 (SE=0.0005) (Figure E.2-3).

Two years (2011 and 2012) of survival data have been analyzed for steelhead from the San Joaquin River Delta. Estimated survival from Mossdale to Chipps Island ranged from 0.26 for the first release in 2012 (lower flows and a physical barrier at head of Old River; Buchanan 2014) to 0.69 for the first release in 2011 (higher flows without a barrier; Buchanan 2013) (Figure E.2-4). Average survival estimates for these two years were 0.32 in 2012, and 0.54 in 2011 (Table E.2-3). Based on these two years of data, survival for steelhead appears to be greater than survival for fall-run Chinook salmon. The steelhead used in the tagging study are substantially older (yearlings) and larger than the fall-run Chinook salmon (subyearlings) used for the CWT or AT studies in the San Joaquin River and Delta.

E.2.2 Data on Survival Versus Water Export Operations

Formal analysis relating survival of fall-run San Joaquin River Chinook salmon through the Delta to inflow and exports is available for CWT data from release years 1994 to 2006 in Newman (2008), with additional analysis of CWT data from 1985 to 1991 to compare route-specific survival in the San Joaquin and Old rivers. Newman (2008) used hierarchical Bayesian analysis to explore the dependency of juvenile fall-run Chinook salmon survival on flow at Vernalis and exports, as well as the flow proportion at the head of Old River and flow both past Dos Reis and into upper Old River. Newman (2008) defined conditions using the two-day average (starting the day of release) of San Joaquin flows at Vernalis (from Dayflow), or an eight-day median flow at Stockton or Dos Reis (from DSM2 or equations

from California Department of Water Resources [DWR], depending on the study year; see Table 6 of Newman [2008] for more details). To characterize exports, he used either the two-day average or the eight-day median of combined exports from CVP and SWP, depending on release site (Mossdale or Dos Reis, respectively). Regression analyses on the 1994 to 2006 data are available in SJRGA (2007).

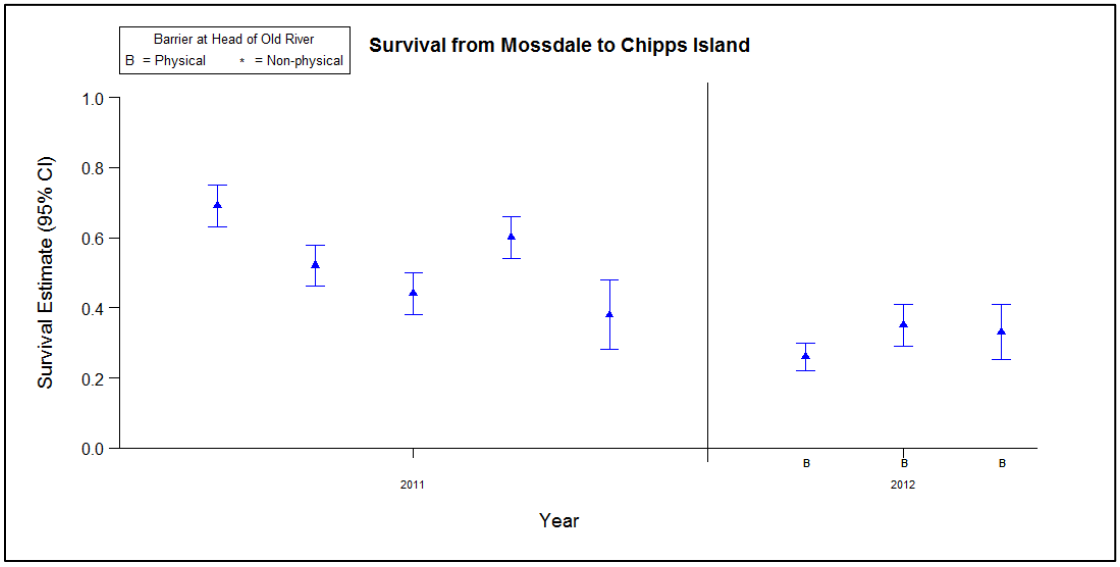

Figure E.2-4. Estimated Survival of Acoustic-tagged Juvenile Steelhead from Mossdale to Chipps Island; Intervals are 95% Confidence Intervals

Newman and Brandes (2010) used hierarchical models with CWT data to assess the effect of exports on survival of juvenile Sacramento River Chinook salmon (late-fall-run) migrating through the Delta as part of the Delta Action 8 study (winter releases 1993 to 2005). In particular, the relative survival of fish released in the Interior Delta to fish released in the Sacramento River mainstem was compared to exports (three-day average from SWP and CVP). Additionally, Newman and Rice (2002) modeled survival of fall-run juvenile Chinook salmon from the Sacramento River through the Delta as a function of various measures, including Sacramento River flow and the ratio of exports to inflow (E:I) (spring CWT releases 1979 to 1995). Newman (2003) further analyzed relative survival of upstream and downstream releases of juvenile fall-run Chinook salmon from the Sacramento River (including data analyzed by Newman and Rice [2002]), exploring the effects of multiple covariates including flow and exports.

Zeug and Cavallo (2013) also analyzed CWT data from fall-run Chinook salmon released in April and May in 1993 to 2003 in the San Joaquin River (Durham Ferry, Mossdale, or Dos Reis) and Sacramento River (near the tidal limit). Unlike the previous analyses of CWT data (Newman 2003), Zeug and Cavallo (2013) analyzed only ocean recovery rates, and thus did not isolate Delta survival from ocean survival; they also assumed similar ocean capture probabilities between years. Their analysis used an information theoretic approach to assess

competing hypotheses regarding factors influencing ocean recovery rates, including Delta inflow (from either the San Joaquin River or the Sacramento River, depending on the release location) and export rates, water temperature and fish size at release, water quality, and ocean productivity. Although ocean recovery rates represent more than just juvenile survival through the Delta, this analysis offers an opportunity to asses a possible population-level effect of Delta conditions during juvenile outmigration.

AT data from the Sacramento River have been analyzed by Perry (2010). Perry (2010) used a release-recapture analysis to model survival through the Delta of acoustic-tagged late-fall-run Chinook salmon released in various locations in the Sacramento River and interior North Delta as a function of Sacramento River discharge, exports, and fish length.

No formal analysis has been completed relating survival estimates from San Joaquin River AT studies to measures of flow and exports for either fall-run Chinook salmon or steelhead. Such AT studies are ongoing; formal analysis relating survival to flow and exports is underway for fall-run Chinook salmon, and is planned to be completed for steelhead after survival results from more years have been analyzed. Preliminary, informal, and unpublished analysis using existing results from both CWT and AT data, as available, is presented here as an indication of the types of results and limitations that may be expected from more complete analysis. This type of visual inspection is only the first step in any analysis of the data, useful for observing obvious patterns but insufficient for accommodating multiple covariates with high correlation, accounting for unbalanced study designs, or objectively measuring the variability in the data. Furthermore, the simple scatterplots available here ignore other factors and do not provide insight into mechanisms that may relate survival to inflow or water exports; causal inference is not possible from observational, correlative analysis such as this. Thus, 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.

The data used in these graphical analyses include daily averages of observed inflow at Vernalis, exports at CVP and SWP, and the daily I:E, averaged over a multi-day period starting the final day of release of tagged study fish either at Mossdale (CWT releases) or at Durham Ferry (CWT and AT releases). For the I:E graphs, only tag releases from April and May were used, to address one of the management questions. The duration of the time period used to measure covariates was selected based on observed travel times through the Delta. Observed travel times from Durham Ferry to Chipps Island of acoustically tagged fish ranged from less than two days to over twelve days in 2010, 2011, and 2012; the median travel time was approximately four to five days in these years (Figure E.2-5). Travel times of acoustic-tagged salmon in 2007 from Durham Ferry to Route 16 on the San Joaquin River (just downstream of Columbia Cut) averaged six to seven days (SJRGA 2008). Travel times of

CWT salmon in 2006 from Mossdale to Antioch and Chipps Island ranged from six to twelve days (SJRGA 2007).

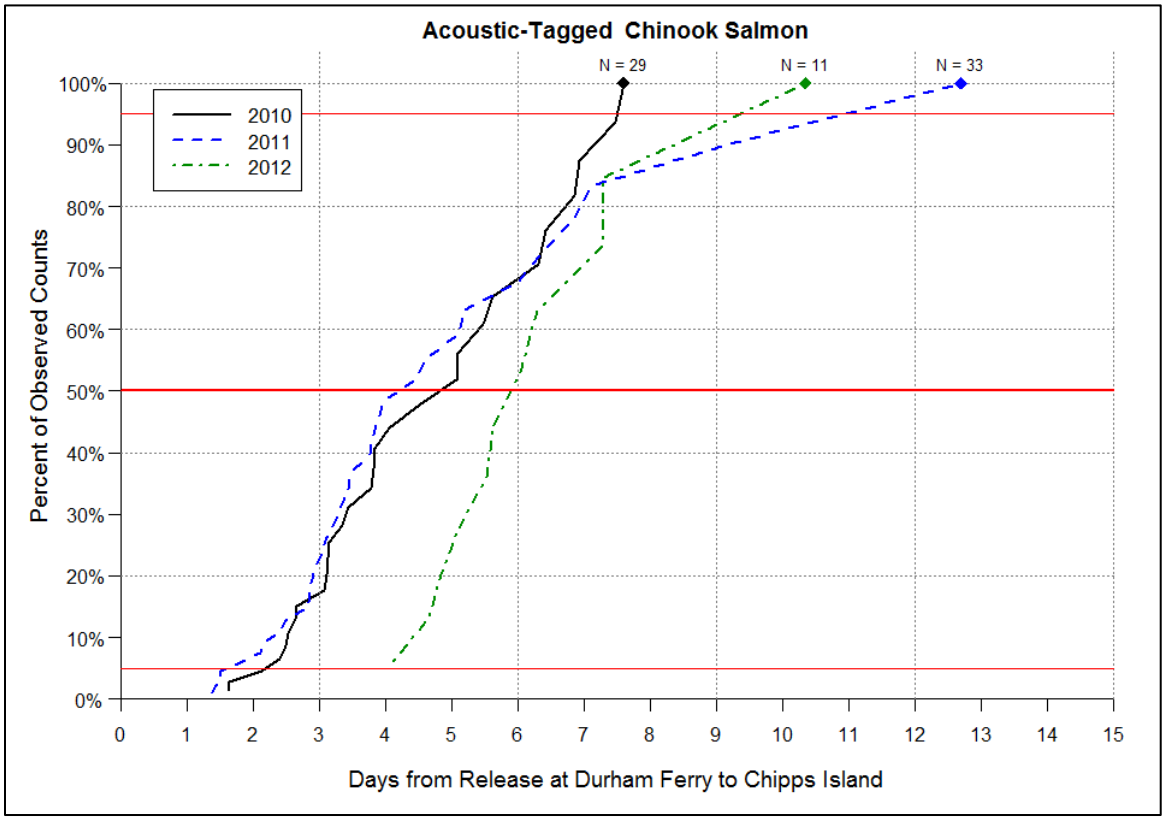

Figure E.2-5. Observed Travel Times from Release at Durham Ferry to Chipps Island for Acoustic-tagged Juvenile Fall-run Chinook Salmon

Note: Red lines indicate 5th, 50th, and 95th percentiles of arrival time distribution.

Baker and Morhardt (2001) report a median travel time through the San Joaquin Delta of eleven days (range = 5 to 26 days) from CWT Chinook salmon released in the Merced, Stanislaus, and Tuolumne rivers in 1986 to 1990. There was variation in travel time between fish within a release group and within each available study year. Thus, identifying the appropriate time period over which to measure inflow and exports for any particular release group is somewhat arbitrary. Periods of four days and ten days were considered. The linear correlation between the four-day measures and the ten-day measures were high for both inflow (0.998) and exports (0.970), so a ten-day average was used in the inflow, exports, and I:E plots in this appendix.

All inflow and export data were downloaded from the Dayflow database[2]. In addition to through-Delta survival (Durham Ferry or Mossdale to Jersey Point or Chipps Island), survival

[2] Observed measures of Delta inflow from the San Joaquin River at Vernalis and export rates at the CVP and SWP are available from several databases. Daily averages are available from the Dayflow database

was also compared with inflow, exports, and the I:E ratio for the reach from Mossdale to Turner Cut (predominantly riverine) and for the reach from Turner Cut to Chipps Island (predominantly tidal) (Figure E.2-2). The informal results presented here have not been published and are merely preliminary, simple comparisons between survival and hydrological conditions.

Another way in which survival has been related to measures such as flow is to compare adult escapement to juvenile conditions 2.5 years earlier, when the returning adults were presumably outmigrating as juveniles (Kjelson and Brandes 1989). In the VAMP study, adult escapement of fall-run Chinook salmon to the San Joaquin River basin between 1951 and 2003 was compared to San Joaquin River flow and the ratio of flow to CVP and SWP exports two and a half years before adult return (SJRGA 2007). These analyses assume that adults return to freshwater at age 3. Although patterns of adult escapement represent more than just juvenile survival through the Delta, these comparisons provide an opportunity to assess a possible population-level effect of Delta conditions during juvenile outmigration using data other than tagging data. We briefly present the findings from these analyses in the pertinent sections below—both the original results from the 2006 VAMP report (SJRGA 2007) and those updated by the SST using adult return data through 2012.

E.2.3 Inflow and Export Conditions

A central issue confounding the ability to identify and isolate the influence of export and inflow as drivers of 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 to 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 (Table E.2-4, Figure E.2-6). 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 E.2-6, Table E.2-4). Correlation between inflow and exports was r=0.86 (r^2=0.74) for the CWT studies (pre-VAMP and VAMP) when the barrier was installed at the head of Old River (Figure E.2-7). Newman (2008) also reported that "exports and flows were highly positively correlated" (r=0.88) in an analysis of VAMP and pre-VAMP CWT data (Newman 2008). The overall correlation between the ten-day average values of inflows and

(http://www.water.ca.gov/dayflow/) maintained by DWR. Both daily averages and 15-minute event data (for inflow) are available from the California Data Exchange Center (CDEC) (http://cdec.water.ca.gov/), but these are preliminary data that may include errors. The Dayflow data come from the same source as the CDEC data but have gone through some level of quality control. Exports rates from Dayflow are measured in cubic feet per second. The measure of the SWP export rate has changed over the years. Except in 2002, the SWP measure consisted of the Clifton Court Forebay inflow, but it omitted the Byron Bethany Irrigation District component before 2002 and included it after 2002. In 2002, the SWP exports metric measured the Banks Pumping Plant flow (as described at http://cdec.water.ca.gov/selectQuery.html).

exports used in the simple graphical analyses presented here, when all data points are included, is considerably lower (r=0.34) than the value presented in Newman (2008). However, when data are separated by tag type and barrier status, the observed correlation between inflow and exports is often higher (r≤0.89; Figures E.2-8 through E.2-10). Inflow is also partially confounded with the status of the barrier at the head of Old River because the barrier cannot be installed when flows are greater than 5,000 cfs or operated when flows are greater than 7,000 cfs.

Table E.2-4. Summary of Observed Flows at Vernalis and Observed Delta Exports During VAMP Periods, 2000 – 2011

Year	VAMP Target Flow Period	Observed Flow at Vernalis – VAMP period mean (cfs)	Observed Delta Exports – VAMP period mean (cfs)
2000	4/15 – 5/15	5,870	2,160
2001	4/20 – 5/20	4,220	1,420
2002	4/15 – 5/15	3,300	1,430
2003	4/15 – 5/15	3,240	1,450
2004	4/15 – 5/15	3,160	1,330
2005	5/1 – 5/31	10,390	2,990[a]
2006	5/1 – 5/31	27,900/24,260[b]	1,560/5,750[b]
2007	4/22 – 5/22	3,260	1,490
2008	4/22 – 5/22	3,160	1,520
2009	4/19 – 5/19	2,280	1,990
2010	4/25 – 5/25	5,140	1,520
2011	5/1 – 5/31	12,650	3,360

Notes: Reproduced from SJRGA 2013, Chapter 2, p. 25, Table 2-8. a = May 1 – 25 average was 2,260 cfs; exports increased starting May 26 in conjunction with increasing existing flow; May 26 – 31 average was 6,012 cfs.
b = First fish release-recapture period (May 1 – 15 for flow at Vernalis, May 3 – 17 for Delta exports)/Second fish release-recapture period (May 16 – 31 for flow at Vernalis, May 18 – June 2 for Delta exports).

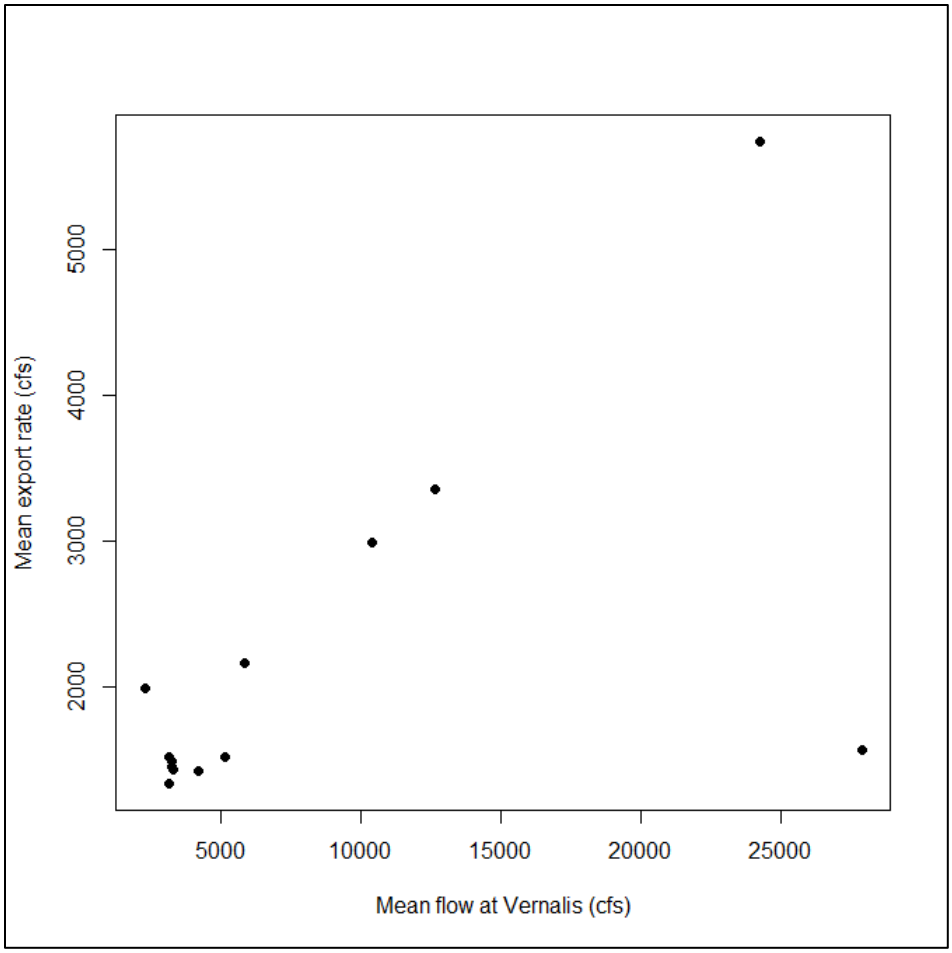

Figure E.2-6. Observed Mean Inflow and Exports During VAMP Period, 2000 – 2011

Note: Reproduced from SJRGA 2013, Chapter 2, pg. 25, Table 2-8. The observation with mean flow = 27,900 cfs and mean export rate = 1,560 cfs (in lower right corner of plot) is from 2006.

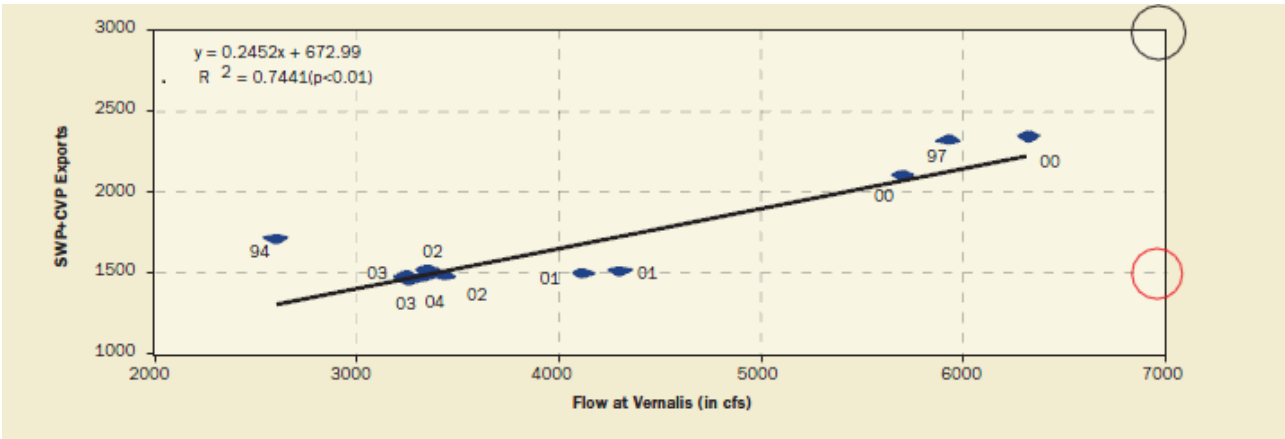

Figure E.2-7. Inflow and Exports During CWT Studies in the San Joaquin River with the Head of Old River (physical) Barrier in Place for 1994, 1997, and 2000 – 2004

Note: Reproduced from SJRGA 2007, Chapter 5, pg. 61, Figure 5-16.

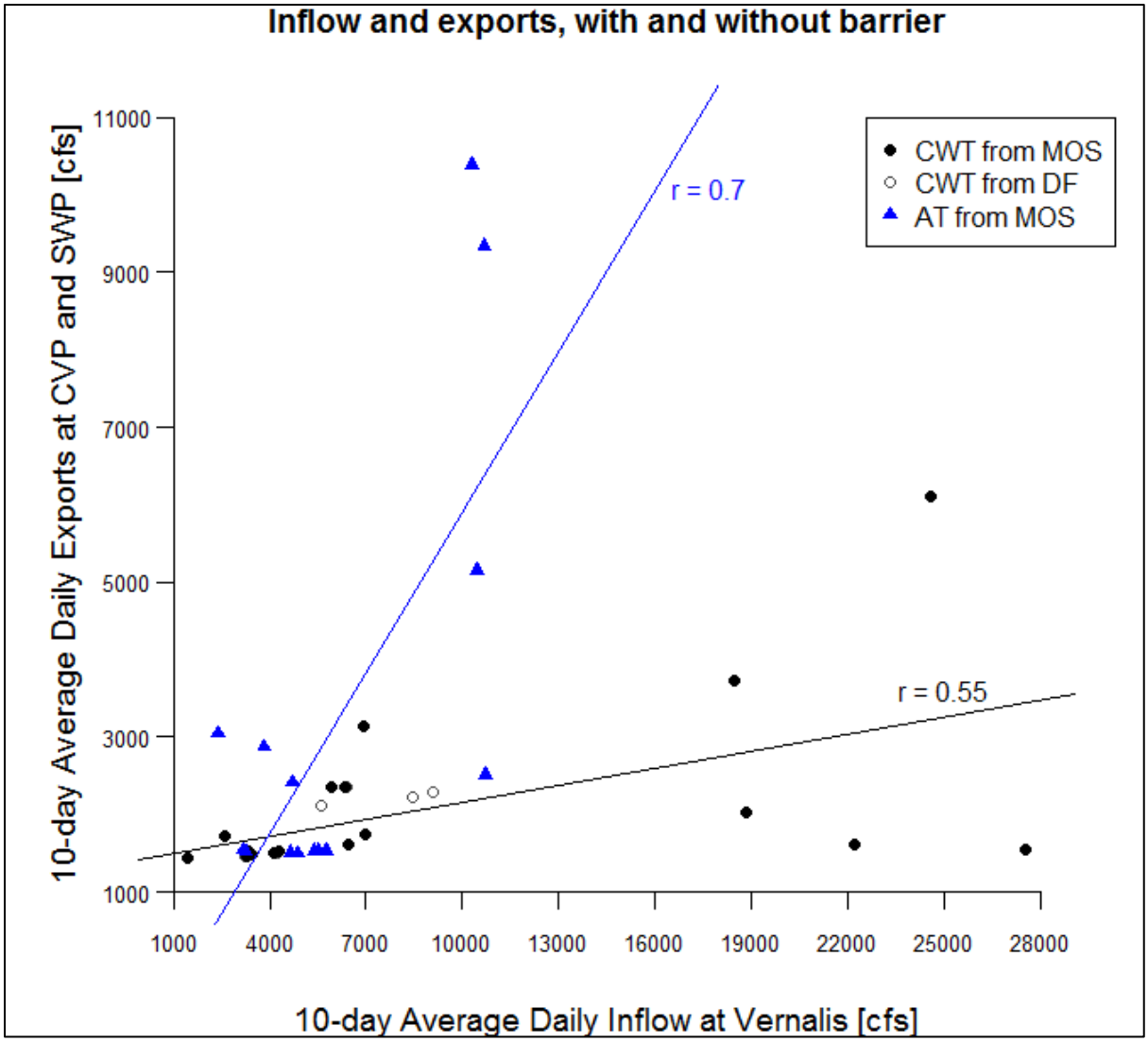

Figure E.2-8. Observed Average Inflow and Export Rates for the Release Groups of CWT and Acoustic-tagged Fall-run Chinook Salmon Presented in this Section, Regardless of Barrier Status at the Head of Old River, with Pearson Correlation Coefficient (r) for Each Tag Type; Fish Were Released at Either Durham Ferry (DF) or Mossdale (MOS)

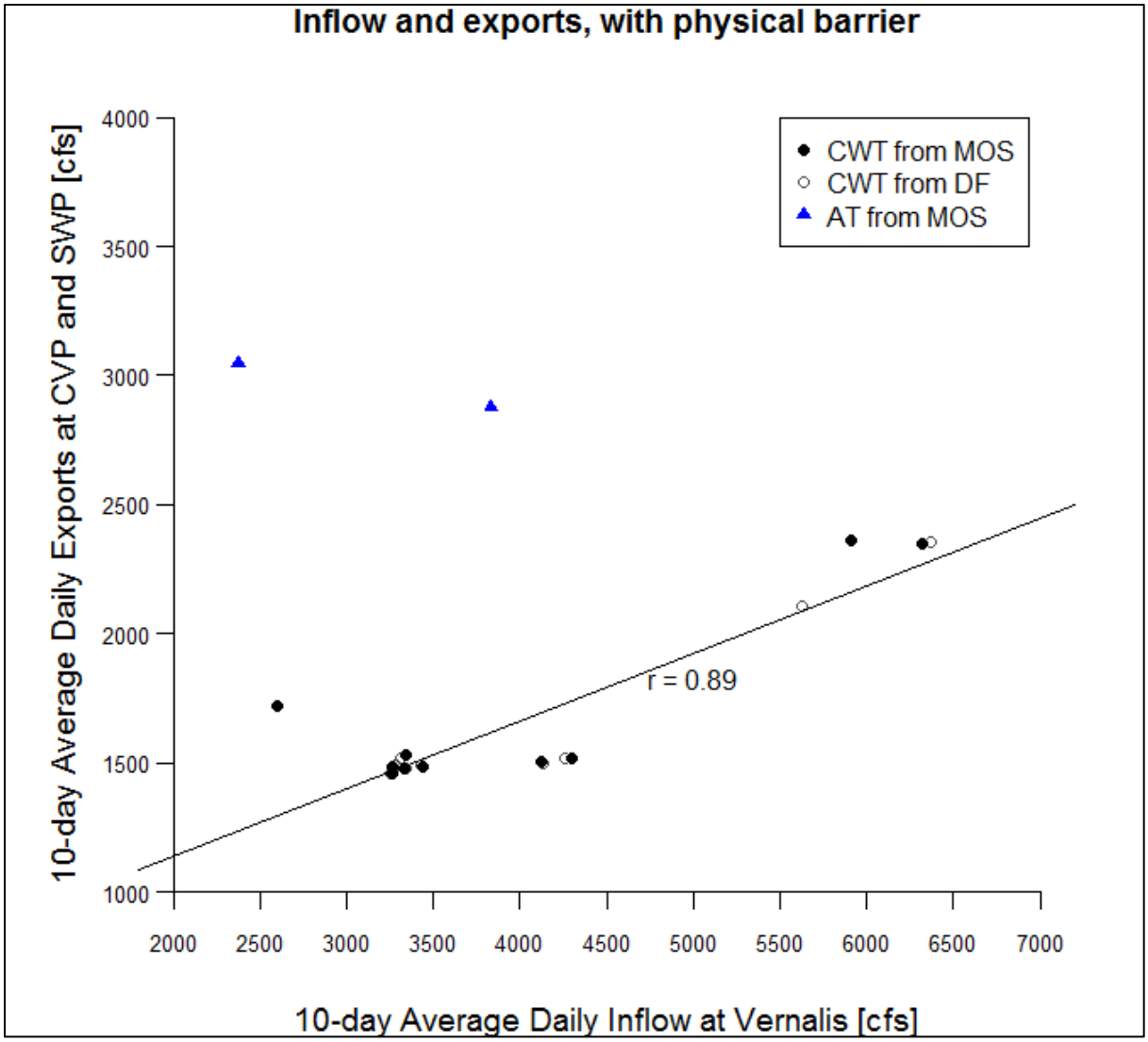

Figure E.2-9. Observed Average Inflow and Export Rates for the Release Groups of CWT and Acoustic-tagged Fall-run Chinook Salmon Presented in this Section, with Physical Barrier Installed at the Head of Old River, with Pearson Correlation Coefficient (r) for CWT Releases; Fish Were Released at Either DF or MOS

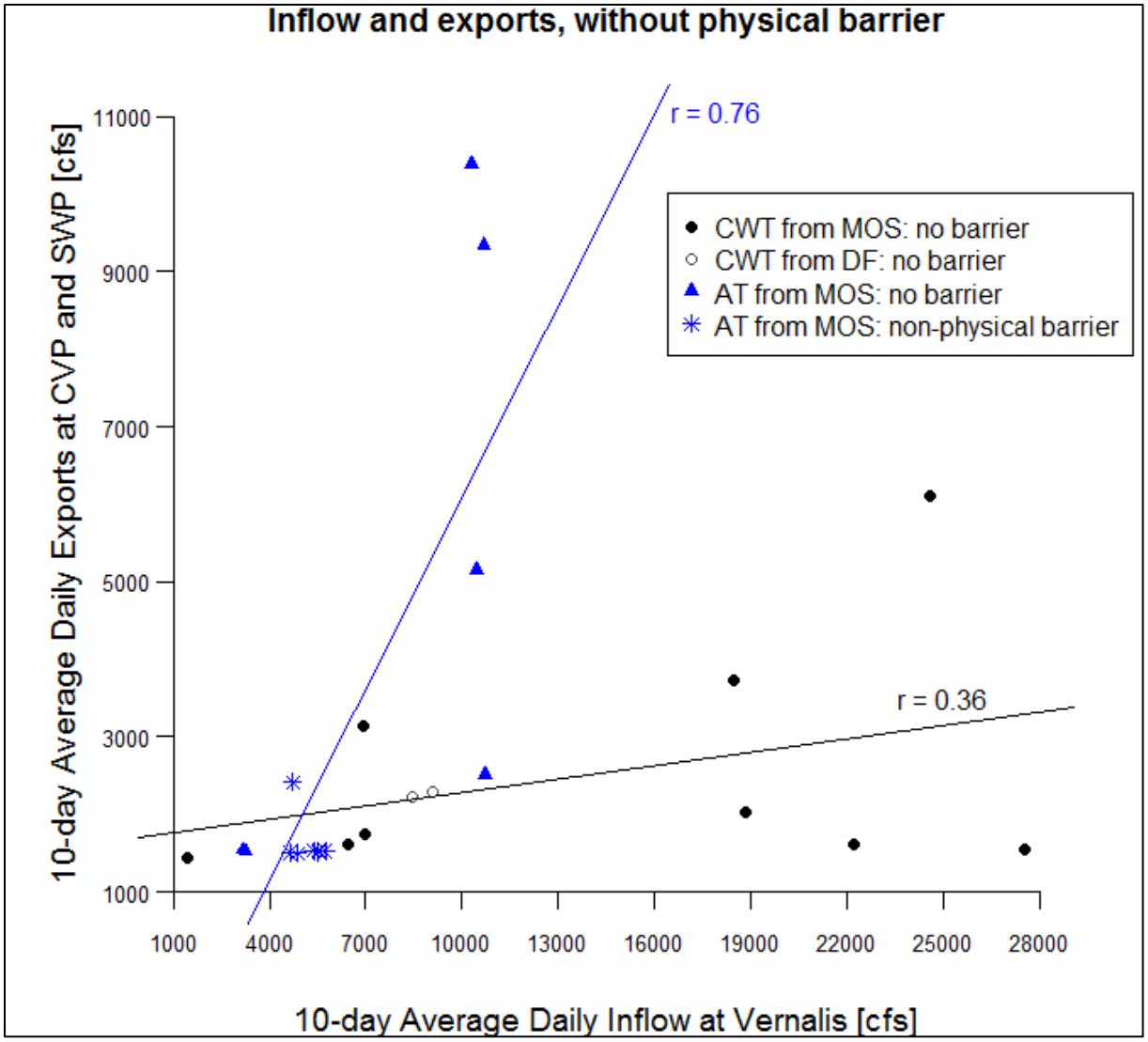

Figure E.2-10. Observed Average Inflow and Export Rates for the Release Groups of CWT and Acoustic-tagged Fall-run Chinook Salmon Presented in this Section, without Physical Barrier at the Head of Old River, with Pearson Correlation Coefficient (r) for each Tag Type; Fish Were Released at Either DF or MOS

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 to 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. Additional data that include observations for previously unobserved or uncommon combinations of inflow and exports (e.g., low exports combined with high flows or a range of exports for a given inflow level) is likely necessary to properly identify the relative effects of inflow and exports on survival. Separating the effects of inflow and exports on survival is further complicated

by the practice of increasing upstream reservoir releases to provide water for export and irrigation supply.

Existing analysis found in the literature has focused on modeling the mean survival probability as a function of covariates (e.g., exports, inflow, barrier status). An alternative approach is to model a quantile of the survival response, such as the maximum, as a function of covariates (e.g., quantile regression). This approach may be more appropriate than modeling the mean response if the covariate is a limiting factor in the survival distribution. For example, the covariate (e.g., exports) may determine the range of possible survival values, while other factors determine the mean survival within the possible range. This hypothetical situation is an example of a factor-ceiling relationship (Thomson et al. 1996). We have not found analyses of these data in the literature that assess potential factor-ceiling relationships or attempt to model quantiles of the survival distribution. It is outside the scope of this report to perform new, formal analysis here, but we take the opportunity to visually examine scatterplots and address the possibility of a factor-ceiling relationship in the results that follow.

It is important to note that limitations on inference exist regardless of the analysis method used, whether it is regression of the mean, quantile regression, factor-ceiling analysis, or correlation analysis. In particular, inference is valid only over the range of the explanatory variable (e.g., exports or inflow) that is observed in the data, and the quality of the inference may be poor in regions with few observations (e.g., high export levels in the results that follow). Additionally, problems of correlation among covariates and confounding of effects still apply.

E.3 DIRECT MORTALITY FROM THE FISH FACILITIES

The conceptual model frames direct mortality from the fish facilities as a function of both route selection, resulting from tidal and water project operation influences on migration cues, and stressors within the facilities after the fish has selected a facility route. The export rate affects both route selection and factors such as pre-screen mortality and louver efficiency, and thus the possibility of salvage, within-facility mortality, and the opportunity for effects of handling and transport (Figure E.3-1). We consider salvage facility operations separately from other questions of migration route because the mechanisms of mortality are potentially different in the facilities than in other regions of the Delta. Fish collection and transport, in particular, are unique to the salvage facilities apart from other Delta habitats. Additionally, focused studies have examined the mechanistic linkages between salvage facility operations and survival. We consider those mechanistic linkages in detail here, and address other effects of route selection in Section E.4.

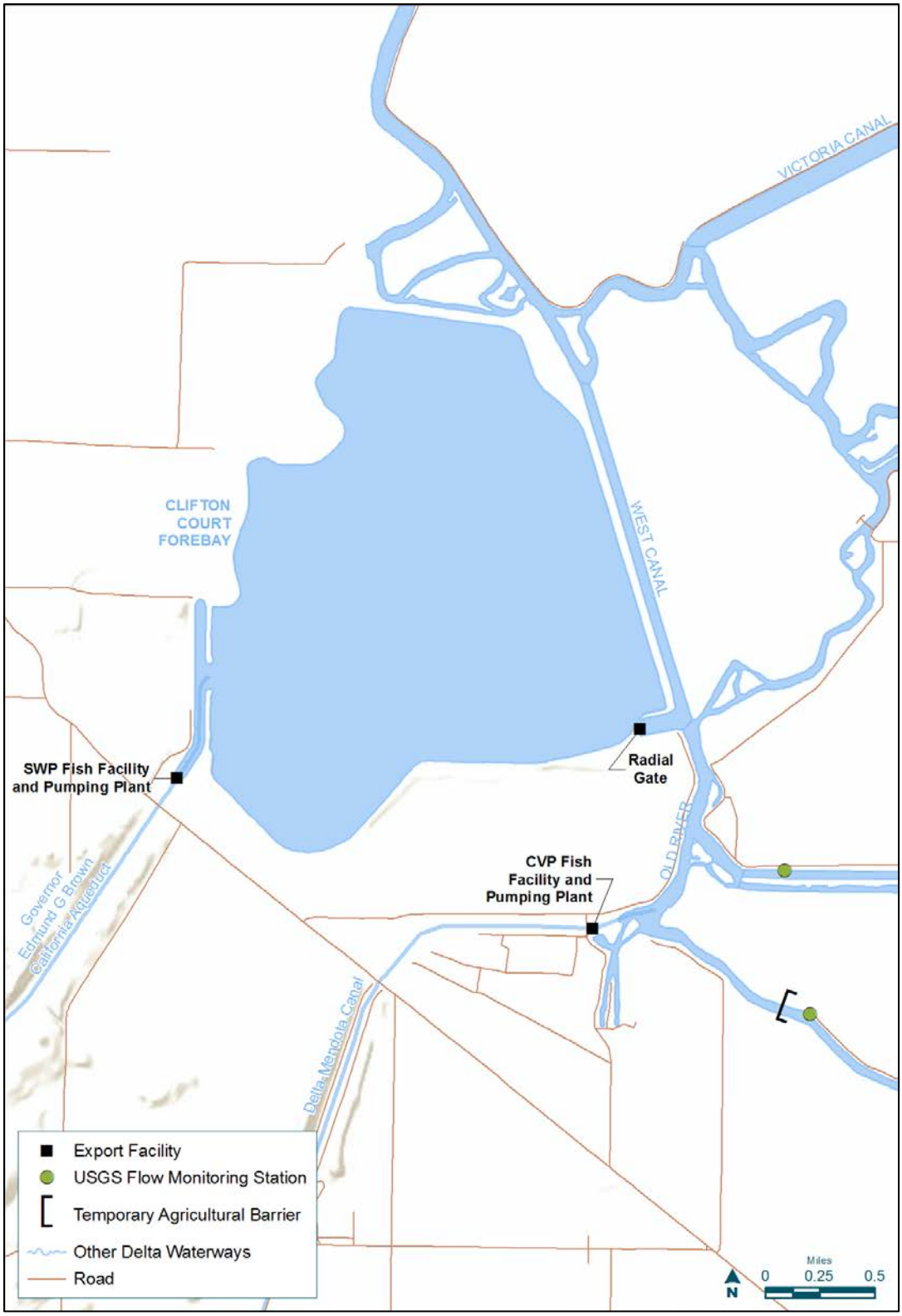

Figure E.3-1. Location of CVP and SWP Fish Salvage Facilities Relative to Clifton Court Forebay

The geographic extent of the facility operations includes the Clifton Court Forebay (CCF), louver and salvage facilities, and intake canals leading to the facilities (Figure E.3-1). Salvage facilities are located on the intake canals for the South Delta pumping plants—Tracy Fish Collection Facility (CVP) and John F. Skinner Delta Fish Protection Facility (Skinner 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 system, at SWP) on the secondary channels directs fish into holding tanks, where fish are concentrated. As needed, fish in holding tanks are transferred to transport trucks, moved to release sites on the lower Sacramento and San Joaquin rivers (Figure E.2-2), and released back into Delta waters through a pipe. 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 juveniles suffer high mortality rates in the forebay compared to the salvage facilities (i.e., from the trash racks at the entrance of the facilities through release after salvage) at the SWP (Gingras 1997; Clark et al. 2009). On the other hand, 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; nevertheless, the cumulative survival rate for juvenile salmonids routed through the CCF and SWP salvage facility is lower than through the CVP facility.

The conceptual model predicts the following:

- Direct mortality is a function of export rates.
- Pre-screen mortality is higher at the SWP than at the CVP because fish must navigate the CCF outside the SWP.
- Pre-screen mortality 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 an index for rates of direct entrainment mortality through the louvers and into the intake canals, and also total mortality at the facilities.

E.3.1 Summary: Conceptual Model Predictions on Direct Mortality from the Fish Facilities

The conceptual model predicts that direct mortality is a function of exports rates. This prediction is supported indirectly, but the relationship is complicated.

- Direct mortality (loss) is estimated from salvage counts, which have been found to increase with increasing export rates (Kimmerer 2008; Zeug and Cavallo 2014).

- Mortality due to louver inefficiency has been found to decrease at the CVP for higher secondary channel velocities, which are controlled by export rates (Bowen et al. 2004; Karp et al. 1995).

The conceptual model predicts that pre-screen mortality is higher at the SWP than at the CVP. Evidence for this prediction is indirect.

- A large population of striped bass large enough to eat juvenile salmon has been observed in the CCF (Brown et al. 1996; Gingras and McGee 1997).
- Pre-screen mortality at the SWP was estimated at 0.63 to 0.99 for Chinook salmon between 1976 and 1993 (Gingras 1997); no comparable estimates of pre-screen mortality have been made for the CVP.
- Detections of AT Chinook salmon show a higher probability of moving to Chipps Island via the CVP than via the SWP (Holbrook et al. 2009; SJRGA 2011, 2013).

The conceptual model predicts that pre-screen mortality is higher for Chinook salmon than for steelhead. This prediction has moderate direct and indirect support.

- Pre-screen mortality estimates at the SWP have ranged from 0.63 to 0.99 for Chinook salmon between 1976 and 1993 (Gingras 1997), and from 0.78 to 0.82 for steelhead (Clark et al. 2009).
- No estimates of pre-screen mortality have been made for the CVP; the assumed value is 15%, but it unknown how representative that value is (Anonymous 2013).
- AT data have resulted in higher estimates of survival for steelhead than for Chinook salmon from CVP trash racks to Chipps Island via salvage, and from the CCF radial gates to Chipps Island (presumably via the SWP) (VAMP study, 6-year steelhead study; also shown in Figures E.4-5 and E.4-6 of this appendix; Holbrook et al. 2009; SJRGA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015).

The conceptual model predicts that louver efficiency is higher at higher export levels. This prediction has been supported by studies at the CVP.

- Bowen et al. (2004) reported a positive association between secondary louver efficiency and average channel velocity, although the authors state the relationship is weak.
- Sutphin and Bridges (2008) report higher efficiency of the secondary louvers for higher bypass water velocities.
- Channel velocity at the CVP is controlled by the export rate.

The conceptual model predicts that salvage can be used as an index for direct entrainment mortality through the louvers into the intake canals, and also total mortality at the facilities.

- Both intake canal entrainment mortality and total facility mortality ("loss") are currently estimated as functions of salvage counts.

- However, no studies have been found that directly test the relationship between salvage and total mortality at the facilities.

E.3.2 Findings on Conceptual Model Linkages and Predictions: Direct Mortality from the Fish Facilities

E.3.2.1 Understanding Loss Calculations

Before considering the basis of knowledge that supports our conclusions regarding exports and mortality at the facilities, it is helpful to understand the components that comprise facility loss and how they are estimated, and how salvage is incorporated into loss estimates. Direct mortality of juvenile salmon at federal and state water projects is typically attributed to three general components: pre-screen mortality, entrainment into the water project intakes, and within-facility or salvage mortality, which includes mortality due to predation and handling within the facility, during trucking and release, and potentially after release. Pre-screen mortality is defined as mortality occurring on the facility side of the trash racks at the federal facility, and on the facility-side of the radial gates at the entrance to CCF at the SWP, and is assumed to be due to predation.

Loss at the SWP and CVP salvage facilities is estimated from a formula that uses salvage counts as the primary biological input variable (CDFW 2013). From salvage counts, the number of juveniles encountering the fish screens (encounter rate) on the intake canals is estimated based on water-velocity-modulated louver efficiency; from encounter rate, pre-screen mortality (assumed due to predation) is estimated using a formula agreed upon by resource and regulatory agencies. Total loss is equivalent to the number of juveniles encountering the screens, plus the pre-screen predation mortality, minus the number of fish salvaged, plus salvaged juveniles that die during trucking and handling.

Here, we consider three forms of mortality (pre-screen mortality, intake canal entrainment mortality, and within-facility mortality), as well as salvage as linkages between water export operations and survival. We examine what is known about contributions to direct mortality and survival from each component separately, and briefly consider the larger effects of each component on individual-level and population-level survival through the Delta.

One of the challenges of evaluating impacts to or apportioning mortality among different stocks 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. Genetic tissue sampling for the winter run has occurred at the fish facilities for many years, and has occurred for some spring-run stocks more recently (Banks et al. 2014; Harvey et al. 2014) but not consistently in monitoring for juvenile salmon entering, within, and leaving the Delta. Genetic sampling of winter and some spring-run stocks of Chinook has also occurred for three years for fish entering the Delta at Sacramento (2009, 2010, and 2011); additional

genetic testing is planned for 2016. Additional analyses of these samples could provide an opportunity to better enumerate the proportional mortality of winter-run and spring-run fish 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 into a population context.

Pre-screen Mortality

Our basis of knowledge related to pre-screen mortality of Chinook salmon and steelhead is medium at the SWP fish facility, and low at the CVP fish facility. Multiple non-peer-reviewed agency studies have attempted to directly monitor pre-screen mortality or factors assumed to contribute to pre-screen mortality, for both Chinook salmon and steelhead. Our understanding is lower at the CVP than at the SWP because studies have not been able to successfully partition pre-screen mortality as a part of whole facility loss at the CVP.

Pre-screen mortality is mortality that occurs on the facility side of the trash racks at the CVP and of the radial gates at the entrance to the CCF. It is assumed to result from predation by a large predator population adjacent to the facilities, and from physical structures and altered hydrodynamics that increase predator efficiency. The magnitude and variability of the pre-screen mortality contribution to estimates of overall facility survival and through-Delta survival is unknown, and has been identified as a key uncertainty in attempts to estimate population mortality to direct effects of exports (Kimmerer 2008).

The evidence of mortality due to predation adjacent to the facilities comes from a variety of sources. Indirect evidence from outside of the Delta 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. Furthermore, during a one-month beach seining effort in 1992, more than 80% of the fish sampled from the 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.

Structures provide conditions that improve predator effectiveness by providing sites used for ambush, and prey may be confused as they pass into or through pipes (Tucker et al. 1998 as cited in Sutphin et al. 2014). Additionally, both the SWP and the CVP have structures that create conditions considered to make juveniles more vulnerable to predators, such as sudden drop in elevation, flow concentration, and changes in light levels in bypass canals that serve to disorient juvenile salmonids and affect their ability to evade predators (Rieman et al. 1991; Larinier 2001 as cited in Sutphin et al. 2014). Clark et al. (2009) reported that 65% (29 of 44) of the tagged steelhead remaining in CCF until the end of an acoustic telemetry study were

last detected at the radial gates; several of the tags were stationary, and were assumed to have been consumed and defecated by striped bass; in addition, several steelhead were observed within the intake canal, but never salvaged (Clark et al. 2009). Clark et al. (2009) hypothesized that steelhead may perceive the trash rack at the intake canal as a barrier and congregate there without moving into the salvage facility, which may make them more vulnerable to predation.

Estimates of pre-screen mortality at the Skinner Facility (SWP) ranged from 63 to 99% for a series of tagged Chinook salmon releases between 1976 and 1993 (summarized in Gingras [1997]). Studies conducted with tagged steelhead reported estimated mortality between 78% (+/- 4%, 95% CI) and 82% (+/- 3%, 95% CI) (Clark et al. 2009). These pre-screen mortality rates were considerably higher than those estimated for steelhead once they had entered the Skinner Facility (26%, +/- 7%, 95% CI) (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 the CCF was reduced to approximately 0.28 to 0.36 (SE=0.05), depending on the status of the gate 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).

Tracy salvage facilities (CVP) provide favorable habitat for piscivorous 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 may still be an issue in front of the CVP trash racks, with a total of 37 ATs detected near this location (SJRGA 2011).

Since 2008, DWR has not allowed installation of AT receivers at the SWP inlet or in the holding tanks; instead, DWR evaluates facility mortality at the CCF and SWP based on passive integrated transponder (PIT)-tagged fish. Allowing the installation of acoustic receivers throughout the SWP would provide additional information on the areas of mortality within the SWP that are of greatest concern to salmon and steelhead. Interrogation of ATs in salvage at the SWP to verify that tags are still in salmonids would inform the various predator data filters that are used in estimating salmonid survival throughout the Delta.

Entrainment into Intakes

Our basis of knowledge for entrainment mortality into the canals at the CVP and SWP fish facilities is high. Early published engineering studies and multiple non-peer-reviewed agency studies have measured intake canal entrainment mortality by monitoring louver efficiency at both fish facilities. The predictability of the relationship is largely constrained by variability in operations or other management actions, but also depends on external factors including fish size.

Entrainment into canal intakes depends on the efficiency of the louver system that is designed to guide fish away from intakes and into the salvage facilities. Louver efficiency varies for size of fish, and between species and facilities, and may be influenced by operational parameters (e.g., day or night operation, water velocity approaching louvers) (Anonymous 2013). Variability in louver efficiency contributes to uncertainty about how salvage and loss rates affect the proportional loss of the population of salmonids by direct entrainment through the louvers at the fish collection facilities and into the pump canals (Kimmerer 2008).

Some early louver efficiency experiments at the Skinner Facility (SWP) and the Tracy Fish Collection Facility (CVP) reported overall efficiency estimates ranging from 50 to 90%, where the lower efficiencies were observed for the smaller fish (less than 38 mm) passing through the system (Skinner 1974; Heubach and Skinner 1978 as summarized in Odenweller and Brown 1982). However, for Chinook salmon ranging in size from approximately 50 mm to 125 mm, smaller fish have been observed to have higher louver efficiency at the SWP (CDWR/CDFG 1973 as cited in Brown et al. 1996; Anonymous 2013). Estimates of overall louver efficiency at CVP from a 1993 study ranged from 12 to 72% (average = 47%) for Chinook salmon; however, these estimates include mortality due to predation within the facility as well as entrainment into the intakes (Karp et al. 1995).

The efficiency of the louver system depends on the efficiency of both the primary and secondary louvers. In 1993, daytime releases of juvenile Chinook at the CVP found the secondary louvers individually were 70 to 87% efficient at recovering Chinook salmon released directly upstream of louvers; as a pair they were 98 to 100% efficient (Karp et al. 1995). The primary louvers recovered only 13 to 25% of fish, but this estimate does not factor out predation mortality between the release site and the holding tanks where fish were recovered, nor fish that exited the facility, which were not identifiable in the study (Karp et al. 1995). Nighttime releases had similar recovery rates for the secondary louvers, but much higher recovery rates for the primary louvers (75 to 77%; Karp et al. 1995). Even greater recovery rates of 81 to 84% occurred for releases upstream of the trash rack at nighttime, suggesting that release strategy above the primary louvers may have accounted for some of the poor performance (Karp et al. 1995). Compared to secondary louvers, primary louvers are also exposed to greater variability in tidal and export driven water velocity and

debris load, all of which may have affected louver efficiency measurements. Efficiency of the primary louver system is also related to the behavior of salmonids entering the primary channel. Haefner and Bowen (2002) identified both the cross-channel position of fish as it enters and the energy reserves of those fish as important variables that influence entrainment into the intakes.

Variability has been observed between salmonid species in efficiency estimates for the secondary louver at CVP. In a study of the secondary CVP louver system from March 1996 to November 1997, Bowen et al. (2004) reported average secondary louver efficiency estimates of 85% for Chinook salmon and 100% for steelhead. Bowen et al. (2004) also reported a statistically significant positive association between secondary louver efficiency and average channel velocity, although the authors state that the relationship is too weak to use average channel velocity as a predictor for secondary louver efficiency. More recent fish insertion experiments conducted in May 2005, across a broad range of bypass velocities at the CVP, including lower velocities resulting from export restrictions related to the Biological Opinion (NMFS 2009), suggested a positive effect of bypass water velocity on secondary louver efficiency; efficiency estimates for Chinook salmon ranged from less than 40% at low velocities (less than 1 foot per second [ft/s]) to over 80% at high velocities (greater than 4 ft/s) (Sutphin and Bridges 2008).

Within Facility Mortality

Our basis of knowledge for within-facility mortality is medium at both the CVP and SWP facilities. Multiple agency studies have measured and reported within-facility mortality at the CVP, but there have been fewer studies at the SWP; handling and transport effects have been evaluated in peer-reviewed literature from other systems. The predictability of the relationship is largely constrained by variability in operations or other management actions.

During and after the salvage process, salmonids may be exposed to additional mortality caused by predation within the facility, stressors during handling or trucking, or post release predation. At the CVP, juvenile Chinook salmon survival estimates from just downstream of the secondary louvers to the holding tanks ranged from 91 to 100% in a 1993 study, indicating within-facility predation mortality of up to 9% (Karp et al. 1995). Karp et al. (1995) also reported that the overall survival probability from the primary louvers to the holding tank was estimated at 12 to 24% for daytime releases and 66 to 72% for nighttime releases, although these values represent both canal entrainment mortality (i.e., passing through the louvers) and predation after passing either the primary or secondary louvers and within the holding tank. Predators (e.g., striped bass large enough to eat juvenile Chinook salmon) have been observed in the holding tanks at the CVP (Karp et al. 1995). Comparisons of predator avoidance in laboratory tests indicated that the shape of holding tanks may influence predation rates, but holding time had no significant effect on those tests (Portz 2007).

Sutphin et al. (2014) concluded that the Tracy Fish Collection Facility (CVP) supports a higher density of predators than the natural environment. The secondary channel allows natural light into the water and may explain why more striped bass, which are visual predators, are present relative to tactile predators such as catfish (Sutphin et al. 2014; Stevens 1966 as cited in Sutphin et al. 2014). Furthermore, using a bioenergetics model and salvage estimates, Sutphin et al. (2014) estimated that 6% of the Chinook salmon salvaged in 2005 at the CVP (total of 25,637) were eaten in the secondary channel by predators, with most of the Chinook salmon consumed by striped bass greater than 200 mm FL.

Within-facility mortality at the SWP (i.e., between the trashracks and release from salvage) was estimated for steelhead using PIT tags in 2007, and reported to be between 26% (95% confidence interval = 19 to 33%) and 18% (11 to 25%); estimates ranged from 0 to 83% (Clark et al. 2009). Only pre-screen mortality estimates (i.e., no within-facility mortality estimates) were found for Chinook salmon at the SWP (Gingras 1997).

Salvage handling and trucking may have a variable impact on collected fish. Early studies noted "substantial" trucking and handling mortality for Chinook collected at the CVP (Menchen 1980 as cited in Raquel 1989). Studies of juvenile fishes undertaken to develop an estimate of handling and trucking mortality found that for Chinook salmon at the SWP, mortality during holding and trucking was estimated at 2% for fish less than 100 mm and 0% for larger fish; most mortality was attributed to handling during transfer (Raquel 1989). Karp and Lyons (2008) found 100% survival for 11 steelhead monitored for 24 hours following salvage handling. In general, handling and trucking procedures are not believed to directly cause significant reductions in survival compared to other sources of mortality around the CVP/SWP export facilities (NMFS 1997 as cited in Kimmerer 2008).

It is possible that handling and trucking procedures may contribute to mortality indirectly, however. The stress of handling and transporting salmonids may decrease predator avoidance capability (Olla et al. 1995) and increase susceptibility to predation after release from trucking. In general, handling and transporting salmonids increases physiological indices of stress (Maule et al. 1988; Congleton et al. 2000), and predator avoidance response time may be increased for fish that are exposed to acute handling stress (Sigismondi and Weber 1988). Predators have been found to disproportionately capture stressed salmon compared to unstressed salmon, although salvaged Sacramento Chinook salmon were observed to more closely resemble the stress level of the control group than experimentally stressed groups (Portz 2007).

In addition to the possibility of reduced predator avoidance ability following salvage and trucking, hydroacoustic and DIDSON camera observations have documented aggregations of predatory species at salvage release sites following large releases of transported salmonids (Miranda et al. 2010). Also, hydroacoustics monitoring at the salvage release sites was able to document predator abundance changing between seasons and related to the number of fish

being salvaged, with higher abundances in the early spring, summer, fall, and late fall (Miranda et al. 2010). Thus, the release of salvaged fish from single point locations may attract predators and result in higher mortality than if release sites were moved frequently (e.g., Collis et al. 1995).

Salvage

Our basis of knowledge regarding salvage at the fish facilities as an index for mortality at the facilities is minimal. Also, our basis of knowledge regarding population-level effects (e.g., benefits) of salvage is minimal. Multiple studies have measured salvage rates of tagged fish releases at both fish facilities; indirect evidence of salvage is also found via acoustic telemetry studies that are available in agency reports. The relationship between salvage counts and total facility mortality is not well understood, nor is the extent to which operations constrain that relationship.

Despite the risks associated with within-facility mortality and the salvage process, salvage has the potential to improve survival because it moves fish away from the Interior Delta. On the other hand, Muir et al. (2006) observed that transported fish may have increased vulnerability to predation in the estuary or ocean because they are potentially smaller and may have different ocean entry timing than non-transported fish. This mechanism may increase mortality of salvaged rearing salmonids compared to migrants, which spend more time growing within the Delta, by lowering post-release survival. However, travel time differences between transported and non-transported salmonids in the Delta are likely to be small compared to the differences observed by Muir et al. (2006) for Columbia River Basin fish because the travel distance truncated by salvage is much shorter in the Delta.

Salvage rates and the survival of salvaged fish have been estimated but there is considerable uncertainty about the 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 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, and for juvenile steelhead in 2011 and 2012 (SJRGA 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015). In each of these cases, survival from Mossdale to the facilities (CVP trash rack or CCF radial gates) or Highway 4 (annual average = 0.66 to 0.77 for Chinook salmon, 0.55 to 0.78 for steelhead) was considerably higher than total survival from Mossdale to Chipps Island for fish migrating through the Delta via the Old River route from the head of Old River (annual average = 0.04 to 0.07 for Chinook salmon, 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 the CCF. In 2012, too few salmon were observed passing the physical barrier at the head of Old River and entering Old River to provide spatially detailed estimates of survival probabilities within the Old River route (Buchanan et al. 2015).

Among the fish that entered the facilities in these acoustic telemetry studies, similar proportions of Chinook passed through the CVP trash racks as entered the CCF in 2010 and 2011 (SJRGA 2011, 2013; Buchanan 2013, 2014). Nevertheless, for Chinook salmon in 2010 and 2011, estimated survival probabilities from the CVP trash rack to Chipps Island (0.20 to 1.00) were higher than from the CCF to Chipps Island (0 to 0.03), indicating higher mortality due to some combination of pre-screen mortality, canal entrainment mortality, and facility mortality at CCF and SWP than at the CVP in those years (SJRGA 2011, 2013). In 2012, very few Chinook salmon were observed entering the Old River route, none were detected at CCF, and only one was detected at the CVP (which was later detected at Chipps Island) (Buchanan et al. 2015). In contrast to Chinook salmon, more steelhead entered the CCF than 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, 2014).

Despite the high mortality observed through the facilities in these studies, the route through the CVP salvage, holding tank, and truck transport sometimes provided the majority of the tagged Chinook salmon observed at Chipps Island from all possible migration routes through the South Delta. In 2010 and 2011, over 60% of the acoustic-tagged Chinook 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 head of Old River route, and of the 29 tagged salmon that survived to Chipps Island via all routes combined, came by way of salvage at the CVP (Buchanan et al. 2013), suggesting that survival through the CVP was higher than through all alternative South Delta routes. However, the estimated transition probability from the CVP trash racks to the holding tanks in 2011 was only 0.23 (SE=0.03), implying that there is considerable mortality in the CVP migration route. Additionally, based on acoustic data, the per-kilometer survival rate from the radial gates at CCF to Chipps Island was the lowest of all Interior Delta routes for Chinook salmon and steelhead (Figures E.4-5 and E.4-6, Table E.4-3).

The proportion of various salmon populations that are salvaged or lost to the facilities is not well understood. Overall, low survival prior to the facilities will result in low salvage rates because few fish are available, and vice versa. Zeug and Cavallo (2014) reported that 0.2% of CWT late-fall-run Chinook salmon released in the Sacramento River basin from 1993 to 2007 were salvaged. This result suggests that a small proportion of the population of juvenile Chinook salmon enter the facilities. However, this estimate includes mortality experienced from the release site to the Delta, selection of the facilities route among all routes through the Delta, and mortality during migration through the Delta to the fish facilities, in addition

to salvage and facility mortality. For example, from 64 to 100% of acoustic-tagged fish that were released in the Sacramento River died before arriving at the Delta (fifth column in Table E.2-2). Also, release site and export conditions may affect the proportion lost to the facilities. For example, Zeug and Cavallo (2014) reported that relative loss (i.e., combined loss at the diversions [CVP + SWP] compared to total migration mortality) ranged from less than 1 to 17.5% for San Joaquin River fall-run Chinook salmon depending on diversion rate and release location. Newman and Brandes (2010) examined CWT data from late-fall-run Chinook salmon released from 1993 to 2005, and found that the proportion of fish released into Georgiana Slough that were subsequently recovered in salvage varied between 0 and 2.5%, and was higher as exports increased.

For juvenile winter-run Chinook salmon, estimates of combined facility loss as a proportion of the juvenile population are based on Delta length-at-date race assignments from fish observed during salvage sampling at the facilities (Harvey et al. 2014); juvenile population abundance is taken from the juvenile production estimate (JPE), an estimate of the number of juvenile winter-run salmon from each brood year that enter the Delta (Pyper et al. 2013). It should be noted that the false positive error rate for the Delta length-at-date race assignment of winter run varies among years, depending on the relative numbers of Chinook juveniles from all races that are encountered at the fish facility and fall into the winter-run length-at-date category (Harvey et al. 2014). This fact is addressed in the Endangered Species Act (ESA) take limits for winter run, which allow half of all winter-run-length fish to be considered non-winter-run. However, genetic testing has shown the false positive error rate to vary widely both inter- and intra-annually, with incidents of both positive and negative bias occurring in annual take estimates over the years (Harvey et al. 2014). A program of rapid genetic testing of salvaged winter-run length fish has been implemented in recent years to provide more accurate take estimates.

E.3.2.2 Summary: Direct Mortality

There is evidence of direct mortality at the facilities in several components: pre-screen mortality after passing the trash racks at CVP or entering the CCF radial gates; entrainment mortality in the intake canals due to variable louver efficiency; and within-facility mortality due to predation after passing the louvers or stressors during salvage. Survival of Chinook salmon is low in both facilities, and especially in the CCF. Survival of steelhead appears to be higher, but there is considerable uncertainty because only a few years of data are available for steelhead. However, although there is evidence of direct facility mortality of juvenile salmonids, the available data suggest that direct facility mortality is not the primary cause of low salmonid survival in the Delta. The population-level effect of direct mortality due to the facilities is difficult to estimate and varies with run and diversion rates; available estimates of combined mortality at the facilities as a proportion of total migration mortality have ranged from less than 1 to 5.5% for winter-run Chinook salmon, and from less than 1 to 17.5% for San Joaquin River fall-run Chinook salmon (Zeug and Cavallo 2014). Additionally, in some

recent acoustic telemetry studies of Chinook salmon released in the San Joaquin River, salvage at the CVP provided the most surviving fish to Chipps Island of all routes through the Delta, possibly because survival has been very low in all routes.

In conclusion, there has been considerable attention devoted to the components of direct mortality at the CVP and SWP/CCF. However, estimates of mortality (pre-screen mortality and louver efficiency) have shown high variability between years and species. The estimation of total loss depends on relationships between export rates and pre-screen mortality and entrainment. At very low regional survival rates, migration to the Delta exit at Chipps Island has been shown to be more successful through the CVP than through Delta waters, reflecting the complicated effect of export operations on the migration population.

Suggestions for actions to reduce direct facility mortality include:

- Control predator populations in the 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.

E.3.3 Summary: Knowledge Gaps on Direct Mortality

There is a need for improved understanding of the factors affecting direct mortality at the facilities and the population-level effect of this type of mortality, including:

- Improved identification of run among salvaged fish at the fish facilities
- Improved estimates of juvenile abundance for population-level loss estimates
- Improved identification of mortality hot spots within the facilities, including within the CCF
- Additional and/or improved estimates of pre-screen mortality and predation pressure within the CCF for both Chinook salmon and steelhead
- Better understanding of salmonid and predator behavior in and around the facilities
- Estimates of pre-screen mortality at the CVP separate from whole facility mortality
- Improved estimates of primary louver efficiency at the CVP, separated from within-facility predation
- Variability in the relationship between salvage counts and total facility mortality within and between different populations of salmonids
- Magnitude and variability of the pre-screen mortality contribution to estimates of overall facility survival and through-Delta survival
- Improved understanding of mortality during salvage handling and trucking, and the extent to which moving release locations often may reduce post-release mortality

Several of these data gaps may be addressed by tagging studies. However, the potential of detecting tags from predated salmonids complicates interpretation of acoustic telemetry data in predator-rich environments. Development and use of an effective predation tag, or other method to precisely indicate when a tagged study fish has been predated, would be useful. Such tags are in testing or are newly available.

E.4 SURVIVAL AS A FUNCTION OF ROUTE SELECTION

The conceptual model assumes that route selection is a major factor in determining the probability of survival, as migrating fish enter or avoid habitats that vary in predation pressure, entrainment risk in the water export facilities or other pump intakes, and water quality (e.g., temperature). The underlying hypothesis of this component of the conceptual model is that different routes through the Delta have probabilities of survival that vary in a predictable way. For example, because the water export facilities are located on or near Old River in the Interior Delta, it is reasonable to expect that the migration route through the South Delta that uses Old River at its distribution point from the San Joaquin River is likely to have lower probability of survival through the Delta than the route that uses the San Joaquin River at that river junction. 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. In addition, survival rates (per kilometer) are expected to vary among regions within the Delta because of differences in habitat and predation pressure.

In this section, predictions from the conceptual model regarding migration route and survival are identified and reviewed considering findings from both Chinook salmon and steelhead. Our primary focus in this section is on survival of fish migrating from the San Joaquin River through the Delta (Figure E.2-2).

E.4.1 SUMMARY: CONCEPTUAL MODEL PREDICTIONS ON SURVIVAL AS A FUNCTION OF ROUTE SELECTION

The conceptual model predicted that survival through the South Delta is higher in the San Joaquin River route than in the Old River route, from the head of Old River to Chipps Island.

- Results from CWT studies from 1985 to 1990 are consistent with that hypothesis, 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 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 (in 2010 and 2011).

- 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, estimated survival from the CVP to Chipps Island was sometimes higher than survival estimates 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 Interior Delta.

The conceptual model predicts that survival to Chipps Island from downstream entry points to the Interior Delta is higher for fish that remain in the San Joaquin River mainstem than for fish that enter the Interior Delta. This finding has partial support from data.

- 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. This is despite the possibility that fish that stay in the San Joaquin River at Turner Cut may enter the Interior Delta further downstream.
- No data are available for other junctions on the San Joaquin River, including Columbia Cut, Old River mouth, and Middle River mouth.

The conceptual model predicts that survival rates per kilometer will vary in different reaches of the Delta because of differences in habitat and predation pressure. This finding has partial support from data.

- Survival rate per kilometer tends to be higher in the upstream reaches and in the San Joaquin River mainstem compared to the Interior Delta, although survival rate through the lower San Joaquin River reaches appears comparable to survival through Interior Delta reaches.
- The linkages relating survival rate to migration route are not well understood. Predation is hypothesized to be a major factor in mortality, but there is little direct information on predation rates, predator communities, and habitat characteristics that might affect predation rates throughout the South Delta.
- Entrainment is also hypothesized to be a major factor in mortality; because it is pertinent only to fish passing the fish facilities, it may contribute to differences in survival rate in different regions of the Delta. Survival of acoustic-tagged salmonids tends to be low in the reaches that include the SWP and CVP facilities, but mortality due to entrainment into the canals is not estimated separately from predation mortality in the available studies. Additionally, survival from the CVP to Chipps Island was sometimes higher than survival through the lower San Joaquin River reaches. Entrainment is addressed further in Section E.3.

The interannual variability observed among the Chinook salmon data suggest that more survival data are necessary to draw firm conclusions about many of the reaches, for Chinook salmon and especially steelhead. However, the following conclusions can be made even with the observed variability:

- Entering the Interior Delta at Turner Cut is not a successful migration route for Chinook salmon, and has low (but greater than 0) survival compared to other routes for steelhead.
- For Chinook salmon that approach the water export facilities, the route through the CVP has higher survival than the route through the CCF and SWP.
- For Chinook salmon, the survival rate per kilometer tends to be lower through the city of Stockton than from Lathrop to Stockton.

E.4.2 Findings on Conceptual Model Linkages and Predictions: Effects of Route Selection on Survival

We first describe the major routes through the Delta and examine findings on their relative survival. We then examine survival in different reaches of the various routes to explain any differences in route selection observed or the lack of anticipated differences. We then consider possible mechanisms linking migration route and survival.

Two primary migration routes through the Delta were examined for salmonids migrating from the San Joaquin River: the "San Joaquin River route" (Figure E.4-1) and the "Old River route" (Figure E.4-2), classified by route selection at the head of Old River. Migration through the CVP and SWP fish facilities is a component of both the Old River route and the San Joaquin River route (for fish that enter the Interior Delta at Turner Cut or downstream); the analysis of migration through the fish facilities is described separately in Section E.3 because of the unique operational and facility attributes that exist at those facilities. Within the San Joaquin River route, we also examined the use of Turner Cut, which diverts fish from the San Joaquin River to the Interior Delta. Because the San Joaquin River route includes the Interior Delta, the Old River and San Joaquin River migration routes encompass potentially overlapping migration regions. The primary differences in the routes are the upstream reaches, the proportion of fish actually entering the Interior Delta from the two routes, and the entry points to the Interior Delta.

It should be noted that migrating salmonids can also enter the Interior Delta through other junctions on the San Joaquin River downstream of Turner Cut (Columbia Cut, OMR, and False River; Figure E.2-2). We do not examine these other junctions here because there are no data on their use, but we recognize that they may be important entrances to the Interior Delta.

We first examined broad scale route-specific survival from the head of Old River junction through the Old River and San Joaquin River routes, then focused on reach-specific

information to better understand patterns of survival at a smaller spatial scale. Finally, we looked at the evidence to link route and reach survival to specific mechanisms.

For all routes, the outcome evaluated is survival, and conversely mortality. The linkages between migration route and survival are exposure to variables (e.g., habitat and predators) that affect survival between routes or between years for the same route (Figure E.1-1, Table E.1-1).

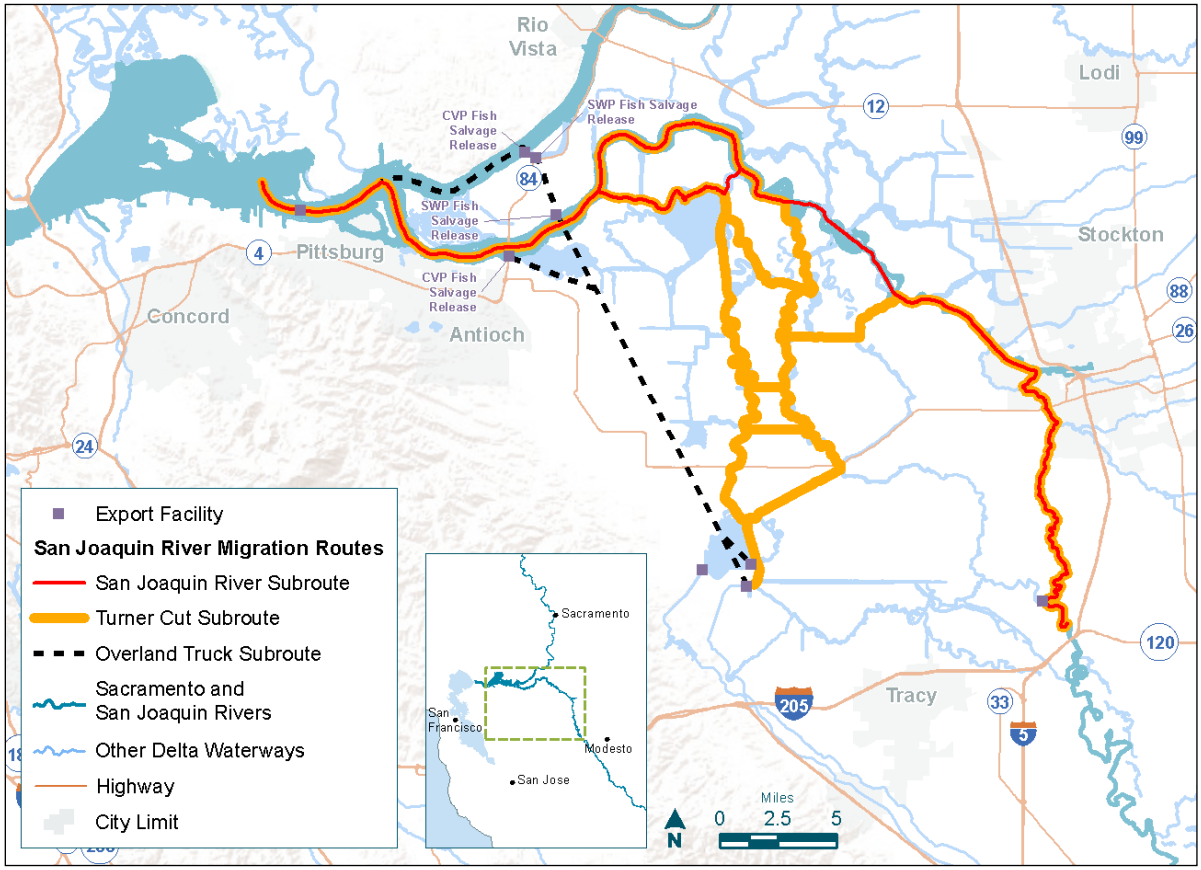

Figure E.4-1. Migration Routes to Chipps Island for Fish that Remain in the San Joaquin River at the Head of Old River ("San Joaquin River Route")

Note: Migration route of salvaged fish is shown as dashed line. The San Joaquin River mainstem sub-route is shaded in red, and the Turner Cut sub-route through the Interior Delta is shaded in orange.

E.4.2.1 Route Survival from Head of Old River Junction

Our basis of knowledge regarding how migration route selection at the head of Old River affects juvenile Chinook salmon through-Delta survival is low. Multiple field studies have collected Chinook salmon data on this question, and results have been presented in peer-reviewed publications, agency reports, and this report. However, the route from the head of Old River that produced the highest through-Delta survival has varied across and within years. Our basis of knowledge regarding migration route selection at the head of

Old River and juvenile steelhead through-Delta survival is low. A single multi-year field study has collected steelhead data on this question, and results are available in technical reports and in this report. The extent to which operations constrain the relationship between route selection at the head of Old River and through-Delta survival is not well understood.

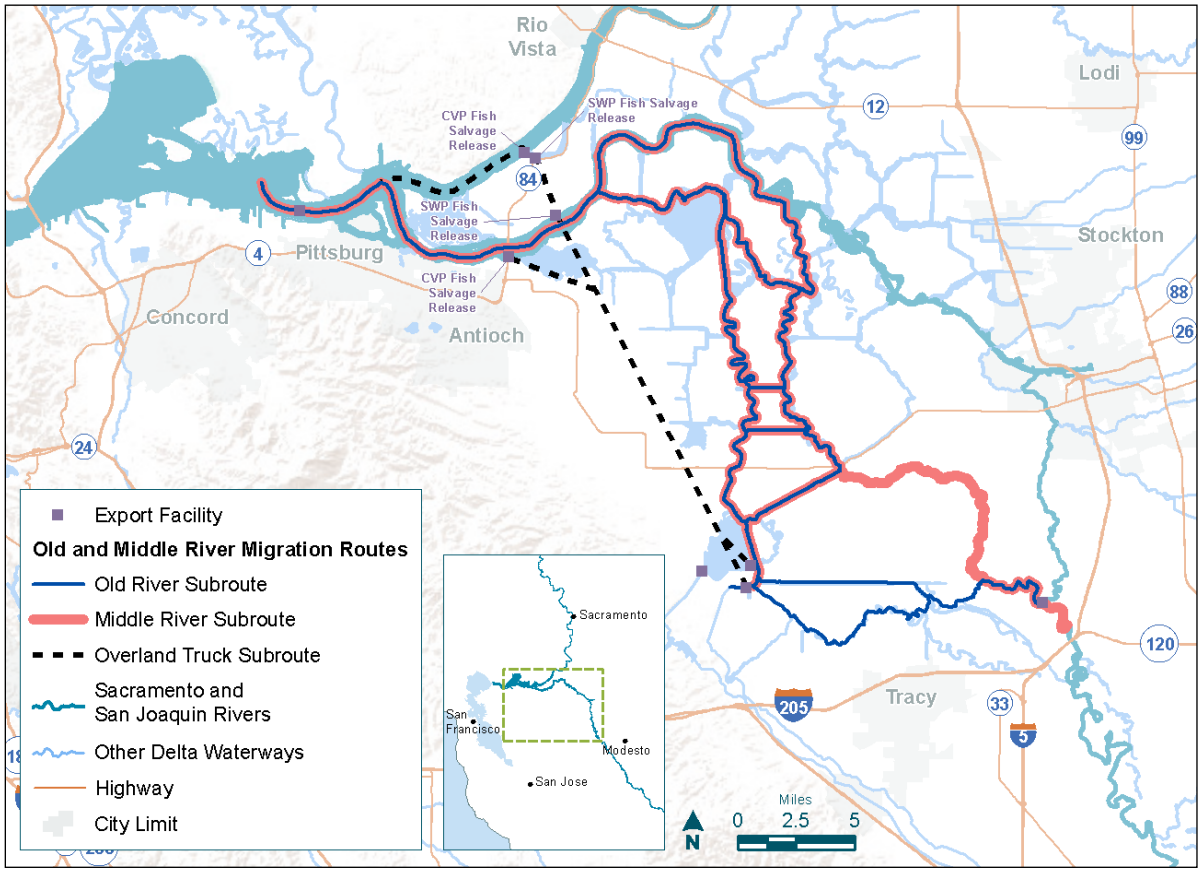

Figure E.4-2. Migration Routes to Chipps Island for Fish that Enter Old River at the Head of Old River ("Old River Route")

Note: Migration route of salvaged fish is shown as dashed line. The Old River sub-route is shaded blue, and the Middle River sub-route is shaded pink.

At the head of Old River, fish enter one of two routes. Fish may enter Old River and move into the Interior Delta or fish may remain in the San Joaquin River (Figure E.4-1, Figure E.4-2). Fish that remain in the San Joaquin River, however, may enter the Interior Delta further downstream (e.g., through Turner Cut, Columbia Cut and OMR, and False River; Figure E.2-1). In many years, a temporary physical barrier has been installed at the head of Old River to reduce the number of migrating salmon entering the Interior Delta at that river junction. In 2009 and 2010, an experimental non-physical barrier (bioacoustic fish fence) was tested in place of the physical barrier. In 2012, the physical barrier was installed (DWR 2015).

Measures of survival for fall-run Chinook salmon are available from CWT releases into Old River and at Dos Reis in 1985 to 1990 (Brandes and McLain 2001), and from acoustic-tagging studies in 2008 and 2010 to 2012 (Holbrook et al. 2009; SJRGA 2011, 2013; Buchanan et al. 2015). The relative survival to Chipps Island of Chinook salmon that entered Old River versus those that remained in the San Joaquin River route at the head of Old River has varied in these years. Survival indices (i.e., recovery rates expanded by sampling effort) to the Chipps Island trawl of CWT fish in 1985 to 1990 were generally greater for fish released at Dos Reis in the San Joaquin River compared to those released into upper Old River (Figure E.4-3; Brandes and McLain 2001; Newman 2008). There has been no consistent pattern among the AT data, and survival estimates have been similar (≤0.16) in both routes (Figure E.4-3, Table E.4-1).

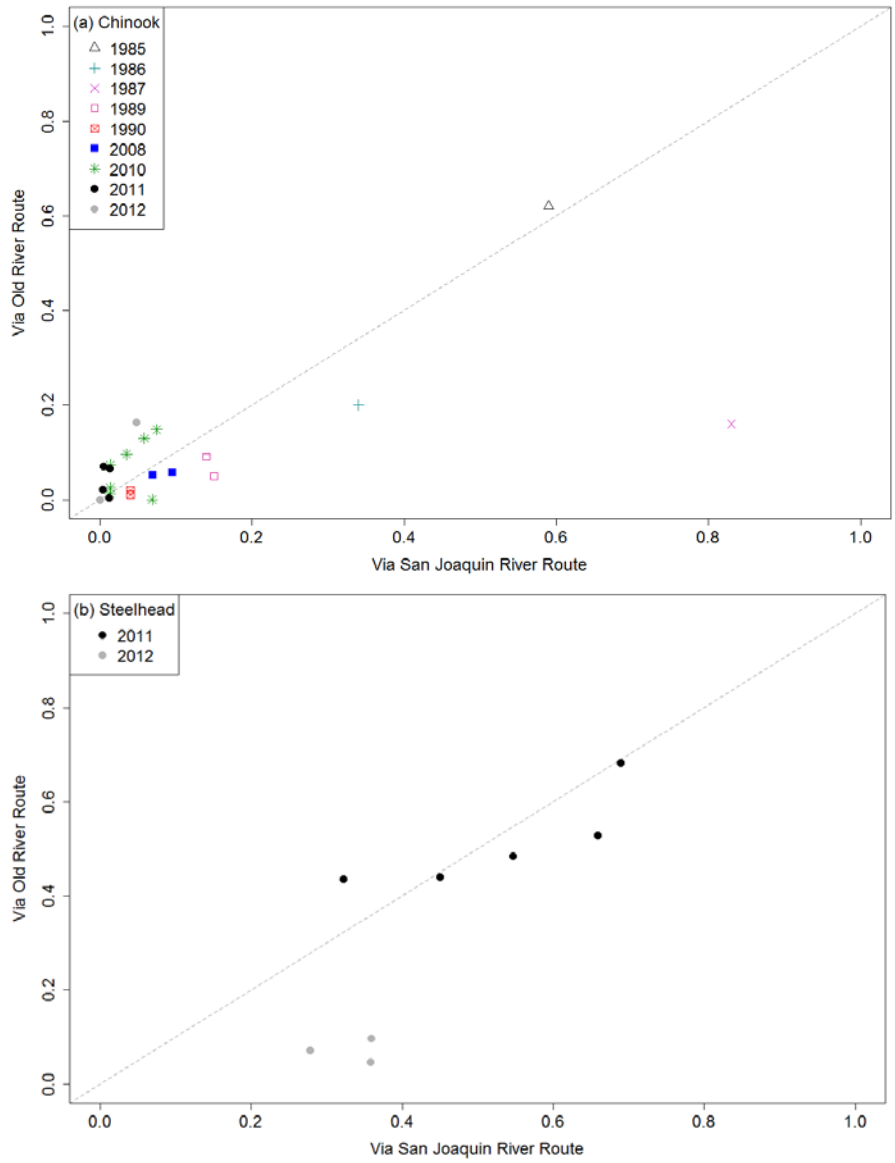

Figure E.4-3. Estimates of Route-specific Survival to Chipps Island via the Old River Route Versus the San Joaquin River Route, from CWT Salmon and AT Salmon (a) and Steelhead (b) Studies

Note: Chinook: Years 1985 – 1990 are CWT survival indices (recoveries expanded by sampling effort) to Chipps Island from release in upper Old River or Dos Reis in the San Joaquin River; years 2008 – 2012 are AT survival estimates from Mossdale. Dashed line indicates equal survival between routes. Sources: Brandes and McLain 2001; Holbrook et al. 2009; SJRGA 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

Table E.4-1. Entrainment Rates and Route Specific Survival to Chipps Island for Acoustic-tagged Fall-run Chinook and Steelhead Released in the San Joaquin River

Species	Year	Number of Release Groups	Entrainment into Old River (SE)	Survival through South Delta[2] (SE)	Route-Specific Survival to Chipps: San Joaquin	Route-Specific Survival to Chipps: Old River
Fall-run Chinook	2008[1]	2	0.66 (0.03)	NA	0.08 (0.01)	0.06 (0.01)
	2009	3	0.53 (0.03)	0.06 (0.01)	NA	NA
	2010	7	0.53 (0.02)	0.56 (0.03)	0.04 (0.01)	0.07 (0.01)
	2011	4	0.42 (0.01)	0.56 (0.01)	0.01 (less than0.01)	0.04 (0.01)
	2012	2	0.02 (0.01)	0.23 (0.02) (SJR route)	0.03 (0.01)	0.11 (0.10)
Steelhead	2011	5	0.49 (0.02)	0.81 (0.01)	0.55 (0.02)	0.52 (0.02)
	2012	3	0.06 (0.01)	0.81 (0.02)	0.33 (0.02)	0.07 (0.03)

Notes: 1 = Minimum estimates of survival due to high tag failure. 2 = "South Delta" = from Mossdale to either the Turner Cut junction in the San Joaquin River or the water export facilities, or Highway 4 on OMR. Sources: Holbrook et al. 2009; SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

In 1985 to 1990 (CWT survival indices), the Chinook salmon survival index to Chipps Island was greater for the San Joaquin River release than for the Old River release for all but one release group (Figure E.4-3); no barrier was installed in these years (Brandes and McLain 2001). In 2008 (no barrier), acoustic-tagged Chinook salmon that remained in the San Joaquin River at the head of Old River had higher apparent survival than fish that entered Old River, although fish mortality was confounded with a high rate of premature tag failure (Holbrook et al. 2009) and there was no predator filter applied that year. In 2010 (non-physical barrier), the relative survival of Chinook salmon in the San Joaquin River route versus those that took the Old River route varied throughout the study: only the first release group had significant differences between routes, with higher survival in the San Joaquin River, but when pooled across all releases, fish that took the Old River route had higher survival (SJRGA 2011). In 2011 (no barrier), survival to Chipps Island was consistently low, but was higher (less than 0.05) for the Old River route than for the San Joaquin River route for the two groups released during higher export levels. There were no significant differences between routes for the other individual release groups in 2010 or 2011 (SJRGA 2013). In 2012 (physical barrier), survival was not significantly different for fish that remained in Old River, but very few (ten) fish migrated through that route, increasing the uncertainty in the estimate (Buchanan et al. 2015).

Acoustic telemetry studies using juvenile steelhead began in 2011 as part of the six-year study, and results are available from the 2011 and 2012 studies (Buchanan 2013, 2014). In 2011 (no barrier), route-specific survival to Chipps Island varied throughout the study, and survival depended significantly on route for only one of five release groups; for this group, survival was higher in the San Joaquin River route. Averaged over all release groups, there was no statistical difference in survival between routes. In 2012 (physical barrier), survival was consistently higher in the San Joaquin River route than in the Old River route (Figure E.4-3, Table E.4-1; Buchanan 2013, 2014).

A comprehensive analysis of the existing acoustic telemetry data from fall Chinook salmon and steelhead that combines data from multiple years has not been performed. However, work to examine multiple years of AT data from fall Chinook salmon is underway (R. Buchanan, personal communication). Similar work is planned for steelhead as part of the six-year study, but requires more individual years of acoustic telemetry data than are currently available (J. Israel, USBR, personal communication).

E.4.2.2 Route Survival from Turner Cut Junction

Our basis of knowledge regarding migration route selection at the Turner Cut junction and survival to Chipps Island is low. Several years of field studies have collected data relevant to this question for both Chinook salmon and steelhead, and results are presented in this report. The extent to which operations constrain the relationship between migration route selection at the Turner Cut junction and through-Delta survival is not well understood.

Turner Cut connects the Interior Delta with the San Joaquin River from approximately 10 km downstream of the city of Stockton, California (Figures E.2-1 and E.2-2). Fish entering the Interior Delta at Turner Cut may either eventually turn north and navigate out of the Delta through the Delta channels, or they may turn south and enter the water export facilities, where they may be salvaged and trucked to a release point just upstream of the Delta exit at Chipps Island (Figure E.4-1). Mortality occurs along all portions of all routes. Fish that remain in the San Joaquin River at Turner Cut may either continue to Chipps Island via the San Joaquin River, or they may enter the Interior Delta from downstream entrance points (Columbia Cut, OMR, or False River). Estimates of survival from the Turner Cut junction to Chipps Island via these two major routes are available from acoustic-tagged studies in 2008 and 2010 to 2012 for Chinook salmon (Holbrook et al. 2009; SJRGA 2011, 2013; Buchanan et al. 2015) and 2011 to 2012 for steelhead (Buchanan 2013, 2014).

For Chinook salmon, estimated survival to Chipps Island in the Turner Cut route was 0 for all but one release group; the only fish observed successfully moving from Turner Cut to Chipps Island passed through the CVP holding tank in 2008 (Holbrook et al. 2009). Survival from the Turner Cut junction to Chipps Island in the San Joaquin River route was

consistently higher except for one release group from 2012, when survival was 0 in both routes (Figure E.4-4a); however, survival to the Turner Cut junction was very low for that release group, and there were very few fish available for estimating survival downstream of that junction. For steelhead, estimated survival to Chipps Island was positive in both routes for all release groups, but survival was consistently higher for fish that stayed in the San Joaquin River at the Turner Cut junction (Figure E.4-4b).

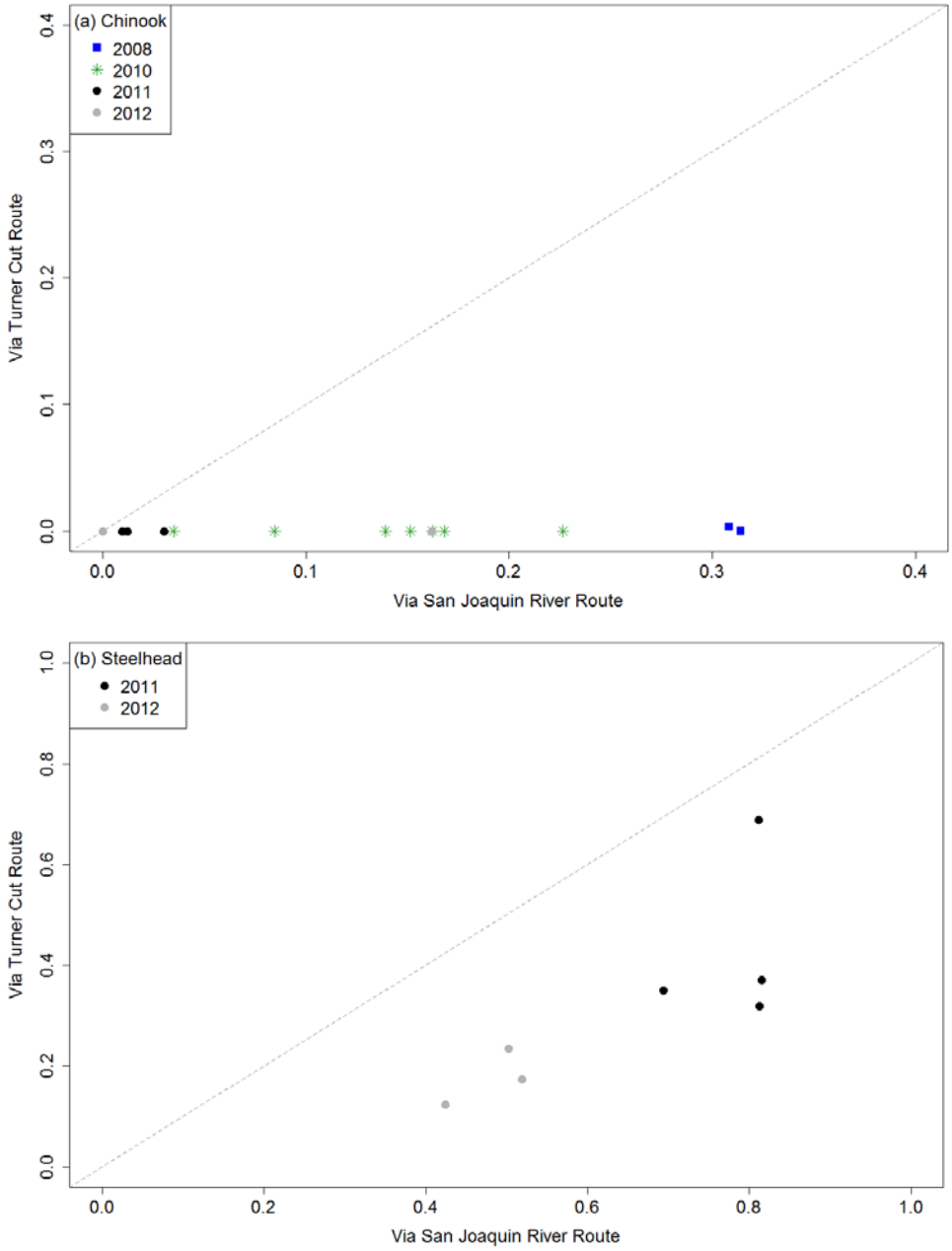

Figure E.4-4. Estimates of Route-specific Survival from Turner Cut Junction to Chipps Island via the Turner Cut Route Versus the San Joaquin River Route, from AT Salmon (a) and Steelhead (b) Studies

Sources: Holbrook et al. 2009; SJRGA 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.
Notes: Dashed line indicates equal survival between routes.

The impact on through-Delta survival of the typically low probability of survival to Chipps Island for fish that enter the Turner Cut route depends on the proportion of migrating fish that enter Turner Cut. For AT fall-run Chinook salmon that survived to the Turner Cut junction in the 2008 to 2012 San Joaquin River tagging studies, the estimated probability of entering Turner Cut ranged from 0 for two release groups in 2009 and one group in 2010, to 0.32 (SE=0.05) for one release group in 2008 (mean = 0.12, SE=0.02) (Holbrook et al. 2009; SJRGA 2011, 2013; Buchanan et al. 2015). Thus, for Chinook salmon that remain in the San Joaquin River past the head of Old River, the expected impact of the very low survival expected in the Turner Cut route is variable but expected to be fairly low. For acoustic-tagged steelhead from the first two years of the six-year study, the probability of entering Turner Cut (for fish that survived to the Turner Cut junction) ranged from 0.09 (SE=0.02) for one release group in 2011, to 0.37 (SE=0.04) for a single release group in 2012 (mean = 0.26, SE=0.03) (Buchanan 2013, 2014). Overall, it appears that steelhead are more likely than Chinook salmon to enter Turner Cut, and that they are more likely to successfully reach Chipps Island after entering Turner Cut (no formal testing has been done).

The full impact of low survival in the Turner Cut route depends not only on route selection probabilities at the Turner Cut junction, but also on route selection probabilities at all other river junctions along the San Joaquin River migration route: head of Old River, Columbia Cut, and the downstream confluence of the San Joaquin River with OMR. The effectiveness of blocking the Turner Cut route will depend on how that action changes route selection probabilities at downstream junctions (e.g., Columbia Cut). Also pertinent are the relative survival probabilities in those alternative routes; if survival is very low in all routes, then improvements to survival in the Turner Cut route will have minimal effect on overall survival through the Delta. A formal sensitivity analysis of through-Delta survival to either the probability of entering Turner Cut or the low survival once in Turner Cut has not yet been performed for either Chinook salmon or steelhead, although such analysis is planned (R. Buchanan, personal communication). Nevertheless, despite the uncertainty, a tentative conclusion is that the increase in overall Delta survival resulting from either improving survival in the Turner Cut route or else blocking salmon from entering Turner Cut is expected to be small, and will likely be insufficient to raise Delta survival rates to desired levels without additional improvements in survival elsewhere in the Delta.

E.4.2.3 Route Survival within Interior Delta

Our basis of knowledge regarding route selection and route-specific survival within the Interior Delta is minimal. Few studies have attempted to measure route selection or route-specific survival within the Interior Delta; the single study found was published in an agency report. The extent to which operations constrain the relationship between route selection in the Interior Delta and survival in the Interior Delta is not well understood.

The complexity of the channels in the Interior Delta and the strong tidal influence in this region has prevented robust estimation of route selection and route-specific survival in the Interior Delta. The AT Chinook salmon studies and the six-year steelhead study estimate the probability of successfully moving from one location in the Interior Delta to another (e.g., from Turner Cut to the CCF), but do not attempt to separate the probability of dying along a particular route from the probability of selecting an alternative route (SJRGA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015). Survival estimates are available from some locations in the Interior Delta to Chipps Island from these AT studies (see "Reach Survival" below). The 2012 steelhead stipulation study measured route selection at the junction of Railroad Cut with Old River but did not measure route-specific survival from that junction to Chipps Island (Delaney et al. 2014).

E.4.2.4 Reach Survival

Our basis of knowledge regarding differential survival in various river reaches and regions of the South Delta is medium. Several years of field studies have collected data relevant to this question for both Chinook salmon and steelhead; individual year results are presented in technical reports and peer-reviewed literature, and data compilations across multiple years are presented in this report. The extent to which operations constrain differential survival in various river reaches and regions of the Delta is not well understood.

We next examined survival rates at the reach scale for Chinook salmon and steelhead in the San Joaquin River and Old River to see how specific reaches contribute to route-specific survival. The examination used reaches and subreaches that generally corresponded with landmarks from previous studies and important junction locations within the Interior Delta, including the head of Old River, Lathrop, and the Turner Cut junction (Figure E.2-2). For the San Joaquin River route, these reaches were: 1) Lathrop to Stockton Deep Water Ship Channel (SDWSC); 2) SDWSC to Turner Cut; and 3) Turner Cut to Chipps Island. The breakdown of estimated survival rate per kilometer within reaches and subreaches is presented in Table E.4-2, Figure E.4-5, and Figure E.4-6 for years with data available. The Old River reaches included parts of Old River, Middle River, Grant Line Canal, and the fish facilities, as described in Section 4.2.2.2.

Table E.4-2. Heat Map Depicting Survival Rates ($S^{(1/km)}$) Through San Joaquin River Reaches to Chipps Island

	Survival estimate per km ($S^{(1/km)}$)						
	Chinook					Steelhead	
Reach Name (km)	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 SJR at Garwood Bridge (18/15)	0.986	0.971	0.989	0.993	0.980	0.995	0.997

Reach Name (km)	Survival estimate per km ($S^{(1/km)}$)						
	Chinook					Steelhead	
	2008	2009	2010	2011	2012	2011	2012
Garwood Bridge to SDWSC (3)	0.955	0.921	0.983	0.980	0.936	0.993	0.990
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 SJR) (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: Red boxes indicate lowest survival rate (less than 0.90 per km) and lighter boxes indicate higher survival rate (white: ≥ 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.

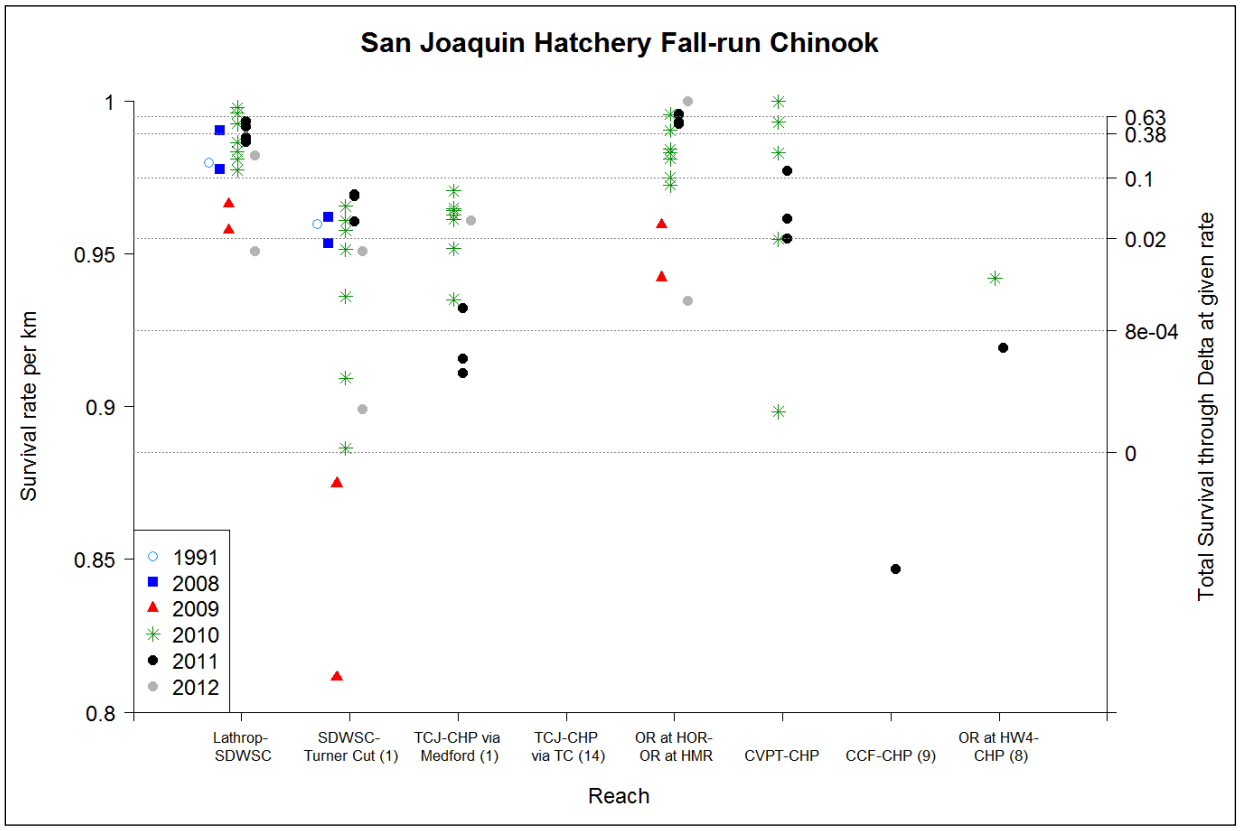

Figure E.4-5. Estimated Survival Rate ($S^{(1/km)}$) by Reach for Acoustic-tagged Fall-run Chinook Salmon in the VAMP Studies, and CWT fall-run Chinook Salmon in 1991

Sources: Brandes and McLain 2001; Holbrook et al. 2009; SJRGA 2010, 2011, 2013; Buchanan et al. 2015.
Notes: Total Survival through Delta assumes a travel distance of 91 rkm. Reach labels: Numbers in parentheses = number of releases with survival estimate of 0. SDWSC = Stockton Deep Water Ship Channel; TCJ = Turner Cut junction; CHP = Chipps Island; OR = Old River; HOR = Head of Old River; HMR = Head of Middle River; CVPT = Central Valley Project Tank; CCF = Clifton Court Forebay (just inside entrance gates), HW4 = Highway 4.

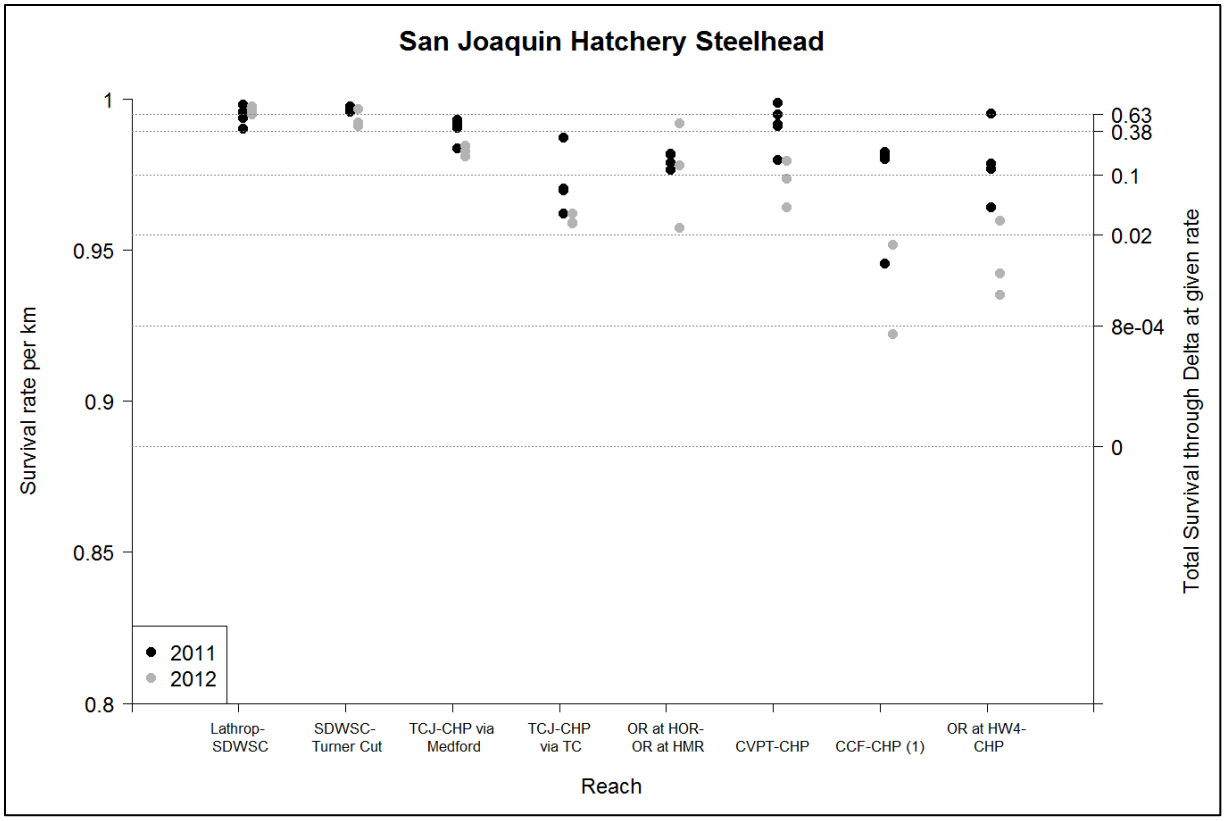

Figure E.4-6. Estimated Survival Rate ($S^{(1/km)}$) by Reach for Acoustic-tagged Steelhead in the 2011 and 2012 6-year Study

Notes: Total Survival through Delta assumes a travel distance of 91 rkm. Reach labels: Numbers in parentheses = number of releases with survival estimate of 0. SDWSC = Stockton Deep Water Ship Channel; TCJ = Turner Cut junction; CHP = Chipps Island; OR = Old River; HOR = Head of Old River; HMR = Head of Middle River; CVPT= Central Valley Project Tank; CCF = Clifton Court Forebay (just inside entrance gates), HW4 = Highway 4. Source: Buchanan 2013, 2014.

San Joaquin River Reaches

Survival rates per kilometer in San Joaquin River reaches tended to be higher in the upstream reaches, although there was considerable variability between years and species (Table E.4-2). Figure E.4-7 shows an illustration of survival rate estimates for Chinook salmon in 2011, in which survival rate tended to decrease as the population of tagged fish moved downriver. Survival from the Turner Cut junction through both the Interior Delta and the San Joaquin River mainstem was very low in 2011 (Figure E.4-7). Over all common reaches and study years, survival rates tended to be higher for steelhead than for Chinook salmon, although Chinook salmon had higher survival rates in some upstream reaches (Table E.4-2).

Lathrop to SDWSC: The reach of the San Joaquin River between Lathrop, located just downstream of the head of Old River, and the upstream entrance of the SDWSC just past the Navy Bridge toward the downstream end of Stockton, typically includes the transition zone

between riverine (unidirectional flow) habitat and tidal (bidirectional flow) habitat (Figure E.2-2). In low flow years, the transition point between riverine and tidal habitat occurs in the upstream region of this reach, near the head of Old River. In high flow years, the transition point occurs toward the downstream end, close to the SDWSC.

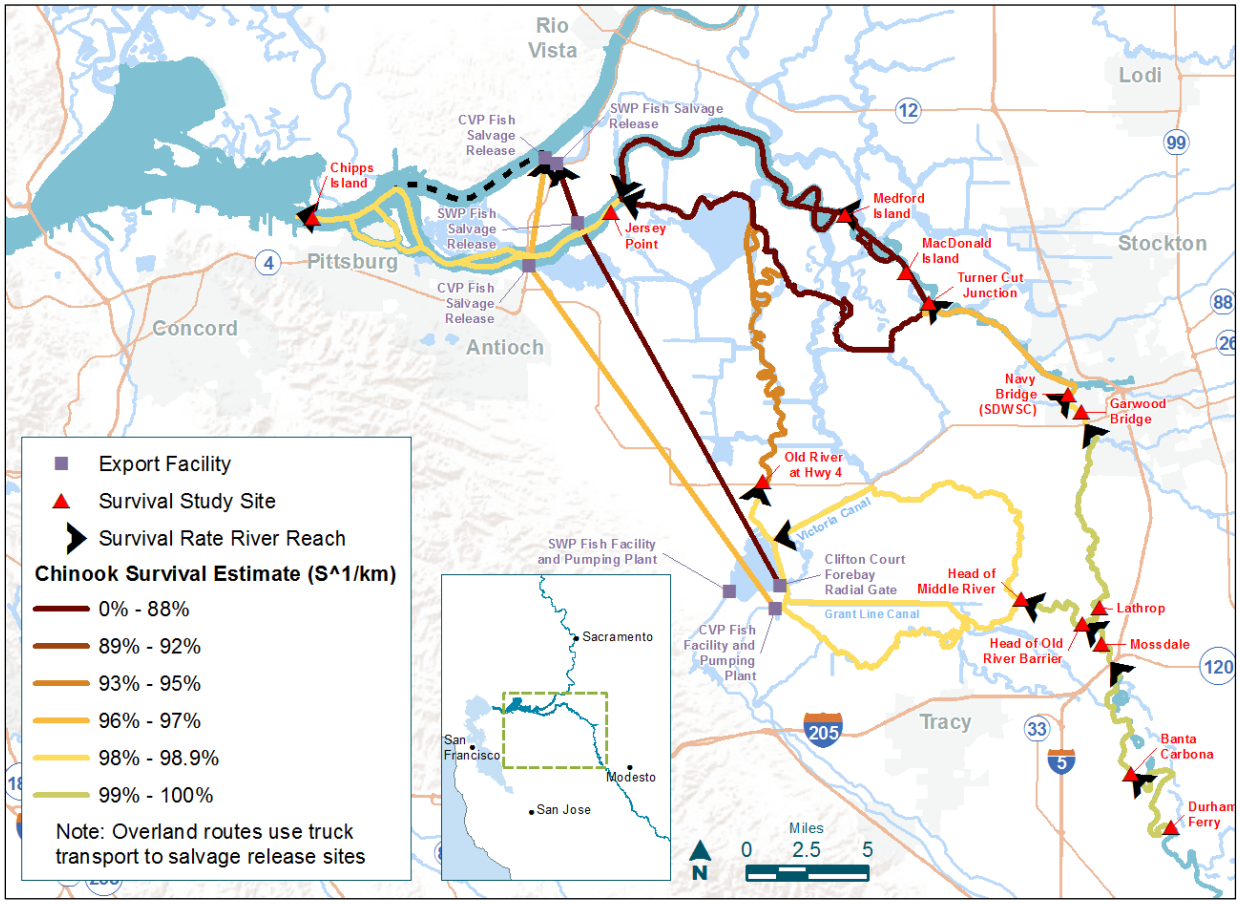

Figure E.4-7. Geographical Illustration of Heat Map Survival Rate (per kilometer) Estimates for 2011 Chinook Salmon

Note: See Table E.4-2 and Table E.4-3 for complete results from all years and species.

Salmonid survival in this reach (Lathrop to SDWSC) has been estimated directly using ATs for Merced River hatchery fall-run Chinook salmon in four years (2008 and 2010 to 2012) and for Mokelumne River hatchery steelhead in two years (2011 and 2012) (Holbrook et al. 2009; SJRGA2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015). Estimates are available from 2009 for acoustic-tagged fall/spring-run hybrid Chinook salmon from the Feather River hatchery (SJRGA 2010). Data from additional years of study have yet to be completely analyzed. An indirect estimate of survival is available for 1991 from CWT data using hatchery fish from Feather River hatchery. These six years of data show that survival tends to be higher in this reach than in reaches farther downstream, on a per-kilometer basis, but that it varies considerably within and between years (Figure E.4-5 and Figure E.4-6).

SDWSC to Turner Cut: The reach of the San Joaquin River from the upstream end of the SDWSC to the Turner Cut junction is tidal, and considerably wider and deeper than the reach from Lathrop to the SDWSC. The reach is 15 km long, and at the downstream end of the reach is an entrance to the Interior Delta (Turner Cut) (Figure E.2-2).

AT studies of fall-run Chinook salmon (Holbrook et al. 2009; SJRGA 2010, 2011, 2013; Buchanan et al. 2015) and steelhead (Buchanan 2013, 2014) have measured survival through this reach during the spring outmigration. One year of CWT data (1991) also provided a survival estimate through this approximate reach, using a paired release in Stockton and at Empire Cut, approximately 20 km downstream of Turner Cut.

Survival probability estimates for fall-run Chinook salmon for this reach were consistently lower than survival estimates for the same release groups in the preceding reach (Lathrop to SDWSC; Figure E.4-5). The average survival probability estimated for fall-run Chinook salmon between 2009 and 2011 ranged from 0.06 (2009) to approximately 0.60 (2011). The two years (2011, 2012) of steelhead data available, however, show comparable survival estimates between this reach and the upstream reach (Figure E.4-6). Steelhead survival probability estimates in this reach averaged 0.96 in 2011 (Buchanan 2013) and 0.91 in 2012 (Buchanan 2014).

Turner Cut junction to Chipps Island: Survival of fish on the San Joaquin River mainstem between the Turner Cut junction and Chipps Island (Figure E.2-2) is among the lowest for both Chinook salmon and steelhead (Turner Cut junction to Chipps Island via Medford in Figures E.4-5 and E.4-6), but it appears better than migrating into Turner Cut (Turner Cut junction to Chipps Island via Turner Cut in Figures E.4-5 and E.4-6). Chinook salmon acoustic telemetry data strongly suggest that migrating into Turner Cut results in poorer survival to Chipps Island, compared to remaining in the San Joaquin River at Turner Cut. Results in 2010, 2011, and 2012 indicate that none of the 13%, 21%, or 11% of the Chinook salmon estimated to have migrated into Turner Cut in those three years, respectively, 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 fish that remained in the San Joaquin River at Turner Cut was estimated at 0.14, 0.02, and 0.14 (SE≤0.04) for these three years, respectively (SJRGA 2011, 2013; Buchanan et al. 2015).

The acoustic telemetry study of juvenile steelhead that was part of the 2012 stipulation study found that survival to Chipps Island was lower for steelhead that entered Turner Cut than for steelhead that remained in the San Joaquin River. Specifically, the study reported the route-specific survival probability to Chipps Island via Turner Cut was 0.270 (SE=0.03), and was 0.567 (SE=0.024) to Chipps Island for fish that did not use Turner Cut (Delaney et al. 2014). A similar pattern was observed in the first two years of the six-year study of acoustic-tagged steelhead: in 2011 and 2012, respectively, the estimated probability of surviving from

the Turner Cut junction to Chipps Island was 0.43 and 0.18 (SE≤0.05) for fish that entered Turner Cut, compared to 0.78 and 0.49 (SE≤0.03) for fish that remained in the San Joaquin River (Buchanan 2013, 2014). This suggested that staying in the San Joaquin River at Turner Cut was beneficial for steelhead, as well as Chinook salmon. Some of the steelhead that entered Turner Cut and survived to Chipps Island were observed passing through the salvage facility at CVP or entering the CCF after leaving Turner Cut in both 2011 and 2012; however, these were a minority (44% and 28% in 2011 and 2012, respectively) of those that survived to Chipps Island from Turner Cut (Buchanan 2013, 2014).

Old River Reaches

Reaches within the Old River route are typically narrower and shallower than the San Joaquin River reaches, and in some cases completely lack sinuosity (e.g., Grant Line Canal) (Figure E.2-2). The higher water temperatures typical of shallower water and the lack of channel complexity that may accompany a lack of sinuosity suggest that reaches in the Old River would have lower survival than reaches in the San Joaquin River. It may also be expected that the reaches without sinuosity (Grant Line Canal) will have lower survival among the Old River reaches than those with a more natural construction (e.g., Old River north of the water export facilities).

Reaches evaluated in the Old River migration route are identified in Table E.4-3, and include the head of Old River to the head of Middle River, the head of Middle River to the entrances to the water facilities or Highway 4, Old River near Highway 4 to Jersey Point or Chipps Island, and the CVP holding tank or CCF radial gates to Chipps Island (Figure E.2-2). Survival rates per kilometer were often higher in the most upstream reach (Old River from its head to the head of Middle River), but there is considerable variability between years (Table E.4-3). Survival rates for reaches leading to or bypassing the fish facilities (i.e., not passing through the facilities) were generally comparable to those observed in the San Joaquin River (Tables E.4-2 and E.4-3) for both Chinook and steelhead for years in which estimates were available. However, survival estimates are missing for some reaches and Chinook salmon release groups, either because the study design did not allow for survival estimation in the reach (e.g., survival to Jersey Point or Chipps Island in 2009; Table E.4-3) 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 E.4-3). The survival rates for fish passing the radial gates into the CCF were consistently low compared to other reaches for Chinook and steelhead (Table E.4-3). 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 was sometimes higher than survival through the lower San Joaquin River reaches (Tables E.4-2 and E.4-3). Figure E.4-7 shows an illustration of survival rate estimates for Chinook salmon in 2011, in which it is apparent that the survival rate from the salvage

tank at the CVP was considerably higher than in many downstream reaches, while the survival rate through the CCF and SWP salvage was the lowest of all Old River reaches for Chinook salmon in that year.

Table E.4-3. Heat Map Depicting Survival Rates ($S^{(1/km)}$) through Old River Reaches to Chipps Island

Reach Name/(km)	Survival Estimate per km ($S^{(1/km)}$)						
	Chinook					Steelhead	
	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

Note: Red boxes indicate lowest survival rate (less than 0.90 per km) and lighter boxes indicate higher survival rate (white: ≥ 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.

Old River at its Head to Head of Middle River: The reach of the Old River from its head to the head of Middle River is approximately 6 km long, and tended to have survival rates that were similar for the upstream San Joaquin River reach for Chinook salmon (Figures E.2-2 and E.4-5). For steelhead, survival rates in this Old River reach tended to be lower than for the upstream San Joaquin River reaches (Figure E.4-6). Annual survival estimates in this reach ranged from 0.67 to 1.00 for Chinook salmon, and 0.77 to 0.95 for steelhead (SJRGA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015).

Old River at Highway 4 to Chipps Island: The reach from Old River at Highway 4 to Chipps Island includes the lower Old River and the lower San Joaquin River between Jersey Point and Chipps Island, and potentially the lower Middle River, Frank's Tract, and False River (Figure E.2-2). Although fish may also move from Highway 4 to Chipps Island via the facilities, the estimates shown in Figures E.4-5 and E.4-6 represent only the in-river migration route, and exclude the facility routes.

In the Chinook salmon AT studies, survival from Old River at Highway 4 to Chipps Island was estimated at 0 for eight of ten release groups. The two positive survival rate estimates were comparable to survival estimates in the San Joaquin River from Turner Cut junction to Chipps Island (Figure E.4-5). For steelhead, survival rates in this reach were generally higher than for Chinook, but demonstrated considerable variability between years and among release groups within years (Figure E.4-6).

E.4.2.5 Linkages Between Migration Route and Survival

Although data for migration route and survival both exist, the specific mechanisms linking migration route to survival are poorly understood for these routes, apart from the fish facilities. The primary mechanisms linking route with survival in the conceptual model are predation and entrainment in the fish facilities. Entrainment is considered in Section E.3. Predation and the possible migration route characteristics associated with predation are considered here.

Our basis of knowledge regarding migration route characteristics and route-specific survival is minimal. The extent to which operations constrain the relationship between migration route characteristics and route-specific survival is not well understood.

In general, predation is hypothesized to represent a potentially high risk for salmonids within the South Delta (Grossman et al. 2013; Hayes et al. 2015; Demetras et al. 2016) and is identified as a threat to ESA-listed winter-run Chinook salmon, spring-run Chinook salmon, and steelhead (NMFS 2014). However, most evidence for the magnitude of predation and specific habitat factors influencing interactions among predators and salmonids is circumstantial or indirect. Predators are clearly abundant throughout the Delta (e.g., Moyle 2002; Nobriga and Feyrer 2007; Hayes et al. 2015); nevertheless, many of the reaches in which salmonid survival is measured (and ostensibly linked to predation) lack site-specific data for predation pressure specifically on salmonids, predator abundance, predator community composition, and evaluations of habitat conditions that might influence predator effectiveness. Thus, the supporting evidence for the influence of predation on route-specific survival is mostly indirect, using ecological principles and relationships observed in general or for salmonids in particular, but from elsewhere in the Delta or in other river systems.

A recent predation study by the National Marine Fisheries Service (NMFS) explored the community of predatory fishes, predator movements, and salmonid predation pressure in the San Joaquin River between Mossdale Bridge and the SDWSC; preliminary results found differences in predator density and site fidelity in different reaches of the river, and more predators in the reach that includes the head of Old River than further downstream (Hayes et al. 2015). Striped bass and largemouth bass were most prevalent, although genetic testing of stomach contents suggested more targeted predation of salmonids by channel catfish than by either of the bass species; analysis is ongoing (Hayes et al. 2015).

Aside from the new NMFS study of predation, much of the evidence of assumed predation is based on interpretation of data from ATs implanted in migrating salmonids in specific reaches of the San Joaquin River and Old River. In particular, the observation of motionless tags or tags that exhibit unusual tracking patterns may indicate that a predation event has occurred (Table E.4-4); however, predator behavior and smolt behavior can overlap

(C. Karp, personal communication) and motionless tags indicate only mortality, not that the mortality occurred from predation.

Table E.4-4. Results of Mobile AT Monitoring Showing Locations of Stationary Tags, Which May Be the Result of Predation Mortality

Year	Mobile Tracking Region in SJR*	Hot Spots from VAMP
2007	Head of Old River to SDWSC	Railroad bridge, just upstream from Stockton Waste Water Treatment Plant
2009	Head of Old River to SDWSC	Throughout Lathrop to Stockton, especially toward upstream end; channel bends, scour holes, pump stations
2010	Head of Old River to Turner Cut	Primarily in Stockton DWSC; of those between HOR and SDWSC, about 56% between HOR and Stockton, and 44% between Stockton and DWSC (shorter reach, so higher concentrations in Stockton than upstream)
2011	Head of Old River to Turner Cut	SDWSC near Turner Cut, and close to Stockton; evenly distributed through reach between HOR and SDWSC

** = mobile tracking typically included regions upstream of the Head of Old River and regions in Old River and near the export facilities, as well. See Figure E.2-2 for site locations.*
Source: SJRGA 2011.

Within the Delta, habitat that has been hypothesized to attract predators includes scour holes and structures such as bridges (Vogel 2010). The Mossdale Bridge crosses the San Joaquin River upstream of the head of Old River; there are five bridges that cross the San Joaquin River in or near Stockton, California, including Highway 4 and a railroad bridge just upstream of the Stockton Waste Water Treatment Plant. Scour holes are often found at river bends, in particular if the shoreline is covered with riprap. Vogel (2010) found immobile ATs from juvenile Chinook salmon deposited in channel bends and scour holes, and near pumping stations in the reach from Lathrop to the SDWSC in 2009. This stretch of river has several bends compared to regions downstream, especially toward the upstream portion of the reach. Additionally, there is a large scour hole just upstream of Lathrop, at the head of Old River, thought to be a predator hot spot (Vogel 2010).

The Stockton area appears to be a region where concentrations of non-moving tags are found, and may be an area of high predation, based on the mobile acoustic telemetry surveys. The Stockton Waste Water Treatment Plant has an outfall toward the southern end of the city. It has been hypothesized that the changes in water chemistry or temperature in this region either attract predators or else affect smolt ability to evade predation, or result in death of smolts due to exposure to toxics or high ammonia levels. In 2007, when many salmon ATs were detected in this region, a subsequent investigation determined that the waste water treatment plant had higher levels of certain constituents downstream of the waste water discharge than upstream when measured the following spring (SJRGA 2009), but had been in compliance with discharge permit requirements during the 2007 VAMP study (SJRGA 2008). In 2010, a predator-tagging study tagged several striped bass and largemouth

bass caught in the Stockton area with ATs and monitored their movements using fixed site receivers (Vogel 2011). Individuals of both species that were tagged in Stockton were observed to either remain there or return there after moving elsewhere, suggesting that this region provides favorable habitat for some predators. However, other individuals (striped bass) left and did not return during the duration of the study (Vogel 2011). Preliminary results from acoustic tagging of predatory fish in 2014 and 2015 also showed variable site fidelity among striped bass, largemouth bass, channel catfish, and white catfish (Hayes et al. 2015).

Mobile telemetry surveys as part of the 2010 and 2011 VAMP studies covered the SDWSC to Turner Cut reach, and found a considerable number of immobile ATs (Table E.4-4). In 2010, mobile tracking found that the majority of immobile tags observed in the San Joaquin River between the head of Old River and Turner Cut were located in the SDWSC, but identified no hot spots (SJRGA 2011). In 2011, mobile tracking found a large number of immobile tags from Chinook salmon in the SDWSC within 2 miles of Turner Cut, and also toward the upstream portion of the reach near Stockton (SJRGA 2013; Table E.4-4). The large number of immobile tags from Chinook salmon found in the SDWSC in both 2010 and 2011, relative to the numbers found upstream of SDWSC in those years, is consistent with the observed pattern of estimated survival rates in those reaches: the estimated survival rate was lower from the entrance of the SDWSC to Turner Cut than from Lathrop to SDWSC in both years (Figure E.4-5, Table E.4-2). However, the higher concentration of immobile tags observed near Lathrop than in Stockton in 2009 is inconsistent with the lower survival rate observed between Garwood Bridge and SDWSC in 2009 (Tables E.4-2 and E.4-4).

Within the Interior Delta, mobile monitoring in 2011 identified a total of 162 Chinook salmon tags detected in Old River and Grant Line Canal between the head of Old River and the state and federal pumping facilities (SJRGA 2013). The highest concentration of the tags detected by mobile monitoring in this reach were detected in Grant Line Canal at 54%, while 29% were found in the vicinity of the state and federal pumping facilities, and the remaining 17% were detected in Old River upstream of Grant Line Canal. The number of tags detected in Grant Line Canal in 2011 was much higher than in previous years (SJRGA 2013) suggesting high numbers of predators in Grant Line Canal, or an increase in predator effectiveness possibly due to the lack of cover habitat in Grant Line Canal that year. Nevertheless, the 2011 survival rate estimate in the reach that includes Grant Line Canal was intermediate compared to 2009 and 2010 (Table E.4-3).

Additional understanding of how predation may influence survival in various reaches of the South Delta is based mostly on more general ecological principles or observations from elsewhere in the Delta. For instance, Cavallo et al. (2012) and Sabal (2014) both performed predator removal studies from elsewhere in the Delta, and observed that predator removal was followed by increased salmonid survival. However, Cavallo et al. (2012) also observed that salmonid survival quickly reverted to pre-manipulation levels. The 2014-2015 NMFS

predation study included a BACI (Before-After Control-Impact) predator removal experiment to assess the effect of moving predators from one reach to another on survival of juvenile salmonids; results are not yet available (Hayes et al. 2015).

The distribution and effectiveness of predators in the Delta depend on habitat features and water quality factors. For instance, invasive ambush predators such as largemouth bass have been observed favoring regions with high densities of submerged aquatic vegetation (SAV; Miranda et al. 2010), whereas poor water quality reflected by high concentrations of dissolved solids may block adult striped bass from migration further upstream (Radke 1966). Predation rate and predator effectiveness also depend on water quality. Metabolic rate is known to increase with warmer water temperatures (e.g., Brown et al. 2004); thus, channels with higher water temperatures, such as those with little riparian vegetation, may be expected to have higher predation rates and lower salmonid survival. Higher water temperatures may also lower salmonid survival by impairing their swimming ability (Hayes et al. 2015); water velocity and swimming depth are also associated with predation events (Hayes et al. 2015; Demetras et al. 2016). Lower survival is also expected in years with lower flows and higher temperatures, as anticipated during drought years and as a consequence of climate change. Riparian vegetation also provides protective cover for juvenile salmonids, so predation effectiveness is expected to be lower in regions with higher riparian vegetation (Tabor and Wurtsbaugh 1991). Turbidity may affect salmonid survival by limiting predator effectiveness; salmonid predators that rely on visual prey acquisition are more efficient in less turbid water (Gregory and Levings 1998). Finally, the rate of piscivory among the predator community has been observed to depend on both predator size and season. In particular, a study by Nobriga and Feyrer (2007) found that although striped bass, largemouth bass, and Sacramento pikeminnow were consistently collected from Medford Island, downstream of the Turner Cut junction, largemouth bass and Sacramento pikeminnow piscivory was mostly a function of predator size, whereas striped bass piscivory was a function of season and was most intense in summer and fall.

These findings suggest that salmon mortality due to predation may be strongly influenced by reach- or route-specific habitat conditions within the Delta. However, other linkages may exist between migration route and survival, reflecting the variability in habitat and water quality through the Delta; clear mechanistic relationships have not been evaluated in this analysis. Without additional survival studies that are specifically designed to address habitat and predator interactions on small and large spatial scales, the baseline of existing survival data has limited utility for identifying causal relationships between migration route and survival.

E.4.3 Summary: Knowledge Gaps on Migration Route

A variety of knowledge gaps exist regarding both the spatial use of the Delta by migrating juvenile salmonids and their survival in general, and how their survival in different regions is

affected by exports in particular. Additional information is needed about the following issues:

- Conditions that correlate with higher survival in the San Joaquin River route over the Old River route, or vice versa (e.g., head of Old River barrier [HORB], flow, export rate, temperature).
- Survival and route selection on various spatial and temporal scales
  - Survival on the scale of reaches and subreaches throughout the Delta, including the Interior Delta, on the same spatial and temporal scale as measures of habitat characteristics.
  - Survival in the lower reaches of the San Joaquin River, especially between Medford Island and Jersey Point, including through Frank's Tract.
  - Route selection at river junctions in San Joaquin River downstream of Turner Cut (i.e., Columbia Cut, the mouths of OMR, and False River).
  - Route use within the Interior Delta.
- Habitat characteristics and water quality on the reach-scale throughout the Delta
  - Predator communities and predator-friendly habitat structures in various regions of the Delta.
  - Water quality in various regions of the Delta.
  - Reach-specific habitat characteristics, and how these relate to juvenile salmonid and predator use of habitat (e.g., distribution of SAV, riparian vegetation, water quality measures).
- Nature of the relationship between salmonids and predators
  - Reach-specific and temporal characterizations of predator pressure on juvenile salmonids during the time period when juvenile salmon and steelhead are migrating through the reach.
  - Direct evidence of predation as a cause of mortality on a reach-specific level, including evidence of predation by either predatory fish or avian predators.
  - Potential of predator removal to affect juvenile salmonid survival in various reaches and on various spatial and temporal scales.
  - Effect of fish condition and species on predation risk.
- Extent to which water project operations drive changes in physical habitat, water quality, and species assemblages, and the extent to which these changes influence salmonid growth and survival
  - The potential of water project operations to affect the spatial and temporal composition of the ecological community in various reaches of the Delta, including SAV, predatory fish and avian predators, invertebrates, phytoplankton, and zooplankton.
  - The potential of water project operations to affect river channel geometry and riparian vegetation.
  - The potential of water project operations to affect water temperature and water quality gradients in various regions of the Delta.

- The potential of actions that support water project operations (e.g., levee maintenance, riprap installation on shorelines) to affect the Delta ecosystem.

A further knowledge gap has been identified regarding the incremental role of water project operations on juvenile salmonid survival in the Delta in relation to other factors, and the management actions needed to significantly increase juvenile survival from current levels. The SST believes that management actions beyond the current water project and related management actions are required to increase survival, including actions that address non-project-related stressors, but has not identified the specific mix of actions required. The necessary management actions are expected to involve water project exports as well as an integrated set of actions addressing flow, habitat, juvenile migration conditions, and other stressors such as predation and climate change, some of which are outside the scope of this analysis.

E.5 SURVIVAL AS A FUNCTION OF MIGRATION RATE

The conceptual model views migration rates as a driver of survival by varying the exposure of the migrating salmonid to either positive or negative conditions. Extended exposure to higher water temperatures may reduce fitness because of increased disease, or increase predation rate because of heightened metabolic rate of the predators. Independent of temperature, prolonged exposure to regions with higher predation risk is expected to increase the probability of mortality. It is also possible that a faster migration rate reduces growth opportunities of migrating salmonids in the Delta, resulting in smaller smolts that experience higher predation risks upon entry to estuarine and ocean environments after exiting the Delta (Muir et al. 2006). Although ocean survival is outside the scope of this report, the SST acknowledges it as an important element of assessing population-level effects of any management actions.

This section focuses on the hypothesis that a slower migration rate (longer travel time) through a reach results in increased mortality through the reach by increasing exposure to predation or poor habitat. The specific mechanism may be exposure to either a higher abundance of predators or to habitat that augments the efficiency of predators that are present, or a combination of both. Habitat that lowers the vitality of migrating salmonids is included in the latter. A further prediction is that the relationship between migration rate and survival varies with reach or region of the Delta.

E.5.1 SUMMARY: CONCEPTUAL MODEL PREDICTIONS ON SURVIVAL AS A FUNCTION OF MIGRATION RATE

The conceptual model predicts that fish with slower migration rates will have lower survival probabilities through the Delta. Evidence for this prediction is mixed.

- Research in the North Delta and lower Mokelumne River has observed this pattern (Perry et al. 2010; Cavallo et al. 2012).
- CWT Chinook salmon data from 1996 to 2006 showed no such pattern for survival from Mossdale to Chipps Island (data from Newman 2008; analysis by SST).
- Preliminary analysis by the SST of survival and travel time estimates from AT Chinook salmon in the South Delta observed this pattern for some reaches (Lathrop to SDWSC, Old River between the heads of Old and Middle rivers) but not for other reaches (e.g., Turner Cut junction to Chipps Island); conclusions could not be made for some reaches because of insufficient data (SJRGA 2010, 2011, 2013; Buchanan et al. 2015).
- Preliminary analysis by the SST of survival and travel time estimates from AT steelhead in the South Delta observed this pattern between Lathrop and SDWSC, SDWSC and the Turner Cut junction, and Turner Cut junction and Chipps Island, but not in Old River between the heads of Old and Middle rivers or between Highway 4 and Chipps Island (Buchanan 2013, 2014).

The conceptual model predicts that the relationship between migration rate and survival will vary for different reaches, and be stronger in more tidal reaches. Evidence for this prediction is mixed.

- Preliminary analysis of AT data by the SST found that the relationship between migration rate and survival varies between reaches (see above).
- There was little or no evidence that the relationship is stronger in more tidal reaches.

The conceptual model predicts that the relationship between migration rate and survival is due to increased exposure to predation.

- The XT predator-prey 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).
- Mechanisms (e.g., predation) relating mortality to migration rate have not been explored directly.

E.5.2 Findings on Conceptual Model Linkages and Predictions: Effects of Migration Rate on Survival

Our basis of knowledge of the linkages between migration rate and survival is high for Chinook salmon in the North Delta, low for Chinook salmon in the South Delta, and low for steelhead in the South Delta. Multiple field studies have collected data relevant to this question, and results have been published in peer-reviewed literature, agency reports, and this report. Low understanding is due to mixed results from these studies, and sparse data in some cases. Additional support comes from the ecological theory literature or other river systems. The extent to which operations constrain the effect of migration rates on survival is not well understood.

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; however, no effort was made to relate this finding directly to predator density (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. Finally, the XT predator-prey 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).

The majority of information pertaining to the South Delta comes from CWT and AT tagging studies, compiled and analyzed by the SST. We examined migration rates and survival in the San Joaquin River and Old River for the same reaches used in the examination of migration route on the reach scale (Section E.4.2.4) to better understand potential relationships. Reaches in the San Joaquin River examined include: 1) from Lathrop to the upstream entrance of the SDWSC; 2) from SDWSC to the Turner Cut junction; and 3) from Turner Cut junction to Chipps Island. Reaches in the Old River examined include: 1) between the heads of Old and Middle rivers; and 2) between Highway 4 and Chipps Island. Data come from acoustic telemetry studies of Chinook salmon and steelhead in the South Delta (Holbrook et al. 2009; SJRGA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015). 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 to 2006 (Newman 2008).

Migration rate (kilometers per day) 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 (Figure E.5-1; see Figure E.2-2 for site locations). 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, although too few Chinook salmon estimates were available for this reach to make comparisons (Figure E.5-1).

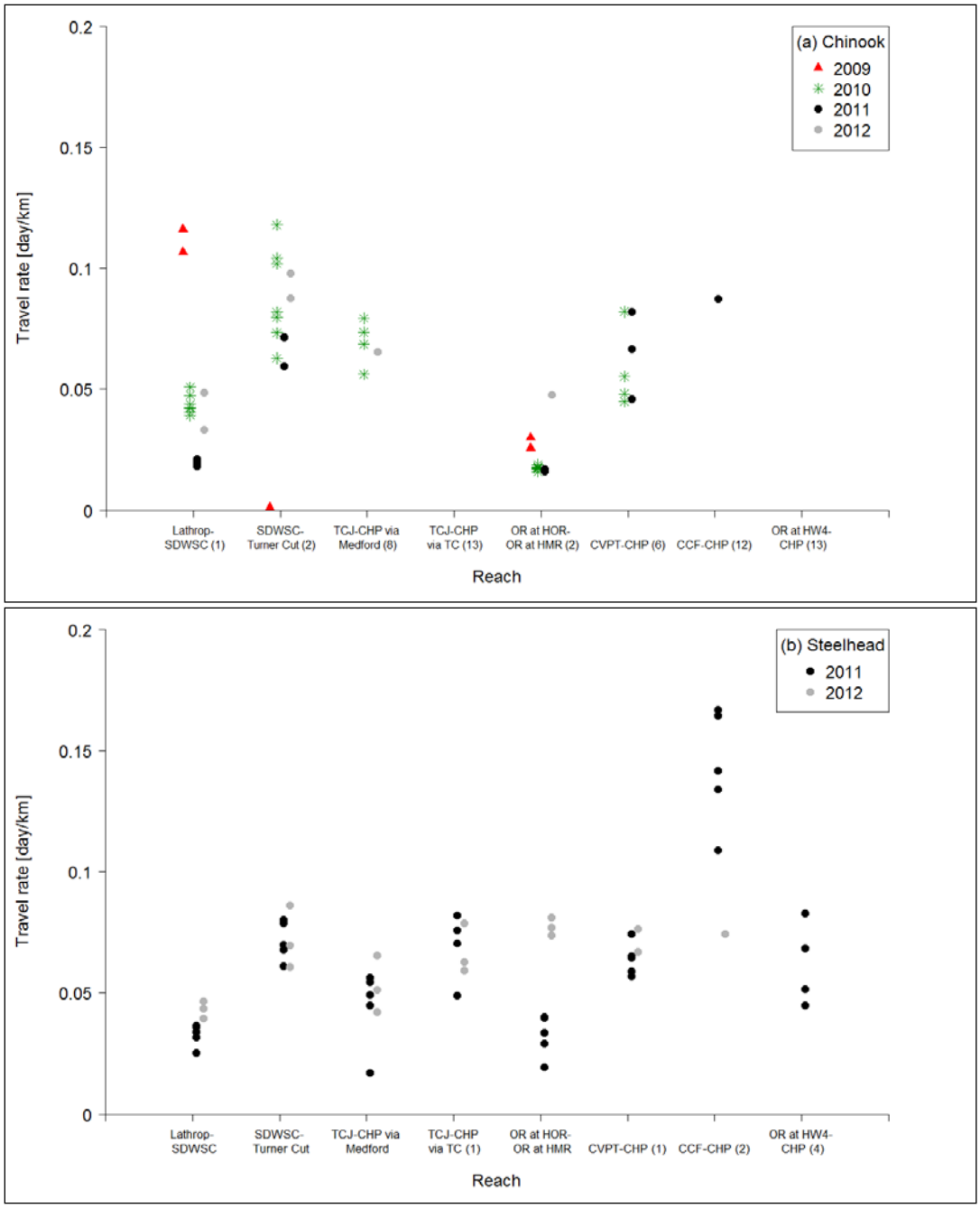

Figure E.5-1. Average Travel Rate (day/km) by Reach for Acoustic-tagged Fall-run Chinook Salmon (a) and Steelhead (b) Studies

Notes: Reach labels: Numbers in parentheses = number of releases with insufficient detections to measure travel rate. SDWSC = Stockton Deep Water Ship Channel; TCJ = Turner Cut junction; CHP = Chipps Island; OR = Old River; HOR = Head of Old River; HMR = Head of Middle River; CVPT= Central Valley Project Tank; CCF = Clifton Court Forebay (just inside entrance gates), HW4 = Highway 4. See Figure E.2-2 for site locations. Sources: SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

E.5.2.1 Lathrop to SDWSC

Migration rate tends to be faster in the reach from Lathrop to the upstream entrance of the SDWSC than in reaches farther downstream for fall-run Chinook salmon, but not consistently (SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Figures E.5-1a and E.2-2). Data from the first two years of the six-year steelhead AT study (2011, 2012) show that migration rates are faster for steelhead in this reach than farther downstream (Buchanan 2013, 2014; Figure E.5-1b). Chinook and steelhead that are in faster moving release groups tend to have higher probabilities of survival in the reach from Lathrop to SDWSC (Figure E.5-2), although the relationship is not consistent for all years and species (e.g., 2011 Chinook salmon versus 2011 steelhead, 2012 steelhead).

E.5.2.2 SDWSC to Turner Cut Junction

The reach between the upstream entrance of the SDWSC and the Turner Cut junction (Figure E.2-2) is predominantly tidal and, thus, the XT predator-prey model predicts that survival of prey (salmonids) will be proportional to migration rate, as prey slow down relative to predators (Anderson et al. 2005). Both fall-run Chinook salmon and steelhead have been observed to decrease their rate of travel in this reach relative to the previous, partly riverine reach (Figure E.5-1; SJRGA 2010, 2011, 2013; Buchanan 2013, 2014; Buchanan et al. 2015). Analysis of steelhead data from the first two years of the six-year study suggested a possible proportional relationship between survival and migration rate in this reach (Figure E.5-3; Buchanan 2013, 2014). However, analyses of Chinook data suggested little or no apparent relationship between migration rate and survival in this reach (2009 to 2012) other than 2012 (Figure E.5-3). No formal analysis relating survival to migration rate or the XT model has been performed for this reach of the San Joaquin River.

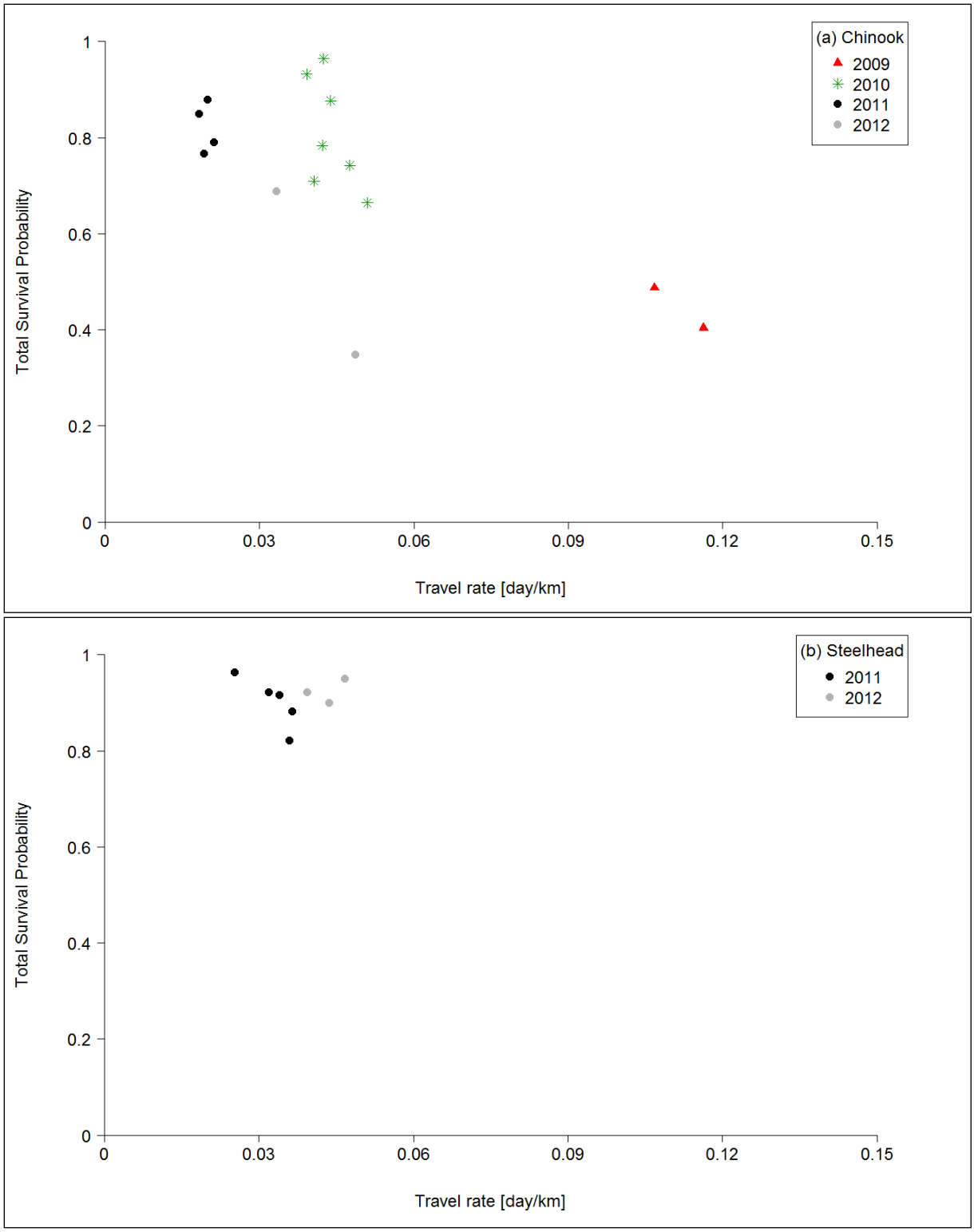

Figure E.5-2. Estimated Survival Probability Versus Travel Rate (day/km) in the San Joaquin River from Lathrop to the Acoustic Receiver at the Navy Drive Bridge in Stockton (near the start of the SDWSC), from Acoustic-tagged Salmon (a) and Steelhead (b) Studies

Source: SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

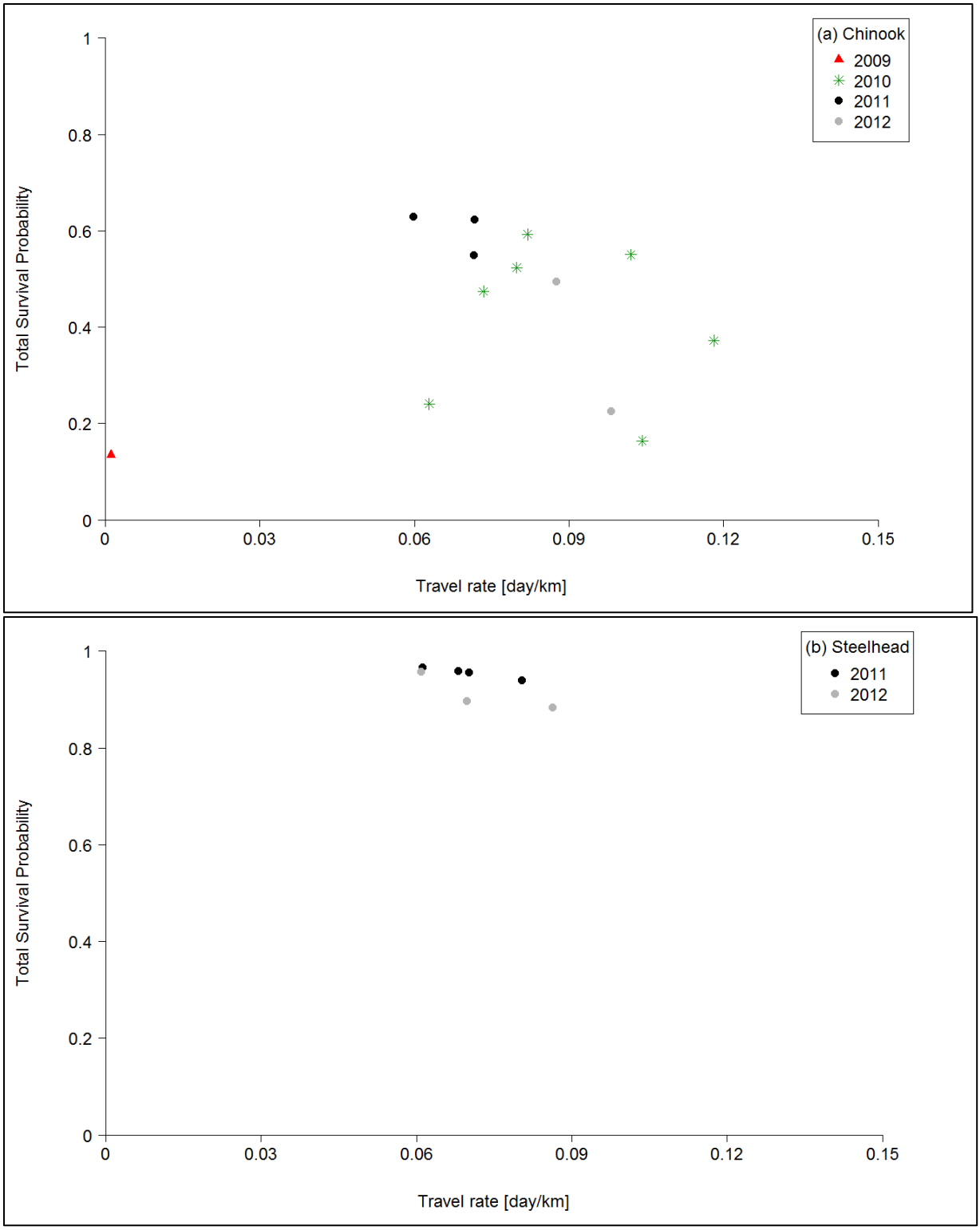

Figure E.5-3. Estimated Survival Probability Versus Travel Rate (day/km) in the San Joaquin River from the Acoustic Receiver at the Navy Drive Bridge in Stockton (near the start of the SDWSC) to Turner Cut Junction, from Acoustic-tagged Salmon (a) and Steelhead (b) Studies

Source: SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

E.5.2.3 Turner Cut Junction to Chipps Island

In 2010, average travel times from the Turner Cut junction to Chipps Island (Figure E.2-2) for fish that stayed in the San Joaquin River downstream of Turner Cut ranged from 2.8 to 4.9 days for acoustic-tagged juvenile Chinook salmon (SJRGA 2011). In 2011, there were too few fish detected at Chipps Island from this route to estimate travel time (SJRGA 2013). The assessment of any relationship between migration rate and survival in this reach is hampered for Chinook salmon because of sparse data and consistently low survival; the five data points available do not indicate a strong relationship (SJRGA 2011; Buchanan et al. 2015; Figure E.5-4). Steelhead data for the first two years of the six-year study are consistent with the XT model prediction of higher survival for faster moving fish (Buchanan 2013, 2014; Figure E.5-4). Overall, strong conclusions are not possible because of sparse data and potential differences between species.

E.5.2.4 Head of Old River to Head of Middle River

The reach of Old River from the head of Old River to the head of Middle River is 6 km (Figure E.2-2). Average travel time for Chinook salmon was relatively short in this reach compared to downstream reaches, and ranged from 0.1 days (2.4 hours) in 2010 and 2011 to 0.3 days (7 hours) in 2012 (Figure E.5-1a). Survival in this reach tends to vary between years more than within years. Within each year, there is little sign that release groups that move more quickly through the reach have higher survival; however, when combined over years, it appears that the faster moving groups have higher survival in general (Figure E.5-5a). Steelhead tended to move more slowly through this reach, and there was less variability in survival estimates for steelhead than for Chinook salmon (Figures E.5-1 and E.5-5). There is no indication that shorter travel times in this reach are associated with higher survival for steelhead, from a visual inspection of the data (Figure E.5-5b) (Buchanan 2013, 2014).

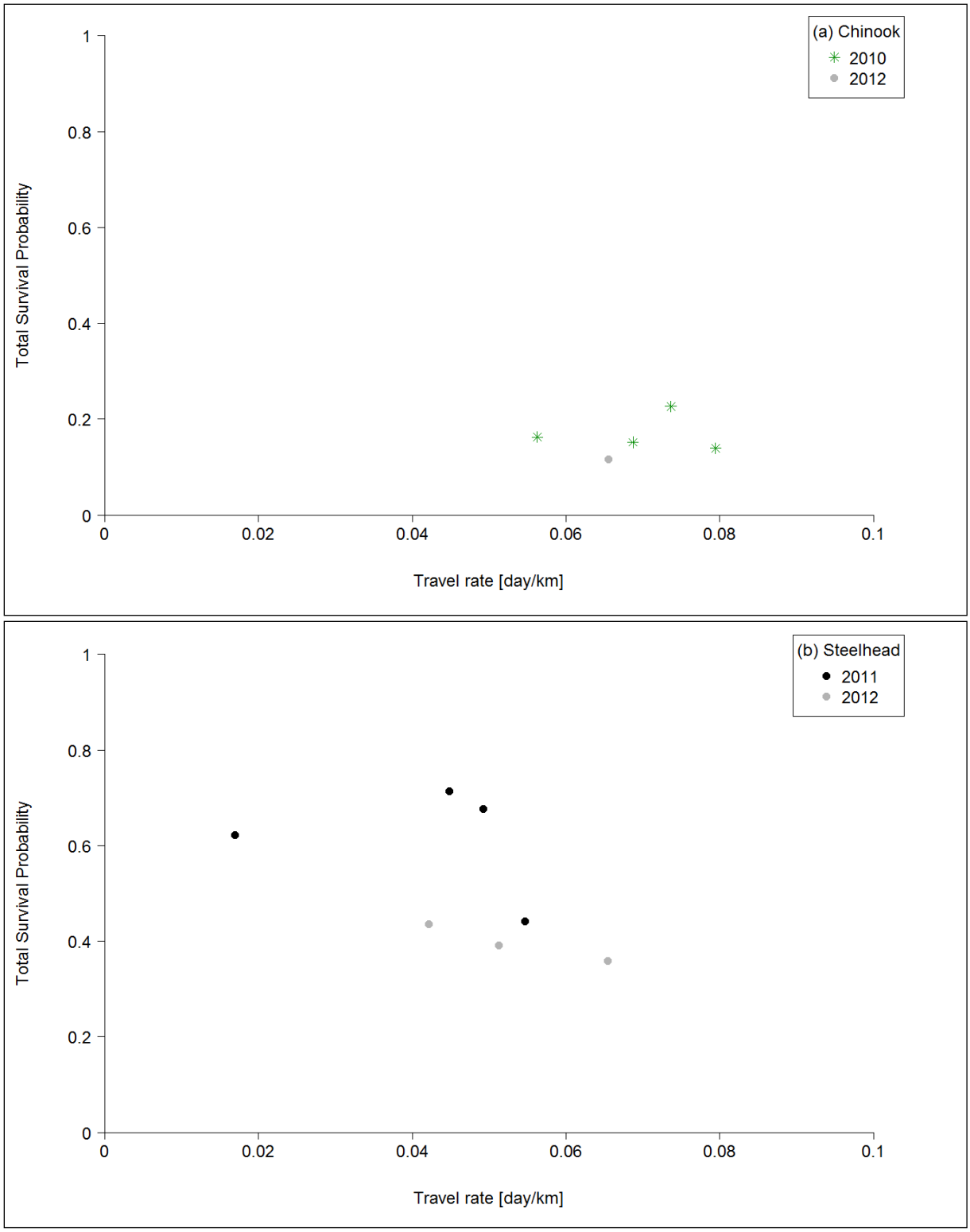

Figure E.5-4. Estimated Survival Probability Versus Travel Rate (day/km) from the Turner Cut Junction to Chipps Island, from Acoustic-tagged Salmon (a) and Steelhead (b) Studies

Note: For fish that remained in the San Joaquin River past Medford Island.
Sources: SJRGA 2011; Buchanan et al. 2015; Buchanan 2013, 2014.

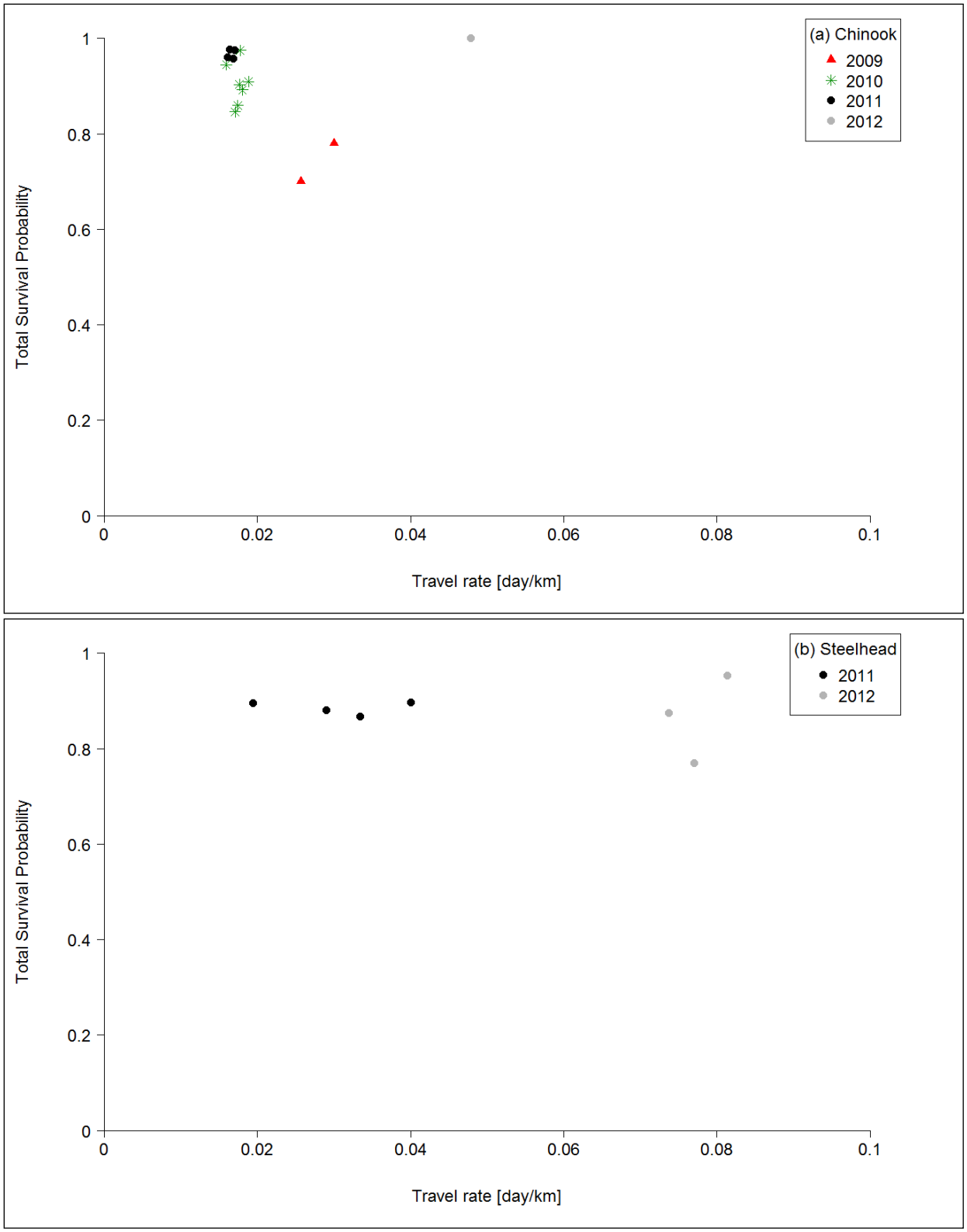

Figure E.5-5. Estimated Survival Probability Versus Travel Rate (day/km) in Old River from the Head of Old River to the Head of Middle River, from Acoustic-tagged Salmon (a) and Steelhead (b) Studies

Source: SJRGA 2010, 2011, 2013; Buchanan et al. 2015; Buchanan 2013, 2014.

E.5.2.5 Old River at Highway 4 to Chipps Island

The reach from Highway 4 on Old River to Chipps Island includes the lower Old River and San Joaquin River, and either the lower Middle River or Frank's Tract and False River, depending on the route taken by the fish (Figures E.2-2 and E.4-2). There were too few observations of travel time from acoustic-tagged Chinook salmon for a comparison to survival for that species. For steelhead, estimates are available only for 2011, because too few steelhead used the Old River route in the 2012 AT study to measure travel time through this reach. For 2011 steelhead, there is no indication that faster moving fish had higher survival, and instead the opposite is indicated (Figure E.5-6). However, strong conclusions are not possible for either species because of insufficient data.

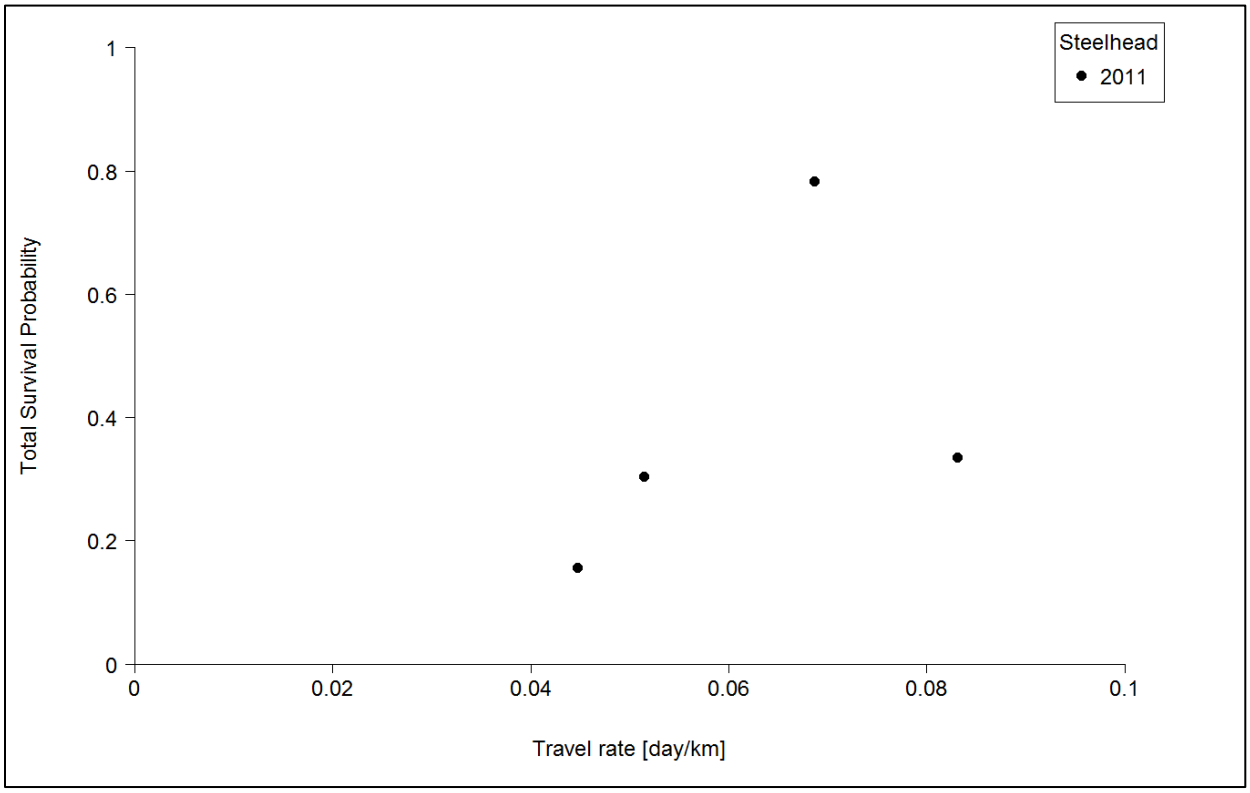

Figure E.5-6. Estimated Survival Probability Versus Travel Rate (day/km) from Old River at Highway 4 to Chipps Island, from Acoustic-tagged Steelhead Studies

Note: For fish that remained in the San Joaquin River past Medford Island.
Source: Buchanan 2013.

E.5.2.6 Mossdale to Jersey Point

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 (DRRs) of CWT fish released in 1996 to 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 (Figure E.2-2; Newman 2008). Under assumptions of common sampling and conditional capture probabilities in the trawl and fisheries between the paired upstream and downstream releases, the DRR estimates survival between the upstream release site and Jersey Point; see Newman (2008) and SJRGA (2013) for more information on these data. 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 (S. Greene, personal communication). Comparison of the DRR to average travel time showed no significant relationship between travel time and survival for these CWT data (P=0.5157; r=0.17; Figure E.5-7).

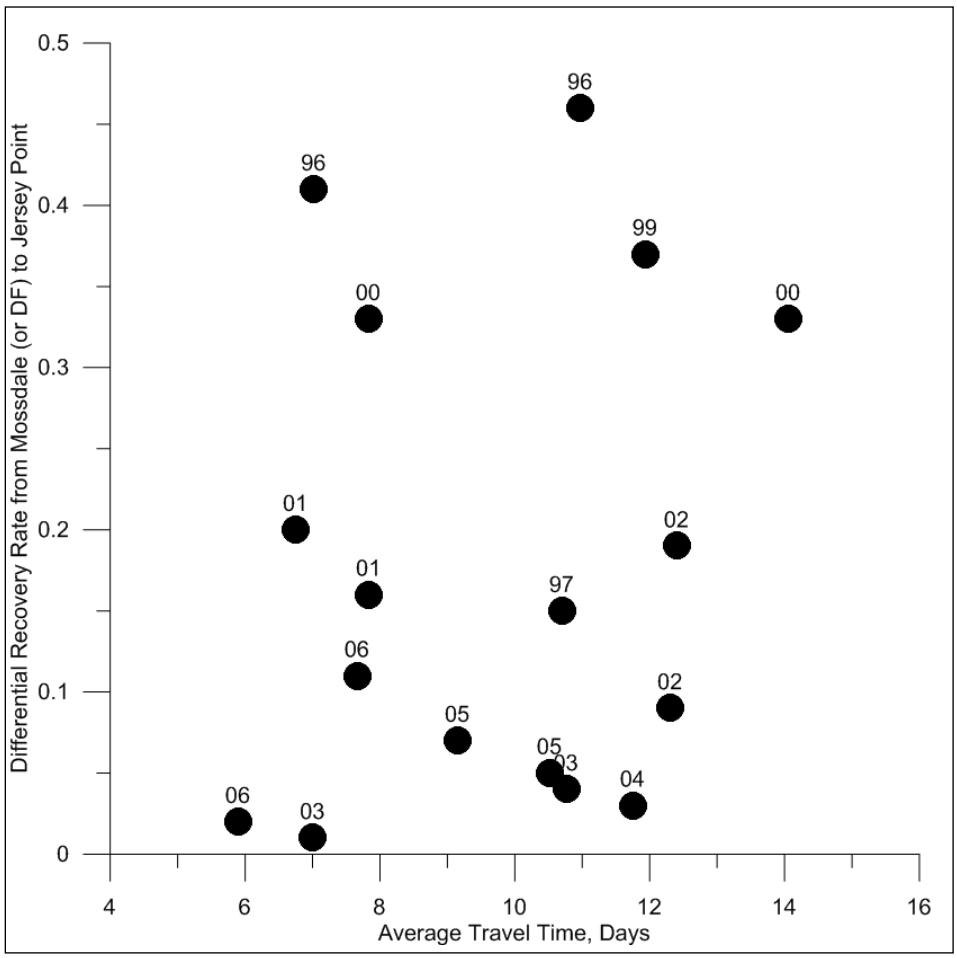

Figure E.5-7. Average Travel Time of Specific Releases of Fall Chinook Salmon Versus an Estimate of Survival Based on a Ratio of Recovery Fractions for Upstream Releases to Downstream Releases at Jersey Point for the Mossdale to Jersey Point Reach

Notes: Releases were conducted from 1995 to 2006. The Differential Recovery Rate was developed and computed by the USFWS (Newman 2008). Data plotted by Sheila Greene (Westlands Water District).

E.5.3 SUMMARY: KNOWLEDGE GAPS ON MIGRATION RATE

Several knowledge gaps exist regarding the relationship between migration rate and survival of juvenile salmonids in the Delta, and how this relationship may be influenced by water project operations. 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. This knowledge gap is a result of:

- Few estimates of either or both survival probabilities and migration rate in some regions of the Delta, especially the San Joaquin River downstream of Turner Cut and the Interior Delta.
- Interannual and spatial variability in either or both survival probabilities and migration rate.
- Incomplete analysis of existing acoustic telemetry data, including consideration of additional effects of hydrological conditions such as water temperature, flow, and water velocity; analyses are planned or ongoing, but are not yet complete.

Furthermore, additional information is needed about the following issues:

- The relationship between migration rate and survival through reaches in OMR and through the facilities.
- Mechanisms for increased mortality resulting from lower migration rate.
- The extent to which predicted changes in hydrological conditions resulting from water project operations may result in changes in migration rate, and consequently influence survival.
- The benefit-risk tradeoff for faster migration rate, which reduces exposure time to predators in the South Delta and, thus, potentially increases immediate survival rate, but also potentially decreases future survival rate in the ocean due both to less time spent rearing prior to ocean entry and to accelerated ocean-entry timing, possibly before seasonably favorable ocean conditions have become established.

E.6 SURVIVAL AS A FUNCTION OF EXPORT RATE

The conceptual model links mortality to exports via effects of exports on Delta hydrodynamics, the effect of hydrodynamics on route selection and migration rate, and the effect of route and rate on survival. The conceptual model also links exports to mortality via direct mortality at the facilities from pre-screen mortality, entrainment mortality or impingement on screens, and within-facility mortality. Via both direct and indirect effects, possibly including linkages that are not analyzed here, the conceptual model predicts that survival in the Delta will depend at least partly on export rate. This section provides a review of available information for evidence of a relationship between export rate and survival through and within the Delta. Direct mortality is considered in detail in Section E.3. Here, we review findings on survival in various regions relative to export rate.

Increased export rates are expected to draw more fish into the Interior Delta and into the water export facilities, and via direct mortality to decrease migration survival through the Delta to Chipps Island. Due to spatial heterogeneity in the effect of exports on Delta hydrodynamics, it is expected that some routes will exhibit a stronger negative effect of increased export rates than others. Likewise, different regions of the Delta may exhibit different relationships between exports and survival.

In this section, predictions from the conceptual model are identified and considered in light of findings relative to Chinook salmon and steelhead. Findings come mostly from peer-reviewed literature and technical reports, but we also present new compilations of data from CWT and AT studies of San Joaquin River fish; the data used in these compilations are described in Section E.2.

E.6.1 Summary: Conceptual Model Predictions on Survival as a Function of Export Rate

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 are limited for steelhead.

- 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).
- CWT data from San Joaquin River fall-run Chinook salmon provided moderate evidence of a positive relationship between through-Delta survival and export rates, but may be due to high correlation between exports and San Joaquin River inflow (Newman 2008; SJRGA 2006).
- 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 hydrodynamics, including export rates, found no evidence of a relationship, but Delta survival was not modeled separately from 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.

The conceptual model predicts increased entrainment mortality as a result of increased exports. Evidence is indirect.

- This has been observed indirectly via entrainment mortality estimates based on salvage for Chinook salmon from the Sacramento and San Joaquin rivers, but depends

on assumed values of pre-salvage survival (Kimmerer 2008; Zeug and Cavallo 2014); see Section E.3.

- Higher rates of entering the CVP (i.e., moving past the trash racks) have been observed with higher CVP flows for both juvenile Chinook salmon and steelhead (Karp et al. 2014); however, for both species, the efficiency of the secondary louver system at the CVP was also higher at higher channel velocities (controlled by exports) (Bowen et al. 2004; Karp et al. 2014). Thus, there is evidence that higher export rates bring more juvenile salmonids into the CVP and improve the louver efficiency; these two components counteract to limit the overall effect of export rates on entrainment mortality, based on these two studies (unpublished).

The conceptual model predicts variable effects of exports on survival in different regions of the Delta. Data are limited but generally support the prediction.

- The relative success of the Interior Delta route compared to a 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 exports models (Newman and Brandes 2010).
- This has been observed in a provisional assessment by the SST of AT data from San Joaquin River fall-run Chinook salmon: there is evidence of a negative relationship between exports and survival from the Turner Cut junction to Chipps Island, but not from Mossdale to the Turner Cut junction. However, there are very few observations at high export rates.
- The two years of San Joaquin River steelhead AT data show no obvious relationship between export rates and survival except for increased survival through the CVP to Chipps Island for higher CVP export rates (Figure E.6-7).

E.6.2 Findings on Conceptual Model Linkages and Predictions: Effects of Exports on Survival

E.6.2.1 Effects of Exports on Survival of Chinook Salmon

Through-Delta Survival

Our basis of knowledge regarding exports and through-Delta survival for juvenile Chinook salmon is low. Multiple directed field studies have collected data to evaluate this relationship; results from these studies are available in both peer-reviewed literature and agency reports. Additional results are newly compiled for this report. Evidence from these sources is inconsistent.

The VAMP study was designed to explore how Delta survival of fall-run Chinook salmon from the San Joaquin River is affected by exports and inflow in the presence of a barrier at the head of Old River. However, as discussed in Section E.2, the treatments needed to

distinguish the role of exports from the role of inflow were not obtained; flow and exports were correlated during the VAMP study and, thus, effects of these two factors were confounded (Figures E.2-6 and E.2-7). The one exception was the VAMP study in 2006, which succeeded in de-coupling flow and export treatments using one treatment of high flow and low exports (1,500 cfs, first release group) and a second treatment of high flow and high exports (6,000 cfs, second release group). The survival estimates to Jersey Point were 0.12 for the first release group (low exports) and 0.02 for the second release group (high exports), but the difference was not statistically significant. Recovery numbers were reduced from the 2006 releases due to the closed or restricted ocean fishery in 2008 and 2009, which may have resulted in lower precision of estimates and lower ability to detect any significant differences in survival. Furthermore, the period of high exports coincided with higher water temperatures, and so any effect of exports was confounded with temperature effects.

The analysis of survival, exports, and inflow using CWT data found that survival of San Joaquin River Chinook salmon through the Delta increased with inflow (Newman 2008). Newman reports "little evidence for any association between exports and survival"; however, Figure 26 and Table 14 from Newman (2008) indicate some evidence for a positive association between exports and survival (i.e., 79% probability of a positive association from Dos Reis to Jersey Point). Newman (2008) also found a 67% probability of a positive association between flow in the upper Old River and survival from Old River near its head to Jersey Point. Previous analysis of the CWT data by the U.S. Fish and Wildlife Service also found a possible positive relationship between exports and survival of San Joaquin River Chinook salmon (SJRGA 2006); Newman (2008) hypothesized that the perceived positive association may be due to positive correlation between exports and inflow (correlation coefficient = 0.88).

Zeug and Cavallo (2013) compared four models representing competing but not mutually exclusive hypotheses about factors affecting an index of joint Delta survival and ocean survival using ocean recovery rates of fall-run Chinook salmon. The models and the variables included in each were release-specific (water temperature, FL, release location, barrier status at head of Old River), hydrologic (seven-day average of inflow and exports, and proportion salvaged at the export facilities), water quality (ammonium concentration, ratio of dissolved inorganic nitrogen to dissolved inorganic phosphorous, and turbidity), and ocean productivity (Wells' Index). The models found to have the most support were the release-specific and water quality models for San Joaquin River Chinook salmon, and the water quality model for Sacramento River Chinook salmon. Ammonia concentrations had significant effects for both Sacramento River and San Joaquin River fish, but opposite relationships were observed in the two rivers (negative effect in the Sacramento River and positive effect in the San Joaquin River), possibly caused by lower and less variable concentrations of ammonia in the San Joaquin River. The hydrologic model (inflow, exports, proportion salvaged) was given negligible support compared to the alternative models for both San Joaquin River and Sacramento River fish (Zeug and Cavallo 2013). Zeug and

Cavallo (2013) suggest tidal flux and the use of ocean recovery data were possible factors influencing the lack of a detectable inflow effect, as well as the fact that the data they used came after initiation of water operations designed to protect juvenile salmonids. The results of Zeug and Cavallo (2013) are inconsistent with those of Newman (2008), who found a significant effect of inflow on Delta survival using differential recoveries at Chipps Island and in the ocean fishery for upstream and downstream groups released in the Delta. However, a key difference in methodology between Newman (2008) and Zeug and Cavallo (2013) is that the former modeled only the probability of Delta survival, whereas the latter modeled the joint probability of Delta and ocean survival. Despite this methodological difference, the differences in results warrant additional analyses using more recent data, in particular using the acoustic telemetry data collected from 2008 to 2015.

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 fish released in the Interior Delta to those released in the Sacramento River mainstem (Figure E.6-1). However, they also reported equal support for a model that replaced exports with the ratio of exports to flow, and more or nearly equal support for a simpler model that excluded exports entirely (Newman and Brandes 2010). They suggest that the indeterminacy of the modeling results may have resulted from a low signal-to-noise ratio in the data. In particular, a large amount of the variability observed in the relative survival estimates was unexplained by exports (R^2=0.21 for the non-hierarchical model; Figure E.6-1). 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 (i.e., DCC and Georgiana Slough); he did not explore the possible effect of exports on survival in mainstem routes.

Simple single-variable graphical analyses performed by the SST using both CWT and AT data from San Joaquin River Chinook salmon also show equivocal patterns in survival and exports (Figures E.6-2 through E.6-4). 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 E.6-2); 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 (Figure E.2-8). Unlike for 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 predated AT studies).

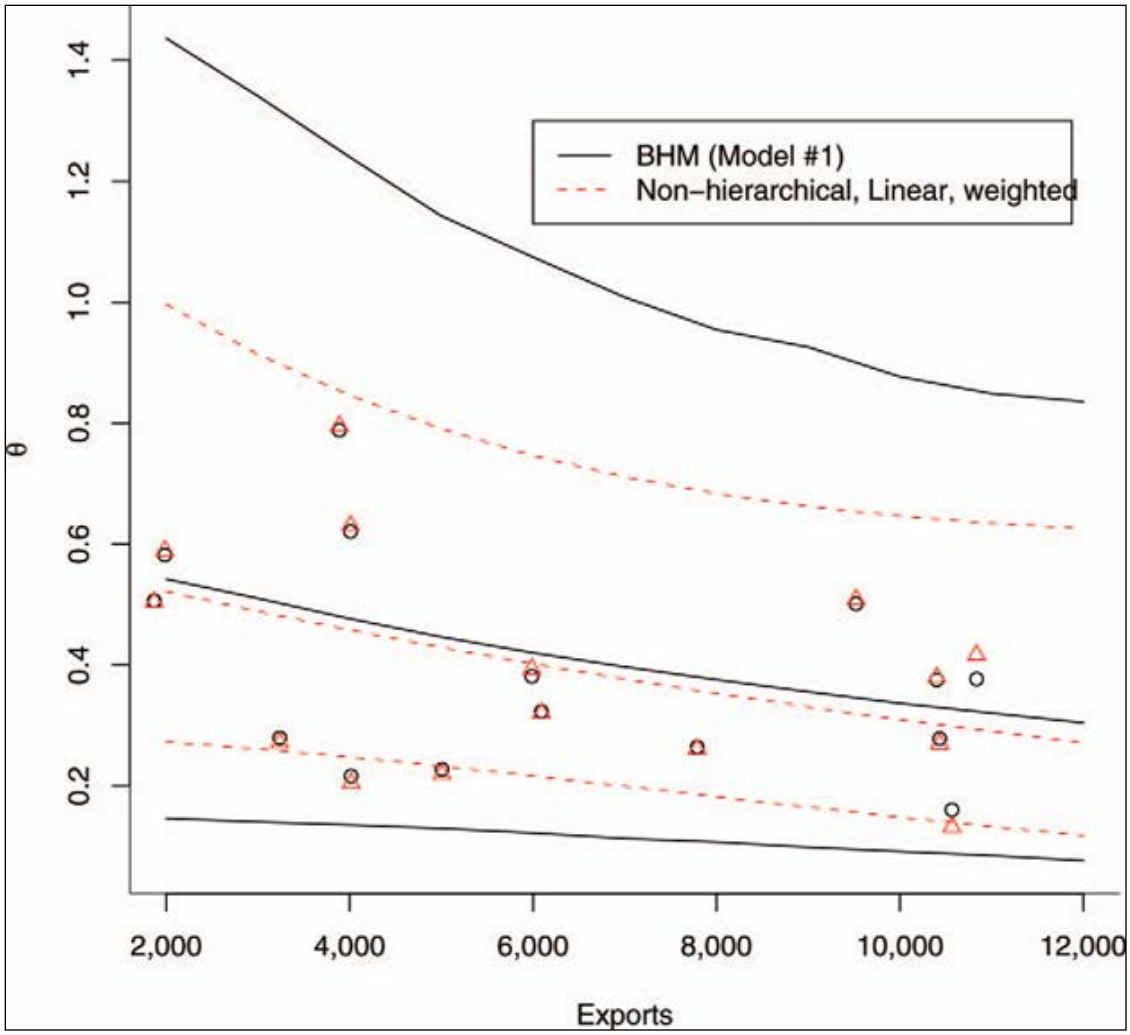

Figure E.6-1. Expected Values and 2.5–97.5% Prediction Intervals for Theta at Different Levels of Exports Produced By Bayesian Hierarchical Model (BHM) 1 (Solid Lines) and the Non-hierarchical Model (Dashed Lines) Using Chipps Island and Combined Ocean and Inland Recoveries

Notes: The circles denote posterior mean fitted values for θ from the BHM, the triangles maximum likelihood estimates. θ = relative recovery of Interior Delta (Georgiana Slough) release to Sacramento River mainstem (Ryde) release. R^2=0.21 (non-hierarchical model).
Source: Newman and Brandes 2010

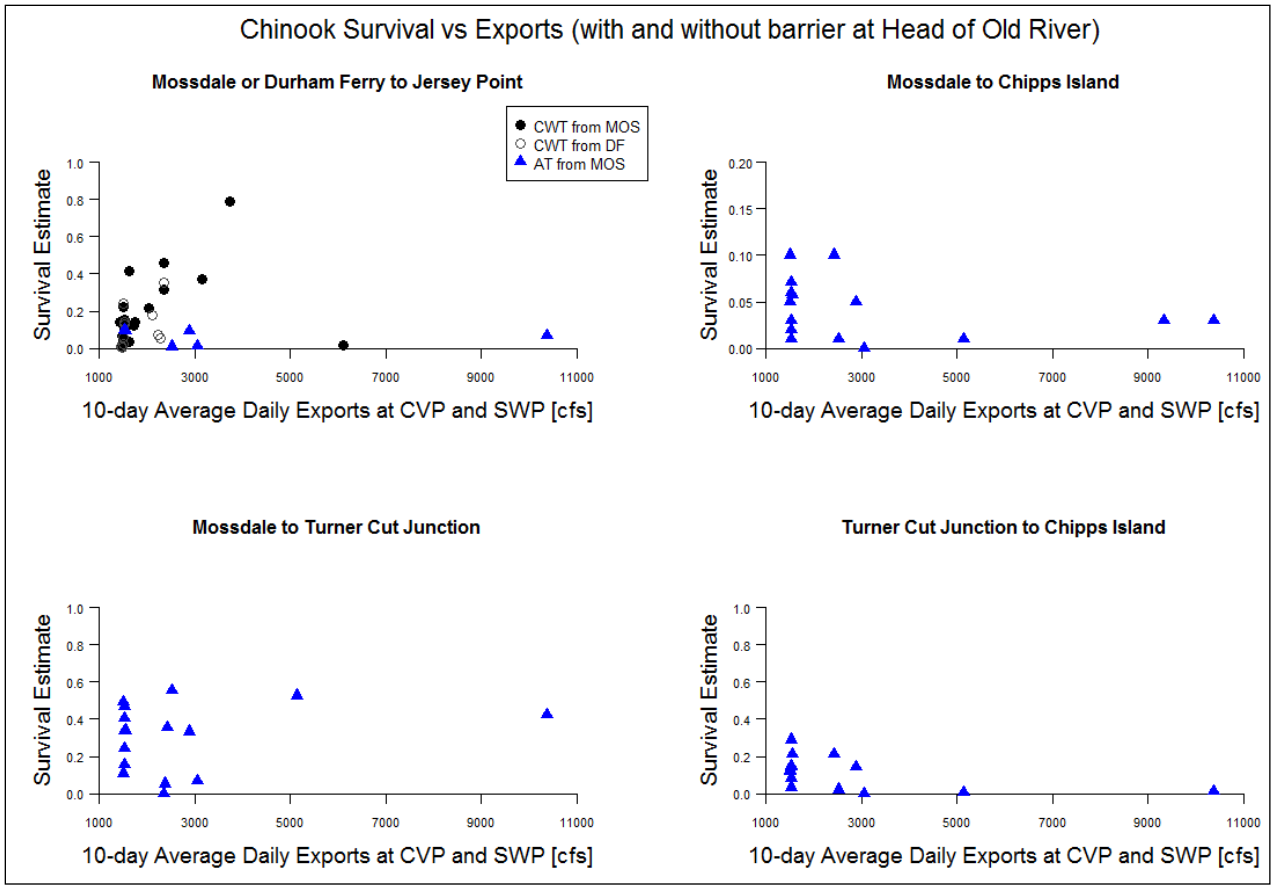

Figure E.6-2. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Exports at CVP and SWP, Regardless of Barrier Status at the Head of Old River

Notes: Exports 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 intake (BBID); 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.

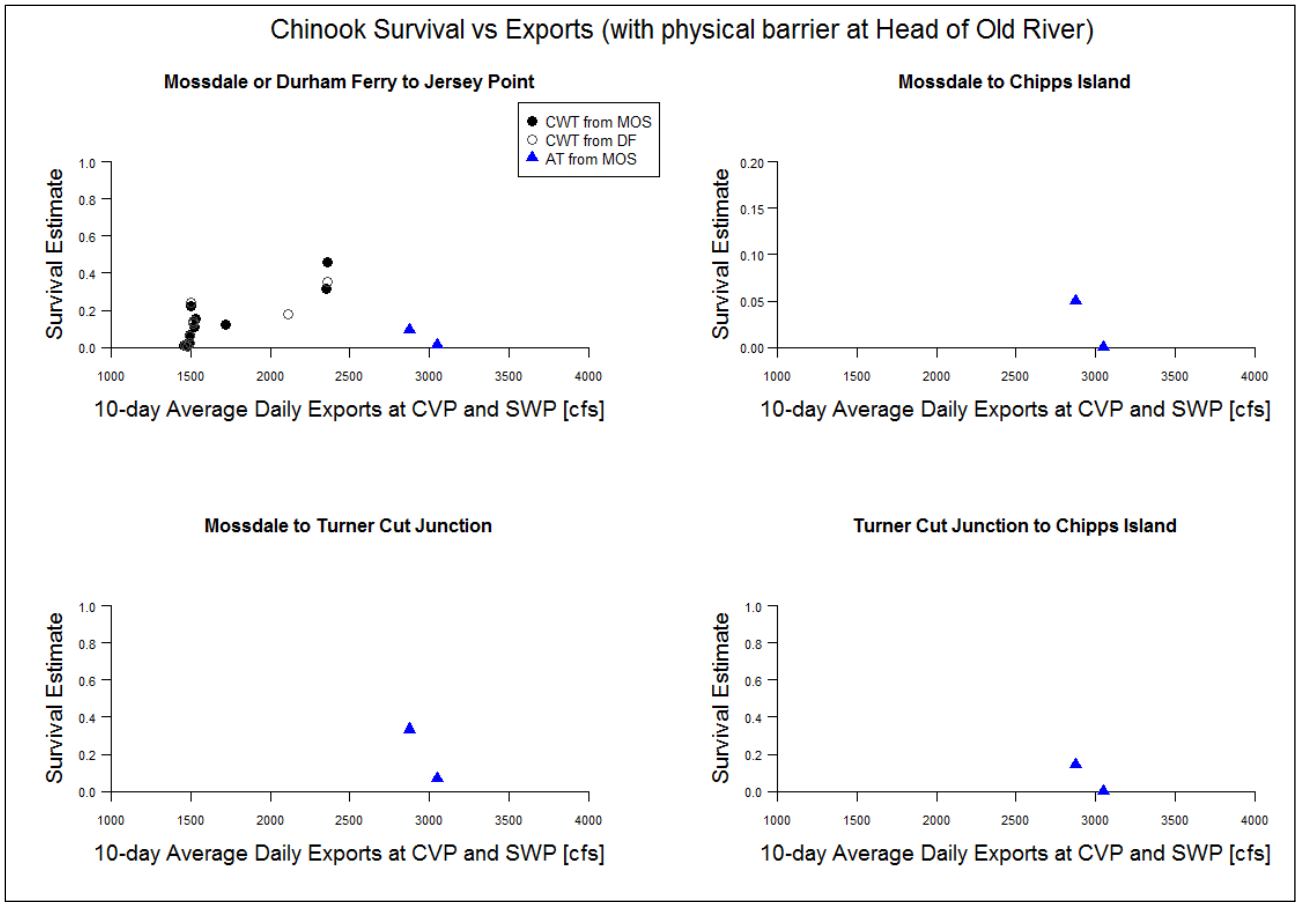

Figure E.6-3. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Exports at CVP and SWP, in the Presence of a Physical Barrier at the Head of Old River

Notes: Exports 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 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.

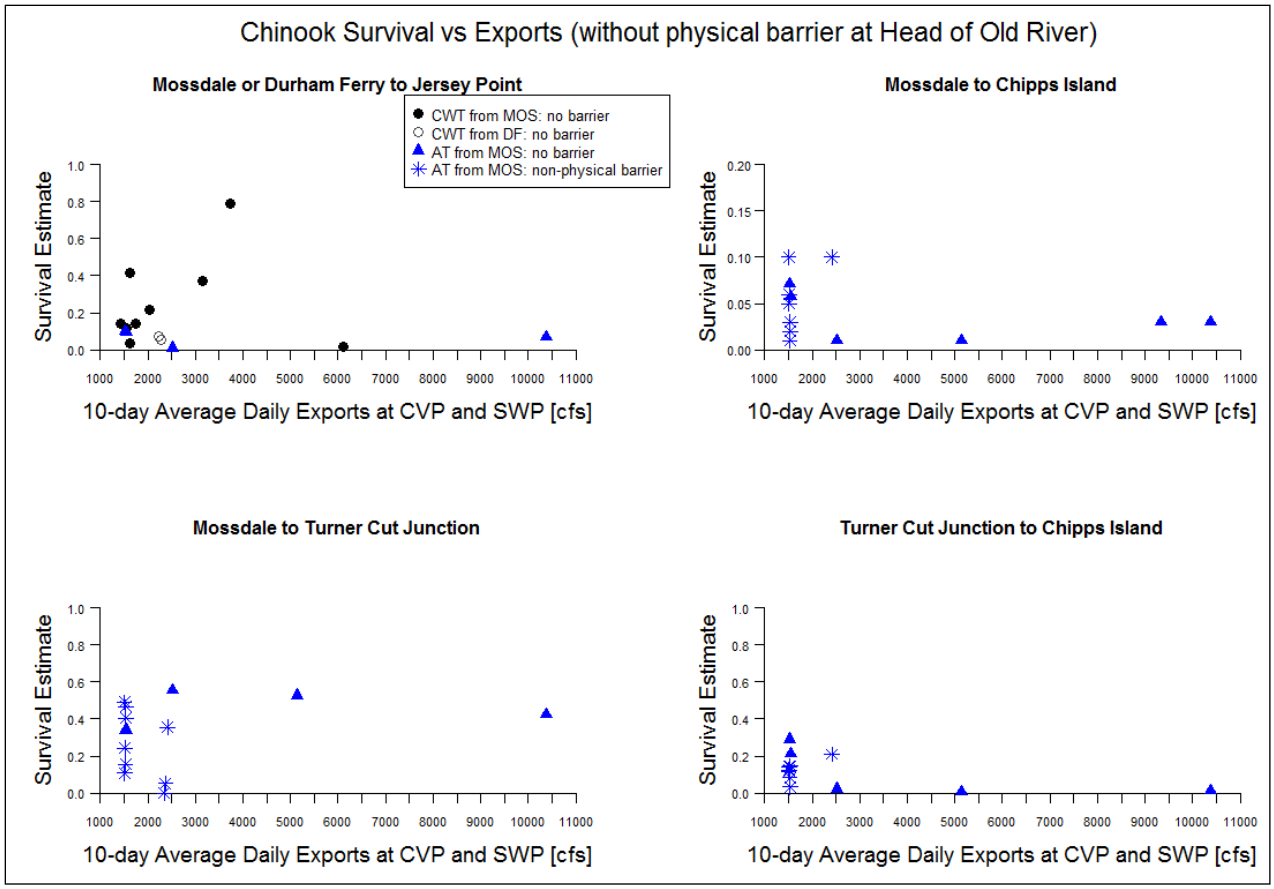

Figure E.6-4. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Exports at CVP and SWP, in the Presence of Either a Non-physical Barrier or No Barrier at the Head of Old River

Notes: Exports 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 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

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 plots in Figures E.6-2 and E.6-4). Similar patterns are observed for survival from Mossdale to Chipps Island from AT data (top right plots in Figures E.6-2 and E.6-4). 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 export levels. 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 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 only to chance. To explore that possibility, the SST 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., ≤ 0.07). The event of observing only survival estimates ≤ 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 and the range of export levels that impose such a maximum.

Reach-Specific Survival

Our basis of knowledge regarding evidence of a relationship between exports and reach-specific Delta survival for juvenile Chinook salmon is low. While multiple directed field studies have collected data to evaluate this relationship, compiled results from these studies are first presented primarily in this report, where it is a preliminary conclusion. Our understanding is low due to inconsistent results and sparse data.

Survival of juvenile Chinook salmon from Mossdale to Turner Cut junction is quite variable for low export levels, but relatively high (0.42 to 0.52) for export levels greater than 4,000 cfs (bottom left plots in Figures E.6-2 and E.6-4). At export levels less than 4,000 cfs, it appears that factors other than the export rate drive the variability in survival between Mossdale and Turner Cut junction. It is possible that the export rate limits the maximum possible survival in this lower range of export levels, but the data give no indication of a relationship between export levels and maximum survival rate for these export levels. The relatively high survival estimates observed in this reach for higher export levels (greater than 4,000 cfs) are inconsistent with a factor-ceiling relationship. However, it is consistent with a positive relationship between inflow and survival in this reach, based on the assumption that high exports depend on high inflow; in fact, the inflow values for these two data points were both greater than 10,000 cfs, whereas the average inflow for all data in this plot was approximately 5,000 cfs. Attempting to theorize about the nature of the relationship between exports and survival in this reach when the export rate is high demonstrates the danger of making inference based on insufficient data (in this case, only two data points). Furthermore, hydrological model simulations reported in Volume 1, Appendix B show little effect of exports on flow and velocity in the San Joaquin River between the head of Old River and Turner Cut (Figure E.2-2), compared to the Interior Delta, so any effect of exports on survival in this region is likely to be indirect.

There is some indication that survival from Turner Cut to Chipps Island may decrease with increasing exports (Figures E.6-2 and E.6-4), but there is considerable variability 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.

Facility Survival

Our basis of knowledge regarding the conceptual model's linkage between exports and facility survival is medium. Multiple directed field studies have collected data to evaluate this relationship, and the results from these studies are published primarily in agency reports. Additionally, multiple peer-reviewed articles have quantified the relationship between exports and direct mortality of Chinook salmon at the facilities. However, uncertainties remain about the magnitude and variability of pre-screen mortality at the CVP.

The effect of exports on survival through the water export facilities has been studied indirectly by the effect of water velocity through the facility on louver efficiency and entrance to the facilities. Higher louver efficiencies are equated with lower mortality in the facility. At the CVP, higher louver efficiencies have been shown during periods of higher velocity (e.g., 5.58 ft/s vs. 0.33 ft/s) in the facility, which is a result of high export rates (Bates and Vinsonhaler 1957; Karp et al. 1995; Bowen et al. 2004; Sutphin and Bridges 2008). Karp et al. (2014) observed higher facility entrance rates of acoustic-tagged Chinook salmon during higher flows, compared to increased looping behavior in front of track racks and in bypass channels during low or medium flows. Because export rates influence flow at this location, this finding suggests that survival through the facility may be higher at higher export rates. However, these studies compared louver efficiency with flows or channel velocity rather than export rates directly, and so the conclusions about export rate are indirect.

Findings from statistical comparisons of export rates to survival or recovery rates are mixed. During the VAMP study (2000 to 2011), low export rates were maintained during the spring outmigration, resulting in low primary velocities at the Tracy Fish Collection Facility at the CVP; increasing the primary bypass ratio (ratio of average water velocity at entrance of bypass No. 4 to average water velocity in the Tracy Fish Collection Facility primary channel) during these times resulted in increased secondary channel velocities, and higher recovery rates of Chinook salmon (Sutphin and Bridges 2008). In the CCF, Gingras (1997) found greater efficiencies and higher survival for Chinook salmon in the CCF when exports were higher. Nevertheless, visual inspection of simple scatterplots compiled by the SST of estimated facility survival, from the 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 (2008 to 2011) and the 2012 Chinook tagging study in the South Delta (Figure E.6-5). 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 (top row, Figure E.6-5). This suggests that at very low export levels, a combination of factors that are not directly related to exports determine survival through the CVP. However, 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; nevertheless, there does not appear to be a relationship between export rate and average survival probability (Figure E.6-5). It is possible that a related factor determines survival at these export levels. 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 the CCF to Chipps Island, Chinook salmon survival was at or near 0 for all observations, except for one of the highest export levels (Figure E.6-5). No survival estimates are available from the SWP trash racks to Chipps Island because acoustic telemetry receivers were not placed at the SWP except in 2008, when estimated survival was confounded with premature tag failure.

On a population level, Zeug and Cavallo (2014) explored the factors affecting salvage of juvenile Chinook salmon into 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 and Sacramento River releases. By estimating entrainment and direct mortality at the facilities from the salvage numbers, they concluded that increased exports results in increased facility mortality (including pre-screen mortality, entrainment mortality, and within-facility mortality). 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 depends on pre-salvage survival (i.e., survival from pre-screen mortality and mortality due to entrainment in the canals) (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 mortality for exports greater than 3,531 cfs).

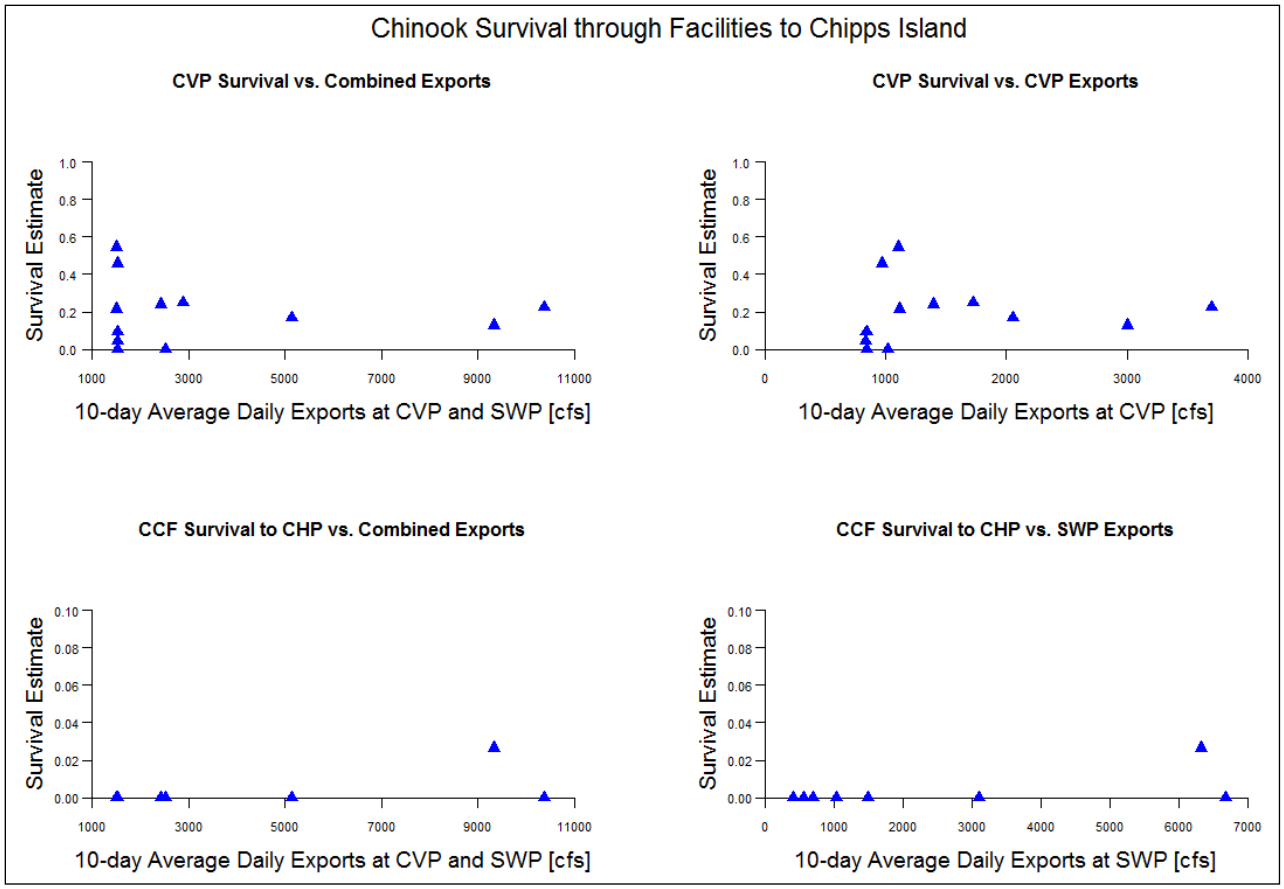

Figure E.6-5. Estimated Survival of Fall-run Chinook Salmon Based on AT Data (2008, 2010-2012 Studies), Versus the 10-day Average of Daily Exports at CVP and SWP

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

Summary: Chinook Salmon

In summary, there is not clear and consistent evidence of a relationship between the combined export rate from the CVP and SWP and survival of San Joaquin origin fall-run Chinook salmon through the Delta. Comparisons of survival to export rates are complicated by the high correlation (up to r=0.98 in historical data) between inflow and exports and the sparse data available for higher export rates (e.g., greater than 4,000 cfs). For San Joaquin River salmon, Newman (2008) found "little evidence for any association between exports and survival" through the Delta, and hypothesized that a possible positive relationship observed in a previous analysis (SJRGA 2006) may have been driven by the positive correlation between exports and inflow. Zeug and Cavallo (2013) also found no evidence of a relationship between exports (combined with other hydrological metrics) and ocean recovery rates, which reflect the combination of both Delta survival and ocean survival and capture; however, it is possible that any effect on Delta survival was swamped by variability

in ocean survival and capture. Visual inspection of AT survival data shows no clear evidence of a relationship between exports and mean survival through the Delta. The AT data are consistent with a factor-ceiling relationship, in which higher levels of exports limit the possible maximum survival probability, especially through the downstream reaches of the Delta; however, because very few observations are available for higher export rates (e.g., greater than 2,000 cfs), it is not possible to make firm conclusions. For Sacramento River salmon, there is some evidence of a negative relationship between exports and through-Delta survival for fall-run Chinook salmon migrating from the Sacramento River in spring (Newman 2003). Some evidence of a relationship between exports and survival has been found for late-fall-run Chinook salmon migrating from the Sacramento River in the winter; however, other models that omitted exports had similar support in Newman and Brandes (2010), and Perry (2010) found no evidence of a relationship. For facility survival, louver efficiency experiments at the CVP (Bates and Vinsonhaler 1957; Karp et al. 1995; Bowen et al. 2004; Sutphin and Bridges 2008) and pre-screen mortality studies at the CCF (Gingras 1997) suggest that survival may be higher through the facilities when exports are higher; also, salvage rates at the water export facilities from the mainstems of San Joaquin River and Sacramento River and northern Interior Delta release points are positively associated with exports (Zeug and Cavallo 2014). However, there was only limited indication from the available AT data of higher facility survival at higher export rates. A formal analysis of AT data is ongoing but not yet completed, and may provide insight into the relationship between survival and exports. However, sparse observations at high export levels (e.g., greater than 4,000 cfs) combined with small sample sizes at the export facilities will limit inference even from a formal analysis of the existing AT data.

E.6.2.2 Effects of Exports on San Joaquin River Steelhead

No formal analysis of steelhead survival through the South Delta is available in the literature, although annual survival estimates are available in agency reports for two study years. Thus, the basis of knowledge for the conceptual model's linkage between exports and steelhead regional survival and facility survival is low. Analysis of four additional years of steelhead data is ongoing or planned.

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 E.6-6). 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). However, there was little variability in export levels during the study periods in these two years compared to the variability observed during the multi-decade Chinook studies (Figures E.6-2 and E.6-6). The survival estimates from Mossdale to Chipps Island include both the route through the San Joaquin River and the route through

salvage at the facilities. Restricted only to the San Joaquin River route from Mossdale to the Turner Cut junction, there was no indication of a relationship between exports and survival (Figure E.6-6). From the Turner Cut junction to Chipps Island, and including routes from the Turner Cut junction through the salvage facilities, the pattern mimics the pattern for survival through the entire South Delta: 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 E.6-6). 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, barrier status at the head of Old River, fish condition, or other factors, or simply interannual and seasonal variability. There is no suggestion of a factor-ceiling relationship between exports and survival on any spatial scale, based on visual inspection of Figure E.6-6. More years of survival estimates from steelhead at a variety of exports levels, including both higher and lower export levels, will be required to assess the relationship between exports and survival for steelhead.

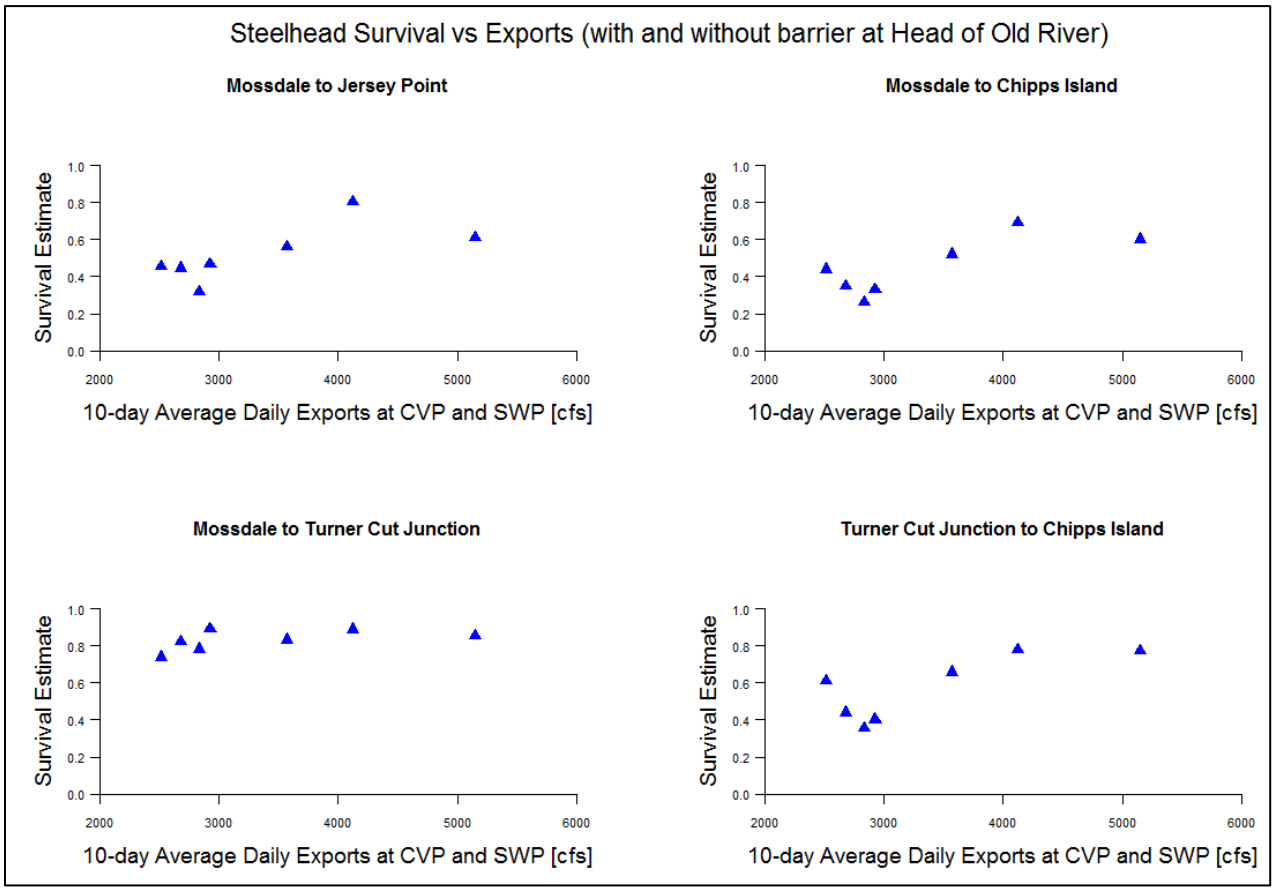

Figure E.6-6. Estimated Survival of Steelhead Based on AT Data (2011 and 2012 Study Years), Versus the 10-day Average of Daily Exports at CVP and SWP, Regardless of Barrier Status at the Head of Old River

Notes: Exports 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 facilities shows some relationship to export rates. Karp et al. (2014) observed higher probability of entering the CVP facility (i.e., pass through the trash racks) by acoustic-tagged steelhead when exports through the CVP were higher, and Bowen et al. (2004) found higher efficiency of the secondary louver system at the CVP when exports were higher; these findings suggest that survival through the region of the Delta near the export facilities may be affected by export rates, although the combination of these two factors (facility entrance and louver efficiency) may limit the strength of such a relationship. Visual inspection of simple SST 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 shows a positive association between the CVP export rate (≤ 4,000 cfs) and survival through the CVP to Chipps Island (Figure E.6-7). For survival from the CCF radial gates to Chipps Island, the relationship with either combined exports or SWP exports is similar to that observed for CVP survival of Chinook salmon (Figure E.6-5): 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 (bottom row, Figure E.6-7). However, there are insufficient data to adequately characterize a relationship, both 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.

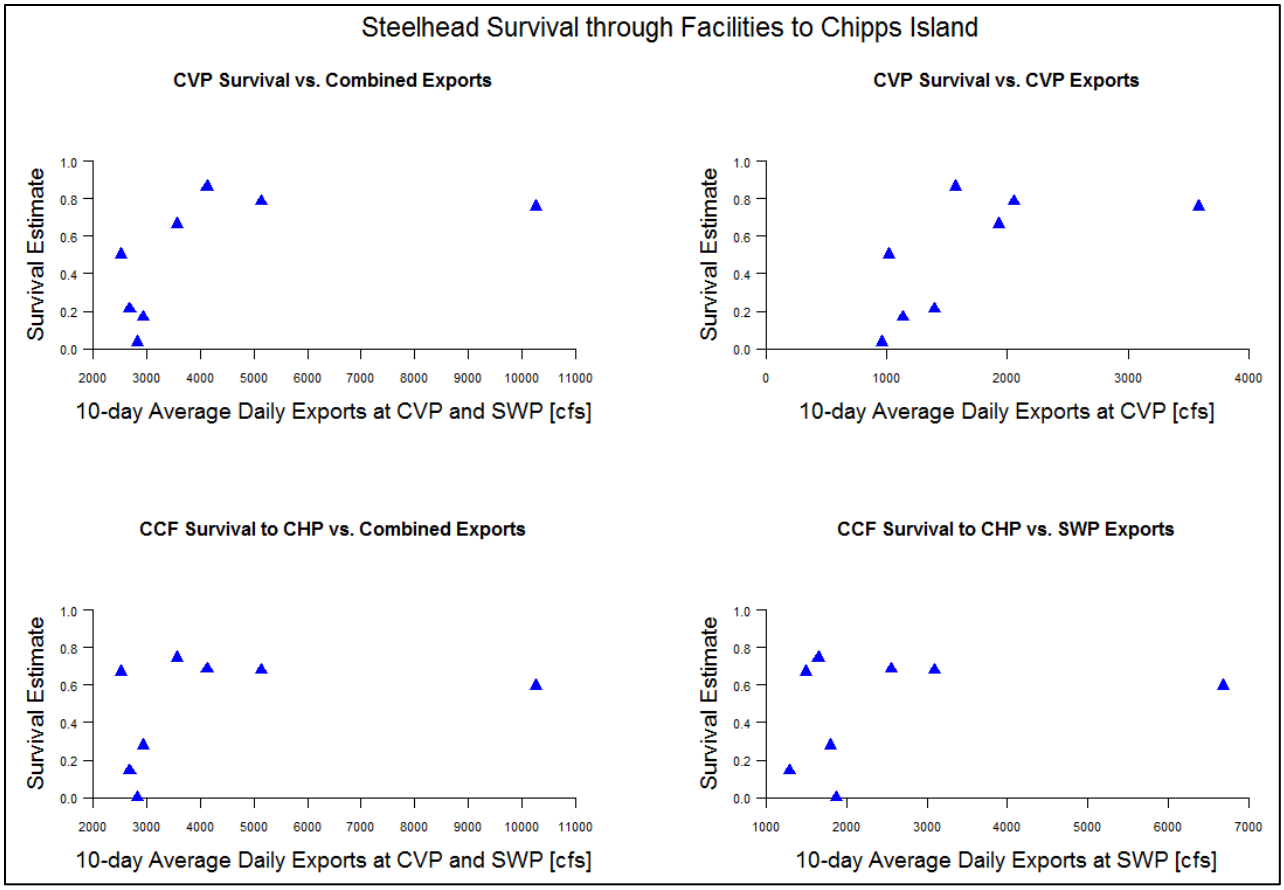

Figure E.6-7. Estimated Survival of Steelhead Based on AT Data (2011 and 2012 Studies), Versus the 10-day Average of Daily Exports at CVP and SWP

Notes: Survival is from trash racks for CVP, and from radial gates at entrance to CCF for SWP. Survival from the CCF to Chipps Island is through the SWP. Exports 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.

E.6.3 Summary: Knowledge Gaps on Survival as a Function of Export Rate

There are a number of gaps in our understanding of how Delta survival depends on export rates.

- The influence of export rates on the relative survival in different routes through the Delta for San Joaquin River salmonids.
- The interannual and within-season variability in survival at high export rates on various spatial scales.
- The mechanism for lower survival observed in the lower reaches of the San Joaquin River route (i.e., Turner Cut junction to Chipps Island) for higher export rates.
- The dependency of a survival-exports relationship on the presence of a physical barrier at the head of Old River.
- The effect of exports on survival apart from an effect of San Joaquin River inflow (inflow and exports have been highly correlated in past studies).

- The effect of exports on mortality mechanisms, including predator distribution and abundance.
- Incomplete multi-year analysis of existing Chinook salmon and steelhead AT data (analysis is ongoing); however, conclusions will remain uncertain due to limited observations at high export levels and correlation between exports and inflow, and possibly other variables (e.g., water temperature).
- The component of Delta mortality that is due to indirect effects of exports, compared to direct mortality at the facilities.
- Variability in pre-salvage survival, including pre-screen mortality (unknown at the CVP), entrainment mortality, and within-facility mortality, and how these responses depend on export rate.

E.7 SURVIVAL AS A FUNCTION OF OMR REVERSE FLOW

The conceptual model links flow through the Old and Middle rivers to survival via the influence of OMR reverse flow management on migration route selection and migration rate. Specifically, increased negative OMR flow is expected to draw (i.e., act as a flow cue) fish from the Sacramento River or lower San Joaquin River into the Interior Delta and toward the facilities, and to prevent fish that have entered the Interior Delta from navigating northward through Delta channels to the Delta exit (Figure E.2-1). Thus, increased negative OMR flow is expected to decrease through-Delta survival of Sacramento River and San Joaquin River fish. On the other hand, for San Joaquin River fish that have already entered the Interior Delta at the head of Old River, increased negative OMR flow may result in faster entry to salvage facilities at the CVP and SWP and, therefore, may be associated with higher survival from the head of Old River to Chipps Island via the Old River route. However, the SST did not look specifically at the effects of OMR reverse flows on survival. The effect of OMR reverse flows on survival in the Delta remains a knowledge gap. Additional analyses should be done to evaluate the effect of OMR reverse flows on survival.

E.8 SURVIVAL AS A FUNCTION OF SAN JOAQUIN RIVER INFLOW

The conceptual model links survival to San Joaquin River inflow via the effect of inflow on Delta hydrodynamics, route selection, and migration rate in the Delta. Higher inflow is expected to increase survival through regions of poor habitat such as the Interior Delta, and to discourage selection of migration routes that use the Interior Delta and fish facilities. Higher inflow may also increase migration rate through regions of beneficial habitats, which may result in lost growth potential during Delta migration and consequently lower survival upon exiting the Delta; we do not consider post-Delta survival specifically here.

The presence of the physical rock barrier at the head of Old River depends largely on San Joaquin River inflow: it cannot be installed for flows greater than 5,000 cfs, and cannot be operated (e.g., without overtopping and potential wash-out) for flows greater than

7,000 cfs. The present configuration of the barrier (2012, 2014 to 2016) includes eight culverts. Because the barrier restricts route selection at the head of Old River and may affect downstream survival due to flow effects and predator distribution, this restriction means that any effect of San Joaquin River inflow on survival may depend on the status of the barrier. In addition, the effect of inflow is expected to be stronger in the upstream reaches of the San Joaquin River or Interior Delta because tides override the influence of San Joaquin River inflow on hydrodynamics further downstream.

In this section, predictions from the conceptual model relating to survival as a function of inflow are identified and reviewed considering findings for Chinook salmon and steelhead. Findings come mostly from peer-reviewed literature and technical reports, but we also present new compilations of data from CWT and AT studies of San Joaquin River fish; the data used in these compilations are described in Section E.2.

E.8.1 Summary: Conceptual Model Predictions on Survival as a Function of San Joaquin River Inflow

The conceptual model predicted a positive relationship between San Joaquin River inflow and through-Delta survival. Findings have been inconsistent for Chinook salmon, and data are limited for steelhead.

- A positive relationship was found between Vernalis inflow and Delta survival of Chinook salmon, based on Chipps Island and ocean recoveries of CWTs (Newman 2008).
- Analysis of CWT recoveries from ocean recoveries alone showed no effect of Vernalis inflow on the joint probability of Delta and ocean survival for Chinook salmon, but Delta survival was not modeled separately from ocean survival (Zeug and Cavallo 2013; inflow was assessed in combination with exports).
- Comparison of adult escapement to the San Joaquin River basin between 1951 and 2012 with San Joaquin River flow at Vernalis two and a half years before adult return showed a positive association (years 1951 to 2003; SJRGA 2007; updated by the SST through 2012).
- Visual inspection by the SST of the few years of AT data available shows that higher Delta inflow at Vernalis does not always result in higher survival to Chipps Island, especially for Chinook salmon.

The conceptual model predicted a stronger relationship between San Joaquin River inflow and survival in upstream regions of the San Joaquin River and Interior Delta compared to downstream regions. Data are limited.

- Only AT data are available for assessing this prediction.
- Chinook salmon data show different trends in regional survival with San Joaquin River inflow (positive trend for Mossdale to Turner Cut junction, negative trend for

Turner Cut junction to Chipps Island), but formal analysis is lacking for the relative strengths of these trends.

- In contrast, the two years of steelhead AT data show no effect of San Joaquin River inflow on survival from Mossdale to Turner Cut junction and a positive association between inflow and survival from Turner Cut junction to Chipps Island.

E.8.2 Findings on Conceptual Model Linkages and Predictions: Effects of San Joaquin River Inflow on Survival

E.8.2.1 Effects of San Joaquin River Inflow on Survival of Chinook Salmon

Through-Delta Survival

The basis of knowledge regarding the conceptual model's linkages between San Joaquin River inflow at Vernalis and through-Delta survival of San Joaquin River Chinook salmon is medium. Although multiple directed field studies have collected data to evaluate this relationship, and the results from these studies are in peer-reviewed literature, agency reports, and this report, the relationship has become uncertain as more recent result have been considered. The predictability of the relationship may depend on whether a physical barrier is installed at the head of Old River. The extent to which other operations (e.g., export rates) affect the relationship between San Joaquin river inflow and through-Delta survival is unknown.

Comparison of adult escapement to the San Joaquin River basin between 1951 and 2003 with San Joaquin River flow at Vernalis two and a half years before adult return showed a positive association ($P < 0.01$), with higher adult escapement associated with higher San Joaquin River inflow (r^2=0.40 without the barrier in place at head of Old River; SJRGA 2007). An updated comparison performed by the SST using adult escapement data from 1951 to 2012 found similar results, although with a lower r^2 of 0.30. This finding is consistent with the hypothesis that higher Delta inflow from the San Joaquin River results in higher juvenile survival through the Delta. However, because adult escapement represents mortality factors throughout the life history, this finding is not unique to that hypothesis; for example, region-scale weather patterns may influence spawning, incubation, rearing, and ocean survival as well as juvenile through-Delta survival, and may also influence Delta inflow.

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 barrier at the head of Old River could not be installed when flows were high, 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, compared to a water quality model; it is possible that any effects on Delta survival were swamped by variability in ocean survival.

Single-variable graphical analyses performed by the SST suggest that the range of possible survival values may increase up to a point as inflow at Vernalis increases, when the status of the barrier at the head of Old River is not accounted for, despite considerable variation in observed survival under most inflow values (Figure E.8-1). Based on CWT data for which survival index estimates were available for inflows up to approximately 28,000 cfs, survival to Jersey Point appears generally to increase for inflow less than 19,000 cfs and decrease for inflow greater than 19,000 cfs (Figure E.8-1); observations at high inflows were all in years without the HORB, which cannot be installed when inflow greater than 5,000 cfs or operated for inflow greater than 7,000 cfs. In such years without a barrier, fish may have migrated either via the San Joaquin River or Old River, including through the facilities. When a physical barrier was installed at the head of Old River, there appears to be a stronger effect of flow on survival to Jersey Point, based primarily on the CWT data, with higher survival typically observed with higher inflow (up to approximately 6,500 cfs) (Figure E.8-2). Results from AT data are similar to CWT results for similar values of inflow at Vernalis, although no AT data are available for inflow greater than approximately 12,000 cfs and only one year of AT data are available in the presence of the physical barrier (top row of plots in Figures E.8-1 and E.8-2).

It is apparent that understanding the effect of inflow on survival in the Delta requires accounting for the presence or absence of the barrier at the head of Old River. For example, 2011 was a high flow year 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 E.2-3). The HORB was absent in 2011 because of the high flows; although most acoustic-tagged Chinook salmon reaching the head of Old River continued migrating down the San Joaquin River, approximately 40% entered Old River at that junction, and survival to Chipps Island was low in both routes (≤ 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 E.2-3). 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 5,000 cfs (the highest inflow for which the barrier may be installed).

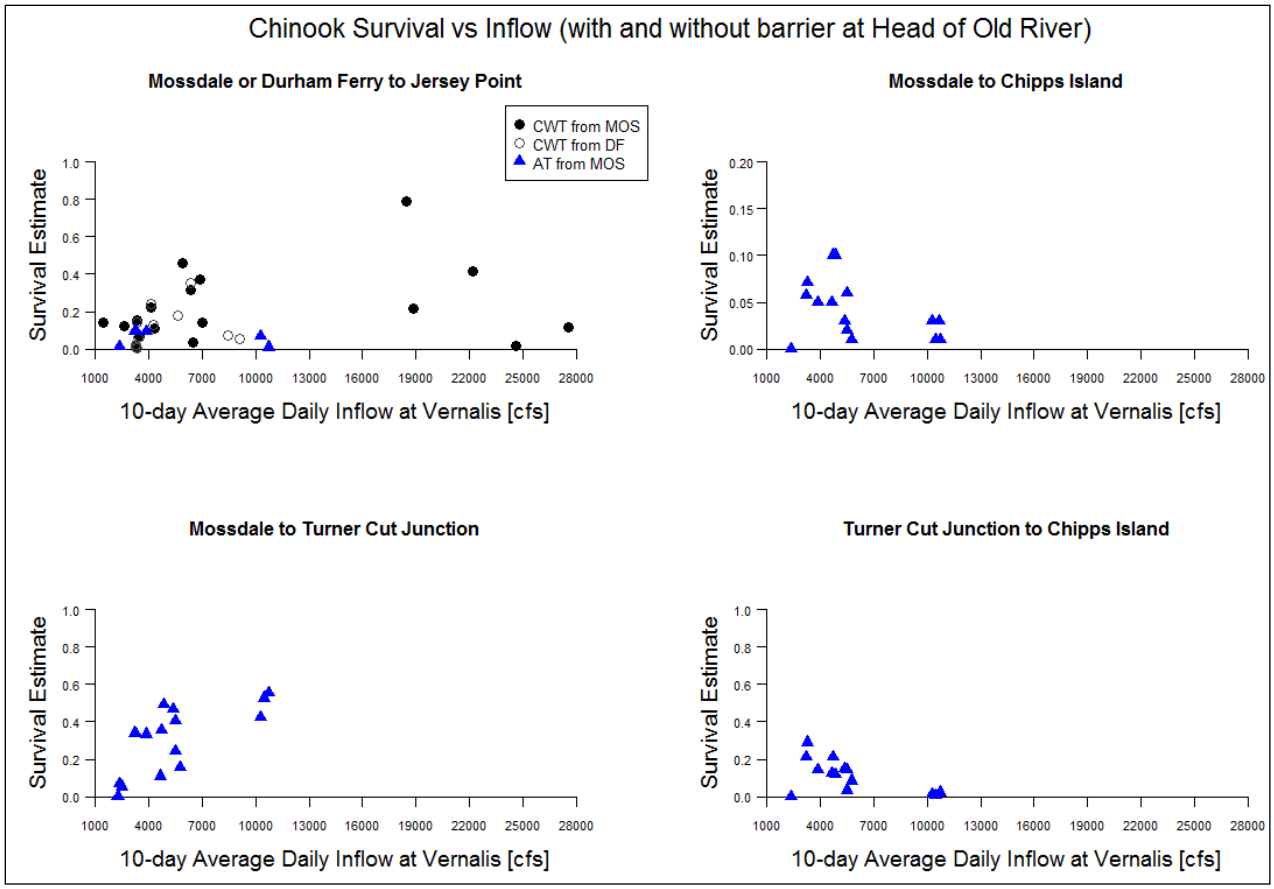

Figure E.8-1. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Average Inflow at Vernalis, Regardless of Barrier Status at the Head of Old River

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

Reach-Specific Survival

Our basis of knowledge regarding the conceptual model's linkage between San Joaquin River inflow and region-specific survival of juvenile Chinook salmon is low. Multiple directed field studies have collected data to evaluate this relationship but the analysis of these data relative to inflow is ongoing, and presently is described only in this report. The extent to which operations affect the relationship between San Joaquin River inflow and reach-specific survival is unknown.

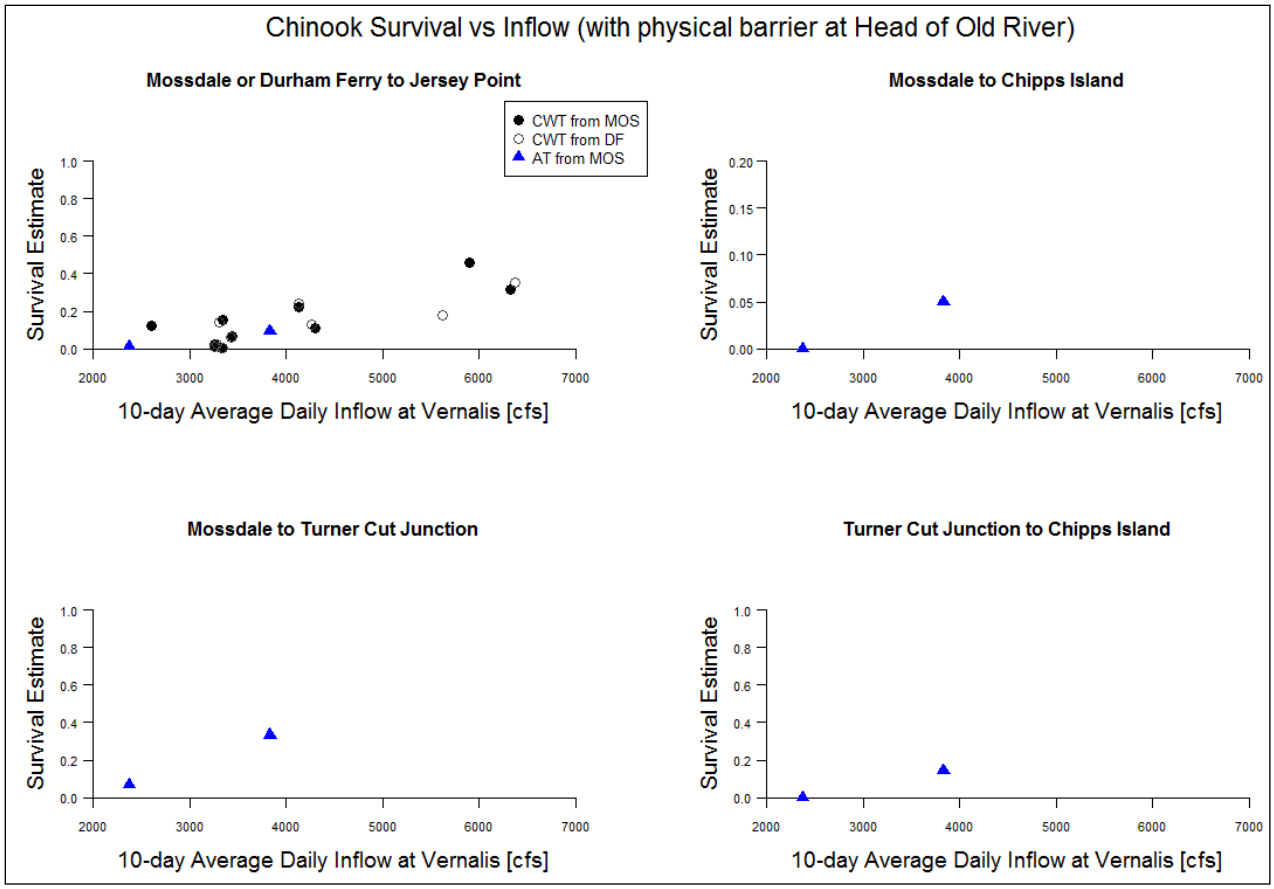

Figure E.8-2. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Average Inflow at Vernalis, in the Presence of a Physical Barrier at the Head of Old River

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

Most estimates of survival in individual reaches between Mossdale and Chipps Island come from AT data (with the exception of CWT data from 1991), most of which were taken during periods of low inflow (Figure E.8-1), and all but two of which from studies without a physical barrier at the head of Old River (Figures E.8-2 and E.8-3). There were only four observations of AT survival for inflow greater than 10,000 cfs (all from 2011), and no observations with inflow between 7,000 cfs and 10,000 cfs. For inflow less than 7,000 cfs, there is considerable variability in AT survival estimates in all three spatial regions or scales considered: Mossdale to Chipps Island, Mossdale to Turner Cut junction, and Turner Cut junction to Chipps Island. Nevertheless, there appears to be a positive relationship between inflow and survival from Mossdale to Turner Cut, and a negative relationship from Turner Cut to Chipps Island (based only on AT data), especially when no physical barrier was installed at the head of Old River (Figure E.8-3). The three observations for inflow greater than 10,000 cfs (all without a physical barrier at the head of Old River), however, show considerably less variability in survival estimates: estimated survival from Mossdale to

Turner Cut junction was relatively high (range = 0.42 to 0.55) for these inflow values compared to lower inflow values, while estimated survival from Turner Cut junction to Chipps Island was very low (range = 0.01 to 0.02) for inflow greater than 10,000 cfs, and lower than all but one estimates for inflow less than 7,000 cfs (Figure E.8-1). A positive effect of inflow in the more riverine sections is consistent with findings for late-fall-run Chinook salmon in the Sacramento River (Michel et al. 2015).

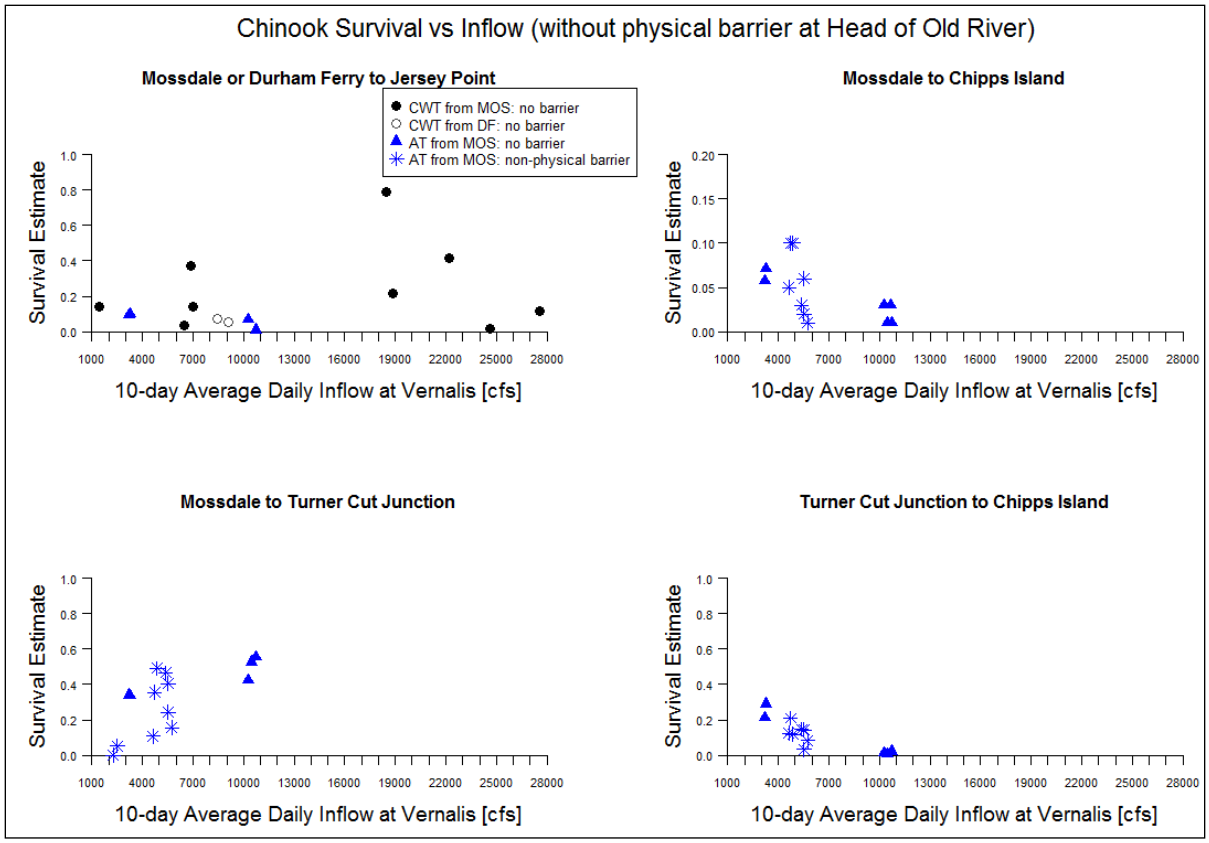

Figure E.8-3. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of Daily Average Inflow at Vernalis, in the Presence of Either a Non-physical Barrier or No Barrier at the Head of Old River

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

Without the barrier in place, a relatively strong positive relationship between inflow and survival appears to exist for the reach between Mossdale and the Turner Cut junction, whereas there appears to be a negative relationship between flow at Vernalis and survival from Turner Cut to Chipps Island (Figure E.8-3). 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 (Figure E.8-2), which are too few observations to characterize the variability in reach-specific survival in the presence of a physical barrier. Thus, it is not currently possible

to determine the relationship between Vernalis inflow, the barrier, and survival in different regions of the Delta. The lack of reach-specific survival estimates in the presence of a physical barrier is considered a data gap, as is the lack of estimates of reach-specific survival at high inflow levels. More estimates in the presence of the physical barrier will be available when recent data (2014 to 2016) have been analyzed. A rigorous analysis of the spatial pattern of survival and inflow observations, combined with barrier, tag type, and correlation between export and inflow, and based on additional data at higher inflow levels and with and without the physical barrier, is required to adequately address the relationship between inflow and survival in the Delta for Chinook salmon.

Facility Survival

The basis of knowledge regarding the conceptual model linkages between San Joaquin River inflow and facility survival of juvenile Chinook salmon is low. Although no formal field studies have been conducted on this specific question, analyses of relevant data from existing studies have been published in peer-reviewed literature and in this report; the nature of the data mean that findings are indirect. The extent to which operations affect the relationship between San Joaquin River inflow and facility survival is unknown.

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 inflow on entrainment at the SWP. At the CVP, they found a positive association between flow and the probability of observing any fish in salvage (Zeug and Cavallo 2014). This finding is counter to expectations, but may partially reflect positive correlation between exports and inflow during CWT studies (see Section E.1.3).

No formal studies have been found relating facility survival to San Joaquin River inflow. The available AT survival estimates from the CVP trash racks to Chipps Island for acoustic-tagged Chinook salmon demonstrate considerable variability and no obvious pattern (SST data compilations). However, survival through the CVP was more variable (and included the highest estimates) for the lower levels of inflow (less than 7,000 cfs); all estimates through CVP were ≤ 0.22 for inflow greater than 10,000 cfs (Figure E.8-4). However, estimates were available for only a limited range of inflow values (Figure E.8-4). All but one of the estimates of survival from the CCF to Chipps Island was 0; the single non-zero estimate was for inflow = 10,690 cfs (Figure E.8-4). It is worth noting that if survival from the CCF to Chipps Island via the SWP is low overall, then it would require a relatively large number of tagged study fish attempting to use that route to reliably observe a survival estimate greater than 0. Low inflow at Vernalis may limit the probability of reaching the CCF, and thus lower the effective sample size available for estimating CCF-Chipps Island survival, and increase the chance of observing a survival estimate of 0 through this route. This may explain why the only non-zero estimate of survival from CCF to Chipps Island via the SWP was for a

relatively high inflow value (10,690 cfs) compared to the other observations available (Figure E.8-4). Low inflow at Vernalis may lower the probability of taking the CCF route either by increasing mortality before reaching the CCF, or by increasing the probability of taking another route (e.g., San Joaquin River route or CVP); further analysis of the existing data may provide insight in this issue.

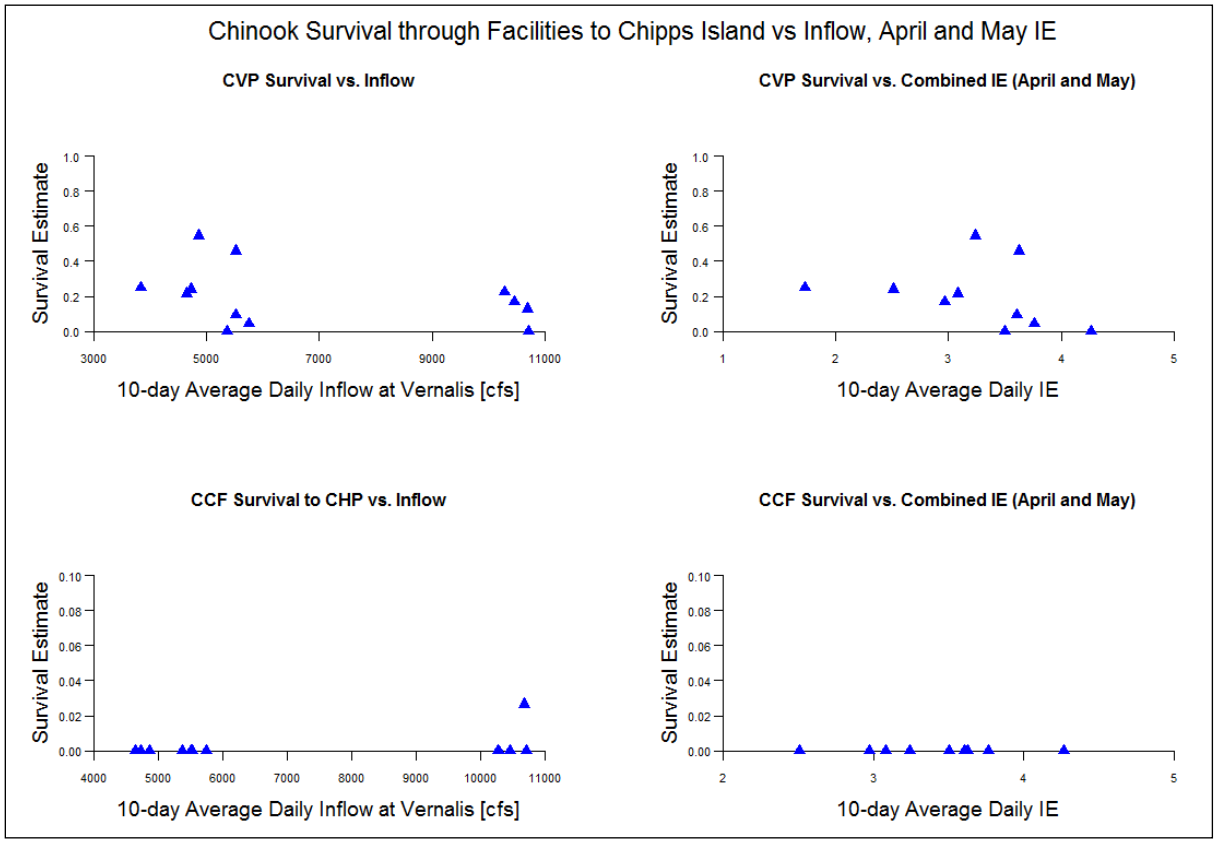

Figure E.8-4. Estimated Survival of Fall-run Chinook Salmon Based on AT Data (2008, 2010 – 2012 Studies), Versus the 10-day Average of Inflow or I:E (only April and May Releases for I:E)

Notes: Survival is from trash racks for CVP, and from radial gates at entrance to CCF for SWP. Survival from the CCF to Chipps Island is through the SWP. I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, regardless of barrier status at the Head of Old River. Inflow and exports rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rates at SWP include BBID intake.

E.8.2.2 Effects of San Joaquin River Inflow on Steelhead

Our basis of knowledge regarding the conceptual model's linkage between San Joaquin River inflow and through-Delta, reach-specific, and facility survival for steelhead is low. A single multi-year field study has collected data to evaluate this relationship but only the first two years of data are currently available (in an agency report), and they are compared to inflow only in this report. The extent to which operations affect the relationship between San Joaquin River inflow and steelhead survival is unknown.

Visual inspection by the SST of the few steelhead data available show an overall increase in survival from Mossdale to Jersey Point or Chipps Island as San Joaquin River inflow increases (Figure E.8-5). The increase is noticeable on the reach scale from the Turner Cut junction to Chipps Island, but not from Mossdale to the Turner Cut junction. 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 barrier was installed and operating. Survival to the Turner Cut junction was similar in both years (Figure E.8-5). Overall, survival to Chipps Island was slightly lower in 2012 (Figure E.2-3). 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 (Figure E.8-1). 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 Interior Delta at Turner Cut, whereas only one acoustic-tagged Chinook salmon that has entered Turner Cut has been observed at Chipps Island in four years of studies (e.g., Figure E.4-4). Survival through both the CVP and the SWP to Chipps Island was higher for higher inflow levels in these two years (Figure E.8-6). This observation is consistent with findings that louver or salvage efficiency is positively associated with bypass velocity at the CVP for Chinook salmon (e.g., Karp et al. 1995; Sutphin and Bridges 2008). However, two years of data for steelhead are insufficient to characterize a relationship between inflow and survival because of possible interacting factors (e.g., barrier status, water temperature) and interannual variability.

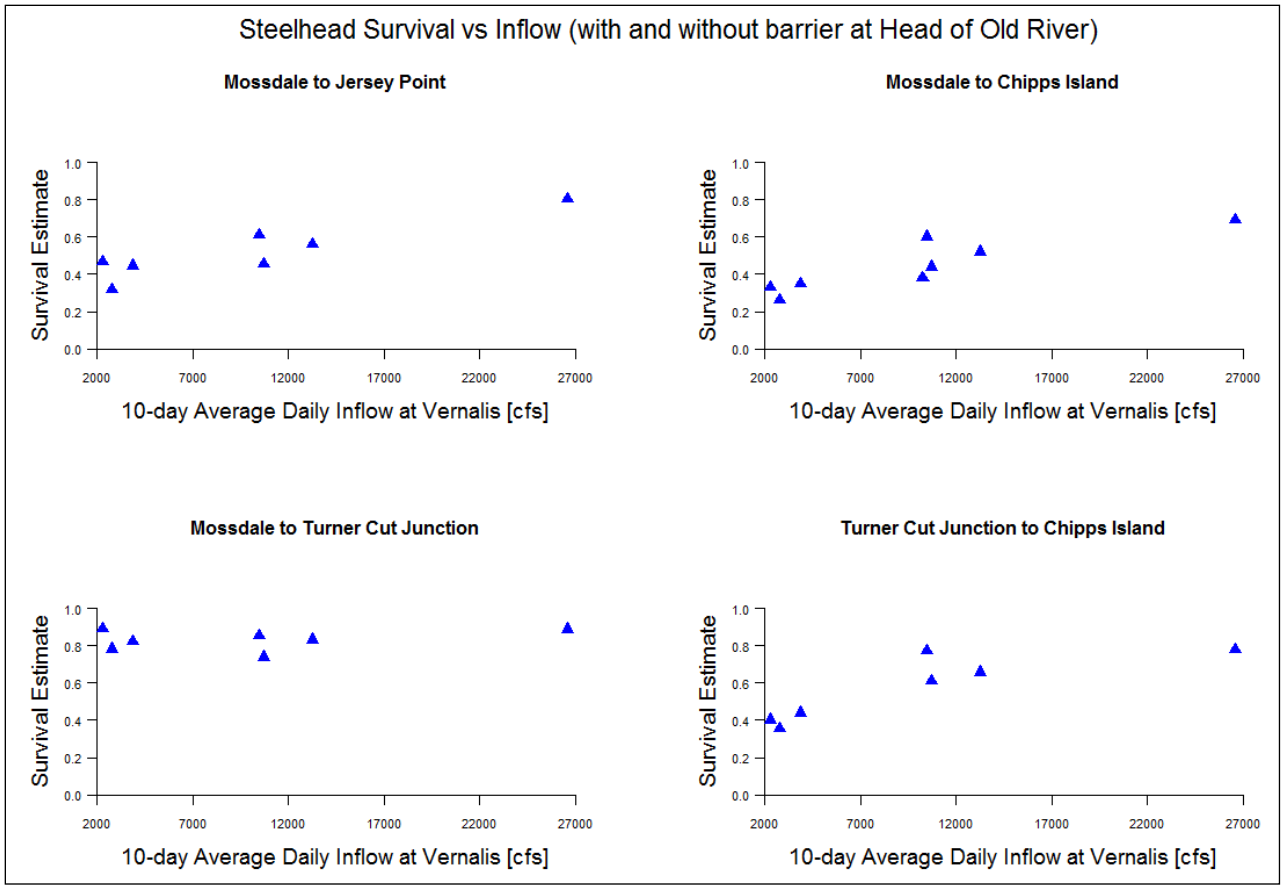

Figure E.8-5. Estimated Survival of Steelhead Based on AT Data (2011 and 2012 Study Years), Versus the 10-day Average of Daily Average Inflow at Vernalis, Regardless of Barrier Status at the Head of Old River

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.

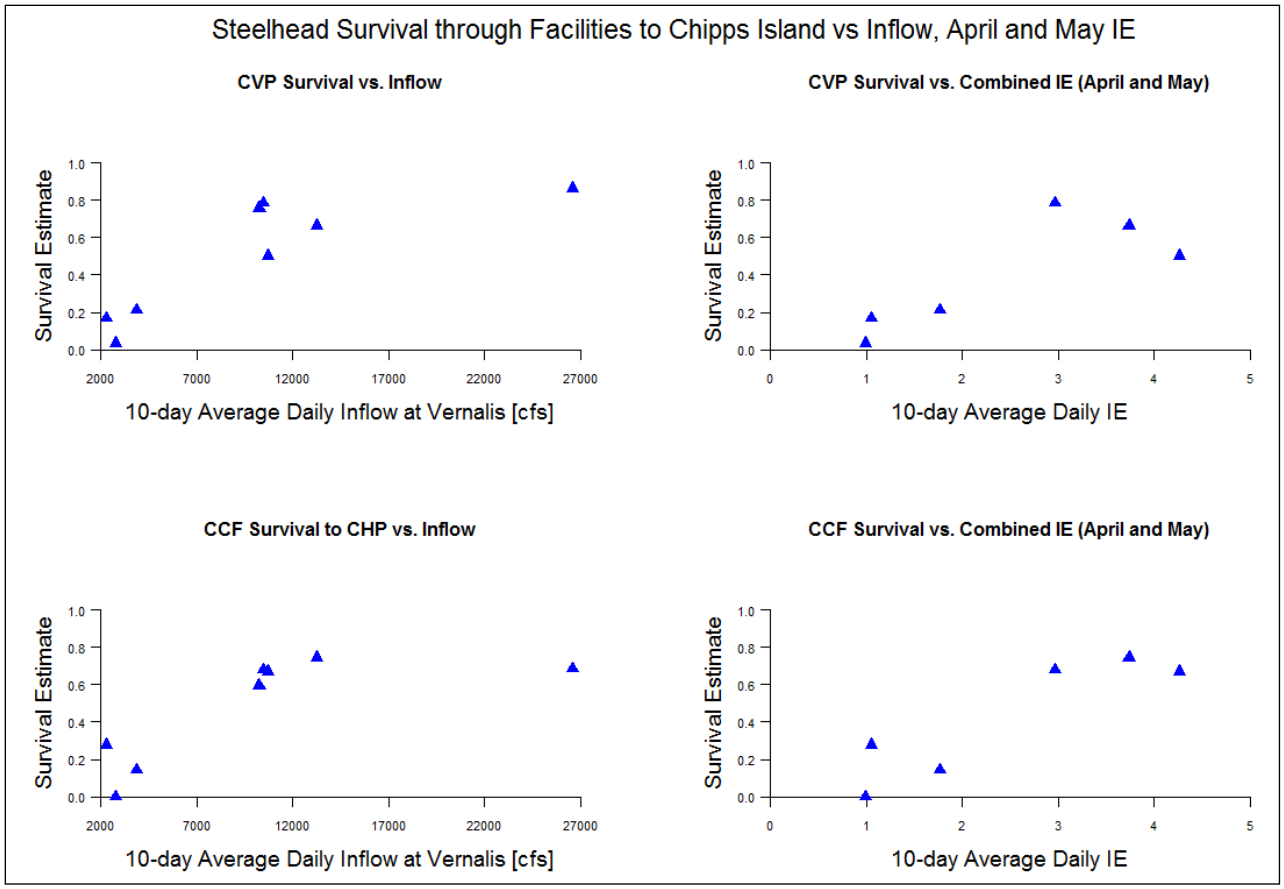

Figure E.8-6. Estimated Survival of Steelhead Based on AT Data (2011 – 2012), Versus the 10-day Average of Inflow or I:E (only April and May Releases for I:E)

Notes: Survival is from trash racks for CVP, and from radial gates at entrance to CCF for SWP. Survival from the CCF to Chipps Island is through the SWP. I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, regardless of barrier status at the Head of Old River. Inflow and exports rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rates at SWP include BBID intake.

E.8.3 Summary: Knowledge Gaps on Survival as a Function of San Joaquin River Inflow

Several knowledge gaps exist in our understanding of how Delta survival of migrating salmonids depends on San Joaquin River inflow.

- Interannual and within-season variability in survival in different regions at high inflow levels and/or in the presence of the physical barrier at the head of Old River.
- Insufficient observations of survival on various spatial scales at higher inflow levels.
- Insufficient observations of survival on various spatial scales in the presence of a physical barrier at the head of Old River.
- The mechanisms for lower survival observed in the lower reaches of the San Joaquin River route (i.e., Turner Cut junction to Chipps Island) for higher inflow levels.

- The dependency of a survival-inflow relationship on the presence of a physical barrier at the head of Old River.
- The effect of inflow on survival apart from an effect of water exports.
- The effect of inflow on mortality mechanisms, including temperature and predator distribution and abundance.
- Incomplete multi-year analysis of existing Chinook salmon and steelhead AT data, although conclusions will remain uncertain due to limited observations at high export levels and correlation between exports and inflow, and possibly other variables (e.g., water temperature).

E.9 SURVIVAL AS A FUNCTION OF SACRAMENTO RIVER INFLOW

The conceptual model links survival to Sacramento River inflow via inflow effects on migration route selection and migration rate. In particular, higher Sacramento River inflow is predicted to reduce the proportion of fish entering the Interior Delta via Georgiana Slough or the DCC by pushing the tidal prism downstream, and survival to Chipps Island is anticipated to be higher in the Sacramento River mainstem routes than in Interior Delta routes (Figure E.2-1). These two predictions together yield a prediction of higher survival to Sacramento River resulting from higher Sacramento River inflow.

E.9.1 SUMMARY: CONCEPTUAL MODEL PREDICTIONS ON SURVIVAL AS A FUNCTION OF SACRAMENTO RIVER INFLOW

The conceptual model predicted that increased Sacramento River inflow is associated with increased survival to Chipps Island for Chinook salmon migrating from the Sacramento River.

- CWT recovery rates and through-Delta survival estimates from AT data are consistent with this prediction (Newman and Rice 2002; Newman 2003; Perry 2010).
- Inflow was observed to have a stronger effect on survival in the riverine reaches of the Sacramento River and less effect in the estuarine or tidal reaches (Michel et al. 2015).
- Both the Perry (2010) model and the Newman (2003) model predict that the flow-survival relationship “flattens out” as discharge increases.
- Salvage rates (and by assumption, entrainment mortality rates) of CWT fish have been found to be negatively associated with Sacramento River inflow by Zeug and Cavallo (2014), but no significant relationship was found by Kimmerer (2008).

E.9.2 Findings on Conceptual Model Linkages and Predictions: Effects of Sacramento River Inflow on Survival

E.9.2.1 Through-Delta and Regional Survival

The basis of knowledge regarding Sacramento River inflow and through-Delta and regional survival is high. Multiple field studies have collected data to evaluate this relationship; results have been published in peer-reviewed literature, agency reports, and doctoral dissertations. The extent to which other operations (e.g., export rates) affect the relationship between Sacramento River inflow and through-Delta survival is unknown.

The relationship between Sacramento River inflow and survival through the Delta for Sacramento River 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) modeled survival of fall-run Chinook salmon with a mean size of 81 mm 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 with a mean size of 156 mm 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 (Figure E.2-1 and Figure E.9-1). Additionally, Michel et al. (2015) reported higher survival of acoustic-tagged late-fall-run Chinook salmon through the riverine reaches of the Sacramento River when flow was higher, but no effect of flow in the more tidal or estuarine reaches; the flow comparison was based on a single high-flow year compared to multiple low-flow years.

To explore both the CWT data and the AT data further, in 2015, Russell Perry (U.S. Geological Survey [USGS]) plotted the estimated flow-survival models from both the Newman (2003) study and the Perry (2010) study using a standardized measure of fish length and river discharge (flow), and controlling for river reach and DCC operations (R. Perry, personal communication) (Figure E.9-1). Both models were available for the Sacramento River reach from Ryde to Chipps Island (Figure E.2-1), either with the DCC closed (Perry [2010] model) or with the DCC status unspecified (Newman [2003] model) (left-hand column of Figure E.9-1). Only the Newman (2003) model was available for the reach from Sacramento to Chipps Island and when the DCC was closed (right-hand column of Figure E.9-1). The CWT model from Newman (2003) was very similar to the AT model from Perry (2010) when standardized for reach and a common fish size. In particular, the general trend is that the marginal increase in survival per unit increase in flow tends to decrease as flow

increases. That is, the flow-survival relationship "flattens out" as discharge increases. This relationship was observed for both river reaches.

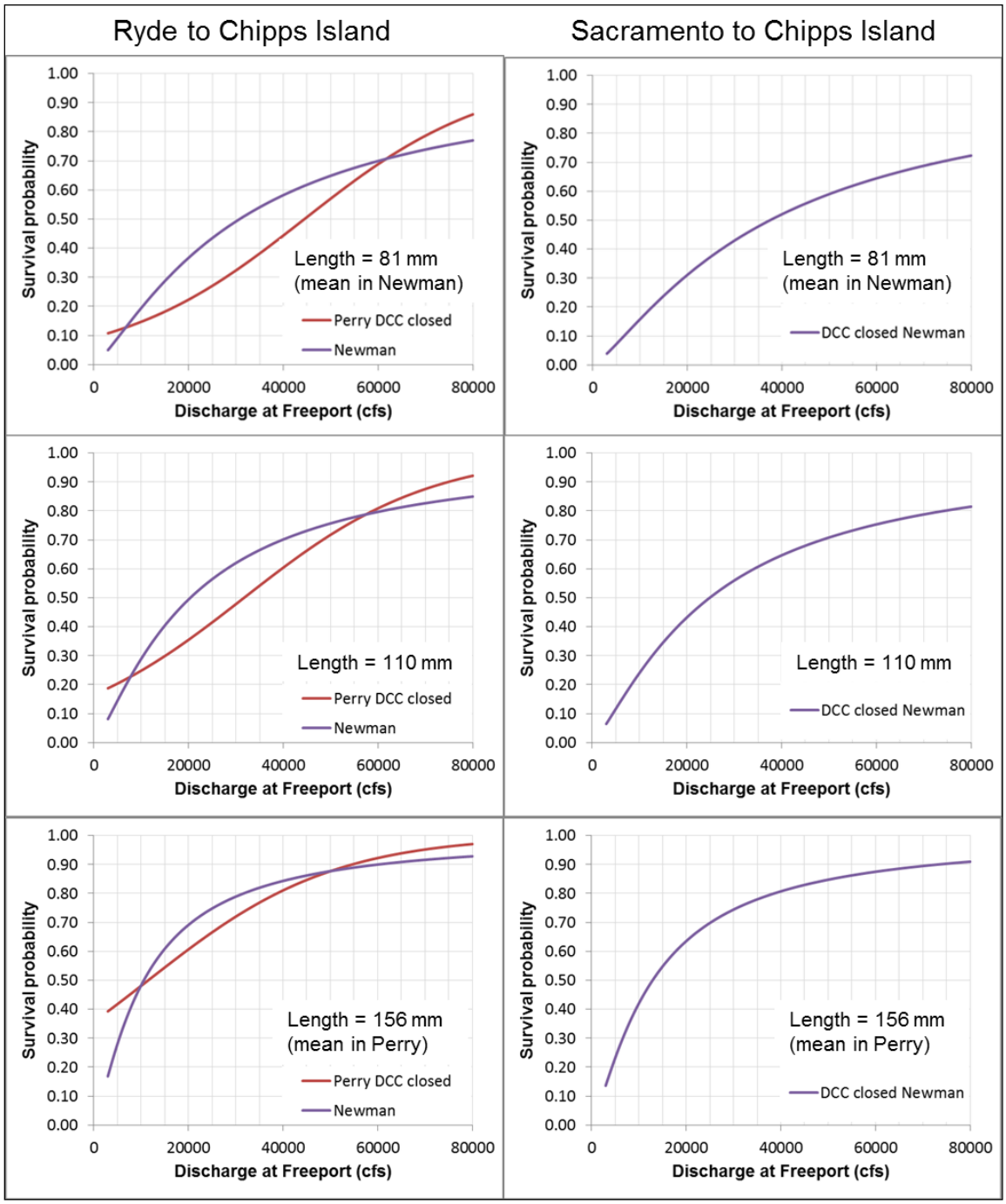

Figure E.9-1. Predicted Survival in the Sacramento River from Ryde to Chipps Island as Function of Sacramento River Discharge at Freeport for Different-sized Fish, for the Perry (2010) Model and the Newman (2003) Model

Note: The relationships from both studies have been extended beyond the range of observed data used to estimate the relationships with respect to both fish size and discharge. Source: R. Perry, USGS.

Perry noted that FL, Freeport discharge, and DCC position were included as covariates for the Newman plots. All other covariates (i.e., salinity, hatchery temperature and release temperature, turbidity, tides, and exports) were set to mean values. Newman (2003) did not include DCC position as a covariate for survival for the Ryde to Chipps Island reach. For Perry (2010), survival was based on discharge of the Sacramento River below Georgiana Slough. Discharge below Georgiana Slough was then related to Freeport flow using a regression equation provided to Perry by John Burau (USGS). The flow-survival relationship is plotted at the median of release-specific intercepts. Perry noted that the relationships from both studies have been extended beyond the range of observed data used to estimate the relationships, both for fish size and for river discharge.

E.9.2.2 Facility Survival

Our basis of knowledge regarding the linkages between Sacramento River inflow and facility survival is low. Two peer-reviewed publications address this linkage between Sacramento River inflow and salvage, but results were conflicting and the extent to salvage is an indicator of facility loss is unknown.

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) found that the probability of collecting any fish in salvage was negatively associated with Sacramento River inflow for both CVP and SWP, and the number of fish salvaged was also negatively associated with inflow for CVP for winter-run, late-fall-run, and fall-run Chinook salmon. If it is true that salvage and entrainment consistently vary together, this finding suggests that entrainment mortality is also negatively associated with Sacramento River inflow.

E.9.3 Summary: Knowledge Gaps on Survival as a Function of Sacramento River Inflow

Knowledge gaps on survival as a function of Sacramento River inflow include:

- Relationship between Sacramento River inflow and survival to Chipps Island for winter and spring Chinook salmon runs.
- Insufficient observations of survival in different regions under high-flow conditions for some salmon runs (e.g., late-fall run in more tidal regions of the Delta; winter and spring runs).
- The extent to which salvage is an index of entrainment and facility mortality; this requires knowing the magnitude and variability in pre-screen mortality at the CVP.

E.10 SURVIVAL AS A FUNCTION OF DELTA E:I

The conceptual model links survival to Delta exports and Delta inflow via direct mortality and effects on hydrodynamics, and resulting effects of hydrodynamics on migration route and rate. Exports are expected to have a negative effect on survival, and inflow a positive effect on survival. Thus, as the ratio of exports to inflow increases, survival is expected to decrease. Direct mortality in the facilities affects only fish that enter the Interior Delta, so the relative survival in the Interior Delta route to survival in the Sacramento River mainstem route is expected to also decrease as the ratio of exports to inflow increases.

E.10.1 SUMMARY: CONCEPTUAL MODEL PREDICTIONS ON SURVIVAL AS A FUNCTION OF DELTA E:I

The conceptual model predicted that survival through the Delta will decrease as Delta E:I increases. 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:

- A small, non-statistically significant negative effect of E:I on survival of fall-run Chinook (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 exports (E) and inflow (I) separately for late-fall-run Chinook salmon (Newman and Brandes 2010) and fall-run, late-fall-run, and winter-run Chinook salmon (Zeug and Cavallo 2014).
- A stage-structured life-cycle model found a negative effect of E:I on survival through the Delta for fall-run Chinook salmon (Cunningham et al. 2015).

E.10.2 FINDINGS ON CONCEPTUAL MODEL LINKAGES AND PREDICTIONS: EFFECTS OF DELTA E:I ON SURVIVAL

Our basis of knowledge for the conceptual model's linkages between Delta E:I and survival in the Delta is high. Multiple field studies have collected data relevant to this question, and results have been published in peer-reviewed literature and a technical report. Some of the studies have used Sacramento River inflow rather than the combined Delta inflow from the Sacramento and San Joaquin rivers.

Newman and Rice (2002) found that increases in the ratio of exports to Sacramento River inflow was associated with lower survival of Sacramento River fall-run Chinook salmon through the lower Sacramento River 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, or no

exports. Zeug and Cavallo (2014) found that E:I explained less variation in salvage rates of hatchery CWT fish from the Sacramento River than using measures of exports and inflow separately.

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

E.10.3 Summary: Knowledge Gaps on Survival as a Function of Delta E:I

Knowledge gaps on survival as a function of Delta E:I include:

- Assessment of existing AT data for a relationship between Delta E:I and survival through the Delta.
- The role of interannual variability in the relationship between Delta E:I and Delta survival.
- The difference in the relationship between Delta E:I and Delta survival for different runs of salmon.

E.11 SURVIVAL AS A FUNCTION OF SAN JOAQUIN RIVER I:E

The San Joaquin River I:E is the ratio of San Joaquin River inflow at Vernalis to exports. The conceptual model predicts that for fish migrating from the San Joaquin River, Delta survival will increase with inflow and decrease with exports; thus, survival is expected to increase with I:E. Inasmuch as inflow and exports have variable effects in different regions of the Delta, the strength of the relationship between I:E and survival may vary in different regions of the Delta. The I:E-survival relationship may also depend on the status of the barrier at the head of Old River.

E.11.1 Summary: Conceptual Model Predictions on Survival as a Function of San Joaquin River I:E

The conceptual model predicted that Delta survival increases with I:E, and that the relationship may depend on the status of the barrier at the head of Old River. Findings show a complicated relationship with considerable variability, based mostly on provisional visual inspection of scatterplots.

- CWT Chinook 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 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 data show more variable 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 to 2003, SJRGA 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.

The conceptual model predicted that the relationship between I:E and survival may vary in different regions of the Delta.

- AT Chinook salmon data, in the absence of a physical barrier at the head of Old River, show a positive trend in survival between Mossdale and the Turner Cut junction with I:E, a negative trend for survival between Turner Cut junction and Chipps Island, and no relationship for survival through the facilities to Chipps Island.
- AT steelhead data show no relationship between I:E and survival from Mossdale to Turner Cut, and a possible positive relationship for survival from Turner Cut junction to Chipps Island and from either the CVP trash racks or the CCF radial gates through salvage to Chipps Island.

E.11.2 Findings on Conceptual Model Linkages and Predictions: Effects of San Joaquin River I:E on Survival

E.11.2.1 Effects of San Joaquin River I:E on Survival of Chinook Salmon

Through-Delta Survival

The basis of knowledge regarding the conceptual model linkages between San Joaquin River I:E and through-Delta survival of Chinook salmon is low. Multiple field studies have collected data to evaluate this relationship; most results are presented in agency reports or in this report.

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 = 0.2182, $P < 0.05$, r^2=0.26); no significant relationship was observed without the barrier in place (SJRGA 2007). Using VAMP CWT data, the California Department of Fish and Game (CDFG 2005) found weak negative correlation between the CWT survival index and the ratio of Delta exports to

inflow at Vernalis (r^2=0.16) with the HORB in place, and concluded that inflow had a stronger effect on juvenile survival of fall-run Chinook salmon through the Delta than the ratio of exports to inflow. The 2006 VAMP report also compared adult Chinook salmon escapement to the San Joaquin River basin between 1951 and 2003 with San Joaquin River I:E, measured between April 15 and June 15, two and a half years before adult return, and found a positive association between I:E and adult return ($P < 0.01$, r^2=0.56 without the barrier; SJRGA 2007). Values of I:E ranged up to greater than 300 during this time period, although most observations were less than 10. This analysis from the VAMP report was updated by the SST using adult escapement data through 2012 and found similar results (r^2=0.51). Similarly, CDFG (2005) found a negative correlation between adult escapement (years 1970 to 2002) and the ratio of Delta exports to Vernalis flow two and a half years prior to adult return (r^2=0.44). These findings on adult escapement are consistent with the hypothesis that higher San Joaquin River I:E results in higher juvenile survival through the Delta, assuming that returning salmon were all three years old. However, because adult escapement represents mortality factors throughout the life history, this finding is not unique to that hypothesis; for example, region-scale weather patterns, which may influence I:E to some extent, may also influence spawning, incubation, rearing, and ocean survival as well as juvenile through-Delta survival.

The available estimates of survival through the Delta, from either CWT or AT data, were plotted against the ten-day average I:E (Figures E.11-1 through E.11-3). Visual inspection of SST scatterplots of the available survival estimates through the Delta to Jersey Point show that most estimates are for ten-day average I:E less than 5 (top left plots in Figures E.11-1 through E.11-3). Ignoring the status of the barrier at the head of Old River, there is considerable variability in survival for I:E less than 5 (Figure E.11-1). 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 to 0.14) were observed for I:E of approximately 4. The highest survival estimate to Jersey Point (0.79, from 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 (top left plot, Figure E.11-1). All estimates for I:E greater than 4.5 were from CWT studies. Estimated survival to Jersey Point tended to increase with one-day average I:E when the head of Old River physical barrier was installed, but no estimates for I:E greater than 3 were observed with the physical barrier (top left plot, Figure E.11-2). 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 (compare top left plots in Figures E.11-1 and E.8-1). There is less similarity between the I:E plot and the exports plot (compare top left plots in Figures E.11-1 and E.6-2); although there is considerable variability in survival estimates for export rates less than approximately 3,000 cfs, there is no indication that the range (e.g., maximum) of possible survival values depends on exports, as there is for I:E less than 3.

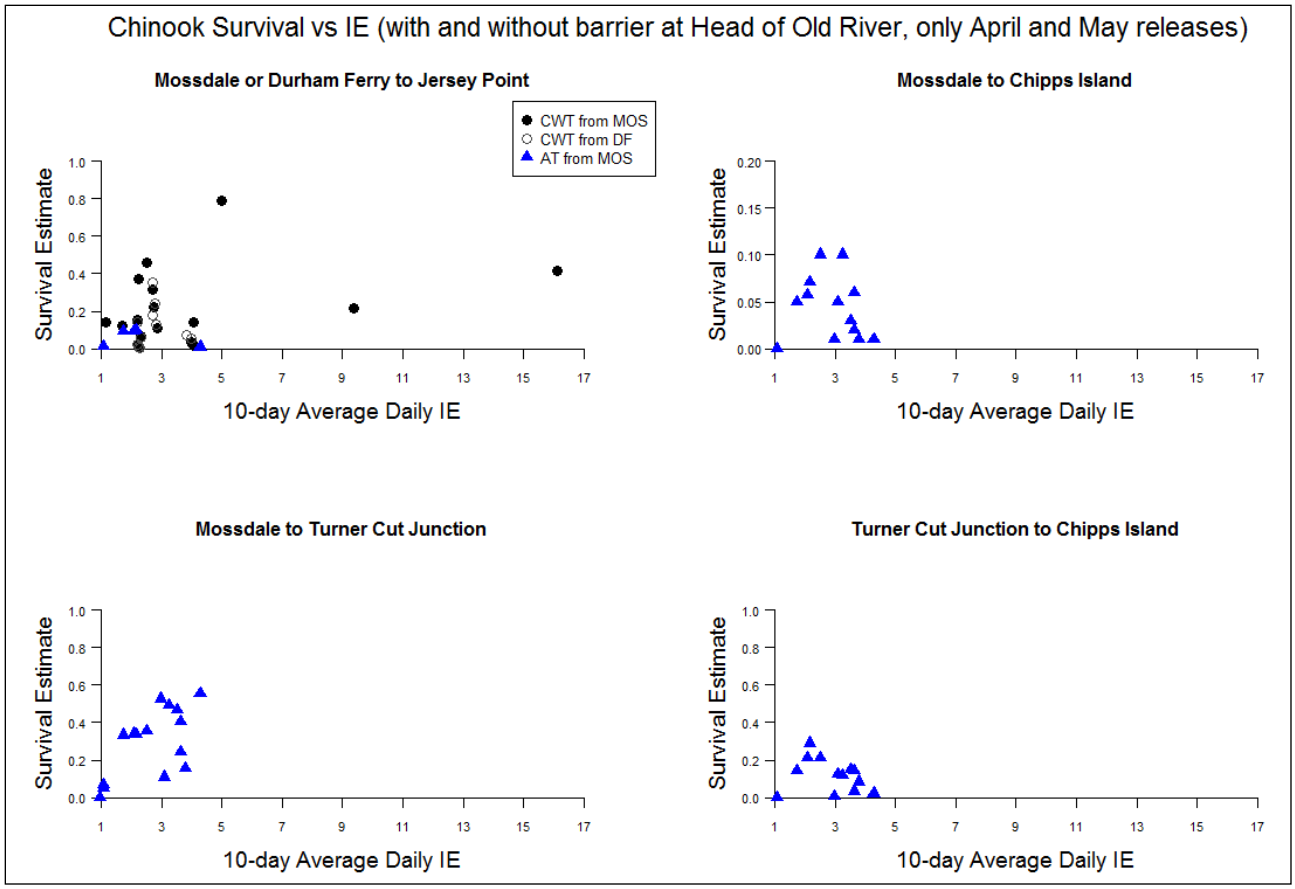

Figure E.11-1. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of I:E for April and May Releases

Notes: I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, regardless of barrier status at the Head of Old River. Inflow and exports 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 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.

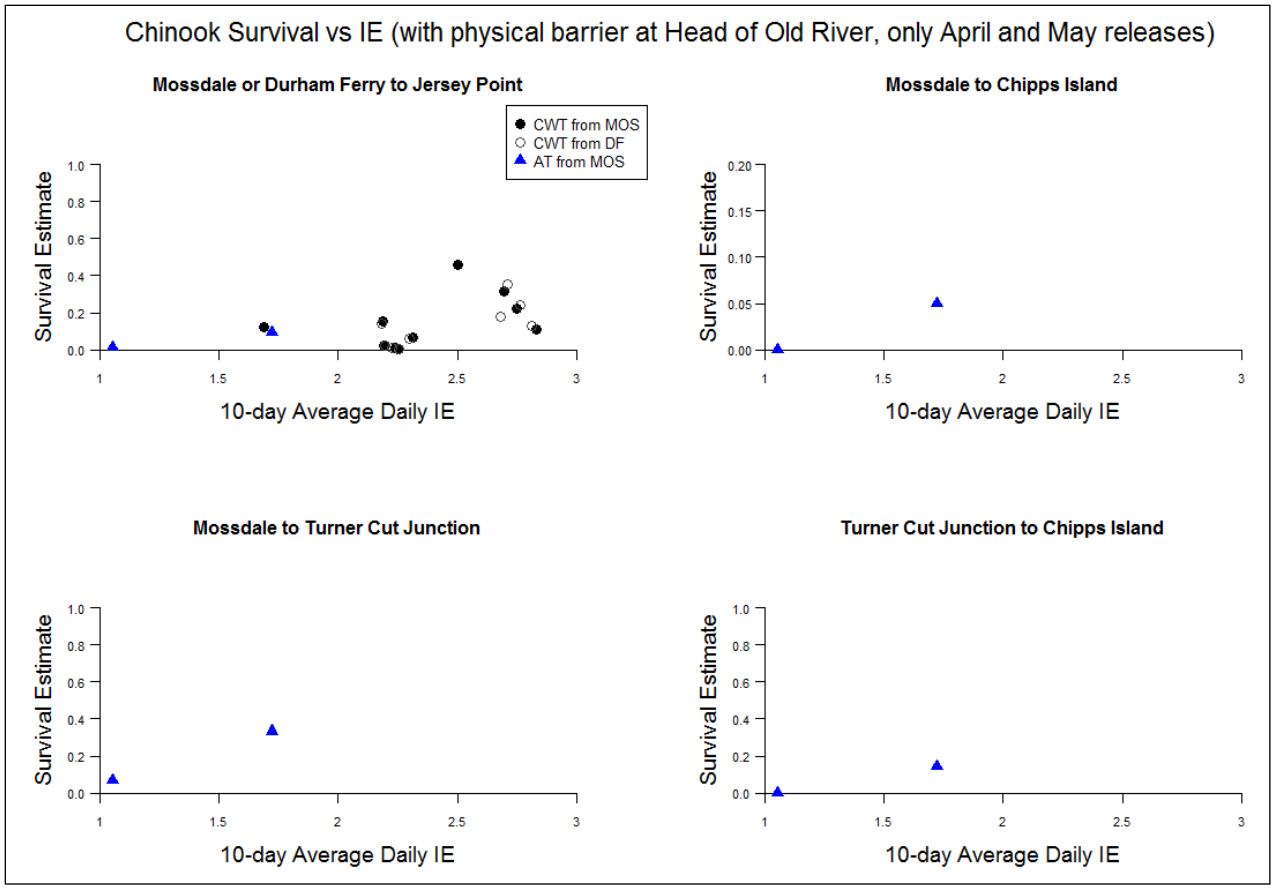

Figure E.11-2. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of I:E for April and May Releases

Notes: I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, in the presence of a physical barrier at the Head of Old River. Inflow and exports 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 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.

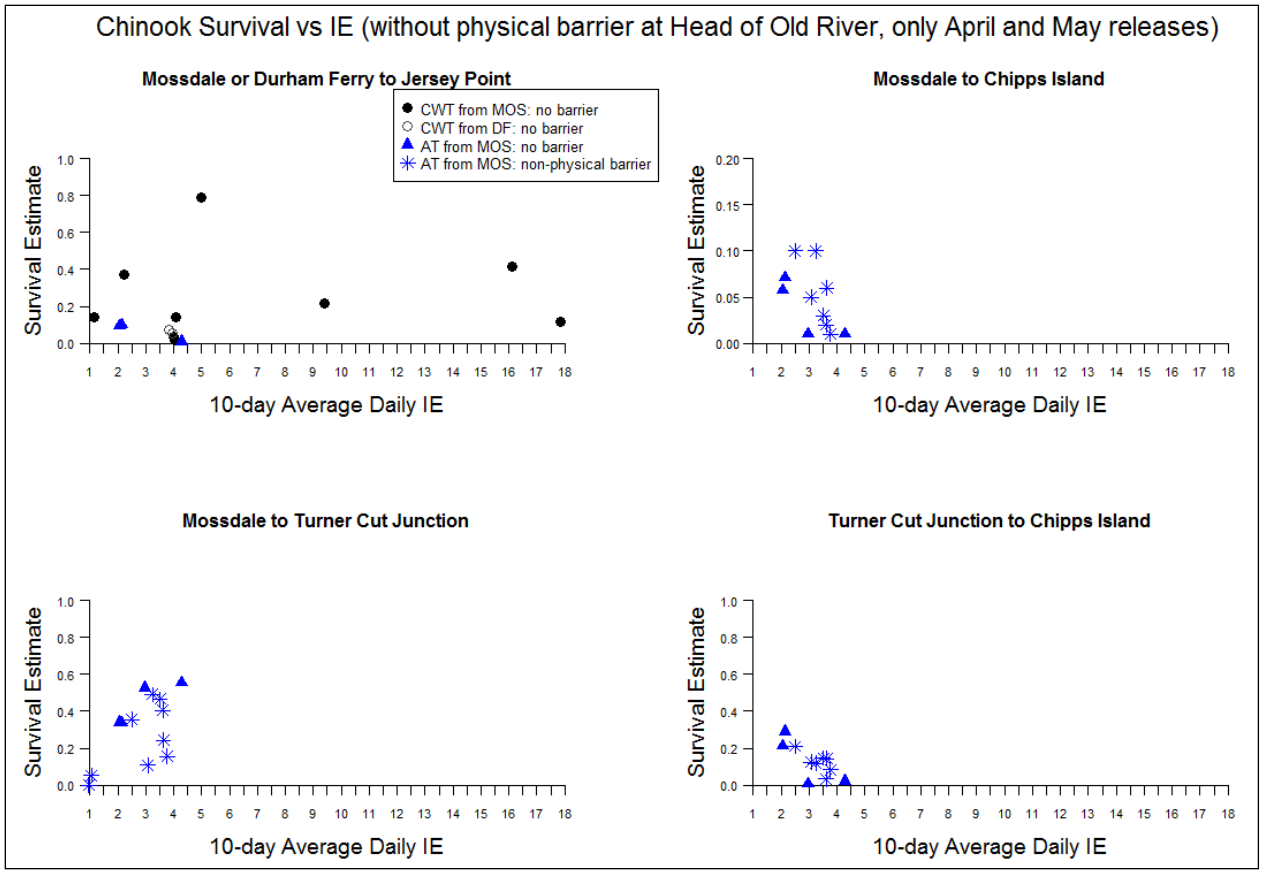

Figure E.11-3. Estimated Survival of Fall-run Chinook Salmon Based on CWT or AT Data, Versus the 10-day Average of I:E for April and May Releases

Notes: I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, in the presence of either a non-physical barrier or no barrier at the Head of Old River. Inflow and exports 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 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.

Reach-Specific Survival

The basis of knowledge regarding the conceptual model linkages between San Joaquin River I:E and reach-specific survival of Chinook salmon is low. Multiple years of field studies have collected data to evaluate this relationship, but all results relative to I:E and reach-specific survival are first presented in this report and, thus, are preliminary.

On the reach level, survival estimates are available only from AT data, and only for ten-day average I:E less than 5; all but two estimates were in the absence of the physical barrier at the head of Old River. Between Mossdale and Turner Cut junction, both the average and the maximum survival estimates tended to increase as I:E increased from 1 to 4.3 (bottom left plots, Figures E.11-1 and E.11-3). Between Turner Cut junction and Chipps Island, the survival estimates were maximized for I:E of approximately 2, and then steadily decreased as I:E increased to 4.3 (bottom right plots, Figures E.11-1 and E.11-3). Similar patterns were

observed for inflow in both reaches (bottom row plots, Figures E.8-1 and E.8-3), and for exports between Turner Cut junction and Chipps Island (bottom right plots, Figures E.6-2 and E.6-4). However, a different pattern was observed for survival between Mossdale and Turner Cut junction against exports (bottom left plots, Figures E.6-2 and E.6-4). It is not apparent how much the similarity between the I:E plots and the inflow plots may reflect the relatively stable export rates across annual release groups during some of the AT studies, or, alternatively, the correlation between inflow and export rates observed among the CWT and AT studies, and the dependence of HORB installation on low inflows. A more comprehensive analysis is required that accounts for the covariation between inflow and export rates, annual variability combined with differing numbers of release groups in different years, and the status of the HORB.

Facility Survival

The basis of knowledge regarding the conceptual model linkages between San Joaquin River I:E and facility survival of Chinook salmon is low. Multiple years of field studies have collected data that are relevant to this relationship but do not directly measure facility survival; results are published in peer-reviewed literature and in this report (SST analyses) and, thus, are preliminary.

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 (E:I) 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 demonstrate considerable variability relative to I:E (SST analyses). 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 (Figure E.8-4). All Chinook salmon AT estimates of survival through the CCF and SWP to Chipps Island during April and May (the period of interest for the I:E ratio) were 0, so no relationship is apparent between I:E and survival from the CCF to Chipps Island via the SWP (Figure E.8-4).

E.11.2.2 Effects of San Joaquin River I:E on Survival of Steelhead

The basis of knowledge regarding the conceptual model linkages between San Joaquin River I:E and survival of steelhead is low for all spatial scales. Two years of relevant data from a multi-year study are available, but analysis relative to I:E has been presented only in this report and, thus, is preliminary.

For the two years of survival estimates from steelhead (2011 and 2012), patterns of survival compared to the I:E ratio show a small increase in survival estimates from Mossdale to either Jersey Point or Chipps Island as I:E increases for April and May releases. The survival

increase was observed in the region from the Turner Cut junction to Chipps Island, but not from Mossdale to the Turner Cut junction (Figure E.11-4). Survival through the facilities tended to increase as I:E increased in these two years (Figure E.11-4). As with consideration of the relationship between inflow or exports and survival, more years of steelhead survival estimates are required to confidently characterize the relationship between I:E and survival.

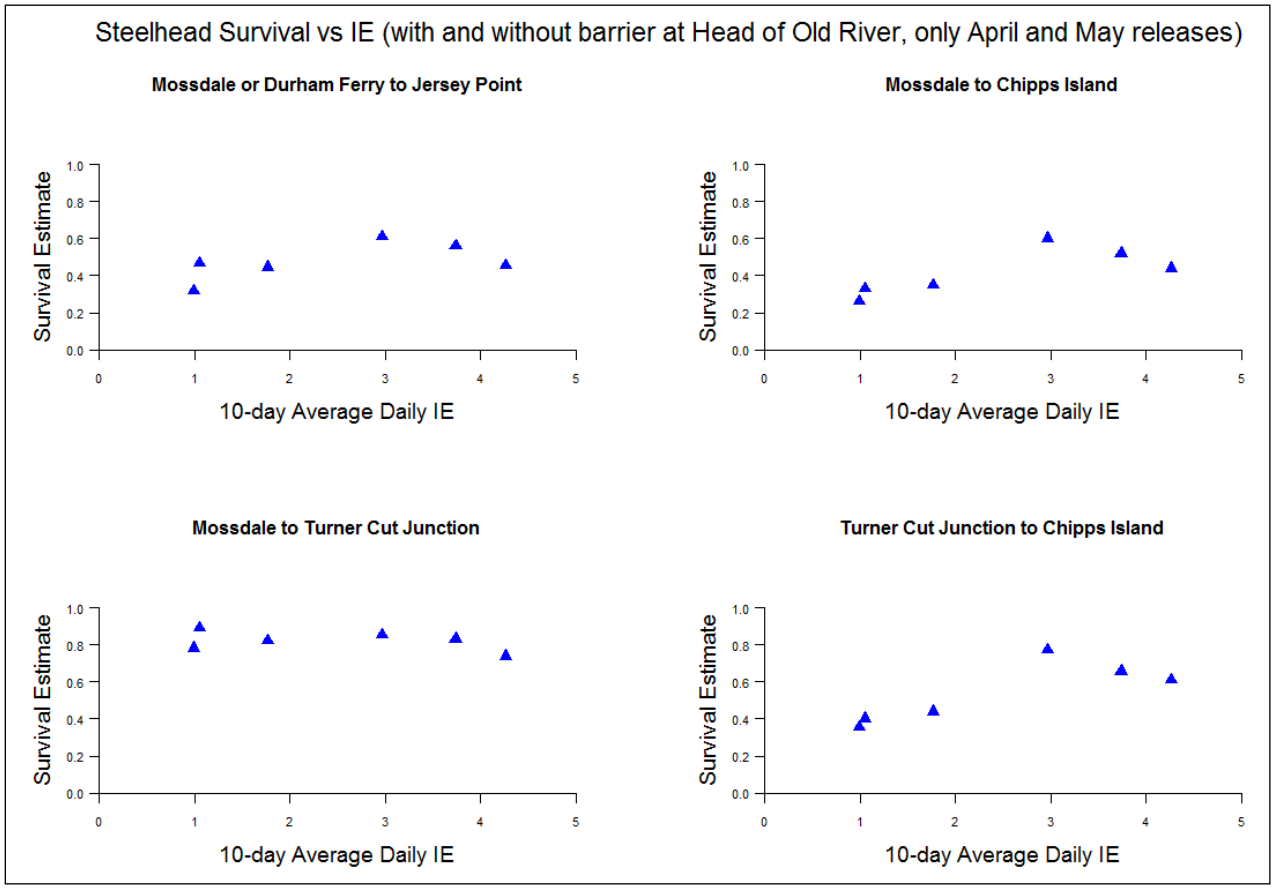

Figure E.11-4. Estimated Survival of Steelhead Based on AT Data (2011 and 2012 Study Years), Versus the 10-day Average of I:E, for April and May Releases

Notes: I:E = Inflow at Vernalis/Exports, where exports = CVP + SWP, regardless of barrier status at the Head of Old River. Inflow and exports rates are measured from the final day of release at Durham Ferry, downloaded from www.water.ca.gov/dayflow/. Export rate at SWP includes Byron Bethany Irrigation District intake. Survival from Mossdale to Jersey Point and Chipps Island includes all routes.

E.11.3 Summary: Knowledge Gaps on Survival as a Function of San Joaquin River I:E

Gaps exist in our understanding of how survival in the Delta varies as a function of San Joaquin River I:E.

- The actual nature of the relationship between I:E and survival, including whether there is a consistent I:E value that optimizes survival.

- Extent to which the perceived relationship between I:E and survival depends on the relatively stable export levels for most observations to date.
- Variability in survival through the Delta and in various reaches for high levels of I:E.
- Reach-specific survival in the presence of a physical barrier at the head of Old River.
- Incomplete multi-year analysis for Chinook salmon and steelhead.

E.12 SURVIVAL AS A FUNCTION OF GATE AND BARRIER OPERATIONS

Temporary, operable, and non-physical barriers are used as part of CVP and SWP operations during the salmonid migration; for a more complete description of the barriers used in the Delta, see Appendix A. In the South Delta, three temporary agricultural barriers are installed during spring in Old River at Tracy, Middle River, and Grant Line Canal (Figure E.12-1). Additionally, a temporary rock barrier is installed in some years at the head of Old River to prevent juvenile salmonids from entering Old River. However, it usually includes culverts that allow limited flow and fish to pass through the barrier into Old River (eight culverts in recent years). The present barrier at the head of Old River cannot be installed when flows are greater than 5,000 cfs and, if installed, cannot be operated if flows are greater than 7,000 cfs. In 2009 and 2010, an experimental non-physical barrier (bioacoustic fish fence) was installed at the head of Old River in place of the rock barrier. In the North Delta, use of a non-physical barrier has been investigated at Georgiana Slough, and an operable barrier (radial gates) is in place at the DCC (Figure E.12-2). Radial gates are also used to regulate water flow into the CCF outside the SWP (Figure E.3-1).

The conceptual model predicts that survival to Chipps Island is higher in routes that avoid the Interior Delta; thus, overall survival to Chipps Island is anticipated to be higher in the presence of barriers that block access to the Interior Delta routes (e.g., at the head of Old River, Georgiana Slough, DCC gates). Because barriers use underwater structures that may attract predators, the conceptual model predicts that mortality may be higher in the region of the barrier when the barrier is in place than when it is absent, but also that the level of mortality will depend on other factors such as flow.

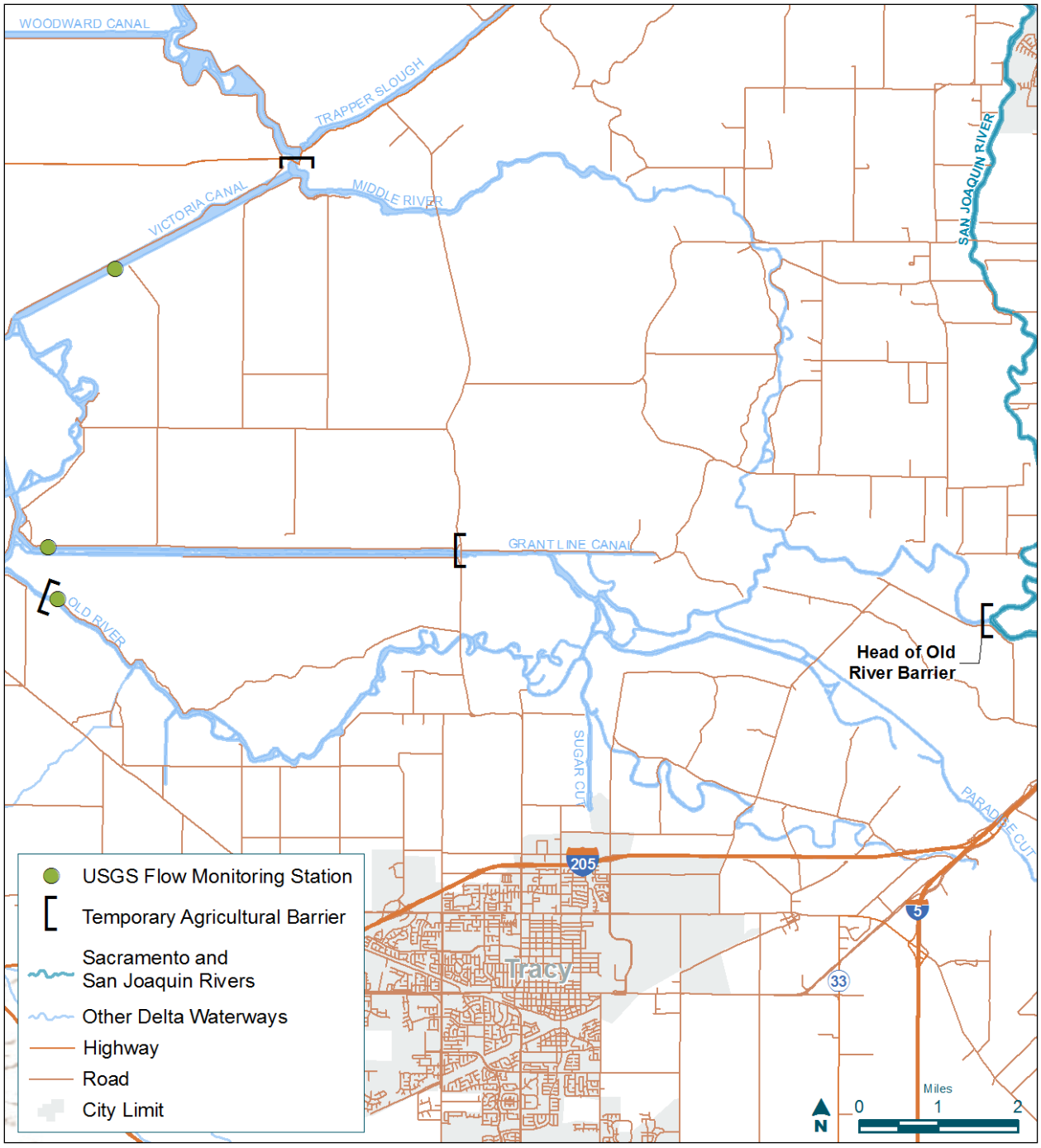

Figure E.12-1. Map of South Delta Showing Temporary Agricultural Barriers

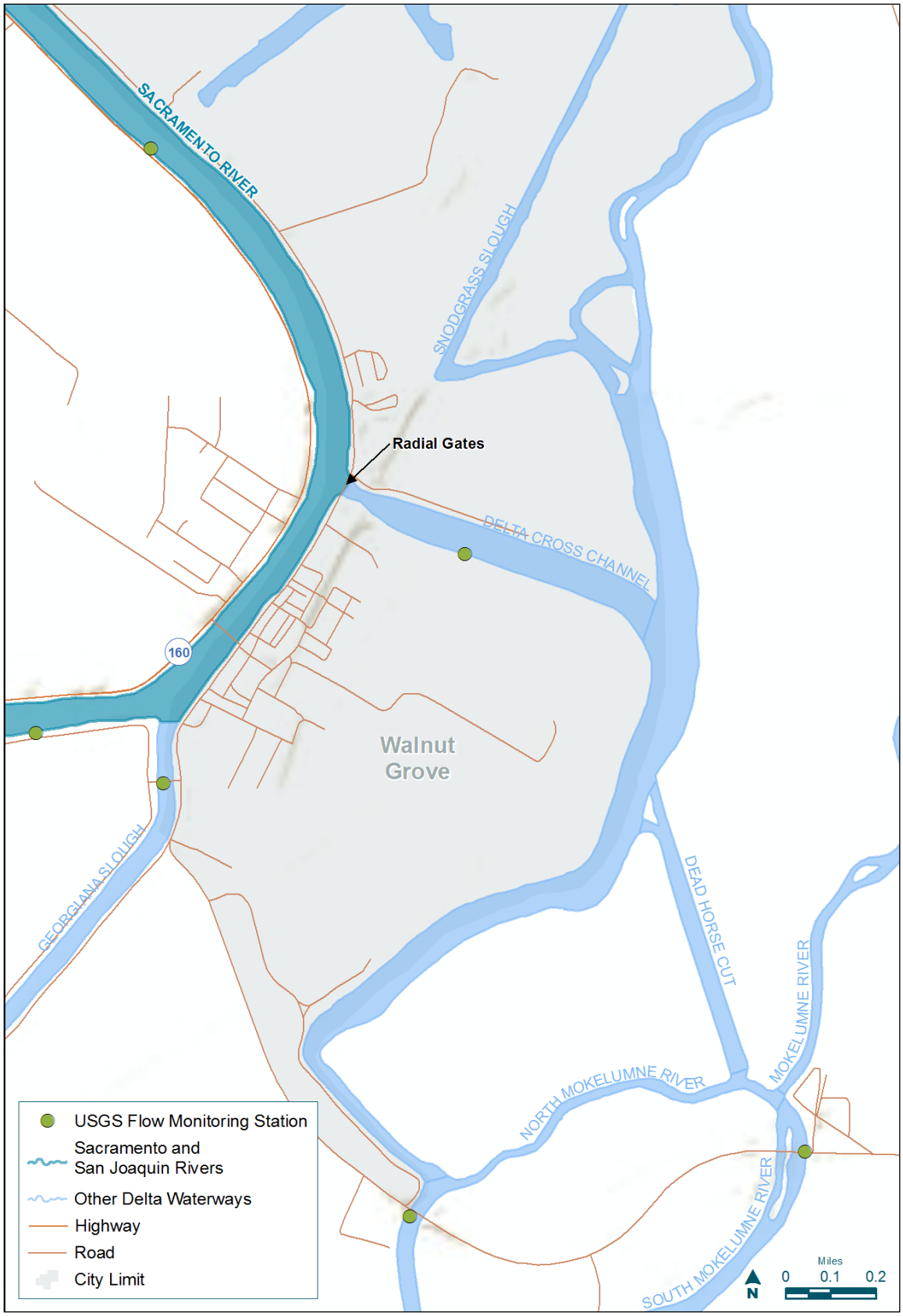

Figure E.12-2. Map of Sacramento River at Delta Cross Channel and Georgiana Slough

E.12.1 Summary: Conceptual Model Predictions on Survival as a Function of Gate and Barrier Operations

- The SST did not review literature and data on the effects of the temporary barriers on juvenile salmon survival.
- Increased predation rate estimates have been observed in the vicinity of the head of Old River when either the physical and non-physical barrier was in place (Bowen et al. 2009; Bowen and Bark 2012; CDWR 2015).
- The graphs presented in this section reflect the status (presence or absence) of the temporary barriers at the time the tagged release groups passed through the South Delta.

E.12.2 Findings on Conceptual Model Linkages and Predictions: Effects of Gate and Barrier Operations on Survival

The basis of knowledge regarding the conceptual model linkages between gate and barrier operations and survival is low for the South Delta temporary agricultural barriers and medium for the HORB. Several studies have been conducted on effectiveness of these barriers on fish guidance and/or survival, either in the Delta overall or in the region of the barrier, and published in agency reports. Effects on survival of these barriers are addressed briefly in this report. Effects on survival of other barriers and gates (e.g., DCC gate, Georgiana Slough, CCF radial gates) have not been evaluated in this report.

In the SJRGA (2013) report, the effect of the temporary agricultural barriers in Old River near Tracy, Middle River, and Grant Line Canal on juvenile salmon migration rate and survival was evaluated as a separate study complementary to the 2011 acoustic-tagging study. Survival and travel time through the Delta were compared before and after the initiation of barrier installation. However, because of temporal changes in conditions through the study season, effects of the barriers on survival and travel time were confounded with other temporally varying conditions (e.g., flow, exports, water temperature). In particular, installation of all three barriers began near the time of increase in combined export rates (approximately June 1) from less than 4,000 cfs to greater than 8,000 cfs. 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 the CCF was also shorter after installation of the OMR barriers began (SJRGA 2013). The only effect observed of the Grant Line Canal barrier was on route selection at the head of Middle River (more fish selected Old River at that junction after barrier installation began), and fewer Chinook salmon successfully passed the immediate vicinity of the barrier after installation began (passage success = 0.9972 before versus 0.9732 after, P=0.04; SJRGA 2013). In summary, from this single year of study, the effect of the temporary agricultural barriers was limited and somewhat paradoxical (e.g., shorter travel time and higher survival through the Old River route after barrier

installation). In interpreting these findings, it is important to note that other factors than barrier installation changed between passage of treatment groups, in particular increasing exports. Also, comparisons were made relative to the initiation of barrier installation, which lasted 1 to 4 weeks, depending on the barrier; fish had relatively unimpeded passage during early parts of installation. Most tagged fish had passed through the region before the barriers were installed. The SST did not spend time discussing the effects of the temporary barriers on juvenile salmon survival; however, the graphs presented in this section reflect the status (presence or absence) of the temporary barriers at the time the tagged release groups passed through the South Delta.

The effect of a physical rock barrier or a non-physical barrier on predation risk in the vicinity of the head of Old River was investigated using acoustic-tagged juvenile Chinook salmon and steelhead in 2009 to 2012 (CDWR 2015). The rock barrier was found to increase predation risk in the vicinity of the head of Old River in 2011; the non-physical barrier was found to increase predation risk when it was operational in 2009 but not in 2010. Predation risk was monitored using two-dimensional tracks of acoustic-tagged juvenile salmonids and assumed behavioral differences between salmonids and predatory fish.

The impact of the physical HORB on hydrodynamics and survival is discussed at length in various parts of this document (Appendix B, Appendix D, Section D.3.2, and Sections E.4, E.6, E.8, and E.11 of this appendix, and in some of the management questions). We also included some discussion on the impact of the DCC and Georgiana Slough on juvenile salmon movement into the Interior Delta (Perry et al. 2010). Results of studies of non-physical barriers at the head of Old River and Georgiana Slough are discussed in Appendix D. Due to time constraints, the SST has not been able to discuss in depth the effect of these barriers on survival. In addition, we did not evaluate the effect of CCF operations or the effects of OMR reverse flow on survival through the Delta. The effect of the CCF gate operation on survival is difficult to discern as fish may linger in the area until the gates open (SJRGA 2011).

E.12.3 Summary: Knowledge Gaps on Survival as a Function of Gate and Barrier Operations

Knowledge gaps on survival as a function of gate and barrier operations include:

- A review of existing literature and data regarding the effect of gate and barrier operations on survival in the Delta has not been performed.
- Most AT survival data are in the absence of a physical barrier at the head of Old River.
- Distinguishing between a barrier effect and an inflow effect for San Joaquin River fish is complicated by the fact that the HORB cannot be installed or operated at high inflows.

- A comprehensive analysis of available data that combines inflow, exports, and barrier status has yet to be completed for AT Chinook and steelhead data from the San Joaquin River.
- Studies to confirm predation and estimate predation rates near the barriers and at other locations; present estimates depend on assumed behavior differences between predators and juvenile salmonids, but behavior has been shown to overlap between predators and salmonids.

E.13 DISCUSSION AND CONCLUSIONS

The conceptual model predicted that survival of juvenile salmonids migrating through the Delta is:

- Lower during periods of higher export rates
- Higher during periods of higher inflows
- Higher during periods of higher San Joaquin River I:E or lower Delta E:I
- Lower for fish that migrate through the Interior Delta, and especially for those that pass near or through the export facilities
- Higher for fish that move faster through a region

This review has identified varying levels of support for these predictions. The concept of higher survival during 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. The conclusion is that although inflow is an important 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 effect of exports on survival is less obvious. The installation and operation of the water export system introduced a new mortality factor for migrating salmonids via entrainment in the pumping facilities or other direct mortality at the facilities. 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 canal 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 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 San Joaquin River fall-run Chinook salmon). This pattern indicates that the short-term modifications in export operations that have been implemented are not sufficient to boost survival through the Delta to desired levels, perhaps because of coincident factors such as predation by non-native species, large-scale habitat change, the pelagic organism decline, and climate change. There also remain questions of making inferences from tagged hatchery fish to the untagged hatchery or wild populations. Additional analyses that incorporate a wider range of life stages (e.g., smolt-adult return rates or spawner-recruit relationship) may be necessary to adequately relate the available small-scale tagging results to populations of interest.

A considerable amount of tagging data has been collected from salmon migrating through the Delta; several years of steelhead data have been collected as well. Clear and obvious results are not available for most conceptual model predictions, however. One reason is that analysis of the acoustic telemetry tagging data is not yet complete; implementation of the annual survival model has yet to be completed for some study years, and the multi-year analyses necessary for detecting relationships are also ongoing. Another reason is that the Delta ecosystem is complex and relationships between factors such as inflow, exports, and survival are unlikely to be simple and easily observable. Inflow and export rates often vary together, along with water temperature and status of barriers and gates. Other factors that have not been considered in this report may also covary with inflow and export rates, such as fish condition, water quality, and the composition and size of the community of both predators and alternative prey. This makes it difficult if not impossible to separate the effects of one factor from another. Observational data in particular will not yield precise results, especially in the short term. Experiments in which the combination of inflow and export rates is controlled have the potential to uncouple the effects of these two factors, but the influence of other factors means that any such experiment will need to be implemented over a long period of time to achieve adequate replication, during which there is a potential for large-scale regime change or even population extirpation.

An additional complication is the fact that the data that form the basis of most conclusions are from tagged hatchery fish, rather than the untagged wild populations that are the target of management. This type of surrogacy is common in population dynamics studies, but differences between hatchery and wild fish and potential effects of tagging a fish nevertheless make forming inferences for the untagged wild population somewhat risky.

Additional considerations of these and other types of surrogacy are discussed further in Volume 2.

What is the potential for more data to clarify relationships to be helpful for management? To some extent, the answer to this question depends on the objectives and range of policies available. For example, there appears to be little relationship between 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 consistently 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 very low under conditions of 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.

In this appendix, we have investigated the relationship between water export 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.

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