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DWR-1223

BEFORE THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING IN THE MATTER OF CALIFORNIA DEPARTMENT OF WATER RESOURCES AND UNITED STATES BUREAU OF RECLAMATION REQUEST FOR A CHANGE IN POINT OF DIVERSION FOR CALIFORNIA WATER FIX	**TESTIMONY OF CHARLES H. HANSON**

I, Charles H. Hanson, do hereby declare:

I am a fisheries biologist and Certified Fisheries Professional with over 35 years of experience in freshwater, estuarine, and marine biological studies. I have a Ph.D. in Ecology and Fisheries Biology from the University of California, Davis, and a M.S. and B.S. in Fisheries Biology from the University of Washington. I serve as co-chair of the Collaborative Adaptive Management Team (CAMT) Salmon Scoping Team (SST) and was one of the co-authors of the 2017 report titled Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta (See DWR Ex. 1324). I have contributed to the study design, analysis, and interpretation of fisheries, stream habitat, and stream flow (hydraulic) data used to develop habitat restoration strategies, Habitat Conservation Plans, Endangered Species Act consultations, and environmental analyses. I have directed numerous investigations and environmental impact analyses for projects sited in freshwater, estuarine, and marine environments of the San Francisco Bay/Delta, the central and northern California coast, Puget Sound, Hudson River, and Chesapeake

Bay. I have participated as an expert witness on fisheries and water quality issues in numerous public hearings and state and federal court litigation regarding salmon and steelhead. I have been extensively involved in incidental take monitoring and investigations of endangered species, development of recovery plans, consultations, listing decisions and identification of critical habitat, and preparation of aquatic Habitat Conservation Plans. I served as a member of the USFWS Native Delta Fish Recovery Team, Central Valley Technical Recovery Team, 2007 USFWS Delta Smelt Recovery Team, numerous technical advisory committees, and as science advisor to settlement negotiations. I have also participated in the development of adaptive management programs including real-time monitoring, management of power plant cooling water and other diversion operations, and the San Joaquin River Vernalis Adaptive Management Plan. I have authored more than 125 technical and scientific reports including reports and publications related to Chinook salmon, steelhead, and other estuarine fish. My professional resume is included as DWR Ex. 1205 and a PowerPoint presentation of this testimony is included as DWR Exhibit 1386.

The purpose of this rebuttal testimony is to respond to the testimony provided by several parties regarding Bay-Delta fishery issues with an emphasis on Chinook salmon and steelhead produced in the Sacramento River watershed. My testimony is in direct response to CSPA (CSPA-202, p.2) testimony that:

> In considering conditions to place on the permits for the SWP and CVP in this proceeding, the Board can and must evaluate conditions for all aspects of SWP and CVP operation, not just those immediately related to the new points of diversion.

In addition, my testimony is responding to issues raised regarding impacts to existing conditions, specifically, CSPA-204, pp. 7 and 31-32; CSPA-202, errata, pp. 7-8; CSPA-202, errata, p. 9, CSPA-202, errata, pp. 10-11; CSPA-202, errata, pp. 11-12; NRDC-58, errata, pp. 4-24; April 11, 2018, Transcript, Vol. 28, pp. 24 and 111-112; April 16, 2018, Transcript, Vol. 29, pp. 19:9 to 20:18, p. 22:10-18 and p. 24:12-19; and PCFFA-145.

I am also responding to several parties who's experts suggested that the SWRCB's 2010 Flow Criteria Report and the SWRCB's Phase II Technical Basis Report should be accepted without modification, suggesting that there was no new relevant information that should also be considered. (See e.g., CSPA-202, errata, pp. 7-11; April 11, 2018, Transcript, Vol. 28, p. 122; April 24, 2018, Transcript, Vol. 33, pp. 110-115; PCFFA-161, p. 8:7-9.) This is inaccurate. Since 2010, there has been a large body of highly relevant scientific investigation, and this testimony is intended to identify some of that new information. This information suggests that the 2010 Flow Criteria Report and the Phase II Technical Basis Report should not be accepted by the SWRCB as the best available science without further consideration of current science. In further response, I am attaching technical comments on the 2010 Flow Criteria Report and the Phase II Technical Basis Report that provide a more detailed explanation of science that should be considered in SWRCB decision-making. (DWR-Exhibit 1325)

I. SUMMARY OF TESTIMONY

- Multiple historical physical and hydrologic changes have shaped the current Delta;
- The current state of the Delta is the result of multiple physical and hydrologic factors operating over multiple time scales;
- There is significant uncertainty regarding the nature, extent and magnitude of the effect of current SWP-CVP operations as well as other stressors on salmonid survival;
- The relationship between Sacramento River flow rates and juvenile salmonid survival is weak (large changes in river flow are needed to achieve even a small change in salmonid survival in the Sacramento River and Delta) with high uncertainty (low R2 values); and
- Multiple authors have concluded that flow alone cannot be used to restore the Delta. As stated by the NAS, "The Delta as it existed before large-scale alteration by humans cannot be recreated." (NAS 2012, p. 10, DWR Exhibit 1326) Buchanan et al. (2018, p. 663; DWR Exhibit 1327) also concluded that increased flow alone will not be

sufficient to resolve the low salmonid survival in the Delta.

II. TESTIMONY

A. MULTIPLE PHYSICAL AND HYDROLOGIC CHANGES HAVE SHAPED THE CURRENT DELTA, THE RESULTS OF WHICH HAVE AFFECTED SALMONID ABUNDANCE AND SURVIVAL.

Protestants have suggested that the current state of the Delta is primarily a result of the operation of the existing SWP-CVP. (See citations, above.) However, the current state of the Delta should be recognized as being the result of multiple factors that have occurred over varying time periods and regions of the Delta. Before European settlement began in the early 1800s, the Central Valley rivers flowed through approximately 400,000 acres of wetlands and other aquatic habitats in the Delta (Whipple et al. 2012, p. 83, DWR Exhibit 1328) as well as upstream in the Sacramento River and other tributaries to the Delta. The primary landscapes in the historical Delta included flood basins in the north Delta, tidal islands in the central Delta, and a complex network of channels formed by riverine processes in the south Delta. Over the last 160 years, 1,335 miles of levees have been constructed to drain wetlands and convert them into farmland, flood control bypass channels, and for other uses. These changes are summarized in Whipple et al. (2012) and illustrated in Figure 1, (DW Exhibit 1328, p. 15) below. All of these changes have impacted the ecology of the Delta and the abundance and survival of its native species.

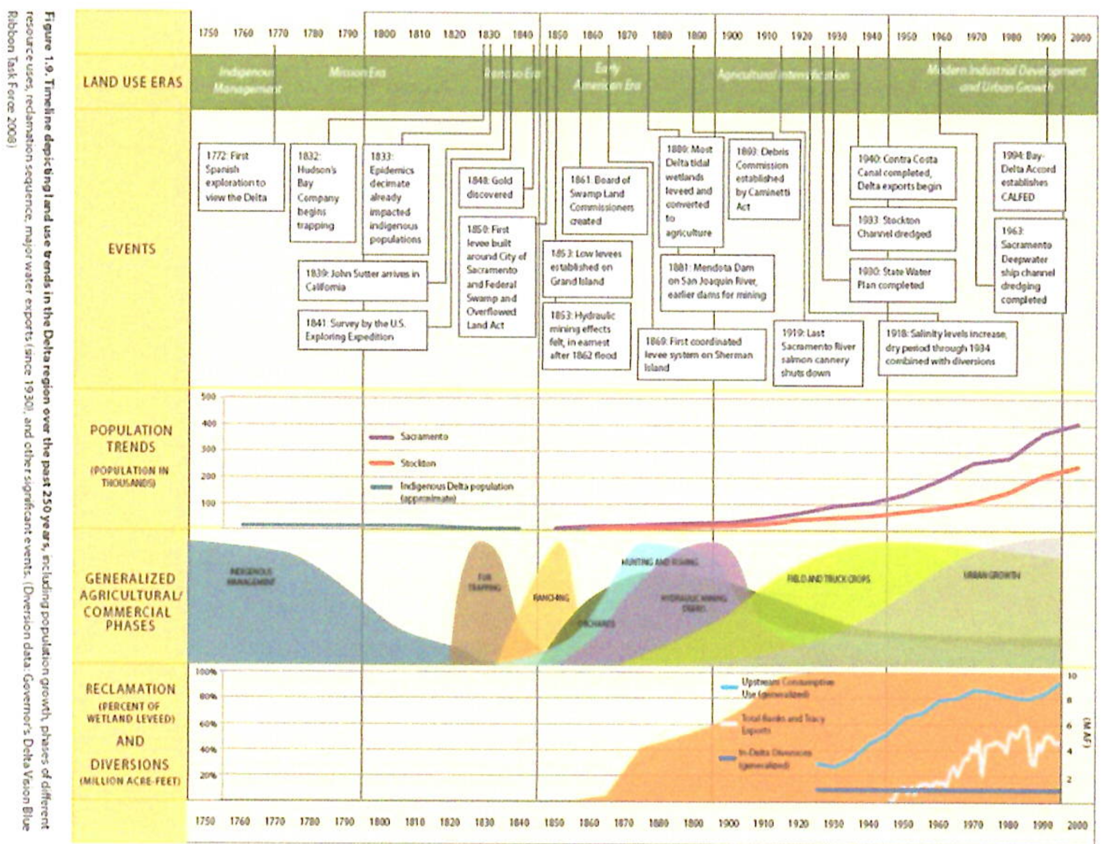


Figure 1. Timeline trends in changes within the Delta over the past 250 years (Source: DWR- Exhibit 1328 Whipple et al. 2012, p. 15)

The current state of habitat conditions in the Sacramento River and Delta, and survival and abundance of Chinook salmon and steelhead populations, is the result of these factors. This finding is consistent with the Delta Science Program panel summary report on the SWRCB Workshop on Interior Flows and Related Stressors (SWRCB Exhibit 56) which stated, "However, it is now generally agreed that population declines are a result of multiple stressors." (Id., p. 7.) It is also consistent with the Phase II Technical Basis Report ("Phase 2 Technical Report") which concluded, "Multiple mechanisms may be responsible for these [abundance] relationships, including effects on habitat suitability, catchability by trawl gear, and correlations with other environmental factors." (Phase 2

Technical Report, p. 3-9). These factors include (but are not limited to): ocean conditions, contaminants, spawning gravel quality and availability, loss of historic floodplains and tidal marsh, invasive species, predation, climate change, and reduced food production. (See e.g., NMFS Recovery Plan for the Evolutionary Significant Unit of Sacramento River Winter-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead Appendix B, p. 2-1 – 4-106 and 4 -132 – A-137,July 2014. SWRCB Exhibit-70).

After more than 100 years of physical and hydrologic changes in the Delta, with multiple stressors acting on a multiple of time scales, the ability to restore fish abundance and ecological processes using flow alone is highly uncertain. Recent science shows that restoration efforts that address, and incorporate actions to improve, multiple factors are more likely to yield positive results. As explained by Dr. Paul Hutton in his testimony, unimpaired flow is not the same as natural flow (DWR-Exhibit 1224, Sec. 4.D. citing Poff and Zimmerman (2010 p. 1 and 9. DWR Exhibit 1330)). Also as explained by Dr. Hutton is that in highly altered systems it is not possible to reliably predict the ecological results of a new flow regime, and we cannot assume that those new flows will provide ecological benefits (Id.) For example, Poff and Zimmerman (Id., p. 194-204) reviewed 165 papers related to the natural flow regime. Their results revealed some sensitivity of different ecological groups to alteration in flow management but robust statistical relationships were not supported (Id.). Of 165 papers, 92% concluded adverse response to changed flows. In largely unaltered river systems, the importance of flow in sustaining biodiversity and ecological integrity is well established (Id.) However, establishing an appropriate flow in an estuary is not as simple (Pierson et al. 2002, p. 7 DWR Exhibit 1331). As Poff et al. 1997, p.780 (DWR- Exhibit 1332) observed, the ability to use flow as a restoration tool depends on the present state of human intervention. The more altered the system, the more uncertain it is that flow alone can achieve positive changes in the environment. For a more detailed analysis of the extent that flow can be used to improve the ecosystem, see DWR 1333 (Ecosystem Change in the Bay-Delta Estuary: A technical assessment of scientific information (2012).

B. THERE IS SIGNIFICANT UNCERTAINTY REGARDING THE NATURE, EXTENT AND MAGNITUDE OF THE EFFECT OF CURRENT SWP-CVP OPERATIONS.

Several Protestants definitively state that there was a high level of certainty regarding the alleged negative effects of current SWP-CVP operations. (See citations, above.) However, this level of alleged certainty is unwarranted. There is no clear evidence that current SWP-CVP diversions in the south Delta are having a direct or indirect population level effect on salmonids.

Juvenile Chinook salmon and Central Valley steelhead migrate from upstream rearing habitat through the Delta and into coastal marine waters. Juvenile migration within the Delta typically occurs during the winter and spring months. During their migration through the Delta juvenile salmon and steelhead are vulnerable to direct losses (mortality) from multiple sources (stressors) that include: predation by fish (e.g., striped bass, largemouth bass, Sacramento pikeminnow, etc.) and birds, exposure to toxins, entrainment at unscreened agricultural, municipal, and industrial water diversions, exposure to seasonally elevated water temperatures, and other factors (Windell et al. 2017, p. 18-24 DWR Exhibit 1334).

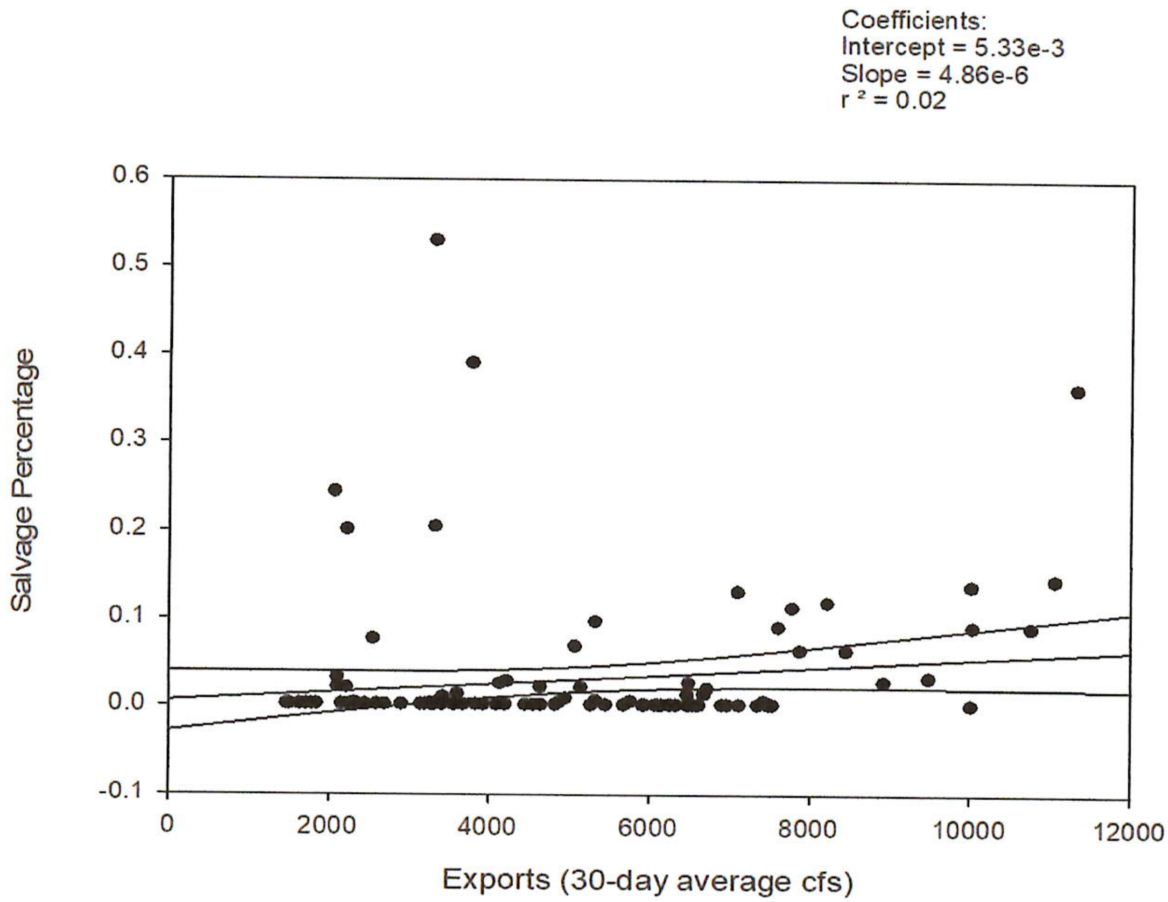
1. The USFWS CWT Studies Suggested that the Effect of Current Entrainment in SWP-CVP Facilities is Low.

It has been hypothesized (Kimmerer 2008 p. 4 and 18-20 (CSPA-Exhibit 357), Windell et al. 2017, p. 19-24) that operations of the SWP and CVP export facilities indirectly affect the survival of juvenile salmon and steelhead. It has been proposed that changes in the direction and magnitude of tidal and current flows within the central Delta (e.g., Old and Middle rivers reverse flows) as a result of water exports during the salmonid emigration period leads to movement of juveniles into the central Delta which, in turn, contribute to delays in downstream migration and increased salmonid mortality (SST 2017, p. 4-20 (DWR Exhibit 1337), Windell et al. 2017, p. 19-24). According to this hypothesis, the survival of juvenile salmon and steelhead migrating through the Delta would be lower, and both direct and indirect mortality would be higher, when export rates are high, and salmonid survival would be higher when exports are low. To help address these management questions, I conducted a series of additional analyses using results of coded wire tag (CWT) studies designed and implemented by USFWS to investigate survival relationships for juvenile salmon migrating downstream through the Sacramento River and Delta. The USFWS has conducted over 100 survival studies on the Sacramento River using juvenile winter-run, spring-run, and fall-run Chinook salmon over the past three decades. The CWT studies used in this analysis included results from 118 studies with a combined total of over 14,200,000 juvenile salmon released (USFWS unpubl. Data. DWR Exhibit 1387). Using the USFWS' study data, I answered three management questions looking at the direct and indirect effects of SWP-CVP operations, as follows:

What is the relationship, if any, between direct mortality of juvenile salmon and steelhead and diversion rates at the SWP and CVP export facilities?

Using the USFWS CWT data, I calculated an index of direct losses as a result of SWP and CVP export operations for each CWT survival test based on the percentage of the number of fish released and the expanded estimate of salvage of that tag group in the combined SWP and CVP fish salvage. For the study data analyzed, the percentage of CWT salmon released into the upper Sacramento River subsequently collected at the SWP-CVP fish salvage facilities averaged 0.03% (n=118; 95% CI = 0.0145), with a range from 0 to 0.53%. The estimated percentage of each CWT group recaptured at the SWP and CVP fish salvage facilities was then plotted against the average combined export rate over the 30 and 60-day periods prior to the date of the last fish recaptured.

I hypothesized that if all other things being equal the SWP and CVP export rates were an important factor affecting the percentage of salmon from the Sacramento River collected in export facility salvage (direct losses), the percentage of tagged fish recaptured at the salvage facilities would increase when export rates were higher. Figure 2 shows the results of the analysis based on average export rates for the 30 days prior to the last recapture. Results for average exports for the 60 days prior to the last recapture are shown in Figure 3. Results of a linear regression model with 95% confidence intervals are also



depicted

Figure 2. **Relationship between SWP and CVP exports (30-day average) and percentage salvage (Data source: USFWS unpubl. data).**

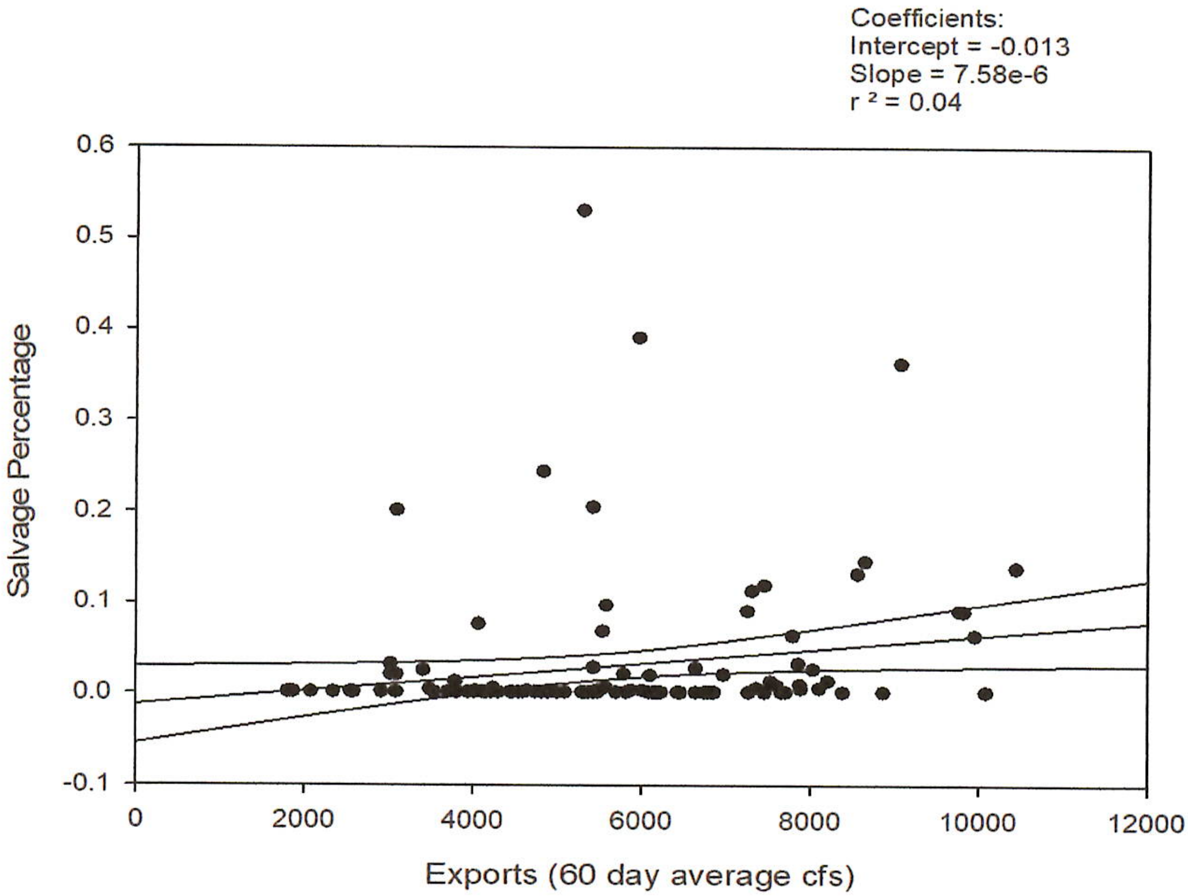


Figure 3. **Relationship between SWP and CVP exports (60-day average) and percentage salvage (Data source: USFWS unpubl. data).**

Overall, my analysis my analysis is consistent with that of others which showed the relationships between export rate and salmon salvage were characterized by very flat slopes (slopes < 0.0001) and low correlation coefficients (R2 = 0.02 for the 30-day exports and 0.04 for the 60-day exports). The relationship between combined SWP and CVP export rates and the percentage of each tag group recaptured (direct loss) was not statistically significant for the 30-day (p=0.12) average export rate. The relationship between the percentage of salvage and average export rate over a 60-day period was significant (p=0.04); however, the relationship was extremely weak (R2= 0.04). There was no evidence (i.e., one cannot conclude) based on results of these analyses that direct losses of salmon migrating downstream in the lower Sacramento River and through the

Delta experience greater direct losses as a result of increases in SWP or CVP export rates. These surrogate salvage estimates are consistent with actual salvage of winter-run Chinook salmon as a function of the Juvenile Production Estimate (JPE) developed by NMFS each year, both of which are consistently low (typically less than 0.5%).

Results of salmon survival studies conducted by Perry (2010, p. 47-71(DWR Exhibit 1335)), Perry et al. (2010,14-25 (DWR Exhibit 1336)), Buchanan et al. (2018 p. 663-669 (DWR Exhibit 1327)) and others within the Sacramento River and Delta over the past three decades have shown that (1) total survival (the overall survival estimate for a specific group of tagged salmon from the point of release to Chipps Island in these analyses) has been highly variable within and among years, and (2) total survival rates have been low in some years. Over the 118 survival studies included in my analysis--all based on CWT salmon released into the upper Sacramento River—the average survival rate to Chipps Island was 0.29 (n=118; 95% CI = 0.04) with a range from 0.016 to 1.0. (Studies in which no CWT salmon were collected were not included in the analysis; maximum calculated survival rates were truncated at 1.0). As discussed above, a number of factors affect the survival of juvenile salmon during migration through the lower Sacramento River and Delta.

A key question to be addressed is whether SWP and CVP export rates are a factor affecting (indirect effect) the survival of juvenile salmon during migration. If SWP and CVP exports are a major factor affecting survival within the Delta, total salmon survival should be reduced in those years when export rates are high and increased in those years when export rates are low (dashed line on Figure 4). If SWP and CVP export rates are not a major factor affecting Delta survival, there would be no relationship between total Delta survival and combined exports during the seasonal period when juvenile salmon are migrating through the lower river and Delta (solid line on Figure 4).

To test this hypothesis, I analyzed the estimates of total Delta survival from the CWT survival studies plotted against average SWP and CVP export rates 30-days prior to the date of last recapture for each CWT group of juvenile salmon. Results of the analysis are shown in Figure 5 using a 30-day average for exports (results of the linear regression and

95% CI are shown). The slope of the regression was low (<0.0001) and characterized by a high variance (R2= 0.01).

The relationship between juvenile salmon survival in the Delta and combined SWP and CVP export rates was not statistically significant for either the 30-day average export rate (p=0.27) or the 60-day average export rate (p=0.1). Results of these analyses show that SWP and CVP exports, overall, are a small incremental factor affecting survival of juvenile salmon and that further regulation of exports would not have a strong predictive effect on total survival of juvenile salmon from the Sacramento River migrating through the Delta.

Conclusions regarding CWT survival study results.

Results of the CWT survival studies have shown that survival of juvenile salmon migrating downstream through the lower Sacramento River and Delta is highly variable within and among years. Survival rates are weakly correlated with Sacramento River flow and Delta inflow and outflow during the seasonal migration period. In these studies, SWP and CVP export rates contributed a small incremental amount to explaining total juvenile salmon survival within the lower river and Delta; however, the contribution of SWP and CVP export rates were not found to be statistically significant (p< 0.05).

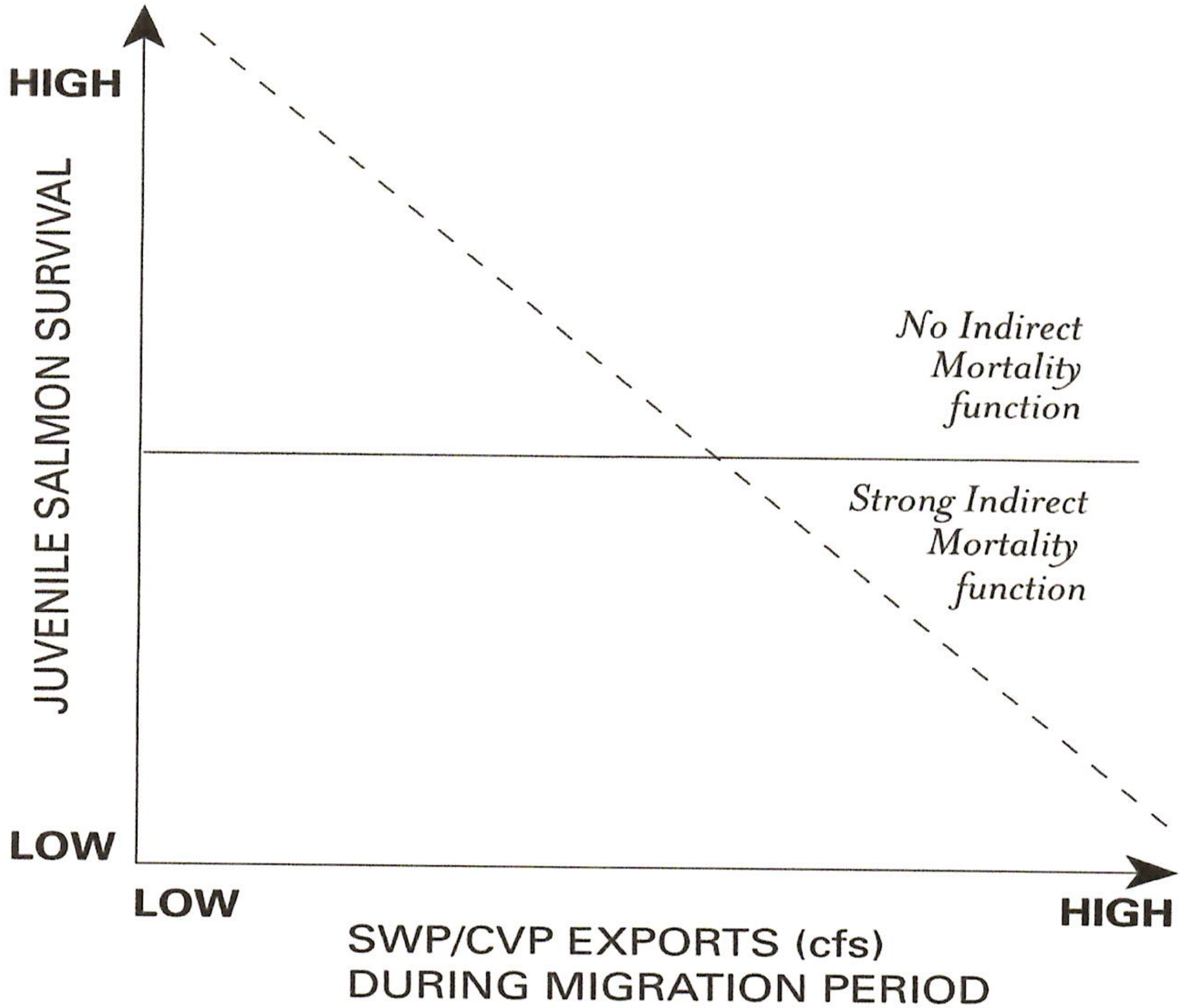


Figure 4. Hypothesis regarding the effect of SWP/CVP exports on indirect mortality of juvenile salmon.

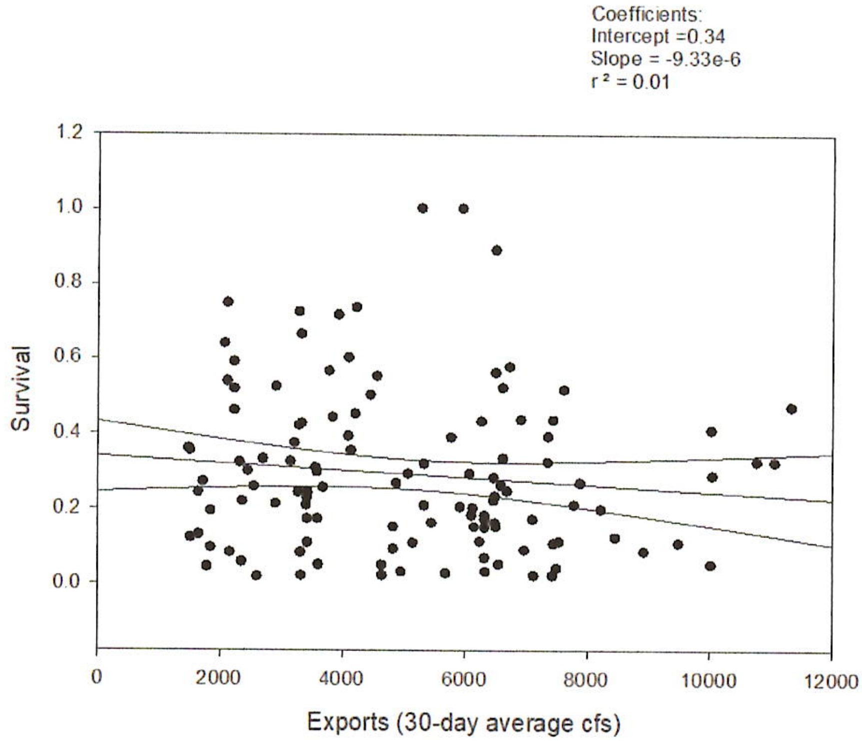


Figure 5. **Relationship between SWP and CVP exports (30-day average) and Delta salmon survival (Data source: USFWS unpubl. data).**

2. Multiple Agency Synthesis Reports also Conclude That There is Significant Uncertainty Regarding the Effects of Current SWP-CVP Project Operations.

In further response to Protestants' definitive statements that there was a high level of certainty regarding the alleged negative effects of current SWP-CVP operations, it is important to understand that several multiple agency investigations have strove to characterize the current state of our collective understanding of the effects of current operations of the SWP-CVP diversion in the south Delta. Their conclusions suggest that even with the significant amount of investments in monitoring and scientific research that has occurred over the past decades, the results are inconclusive and no population level effects have been identified.

This lack of certainty regarding the current effects of SWP-CVP south Delta diversions has been described in 2017 the Collaborative Adaptive Management Team's

Salmon Synthesis Team's two-volume collaborative synthesis of information on juvenile salmon and steelhead migration and survival in the Delta (herein "Salmon Synthesis Report") (DWR Exhibit 1337). The Salmon Synthesis Report identified key gaps, uncertainties, areas of technical disagreement, and recommendations. The report presents results of a collaborative scientific compilation and review of information: 1) primarily related to the application of hydrodynamic simulation models used to assess local and regional flow direction and water velocities in Delta channels that are affected by river inflow, water project exports, and tides; 2) juvenile salmonid migration behavior including migration rate and route selection based on tracking tagged juvenile Chinook salmon and steelhead in the Delta and scientific literature from other basins; and 3) the survival of juvenile Chinook salmon and steelhead as they migrate downstream through the Delta. The assessment of information focused primarily on the effects of water project operations on Delta hydrodynamics and juvenile salmon and steelhead migration and survival. Key findings in the Salmon Synthesis Report regarding the Sacramento River and Delta include:

In regard to through-Delta survival, the Salmon Synthesis Report concluded at p. ES-3:

- Many drivers for low through-Delta survival have been hypothesized, but the role of each has not been quantified. Hypothesized factors contributing to the observed low Delta survival include increased abundance and increased metabolic rate of predatory fish such as striped bass and largemouth bass in the Delta, water project operations affecting the magnitude and timing of flow resulting in increased juvenile salmonid predation mortality, changes in Delta habitat including expansion of non-native submerged aquatic vegetation, increased water clarity, potential exposure to contaminants, and other factors. The potential contribution of these factors to salmonid mortality supports a stronger focus on investigating the mechanisms underlying salmonid mortality in different regions of the Delta and their link to water project operations; and
- Collection and analysis of data on migration and survival of acoustic-tagged Chinook salmon is ongoing. Additional data will be compiled and analyzed to investigate

various hypotheses over observed conditions such as potential relationships between flows and export rates and survival, as well as route selection and migration rate within various regions of the lower rivers and Delta. Other analyses can also be done and support our recommendation to continue studies and do additional data analyses and assessment. However, because these studies were observational in nature, and were not designed to test these hypotheses, the findings from such analyses will be limited and will not obviate the need for future investigations.

In regard to the effects of the SWP-CVP, the Salmon Synthesis Report concluded at p. 88:

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

In regard to gaps in our scientific understanding, the CAMT Salmon Synthesis Report concluded at p. 88-93:

- Additional analyses are needed to investigate the expected change in salmonid route selection and subsequent survival from changes in export rates;
- The evidence of a relationship between exports and through-Delta survival is inconclusive; the key findings are supported by medium or high basis of knowledge, but our

basis of knowledge on the relationship between exports and through-Delta survival is low. Since 2002, juvenile fall-run Chinook salmon survival in the south Delta has been consistently low despite restriction of export rates. Survival rates for acoustic-tagged juvenile steelhead are currently available only for two years (2011 and 2012), which are insufficient to support an analysis of the potential relationship between export rate and survival. Analysis of additional acoustic tag (AT) data for 2013 through 2016 will help further assess potential relationships for both salmon and steelhead;

- Estimates of entrainment mortality at the export facilities from salvage counts depend on pre-screen mortality, but data on the magnitude and variability of pre-screen mortality are unavailable at the CVP;

- The contribution of water project operations to the total mortality of juvenile salmonids has not been quantified. Many of the mechanisms through which changes in Delta hydrodynamics and other factors related to water project operations may contribute to salmonid mortality (e.g., change in vulnerability to predation in Delta channels or change in migration routing as a result of water project operations) are uncertain;

- Estimates of direct mortality (e.g., mortality resulting from pre-screen losses and losses at the louver and salvage facilities, which are directly related to water project export operations) have been developed from CWT data by several authors and show, in general, that the magnitude of direct loss (e.g., percentage of a marked release group observed in fish salvage) is typically low for juvenile Chinook salmon (typically less than approximately 1%). However, such estimates do not include export-induced mortality prior to entering the facilities that is indirectly related to water project operations (e.g., mortality resulting from project related changes in habitat). Estimates of direct facility mortality as a proportion of total migration mortality have been as high as 5.5% for winter-run Chinook salmon (Zeug and Cavallo 2014 (DWR-Exhibit 1364));

- It is unknown whether equivocal findings regarding the existence and nature of a relationship between exports and through-Delta survival is due to the lack of a relationship, the concurrent and confounding influence of other variables, or the effect of low overall survival in recent years. These data gaps support a recommendation for further analysis of available data, as well as additional investigations to test hypotheses regarding export effects on migration and survival of salmonids migrating through the Delta; and

- The effects of OMR reverse flows on salmonid survival and route selection in the Delta (outside of the facilities) have had limited analysis. Data are available from the AT migration and survival studies, as well as earlier CWT data, that might be used in analyses of potential relationships between OMR reverse flows and juvenile salmonid survival. Relationships between OMR reverse flows and migration route and migration rate, as well as reach-specific and regional survival, could be tested using AT data from both Chinook salmon and steelhead.

The findings of the Salmon Synthesis Report are supported by other multiple agency analyses, including The Interagency Ecological Program (IEP) Salmon and Sturgeon Assessment of Life Stage (SAIL) (DWR Exhibit 1334 p. ii-49), which is a program to synthesize data and conceptual models to develop a framework for evaluating existing information on endangered Sacramento River winter-run Chinook salmon and green and white sturgeon. The SAIL assessment identified multiple uncertainties related to the current operation of the SWP-CVP.

Based on my review of the available scientific information I identified areas of scientific uncertainty related to the current operation of the SWP-CVP, including but not limited to:

- High variability and uncertainty in predicting flow-survival relationships for salmonids and the response to management and natural variability in environmental conditions such as riverine and tidal hydrology;
- Statistical uncertainty and variability in the population level response of salmonids to changes in factors such as SWP and CVP export rates, reverse flows within Delta channels, habitat restoration, etc.;
- Population level responses to many of the stressors and management actions remain uncertain: the application of lifecycle models and advanced methods for analyses

are starting to address uncertainty in complex relationships.

3. Salmonid Flow-Survival Relationships

Protestants have alleged that current flow survival relationships explain the current status of salmonids, as well as the future effects of CWF. (See citations, above.) These relationships are not as certain or linear (meaning increased survival with every increment of additional outflow uniformly across the Delta) as has been represented.

Results of many of the flow survival studies conducted on Central Valley rivers for juvenile salmonids have shown a general, but weak trend of increased juvenile survival during migration through the rivers and Delta when river flows are higher. However, these survival studies show: (1) high variability in the actual survival of juvenile salmonids at a given flow, as reflected in the scatter of survival estimates (observations of both high and low survival at a given flow); (2) low R2 values (reflecting that the relationship between survival and flow is weak and flow alone does not explain a substantial proportion of the observed variation in juvenile survival); and (3) based upon the low slope of the flow survival relationship, that a substantial increase in flow is required to achieve a relatively small predicted increase in salmonid survival. A number of experimental studies have been conducted to assess the survival of juvenile Chinook salmon and steelhead migrating downstream in the Sacramento River and through the Delta (Perry 2010 (DWR Exhibit 1335), Perry and Skalski 2010 (DWR Exhibit 1336), DWR 2012 (DWR Exhibit 1369), DWR 2013 (DWR Exhibit 1388, DWR 2015 (DWR Exhibit 1389), and DWR 2016 (DWR Exhibit 1390), Michel et al. 2015 (DWR Exhibit 1340), Kimmerer 2008 (DWR-1257), Newman and Rice 2002 (DWR Exhibit 1370), Newman 2008 (DWR Exhibit 1371), Newman and Brandes 2009 (DWR Exhibit 1372), SJRGA 2006 (DWR Exhibit 1373), SJRGA 2008 (DWR Exhibit 1374), and 2011 (DWR Exhibit 1375), Perry and Skalski 2008 (DWR Exhibit 1376), Perry and Skalski 2009 (DWR Exhibit 1377), and Chapman et al. 2014 (DWR-Exhibit 1378), and others) using both coded wire tags (CWT) and more recently acoustic tags. Results of the acoustic tag studies are currently being used to develop the NMFS Chinook salmon lifecycle model (Hendrix et al. 2017, p. 11-12, 33-34, pers. comm. (DWR Exhibit 1339)), as well as other life cycle models (IOS and OBAN), all of which were used to evaluate CWF.

There is high variability in the actual survival of juvenile salmonids at a given flow, as reflected in the scatter of survival estimates (observations of both high and low survival at a given flow). For example, flows in the Sacramento River during the late winter and spring of 2006 were relatively high throughout the juvenile salmonid migration period and would have been expected to improve juvenile survival and increase abundance of adults. Average flows in the Sacramento River measured at Freeport during the 2006 juvenile migration period were 68,459 cfs in January, 50,211 cfs in February, 67,873 cfs in March, 74,842 cfs in April, and 52,835 cfs in May (Table 1). The flows during the 2006 migration season were substantially greater than in many other years. Despite these favorable conditions, the escapement of adult fall-run Chinook salmon returning to the Central Valley from this cohort in 2008 and 2009 (71,291 and 53,129 adults, respectively; GrandTab 2018 p. 2-3 (DWR-Exhibit 1379)) represented the lowest level of abundance in the last 50 years.

In contrast, flows in January 2009 in the Sacramento River at Freeport averaged 9,147 cfs, 19,977 cfs in February, 21,176 cfs in March, 11,924 cfs in April, and 15,436 cfs in May which were substantially less than flows in 2006, and yet estimated adult fall-run Chinook salmon abundance in 2012 was among the highest in more than a decade (adult fall-run Chinook salmon abundance returning to the Central Valley was estimated by CDFW to be 341,000 fish; GrandTab 2018, p. 2-3).

Table 1. Sacramento River average monthly flows (cfs) at Freeport and subsequent adult fall-run Chinook salmon abundance.

Month	2006	2009
January	66,459 cfs	9,147 cfs
February	50,211 cfs	19,977 cfs
March	67,873 cfs	21,176 cfs
April	74,842 cfs	11,924 cfs
May	52,835 cfs	15,436 cfs
Estimated adult fall-run salmon abundance	53,129 2009	340,819 2012

Source: DWR DAYFLOW and 2018 CDFW GrandTab (p. 3).

These examples illustrate the complexity of interacting factors that affect the population dynamics of Central Valley salmonids and the high degree of uncertainty supporting the hypothesis that simply modifying Sacramento River flows will result in a desired improvement in juvenile salmon survival and adult abundance.

Confidence intervals for the survival estimates were relatively large in several of the years (e.g., survival in the Delta in 2007 was estimated to be approximately 60% but confidence intervals ranged from approximately 35 to 85%; Figure 6) suggesting high variability and uncertainty in survival estimates.

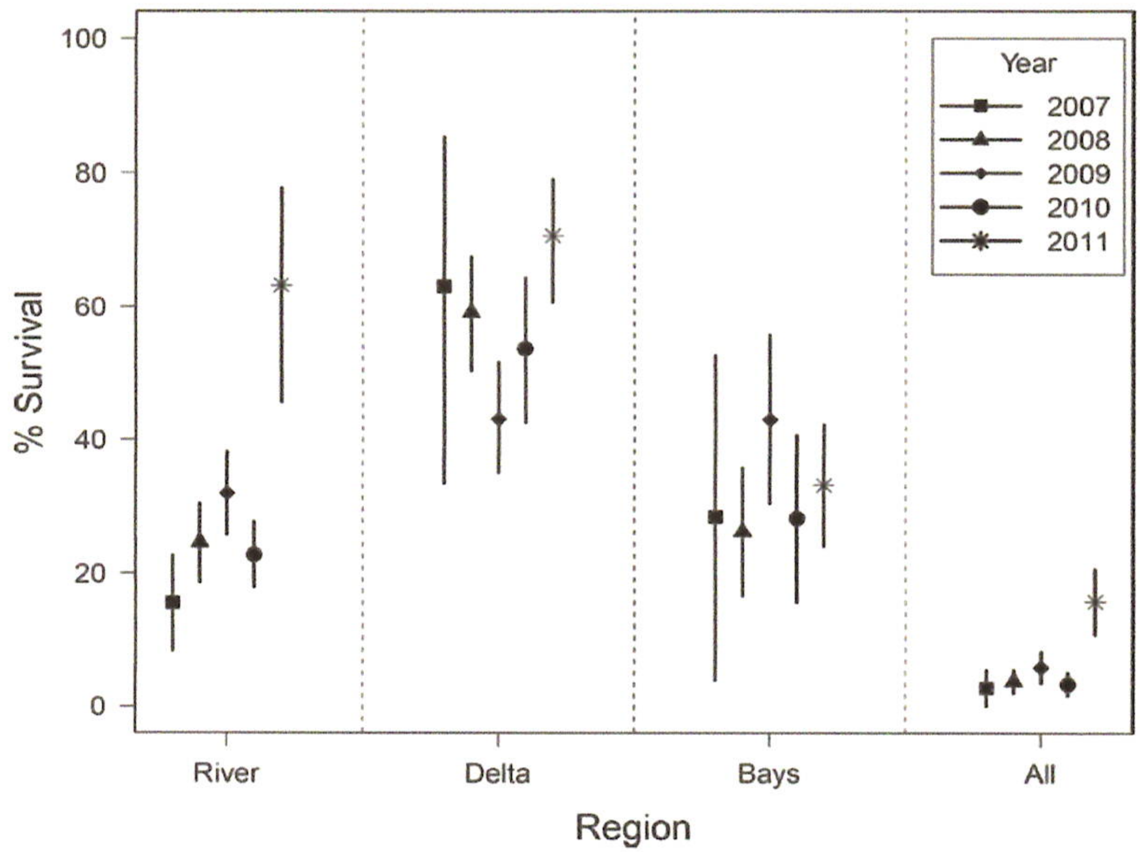


Figure 6. Percent survival per major region for all 5 study years. Regions include river, Delta, Bays, and the percent survival for the entire watershed (II). Error bas represent 95% confidence intervals. (Source: Michel et al. 2015, p. 1,757 (DWR-Exhibit XX)).

The uncertainty and variability in juvenile salmon survival in response to river flow is apparent in results of survival studies that compared survival over a wide range of hydrologic conditions in the south Delta (Buchanan et al. 2018, DWR Exhibit 1327, p. 663-669.) Survival estimates over the period from 2010 through 2015 between Mossdale and Chipps Island ranged from 0 to 5%. The survival estimate for 2011, a wet year with high spring flows was 2%, showing that increased flow alone did not result in a substantial increase in juvenile salmon survival.

Results of the analysis I conducted using the USFWS CWT data of survival as a function of Sacramento River flow at Freeport are shown in Figure 7. Survival as a function of flow at Rio Vista is shown in Figure 8. Results of these analyses show similar trends with high variability and low R2 values (R2=0.07 for flow at Freeport and R2=0.03 for flow at Rio Vista), and relatively flat slopes to the regression lines, suggesting that a large change in flow would be required to achieve a relatively small change in survival (with high uncertainty). These results are similar to results generated from CWT releases that occurred in the upper Sacramento River, suggesting that Sacramento River flow within the range evaluated (approximately 10,000 to 80,000 cfs) has only a small effect on juvenile salmon survival for fish released into the upper watershed (upstream of Red Bluff Diversion Dam) and for those fish released downstream in the vicinity of Sacramento.

The high observed variation in the flow-survival relationship for juvenile salmonids (primarily based on mark-recapture results for fall-run and late fall-run Chinook salmon produced in Central Valley fish hatcheries) reflects, in part, the large number of factors other than river flow affect species survival. Salmonid exposure to predation is a major factor affecting juvenile survival (Vogel 2011, p. iii (DWR-Exhibit 1341), Cavallo et al 2012, p. 343-403 (DWR-Exhibit 1342), Grossman et al. 2013, p. 2-45 (DWR-Exhibit 1343), Grossman 2016, p. 1-16 (DWR-Exhibit 1344)). Indeed, migration studies typically show 50% or more of migrating juvenile salmon were lost before they reach the Delta (Perry and Skalski 2010, DWR-Exhibit 1336, p. 16-17, Michel et al. 2015, DWR-Exhibit 1340 p. 1,754).

Several theories have been advanced to support the notion that higher instream flows will benefit juvenile salmonid survival. One hypothesis is that, at higher flows, the downstream rate of juvenile migration would be faster and, therefore, juvenile salmonids would have reduced exposure to potential predators. Results of acoustic tag studies, however, indicate that juvenile downstream migration rates are faster in the upper Sacramento River and migration rates decrease as the juvenile salmon pass through the tidally influenced areas of the Delta and estuary (Michel 2010, p. 118 (DWR-Exhibit 1340); Figure 6). The duration of migration for each release group shown in Figures 9 and 10 was calculated based on the time between release and the first fish recaptured at Chipps Island reflecting variability in migration rates among experimental release groups. Analysis of the duration between release and recapture of CWT salmon migrating through the Delta do not show a response between Sacramento River flow and migration rate (Figures 9 and 10).

These studies show that the relationship between river flow and migration rates (time from release to recapture downstream at Chipps Island) is very weak and does not support the theory that increasing river flow will result in faster migration rates through the Delta or reduced exposure to in-Delta predation mortality.

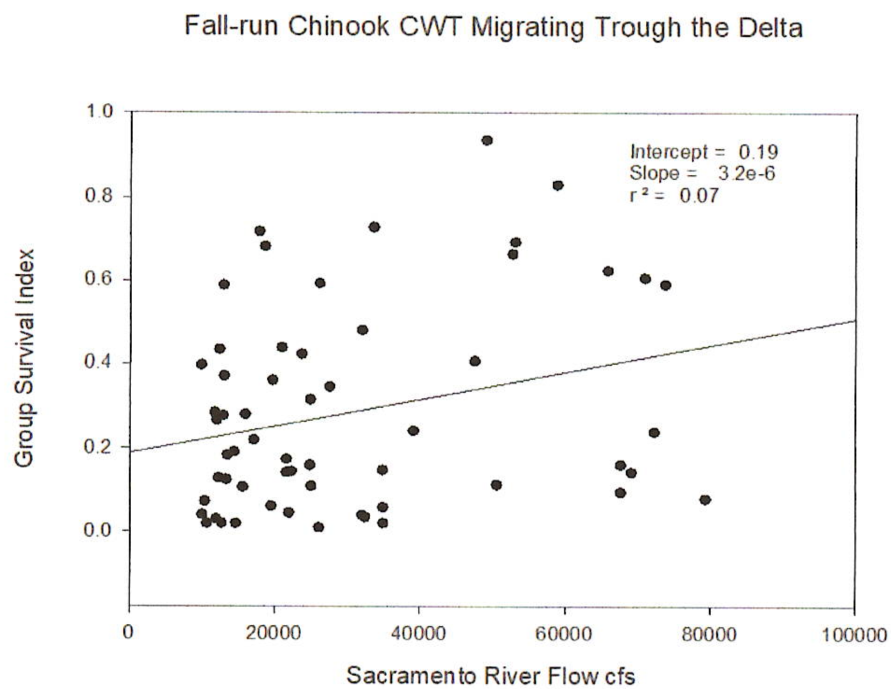


Figure 7. Relationship between average Sacramento River flow at Freeport over a 14 -day period after release and juvenile fall-run salmon survival to Chipps Island for CWT fish released in the vicinity of Sacramento (Data source: USFWS unpubl. Data).

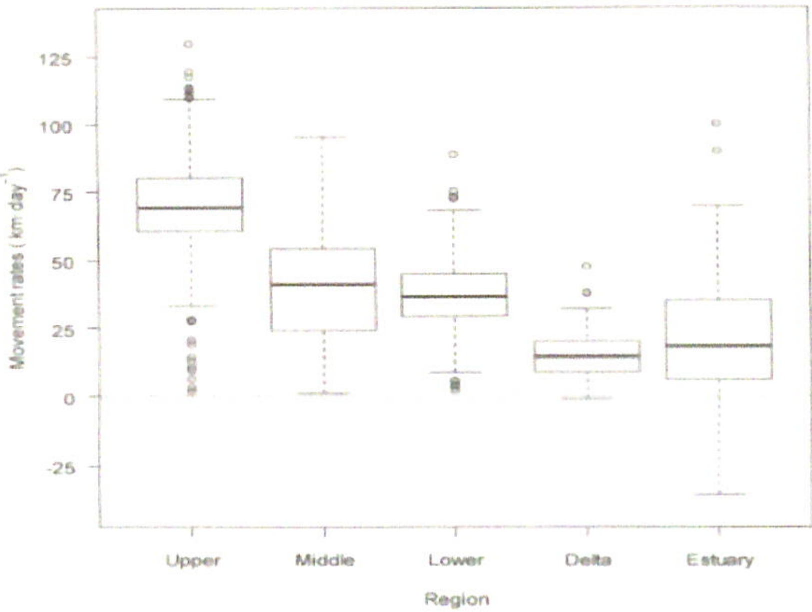


Figure 8. Reach specific migration rates for acoustically tagged late fall-run Chinook salmon in the Sacramento River, Delta, and estuary (Source: DWR-1340, Michel 2010, p. 118).

In sum, the functions and inter-relationships among flow and habitat quality and availability, growth, survival, reproductive success, and abundance of salmonids are complex. The available data show that there is high and low certainty/predictability in flow-survival relationships, although the data also show a general trend toward increased salmonid survival as flow increases during downstream migration.

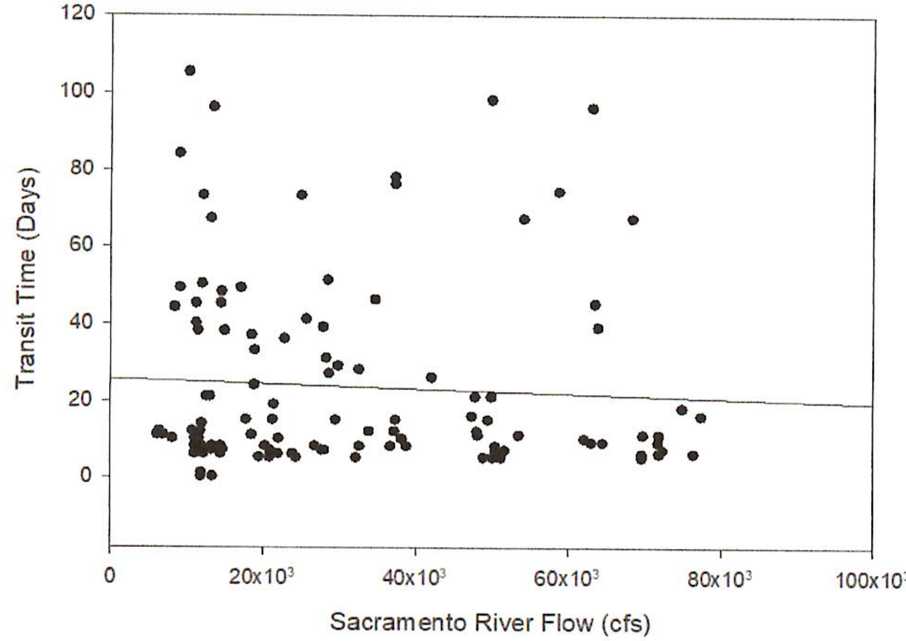


Figure 9. **Relationship between Sacramento River flow (30-day average) and Delta salmon migration duration (Data source: USFWS unpubl. data).**

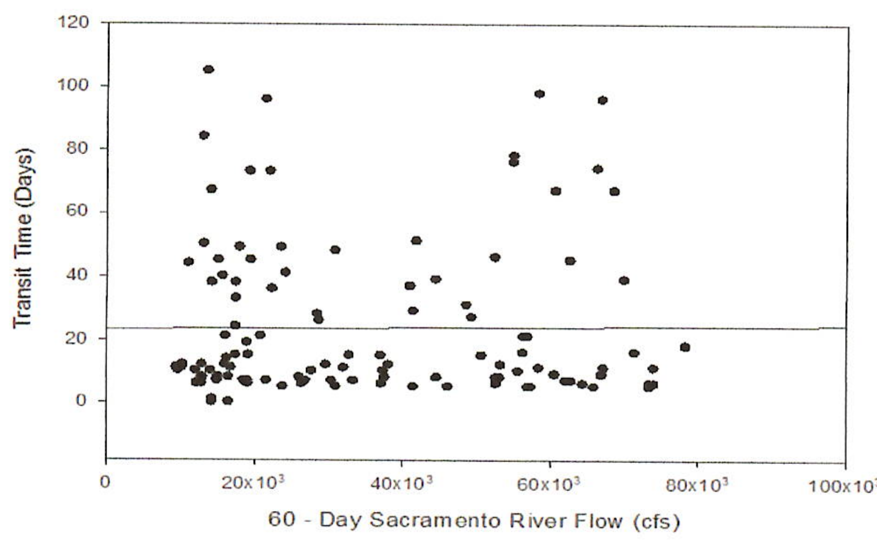


Figure 10. **Relationship between Sacramento River flow (60-day average) and Delta salmon migration duration (Data source: USFWS unpubl. data).**

III. CONCLUSION

- Multiple historical physical and hydrologic changes have shaped the current Delta;
- The current state of the Delta is the result of multiple physical and hydrologic factors operating over multiple time scales;
- There is significant uncertainty regarding the nature, extent and magnitude of the effect of current SWP-CVP operations as well as other stressors on salmonid survival;
- The relationship between Sacramento River flow rates and juvenile salmonid survival is weak (large changes in river flow are needed to achieve even a small change in salmonid survival in the Sacramento River and Delta) with high uncertainty (low R2 values); and
- Multiple authors have concluded that flow alone cannot be used to restore the Delta. As stated by the NAS, "The Delta as it existed before large-scale alteration by humans cannot be recreated." (NAS 2012, p. 10). Buchanan et al. (2018, p. 663) also concluded that increased flow alone will not be sufficient to resolve the low salmonid survival in the Delta.

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