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On behalf of South Delta Water Agency,
Central Delta Water Agency, Lafayette Ranch,
Heritage Lands, Mark Bachetti Farms
and Rudy Mussi Investments L.P.

STATE OF CALIFORNIA

STATE WATER RESOURCES CONTROL BOARD

Hearing in the Matter of California Department of Water Resources and United States Department of the Interior, Bureau of Reclamation Request for a Change in Point of Diversion for California Water Fix	**THOMAS K BURKE'S WRITTEN SUMMARY OF TESTIMONY, PART 2 CASE IN CHIEF**

I, Thomas Burke, submit this written testimony at the request of Protestants South Delta Agency, Central Delta Water Agency, Lafayette Ranch, Heritage Land Company, Mark Bachetti Farms and Rudy Mussi Investments L.P., the ("South Delta Parties/Protestants.") The matters contained herein are true and correct and based upon my personal knowledge. If called upon to testify to them, I would and could do so.

Background and Qualifications

I am a hydrologist and water resources engineer with over 35 years of experience in surface water and groundwater hydrologic modeling. Prior to starting Hydrologic Systems Inc., I held the position of Senior Associate with PWA, Western Regional Director of Water Resources for EA Engineering Science and Technology, and Hydraulic Engineer with the US Army Corps of Engineers. My experience ranges from development of two-, and three-dimensional river and reservoir flow and circulation models to local and regional groundwater and transport models for basin-wide hydrologic analyses. My experience also includes the analysis of one and two-dimensional flow in river and wetland systems. I have worked on a variety of projects evaluating hydrodynamic and flow characteristics in the Delta for the past several years.

I hold a Master of Science in Civil Engineering from Colorado State University, Fort Collins (1992) with a specialty in Water Resources, and hold a Bachelor of Science in Civil Engineering from The University of Florida, Gainesville (1980). My Statement of Qualifications is marked as SDWA 75. I am a registered Professional Civil Engineer in the State of California (License No. C 50051).

I was retained with regard tp Part 2 of the proceedings by the South Delta Parties to conduct a mass balance of salt in the South Delta. The analysis evaluated the change in salt loading between the NAA and the PA scenarios of the WaterFix that were contained in the Biological Assessment. The underlying reason for my analysis is that other parties through this, and other processes, have raised the issue that changes in salinity or salt loads might affect habitat, fisheries or other biological resources. (See for example the California Impact Network, dated 17 March 2017, Exhibit SDWA__, submitted in the Bay-Delta Water Quality Control Plan Phase 1 process. My testimony and modeling show that there are substantial changes in salt loading and that the

Petitioners have failed to examine how these changes might affect habitat and biological resources.

The testimony and modeling contained herein will show that there are substantial changes in salt loading and that the Petitioners have failed to examine how these changes might affect those habitat and biological resources. In my Part 1 testimony I examined how the salinity concentration changed in various channels of the Delta due to the California Water Fix (CWF). My testimony herin is focused on the total salt load that is being delivered to the south Delta, and how that load would change due to the implementation of the CWF Preferred Alternative (PA).

I herein incorporate my prior reports and exhibits submitted in support of the SDWA's Part 1 case in Chief, Rebuttal, and Sur-Rebuttal as part of my testimony. A copy of my CV can be found at Exhibit SDWA 75.

Opinions:

1. Based on my analysis of the hydrodynamic and water quality data contained within the Petitioners hydrodynamic model, DSM2, it is my opinion that there will be a significant increase in salt loading to the South Delta. On average, there will be an increase of roughly 30,000 metric tons of salt brought into the South Delta each year under the CWF PA. The details supporting my opinion are provided below.
2. A review of the comments by other parties indicates that changes in salinity and salt load might/can affect habitat and biological resources; and that Petitioners have not examined the effects of either the increased concentrations set forth by my previous analysis in Part 1 or the increased loads as set for herein.
3. Upon review of Petitioners documentation, it is my opinion that the Petitioners have failed to examine the potential effects on habitat, fisheries and other biological resources from either the increased concentrations as documented in my Phase 1 testimony, or the increased loads as set forth herein. Both the increased

concentrations, and the increased loads were based on the Petitioners own model and data, which I have not modified in conducting this, or my Part 1 analysis.

I. Introduction

The California Delta is one of the largest estuaries in North America, hosting upwards of nearly 500 different plant and animal species. Many of these aquatic species are sensitive to the changes in salinity that are brought about during different phases of the hydrologic cycle. The existing habitat within the Delta is presently under multiple stressors and each of these is taking a toll on the native aquatic organisms. Additional changes to salinity levels can induce additional stress that may adversely affect the vitality of the different native species. The decline in species diversity as well as population stability has been well documented in the Delta.

Changes to the hydrodynamics and circulation patterns within the Delta will also bring about concurrent changes to salt movement through the system. These changes to the movement of salt have been shown to result in substantial changes in salinity, as shown in my Part 1A testimony and exhibits. This increase, or the potential effects on habitat, fisheries and other biological resources remain unexamined by the Petitioners.

The changes proposed by the CWF will affect the existing circulation patterns in the Delta. The project proposes to divert up to 9,000 cfs from the Sacramento River to replace some of the water that is presently being diverted from the South Delta. This change in point of diversion results in less local water being diverted out of the South Delta. The existing diversion of South Delta water by the SWP and CVP is a major source of salt leaving the system, and specifically the study area. With the volume of locally diverted water reduced, in lieu of North Delta Diversions, the volume of salt removed from the system will also be reduced.

To help understand the potential impacts from the CWF project, a salt budget was developed for the South Delta. This budget has provided information on the magnitude and timing of change in salt loading to the area that would result from the CWF PA. The budget does not address what happens to the net flux of salt into or out of the area, but rather identifies what that flux would be.

II. Salt Budget Development

A salt budget for the South Delta was developed by treating the area as a closed volume with specific inflow and outflow points to that volume. An accounting of all the salt flowing into and out of the area will provide for an informed evaluation of the potential salt loading to the South Delta from the CWF. Figure 1 is a delineation the area of the South Delta that was evaluated in this study.

The primary source of salt entering and leaving the South Delta is through Delta channels and the export and diversion points. Water flowing into the South Delta will bring salt into the area. Water flowing out of the area through the channels, or exports, will remove salt from the South Delta. If more salt flows into the area than flows out there will be an accumulation of salt. This accumulation can result in an increase in the salinity of water in the Delta channels. Water flows into the area from the San Joaquin River and tidal flow that pushes existing Delta water and Sacramento River water into the area through Old and Middle Rivers with each tidal cycle. The South Delta export pumps also impose a significant gradient on the Delta resulting in additional Sacramento River water being drawn into the area. The inflow and outflow components of the budget are listed below:

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Table 1 South Delta Water Budget Components

No.	Inflow / Outflow Point	Default Direction
1	The San Joaquin River at Vernalis	(inflow)
2	The San Joaquin River at Burns Cut	(outflow)
3	The Middle River at Victoria Canal	(outflow)
4	Old River Above Indian Slough	(outflow)
5	The CCWD Intake on Victoria Canal	(outflow)
6	The CVP and SWP South Delta Exports	(outflow)

For each of the above components, an outflow from the South Delta can become an inflow to the South Delta if the flow in the river were to reverse. This can and does frequently happen in the Delta. The tidal action causes water to flow back and forth in the channels. The South Delta export pumps can create a gradient across the south Delta, resulting in reverse flows, especially in Old and Middle Rivers. Water that has exited the South Delta can return to the South Delta through the channel it exited by, or since the Delta is an interconnected network of channels, it can return to the South Delta through another channel.

For the purposes of this testimony, the DSM2 model was run for an 81 year simulation from 1923 through 2003. This was the period that was analyzed in the Biological Assessment (BA) of the proposed CWF project. The flow and salinity data that were input to the DSM2 model were provided by the Petitioners as an exhibit to Part 1A of this hearing.

DSM2 is a hydrodynamic model developed for the Delta that computes flow throughout the Delta channels on a 15-minute time step. It also has the capability, through the QUAL Module, to track salinity movement through the system at the same time. By multiplying the flow at a specific location entering or leaving the South Delta by the corresponding salinity for that same location and timestep, you can compute the mass of salt entering or leaving the area.

The DSM2 model, calculates the flow and salinity at specified nodes throughout the modeled area. These values can be used to evaluate flow and salinity at different locations, but the greatest strength of the model is when it is used in a comparative mode.. In a comparative mode, the results from one model scenario is compared to another model scenario to evaluate the relative change to salinity and flow based on the differences between the two scenarios. By using it in this type of comparative mode, all assumptions in the model development are applied identically to each scenario, so the difference in the results are just due to the changes from one scenario to another.

My analysis herin does not address the fate of the salts that enter or leave the area of the South Delta, it only evaluates the net change, or flux, of salt that passes into or out of the area of analysis. The current science and the DSM2 model are not able to accurately determine the amount of salts that enter the soil root zone, or shallow groundwater table. But it is able to effectively evaluate the net flux of salt entering or leaving the area within the Delta channels.

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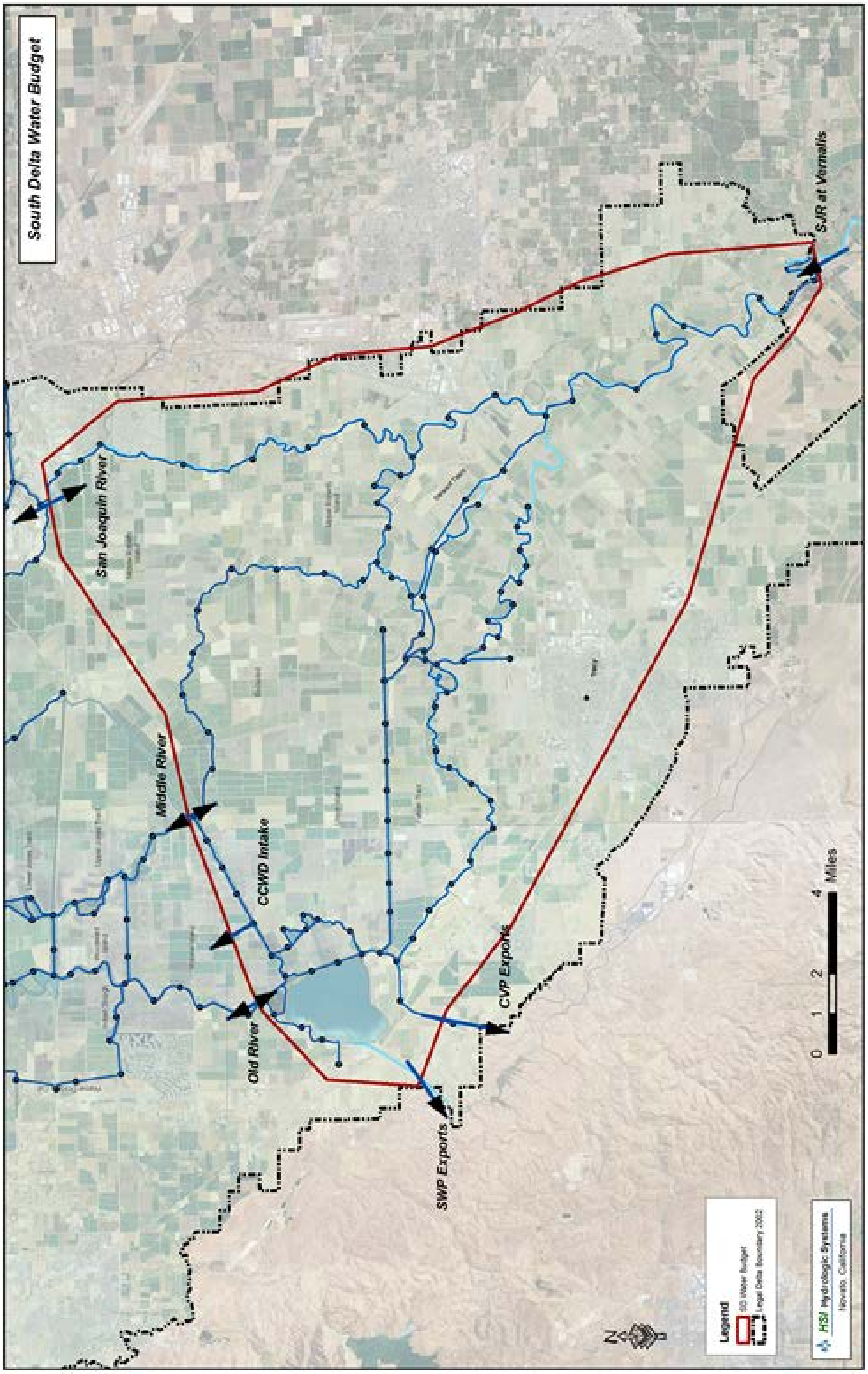

Figure 1 South Delta Budget Area.

All of these channel components and their changing directions are accounted for, and modeled, in the Petitioners DSM2 hydrodynamic model. The model computes flow and salinity on a 15-minute time step. To look at changes over a variety of hydrologic conditions, the model was run from 1921 through 2003. The first two years of the time period were not used in the analysis so that they could be used to allow the model to spin up and come to a quasi-equilibrium.

The DSM2 model provides an estimate of flow and salinity at each inflow and outflow point in the South Delta, for each period. The equation for computing the salt load at each inflow/outflow location for each time step is shown below.

$$Cl_x = Q_x * S_x * T \qquad \text{Eqn 1.}$$

Where:

Cl = Chloride in (mg)

Q = Flow in ft^3/sec, converted to (liters/sec)

S = Salinity in electrical conductivity, converted to (mg/liter Cl)

T = Time (15 minutes for this analysis)

X = Represents the inflow/outflow point

The computed Chloride mass for each time step was summed over a month period to provide a monthly value of salt movement at the inflow/outflow point. The net Chloride mass was computed for each monthly time period using the following equation.

Eqn 2.

$$Net\ Cl = SJR_{south} - SJR_{north} - Old\ River - Middle\ River - CCWD - Exports$$

The change in direction of flow is accompanied by a change of the sign of the flow from positive to negative in the DSM2 model. That way the loss or gain of salt is accounted for correctly.

III. Chloride Calculation

The model represents salinity as electrical conductivity (EC) measured in μS/cm. There is not a single conversion to convert EC to Chloride. The source and chemical composition of the water will result in different relationships between EC and Cl. Several different equations comparing Cl to EC have been developed for the Delta. These equations are derived from measured EC and Cl data collected at different locations in the Delta. The equation most appropriate for the location of the flow source was used to convert the model EC to Cl for the salt budget. The equations used for each inflow and outflow point are shown below.

1. San Joaquin River at Vernalis and Burns Cut

   Gage: San Joaquin River near Vernalis

   $Cl = 0.0218 * EC^{1.285}$ Eqn 3.

   $R^2 = 0.96$

2. Old and Middle Rivers

   Gage: Middle River at Bordon Bridge

   $Cl = 0.2374 * EC - 35.067$ Eqn 4.

   $R^2 = 0.94$

3. CVP and SWP Exports

   Gage: Los Vaqueros intake, Clifton Court Forebay

   $Cl = \frac{EC - 160.6}{3.66}$ Eqn 5.

   $R^2 = 0.99$

   (From DRW Memo from Bob Suits to Paul Hutton)

4. CWF Diversions

Gage: Sacramento River at Sacramento

$Cl = 0.0772 * EC - 4.5951$ Eqn 6.

$R^2 = 0.84$

Plots of the data used in developing the above equations are shown in Figures 2 through 4.

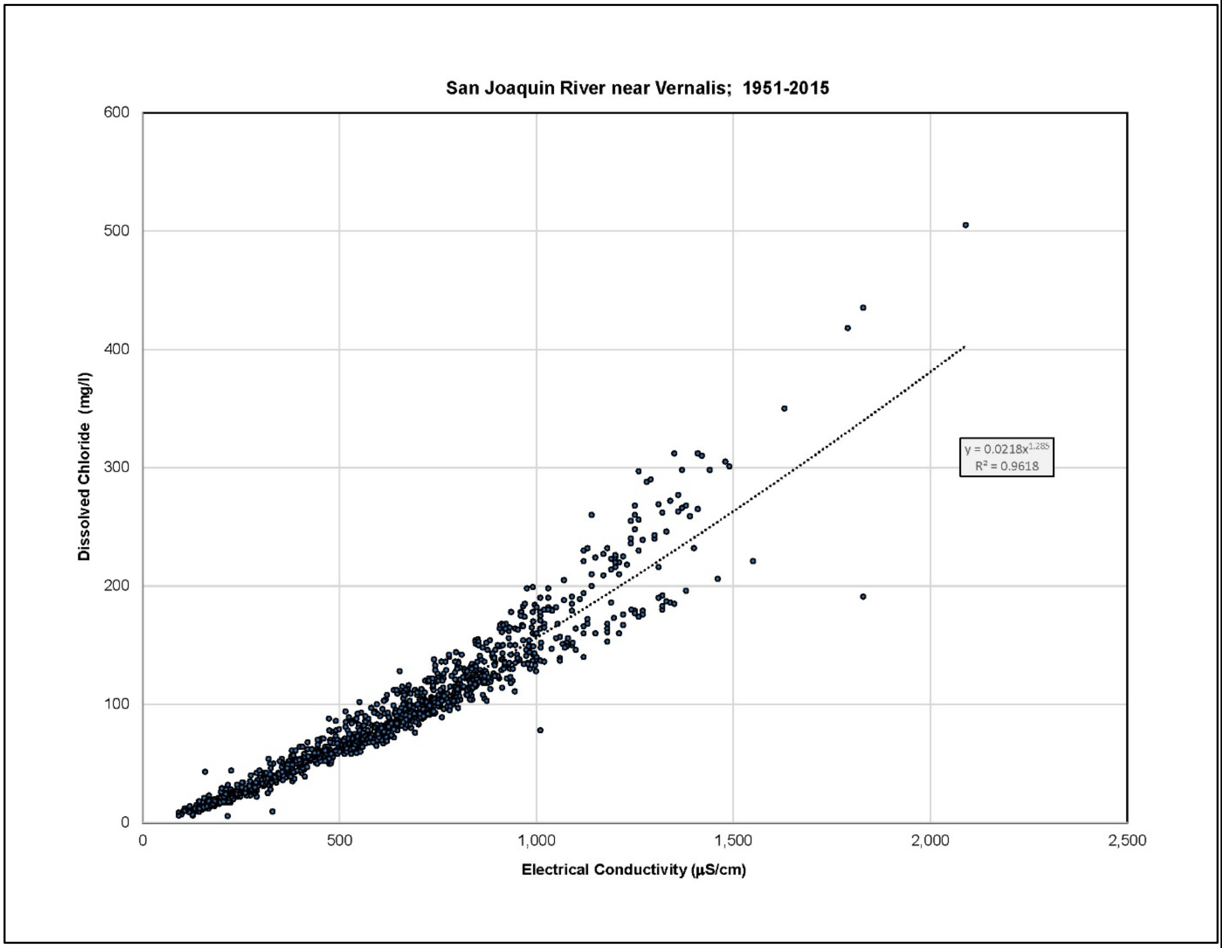

Figure 2 Joaquin River at Vernalis Cl vs EC.

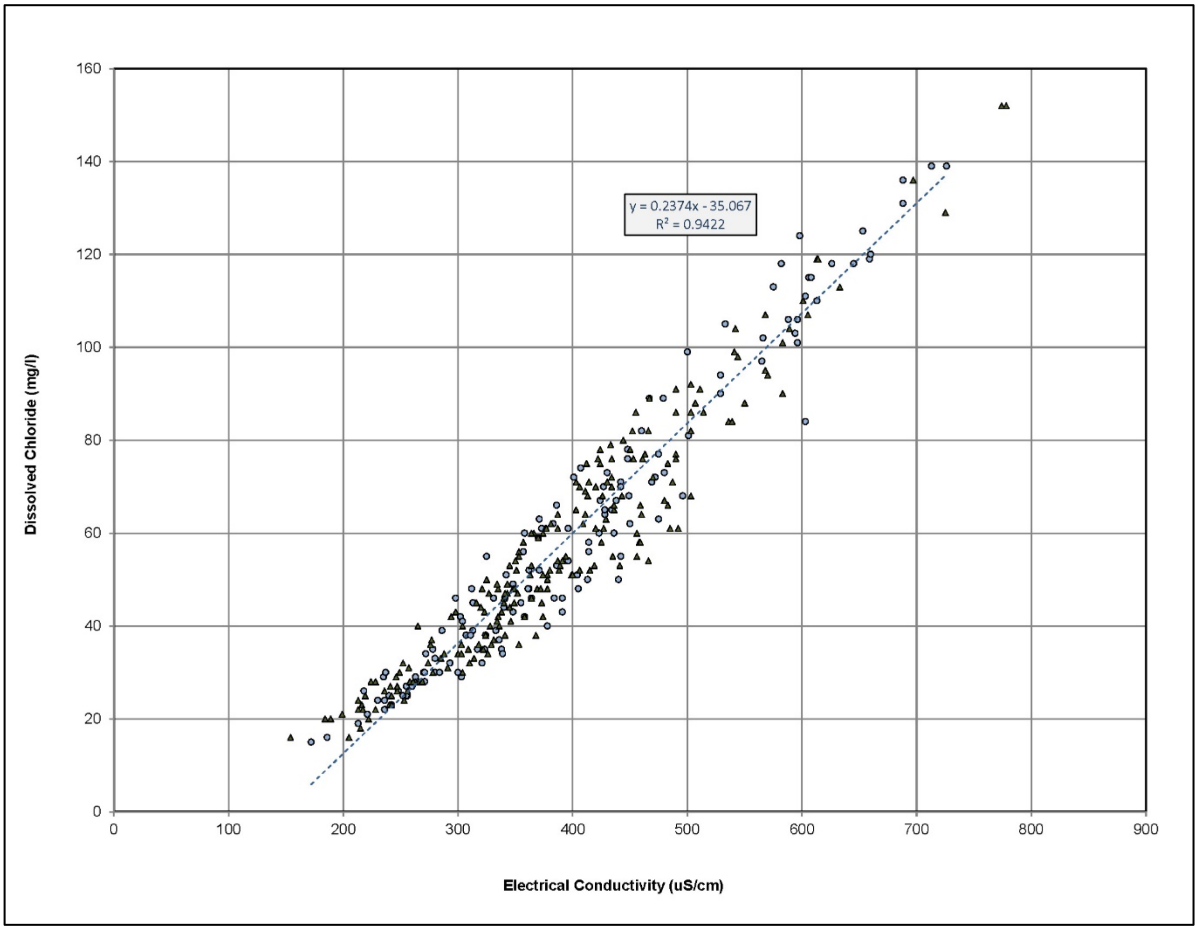

Figure 3 Middle River at Bordon Bridge Cl vs EC.

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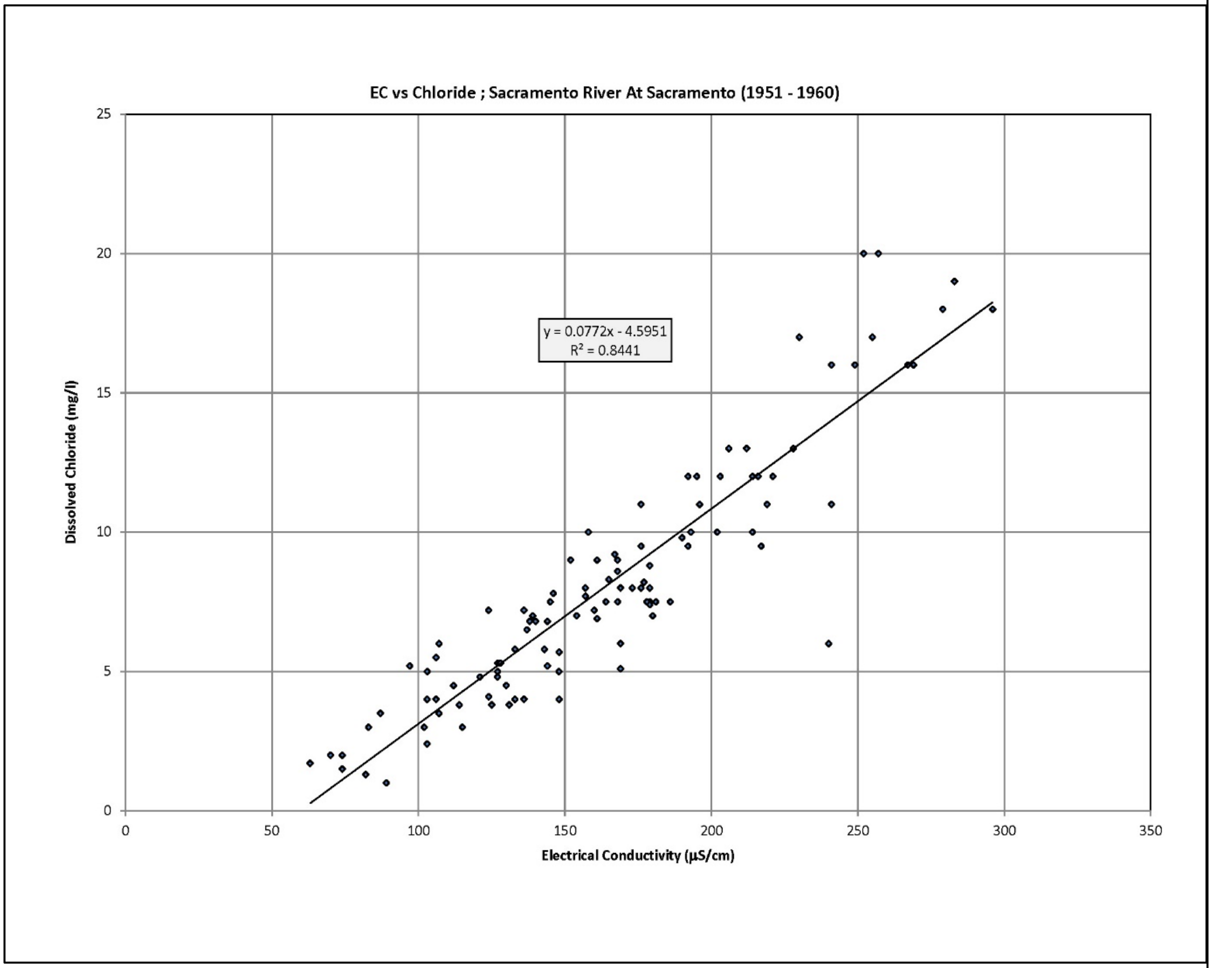

Figure 4 Sacramento River at Sacramento Cl vs EC.

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IV. Model Results

The results of the DSM2 model for the 82 year period were averaged to get daily, monthly, and then mean monthly values for flow and salt flux at each inflow/outflow location. The net salt loss or gain to the South Delta was then calculated using Equation 2.

The monthly net results from the salt budget were computed for both the PA and the NAA scenarios that were presented in the BA for the CWF project. Table 2 is a summary of the mean monthly values from the budget for the NAA and PA scenarios. As can be seen in the table, there are some months that show a net outflow of salt from the area, represented by a negative number, and some months where there is a net inflow of salt for both scenarios, represented by a positive number. The absolute value of the salt flux in any particular month for a particular scenario is not as important as the difference between the two scenarios. As mentioned previously, the DSM2 model is best used in a comparative mode, to evaluate changes from one scenario the another, rather than as a predictive tool for any particular period. Column 4 of Table 2 shows the difference in mean monthly salt load to the South Delta when comparing the PA to the NAA. As can be seen in the table, there is a significant increase in salt load delivered to the South Delta area for all months except June. This is primarily due to the reduction in pumping from the South Delta export pumps, and the replacement of that water with water from the North Delta Diversions on the Sacramento River. The net average annual difference is 30,000 metric tons per year. The difference between the PA and the NAA for each month is plotted in Figure 5.

Table 3 provides a tabulation of the mean monthly values for salt flux and flow for each of the different components of the budget for the NAA. Table 4 shows the same mean monthly values for the PA of the CWF.

Table 2 Summary of Mean Monthly Salt Loading for The PA and the NAA

Month	NAA Chloride (mt)	PA Chloride (mt)		PA-NAA Difference Chloride (mt)
January	-12,728	-8,242		4,487
February	-8,965	-6,322		2,643
March	-5,462	-2,468		2,994
April	-593	-41		552
May	1,495	2,327		832
June	4,954	4,642		-312
July	4,126	4,240		114
August	-564	1,141		1,706
September	-8,604	-1,798		6,806
October	-6,432	-1,488		4,943
November	-7,854	-3,243		4,611
December	-8,065	-7,117		948
			Mean Annual =	30,323

A Negative Value Reflects A Net Outflow Of Salt From The South Delta
A Positive Value Reflects A Net Influx Of Salt Into The South Delta
mt = metric ton = 1,000 Kg

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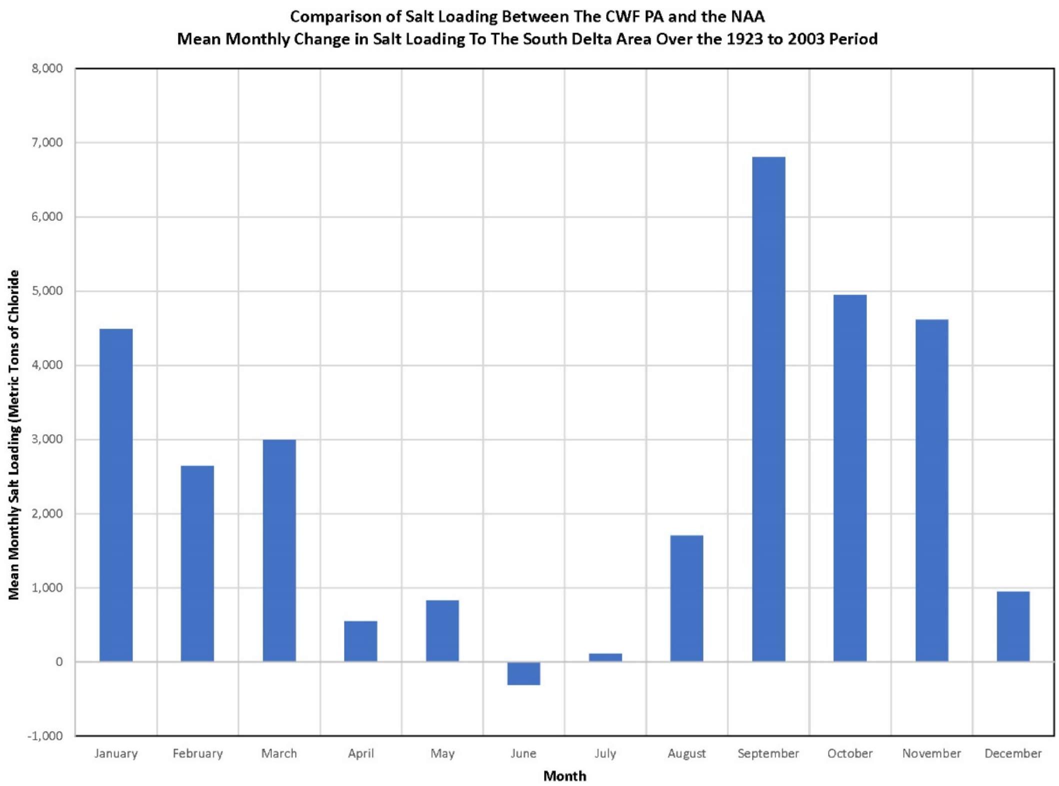

Figure 5 Comparison of Salt Loading Between the CWF NAA and the PA

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Table 3 Mean Monthly Salt Flux and Flow Rate At The South Delta Inflow/Outflow Points For The CWF NAA

Mean Monthly Average From 1923 to 2003

	NAA												
Month	**SJR Vernalis**		**SJR At Burns Cut**		**Middle River**		**Old River**		**Exports**		**CCWD Diversion**		**Total**
	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride
	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)
January	23,319	5,060	8,728	1,904	-11,351	-1,300	-22,386	-2,446	60,683	6,921	374	40	-12,728
February	25,440	6,753	9,952	2,680	-7,251	-991	-11,368	-1,923	43,066	6,978	6	2	-8,965
March	25,330	6,773	9,880	2,765	-6,224	-927	-8,559	-1,784	35,690	6,603	6	1	-5,462
April	15,196	6,146	6,759	2,644	-325	229	262	570	8,901	2,180	193	75	-593
May	14,979	5,971	6,139	2,475	-792	88	-487	336	8,240	2,273	384	118	1,495
June	14,537	3,945	5,875	1,631	-4,662	-1,224	-6,464	-2,078	14,794	4,459	40	7	4,954
July	12,803	2,590	3,745	854	-9,531	-3,066	-20,463	-5,438	34,508	9,024	417	122	4,126
August	8,768	1,828	2,803	594	-10,013	-2,971	-26,105	-5,275	41,881	8,466	767	207	-564
September	10,205	2,199	4,971	1,062	-13,466	-2,885	-39,156	-5,180	65,487	8,572	972	203	-8,604
October	12,152	2,601	7,835	1,651	-10,584	-1,991	-26,911	-3,513	47,683	6,093	562	82	-6,432
November	12,094	2,423	7,568	1,481	-12,455	-2,252	-32,660	-4,056	56,963	7,027	532	72	-7,854
December	19,819	3,294	5,485	1,047	-13,684	-2,292	-31,563	-4,162	67,153	8,513	493	55	-8,065
Mean Annual	16,220		6,645		-8,362		-18,822		40,421		396		-48,693

Notes:

1. The Downstream Direction Is Oriented Towards San Francisco Bay.
2. A Negative Flow Reflects Net Flow In The Upstream Direction.
3. A Negative Chloride Mass Flux Reflects A Net Salt Flux In The Upstream Direction.

Table 4   Mean Monthly Salt Flux and Mean Flow Rate At The South Delta Inflow/Outflow Points For the CWF PA

Mean Monthly Average From 1923 to 2003

	PA												
Month	**SJR Vernalis**		**SJR At Burns Cut**		**Middle River**		**Old River**		**Exports**		**CCWD Diversion**		**Total**
	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride	Mean Flow	Chloride
	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)	(cfs)	(mt)
January	23,319	5,060	14,776	2,727	-6,878	-514	-13,371	-964	36,697	3,811	337	35	-8,242
February	25,440	6,753	15,415	3,542	-4,201	-94	-6,134	-247	26,675	3,548	6	2	-6,322
March	25,331	6,772	15,286	3,651	-2,543	224	-2,359	373	17,406	2,393	8	1	-2,468
April	15,199	6,146	10,014	3,579	-1,057	347	-361	815	6,446	924	199	73	-41
May	14,981	5,971	9,361	3,338	-1,089	275	-739	698	4,819	898	302	96	2,327
June	14,538	3,945	7,382	1,954	-3,156	-600	-4,097	-896	9,747	2,307	20	3	4,642
July	12,803	2,590	4,505	972	-5,330	-1,410	-8,338	-2,315	17,273	4,086	451	122	4,240
August	8,771	1,828	3,279	685	-5,790	-1,641	-11,724	-2,750	21,140	4,531	724	207	1,141
September	10,206	2,199	4,516	969	-4,955	-1,103	-11,288	-1,799	22,849	3,485	883	203	-1,798
October	12,152	2,601	9,300	1,973	-3,980	-643	-8,276	-970	16,026	1,899	570	83	-1,488
November	12,094	2,423	6,881	1,367	-5,441	-907	-11,731	-1,537	25,182	3,284	447	72	-3,243
December	19,819	3,294	5,670	1,071	-11,047	-1,942	-23,246	-3,511	55,143	7,510	417	55	-7,117
Mean Annual	194,652		106,385		-55,467		-101,663		259,402		4,364		-18,370

Notes:

1. The Downstream Direction Is Oriented Towards San Francisco Bay.
2. A Negative Flow Reflects Net Flow In The Upstream Direction.
3. A Negative Chloride Mass Flux Reflects A Net Salt Flux In The Upstream Direction.

V. Conclusion

The results from the salt budget that was developed for the South Delta show a very strong correlation between the flow changes as proposed in the CWF PA and a net increase in salt being delivered to the South Delta. An evaluation of the details of the model output, as presented in Tables 3 and 4 show that the primary source of this increase in salt load comes from the reduction of South Delta Exports, in favor of water from the NDD's. There mass of salt removed through the CVP and SWP South Delta Exports is reduced dramatically. The reduction in South Delta Exports leaves roughly 225,000 metric tons of salt per year in the South Delta that would normally be removed. Some of the other channels pick up some of this salt and help to remove it, but on average, there is still 30,000 metric tons of salt per year that will accumulate in the South Delta. This is a significant amount of salt loading to the area.

This analysis did not evaluate the fate of the net salt that is left in the South Delta. Some of that salt will contribute to a net salinity increase in the water, as shown in my previous testimony in Part 1 of this hearing. Some of that salt will migrate into the shallow groundwater, and some the salt will be retained in the delta soils. An increase in salt for any of these potential areas could be problematic for the ecosystem, and has not been evaluated or studied by the Petitioners.

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VI. Signed

I declare under penalty of perjury under the laws of the state of California that the foregoing is true and correct.

Executed this 30 th. day of November 2017 in Placerville, California.

Thomas K. Burke

THOMAS K BURKE, P.E.

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