TO: Lower San Joaquin River Committee

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SUBJECT: HOFFMAN MODELING RESULTS

In March 2010, Central Valley Regional Water Quality Control Board staff released the draft report titled *Salt Tolerance of Crops in the Lower San Joaquin River (Stanislaus to Merced River Reaches)* (Draft Report) for public review and comment. Staff presented the Draft Report to a joint meeting of the CV-SALTS Executive and Technical Advisory Committees on 11 March 2010. The public comment period closed on 19 May 2010. Minor editorial comments received from stakeholders during the meeting and in public comment letters were incorporated into a revised Draft Report released in June 2010. The comments that were not addressed in the revised Draft Report are to be addressed by the Lower San Joaquin River Committee (LSJRC), a subcommittee of CV-SALTS. The LSJRC has taken over the responsibility for developing the science and policy needed to develop salinity water quality objectives (WQOs) for the San Joaquin River upstream of Vernalis.

To assist with development of Lower San Joaquin River (LSJR) salinity WQOs, the Draft Report utilized the modeling approach that Dr. Glenn J. Hoffman presented in his report titled *Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta* (2010). Some of the inputs utilized in the 2010 model were based on policy decisions, such as protecting for 100% yield for the most salt sensitive crop in the irrigated area. Subsequently, the LSJRC developed science and policy recommendations specific to agriculture irrigated with LSJR water to assist with the establishment of locally protective WQOs. The Committee recommendations have expanded the crop tolerance modeling results presented in the Draft Report. The purpose of this memorandum is to document the results of the revised modeling which was conducted by Central Valley Water Board staff in June and October 2014.

Model Parameter Recommendations

The LSJRC policy recommendations for developing WQOs for the LSJR require changes to model parameters used in modeling for the 2010 Draft Report. The committee has determined that protection of agriculture from salinity in San Joaquin River irrigation water should be based on almond crop sensitivity rather than on bean crop sensitivity as the 2010 Draft Report was based on. The change in crop was based on the most salt sensitive crop included in 95% of the commercially cropped acreage irrigated with LSJR water. The soil water salinity threshold for almond is 3.0 deciSiemens per meter (dS/m) rather than 2.0 dS/m for bean.

The LSJRC also recommended that the effect of rainfall on crop sensitivity be modeled during a year when the annual rainfall is at the 5^{th} percentile of total annual precipitation rather than during a minimum rainfall year as the 2010 Draft Report modeled. The 2014 modeling generated statistical data for climate and annual rainfall measured between 1951 and 2013, whereas the 2010 modeling generated statistical data from measurements collected between 1951 and 2008.

The committee decided that a leaching fraction of 15 percent is appropriate for LSJR Basin agriculture. However, the committee considered a leaching fraction of 10 percent as a means of evaluating possible conditions during a drought.

Daily climate data for various model runs presented in the Draft Report were taken from two weather stations: NCDC station no. 6168 (Newman C) for Crows Landing/Patterson modeling and NCDC station no. 5738 (Modesto C) for Maze modeling. The Crows Landing/Patterson model results were more conservative than the Maze results. That is, the Draft Report modeling predicted higher soil water salinity values using Crows Landing/Patterson climate records when all other parameters such as leaching fraction and irrigation water salinity were held constant. Therefore, staff only utilized Newman C daily climate data for the 2014 model runs.

The CV-SALTS Policy Committee and the LSJRC have recommended the use of the exponential crop water uptake pattern for modeling rather than the 40-30-20-10 pattern. Also, the Central Valley Water Board received many comments on the Draft Report in support of using the exponential over the 40-30-20-10 pattern. Therefore, staff only utilized the exponential pattern for the 2014 modeling.

For the 2014 modeling, staff updated the model spreadsheets used to predict almond soil water salinity values presented in the 2010 Draft Report by including the parameter changes mentioned above. The modeling and cropping assumptions made for both the 2010 and the 2014 modeling are presented in Sections 5.1.1 and 5.1.2 of both the March and June 2010 Draft Report versions.. Also, references for setting model crop coefficients and growth periods for estimating crop evapotranspiration requirements are presented in Section 5.1.3 of both versions. Figure 5.5 of the Draft Report presents the almond crop coefficients and growth periods that were used in the 2010 and 2014 modeling.

Summarizing the task given to Central Valley Water Board staff by the LSJRC, the 2014 modeling was performed to establish the soil water salinity necessary to result in a 95 percent almond crop yield when applying a leaching fraction of 15 percent during a fifth percentile total annual precipitation water year in the LSJR Basin. Also, staff evaluated a 10 percent leaching fraction in modeling to evaluate possible soil water salinity under drought conditions.

2014 Modeling

Table 1 presents model parameters for the Central Valley Water Board staff 2014 Hoffman modeling runs. Using the parameters presented in Table 1, with an assumed leaching fraction of 15 percent applied by irrigators in the LSJR Basin, staff ran the model 16 times, each time varying the irrigation water salinity electrical conductivity value by 0.1 dS/m, from an initial value of 0.5 dS/m through a final value of 2.0 dS/m. The resulting soil water salinity and crop yield values predicted by the model for each of the 16 runs are presented in Table 2. Figure 1 is a plot of irrigation water salinity versus soil water salinity presented in Table 2. Figure 2 is a plot of irrigation water salinity versus relative crop yield presented in Table 2.

Figure 2 shows that the predicted irrigation water salinity necessary for an almond crop yield of 95 percent when the leaching fraction is set at 15 percent is approximately 1.5 dS/m. Through an iteration process, staff determined that the predicted value to two decimal points is approximately 1.55 dS/m. Table 3 is the model input and output table for that run: irrigation water salinity set at 1.55 dS/m and the leaching fraction set at 15 percent. The bottom cell of the total annual precipitation column near the left side of the table shows that the computed 5th percentile annual rainfall total from the 1952 through the 2013 water years was 6.07 inches. The bottom cell of the far right column in Table 3 shows that the model predicts a soil water salinity of 3.53 dS/m during a 5th percentile annual rainfall year.

Figure 3 is a plot of the annual precipitation versus soil water salinity values from Table 3. The plot shows the impact of rainfall on soil water salinity when the irrigation water salinity is 1.55 dS/m and the leaching fraction is 15 percent. Observe that the predicted soil water salinity plot passes through the intersection of the 5th percentile annual precipitation line and the 95 percent crop yield salinity line.

To inform discussions of the LSJRC on drought impacts, Central Valley Water Board staff was asked to perform modeling runs using a leaching fraction of 10 percent, with the parameters presented in Table 1 to establish the irrigation water EC necessary to maintain an almond crop yield of 95 percent. Staff ran the model 16 times, each time varying the irrigation water salinity electrical conductivity value by 0.1 dS/m, from an initial value of 0.5 dS/m through a final value of 2.0 dS/m. The resulting soil water salinity and crop yield values predicted by the model for each of the 16 runs are presented in Table 4. Figure 4 is a plot of irrigation water salinity versus soil water salinity presented in Table 4. Figure 5 is a plot of irrigation water salinity versus relative crop yield presented in Table 4.

Figure 5 shows that the predicted irrigation water salinity necessary for crop yield of 95 percent when the leaching fraction is set at 10 percent is approximately 1.0 dS/m. Through an iteration process, staff determined that the predicted value to two decimal points is approximately 1.01 dS/m.

Results

Table 5 summarizes the results. To achieve an almond crop yield of at least 95 percent during a 5th percentile annual rainfall year with a leaching fraction of 15 percent, the model predicts that the irrigation water EC must be no more than 1.55 dS/m; with a leaching fraction of 10 percent, the model predicts that the irrigation water EC must be no more than 1.01 dS/m.

cc: Administrative Record for the Basin Plan Amendment to establish Lower San Joaquin River Salinity Water Quality Objectives

Table 1

Input Parameters for
Hoffman Modeling of Almond Salinity Requirements

Model Parameters:

1. Patterson Weather Station
   data 01/01/52 thru 09/30/13
2. 5th percentile precipitation = 6.1 inches
3. Exponential crop water uptake pattern
4. Almond crop soil water EC threshold = 3.0
5. 95% crop yield protection
6. Bare soil ET = 0.7 inches/month
7. Runoff coefficient = 77
8. Almond growth stage crop coefficients:
   - B Kc1 = 0.5
   - C Kc2 = 0.9
   - E Kc3 = 0.5
9. Almond growth stage dates:
   - A 15-Feb
   - B 15-Feb
   - C 1-Jun
   - D 1-Sep
   - E 10-Nov
10. S = (1000/CN) - 10 = 3.0
11. Extraterrestrial radiation (mm/day) at 37º latitude

Month	Ra
1	6.88
2	9.00
3	11.65
4	14.47
5	16.31
6	17.04
7	16.65
8	15.18
9	12.69
10	9.84
11	7.39
12	6.31

Table 2

Predicted Soil Water Salinity and Crop Yield at a LF of 15% at Varying Irrigation Water Salinities (µS/cm)

Irrigation Water	Soil Water	Crop Yield
0.5	1.14	100
0.6	1.37	100
0.7	1.60	100
0.8	1.82	100
0.9	2.05	100
1.0	2.28	100
1.1	2.51	100
1.2	2.74	100
1.3	2.96	100
1.4	3.19	98.2
1.5	3.42	96.0
1.6	3.65	93.8
1.7	3.88	91.6
1.8	4.10	89.6
1.9	4.33	87.4
2.0	4.56	85.2

Table 3

Model Output Scenario: Irrigation Water Salinity of 1.55 and LF of 15%

Water Year	Input Variables						Model Output
		EC_i =	**1.55**		LF = 0.15		
	P_T (in.)	P_{NG} (in.)	E_S (in.)	P_{GS} (in.)	P_{EFF} (in.)	ET_C (in.)	EC_{SWb-2} (dS/m)
1952	16.89	8.72	2.2093	8.17	14.6807	46.9106	2.7949
1953	6.78	5.09	2.2323	1.69	4.5477	44.7044	3.4786
1954	6.51	2.69	2.2093	3.82	4.3007	44.3594	3.4940
1955	9.75	6.15	2.2093	3.6	7.5407	45.9497	3.2767
1956	10.89	8.09	2.2093	2.8	8.6807	46.2963	3.2010
1957	8.68	2.85	2.2323	5.83	6.4477	45.9620	3.3538
1958	19.69	6.92	2.2093	12.77	17.4807	45.5127	2.5647
1959	10.84	5.12	2.2093	5.72	8.6307	45.5745	3.1949
1960	6.61	5.29	2.2093	1.32	4.4007	44.9699	3.4911
1961	7.11	5.08	2.2323	2.03	4.8777	44.0289	3.4493
1962	12.00	9.58	2.2093	2.42	9.7907	44.2539	3.0918
1963	14.02	8.48	2.2093	5.54	11.8107	41.3296	2.8829
1964	6.47	2.55	2.2093	3.92	4.2607	42.5748	3.4839
1965	10.28	4.78	2.2323	5.5	8.0477	41.9786	3.1873
1966	10.57	8.86	2.2093	1.71	8.3607	44.9451	3.2058
1967	13.48	7.94	2.2093	5.54	11.2707	43.2268	2.9639
1968	6.06	3.3	2.2093	2.76	3.8507	44.3121	3.5266
1969	18.84	11.23	2.2323	7.61	16.6077	43.5097	2.5724
1970	8.64	5.19	2.2093	3.45	6.4307	44.4480	3.3396
1971	13.36	7.84	2.2093	5.52	11.1507	42.6483	2.9616
1972	6.16	5.56	2.2093	0.6	3.9507	44.5548	3.5208
1973	17.01	11.18	2.2323	5.83	14.7777	43.6354	2.7117
1974	11.53	5.46	2.2093	6.07	9.3207	44.1445	3.1245
1975	10.73	5.72	2.2093	5.01	8.5207	44.9755	3.1947
1976	4.31	0.86	2.2093	3.45	2.1007	44.7450	3.6559
1977	5.66	2.72	2.2323	2.94	3.4277	44.9956	3.5613
1978	17.25	9.61	2.2093	7.64	15.0407	45.0319	2.7268
1979	10.38	5.91	2.2093	4.47	8.1707	46.4518	3.2385
1980	13.03	6.63	2.2093	6.4	10.8207	43.4361	3.0015
1981	8.24	4.47	2.2323	3.77	6.0077	46.0953	3.3860
1982	14.81	6.54	2.2093	8.27	12.6007	43.3500	2.8670
1983	19.78	8.37	2.2093	11.41	17.5707	42.9837	2.4848
1984	8.42	6.56	2.2093	1.86	6.2107	46.8274	3.3786
1985	8.22	4.8	2.2323	3.42	5.9877	45.1595	3.3787
1986	12.90	6.15	2.2093	6.75	10.6907	44.8472	3.0363
1987	6.32	3.63	2.2093	2.69	4.1107	46.4298	3.5213
1988	11.02	6.92	2.2093	4.1	8.8077	46.4231	3.1938
1989	8.15	4.74	2.2323	3.41	5.9177	45.7273	3.3890
1990	6.50	3.11	2.2093	3.39	4.2907	45.5038	3.5027
1991	8.77	2.31	2.2093	6.46	6.5607	42.6840	3.3104
1992	10.80	5.63	2.2093	5.17	8.5907	44.8405	3.1878
1993	17.84	10.9	2.2323	6.94	15.6077	42.2683	2.6127
1994	8.93	4.44	2.2093	4.49	6.7207	43.2184	3.3045
1995	18.72	9.71	2.2093	9.01	16.5107	40.9028	2.5013
1996	14.15	7.66	2.2093	6.49	11.9407	43.9054	2.9276
1997	13.61	11.97	2.2323	1.64	11.3777	44.2045	2.9748
1998	26.02	16.59	2.2093	9.43	23.8107	40.4260	1.9015
1999	8.70	3.71	2.2093	4.99	6.4907	42.4877	3.3134
2000	11.51	5.83	2.2093	5.68	9.3007	43.9027	3.1222
2001	11.14	4.46	2.2323	6.68	8.9077	45.0462	3.1678
2002	7.61	6.09	2.2093	1.52	5.4007	45.0023	3.4194
2003	10.45	4.97	2.2093	5.48	8.2407	43.3956	3.1932
2004	9.77	5.76	2.2093	4.01	7.5607	46.0418	3.2763
2005	15.29	7.11	2.2323	8.18	13.0577	43.2947	2.8317
2006	12.10	5.48	2.2093	6.62	9.8907	47.3294	3.1315
2007	4.34	3.05	2.2093	1.29	2.1307	48.1548	3.6646
2008	8.76	6.84	2.2093	1.92	6.5507	48.9043	3.3743
2009	6.54	3.78	2.2323	2.76	4.3077	42.5211	3.4799
2010	13.99	6.46	2.2093	7.53	11.7807	37.9015	2.8018
2011	12.95	5.46	2.2093	7.49	10.7407	37.4409	2.8793
2012	6.28	1.51	2.2093	4.77	4.0707	40.5814	3.4832
2013	7.74	6.31	2.2323	1.43	5.5077	40.6549	3.3694
5th Percentile	**6.07**						**3.53**

ET_C = crop evapotranspiration

E_S = off-season surface evaporation

P_{GS} = precipitation during growing season

P_T = total annual (infiltrating) precipitation

Table 4

Predicted Soil Water Salinity and Crop Yield at a LF of 10% at Varying Irrigation Water Salinities (µS/cm)

Irrigation Water	Soil Water	Crop Yield
0.5	1.75	100
0.6	2.09	100
0.7	2.44	100
0.8	2.79	100
0.9	3.14	98.7
1.0	3.49	95.3
1.1	3.84	92.0
1.2	4.19	88.7
1.3	4.54	85.4
1.4	4.89	82.1
1.5	5.24	78.8
1.6	5.59	75.4
1.7	5.93	72.1
1.8	6.28	68.8
1.9	6.63	65.5
2.0	6.98	62.2

Table 5

Hoffman Modeling Results for Almond[1]

Leaching Fraction	ECi (dS/m)	ECsw (dS/m)
10%	1.01	3.53
15%	1.55	3.53

1) 95% crop yield, 5th percentile rainfall year

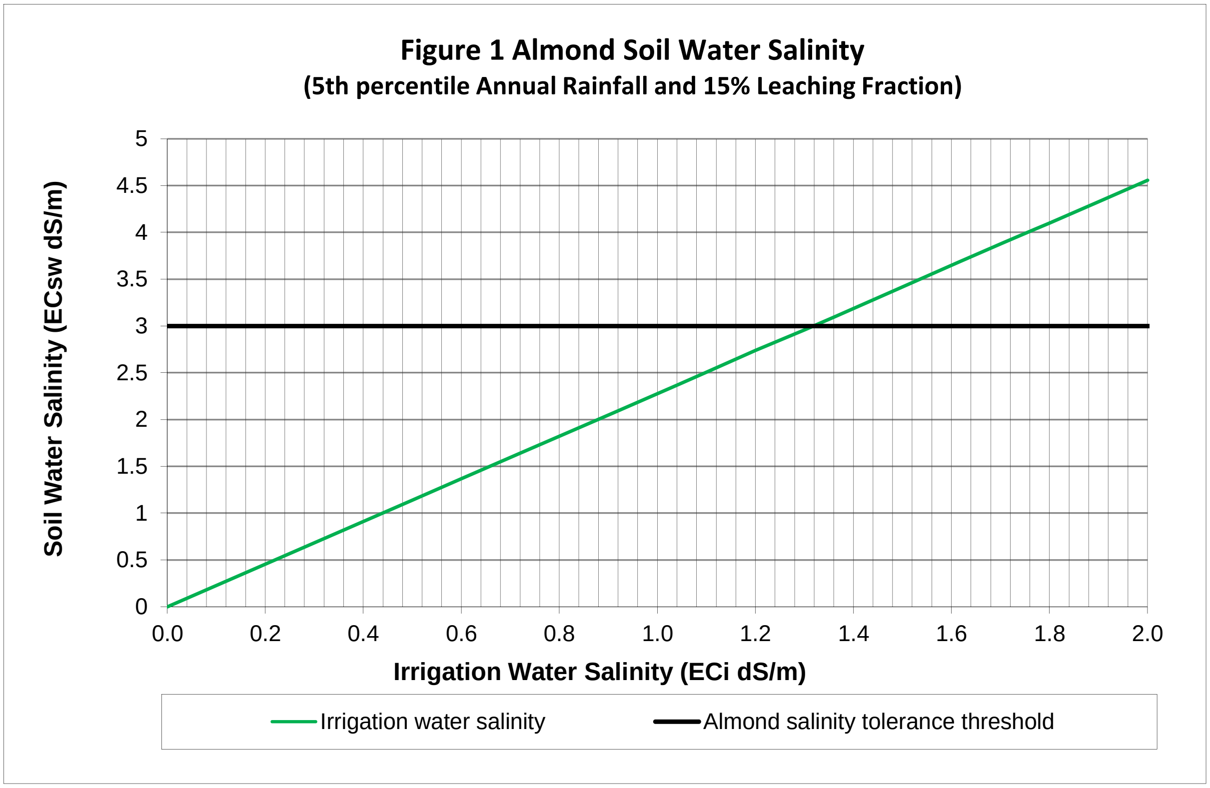
Figure 1 Almond Soil Water Salinity
(5th percentile Annual Rainfall and 15% Leaching Fraction)
Soil Water Salinity (ECsw dS/m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Irrigation Water Salinity (ECi dS/m)
Irrigation water salinity
Almond salinity tolerance threshold

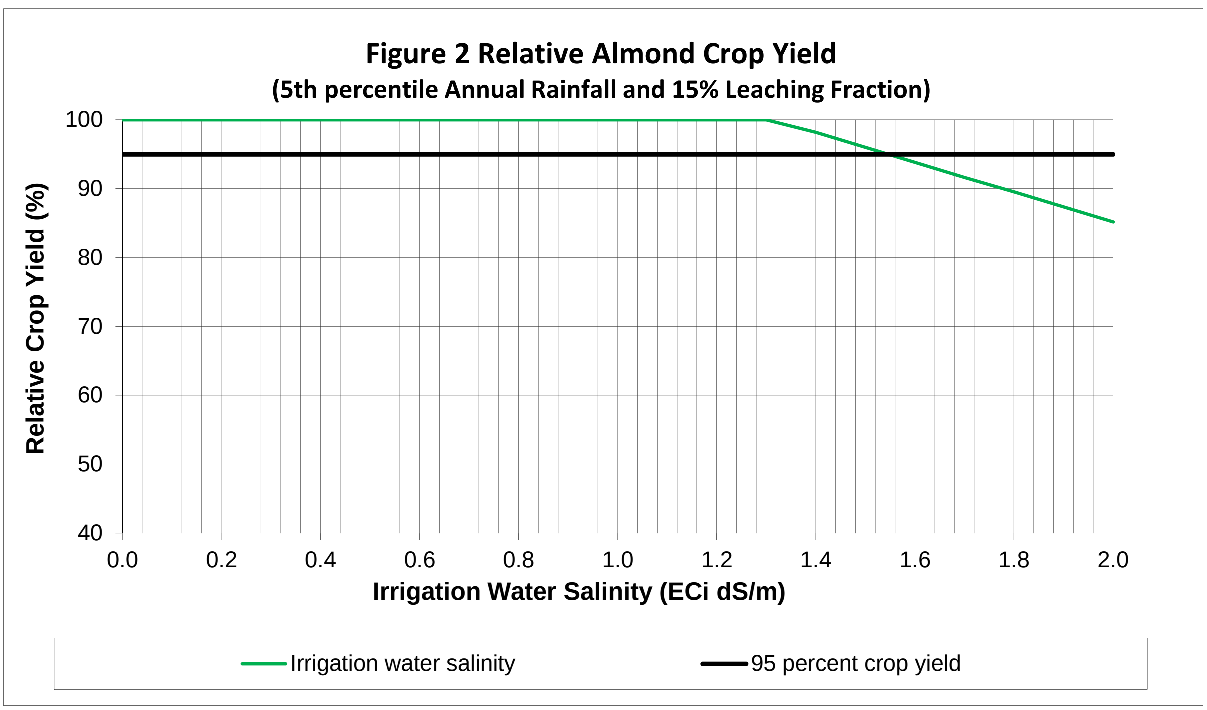
Figure 2 Relative Almond Crop Yield
(5th percentile Annual Rainfall and 15% Leaching Fraction)
Relative Crop Yield (%)
100
90
80
70
60
50
40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Irrigation Water Salinity (ECi dS/m)
Irrigation water salinity
95 percent crop yield

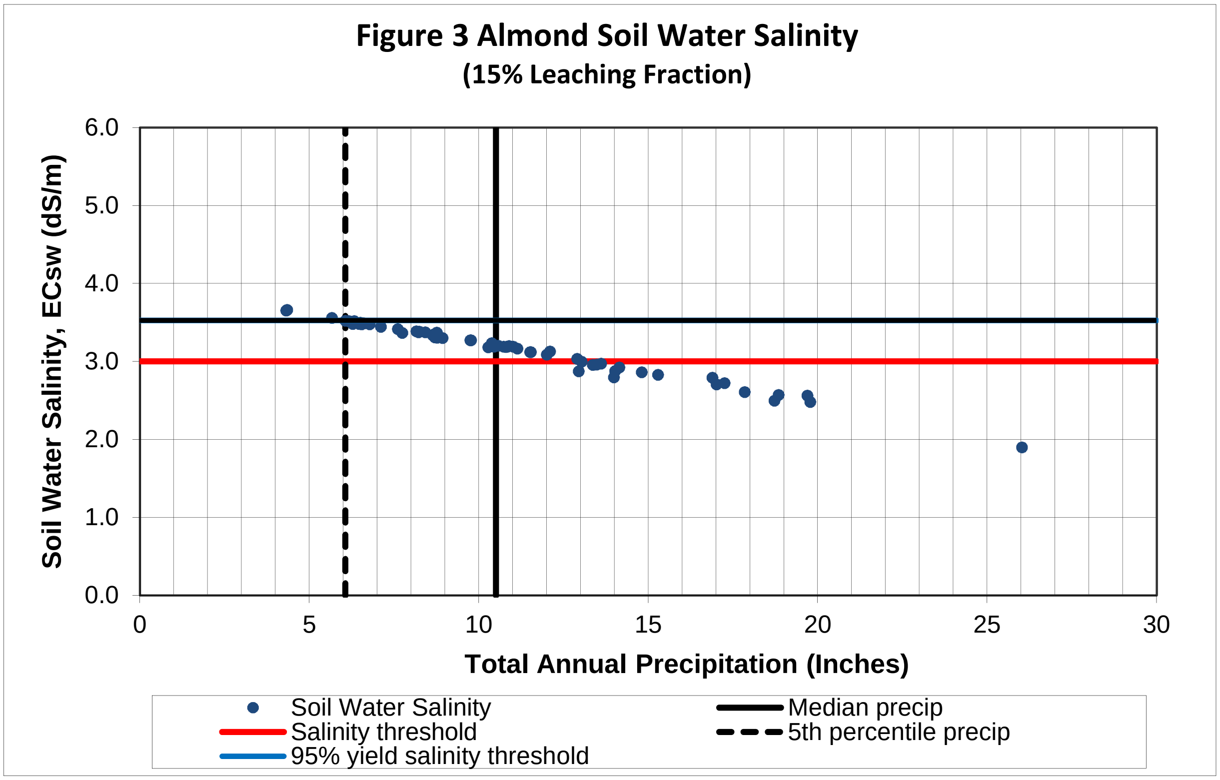
Figure 3 Almond Soil Water Salinity
(15% Leaching Fraction)
Soil Water Salinity, ECsw (dS/m)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
Total Annual Precipitation (Inches)
Soil Water Salinity
Salinity threshold
95% yield salinity threshold
Median precip
5th percentile precip

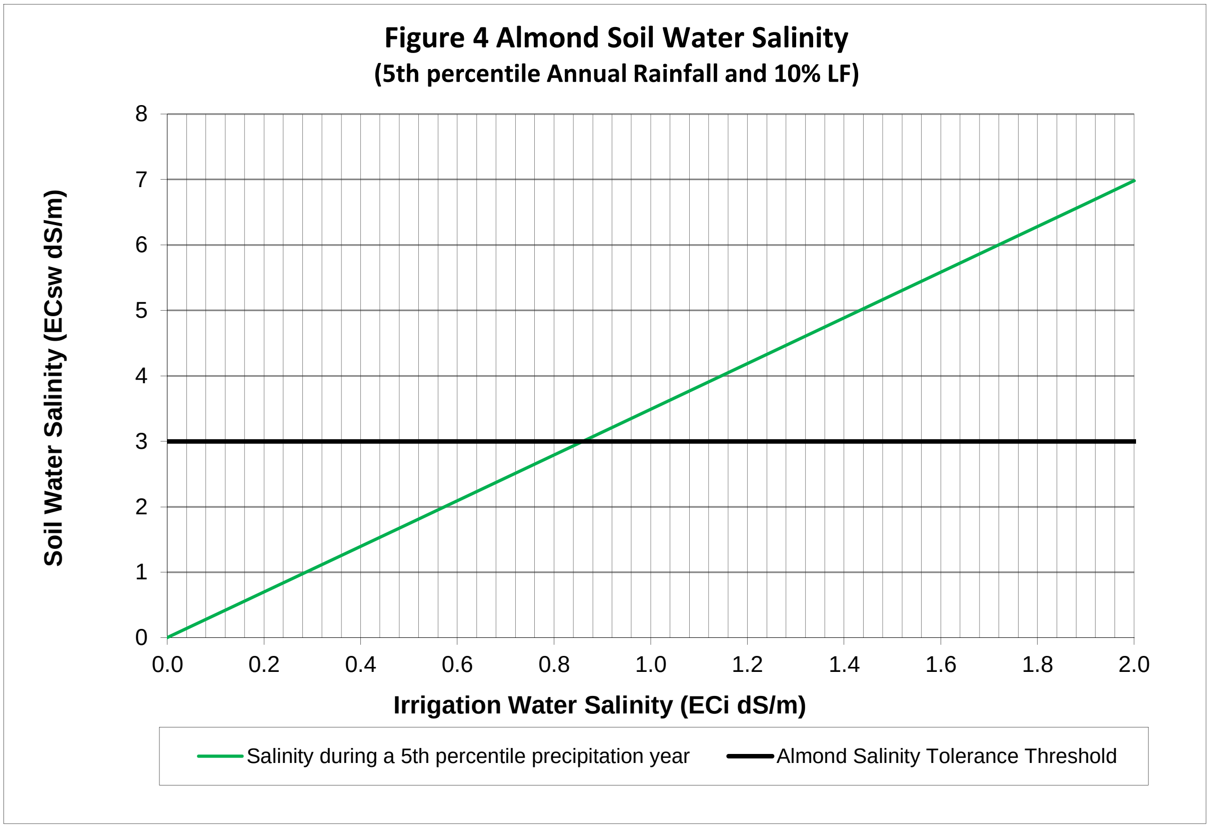
Figure 4 Almond Soil Water Salinity
(5th percentile Annual Rainfall and 10% LF)
Soil Water Salinity (ECsw dS/m)
0
1
2
3
4
5
6
7
8
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Irrigation Water Salinity (ECi dS/m)
Salinity during a 5th percentile precipitation year
Almond Salinity Tolerance Threshold

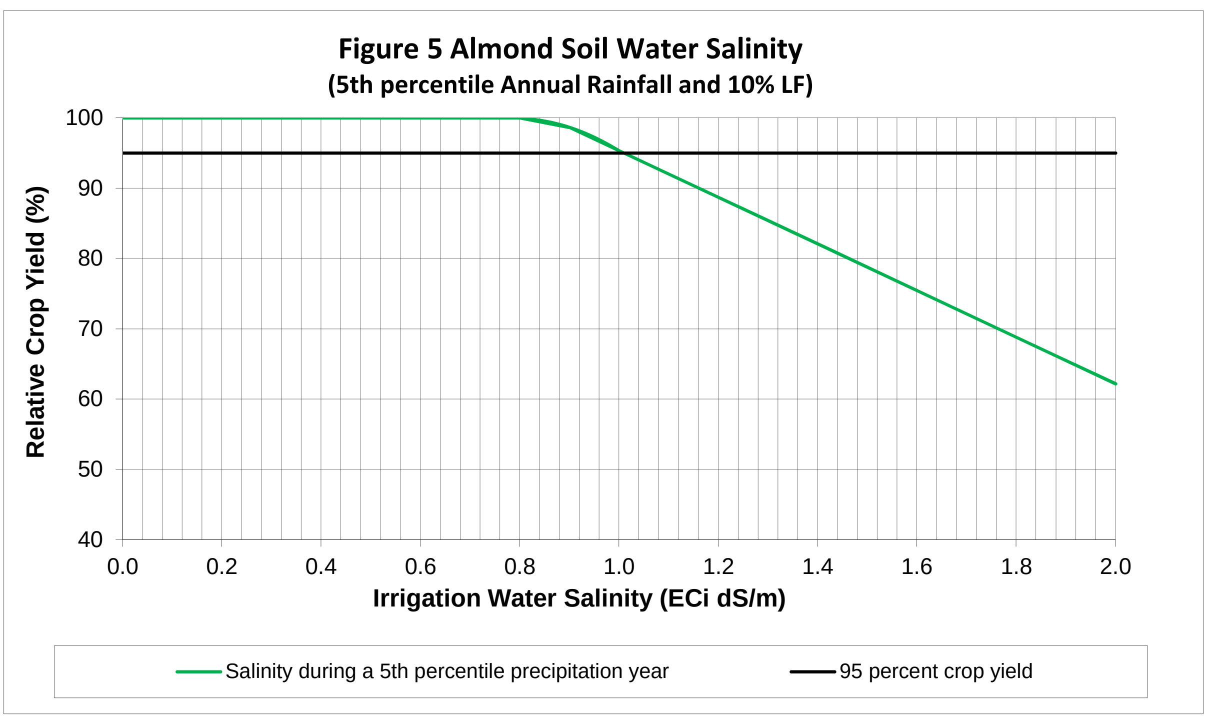
Figure 5 Almond Soil Water Salinity
(5th percentile Annual Rainfall and 10% LF)
Relative Crop Yield (%)
40
50
60
70
80
90
100
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Irrigation Water Salinity (ECi dS/m)
Salinity during a 5th percentile precipitation year
95 percent crop yield