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BEFORE THE

STATE WATER RESOURCES CONTROL BOARD

HEARING REGARDING PETITION REQUESTING CHANGES IN WATER RIGHTS OF THE DEPARTMENT OF WATER RESOURCES AND U.S. BUREAU OF RECLAMATION FOR THE CALIFORNIA WATERFIX PROJECT	TESTIMONY OF TERRY PRICHARD

My name is Terry Prichard and I reside at 6601 Stanley Rd. Stockton CA. I am a soil scientist/agronomist and agricultural consultant with over 40 years of experience in analyzing and testing the effects of water supply and quality on crop production. Over the years much of my work has dealt with the effects of salt on plants and crop production, especially with regard to southern Delta salinity issues. Attached hereto is my curriculum vitae marked as Exhibit

SDWA 91

I was retained by SDWA et.al. for this proceeding to analyze data provided by Tom Burke to determine if any changes in southern Delta channel water resulting from the WaterFIx project would injure users of water in the southern and central Delta. I understand that Mr Burke's data is itself taken from the raw data DWR and USBR submitted on behalf of their Petition which is the subject of this hearing.

Although I do run various computer models as part of my various analyses, I have not run either the CalSim II of DSM2 models which produced the DWR/USBR data. I am familiar with those models to a degree and note that the hearing so far has confirmed my prior understandings about the shortcomings of those models. Importantly, the DSM2 model, which is used to produce flow, quality and other data is best used only as a comparative tool. That is to say, running the model with slight changes in inputs can give one an idea of impacts resulting from operational changes corresponding to the changed inputs. Thus one can make conclusions about the impacts of a project.

However, such differences between model runs should not be understood to indicate what conditions will actually result. The cross-examination by SDWA et.al. of the Petitioners' modeling panel highlights this as the modelers agreed that the EC numbers given in their testimony and evidence were for comparative purposes only and they did not assert that those numbers would reflect what would actually occur. Exhibit SDWA 27 included graphs produced by DWR in support of an email update on ongoing water transfers being pumped through the export facilities of DWR or USBR. The graph for Old River near Middle River "predicted" that EC's from approximately July 12, 2016 to August 1, 2016 would be from 680 EC to 450 EC (my estimates from the lines on the graph). Exhibit SDWA 35 included the actual measured EC for this same location (and three other locations). The actual EC's for that same time period were 770-860 EC. Thus the modeled numbers were substantially lower than the actual numbers. In the worst instance, the difference was 380 EC (830 minus 450; August 1).

Regardless of the underlying reason for this huge difference, it illustrates that the model outputs can only be used as a guide in comparing differences; they are not reliable for predicting actual conditions. This becomes extremely relevant with regard to my analysis. Given that we only have the DWR/USBR modeling numbers, we cannot absolutely analyze what will actually occur if the WaterFix project is approved and operated. To highlight this, let us say my analysis deals with modeling numbers in the range of 300-600 EC. My results will then indicate impacts if any associated with those numbers. However, if the actual EC's resulting from the project are 200-300 EC higher, the impacts can be much greater. As explained below, the long term impacts to a crop result when the soil of the root zone accumulates salt to the point where it exceeds the particular crop's tolerance threshold. When modeled numbers do not result in the soil salinity reaching this threshold impacts can be small or non-existent. When the actual numbers reach or exceed the threshold, impacts begin to rise rapidly as shown in Figures 1. and 2. set forth below.

The best method of determining impacts to legal users of water in the Delta is to examine how salinity might affect crop production. This entails certain necessary steps of selecting/calculating the necessary inputs. Because the Delta has so many varying conditions relating to soils, channel water quality, leaching abilities and scores of different crops, I decided to limit the analysis so that the trier of fact would not be inundated with too much data. I chose to examine two crops, beans and almonds, and limited my comparison between the H3 scenario and the No Action Alternative (NAA) at one location, Tracy Blvd. Bridge at Old River, designated as SDN-1 by Mr. Burke in his testimony/exhibits.

Before relating the results of my analyses I need to explain leaching fractions. The leaching fraction is the fraction of crop water use which should pass through the root zone to control salts at a specific level. Michele Leinfelder-Miles of UC Davis Cooperative Extension recently conducted a leaching study in the southern Delta, which is included as Exhibit SDWA 140. In that study she measured the soil salinity at the begging of the season, measured the salinity of all applied water during the season and then measured the soil salinity at the end of the season. In this way she was able to determine how much salt built up in the root zone and how much salt made it way out of the root zone. This then allowed her to calculate the leaching fraction for each site. Her results indicated that in some areas a leaching fraction of less than 5%

was accomplished. I am familiar with the study as I consulted with her on the design, implementation and analysis of the study.

Other calculated leaching fractions for the area exist but are not the result of any actual in field sampling. Those other calculated leaching fractions depend either on modeling or on old data which does not accurately reflect the amounts of salt actually applied or transported through the root zone. Given this, Ms. Lienfelder-Miles study and the leaching fractions she calculated are scientifically reliable, and the only scientifically reliable one that should be used.

The procedure for evaluating the effect of modeled water qualities at location SDN-1 (Tracy Blvd and Old River) on crop yield includes:

1) Select crop: Beans and Almonds
2) Determine crop water use (ETc) for each crop from Brentwood CIMIS station based on the 10 year average ETo.
3) Determine irrigation date and volume to meet crop water use.
4) Use modeled 5-day average ECi to calculate the average seasonal irrigation water salinity.
5) Calculate the resultant average root zone soil water salinity (ECsw) using inputs of average ECi, crop water use (ETc) at leaching fractions from 5% to 20% using the 40-30-20-10 water uptake pattern.
6) Use average ECsw/2 = ECe to calculate relative yield or yield reduction.
7) Compare yield reductions in the H3 scenario to the NAA scenario at location SDN-1.

Results:

Bean

Figure 1. Yield reduction for H3 and NAA for the SDN-1 site for each year. (Blank cells are no yield reduction)

	H3					NAA			
LF	0.05	0.1	0.15	0.2		0.05	0.1	0.15	0.2
1976	32.3	8.9				33.1	9.4	0.3	
1977	35.3	10.8	1.4			33.6	9.7	0.5	
1978	15.3					15.3			
1979	23.4	3.3				22.2	2.5		
1980	17.5					17.3			
1981	30.9	8.0				30.6	7.8		
1982	4.1					4.1			
1983									
1984	19.8	1.1				19.2	0.6		
1985	29.8	7.3				27.0	5.6		
1986	14.7					14.4			
1987	26.6	5.3				22.0	2.5		
1988	25.6	4.7				26.3	5.0		
1989	25.5	4.7				32.7	9.1		
1990	33.4	9.7	0.5			37.5	12.2	2.3	
1991	32.2	8.8				33.3	9.5	0.3	
Average	24.4	6.6	0.9			24.6	6.7	0.9	
Max	35.3	10.8				37.5	12.2		
Min	4.1	1.1				4.1	0.6		

The above Figure 1. shows the data for crop yield reductions for the 16 years of data at four different leaching fractions for the H3 and NAA alternative scenarios. As above, the leaching fraction is the fraction of crop water use which should pass through the root zone to control salts at a specific level. The higher the irrigation water salinity, the higher leaching fraction required to maintain crop productivity. As we can see, yield reductions are predicted at the 5% - 15% leaching fraction in both the H3 and NAA scenarios. The average crop reduction at the 5% leaching fraction over this time frame was 24% under both the H3 scenario and the NAA Scenario. However, in years like 1977, 1979, 1985 and 1987 we see that the H3 scenario results in significant crop reductions beyond those for the NAA.

Such reductions can only be described as injury to agricultural users in the southern Delta. It does not matter that under some years modeled there might be an improvement (less crop reduction). Farming profits and losses perhaps can be averaged from a statistical standpoint, but any adverse impact in any particular year is just that; an adverse impact. The impact does not go away or become meaningless because in some future year a farmer experiences somewhat less harm.

The yield reductions for the 10% leaching fraction are similar but somewhat lower. The average reductions for H3 and NAA are very similar but there are significant additional reduction in the H3 in years 1977, 1979, 1985, and 1987.

The yield reductions for the 15% leaching fraction were very similar with only 1977 showing any appreciable additional yield reduction in the H3 scenario

Conclusion:

Substantial yield reductions are predicted to occur in most years below a 10% leaching fraction under both the H3 and NAA. Especially at 5% leaching fraction, the 16 year modeled period shows at least 4 years of significant additional crop reduction resulting from the H3 scenario.

I will note here that these predict results for each of 16 years, they are not cumulative. Thus in reality, unless and until some other conditions actually leach the salts from the soil, the previous year's salt build up remains. This means that the following year's added salt is the starting point and a crop soil threshold might be reached, reached sooner or exceeded to a higher degree.

My conclusion also must reiterate the fact that not knowing what the actual EC will be from the WaterFix project, my numbers can only be considered conservative. The actual impacts could be very much worse.

Almond

Figure 2. Yield reduction for H3 and NAA for the SDN-1 site for each year. (Blank cells are no yield reduction)

	H3					NAA			
LF	0.05	0.1	0.15	0.2		0.05	0.1	0.15	0.2
1976	19					19			
1977	24					19			
1978	3								
1979	4					7			
1980						2			
1981	17					16			
1982									
1983									
1984	1					4			
1985	14					12			
1986									
1987	13					7			
1988	17					11			
1989	15					18			
1990	21					23			
Average	13.4					12.6			
Max	24.2					23.3			
Min	0.9					1.8			

My analysis for almonds shows that yield reductions are predicted only at the 5% leaching fraction in most years (73% of the 1976-1990 period) that averaged 13 percent in H3 and the NAA scenarios. Although the average reductions for H3 and NAA are very similar there are significant additional reduction in the H3 in years 1977, 1987, and 1988. I note that the H3 yield reduction calculated for 1987 is nearly double that of the NAA.

Conclusion:

At 5% leaching fraction, the 16 year modeled period shows at least 3 years of significant additional crop production resulting from the H3 scenario. As stated above for the bean analysis, I repeat here that these numbers predict results for each of 16 years, they are not cumulative. Thus in reality, unless and until some other conditions actually leach the salts from the soil, the previous year's salt build up remains. This means that the following year's added salt is the starting point and a crop soil threshold might be reached, reached sooner or exceeded to a higher degree.

Again I repeat that not knowing what the actual EC will be from the WaterFix project, my numbers can only be considered conservative. The actual impacts could be very much worse.

Given these predicted crop reductions at specific leaching fractions, it is imperative that growers be able to attain or exceed a leaching fraction to maintain productivity. Attaining an adequate leaching fraction with these two crops may be difficult in the delta region. First, beans are sensitive to over watering causing saturated soils which encourages root diseases and lack of oxygen in the root zone. Beans use about 21.5 inches of water per an average season while almond uses about 50 inches. Given the many delta soils are low in water permeability it is difficult to infiltrate the extra 10% or 5 inches of water (for almond) required for the 10% leaching fraction. Additionally, the shallow water table does not provide a typical leaching scenario whereby the salts are simply washed below the root zone. The salts move down(by leaching) to the water table where the net movement is not downward causing the salts to pool in the shallow water table waiting to move upward by capillary forces when no net downward water is present.

As referenced above, the leaching study by Michele Leinfelder-Miles indicates that locations in the southern Delta have leaching fractions below the 5% used in my analysis. Anecdotally, I know from my prior association with Alex Hildebrand that he conducted his own study on his own lands and found that in some areas the compacted soil allowed for virtually no leaching. This anecdotal information is consistent with my knowledge ot southern Delta soil permeabilities. The soils with extremely low permeabilities will of course have difficulties leaching salts. When on-site conditions limit the ability of applied water move through the soil profile, virtually little leaching occurs. Under such circumstances virtually little of the applied salt moves out of the root zone and thus all of the salt in that applied water remains in the root zone.

Given the complexity of measuring scores of crops, at numerous locations, under four WaterFix scenarios using sixteen years of modeling data, I prepared Figure 4. for use by Dr. Jeff Michael for his analysis on behalf of SDWA et.al. The generally accepted method (Hoffman and Maas 1977) of calculating relative (or yield reduction) of agricultural crops is based on the use of two salinity coefficients and the seasonal average root zone salinity. These coefficients consist of a threshold and slope. The salinity threshold (a) is the maximum average soil salinity (ECe) the crop can tolerate in the root zone without yield decline. The slope coefficient (b) is the percent loss in relative yield the crop will experience for every unit increase in ECe above the threshold. Using these coefficients, the yield potential (% Yield) can be estimated from the following expression:

$$\%\,Yield = 100 - b\,(ECe - a)$$

Further the slope (b) can be calculated from:

$$b = \frac{100}{ECe\ at\ \ 0\%\ yield\ reduction - EC\ at\ 100\%\ yield\ reduction}$$

The salinity coefficients for six common delta crops are in figure 3.

Figure 3. Salinity coefficients for six common delta crops.

	Bean	Corn	Alfalfa	Tomato	Almond	Grape
Ece Threshold	1.0	1.7	2.0	2.5	1.5	1.5
Ece at 0% yield reduction	1.0	1.7	2.0	2.5	1.5	1.5
Ece at 100% yield reduction	4.2	6.7	10.0	8.4	4.5	7.9
b	31.3	20.0	12.5	16.9	33.3	15.6

The important component needed in the above calculation to determine relative yield is the average seasonal root zone salinity (ECe). That value is estimated using a method referred to as the 40-30-20-10 water uptake function described in FAO 29 Rev 1 (Ayers and Westcott 1985).

The ECe for each corresponding ECi ranging from 0.2 – 1.0 dS/m were estimated at leaching fractions from 5-20%. There were no yield reductions at 15 or 20% leaching fractions. Figure 4. Indicated the yield reductions of the six crops at the 10 and 5% leaching fractions using irrigation waters from 0.1 – 1.0 dS/m.

Figure 4. Yield reductions of the six crops at the 10 and 5% leaching fractions using irrigation waters from 0.1 – 1.0 dS/m.

Leaching Fraction			% Recuction in Yield at LF and Eci					
5%								
		Ave Soil						
	ECi	Ece	Bean	Corn	Alfalfa	Tomato	Almond	Grape
	0.2	0.65	0	0	0	0	0	0
	0.3	0.97	0	0	0	0	0	0
	0.4	1.3	9	0	0	0	0	0
	0.5	1.62	19	0	0	0	4	2
	0.6	1.95	30	5	0	0	15	7
	0.7	2.27	40	11	3	0	26	12
	0.8	2.6	50	18	8	2	37	17
	0.9	2.92	60	24	12	7	47	22
	1	3.25	70	31	16	13	58	27

Leaching Fraction								
10%								
			% Recuction in Yield at LF and Eci					
		Ave Soil						
	ECi	Ece	Bean	Corn	Alfalfa	Tomato	Almond	Grape
	0.2	0.41	0	0	0	0	0	0
	0.3	0.62	0	0	0	0	0	0
	0.4	0.82	0	0	0	0	0	0
	0.5	1.03	1	0	0	0	0	0
	0.6	1.23	7	0	0	0	0	0
	0.7	1.44	14	0	0	0	0	0
	0.8	1.64	20	0	0	0	5	2
	0.9	1.85	27	3	0	0	12	5
	1	2.05	33	7	1	0	18	9

From this Figure, I understand Dr. Michael calculated economic impacts from the possible crop reductions.

There is one addition analysis which should be done but for which there is no acceptable scientific tools to accurately calculate. That analysis deals with the effects on a crop from any particular irrigation or irrigations rather than from the yearly average irrigation salinity. A scientifically acceptable method for modeling this has not been developed but the issue needs to be discussed.

If a particular irrigation uses water quality that is significantly worse than the average water quality over the season is applied during the seedling growth stage, it may adversely affect the crop even if the yearly average shows no effects. Whether or not this occurs is dependent on the soil conditions at the time of the irrigation. If the soil is at or near the threshold for the crop, the application of the poor quality water might push the salinity above the threshold in the shallow root zone and impair the plant growth during the time. We see from the data produced by Mr. Burke that at different locations there can be relatively short (for example 5- 15 days) times when the water quality predicted by the model for H3 is up to 100 EC above that under the NAA (see SDWA 29). Depending on conditions at a particular site, that increase of 100 EC might stress the plant. Such stress can and will adversely affect the eventual crop production to some degree.

In addition it should be noted that local farmers have reported "salt damage" to their crops immediately after the first or second irrigation of the season, even when the applied water is below the 0.7 EC standard. They report seeing a "white" residue on the ground and stressed or even dying seedlings. Not having investigated these particular occurrences, I cannot of course absolutely determine the cause. However, the circumstances in the southern Delta suggest that the initial irrigation(s) pushed the salts already in the soil to the root and to the surface causing both the plant damage and the residue. I mention this as it illustrates the delicate balance of salt control in the southern Delta. Given this severe problem, it is clear that any new salts resulting from the WaterFix project should be assumed to cause injury to local agricultural interests.

The situation in the central Delta is different in that some crops and soils are sub-surface irrigated. This a practice where irrigation water is applied to small ditches space across the field where water is applied and allowed to sub up into the crop root zone. Since the salts moved up and into the root zone these models (estimating the average root zone salinity) do not apply. In general this type of irrigation requires a better quality of water and salts must leached in a planned off-season leaching program

The testimony of Tom Burke includes Table 4-4 which shows the maximum increase or difference in EC between the various scenarios. As you can see, the H3 scenario which I used in my analysis had a maximum EC over the NAA of 363. I note that the B2 scenario shows a maximum of 650 EC over the NAA. This again suggests that my results should be considered cautionary and as an understatement of the possible effects of the WaterFix

CONCLUSION

Using the DWR produced data from its DSM2 modeling for the WaterFix we see that although slight or no significant impacts due to EC changes occur at or above a 10% leaching fraction. However, even using just that data we see that there are years when the WaterFix changes in salinity (modeled) result in additional crop reductions above those of the NAA. For beans in the H3 scenario there are four years of significant impacts to crop production out of 16 years modeled at the 5% leaching fraction. For almonds, there are three years of the sixteen years modeled when significant impacts to crop production occur at the same 5% leaching fraction.

All these numbers are likely very conservative for a number of reasons. First, the DSM2 model is not normally used in a predictive manner but only for comparison. The model results can be 100's of EC off from reality and using numbers hundreds of EC larger would greatly increase the calculated impacts. Second, current information indicates that leaching fractions less than 5% occur in many areas of the southern Delta. The lower the leaching fraction, the more additional salt in applied water will adversely affect crop production

From all of this I conclude that the data clearly shows salinity impacts resulting from the WaterFix Petition will significantly injure Delta farmers.