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Regulatory Planning Unit
Central Valley Regional Water Quality Control Board

RE: Draft Staff Report to Support a Proposed Basin Plan Amendment to Establish and Implement Salinity Water Quality Objectives in the Lower San Joaquin River

Dear Mr. Brownell:

Thank you for the opportunity to review and comment on the above-referenced Draft Report and supporting materials. The documents were expertly prepared and clearly reflect a lot of hard work by a large number of people.

My comments focus on the second scientific review question, i.e.

> **It was appropriate to utilize the conservative, steady-state soil salinity Hoffman Model to calculate ranges of protective salinity criteria for irrigated agriculture in the Lower San Joaquin River Basin and work with local irrigators to determine appropriate parameter inputs to the model**

My judgement, after reviewing all documents, is that if one accepts that the application of the Hoffman modeling approach to the South Delta was correct, then the transference of the modeling approach to the Reach 83 setting was competently done and appropriate. One caveat concerns the treatment of almond, which is clearly an important crop in the region. Relatively little is known about the applicability of a 1D salinity management model to drip irrigated orchards and their multi-dimensional salinity distributions. Drip irrigated orchards

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evidently constitute about half of the almond acreage in the vicinity of Reach 83. I am aware of multiple current projects at the University of California and at USDA-ARS that are investigating salinity management in drip-irrigated orchards. When the planned re-assessment of the water quality criteria occurs in future years, it will be beneficial to specifically seek out any new information that might become available about almond.

With regard to Section 7 (“Next Steps”) of the revised salt tolerance analysis (CVWB, 2016), I want to inform the Board and associated Committees that presently there is a better and simpler way to perform the type of analyses currently being done with the Hoffman model. Although it may be too late to reconsider the methodology used in the current Draft Report, it would be a mistake to continue using the Hoffman Report and model as some sort of template for all future assessments. The Hoffman model (which dates to 1983) has weaknesses, and an updated, improved alternative is available. In the remainder of this commentary, I will expand on that point.

The Hoffman Report (Hoffman, 2010) and Revised Report (CVWB, 2016) both do a good job summarizing general scientific knowledge with respect to salinity and agriculture, and I agree with the conclusion that a 1D steady-state analysis is appropriate for evaluating possible water quality objectives. The reports also do a good job synthesizing available local and regional data and putting them into a form that is compatible with a 1D steady-state analysis. My critique concerns Table 5.2, specifically the two Equations labeled “Steady-State Equations (without consideration of precipitation).” Those two equations are the steady-state leaching model for an “exponential” and “40-30-20-10” water uptake distribution, and they are the basis for the Hoffman model predictions and assessments.

The equations in Table 5.2 are derived from a well-known mathematical model of the soil root zone, but that model is limited because it assumes that the rate that a crop extracts water from soil is not affected by the presence of root zone salinity. That is clearly not correct -- reduced water uptake (and thus reduced crop growth) is a basic feature of saline soils, and it should be accounted for when modeling systems that are yielding below 100% (e.g., the 95% and 75% levels considered in the Draft Report). The transient-state numerical models that Hoffman (2010) reviews and ultimately concludes are more accurate use an expanded mathematical formulation that accounts for uptake reductions. However, Hoffman and van Genuchten (1983) were seeking to develop a simpler tool that could be evaluated analytically, and determined that at that time “no mathematical relationship has been developed to span this gap”. They used the simpler model, and consequently, the methodology used in the Draft Report to evaluate 75% and 95% crop yields ends up being rather *ad hoc*, involving an ill-defined “correction” term in the leaching equation, and the supposition that the resulting *linearly averaged* salt concentration corresponds to an effective root zone salinity that is compatible with Maas-Hoffman salinity response curves. To my knowledge, such a scheme has not been demonstrated to correctly predict submaximal crop yields.

Recently, we developed a steady-state analytical model (Skaggs et al., 2014) that spans the "gap" noted by Hoffman and van Genuchten (1983). In a sense, the new model represents a continuation of the progression of steady-state models that was observed by Hoffman (2010). The new model uses a mathematical formulation that is comparable to the one used by Hoffman and van Genuchten (1983), except that it is expanded to include the uptake reduction functions that are used in transient-state models.

Perhaps counterintuitively, the more complicated underlying mathematical framework results in a steady-state model that in many ways simplifies the analyses currently performed with the Hoffman model:

- In the new model, the effects of salinity are uptake weighted, so results are independent of the assumed "uptake" or "root" distribution. Thus all complications of "exponential" vs. "40-30-20-10" go away.

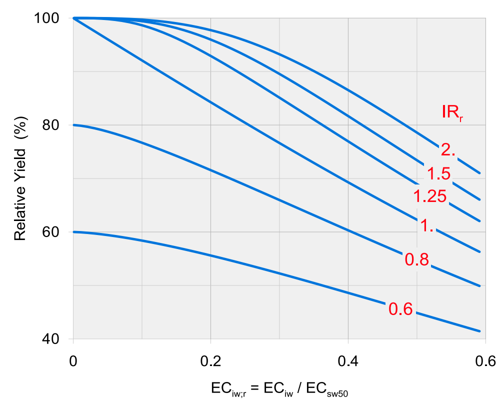
- The new model does not use leaching fraction as an input value, which is at best an elusive parameter that is hard to specify for a given location or region. Instead, the model uses the rate of irrigation as input, a value that can be quantified in accord with evapotranspiration-based methods of irrigation scheduling, something about which local irrigators will have direct knowledge. For example, some recommendations for almond are that seasonal irrigation should be 1.15 times the crop water demand, or 1.15 ETc. The 1.15 value is all that is needed for input. Note also that leaching fraction and irrigation rate are no longer simply related due to the dependence of uptake on salinity. The leaching fraction can be computed as a model output.

- Ambiguity about the relationship between steady-state and transient-state models is eliminated. Under certain specific conditions, the transient models reduce exactly to the steady-state model.

- The model computes relative crop yield (Y_r) from up to four input parameters: irrigation water salinity (EC_{iw}), crop salt tolerance (EC_{sw50}), *potential* crop water demand (ET_c), and irrigation amount (IR). However, the computed relative yield actually depends only on two dimensionless ratios of those four parameters, the relative irrigation rate or amount, $IR_r = IR / ET_c$, and the relative irrigation water salinity, $EC_{iw;r} = EC_{iw} / EC_{sw50}$.

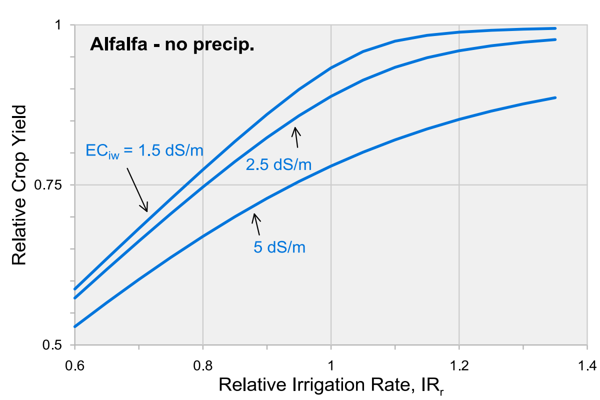
For the sake of brevity, I'm skipping over nuances such as the relationship between relative transpiration and relative yield, the effect of rainfall and direct evaporation, etc. If the Board is interesting in pursuing this analysis further I can in the future expand on these details.

According to the model, the general relationship between irrigation rate, irrigation water quality, crop salt tolerance, and crop yield can be illustrated as:



IR_r = 1 corresponds to an irrigation level that exactly meets the potential water demand of an unstressed crop. The almond recommendation noted previously would be IR_r = 1.15. For a given water (EC_{iw}) and crop (EC_{sw50}) combination, the irrigation requirement (note: not *leaching requirement*) for a particular yield is found by locating EC_{iw}/EC_{sw50} along the x axis and going up from there to find the irrigation rate IR_r that intersects with the target yield. Notice the diminishing returns that are obtained from increasing irrigation as yield approaches 100%.

Alternatively, for a specific crop and irrigation water, the prediction can be viewed as a crop-water production function, e.g.:



The Skaggs et al. (2014) paper includes comparisons with experimental crop yield data, but unfortunately not for almond, alfalfa, or bean. The model itself can be written as:

$$Y_r = \begin{cases} \left(R+\sqrt{\Delta}\right)^{1/3} + \left(R-\sqrt{\Delta}\right)^{1/3} & \Delta \geq 0 \\ 2\sqrt{-Q}\cos(\theta/3) & \Delta < 0 \end{cases}$$

where:

$(\cdot)^{1/3} = \text{real cube root}$ $\quad J = 1 - 1/IR_r$ $\quad \Delta = Q^3 + R^2$

$R = \left(EC_{iw;r}\right)^{-3}$ $\quad Q = (2JR-1)/3$ $\quad \theta = \cos^{-1}\left(R/\sqrt{-Q^3}\right)$

That may look complicated at first glance, but note that only two variables need to be specified to compute Y_r : IR_r and $EC_{iw;r}$. The rest of the symbols are just intermediate parameters used for notational convenience.

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Again, thank you for the opportunity to review and comment on these documents. I am of course happy to answer any questions that may arise about my review.

Sincerely,

Todd Skaggs

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References:

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