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LSJR Reach 83 Water Quality Objectives (WQO) for Electrical Conductivity (EC)

Scientific Peer Review of Conclusion 2

Conclusion 2: "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"

This external peer review addresses the scientific validity of conclusion 2 (quoted above) stated in the Central Valley Regional Water Quality Control Board's Amendment 2 (revised 2 December 2016) proposed basin plan to establish salinity water quality objectives in reach 83 of the San Joaquin River. Conclusions 1 and 3 are outside my area of expertise and therefore I leave those to other qualified reviewers. This review considers the appropriateness and validity of scientific approaches, concepts and assumptions described in 1) Chapters 5 and 6 of the Central Valley's Regional Water Quality Control Board's January 2017 Draft Staff Report, 2) Central Valley Water Board (2016b). Revisions to the 2010 Salt Tolerance of Crops in the Lower San Joaquin River (Merced to Stanislaus River Reaches) and 2016 Addendum and 3) the 2010 report by Dr. Glenn Hoffman "Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta" that were used as the basis for conclusion 2. Because the water quality objective (WQO) focuses on electrical conductivity (EC) as the "protective salinity criteria", this review also address other and potentially more critical "big picture" considerations for the protection of agricultural beneficial uses affected by salinity and its constituents within this reach.

All reports reviewed address important issues that need to be considered for determining the protection of agricultural beneficial uses. For example, criteria were established for determining the most salt-sensitive of the common crops in the study area (i.e. those representing > 5% of cropped area). This is appropriate in that a small area planted to a very salt-sensitive crop does not control the WQOs for the entire region. The reports address the appropriate level of protection under extended dry periods (75% yield potential) and non-drought years (95% yield potential). Not only was the agricultural community consulted on appropriate levels of protection, but such a sliding scale of protection provides flexibility for achieving WQOs in extended dry periods. And they considered the contribution of rainfall which would allow water of higher salinity to be used to achieve the same level of protection. Such an adjustment is appropriate in reach 83 where significant amounts of rainfall often occur and plays an important role in off-season leaching of the soil profile. The choice of selecting the 5th percentile of historical rainfall to include in the model, rather than the 25th percentile, median or mean rainfall amounts, provides a layer of conservativeness to the proposed objective.

The Hoffman 2010 report is thorough and provides detailed narration on the advantages and disadvantages of using both steady-state and transient state models to estimate soil salinity given the salinity of the irrigation water and targeted leaching fractions. While all models have their strengths and weaknesses, Hoffman chose to use a steady-state model pointing out that in most instances it is more conservative than most transient models (Letey et al., 2011). That is, transient models tend to predict lower salinities given the same irrigation water salinity and targeted leaching fraction. Hoffman (2010) chose an exponential root-water uptake pattern (Hoffman and van Genuchten, 1983) rather than the 40-30-20-10 pattern described in Ayers and Westcot (1985) arguing that such an extraction pattern better fits estimated leaching requirements from data using controlled lysimeters and small field plots (Hoffman, 1985). While true, Hoffman concedes that none of the root-water extraction models are completely satisfactory which underscores our lack of understanding of how plants truly respond to salinity in soils with heterogeneous salinity (Hoffman, 1985). More importantly, by using the exponential root-water extraction pattern over the 40-30-20-10 pattern, much of the conservativeness imbedded in Hoffman's steady state model is lost. For example, at 15% leaching fraction and in the absence of rainfall, the steady-state model using a 40-30-20-10 extraction by Ayers and Westcot (1985) yields the relationship; ECe = 1.6 ECw (where ECw and ECe are the electrical conductivity of the irrigation water and saturated soil extract in the crop root zone, respectively). Whereas with the exponential extraction pattern at a steady-state 15% leaching fraction, the relationship is ECe = 1.25 ECw (Hoffman, 2010, Fig 4.2). That is, an irrigation water of 1.0 dS/m under steady-state conditions, not considering rainfall, would result in an average root zone ECe of 1.25 dS/m using the exponential water uptake while using the 40-30-20-10 pattern, the root zone ECe would be 1.6 dS/m. This indicates that the exponential root extraction pattern generates a 22% less "plant perceived" soil salinity than does the 40-30-20-10 extraction pattern, which allows water of higher salinity to be selected. While the exponential root water extraction model translated into lower ECsw than did the 40-30-20-10 model, at lower LF, there is less difference between extraction patterns. As LF increased from 10 to 20%, so did differences in ECsw (electrical conductivity of the soil water) estimates between extraction patterns (Hoffman 2010 Fig 5.16). Therefore, the root-water extraction pattern has a very large influence on predicting root exposure to soil water salinity.

While the leaching fraction concept is easily understood in the classroom, it is a bit more complicated in the real world where vertical water fluxes throughout the soil-plant-atmosphere continuum are constantly changing. Such changes are not considered in a steady-state model. In fact, in well-managed systems with no runoff, inputs (rainfall, irrigation) and outputs (evapotranspiration (ET) and drainage below the root zone) are in constant flux that change not only hourly and daily but seasonally as well. Because the system is in constant flux, it is difficult to set the conditions where leaching begins and ends such and that seasonal leaching estimates can vary considerably from yearly estimates (Isidoro and Grattan, 2011). In the real world, the flux of water during winter months is largely downward, allowing for leaching and drainage during this dormant period when ET is low. However, during summer periods, even with additional water applied to account for leaching, drainage can be much less and in some cases difficult to achieve altogether depending upon soil type. Fine textured soils, such as clays and clay loams which exist in farms within reach 83 (CVWB, 2016; NRCS soilweb), are much less permeable and is difficult to get drainage during summer months when ET is maximal. Applying excess water in these low permeable soils can lead to prolonged saturated conditions in the soil which leads to waterborne root diseases. Steady-state models, such as the one Hoffman uses, are insensitive to these effects whereas transient models can show stepwise increases in root zone salinity with each irrigation cycle as the season progresses despite water applications accounting for a targeted leaching fraction (e.g. Isidoro and Grattan, 2011). The point of this discussion is that while transient models are often labeled as "more conservative" than steady-state models, under real world conditions of high evaporative demand during summer months and fine textured soils, salinity could build up over the season such that the salinity of the irrigation water (ECw) will result in a higher root zone salinity (ECe) than the steady-state model predicts. Therefore, there will be fields where the relationship presented in Figs 5-2 and 5-3 of the LSJR Draft Report does not hold true and that the slope of fig 5-2 (i.e. linear relationship between ECw and ECsw (EC soil water)) would likely increase.

Some readers might dismiss the narration above since surveys have been conducted in the study area to collect 'actual' leaching fractions (e.g. Hoffman, 2010; Table 3.10). It is important to point out that LF estimates as presented in Table 3.10 (Hoffman, 2010) are very rough and are likely inaccurate estimates based on assumed irrigation water salinity and the EC of the effluent from the drains. The EC of water flowing into drains is not the same as the EC of unsaturated flow directly below the root zone (which is the true drainage water the steady-state model predicts). The EC of water in drains reflects the EC of the shallow water table which is a blend of historical drainage water, local groundwater and recent drainage water. But the EC of the 'drainage water' used in steady-state models reflects the EC of the unsaturated water as in drains just below the root zone before it intermingles with the shallow ground water.

In summary, while I find the science and concepts used to develop the WQO's for EC in reach 83 to be sound, some assumptions using the steady-state model (e.g. exponential root water extraction, method to estimate leaching fraction and feasibility of leaching) may be over simplified such that the actual real-world level of protection may not be achievable to the level that is proposed (i.e. 95% during wet years and 75% during extended dry periods).

Big Picture Discussion

There are some other 'Big Picture' elements that need to be considered before adopting/modifying the WQOs for the protection of agricultural beneficial uses. The EC WQOs proposed in the basin plan are to protect beneficial uses of irrigated agriculture in reach 83 of the LSJR. In particular, the WQOs are proposed for the protection of almonds which has been identified as the most salt-sensitive of the common crops in the region. To be protective, however, it is important to review how salinity impacts trees. Trees, including almonds, respond not only to salinity (i.e. EC) but to specific constituents in the water as well (Läuchli and Grattan, 2012; Maas and Grattan, 1999). Researchers have therefore classified these responses to salinity as either 'osmotic' and 'specific ion' effects. Osmotic effects occur because of the concentration of salt in the soil solution, with no reference to the kind of salts present that increase the EC (or lower the osmotic potential of the soil solution). It is this 'osmotic' effect on almonds where the proposed WQOs are derived and ignores the 'specific ion' effects. Moreover, these 'osmotic' effects are based on salts effect on reducing shoot growth, not reducing nut yield. Specific ion effects, on the other hand, occur due to specific ions (i.e. chloride, sodium and/or boron) that accumulate in various plant tissues affecting metabolism and causing injury. Although it difficult to quantify the contribution of growth/yield suppression by either 'osmotic' or 'specific ion' effects, is generally believed that 'osmotic' effects are the dominant growth suppressing factor at early times while ion toxicity can become the dominant stress over the long-term (Grieve et al., 2012). To fully consider protection of trees from salinity, WQOs for both EC and specific ions need to be considered.

In the 2016 Central Valley Water Board report, Table 5-1 presents preliminary ranges of potentially critical water quality criteria for various beneficial uses. For irrigated agriculture, critical ranges for ECw was 1.01-1.55 dS/m and critical concentration ranges for sodium (Na) and chloride (Cl) were 69-115 mg/L and 106-178 mg/L, respectively. But because the LSJR committee found that the MUN criteria for Na and Cl are below the irrigation criteria and are therefore already incorporated as WQOs in the Basin Plans, only EC (surrogate with TDS) was a criterion requiring a numerical value. It is unclear and confusing why Na and Cl criteria are no longer considered since 1) the Na and Cl criteria for irrigation in Table 5-1 are BELOW the MUN criteria and 2) elevation of any EC criteria would most certainly allow an increase in Na and Cl, or vice versa. The two are not mutually exclusive.

Sensitivity to ion toxicity in almond is largely controlled by the rootstock. Tables providing the maximum concentration of chloride that certain sensitive crops can tolerate, beyond which foliar injury develops, can be found in various peer reviewed articles (e.g. Ayers and Westcot, 1985; Grieve et al., 2012; Maas and Grattan, 1999). But the list reported is far from complete and only includes tolerances to older rootstocks. Nevertheless, the table by Ayers and Westcot (1985) reports the maximum permissible Cl concentration in the irrigation water (5-17 mmol/L or 177-602 mg/L) above which leaf injury occurs. The rootstock 'Nemaguard' has been one of the most popular in the SJV for almond production because of its tolerance to nematodes. Unfortunately, recent research has shown that this rootstock is extremely sensitive to Cl toxicity (Brown et al., 2015). This rootstock readily takes up Cl from the soil solution and transports it the transpiring leaves where it can accumulate to toxic levels (> 0.3% dry wt. as defined by Micke, 1996). In the experiment by Brown et al. (2015), two treatments (EC = 2.4 and 4.8 dS/m) were imposed on almonds with different scion/rootstock combinations. The salinity treatments were prepared by adding NaCl to stock nutrient solutions. Leaves from trees within the 2.4 dS/m (20 mM NaCl) treated plots, accumulated over 1% Cl (over 3 times the toxic level) within a month after treatment began, regardless of the almond cultivar budded on the 'Nemagaurd' rootstock, Moreover, concentrations continued to increase over time where they reached 3% (10 times toxic level) just 65 days after treatments were imposed. In the 4.8 dS/m treatment with double the Cl, the rate of Cl accumulation in the leaves doubled. Severe foliar injury was observed on trees shortly after treatments were imposed (see photo 1).

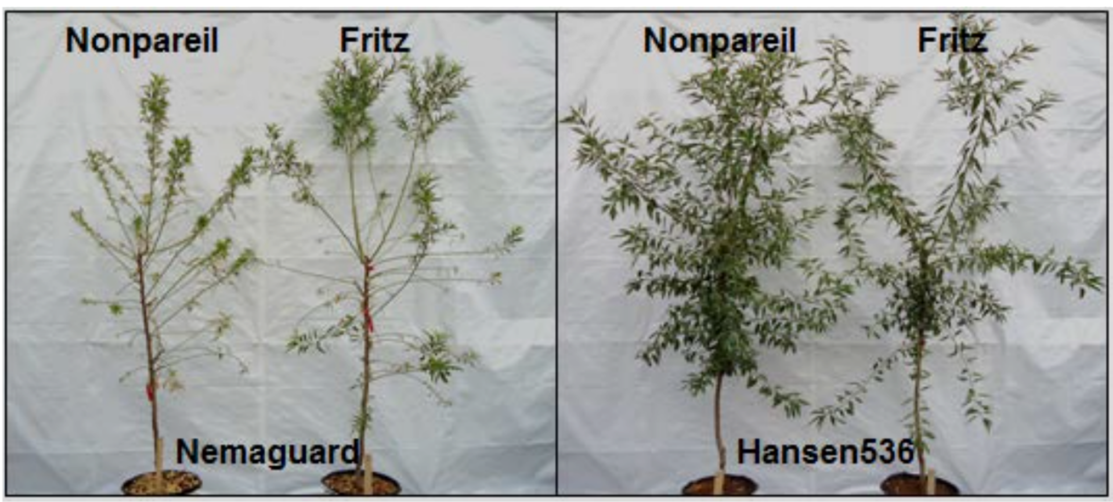

Photo 1. Chloride (Cl) damage to leaves of Nonpareil and Fritz almonds grafted on either 'Nemagaurd' or 'Hansen 536' rootstocks. Photo was taken 2 months after the 4.8 dS/m treatment began (Brown et al., 2015).

However, when the more salt-tolerant rootstock "Hansen 536" was used, leaf Na and Cl concentrations were reduced, injury was not evident, and growth rates were not affected during the first two months after treatments were imposed.

The 'Nemagaurd' rootstock also absorbs Na, albeit at a lower rate, and it too can accumulate in woody tissue for years before it is released to the leaves causing damage as well (Bernstein et al., 1956). Indeed, Na toxicity has been observed in the SJV on almonds grafted on 'Nemagaurd' rootstocks (Doll et al.). While Cl and Na can damage leaf tissue, reducing the photosynthetic capacity of the tree, they may also affect flowering and nut set, which could be potentially even more devastating to almond production. This can also be true for boron (B). Almonds are very sensitive to boron, but unlike Na and Cl, B damages growing tips affecting new growth, flowering and nut production. As mentioned earlier, it is difficult to separate and quantify damages due to 'osmotic' and 'ion-toxicities' but both are working together to reduce almond yields. Therefore, an assessment of the almonds in the study area should be made to determine the percentage of those on the salt-sensitive 'Nemagaurd' rootstock and address potential threats from Na and Cl in the irrigation water to almond productivity.

In the CVWB 2016 revised report, the risk of ion toxicity was assessed using Table 3.8, which was reproduced from Maas and Grattan (1999). It is important to note that this table reflects crop sensitivity to Na and Cl when leaves are wetted by sprinkler irrigation. These saline-sprinkler studies were conducted where the root zone was artificially shielded from salt entering the root zone. This risk to foliar injury reflects crop sensitivity to Na and Cl damage via foliar absorption of salts and not susceptibility to root uptake. In summary, this table is not valid for assessing irrigation water suitability regarding Na and Cl toxicity due to root uptake and accumulation. While there are no guidelines for Cl in the irrigation water above which produces foliar injury for almond on 'Nemagaurd' rootstock, it is very possible that concentrations even below the lowest level (i.e. 177 mg/L) in the range listed by Ayers and Westcot (1985) could be problematic for almonds on 'Nemagaurd' rootstock, even in well managed orchards receiving adequate leaching.

The leaching fraction of 15% is a reasonable target but it is important to point out that trees are typically irrigated by drip or mini-sprinkler irrigation. As such, leaching occurs directly below the emitter or below the wetted area of the mini-sprinkler. Salt accumulates in the root zone between emitters and mini-sprinklers. Therefore, the root zone is subjected to heterogeneous salinity conditions that vary both spatially and temporarily. While root water uptake is considerably higher in the wetter and lower salinity zones, there is little understanding about how the tree performs under these variable conditions. Uncertainty applies to how trees respond to variable conditions not only in terms of 'osmotic effects' but 'ion toxicities' as well.

Therefore, based on discussion above, I disagree with the 'Y' under evaluation criteria 'E' for 'Project Alternatives' 2 through 5 and possibly 6 listed in Table 5-10 of the Basin Plan Amendment Project Alternative Matrix. There is considerable scientific uncertainty whether these WQOs will be protective of irrigated almonds in fields affected by reach 83 of the lower San Joaquin River. It is very likely that the proposed level of protection (95% yield potential during wet years and 75% during extended dry periods) will not be achieved in many fields, particularly almond orchards planted with 'Nemagaurd' rootstock that are sensitive to Na and Cl injury or fields where salinity and sodicity are currently problematic. The conservative portion of using a 'steady-state' model was lost by assuming crops respond to an exponential root water extraction pattern. In summary, these Basin Plan WQOs do not address additional risks associated with ion toxicity to trees, the potential inability to achieve targeted leaching in fine textured soils (e.g. clays and clay loams) with low permeability and the fact that the salinity guidelines for almond are based on decades old literature estimating 'osmotic effects' that reduce shoot growth, not nut yield. Considering these concerns and uncertainties, the proposed WQOs objectives should be reassessed, in my opinion, with the possibility of systematically lowering the WQOs, taking into account these considerations.

Sincerely,

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References

Ayers, R.S., and D.W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1, Food and Agriculture Organization of the United Nations, Rome. 174 pp.

Bernstein, L., J. W. Brown, and H. E. Hayward. 1956. Influence of rootstock on growth and salt accumulation in stone-fruit trees and almonds. Proc. Am. Soc. Hort. Sci. 68:86-95.

Brown, P.H, S.R. Grattan, U.B. Kutman, F. Valenzuela, and B. Sanden. 2015. Physiology of salinity stress in almond. Report submitted to California Almond Board. Project No. 14-HORT20-Brown/Grattan.

Central Valley Water Board. 2016 DRAFT. Proposed Amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins to Establish Salinity Water Quality Objects in the Lower San Joaquin River (Mouth of Merced to Vernalis) Draft Staff Report 275pp.

Central Valley Water Board, 2016b. Revisions to the 2010 salt tolerance of crops in the Lower San Joaquin River (Merced to Stanislaus River reaches) and 2016 Addendum 306pp.

Doll, D., R. Duncan, G. Arnold, L. Hendricks, and W. Micke. Performance of six almond rootstocks with long-term exposure to sodium and chloride. University of California Division of Agriculture and Natural Resources (UC ANR).

Grieve, C.M., S.R. Grattan and E.V. Maas. 2012. Plant salt tolerance. In. (W.W. Wallender and K.K. Tanji, eds). Agricultural Salinity Assessment and Management (2^{nd} edition). ASCE pp 405-459.

Hoffman, G.J. 1985. Drainage required to manage salinity. J. Irrig. Drain. Eng. 111:199-206.

Hoffman, G.J. 2010. Salt tolerance of crops in the southern Sacramento-San Joaquin Delta. Report

Hoffman, G.J. and M.Th. van Genuchten. 1983. Soil properties and efficient water use: Water management for salinity control. In *Limitation to efficient water use in crop production*. (H.M. Taylor, W. Jordan and T. Sinclair, eds.). Am. Soc. Agron. Pp 73-85.

Isidoro, D. and S.R. Grattan. 2011. Predicting soil salinity in response to different irrigation practices, soil types and rainfall scenarios. Irrig. Sci. 29:197-211.

Läuchli, A. and S.R. Grattan. 2012. Plant responses to saline sodic conditions. In. (W.W. Wallender and K.K. Tanji, eds). *Agricultural Salinity Assessment and Management* (2^{nd} edition). ASCE pp 169-205.

Letey, J., G.J. Hoffman, J.W. Hopmans, S.R. Grattan, D. Suarez, D.L. Corwin, J.D. Oster, L. Wu and C. Amrhein. 2011. Evaluation of soil salinity leaching requirement guidelines. Agric. Water Manag. 98:502-506.

Maas, E.V., and S.R. Grattan. 1999. Crop yields as affected by salinity. In: *Agricultural Drainage*, eds. R.W. Skaggs and J. van Schilfgaarde, Monograph 38 Am. Soc. Agron., Madison, WI, pp. 55-108.

Micke, W. 1996. Almond production manual. University of California, Division of Agricultural and Natural Resources publication # 3364.

Natural Resource Conservation District (NRCD)/ University of California, Davis. Soil Web. (A. O'Geen) https://casoilresource.lawr.ucdavis.edu/gmap/