Attachment C. Agronomic Impacts and Mitigation

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ACRONYMS AND ABBREVIATIONS

µmhos/cm	micromhos per centimeter (1 µmhos/cm = 1 µS/cm = 1/1,000 dS/m)
µS/cm	microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
Ad hoc Committee	Ad hoc Water Quality Committee
AEWSD	Arvin-Edison Water Storage District
ATP	adenosine triphosphate
AW	applied water
B	boron
B_e	boron concentration of the saturated soil paste (rootzone boron)
B_{et}	maximum boron threshold of the saturated soil paste
B_w	boron concentration of applied irrigation water
B_{sw}	boron threshold for soil water concentration
Ca	calcium
Ca^{2+}	calcium ion
$CaCO_3$	calcite or calcium carbonate
cfs	cubic feet per second
Check 21	Check Structure 21 at milepost 172,40 on the California Aqueduct
Cl^-	chloride ion
Cl^-_e	chloride concentration of the saturated soil paste (rootzone chloride)
Cl^-_{et}	maximum chloride threshold of the saturated soil paste
Cl^-_w	chloride concentration of applied irrigation water
CO_2	carbon dioxide
CO_3^{2-}	carbonate ion
CVC	Cross Valley Canal
DEID	Delano-Earlimart Irrigation District
dS/m	deciSiemens per meter (1 dS/m = 1,000 µmhos/cm = 1,000 µS/cm)
EC	electrical conductivity
EC_e	electrical conductivity of the saturated soil paste (rootzone salinity)
EC_{dw}	electrical conductivity/salinity of irrigation drainage water
EC_w	electrical conductivity/salinity of applied irrigation water
ET	evapotranspiration
F_c	concentration factor
FKC	Friant-Kern Canal
Friant Division	Friant Division of the Central Valley Project
FWA	Friant Water Authority

HCO_3^-	bicarbonate
Intermediate	Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities
KTWD	Kern Tulare Water District
LF	leaching fraction
LR	leaching requirement
Mg^{2+}	magnesium ion
Mg	magnesium
meq/L	milliequivalents per liter
mg/L	milligrams per liter (equivalent to ppm)
Na^+	sodium ion
Na	sodium
pH	Measure of acidity or alkalinity
Policy	Friant-Kern Canal Water Quality Policy
ppm	parts per million (equivalent to mg/L)
RDI	regulated deficit irrigation
SAR	sodium adsorption ratio
SAR_{adj}	adjusted sodium adsorption ratio
SID	Saucelito Irrigation District
SSJMUD	South San Joaquin Municipal Utility District
SWID	Shafter-Wasco Irrigation District
TDS	total dissolved solids

BACKGROUND

The Guidelines for Accepting Water into the Friant-Kern Canal (Guidelines) were developed in response to concerns regarding the implementation of programs and projects that could introduce water of a lesser quality to the Friant-Kern Canal (FKC), when compared to water quality of historic deliveries from Millerton Lake. The Guidelines define requirements for discharging water into the FKC, water quality monitoring and reporting requirements, mitigation requirements, and forecasting and communication protocols. The Guidelines propose a ledger mechanism to determine the required mitigation for introducing water of lesser quality into the FKC. This attachment to the Guidelines provides additional information on agronomic effects, mitigation requirements, and approach for defining maximum water quality thresholds for key constituents. The thresholds are specific to irrigation periods that correspond to the growing season and agricultural management practices during the year.

AGRONOMIC EFFECTS

When assessing the suitability of water for irrigation, three main hazards or "agronomic thresholds" are considered (Ayers and Westcot, 1985): (1) the salinity hazard (electrical conductivity of the applied irrigation water [EC_w]), (2) the hazard posed by specific ions (chloride [Cl^-], boron [B], and sodium [Na^+]), and (3) the infiltration hazard (sodium adsorption ratio [SAR] and ECw). There are other parameters, such as acidity (pH) or alkalinity, sediments and nutrients that can affect calcite ($CaCO_3$) deposits, emitter clogging, crop development, and corrosion, but these do not fall under "agronomic thresholds."

The primary source of imported water is proposed to come from the Friant-Kern Canal/Cross Valley Canal Intertie (Intertie) and conveyed via reverse-flow, pump-back operations. Water being introduced at the Intertie might include previously banked groundwater of Kern Fan water quality, Cross Valley Contract supplies, recaptured and recirculated San Joaquin River Restoration Program Restoration Flows, and other colors. Water quality conditions from the Cross Valley Canal (CVC)could range from existing conditions in the Cross Valley Canal (CVC) to that from the California Aqueduct, depending on respective canal operations. For the analysis presented herein, both CVC and California Aqueduct (measured at Check 21) water qualities were used, as well as a weighted average of those two sources (Intermediate) applied to show the range of potential imported water qualities. Source water quality concentrations are shown in Table 1 and Table 2.

Table 1. Average Concentrations of Various Irrigation Water Quality Constituents

LOCATION	WATER QUALITY CONSTITUENTS			
	TDS (/L)	EC_w (µS/cm)	Boron (B) (mg/L)	Chloride (Cl^-) (mg/L)
FKC[1, 2]	24	40	0.04	1.9
CVC[1, 3]	180	340	0.11	45.0
Intermediate[4]	232	420	0.16	63.2
Check 21[5]	283	500	0.21[6]	81.3

Note:

[1] Water quality data from AEWSD grab samples lab data from 2010 – 2019. Averages exclude months when mixing occurred.

[2] Sample taken at terminus of FKC.

[3] Sample taken at AEWSD CVC, Pumping Plant 6 or 6B Forebay.

[4] Weighted average of CVC and Check 21 water quality.

[5] California Aqueduct measured at Check 21 from 2009-2017.

[6] Check 21 Boron measurements only available for years 1967 – 1976.

Key:
AEWSD = Arvin Edison Water Storage District
Check 21 = Check Structure 21 at milepost 172,40 on the California Aqueduct
CVC = Cross Valley Canal
µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
EC_w = electrical conductivity of applied water
FKC = Friant-Kern Canal
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities
mg/L = milligrams per liter
TDS = total dissolved solids

Table 2. Average Monthly Electrical Conductivity, Chloride, and Boron Concentrations by Source and Year Type

MONTH	CVC[1]			CHECK 21[2]		
	Wet[3]	Average[4]	Dry[5]	Wet[6]	Average[4]	Critical[7]
Average Monthly Electrical Conductivity Concentrations by Source and Year Type (µS/cm)						
January	431	369	287	309	523	598
February	570	433	378	269	551	680
March	261	273	275	248	545	671
April	240	270	277	255	500	616
May	--	306	306	195	479	575
June	385	384	383	174	471	597
July	257	292	307	206	385	542
August	286	308	335	249	425	643
September	323	326	329	247	524	689
October	429	360	315	539	573	628
November	396	356	330	480	529	614
December	368	349	337	532	554	624
Average Monthly Chloride Concentrations by Source and Year Type (mg/L)						
January	74.5	54.4	27.7	34.0	84.5	99.0
February	104.0	63.0	46.6	31.5	87.4	104.3
March	21.0	21.8	22.0	27.5	82.9	104.3
April	19.0	21.4	22.0	33.5	72.1	100.0
May	--	31.4	31.4	25.0	73.0	88.7
June	48.5	46.1	45.2	19.0	73.4	98.3
July	28.5	33.7	35.8	25.5	55.8	84.0
August	39.6	40.7	42.0	31.0	70.3	109.0
September	53.0	48.4	43.8	22.0	92.6	116.7
October	76.0	55.0	41.0	105.5	101.6	106.7
November	68.5	54.8	45.7	90.5	86.8	95.7
December	55.5	46.7	40.8	101.0	95.5	103.0
Average Monthly Boron Concentrations by Source and Year Type (mg/L)[8]						
January	0.12	0.11	0.10	0.23	0.20	0.20
February	0.16	0.15	0.14	0.30	0.26	0.25
March	0.10	0.11	0.11	0.33	0.31	0.30
April	0.11	0.12	0.12	0.30	0.29	0.10
May	--	0.12	0.12	0.27	0.25	0.20
June	0.16	0.15	0.14	0.20	0.18	0.20
July	0.11	0.11	0.12	0.13	0.16	0.20
August	0.09	0.10	0.12	0.10	0.19	0.20
September	0.08	0.09	0.11	0.10	0.16	0.10
October	0.11	0.10	0.09	0.25	0.19	0.15
November	0.11	0.11	0.11	0.20	0.18	0.15
December	0.11	0.11	0.12	0.20	0.19	0.15

Note:

[1] Water quality data from AEWSD grab samples lab data from 2010 – 2019.

[2] California Aqueduct measured at Check 21 from 2009-2017.

[3] CVC wet year averages represent the monthly average for San Joaquin Index year types below normal, above normal, and wet and excludes months where there is mixing.

[4] Average concentrations shown represent the average of all year types and excludes months where there is mixing.

[5] CVC dry year averages represent the monthly average for San Joaquin Index year types dry and critical and excludes months where there is mixing.

[6] Check 21 wet year averages represent the monthly average for San Joaquin Index wet year types only.

[7] Check 21 critical year averages represent the monthly average for San Joaquin Index critical years only.

[8] Check 21 Boron measurements represent years 1967 – 1976 per available data.

Key:
-- = no available data. CVC water quality in wet years during May were only mixed water quality.
AEWSD = Arvin-Edison Water Storage District
Check 21 = Check Structure 21 at milepost 172,40 on the California Aqueduct
CVC = Cross Valley Canal
µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
mg/L = milligrams per liter

SALINITY EFFECTS ON CROPS

The effects of salinity on crops are due to two separate properties in the saline media that can impact the crop individually but more often collectively (Läuchli and Grattan, 2012): (1) Salinity increases the electrical conductivity (EC) of the soil solution which reduces its the osmotic potential and (2) specific ions (I.e. Cl-, Na+ and B) in the soil solution can potentially be toxic to certain crops.

Osmotic effects occur when the concentration of salt in the soil solution is too high to allow for normal for crop growth. Dissolved salts reduce the osmotic potential of the soil solution. Plants must adjust osmotically through either the absorption of ions from the soil solution, or the synthesis and/or accumulation of organic solutes in the root cells. The synthesis of compatible organic solutes allows a plant to adjust osmotically and survive, but at the expense of plant growth (Munns and Tester, 2008). The synthesis of organic solutes requires a considerable amount of metabolic energy (i.e., adenosine triphosphate (ATP)) that is used for cell maintenance and osmotic adjustment that could otherwise be used for growth. As a result, salt-stressed plants are stunted, even though they may appear healthy in all other regards. Both processes of adjustment (accumulation of ions and synthesis of organic solutes) occur but the extent by which one process dominates depends on the type of crop and level of salinity (Läuchli and Grattan, 2012). And in a cell, compartmentalization is critical to keep toxic ions away from sensitive metabolic processes in the cytoplasm (Hasegawa et al., 2000). Such compartmentation is controlled by transport processes in the plasma membrane and tonoplast (i.e., vacuolar membrane). The efficiency of ion transport processes, as well as metabolic costs for organic-solute synthesis, differ from crop to crop and even within a species giving rise to different salinity tolerances.

TOXIC ION EFFECTS

Specific ions (i.e., Na^+, Cl^-, and B) in the soil solution can cause direct injury to crops, causing further crop damage from what occurs from osmotic effects. Typically, toxic ion effects are commonly found in woody perennials, such as tree and vine crops, while most annual row crops remain injury free unless salinity stress is severe. Woody perennial crops have little ability to exclude sodium or chloride from their leaves, and the plants are long-lived; hence, they often suffer toxicities at even moderate soil salinities. Typically, toxic ion effects become more critical to sensitive tree and vine crops over the years.

Chloride

Chloride and sodium toxicity can damage a plant/tree physically, biochemically and physiologically. As sodium and chloride move in the transpiration stream, they are deposited in the leaves. Older leaves have more water transpire from them and consequently have higher concentrations of sodium and chloride. Once accumulated in a leaf, sodium and chloride typically do not remobilize to other tissues. As the concentration in that leaf increases, the salts can physically desiccate cells causing injury in the form of leaf burn. Necrotic leaves no longer photosynthesize and produce carbohydrates for the tree, which in turn, will impact growth and production. But even before salts accumulate in leaves to levels that cause physical injury, those salts can reduce the chlorophyll content in leaves (Dejampour et al., 2012) and interfere with enzymatic activities affecting key metabolic pathways in both respiration and photosynthesis (Munns and Tester, 2008).

Boron

Although not a main “salinizing” constituent in applied irrigation water, boron can also cause injury to the crop. Boron is an essential micronutrient for plants, but the concentration range of plant-available boron in the soil solution optimal for growth for most crops is very narrow. Above this narrow range, toxicity occurs (Grieve et al., 2012). Boron toxicity, including how and where it is expressed in the plant, is related to the mobility of boron in the plant. Boron is thought to be immobile in most species where it accumulates in the margins and tips of the oldest leaves where injury occurs. However, boron can be re-mobilized by some species due to high concentrations of sugar alcohols (polyols) where they bind with boron and carry it to younger tissues (Brown and Shelp, 1997). These boron-mobile plants include almond, apple, grape, and most stone fruits. For these crops, boron concentrations are higher in younger tissue than in older tissue, and injury is expressed in young, developing tissues in the form of twig die back, gum exudation, and reduced bud formation. Boron-immobile plants such as pistachio, tomato, and walnut do not have high concentrations of polyols, and the boron concentrates in the margins of older leaf tissues. Injury in these crops is expressed as the classical necrosis on leaf tips and margins.

Sodium

Sodium can be problematic to a crop in several ways. It can be directly toxic to the plant, it can interfere with the nutritional status of the plant (e.g., Na^+-induced calcium [Ca^{2+}] deficiency), or it can indirectly affect the crop due to its adverse effect on soil structure. Some trees are very sensitive and can develop Na^+ toxicity when concentrations of Na^+ are as low of 5 milliequivalents per liter (meq/L) (115 mg/L) in the soil water. However, this observation was made before scientists realized the importance of adequate Ca^{2+} in the soil water for root membrane stability to maintain their selectivity for ion uptake. With adequate Ca^{2+}, such as that provided by gypsum applications, sodium toxicity may never be observed in these sensitive trees at such low sodium concentrations. Therefore, rather than having a threshold for Na^+ per se, the sodium-calcium ratio in the soil solution is a better indicator of Na^+ toxicity. The SAR of the applied irrigation water has been used as a surrogate for the sodium-calcium ratio, and the general rule is an SAR < 3 is not problematic.

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

Where Na^+, Ca^{2+}, and magnesium ion (Mg^{2+}) concentrations are expressed in meq/L.

This is different when assessing sodium's indirect effect on soil structural stability (see the Infiltration Hazard section that follows). Table 3 shows critical SAR of the applied irrigation water above which can cause injury or nutritional distress in sensitive crops. Table 4 shows the seasonal average SAR for various water sources.

Table 3. Critical SAR of Applied Irrigation Water

CROP[1]	CRITICAL SAR OF APPLIED IRRIGATION WATER
All Crops	< 3

Note:

[1] Many tree crops are sensitive to Na+ toxicity after several years when sapwood converts to heartwood releasing Na^+ from the root to the shoot. Most annual crops are insensitive to Na^+ per se provided there is sufficient Ca^{2+} in the soil solution to maintain membrane integrity and ion selectivity. Hence, the ratio of sodium to calcium is more critical (Grattan and Grieve, 1992).

Key

Ca^{2+} = calcium ions

Na^+ = sodium ions

SAR = sodium adsorption ratio

Table 4. Seasonal Average SAR for Various Water Sources

VALUE[1]	FKC[2, 3]	CVC[2, 4]	INTERMEDIATE[5]	CHECK 21[6]
Average	0.46	1.68	1.99	2.27
Maximum	0.87	2.04	2.46	2.96
Minimum	0.28	1.10	1.61	1.79

Note:
[1] March through October period.
[2] Water quality data from AEWSD grab samples lab data from 2011 – 2017.
[3] Sample taken at terminus of FKC.
[4] Sample taken at AEWSD CVC, Pumping Plant 6 or 6B Forebay.
[5] Weighted average of CVC and Check 21 water quality.
[6] California Aqueduct measured at Check 21 from 1968-2017.
Key
AEWSD = Arvin Edison Water Storage District
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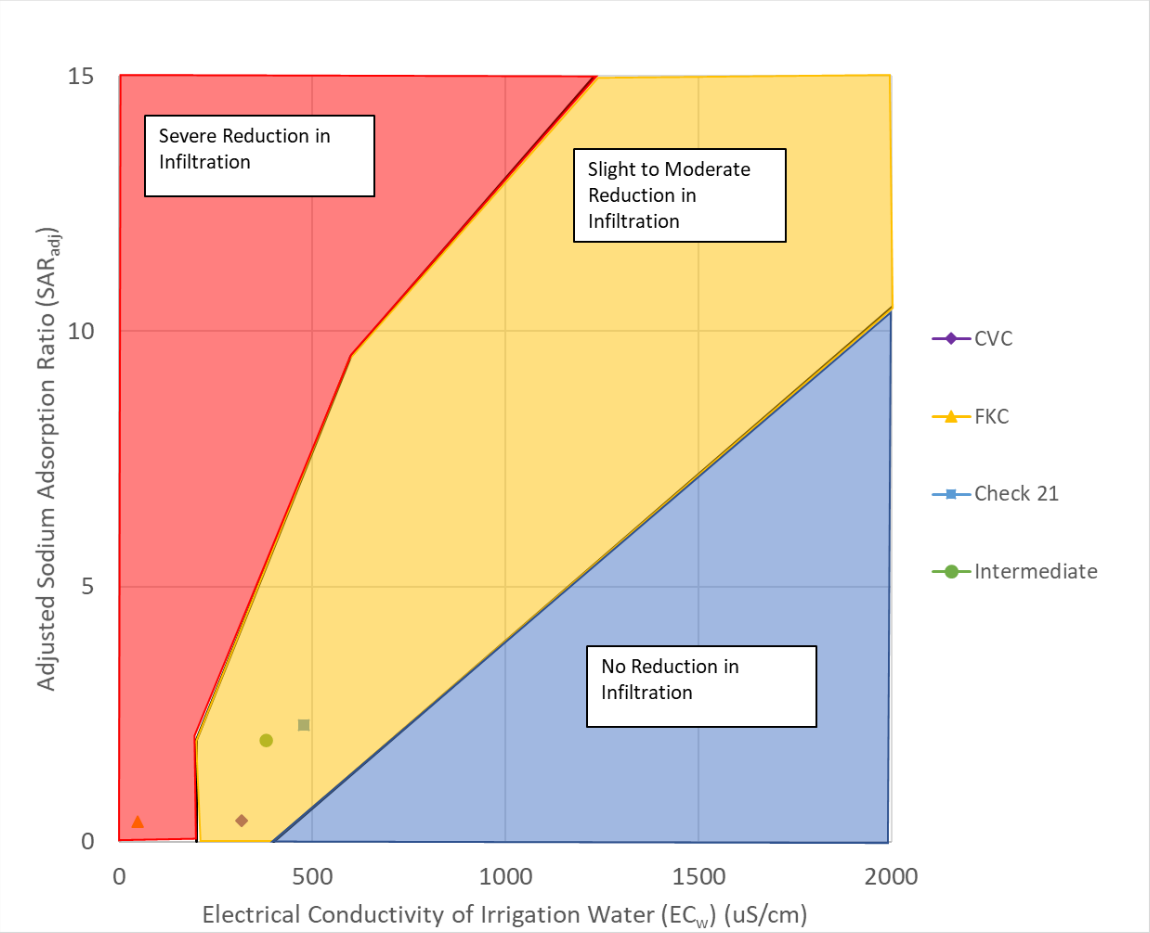
SAR = sodium adsorption ratio

INFILTRATION HAZARD

Sodium Adsorption Ratio

The SAR has been the standard used for assessing the infiltration hazard of applied irrigation water (Ayers and Westcot, 1985). But the actual infiltration hazard is assessed by balancing the opposite effects of salinity (EC_w) and sodicity (i.e., SAR) on aggregate stability. High salinity and low SAR are both important in maintaining adequate soil structure, which promotes better infiltration. Even though coarse-textured soils infiltrate faster than fine-textured soils, the hazard exists for all soil types. Typically, the adjusted SAR (SAR_{adj}) is used rather than the SAR as it more accurately accounts for $CaCO_3$, precipitation, and dissolution processes in the soil solution near the soil surface that control the free Ca^{2+} concentration. Figure 1 shows the relationship between the EC_w of the applied irrigation water and the SAR_{adj} as it relates to zones of “likely reductions” in infiltration rates (red), “slight to moderate reductions” in infiltration rates (yellow) and “no reductions” in infiltration rates (blue), adapted from Hanson et al., 2006. The threshold value is, therefore, variable and is considered to be the line that separates the “blue” and “yellow” zones on Figure 1. It is very important to note that low EC_w concentration (i.e., $EC_w < 200$ µS/cm) causes a reduction in water infiltration regardless of the SAR. Figure 1 also compares this relationship with various water sources. Note that FKC water falls in the red ”severe reduction in infiltration” zone because of its low EC_w concentration, while water from the CVC or mixed with CVC water falls in the yellow ”slight to moderate reduction in infiltration” zone. The addition of gypsum to FKC water increases the EC_w concentration, moving the point to the right and away from the ”severe reduction in infiltration” zone while slightly reducing the SAR.



Key:
µS/cm = microsiemens per centimeter
Check 21 = California Aqueduct Check 21
CVC = Cross Valley Canal
FKC = Friant-Kern Canal
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities

Figure 1. Comparison of Various Water Source Relationship between the Salinity of Applied Irrigation Water and the Adjusted Sodium Adsorption Ratio

Calcium-Magnesium Ratio

Calcium nutrition can be problematic under several conditions. Calcium deficiency can occur under low-saline conditions when the concentration of free calcium [Ca^{2+}] is $\leq$ 1-2 millimoles/L in the soil solution. Deficiency can also occur under high sodic conditions where the SAR exceeds 10-15 in sensitive plants due to high sodium-calcium ratios or in alkaline conditions where Ca^{2+} precipitates out of the soil solution as it forms $CaCO_3$. Due to competition in the plant between calcium and magnesium at the root membrane, calcium nutrition could potentially be compromised when the calcium-magnesium ratio is generally less than 1 (Rhoades, 1992). Table 5 shows the seasonal average calcium-magnesium ratio for various water sources. Note the ratios for both FKC and CVC water are considerably higher than 1, while the ratio at California Aqueduct Check 21 is very close to 1 but will likely increase in the soil solution as the infiltrating water dissolves existing gypsum in the soil from previous amendment use. Therefore, calcium deficiencies, using CVC or Check 21 water or any mixture of the two, are unlikely.

Table 5. Seasonal Average Calcium-Magnesium Ratio for Various Water Sources

VALUE[1]	FKC,[2 3]	CVC[2, 4]	INTERMEDIATE[5]	CHECK 21[6]
Average	3.54	4.37	1.55	0.92
Maximum	6.16	8.24	2.00	1.00
Minimum	0.17	2.14	1.20	0.77

Note:
Based on molar or equivalent concentrations.
[1] March through October period.
[2] Water quality data from AEWSD grab samples lab data from 2011 – 2017.
[3] Sample taken at terminus of FKC.
[4] Sample taken at AEWSD CVC, Pumping Plant 6 or 6B Forebay.
[5] Weighted average of CVC and Check 21 water quality.
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Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities
SAR = sodium adsorption ratio

PH AND BICARBONATE EFFECTS

The pH of both the applied irrigation water and the soil solution are important factors that may affect either the suitability of water for irrigation or its effect on nutrient availability to the crop. And many of the adverse effects of pH are associated with combined high alkalinity (high concentrations of bicarbonate [HCO_3^-] and carbonate [CO_3^{-2}]). In slightly alkaline waters (pH 7- 8.3), the alkalinity is from bicarbonate. Only when the pH exceeds 8.3 does carbonate become present. The pH of the water is an indication of the activity of the hydrogen ion. The numerical pH value is expressed on a negative log scale such that a one-unit increase or decrease corresponds to a ten-fold increase or decrease in the hydrogen ion activity. Therefore, a change of soil pH from 6 to 8 corresponds to a hundred-fold decrease in the hydrogen ion activity.

The pH of applied irrigation water can affect irrigation equipment or cause calcite (i.e. lime) deposits on vegetation. Regarding irrigation equipment, the pH is one of several water quality factors than can influence corrosion of galvanized pipes or other metallic parts. The pH can also influence precipitation of calcite ($CaCO_3$) at the orifices of drip emitters or minisprinklers which will affect the system's overall performance. This can be problematic if alkaline irrigation water, combined with sufficiently high bicarbonate and calcium concentrations, is used over the long term without periodic acid flushes to reduce scale buildup. Calcite precipitation becomes more problematic if the pH of the applied irrigation water exceeds 8.5. In addition, if such water is sprinkler irrigated above the canopy, it can cause unsightly white deposits that form on leaves and fruit. While these deposits typically do not cause harm to the crop, they nonetheless can affect the aesthetic quality. Acid additions to the irrigation water will not only reduce the pH but will reduce the [HCO_3^-], reducing the potential for $CaCO_3$ precipitation. Acid additions convert bicarbonate to carbon dioxide (CO_2) gas.

As the applied irrigation water infiltrates the soil, it interacts with the soil minerals. Therefore, the pH of the infiltrating water will change as it interacts with soil minerals, but soils are typically well buffered, as are soils in the FWA service area. Well buffered soils resist large changes in pH in the soil solution. The seasonal average pH of the irrigation water ranges from 7.1 to 8.4 depending upon the mixture of FKC water and California Aqueduct water. Because of the buffering capacity of the soil, this range in applied irrigation water pH will make little impact of the pH of the soil solution.

The pH of the soil solution has a profound influence on plant nutrient availability, nutrient uptake and ion toxicity to plants. The vast majority of soils that are cultivated for crop production around the world fall within the neutral, slightly acid and slightly basic pH range (i.e. pH 6-8). This is the general range where nutrient availability is optimal. However, there are those soils where the pH falls far from this normal range and these, if not corrected to an adequate range, can pose adverse effects on crops. Soils that are highly acidic ($pH < 5.5$) or highly alkaline ($pH > 8.5$) present a spectrum of challenges for the plant including nutrient availability, ion toxicities, and nutrient imbalances influencing the ion relations and nutrition within the plant itself (Läuchli and Grattan, 2012).

Most nutrients are not equally available to plants across the pH spectrum (Epstein and Bloom, 2005). Several mineral nutrients are severely affected in these non-optimal pH soils, particularly calcium, potassium, phosphorus, and iron. The reactions of plants to these nutrient elements under extreme soil pH conditions can affect plant growth, physiological processes and their morphological development (Läuchli and Grattan, 2012). The majority of the soils irrigated with waters from districts within the FWA, however, fall in the slightly alkaline range with the pH in the rootzone between 7.5 and 8.3 (UC Davis Soilweb https://casoilresource.lawr.ucdavis.edu/gmap/). Therefore, these soils are slightly alkaline, based largely on the natural abundance of calcite in the soil, and are at the upper end of the optimal pH range. Depending on the alkalinity of the soil water and $[Ca^{2+}]$, some of the Ca^{2+} can precipitate out as $CaCO_3$ which decreases the calcium-magnesium ratio. Intermittent injection of acids in the applied irrigation water will reduce the pH and, consequently, the alkalinity of the water. Not only is this a maintenance measure to reduce calcite buildup on the orifices of drip emitters and minisprinklers, it drops the pH of the water which decreases bicarbonate, increases the $[Ca^{2+}]$ and availability of other plant nutrients. Most growers in the San Joaquin Valley have some maintenance, acid-injection program in place. However, in Kern county, this may not be common practice in all districts. Acid applications, the residual gypsum in the soil and periodic applications of additional gypsum, are all a means of providing sufficient free Ca^{2+} in soils in Kern country. Moreover, increasing the $[Ca^{2+}]$ in the soil water simultaneously improves the calcium-magnesium ratio.

Sprinkler irrigated fruit and vegetable crops (approximately 20% of studied districts) could be susceptible to formation of white deposits on leaves and fruit, or “white wash,” and reduced marketability if bicarbonate concentrations, or $[HCO_3]$, in applied irrigation water are too high (> 1.5 meq/L, leaving a white residue on the crop surface. Bicarbonate concentrations in the California Aqueduct water theoretically could cause “white washing” under sprinkler irrigation, especially during dry and breezy conditions. “White washing” is a concern to some growers and has been seen by growers occasionally in the study area; however, it is not known what the exact cause of the “white washing” was, whether it was from undiluted California Aqueduct water or some other source. Bicarbonate levels of 1.5 meq/L or 92 mg/L and higher may increase formation of white deposits. The seasonal average for $[HCO_3]$ of CVC water is 78.5 mg/L. While this concentration is less than 92 mg/L, special management practices may be needed to mitigate or avoid “white wash” impacts during periods of elevated bicarbonate levels. These may include blending with higher quality sources or changing irrigation methods away from sprinklers that wet the foliage (Provost & Pritchard, 2012).

CORROSION AND DEGRADATION OF MATERIALS

The comparison of corrosion potential of California Aqueduct water and FKC water from Millerton Lake was performed by Provost & Pritchard in 2012 on several chemical constituents and calculated indices including: pH, Langelier Index, Ryzner Index, EC, resistivity, sulfates, and chlorides. This comparison generally showed that FKC water has a slight tendency to degrade concrete structures by leaching out minerals, but metallic corrosion will be low. Comparatively, California Aqueduct water will have a lower tendency to leach out minerals from concrete, and will have a more corrosive effect on metals, although there is only a slight difference between the two water sources in either case (Provost and Pritchard, 2012).

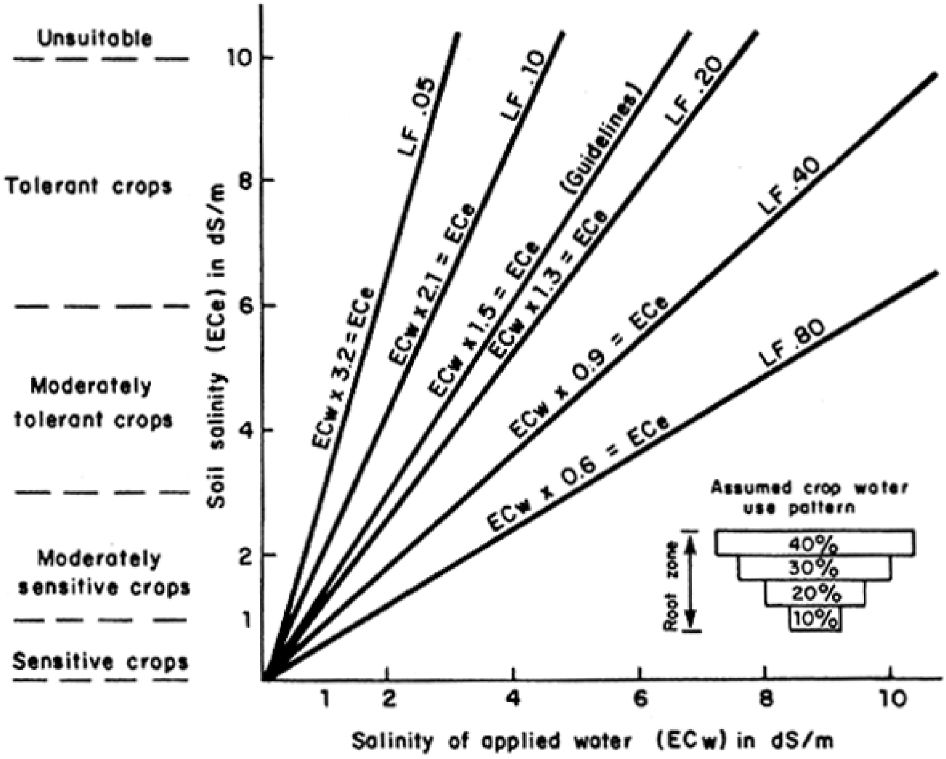
Materials such as brass, bronze, PVC, polyethylene, and stainless steel usually have a high corrosion tolerance, and therefore would not likely be affected by the exchange of source waters. The forecasted increase in corrosion from using more California Aqueduct water is likely manageable with the use of special coatings and proper selection of new materials and would likely result in minor increase in O&M costs (Provost and Pritchard, 2012).

AGRONOMIC LEACHING REQUIREMENTS

Agronomic leaching is the application of irrigation water in excess of the soil water holding capacity to neutralize the agronomic effects associated with increased salinity and ion toxicity in the crop rootzone. This approach aims to balance concerns related to long-term groundwater quality with a multi-layered assessment of agronomic impacts as a durable solution. The amount of leaching required, referred herein as maintenance leaching, depends upon the sensitivity of the crop to salinity and the irrigation water salinity. The higher the salinity of the applied irrigation water and the more sensitive the crop is to salinity, the greater the amount of leaching is required. This same leaching concept can also be applied to chloride and boron.

LEACHING FRACTION VS LEACHING REQUIREMENT

Often, leaching fraction (LF) and leaching requirement (LR) are used interchangeably. The two, in fact, are different. The LF is defined as the volume of water that drains below the rootzone divided by the volume of water that infiltrates the soil surface (equivalent to applied irrigation water assuming no surface runoff or evaporation). The LF can also be estimated based on the salinity of the applied irrigation water, or [EC_w], and that of the drainage water, or [EC_{dw}], where $LF = EC_w/EC_{dw}$. The crop roots extract water from the rootzone leaving the salts behind. If the crop rootzone is divided in quarters, typically the top quarter uses 40% of the water, the second quarter 30%, third quarter 20% and bottom quarter 10%. Therefore, the salt concentration increases with soil depth. The lower the LF, the more salts accumulate and concentrate at lower depths. Figure 2 is a representation of this relationship under conventional irrigation. The relationship between irrigation water salinity (EC_w) and soil salinity (EC_e) is linear but the slopes of the relationships are dependent upon the LF. The slopes decrease with increasing LF. The higher the LF, the higher the irrigation water salinity can be to maintain the yield of a crop. In Figure 2, note the dashed lines along the y-axis indicating the general salt tolerant categories as the salinity of the applied irrigation water changes.



Key:
dS/m = deciSiemens per meter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
LF = leaching fraction

Figure 2. Relationship Between Soil Salinity (EC_e) and Salinity of the Applied Irrigation Water (EC_w) under a Series of Steady-State Leaching Fractions (0.05 to 0.80) (from Ayers and Westcot, 1985)

The LF concept is attractive in that it allows predictions of average rootzone salinity (EC_e) conditions from the applied irrigation water EC (EC_w) and assumed LF. Knowing the scientifically determined salinity threshold value (EC_{et}) for a particular crop, one can use this relationship to determine the maximum irrigation water salinity (EC_w) for a given LF. The relationship between EC_w, EC_e, and LF also depends on irrigation management. That is, EC_e = Concentration Factor (F_c) * EC_w where 'F_c' depends not only on the LF but the type of irrigation method. Applicable F_c values for conventional irrigation methods such as furrow or flood, and high frequency irrigation methods, such as drip and minisprinklers, are provided in Table 6.

Table 6. Concentration Factor Values for Conventional and High Frequency Irrigation (adapted from Suarez, 2012)

LEACHING FRACTION (LF)	CONCENTRATION FACTOR (F_C)	
	Conventional Irrigation	High Frequency Irrigation
0.05	2.79	1.79
0.10	1.88	1.35
0.20	1.29	1.03
0.30	1.03	0.87
0.40	0.87	0.77
0.50	0.77	0.70

The difference in F_c values between conventional and high frequency irrigation is largely based on how crop roots respond to the salinity in the rootzone. Under conventional irrigation, crops typically respond to the average rootzone salinity (i.e. the seasonal average of the four rootzone quarters of salinity). Under high frequency irrigation, crops respond to the water uptake weighted salinity (i.e. the salinity in the top quarter is weighted 40 percent, salinity in the second quarter is weighted 30 percent, and so on). Because the salinity in the top quarter is lower where evapotranspiration (ET) is higher and higher in bottom where ET is lower, the average rootzone salinity is lower under high frequency irrigation.

The LR, on the other hand, is the lowest LF needed to sustain maximum yield given the applied irrigation water salinity concentration, or [EC_w], and yield threshold for the given crop. In other words, it is the minimum leaching needed, given the crop type and water quality, to maintain the salinity (or chloride or boron), at the maximum rootzone concentration in the rootzone that the crop can tolerate. Any increase in rootzone concentration above this maximum level will cause injury or yield reductions. LR is an attractive concept because, given an irrigation water quality and crop sensitivity, the minimum leaching needed to sustain the rootzone salinity EC_e, rootzone chloride (Cl^-_e), or rootzone boron (B_e) at levels that would avoid or reduce damage or yield losses can be estimated.

LR can be estimated using the following equation (Rhoades and Merrill, 1976; Ayers and Westcot, 1985):

$$LR\% = \frac{EC_w}{5(EC_{et}) - EC_w}\ x\ 100$$

EC_w= Electrical conductivity of irrigation water
EC_{et}= Soil salinity threshold for a given crop

Note that the LR relationship can apply to chloride and boron by substituting their respective irrigation water concentrations (i.e. Cl^-_w or B_w) and their threshold values (Cl^-_{et} or B_{et}). The LR equation assumes that crops respond to an average rootzone salinity created by a 40-30-20-10% root water extraction pattern, similar to LF predictions using conventional irrigation. The difference is that LR predicts the minimal LF to achieve maximal yields whereas the LF approach assumes an LF first, then predicts what the EC_e will be given the EC_w of the irrigation water. Both are similar but solve the problem from different directions.

LIMITATIONS TO THE STEADY-STATE LEACHING CONCEPT

The leaching fraction or requirement is an attractive concept but has limitations. First, the leaching concept assumes steady-state conditions and thus has no time element. Therefore, there is no accounting for how long leaching will take, which will differ depending upon the permeability of the soils. Second, the evapotranspiration (ET) of the crop is assumed to be independent of the average rootzone salinity, but it is not (Letey and Feng, 2007). A salt-stressed crop will use less water than a non-stressed crop. Consequently, crop ET will be reduced, and leaching, with the same quantity of applied irrigation water, will be increased. And third, in drip irrigated fields, actual LFs are difficult to quantify because LF, soil salinity, soil water content, and root density all vary with distance and depth from the drip lines.

In light of these limitations, recent studies have shown that the EC_w and EC_e relations described by Ayers and Westcot (1985), which are based on steady-state LF conditions, tend to be too conservative and overestimate soil salinity and, therefore, overestimate yield losses in most cases (Corwin and Grattan, 2018; Letey et al., 2011). Transient-state models may more accurately predict soil salinity, as well as soil chloride, sodium and boron, but they are more complicated and require many more site-specific inputs and assumptions. Therefore, transient models are still too cumbersome and time consuming to replace steady-state models.

The LF and LR concepts are both steady-state, so they assume the amount of irrigation is not limiting. The amount of water needed for irrigation can be estimated as:

$$AW = ET/(1-LR)$$

AW = applied water
ET = evapotranspiration or crop water requirement
LR = leaching requirement

The units for applied water (AW) and ET or crop requirement are typically depths of water (i.e. inches or millimeters). But in many cases, the amount of water is limiting and therefore crops can be under-irrigated and therefore not achieve the required leaching. In this case, the salts in the crop rootzone will increase over time. At some point, depending upon the salinity of the imported water and crop sensitively, the salt content (or chloride or boron) can exceed the threshold level. Because the threshold values are based on seasonal averages, exceedances above the threshold are allowed to some degree without experiencing a reduction in yield. For example, if the average Cl^-_e was 100 mg/L for the first 2/3 the season and then reached 200 mg/L for the last 1/3 of the season due to insufficient leaching, almonds on “Nemaguard” rootstock would not be expected to be damaged because the seasonal average Cl^-_e would be 133 mg/L given the Cl^-_e threshold is 150 mg/L. Nevertheless, if the required leaching is not achieved, reclamation leaching would be required. Similarly, if the preseason soil salinity is over 150 mg/L and little to no leaching is applied during the season, injury would be expected to develop on almonds on “Nemaguard” rootstock. Therefore, the LR values for various crops and salinities are based on soils where the maintenance leaching fraction is achieved each irrigation. If the pre-existing soil salinity is initially high, then the soil is not at steady-state.

DIFFERENCE BETWEEN MAINTENANCE LEACHING AND RECLAMATION LEACHING

There is a distinct difference between maintenance leaching and reclamation leaching. Maintenance leaching occurs during each irrigation by applying more irrigation water than the soil can hold. This is the leaching fraction or requirement concept described above. Therefore, the AW is higher than the ET to accommodate the necessary leaching (see equation above). Reclamation leaching, on the other hand, occurs at the end of the irrigation season by applying excess irrigation water to flush the salts from the crop rootzone. Ideally, reclamation leaching would not be required if correct maintenance leaching is achieved each irrigation during the irrigation season. However, because some fields may not get the necessary leaching, salts can accumulate, and fields may require reclamation leaching at some time. In addition, low pressure systems such as drip and mini-sprinkler systems produce characteristic salt accumulation patterns in fields, even with sufficient downward leaching. Whether salts are building up in the rootzone or between drippers or minisprinklers, reclamation leaching is a valuable preventative measure from time to time at the end of the irrigation season.

At the end of the irrigation season, salt can be removed by sprinkler irrigation (i.e equivalent to intermittent ponding). Figure 3 shows the extent of leaching needed to address rootzone salinity. For example, if the average rootzone salinity (ECe) at the end of the season is 3000 µS/cm and the goal is to reduce the salinity in the soil down to 600 µS/cm the salinity needs to be reduced to 600/3000 = 0.2 (y-axis) or 20% of what it was before leaching. Then the amount of sprinkler irrigation water to apply is 0.5 ft (x-axis) for every foot of soil to reclaim. If the goal is to reduce the top 2 feet, then 0.5 x 2ft = 1ft of water would be needed. This assumes the combined rainfall and applied reclamation leaching water needed.

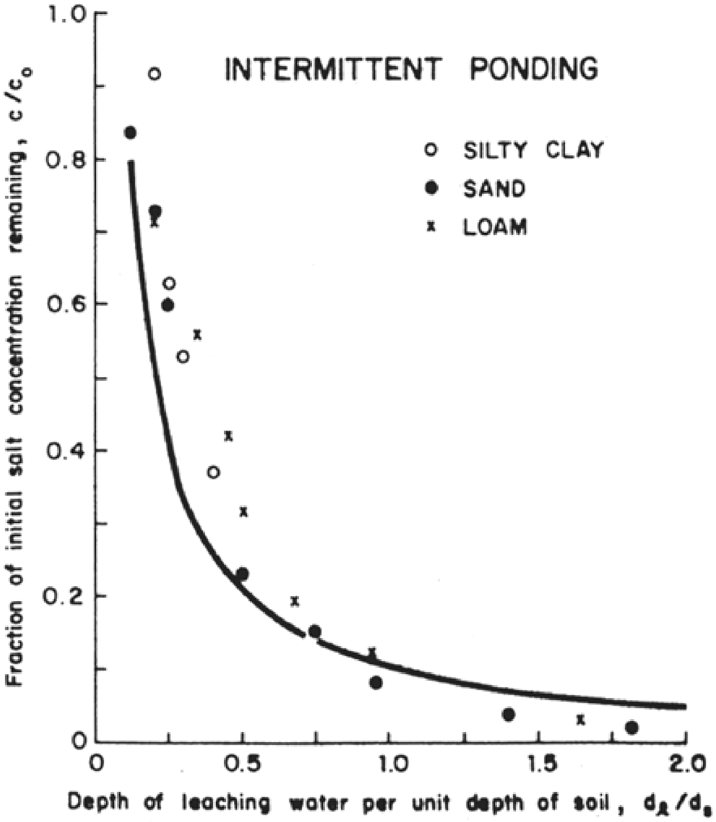


Figure 3. Reclamation Leaching Function under Sprinkler Irrigation or Intermittent Ponding (Ayers and Westcot, 1985).

The amount of reclamation leaching can be reduced by the amount of effective rainfall. To take advantage of rainfall, reclamation leaching should ideally take place after the rainfall season but before spring budding and leaf out begins, typically from October/November through March.

LEACHING AND NITROGEN MANAGEMENT

It is also important to address nitrogen management strategies combined with the salt leaching strategies. Unlike salts, nitrogen is very dynamic in the rootzone as it undergoes form changes from organic pools to inorganic fractions (primarily nitrate [NO_3^-] and ammonium [NH_4^+]). Ammonium, and particularly nitrate, are the forms primarily taken up by plants. Nitrate, being an anion, is relatively mobile in soils and is highly susceptible to leaching below the rootzone. Once nitrate leaches below the rootzone, chemical transformations are less likely to occur, and nitrate commonly continues leaching downward and eventually ends up in the aquifers. A 2002 study conducted by the Lawrence Livermore National Laboratory concluded that nitrate contamination in groundwater is “the number-one contaminant threat to California’s drinking water supply” (LLNL 2002).

Rootzone salinity control and nitrogen management is a conflicting problem. It is necessary to leach salt from the rootzone to avoid damage from salinity or ion toxicity, but nitrates will unavoidably be leaching below the rootzone as well. If soil salinity is low at the beginning of the irrigation season (see reclamation versus maintenance leaching), then leaching at less than the critical LR is possible to avoid salt damage. Then, salinity in the profile will steadily build up over the season while soil nitrogen will be depleted due to crop uptake. At the end of the irrigation season, salinity will be the highest, and nitrate will be the lowest. Therefore, reclamation leaching can be implemented at the end of the irrigation season, and the process cycle repeats itself.

MITIGATION LEACHING REQUIREMENTS

ESTIMATING LEACHING REQUIREMENTS FOR MOST SENSITIVE CROPS

The most sensitive crops in the Friant Division were used for this analysis. Crops selected were based on their varied sensitivities to salinity, chloride, and boron. By using the most sensitive crops, all crops with higher tolerances should also be protected. The most salt-sensitive crops, or those with the lowest soil salinity threshold (EC_{et}), are beans, carrots, onions (seed), melons, and strawberries. All have an EC_{et} of 1000 µS/cm. For chloride, the most sensitive crops are almonds and other stone fruits on "Nemaguard" rootstock. The threshold Cl^{-}_{et}[1] is estimated to be 150 mg/L. The relationship between boron in the applied irrigation water and the saturated soil paste is more complicated because of boron's high affinity to adsorb onto the soil. Irrigation water with higher boron concentrations than predicted can be used until the boron saturates the soil adsorption sites. Because of this complexity, Ayers and Westcot (1985) concluded that the "…maximum concentration (of boron) in the irrigation water are approximately equal to these values (boron tolerance reported based on soil water bases) or slightly less," suggesting that applied irrigation water tolerances would be 0.5 – 0.75 mg/L which would protect the most sensitive crops.. However, over the long term (more than several years), boron will behave similarly to salts and chloride (D. Suarez, US Salinity Laboratory, personal communication). With the boron threshold for soil water ranging from 0.5 – 0.75 mg/L, the B_{et} is equivalent to half of the soil water concentration, or 0.25 – 0.375 mg/L. For more information on conversions from saturated soil paste to soil water concentrations, see Ayers and Westcot (1985). To be conservative, and based on the above tree and vine crop sensitivities, the B_w threshold is assumed to be 0.25 mg/L.

Table 7 shows the acreage and percentage of sensitive crops for representative water districts, and sensitivities to boron, chloride, and EC within each representative water district.

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[1] It is important to note that most 'threshold' values for chloride and boron reported in literature (e.g. Grieve et al., 2012) are based on the soil water concentration. The saturated soil paste concentration (i.e. Cl^{-}_{e} or B_e) for most mineral soils is about half this value over the long-term (Ayers and Westcot 1985).

Table 7. Percentage and Area of Sensitive Crop Types within Representative Water Districts

	WATER DISTRICT											
	AEWSD		**DEID**		**KTWD**		**SID**		**SSJMUD**		**SWID**	
CROP TYPE	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
Boron Sensitive[5]	**15%**	**18,883**	**5%**	**2,842**	**30%**	**5,969**	**6%**	**1,211**	**8%**	**4,629**	1%	**358**
Berries[1]	1%	761	2%	873	1%	200	n/a		<1%	63	n/a	
Cherries	2%	2,196	<1%	228	1%	160	<1%	22	<1%	211	1%	358
Citrus	11%	15,024	2%	1,301	28%	5,609	4%	825	7%	4,355	n/a	
Stone Fruits[4]	1%	902	1%	440	n/a		2%	364	n/a		n/a	
Chloride Sensitive[6]	**6%**	**7,593**	**22%**	**12,399**	**5%**	**1,040**	**17%**	**3,366**	**22%**	**13,577**	**56%**	**21,649**
Almonds (Nemaguard rootstock)	6%	7,593	22%	12,399	5%	1,040	17%	3,366	22%	13,577	56%	21,649
EC Sensitive[7]	**7%**	**8,490**	**<1%**	**175**	**n/a**		**<1%**	**50**	**1%**	**375**	**2%**	**862**
Carrots	3%	3,748	<1%	100	n/a		n/a		<1%	148	2%	784
Melons[2]	1%	777	<1%	74	n/a		<1%	50	n/a		<1%	75
Onions[3]	3%	3,961	n/a		n/a		n/a		<1%	228	<1%	1
Strawberries	<1%	4	n/a		n/a		n/a		n/a		<1%	2

Source: Data compiled from California Department of Water Resources Land Use Viewer (2017) developed by LandIQ using 2014 land use data. Districts provided updates to 2017 land use data where appropriate. DEID data was provided by the District, and data gaps were filled with LandIQ data.

Notes:

Grape Crops in DEID take up 43% (26,443 ac) of the District's land area.

"n/a" indicates that there is zero amount of a crop type in a district.

[1] Data Source lists Berries as "Bush Berries"

[2] Data Source groups Melons with Squash and Cucumbers

[3] Data Source groups Onions with Garlic

[4] Stone Fruits include Apricots, Nectarines, Peaches, Plums, and Prunes

[5] Boron Sensitive Crops include Berries, Citrus, and Stone Fruits

[6] Chloride Sensitive Crops include Almonds

[7] EC Sensitive Crops include Carrots, Melons, Onions, and Strawberries

Key:

% = percentage
AEWSD = Arvin-Edison Water Storage District
DEID = Delano-Earlimart Irrigation District
KTWD = Kern-Tulare Water District
n/a = not applicable
SID = Saucelito Irrigation District
SSJMUD = South San Joaquin Municipal Utility District
SWID = Shafter-Wasco Irrigation District

DEVELOPING MITIGATION LEACHING CURVES

This section describes quantification of mitigation based on leaching requirements for sensitive crops. This approach does not directly address the physical characteristics or dynamic nature of the rootzone, but rather is specific to sensitive crop types grown in the region and implementing sufficient leaching volumes to prevent crop injury. In addition, the volumetric mitigation quantified through this approach is not specific to a water district but is representative of all crops grown in the Friant Division.

For salinity, EC_{et} values were used to calculate LR values, as presented in Table 8 in percentages. For chloride or boron the same LR equation is used except irrigation water concentrations (i.e. Cl^-_w and B_w) in mg/L are used in place of EC_w and respective threshold Cl^-_e and B_e are used in place of EC_{et}. At each location, the quantified LR by water quality constituent is based on the most stringent LR, which assumes all water is applied to the most sensitive crop. Analysis shows a long-term LR between 5.2 and 19 percent, using the average, seasonal statistics for EC, chloride, and boron concentrations.

Table 8. Leaching Requirements for Various Sensitive Crops by Water Source and Water Quality Constituent

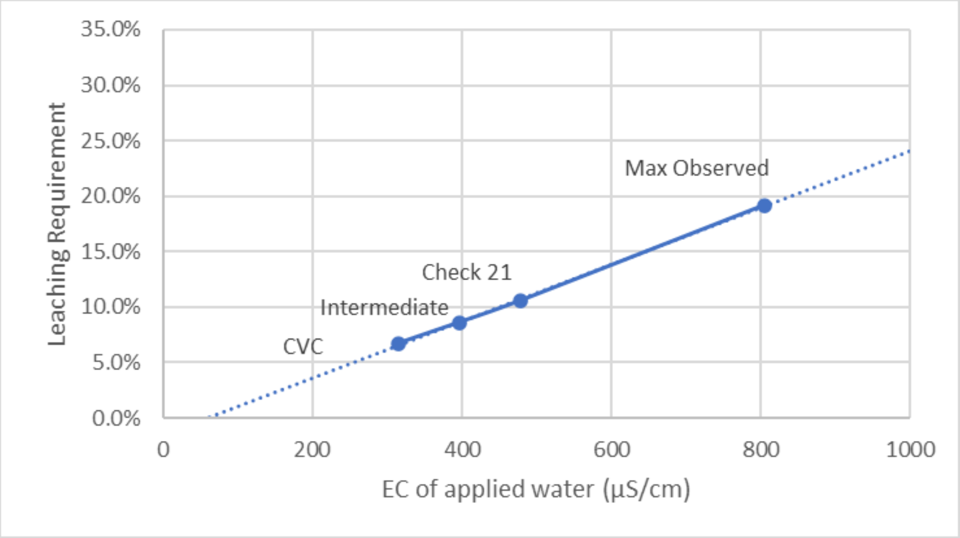
MOST SENSITIVE CROP	CVC			INTERMEDIATE			CHECK 21		
	EC	Cl^-	B	EC	Cl^-	B	EC	Cl^-	B
Carrots, onions, melons, strawberries	6.7%	-	-	8.6%	-	-	10.6%	-	-
Almonds (Nemaguard rootstock)	-	5.2%	-	-	8.1%	-	-	11.1%	-
Stone fruits, citrus, berries	-	-	8.0%	-	-	13.6%	-	-	19.0%

Key:
B = boron
Check 21 = Check Structure 21 at milepost 172,40 on the California Aqueduct
Cl^- = chloride
CVC = Cross Valley Canal
EC = electrical conductivity
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities

Figures 4 through 6 show mitigation rating curves based on LR percentages, source water quality, and constituents of concern. Each mitigation rating curve was extended to show the maximum observed concentration from historical water quality data for both CVC and California Aqueduct Check 21 sources.

The LR percentages presented in Table 8 and Figures 4 through 6 represent quantified volumetric mitigation that would be applied as maintenance leaching. Maintenance leaching occurs at each irrigation by applying more water than the soil can hold, or in other words, the applied irrigation water is more than the crop requirement to accommodate the necessary leaching. The quantified LR assumes long-term steady-state conditions and does not account for leaching from rain or end-of-season reclamation practices. Any rain or end-of-season leaching will decrease the presented values.

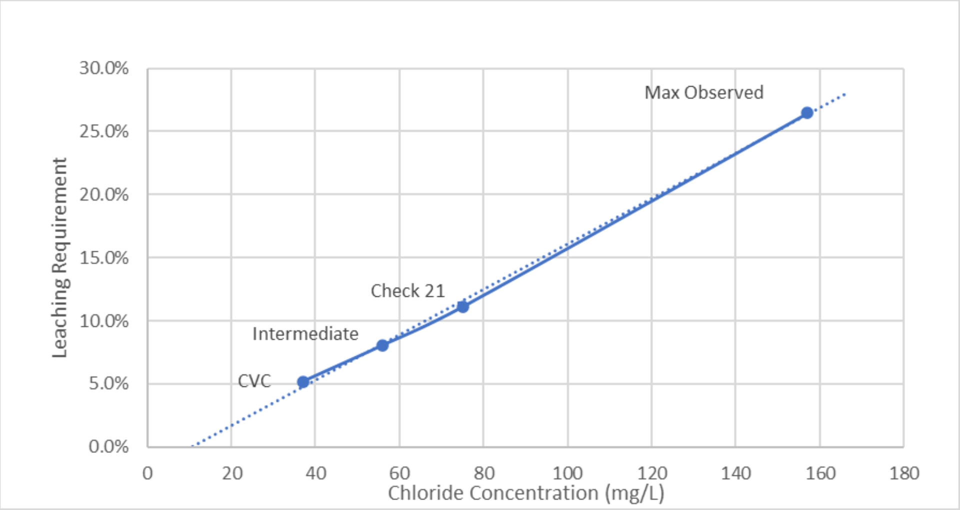
The quantified LR assumes mitigation water is delivered and applied at the same time as surface water delivery is taken. In addition, it assumes mitigation water is of the same water quality as the surface water delivery. Therefore, mitigation is only quantified for water of the same imported quality and not for both reverse flow pump-back and Millerton Lake supplies. If maintenance leaching practices are followed, reclamation leaching is unnecessary, except for in driest of years when surface supply does not meet irrigation demand or to leach salts that have accumulated between drip emitters and mini sprinklers. Using the most stringent LR, it is assumed all mitigation water is applied to the most sensitive crop.



Key:

Check 21 = California Aqueduct Check 21
CVC = Cross Valley Canal
EC = electrical conductivity
µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities

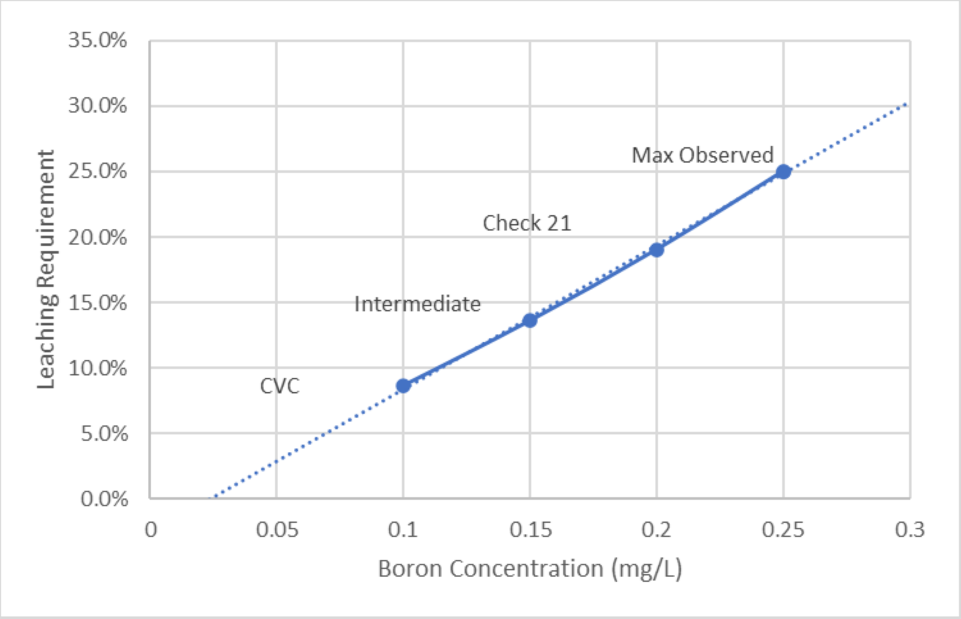
Figure 4. Leaching Requirement for Electrical Conductivity



Key:

Check 21 = California Aqueduct Check 21
CVC = Cross Valley Canal
EC = electrical conductivity
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities
mg/L = milligrams per liter

Figure 5. Leaching Requirement for Chloride

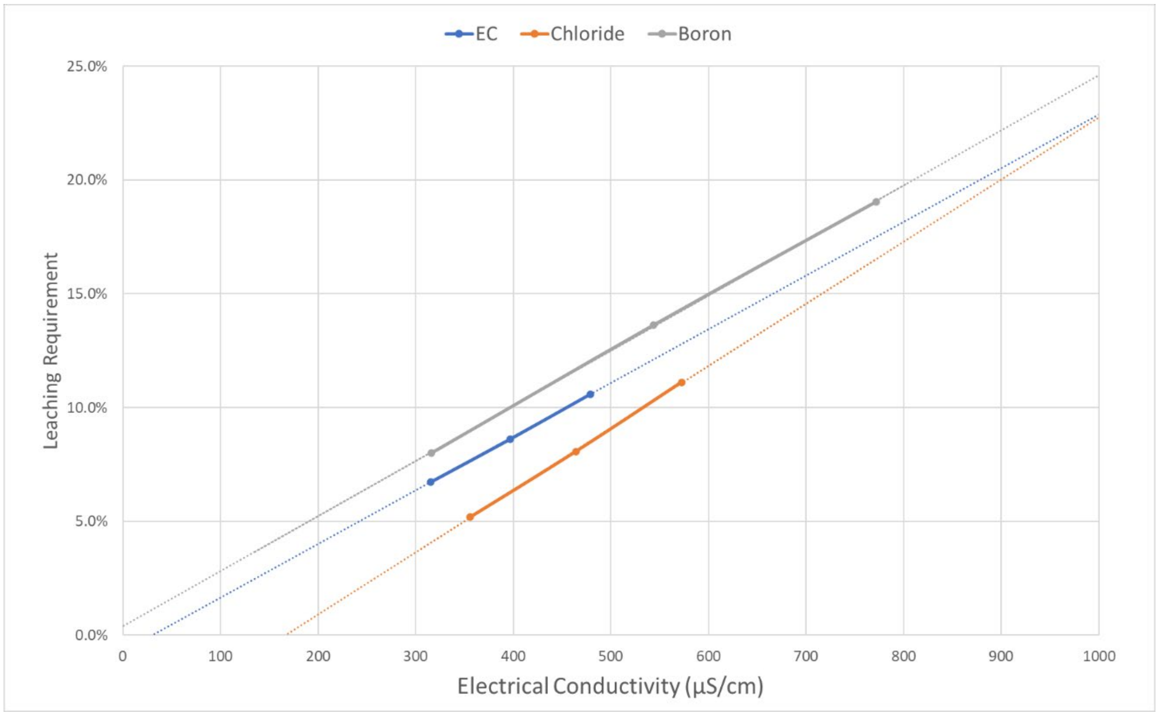


Key:
Check 21 = California Aqueduct Check 21
CVC = Cross Valley Canal
Intermediate = Water quality representing the average of California Aqueduct Check 21 and Cross Valley Canal water qualities
mg/L = milligrams per liter

Figure 6. Leaching Requirement for Boron

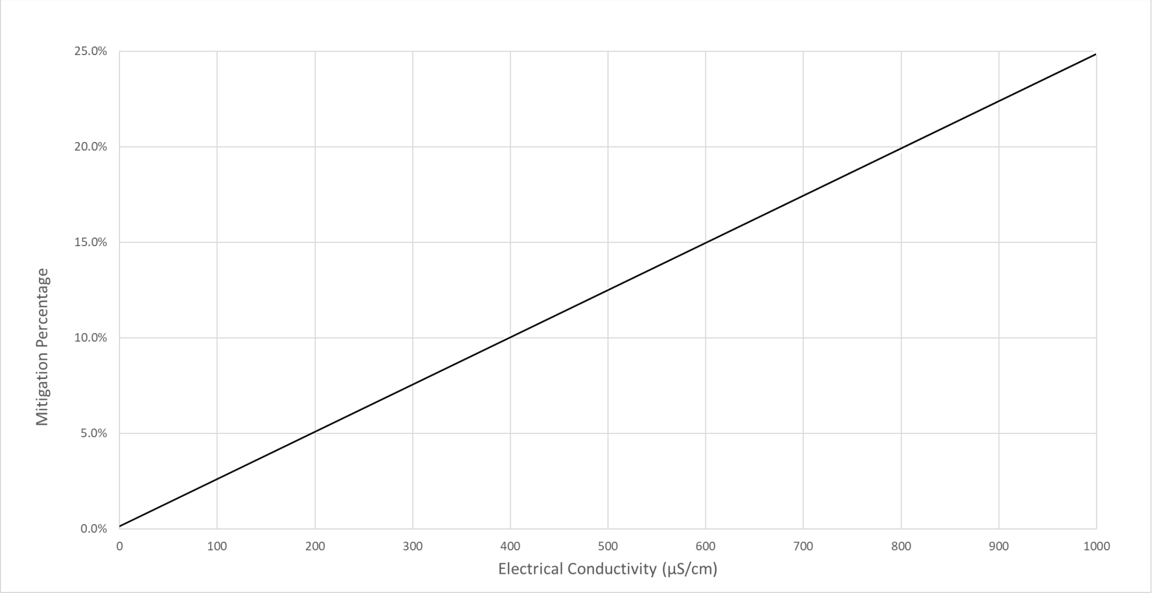
Leaching Requirement Normalization

In order to best understand the LR relationships amongst EC, chloride, and boron and to confirm the dominant constituent trend, individual rating curves were normalized to an EC concentration scale. The EC concentration was used as it can be easily measured in real-time. Figure 7 shows the stacked, normalized mitigation rating curves for all three constituents of concern. Boron is the dominant or driving constituent and has the highest LR, regardless of source water quality. The required leaching based on that curve would be sufficient to prevent crop injury due to increased EC or chloride concentrations in applied irrigation water, and, therefore, the boron curve is the proposed mitigation rating curve for the Water Quality Mitigation Ledger (Figure 8). The method for normalizing each constituent curve is described below.



Key:
µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
EC = electrical conductivity

Figure 7. Rootzone Leaching Curves for Electrical Conductivity, Chloride, and Boron Normalized to an Electrical Conductivity



Key:
µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)

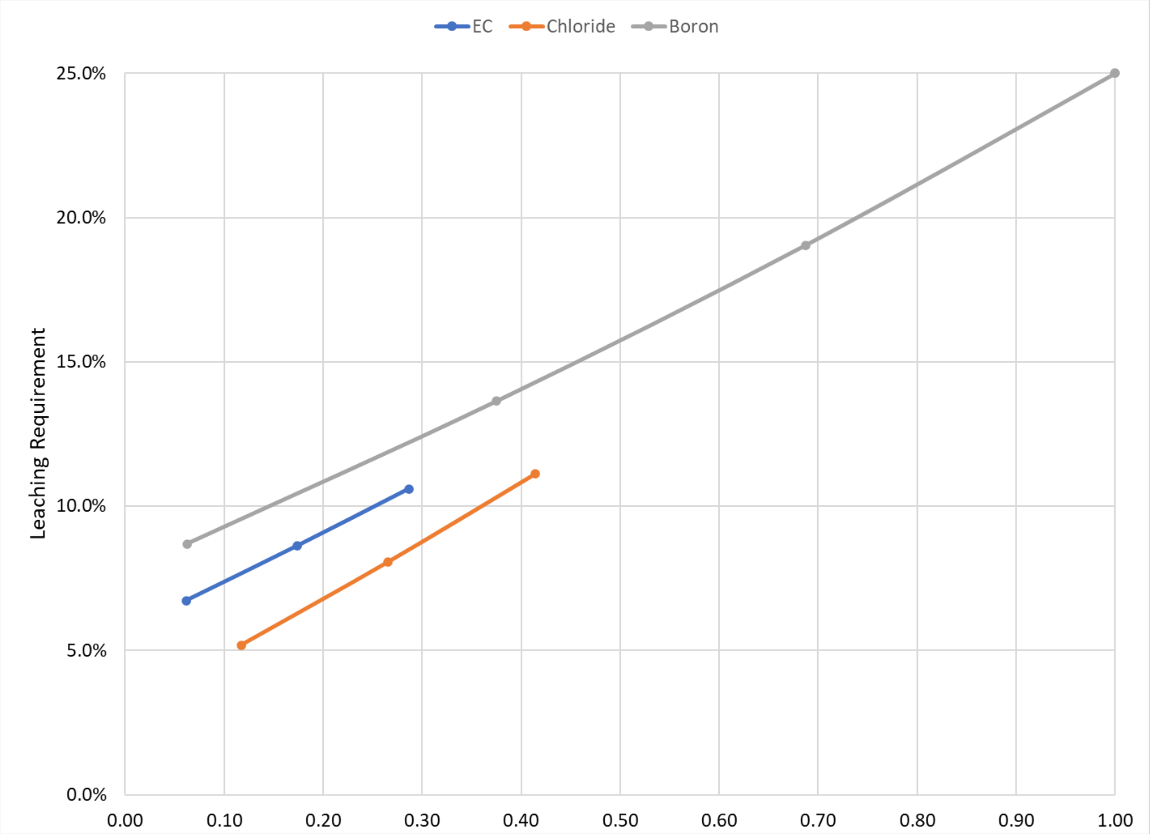
Figure 8. Proposed Mitigation Rating Curve based on Boron Sensitivity and Normalized to Electrical Conductivity

Normalization Method

As the three constituent curves have differing concentration scales and they do not show direct correlations to each other, the constituents were normalized to a common scale using the below equation.

$$X_{new} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

In the equation, X represents the constituent concentration for EC, chloride, or boron. X_{min} is the minimum average, seasonal, observed concentration for a given constituent from either California Aqueduct Check 21 or CVC water quality data. The maximum observed concentration corresponded with varying leaching requirements for each of the constituents. To ensure that all constituents were normalized to the same scale and the full range of possible constituent concentrations was considered beyond the highest observed concentration for California Aqueduct Check 21 water, X_{max} represents the constituent concentration corresponding to a 25 percent LR. Figure 9 displays the normalized curves, and Table 9 presents the normalized data.



Key:
EC = electrical conductivity

Figure 9. Normalized Leaching Requirement curves for Electrical Conductivity, Chloride, and Boron

Normalized concentration values were then converted back to EC using the equation below, where X_{norm} represents the normalized concentration for chloride or boron. LR curves were then replotted using an EC scale (Figure 7).

$$EC = X_{norm}(EC_{max} - EC_{min}) + EC_{min}$$

Table 9. Constituent Normalization

SOURCE WATER	ELECTRICAL CONDUCTIVITY			CHLORIDE			BORON		
	Observed Concentration (µS/cm)	Normalized Value	Leaching Requirement	Observed Concentration (Seasonal Average) (mg/L)	Normalized Value	Leaching Requirement	Observed Concentration (Seasonal Average) (mg/L)	Normalized Value	Leaching Requirement
CVC	315	0.06	6.7%	37.00	0.12	5.2%	0.10	0.06	8.0%
Intermediate	397	0.17	8.6%	56.00	0.27	8.1%	0.15	0.38	13.6%
Check 21	479	0.29	10.6%	75.00	0.41	11.1%	0.20	0.69	19.0%
Maximum Observed	805	0.73	19.2%	157.00	1.05	26.5%	0.25	1.00	25.0%
Maximum normalization (25% Leaching Requirement)	1000	1.00	25.0%	150.00	1.00	25.0%	0.25	1.00	25.0%

Key:
CVC = Cross Valley Canal
µS/cm = microsiemens per centimeter
mg/L = milligrams per liter

APPLIED AGRONOMIC THRESHOLDS

The Policy includes maximum water quality thresholds for the FKC. Although the mitigation rating curve quantifies mitigation water to account for appropriate maintenance leaching, FKC water quality thresholds for EC, chloride, boron, turbidity, total suspended solids (TSS), and SAR and sodium were developed and are proposed herein. These thresholds aim to (1) balance supply reliability, water quality concerns, and agricultural practices, such as regulated deficit irrigation (RDI); and (2) ensure that the EC_{et}, Cl^{-}_{et}, or B_{et} limits are not exceeded for the most prevalent and sensitive crops in the Friant Division. The thresholds are specific to three irrigation periods that correspond to the growing season and agricultural management practices during the year:

- Period one represents the beginning of the growing season (March 1 – June 30);
- Period 2 represents timing of hull split and the duration of RDI practices in the Friant Division (July 1 – August 31); and
- Period 3 is inclusive of the remainder of the growing season and contract year (September 1 – February 28).

Table 10 shows the established water quality constituent thresholds for each period as defined in the Policy. The threshold variations in Period 3, shown as Periods 3a and 3b, are described in more detail in the Threshold Flexibility subsection below.

Sections below describe methods applied to account for annual RDI practices; development of water quality thresholds, including thresholds for RDI; and adjustments to water quality thresholds to accommodate flexibility for water management within the Friant Division.

Table 10. Friant-Kern Canal In-Prism Water Quality Thresholds

Period	Salinity expressed as EC (µS/cm)	Chloride (mg/L)	Boron (mg/L)[1]	Turbidity (NTU)[6]	Total Suspended Solids (ppm)	SAR[7]	Sodium (mg/L)[7]
Period 1 March 1 – June 30	1,000[2]	102[3]	0.4	40	20	3	69
Period 2 July 1 – August 31	500[4]	55[4]	0.4	40	20	3	69
Period 3a September 1 – February 28	1,000[2]	102[3]	0.4	40	20	3	69
Period 3b September 1 – February 28	1,000[2]	123[5]	0.4	40	20	3	69

Notes:

Thresholds adapted from 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 (2nd edition). ASCE pp 405-459; and 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

For addition detail, see Attachment C – Agronomic Impacts and Mitigation.

When Friant-Kern Canal in-prism water quality conditions in this table are exceeded, Friant Division Long-Term Contractors will work together to seek 1:1, unleveraged, and cost-neutral exchanges for pump-in and pump-back programs. This does not apply to spot-market or third-party exchanges.

1 Grapes are used as a representative crop for boron sensitivity and are prevalent in the Friant Division. They are used as a surrogate for many other sensitive crop types such as apricots, figs, and grapefruits. Threshold assumes conventional irrigation with minimum 20 percent leaching fraction applied.

2 Threshold assumes minimum of 20 percent leaching requirement applied and adjusted to account for regulated deficit irrigation during almond hull split period (July 1 – August 31) in order to not exceed maximum EC_{et}. Almonds on Nemaguard rootstock are used as a representative crop for salinity sensitivity and are prevalent in the Friant Division. They are used as a surrogate for many other sensitive crop types such as apples, cherries, pears, pistachios, and walnuts.

3 Threshold assumes minimum of 20 percent leaching requirement applied and then adjusted to account for regulated deficit irrigation during almond hull split period (July 1 – August 31) in order to not exceed maximum Cl-et. Almonds on Nemaguard rootstock used as a representative crop for chloride sensitivity. They are used as a surrogate for other sensitive crops including cherries, pistachios, and walnuts.

4 Threshold applies to almond hull split period when regulated deficit irrigation is applied to avoid hull rot. This threshold is used assuming irrigation applications are reduced to 50 percent of the tree water requirement and subsequently thresholds applied for the remainder of the year have been adjusted to account for additional salt accumulation. This threshold was developed with consideration of existing program operations, historical water quality data, and absolute water quality thresholds.

5 If the measured average chloride concentration in Period 1 (March 1 – June 30) is less than or equal to 70 mg/L, the allowable chloride threshold for Period 3 (September 1 – February 28) is increased to 123 mg/L.

6. Turbidity threshold is taken from section 3 of the Final Initial Study/Negative Declaration for: Warrant Act Contract(s) and License, and Operation and Maintenance Agreement, to Introduced Floodwaters from Reclamation District 770 into the Friant-Kern Canal, March 2017.

7. SAR and Sodium are managed together. If the measured SAR value exceeds 3 AND the measured sodium concentration exceeds a threshold of 69 mg/L, management will be necessary. SAR value is derived from Ayers Table 1 and the 69 mg/L sodium is derived and converted from the Ayers Table 6.

Key:

µS/cm = microsiemens per centimeter (1 µS/cm = 1 µmhos/cm = 1/1,000 dS/m)
ASCE = American Society of Civil Engineers
Cl^{-}_{et} = maximum chloride threshold of the saturated soil paste
EC = electrical conductivity of applied water
EC_{et} = Soil salinity threshold for a given crop
FAO = Food and Agriculture Organization of the United Nations
Friant Division = Friant Division of the Central Valley Project
mg/L = milligrams per liter
SAR = sodium adsorption ratio
TDS = total dissolved solids

REGULATED DEFICIT IRRIGATION

This section describes methods applied to account for annual RDI practices in the Friant Division for EC and chloride agronomic thresholds, specific to almonds. Note, grapes may also be deficit irrigated during the blooming period; however, the deficit irrigation period for grapes is not aligned with that of almonds, and grapes are most prone to boron toxicities. Consequently, a similar RDI analysis and threshold adjustment is unnecessary for grapes. See Boron Thresholds subsection in Water Quality Thresholds section for additional discussion on applied boron thresholds for grapes in the Friant Division.

Hull Rot Control

Hull rot is problematic in almond orchards in the San Joaquin Valley, and trees are particularly sensitive during the hull split period. Hull split is where 1 percent of the almonds exhibit split, and it typically lasts one to two weeks. The initiation of hull split depends on the almond variety, weather conditions, and tree stress. Although variety has the largest influence on hull-split timing, the temperature 90 days after flowering also affects the hull split initiation. Unseasonably cool temperatures delay hull split while unseasonably warm weather accelerates it.

Hull rot occurs due to infestation by one of two types of fungi, *Monilinia fructicola* or *Rhizopus stolonifera* (Holtz, 2009). Some almond varieties, particularly Nonpareil and Monterey, are more susceptible to fungal attack than are other varieties. High nitrogen application to an orchard combined with full irrigation, or irrigation to completely meet tree ET demands, at the time of hull split can make trees considerably more vulnerable to hull rot.

Hull rot can be largely controlled through a combination of nitrogen management, water management, and antifungal sprays. It is best controlled by RDI practices. A 2001 study showed that by cutting back irrigation to 50 percent of the trees' water requirements between June 1 to July 31 (70 percent regulated) or July 1 to July 15 (85 percent regulated), hull rot was substantially reduced as evidenced by fewer dead leaf clusters and fewer dead spurs and branches (Teviotdale et al., 2001). Such mild to moderate water stress results in drier hull conditions, making trees less vulnerable to fungal attack. Many almond growers in the San Joaquin Valley have adopted RDI practices to help synchronize hull split timing and reduce potential for hull rot. To monitor the degree of tree stress, these growers have implemented the University of California recommendation of trying to maintain a stem water potential between -14 to -16 bars using pressure chambers by drying down the soil rootzone (B. Sanden, Personal communication, April 5-6, 2020). The more negative the number, the more stress the tree experiences. It could take between one to six weeks to achieve this stress level, depending on soil type and irrigation systems (B. Lampinen, personal communication, April 7, 2020). Growers should take care to not to stress trees too much because that could compromise kernel size as kernels continue to grow at the onset of hull split (Doll and Shackel, 2015). After almond harvest, irrigation is critical to maximize floral bud development for the subsequent season.

During the RDI period when there is no effective leaching, irrigation application is reduced to 50 percent of the tree water requirement, and some additional salts and chlorides accumulate in the rootzone. Absent leaching, the steady-state model breaks down because the salt content in the applied water would need to be zero to maintain the same rootzone salinity. In this situation, preseason irrigation management should target an adjusted soil salinity to maintain the appropriate soil salinity thresholds and avoid crop injury.

Regulated Deficit Irrigation Analysis

The RDI analysis applied a predictive model based on timing of flowering to estimate hull split for various types of almond varieties in different parts of the Central Valley (UC Fruit & Nut Research & Information Center, 2020). From the model and historical California Irrigation Management Information System (CIMIS) data from the AEWSD weather station, hull split was determined to typically initiate around the end of June or beginning of July and, depending upon the variety, continue through mid-August (B. Sanden, personal communication, April 6, 2020). To account for potential variances in hull split initiation in the Friant Division, an 8-week period (July 1 to August 31) was assumed for this RDI analysis. Determination of water quality thresholds during the RDI practices period, or Period 2, also considered effective rootzone depth, applied irrigation water quality, soil capacity, and irrigation requirements. The RDI analysis is considered to be conservative because: (1) rainfall was not considered; (2) surface irrigation was assumed, despite the fact that crops under high frequency drip irrigation (typical for most water districts in the Friant Division) are able to tolerate higher salinity for the same assumed LF; and (3) steady-state models typically overestimate rootzone salinity (Corwin and Grattan, 2018).

The RDI analysis was completed for both EC and chloride. Salt accumulation was quantified as a percentage increase, and then rootzone and applied irrigation water thresholds (assuming 20 percent maintenance leaching) were adjusted to maintain maximum EC_{et} or Cl^{-}_{et} through the season. Assuming steady-state leaching, the analysis targeted maintenance of rootzone salinity at soil salinity thresholds of 150 mg/L for chloride, and 1,500 µS/cm for EC, resulting in adjustments to Cl^{-}_{w} and EC_{w} thresholds.

The RDI calculation assumed the effective rootzone to be between three and five feet (UC Almond Rootzone Workgroup, 2015). Soil was considered to be at field capacity meaning that volumetric soil moisture content was 25 percent, based on monthly average ET or irrigation water requirements for mature almonds in Kern County during months of July and August, 9.5 inches and 8.8 inches, respectively (Sanden, personal communication, April 6, 2020; Goldhamer 2012). The RDI calculation included soil water concentration thresholds of 300 mg/L for Cl^{-}_{sw}, and 3,000 µS/cm for EC_{sw}, or twice that of the thresholds expressed on a saturated soil paste basis.

During the RDI period, water was assumed to be applied at 50 percent ET_{c}. The total amount of irrigation water required for 100 percent irrigation application, in inches, was calculated but then halved to account for 50 percent deficit irrigation. The amount of irrigation water during RDI periods was then multiplied by the irrigation water concentrations of salt and chloride to determine the percentage increase above the salt and chloride concentrations in the rootzone. Calculating the percentage increase of chloride in the rootzone meant first determining irrigation water and soil water amounts.

For example, 50 percent of the total ET for July and August was 9.1 inches, and the total water in the effective rootzone was 15 inches (rootzone depth (5 ft, or 60 inches) * 25 percent water content = 1.25 feet, or 15 inches). The 15 inches of soil water had 300 mg/L chloride at the beginning of the RDI period. After 9.1 inches of water was applied, adding salts to the soil water in the rootzone, the irrigation water concentration was 55 mg/L. The percentage of additional salt was determined by calculating the ratio of the salt added in the deficit irrigation water to that in the soil water, (9.1 inches x 55 mg/L) / (15 inches x 300 mg/L) = 11 percent. If the salt level in the rootzone remained at critical soil threshold levels at the end of the RDI period, the Cl^{-}_{e} at the beginning of RDI period would have needed to be proportionally lower than the critical soil salinity threshold of 150 mg/L, such that the 150 mg/L threshold concentration would be achieved at the end of the season. Thus, the Cl^{-}_{et} is reduced to 122 mg/L and the corresponding Cl^{-}_{w} becomes 102 mg/L.

WATER QUALITY THRESHOLDS

This section presents the RDI analysis-based chloride and EC thresholds and proposed flexible thresholds for chloride, boron thresholds, turbidity and TSS thresholds, and SAR and sodium thresholds.

Chloride and Electrical Conductivity Thresholds

Tables 11a and 11b show the RDI analysis for a variety of applied irrigation water qualities for chloride and EC, respectively. In consideration of historical water quality data representative of Kern-Fan or CVC programs that currently introduce water into the FKC, as well as temporal water quality trends, an applied irrigation water threshold for the RDI period was selected to be 55 mg/L Cl^{-}_{w}. The Cl^{-}_{w} value of 55 mg/L during the RDI period correlated to an adjusted Cl^{-}_{w} of 102 mg/L for the remainder of the year, assuming a three-foot (36 inch) effective rootzone – a conservative assumption as the effective rootzone is assumed to be three to five feet (Table 12a).

The same logic described above for Cl^{-}_{w} thresholds was applied to determine RDI EC_{w} and adjusted EC_{w} thresholds. The chloride threshold for the RDI period (55 mg/L) was approximately 49 percent greater than the average historical water quality of representative Kern-Fan programs for all year types during months of July and August (37 mg/L). The average EC_w during July and August for all year types representative of Kern-Fan programs was 300 µS/cm, and a 49 percent increase is 447 µS/cm. Rounding up, the RDI threshold for EC_w is 500 µS/cm, and, in order to maintain an EC_{et} of 1,500 µS/cm, the adjusted EC_w for the remainder of the year was 1,000 µS/cm.

Table 11a. Regulated Deficit Irrigation Analysis for Chloride

Cl^-_w (mg/L)	Effective Rootzone (in)	Sum ET_c Average (in)[1]	RDI %	RDI Water (in)	Rootzone Water (in)[2]	% Cl^- Increase	Adjusted Cl^-_e Needed (mg/L)	Adjusted Cl^-_w (mg/L)
10	36	18.3	50%	9.2	9	3.4%	145	121
10	60	18.3	50%	9.2	15	2.0%	147	122
20	36	18.3	50%	9.2	9	6.8%	140	117
20	60	18.3	50%	9.2	15	4.1%	144	120
30	36	18.3	50%	9.2	9	10.2%	135	112
30	60	18.3	50%	9.2	15	6.1%	141	117
40	36	18.3	50%	9.2	9	13.6%	130	108
40	60	18.3	50%	9.2	15	8.1%	138	115
50	36	18.3	50%	9.2	9	16.9%	125	104
50	60	18.3	50%	9.2	15	10.2%	135	112
55	36	18.3	50%	9.2	9	18.6%	122	102
55	60	18.3	50%	9.2	15	11.2%	133	111

Notes:

[1] ETc averages from Sanden and Goldhamer based on water use of mature almond trees in Wasco area for July and August (Goldhamer and Girona 2012).

[2] Rootzone at field capacity is 25 percent by volume.

Key:

Cl^- = chloride
Cl^-_e = chloride concentration in saturated soil paste or rootzone chloride
Cl^-_w = chloride concentration in applied irrigation water
ET_c = evapotranspiration or tree water use
in = inches
mg/L = milligrams per liter
RDI = regulated deficit irrigation

Table 11b. Regulated Deficit Irrigation Analysis for Electrical Conductivity

EC_W (µS/cm)	Effective Rootzone (in)	Sum ET_c Average (in)[1]	RDI %	RDI Water (in)	Rootzone Water (in)[2]	% EC Increase	Adjusted EC_e Needed (µS/cm)	Adjusted EC_w (µS/cm)
200	36	18.3	50%	9.2	9	6.8%	1,400	1,120
200	60	18.3	50%	9.2	15	4.1%	1,440	1,150
300	36	18.3	50%	9.2	9	10.2%	1,350	1,080
300	60	18.3	50%	9.2	15	6.1%	1,410	1,130
400	36	18.3	50%	9.2	9	13.6%	1,300	1,040
400	60	18.3	50%	9.2	15	8.1%	1,380	1,100
500	36	18.3	50%	9.2	9	16.9%	1,250	1,000
500	60	18.3	50%	9.2	15	10.2%	1,350	1,080
600	36	18.3	50%	9.2	9	20.3%	1,200	960
600	60	18.3	50%	9.2	15	12.2%	1,320	1,050

Notes:

[1] ET_c averages from Sanden and Goldhamer based on water use of mature almond trees in Wasco area for July and August (Goldhamer and Girona 2012).

[2] Rootzone at field capacity is 25 percent by volume.

Key:

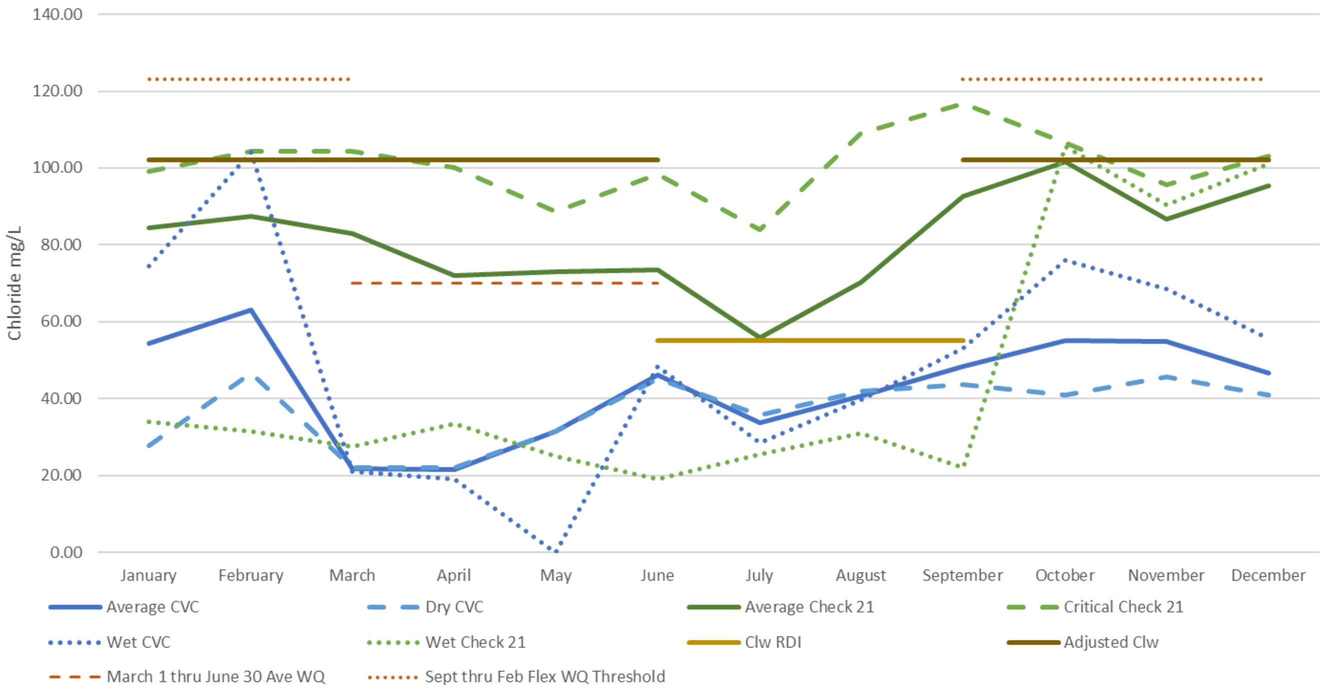
µS/cm = microsiemens per centimeter
EC = electrical conductivity
EC_e = electrical conductivity of saturated soil paste or rootzone salinity
EC_w = electrical conductivity of applied irrigation water
ET_c = evapotranspiration or tree water use
in = inches
RDI = regulated deficit irrigation

By adjusting the Cl^{-}_{e} and EC_{e} thresholds for non-RDI irrigation periods, LR volumes for the assumed 20 percent leaching were adjusted by default, as LR is a function of the saturated soil paste concentration. Adjusted LR volumes and constituent thresholds affect the mitigation curve slope for each constituent. The adjusted curves for chloride and EC were plotted and were below the governing line, so the mitigation curve remained unchanged and further confirmed the conservative nature of the mitigation curve in ensuring that all constituents would be sufficiently mitigated.

Chloride Threshold Flexibility

In evaluating and comparing the developed, in-prism water quality thresholds with temporal water quality trends during Period 1 (March 1 to June 30), or prior to the RDI period (July 1 to August 31), observed average constituent concentrations were typically below the proposed thresholds. If water with lower constituent concentrations was applied to a crop for the first four months of the growing season, assuming that the rootzone concentration was properly maintained, the rootzone concentration would decrease below the threshold and, even with reductions in irrigation and LFs, could allow the application of higher irrigation water concentrations during the post-RDI period. The period following RDI, or Period 3 (September 1 to February 28), is often used for reclamation leaching; however, it is also the period in which new sources of water may be available for the Friant Division. Thus, having flexibility in the allowable irrigation water quality could be opportune for increasing supply reliability for the region.

Based on the RDI analysis and evaluation of water quality temporal trends, the Guidelines define an alternative water quality threshold for chloride for Period 3 to provide flexibility for irrigation management. Determination of whether the alternative chloride threshold for Period 3 is applied is based on the average chloride concentration of the irrigation water during Period 1. The alternative value was developed considering historical, temporal water quality trends and applying a weighted average calculation to meet the targeted rootzone chloride threshold. If the average measured chloride concentration for Period 1 is less than or equal to 70 mg/L, the allowable chloride concentration threshold increases from 102 mg/L to 123 mg/L for Period 3. If the measured average chloride concentrations for Period 1 exceed 70 mg/L, the chloride threshold remains at 102 mg/L for Period 3. Figure 10 shows the proposed thresholds compared to the chloride water quality trends for CVC and California Aqueduct water sources by year type.



Key:
Average = Average of all San Joaquin Index year types and excludes months where there is mixing.
Cl^{-}_{w} = chloride concentration of applied irrigation water
CVC = Cross Valley Canal
Dry= Monthly average for San Joaquin Index year types dry and critical and excludes months where there is mixing.
mg/L = milligrams per liter
RDI = regulated deficit irrigation
Wet = Monthly average for San Joaquin Index year types below normal, above normal, and wet and excludes months where there is mixing.

Figure 10. Chloride water quality trends by source water and year type with proposed water quality thresholds

Because the average water quality for Kern-Fan or CVC programs for Period 1 (March 1 to June 30) was approximately 30 mg/L (see Table 2), 70 mg/L was chosen as a midpoint between the adjusted Cl^{-}_{w} threshold determined in the RDI analysis and the average historic water quality. Using a weighted average approach, if 70 mg/L water was applied for the four months in Period 1, assuming an LR of 20 percent, the resulting Cl^{-}_{e} would be 84 mg/L. With the target weighted average for Cl^{-}_{e} of 122 mg/L, the necessary Cl^{-}_{e} for Period 3, the six months post-RDI (September 1 – February 28) was determined using the following equation:

$$84\frac{mg}{L} * .4 + Cl_{e} * .6 = 122$$

The resulting Cl^{-}_{e} was 147 mg/L, correlating to a Cl^{-}_{w} of 123 mg/L with an assumed 20 percent LR. This approach was conservative in that observed chloride concentrations for Kern-Fan programs were significantly lower than 70 mg/L, and these calculations did not consider rainfall or any reclamation leaching applied in addition to the assumed 20 percent maintenance leaching.

Note that adjusting the Cl^{-}_{e} thresholds for non-RDI irrigation periods (Period 1 and Period 3) would adjust the LR volumes for the assumed 20 percent leaching provided by the mitigation curve. Adjusted curves were plotted and it was confirmed that even with a reduced Cl^{-}_{e}, the established mitigation curve would provide adequate mitigation.

Boron Thresholds

Table 12 shows B_w thresholds for tree and vine crops above which injury occurs under differing irrigation management practices, or LF values of 10 and 20 percent. Grapes have a boron tolerance of 0.4 mg/L when the LF is between 10 to 25 percent (Grattan et al., 2015). The actual boron threshold tolerance range is 0.3-

0.5 mg/L if one considers different combinations of the soil water threshold (B_{sw}) tolerance (0.5 - 0.75 mg/L) and LF (10 - 25%).

The maximum in-prism water quality threshold for boron was set at 0.4 mg/L for all three irrigation periods (Periods 1, 2, and 3). Grapes were used as the representative crop for boron sensitivity because of their prevalence in the Friant Division, serving as a surrogate for other sensitive crop types, such as apricot, fig, and most citrus. The applied threshold assumed conventional irrigation with a LF of 10-25 and was used rather than the LR concept that was used in development of the mitigation curves.

Table 12. Boron Tolerance of Various Crops

CROP	BORON CONCENTRATION OF APPLIED WATER (B_w) (mg/L)	
	Leaching Fraction 10%	Leaching Fraction 25%
Alfalfa	2.0	2.8
Apricot	0.4	0.4
Asparagus	4.8	6.7
Barley	1.4	1.9
Bean (kidney, lima, mung)	0.4	0.6
Bean, snap	0.5	0.6
Beet, red	2.0	2.8
Bluegrass, Kentucky	1.2	1.7
Broccoli	0.5	0.6
Cabbage	1.2	1.7
Carrot	0.7	0.9
Cauliflower	1.6	2.2
Celery	3.8	5.3
Cherry	0.4	0.4
Clover, sweet	1.2	1.7
Corn	1.2	1.7
Cotton	3.1	4.3
Cucumber	0.7	0.9
Fig, Kadota	0.4	0.4
Garlic	1.7	2.4
Grape	0.4	0.4
Grapefruit	0.4	0.4
Lemon	<0.3	<0.4
Lettuce	0.6	0.8

Note: Adapted from data in Grattan, S.R., F.J. Diaz, F. Pedrero and G.A. Vivaldi. 2015. Assessing the suitability of saline waste waters for irrigation of citrus: Emphasis on boron and specific ions interactions. Agric Water Manag. 157:48-58.

Key:
mg/L = milligrams per liter

In addition, the applied B_w threshold of 0.4 mg/L was far more conservative than those defined in literature by Ayers and Westcot (1985). This analysis indicated that B_{sw} could be used as protective irrigation water thresholds (B_e) because of the complexities related to boron adsorption and equilibrium concentrations with the soil water. Historical water quality data also indicate that CVC or California Aqueduct water would be below this threshold.

Turbidity and Total Suspended Solids Thresholds

Turbidity and TSS are of concern to water users in the Friant Division. Turbidity and TSS are not agronomic constituents of concern, but elevated levels are problematic for water management infrastructure and facilities, specifically spreading and groundwater recharge basins. TSS and Turbidity are also less of a concern in water supplies introduced via the Intertie and apply more to water being introduced via gravity flow to the FKC during high-flow or flood events.

The precedent for the defined thresholds was established under the environmental compliance documentation Final Initial Study/Negative Declaration for the Warren Act Contract and License and Operation and Maintenance Agreement to Introduce Floodwaters from Reclamation District 770 into the Friant-Kern Canal (DL770 Contract). As part of the agreement, water introduced into the FKC by Delta lands

Reclamation District 770 would not cause in-prism water quality to exceed 40 nephelometric turbidity units (NTU) of turbidity or more than 20 parts per million (ppm) of TSS (Delta Lands Reclamation District 770 2017). These same thresholds are included in the Guidelines.

The TSS and turbidity thresholds defined are based on operational and maintenance practices for spreading and groundwater recharge basins in the region. AEWSD has an allowable upper limit for TSS, 25 ppm, for water applied to spreading basins in their district (Bookman-Edmonston Engineering, Inc. 1972). A value of 20 rather than 25 ppm is included in the document to be protective of this upper, allowable limit. Monitoring of TSS requires lab analysis of water quality samples and thus management cannot be done in real time, however turbidity can be measured with a handheld meter and can be done in real time. Although the numerical relationship between turbidity and TSS can be affected by water source location, seasonal timing, and flow velocities (Meozzi 2011), a generalized relationship between the two constituents was developed to facilitate real-time water quality management. The defined turbidity threshold of 40 NTU correlates with the 20 ppm TSS value based on correlation analysis that AEWSD performed between 2011 and 2016.

SAR and Sodium Thresholds

The established SAR and sodium thresholds defined in the Guidelines are designed to be managed together. As detailed under the Agronomic Effects section, sodium by itself can be potentially problematic and cause direct toxicity to tree crops. However, because of the importance of adequate Ca^{2+} in the soil water as a means of stabilizing root cell membranes and maintaining selective ion uptake by tree crops, the sodium-calcium ratio in the soil solution is often a better indicator of Na^{+} toxicity. Therefore, SAR of the applied irrigation water has been used as a surrogate for the sodium-calcium ratio. The general rule is an SAR less than 3 is not problematic. However an SAR threshold on its own was not acceptable to water managers and water users as there are concerns related to potential acute crop injuries due to observed spikes in sodium concentrations of applied irrigation water. A combination approach to sodium management was developed, where if the measured SAR value exceeds 3 and the measured sodium concentration exceeds 69 mg/L, introduced water would need to be managed. The SAR threshold of 3 is from Ayers and Westcot Table 1 and assumes surface irrigation. The sodium concentration threshold of 69 mg/L is also derived from Ayers and Westcot Table 1 and suggests that irrigation waters < 3 meq/L (69 mg/L) [2] is suitable for crops that are sprinkler irrigated. Crops that are sprinkler irrigated are more susceptible to salt damage than by other irrigation methods as sodium can accumulate in the leaves by direct foliar absorption in addition to root absorption processes. Surface and low-pressure irrigated crops (i.e.. drip and mini-sprinklers), on the other hand, can only accumulate sodium in leaves by root absorption and translocation. The defined thresholds are conservative as the assumed sprinkler irrigation and more salt-damaging method is not widely used for crops within the Friant Division, as growers tend to use more efficient, on-the-ground irrigation methods.

The defined thresholds are designed to address sodium toxicities and although SAR is also used to assess the infiltration hazard (described previously), it assumed that given the wide range of observed SAR values relative to water supply source, growers already appropriately manage SAR through the application of gypsum to increase EC and maintain adequate infiltration.

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[2] The value assumes that calcium and magnesium are both at or above 2 meq/L (40 mg/L Ca^{2+} and 24 mg/L Mg^{2+}) where equivalent concentration of Ca^{2+} is greater or equal to Mg^{2+}. It is further assumed that this condition is met as the protection of these divalent constituents is their presence in the rootzone soil water. Nearly all growers in the region apply amendments such as gypsum ($CaSO_4$), and thus soil water concentrations would meet the criteria. (Maas and Grattan, 1999).

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