City of Dixon WWTF: Site Specific Salinity Objectives Study

Addendum to "Site Specific Boron Objective Study", February 7, 2014

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Sign-off Sheet

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Prepared by ______________________________
(signature)

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Certification Statement

On behalf of the City of Dixon this Report is submitted to the Regional Board in conformance with the Requirements of CDO R5-2008-0136, Order No. 9, as modified by the January 30, 2013 letter from Pamela Creedon, and subsequent Regional Board letter of January 24, 2014 (Item 2).

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

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1.0 Introduction

In a letter dated 24 January 2014, and a follow-up meeting on 5 February 2014, the Regional Water Quality Control Board (Regional Board) requested evaluation of other salinity related parameters in addition to boron to complete the Regional Board staff's review and analysis of the Report of Waste Discharge for the City of Dixon Wastewater Treatment Facility (WWTF). Since the Site Specific Boron Objective Study Report (Report) was complete at that time, it was submitted to the Regional Board on February 7, 2014. The additional evaluation of total dissolved solids (TDS), sodium, and chloride is compiled in this addendum to the Report. Since site specific climate, crops, soils, and agricultural practices documented in the Report and used to model soil boron concentrations are the same as those that affect overall salinity, this addendum does not reiterate that discussion, and rather it relies upon the Report for these background details.

Unlike the case of Boron, for these constituents of concern anticipated effluent quality is better than background groundwater quality[1] , and the Regional Board has requested additional information to assist with the interpretation of the narrative water quality objective for the beneficial use of agriculture. Therefore, this addendum presents site specific water quality objectives based on the local agricultural beneficial use of groundwater. Other local beneficial uses may have water quality objectives more stringent than presented here.

1.1 SALINITY AND AGRICULTURE

The detrimental impacts of salinization on agriculture production have been observed throughout history and are a global concern (Abrol et. al, 1988: Pillsbury, A.F. 1981, The Salinity of Rivers, Scientific American, 245(1):54-65). Extensive research into crop salinity in the Central Valley of California began in the late 1930's and continues on today. A large part of this research was conducted between 1950 and 1980. During this same time period, large scale water delivery projects were completed to supply fresh surface water to a large portion of the Central Valley. As agriculture became less reliant on groundwater, especially its salinization due to consumptive use, the pace of salinity research slowed and focused more on soil reclamation and salt management.

The major findings of the salinity research were that osmotic stress was the primary cause of crop decline and, that so long as the root zone could be drained, the osmotic stress could be controlled by leaching salts out of the root zone. Additionally, the research primarily focused on osmotic stress as measured by the electrical conductivity of the saturated soil extract (ECe), since studies using TDS lacked reproducibility due to variability in plant and soil responses to various solute mixtures, especially effects of sodium versus calcium. Therefore, this addendum will use EC as a measure of salinity to be consistent with the research, and TDS objectives will be based on a ratio to EC.

[1] Effluent TDS and chloride values were moderated by the successful softener exchange program and control ordinance and are projected to be below calculated background values. Effluent sodium values may approach background values and State law precludes further City control of residential softener sodium sources.

Excess concentrations of the individual ions of sodium and chloride have caused deleterious effects, especially when overhead sprinkling is used. Levels of these ions as low as 3 mol/m^3 can cause leaf burn on sensitive species during overhead sprinkling, which corresponds to the customary agriculture water quality objectives of 69 and 106 mg/L used for sodium and chloride, respectively. However, these effects can be controlled by the timing of irrigation as well as the height of sprinklers, allowing for the use of higher salinity water even with sprinkler irrigation. Toxicity from sodium and chloride is primarily observed in perennial woody crops, where sodium levels as low as 115 mg/L and chloride levels as low as 355 mg/L can cause problems on the most sensitive cultivars (Maas and Grattan, 1999). Where sodium and chloride are anticipated to be problematic, the use of different rootstocks and/or cultivars that limit the uptake of these ions has been used to alleviate toxicity.

Generally, annual crops are not susceptible to sodium and chloride toxicity. Since the bulk of salinity tolerance research used chloride salts to achieve the desired soil salinity, the tolerance threshold can be estimated from the soil salinity (Maas and Grattan, 1999). Where chloride is the dominant anion, the concentration of chloride (mol/m^3) in the saturated soil extract is roughly equivalent to 10 times the ECe in dS/m (U.S. Salinity Lab, 1954). Thus, an objective for chloride can be directly related to the salinity tolerance of a crop.

For sodium, the relationship to plant growth is more complex largely due to indirect effects of nutrient imbalance and deterioration of soil permeability, as well as, the ability of calcium to regulate sodium uptake in plants and prevent toxic effects. Generally, irrigation water with a sodium adsorption ratio (SAR) of less than 9 can be used with moderate limitations based on soil permeability (CA WQCB, 1984). Waters with SAR's greater than 9 can be used in certain circumstances to produce crops, and in sodic soils (SAR > 13) where the soil solution contains at least 2 mol/m^3 of calcium and magnesium combined there is generally no toxicity associated with sodium (Maas and Grattan, 1999)[2]. Assuming the same relationship exists for cations as anions (i.e. chloride) in the salinity tolerance research studies and maintaining 2 mol/m^3 of calcium and magnesium combined in the soil solution, then 6 mol/m^3 of sodium for each dS/m of the threshold ECe would be protective of the crop yield (e.g. the charge balance is maintained; 1 mol Na = 1 mol Cl, and 1 mol Ca=1 mol Mg = 2 mol Cl). This addendum uses this relationship; 6 times ECe in dS/m is equivalent to the objective sodium concentration as a guideline. However, it is recommended that rigid agricultural water quality limits for sodium not be developed due to highly variable interactions of soil/water/plant chemistry and the ability of farmers to manage several parameters with respect to sodium hazard.

[2] The City's WWTF effluent SAR ranges from 4.1 to 7.7, with 5.7 average.

2.0 Site Specific Crop Salinity Tolerance

This Addendum uses the same study area as the Study Report, including crops of regional importance (e.g. Dixon Resource Conservation District listed "Million Dollar Crops") grown down gradient of the WWTF. Crops grown in the study area during the 2013 crop survey by City staff are presented in Figure 1.

2.1 LIMITING CROPS

The relative salinity tolerance of crops grown, planned to be grown, or historically grown in the area on greater than five percent of the study area is presented in Table 1. The 100 percent yield threshold and 95 percent yield ECe values are also presented. Generally, orchard and vineyard crops are relatively sensitive to salinity, but these crops are not grown on significant acreage in the study area or down gradient of the WWTF. The most limiting crops based on sensitivity to salinity are beans, corn, and alfalfa. The yield response of these crops to soil salinity is presented in Figure 2. Beans were not identified as a potential crop in the City's survey, and the most recent 2003 DWR survey reported that all beans near the study area were irrigated with a surface water supply. This suggests that bean cultivation may already be limited by current groundwater irrigation water quality in the area.

Table 1 Salinity Tolerance of Commercial Crops Grown in the Study Area

Crop	Salinity Threshold ECe (dS/m) [(a)]	95 % yield ECe (µS/cm)[(a)]	95 % yield Chloride[(b)] (mg/L)	95 % yield Sodium[(b)] (mg/L)
Beans	1.0	1,263	448	174
Corn	1.7	2,117	750	292
Alfalfa	2.0	2,685	952	370
Tomatoes	2.5	3,005	1,065	415
Sudan	2.8	3,950	1,400	545
Mixed Pasture	3.0	3,450	1,223	476
Sunflowers	4.8	5,800	2,056	800
Wheat	6.0	6,704	2,377	925
Sugar Beets	7.0	7,847	2,782	1,082
Small Grain	8.0	9,000	3,191	1,241

a) 1 dS/m= 1,000 µS/cm = 1 mmhos/cm = 1,000 µmhos/cm
b) Chloride and sodium calculated from salinity threshold using 10 mol Cl/m^3 per dS/m and 6 mol Na/m^3 per dS/m (see section 1.1)

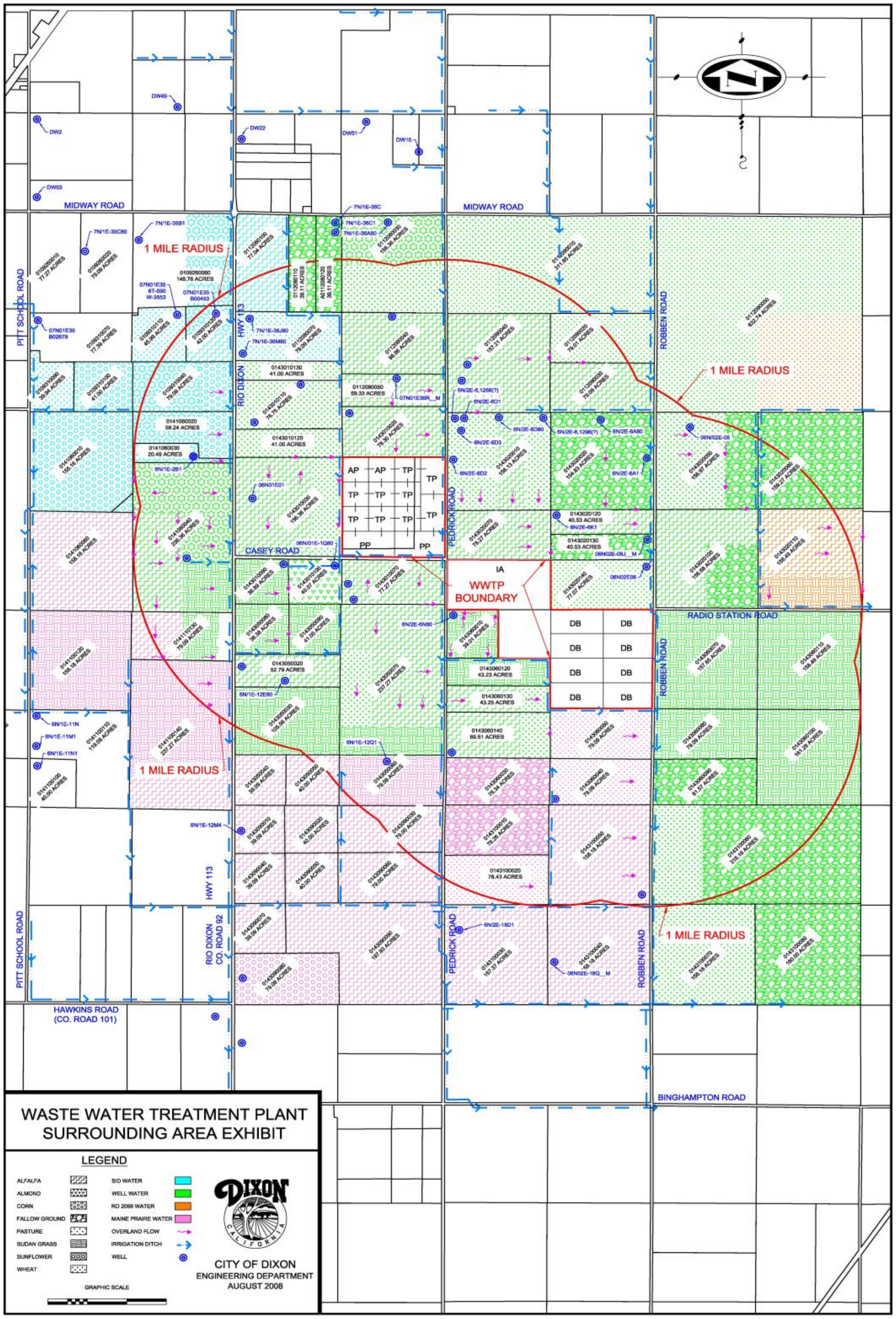

Figure 1 Crops Grown in the Dixon WWTF Site Specific Salinity Objective Study Area

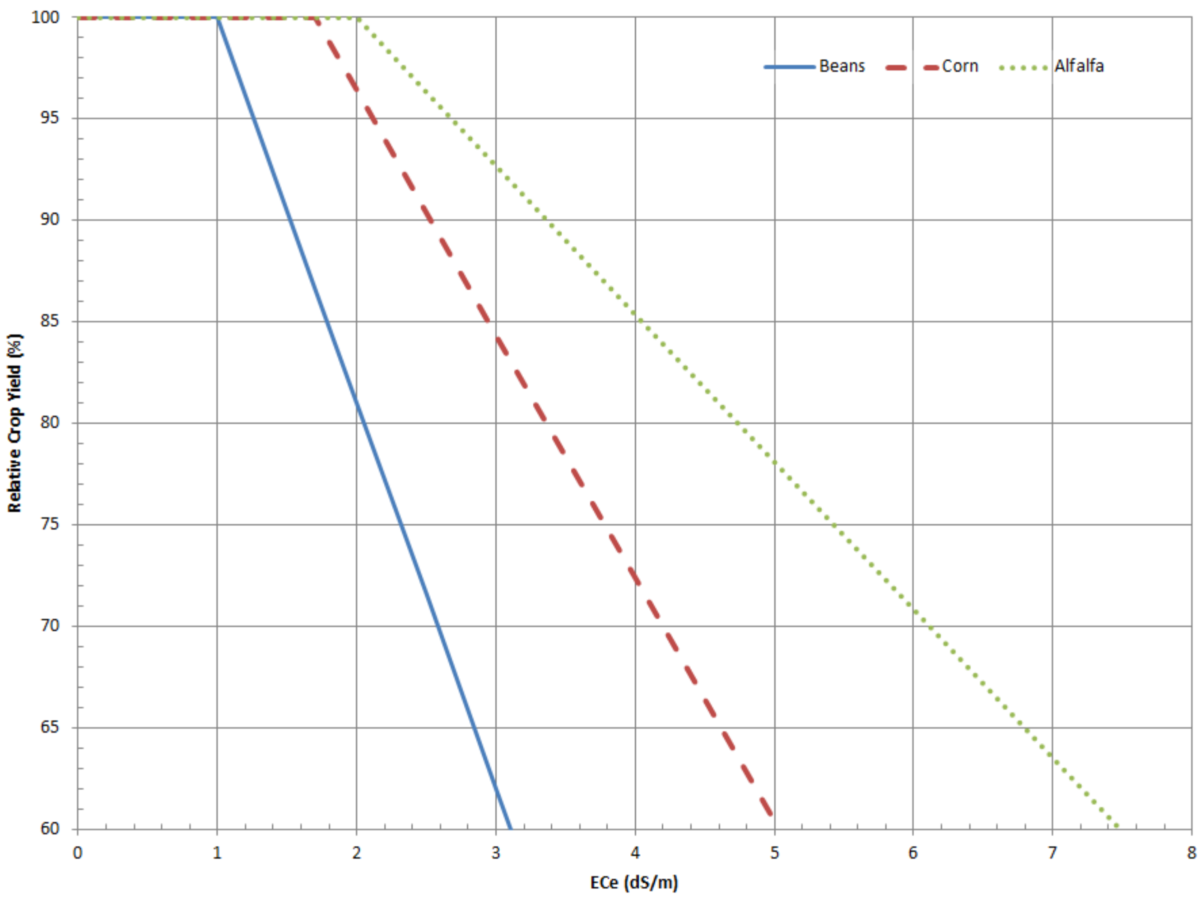

Figure 2 Crop Yield Response to Soil Salinity.

2.2 SALINITY BUILDUP MODELING

A relatively simple steady state salinity model based on plant uptake, referred to as "40-30-20-10" (Rhodes and Merril, 1976), was used to calculate boron buildup in the soil solution for the Study Report. This model calculates the salt concentration in quarter fractions of the root zone, and the linear average of these concentrations is recommended to represent soil salinity under infrequent irrigations. More recent investigations have shown that crops respond to a weighted average of the root zone salinity as presented by Rhodes and Merril, 1976 for frequent irrigations, and Hoffman and VanGenuchten, 1983 developed an exponential model for the weighted uptake of water by crops to determine weighted root zone ECe. Generally, the "40-30-20-10" model is highly conservative in most instances, while the exponential model is more representative of field test results (Hoffman, 2010). In the case of boron, where sensitivity is not directly tied to salt build up alone and significant soil adsorption occurs, the uptake pattern may not govern its crop availability, so the conservative weighted average approach was used. For salinity, including both sodium and chloride which tend to remain in the soil solution, the crop response would be tied directly to crop uptake of water. Therefore, both models are presented in this addendum to show a range from conservative to likely.

Since crop types on a specific field in the study area vary from season to season and annually due to variations in economic, climatic, and crop and soil health considerations, the model was based on an annual time step using average conditions. Average monthly climatic data from the Dixon CIMIS station and Vacaville NOAA COOP station were used in the model to calculate crop irrigation requirements accounting for rainfall. A bare soil evaporation value of 0.7 inches per month, consistent with DWR data for the Central Valley, was applied to rainfall occurring outside of the growing season; however, non-growing season rainfall was never reduced below zero by bare soil evaporation. The amount of rainfall exceeding the non-growing season bare soil evaporation was added to all rainfall during the growing season to calculate effective precipitation (i.e. the amount used by the crop). Two different leaching requirements were applied to the model to calculate irrigation requirement. The results of the modeling are discussed below and presented in Figure 3 and Table 2.

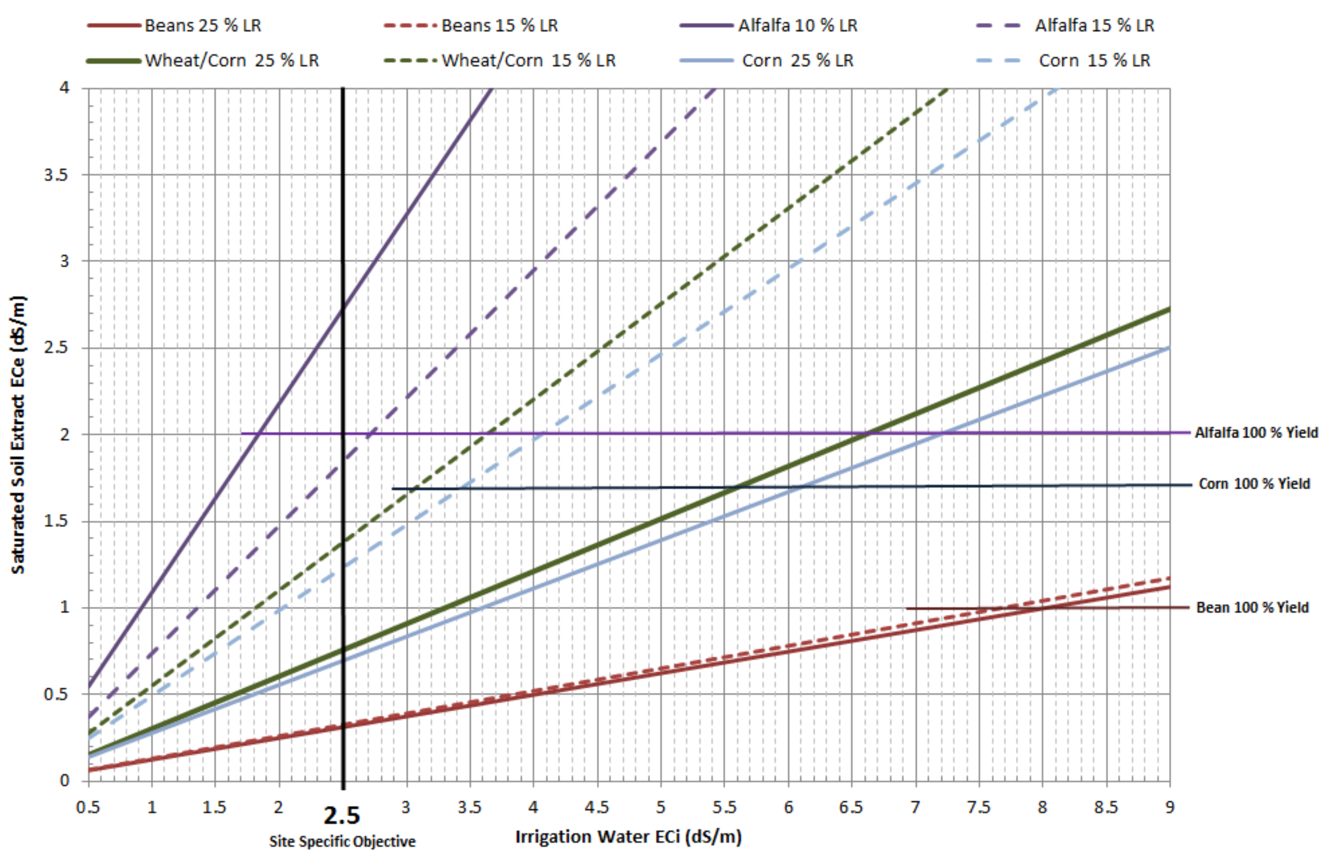

Figure 3 Soil Salinity Calculated from Irrigation Water Salinity Using the Exponential Model for Site Specific Climate and Crop Parameters.

Table 2 Crop Specific Irrigation Water Requirements and Modeled Salinity Levels Protective of Crop Yields at the 95 Percent Level.

					40-30-20-10		Exponential	
Crop	LR[(a)]	Irrig.[(b)] Water (in)	ETc[(c)] (in)	Eff. Prec.[(d)] (in)	EC_i (dS/m)	EC_e (dS/m)	EC_i (dS/m)	EC_e (dS/m)
Alfalfa	10	33.3	52.1	24.55	2.3	2.7	2.5	2.7
Alfalfa	15	36.7	52.1	24.55	2.8	2.7	3.7	2.7
Beans	15	2.2	17.7	18.62	7.4	1.25	10.0	1.25
Beans	25	5.0	17.7	18.62	5.1	1.25	9.6	1.25
Corn	15	13.2	27.9	19.67	3.3	2.1	4.3	2.1
Corn	25	17.5	27.9	19.67	3.8	2.1	7.5	2.1
Wheat/Corn	15	13.2	37.8	24.55	2.9	2.1	3.8	2.1
Wheat/Corn	25	17.5	37.8	24.55	3.5	2.1	6.9	2.1

a) LR is the leaching requirement, percentage of water applied above crop requirement to control soil salinity.
b) Irrig. is the amount of irrigation water (surface and/or groundwater) applied.
c) ETc is the crop requirement for water based on reference evapotranspiration (ETo) adjusted for crop properties.
d) Eff. Prec. is the effective precipitation, or the amount of precipitation that is used by the crop. This includes all precipitation falling during the growing season and a portion of precipitation falling outside of the growing season adjusted for evaporation from the soil surface.

2.2.1 Alfalfa

Alfalfa is a perennial crop that typically is grown over a five year period; in areas of frost it will go dormant and sprout from the roots when the weather turns favorable. In the study area, even when frost does not occur, growing conditions are slow enough, and soils too wet, that cuttings are generally not harvested between November and April. Alfalfa is generally a water intensive crop, and average annual precipitation in the study area only supplies about half of its irrigation demand. Therefore, soil salinity under alfalfa is directly tied to irrigation water quality. Additionally, the economics of applying irrigation water are a key component of alfalfa farming, and leaching fractions are generally the smallest. Therefore, a lower 10 percent leaching fraction was modeled for alfalfa. Under this lower leaching fraction, the conservative model indicates irrigation water with an EC of 2.3 dS/m is protective of yields at the 95 percent level. The exponential model shows that modest increases in irrigation water applied, will allow this same yield level with irrigation water EC of 3.7 dS/m.

2.2.2 Beans

For the study area beans are cultivated during the dry season; however, their irrigation requirement in an average year can be met by effective precipitation during the nongrowing season. When a leaching requirement (LR) of 15 or 25 percent is applied, supplemental irrigation is required. Since the salt load actually increases with increasing irrigation water application, linear average soil salinity will increase with leaching fraction when crop demand can be met by precipitation. Conversely, the exponential model shows that weighted average crop salinity declines with leaching fractions, since the soils have been leached with a greater volume of water the salts will be concentrated deeper in the root zone, reducing the salinity of the soil near the surface, where the plants get the majority of their water. As observed in Table 2 if beans are grown as a single crop (i.e. winter fallow), the most conservative model, 40-30-20-10, shows they can be grown with irrigation water having an EC of 7.4 dS/m during an average precipitation year at the lowest leaching fraction.

2.2.3 Corn

Similar to beans, corn is cultivated during the dry season, but effective precipitation does not fulfill the irrigation requirement during average precipitation years. The conservative model indicates irrigation water EC of 3.3 dS/m is protective of the 95 percent yield level at the lower 15 percent LR. The exponential model shows that irrigation water EC of 7.5 dS/m is protective of the 95 percent yield at the higher 25 percent LR for the study area.

2.2.4 Crop Rotations

Growing two crops a year is common in the area, and the DWR Crop Surveys reported small grains, including wheat, being grown with a summer field crop on 10 to 15 percent of the acreage. The field crops used in these rotations included beans, corn, sudan, and sugar beets. Of these rotations, wheat followed by corn would be the most sensitive to salinity buildup, and corn is the most sensitive crop in this rotation with an ECe threshold (100 percent yield) of 1.7 dS/m. The conservative model estimates that an irrigation water EC of 2.9 to 3.5 dS/m is protective of the 95 percent yield level of corn following a wheat crop in the study area under average precipitation conditions with a 15 to 25 percent LR. The exponential model estimates that an irrigation water EC of 3.8 to 6.9 dS/m is protective of the 95 percent yield of corn for a wheat corn rotation under these same conditions.

2.3 INDIVIDUAL ION AND TDS BUILDUP

The City of Dixon effluent has a historic average (2006 through 2013) ratio of 600 mg/L TDS for each dS/m EC, which is consistent with the average ratio of all shallow groundwater monitoring locations that the City monitors. This is somewhat less, and yields a more conservative result, than the rule of thumb ratio of 640:1. Applying this long term ratio to the irrigation water EC values calculated in the salinity build up models provides a range of irrigation water TDS protective of site specific limiting crops at the 95 percent yield level. Table 3 presents these suitable irrigation TDS values during average precipitation conditions.

Table 3 Modeled Crop Specific Irrigation Water Salinity Parameters Protective of Crop Yields at the 95 Percent Level.

		40-30-20-10			Exponential		
Crop	LR[1]	TDS (mg/L)	Na (mg/L)	Cl (mg/L)	TDS (mg/L)	Na (mg/L)	Cl (mg/L)
Alfalfa	10	1,400	320	810	1,500	340	880
Alfalfa	15	1,700	390	1,000	2,200	500	1,300
Beans	15	4,600	1,000	2,600	5,900	1,300	3,400
Beans	25	3,100	700	1,800	6,200	1,400	3,600
Corn	15	2,000	450	1,200	2,600	590	1,500
Corn	25	2,400	530	1,400	4,600	1,000	2,700
Wheat/Corn	15	1,800	410	1,000	2,300	530	1,400
Wheat/Corn	25	2,200	490	1,300	4,300	960	2,500

1. LR is the leaching requirement, percentage of water applied above crop requirement to control soil salinity.

Similarly, the individual sodium and chloride concentrations associated with the salinity build up models were calculated using the approximate chloride conversion developed by the U.S. Salinity Lab, and assuming the sodium concentration could account for 60 percent of the cations in the soil solution. These values are presented in Table 3, and rounded to two significant figures to reflect the level of precision of these estimated values. It should be noted that there were no crops particularly sensitive to chloride or sodium toxicity identified in the study area that are grown over a significant area, and that overhead sprinkler irrigation is not a common practice.

3.0 Water Quality Objective

Utilizing the same model employed by Ayers and Westcott (1976) to determine salinity related agriculture water quality objectives in the FAO Irrigation and Drainage Paper 29, water quality objectives for EC, TDS, sodium, and chloride were calculated based on local climate and cropping conditions. This model assumes a linear average of root zone salinity while recent research suggests response to root zone salinity is weighted by crop uptake, and the linear average results in water quality objectives that are highly conservative. An exponential crop uptake model has been shown to better predict actual field crop performance than the linear average (Hoffman & VanGenuchten, 1983; Hoffman 2010). This model was also used to calculate salinity related water quality objectives, and these values are expected to more accurately reflect the actual threat to the agriculture beneficial use crop yield. The production of alfalfa at a low leaching requirement (10 percent) provides the most limiting cropping condition, and the water quality objectives calculated using the exponential model are:

EC = 2,500 µS/cm

TDS = 1,500 mg/L

Sodium = 340 mg/L

Chloride = 880 mg/L

These values are based on annual average rainfall conditions. During dry years salinity problems may be exacerbated due to the lack of precipitation (i.e. low salt content water). Additional irrigation water will be needed to sustain crops during a dry year, and additional leaching may be needed to control soil salinity with the increase in irrigation water applied. During a drought with a 20 year return period, the EC of the irrigation water to maintain 95 percent yield of alfalfa and the low 10 percent leaching requirement is 2,000 µS/cm. However, if an additional 1.5 inches of irrigation water are applied to remove salts (i.e. a 13 percent leaching requirement) during a 20 year drought, the 95 percent yield of alfalfa is maintained with the 2, 500 µS/cm value.

The application of a water quality objective to set effluent limits should address averaging periods based largely on the potential impact to the beneficial use. Crops may exhibit different levels of sensitivity to salinity at various growth stages. In particular, seedling emergence and growth are thought to be most vulnerable to salinity; however, salinity at the yield threshold level only delays emergence while percent emergence remains roughly the same (Maas & Gratan, 1999). Although some crops have been shown to be more sensitive during seedling growth stages in greenhouse studies, the effects of salinity near its yield threshold on seedling growth and ultimate yield in field conditions needs to be explored further to identify if there is a real need to limit salinity beyond the yield threshold. Several site specific conditions exist in the study area that make seasonal salinity objectives unnecessary: 1) salt sensitive crops are generally planted in the spring after seasonal precipitation has leached soluble salts from the soil; 2) Pre-plant irrigations can be applied to minimize soil salinity encountered during the early growth stages; and 3) the users of groundwater expect many years of relative constant water quality due to the compositing and averaging of multiple and widely dispersed groundwater replenishment sources .

4.0 Conclusion

Agricultural use site specific salinity objective study was conducted for the area within 1 mile of the City of Dixon's WWTF. Available crop surveys for the area for the past 20 years were used to identify specific commercially viable crops grown in the area. The relative salinity sensitivity of crops identified from the surveys, as well as regionally important crops, was used to determine the most limiting crops potentially grown in the area. The most limiting salinity sensitive crops were beans, corn, and alfalfa. The most sensitive potentially irrigated cropping practice was found to be alfalfa at a 10 percent LR.

Two simple steady state salinity models based on water uptake were used to calculate soil salinity from irrigation water salinity and accounting for average local precipitation and evapotranspiration conditions. The exponential model, which is thought to best reflect modelled field conditions, was used to calculate the recommended water quality objectives. Based on this model, irrigation water quality with an EC of 2,500 µS/cm, and TDS, Sodium, and chloride concentrations of 1,500, 340, and 880 mg/L, respectively, is protective of the 95 percent yield of alfalfa.

As noted in the February 7, 2014 Report the calculated objective is based on a model that includes a wide range of assumptions that may in total affect, or be affected by, other production agricultural practices, including the ability of the local agricultural users to meet discharge requirements based on the local agricultural use objectives. Therefore the City submits this addendum to the Report based on our current understanding of Regional Board policy in respect to the application of yield based models. The City also understands the local agricultural users may collectively evaluate the proposed objectives and may propose alternative values that consider factors beyond the scope of this Report as amended. It is also expected other beneficial use objectives (i.e.; MUN) may govern as the Regional Board evaluates appropriate local groundwater discharge limitations.

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