CITY OF DIXON: SITE SPECIFIC BORON OBJECTIVE STUDY WORK PLAN

August 2, 2013

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The City of Dixon Wastewater Treatment Facility (WWTF) treats municipal wastewater produced in the City of Dixon in Solano County, CA. The potable water supply for the City is comprised of groundwater that is generally considered mineral rich and hard, resulting in widespread water softening in the area. The natural occurring and softener salts as well as salt additions attributed to public use are currently concentrated in the City's wastewater due to the significant evaporative losses associated with pond treatment. This has historically resulted in the potential for salinity related impacts to the local groundwater from the land discharge disposal of the effluent from the WWTF.

The WWTF is located south of the City of Dixon in a largely agricultural area, and disposes of its wastewater through discharge to slow rate evaporation and percolation basins. Historically, they have also used the WWTF effluent for irrigation; however, irrigation with effluent has ceased due to the significant increase in salinity of percolated water associated with that practice. Although salt loads are relatively unaffected by the historic, current, and proposed future treatment and disposal operations, the salinity load will be dramatically lessened (i.e. halved) by best practicable treatment and control (BPTC) improvements that target the dominant driver, or source, of salinity: *evaporative losses of water*.

The most sensitive constituents of concern for the City of Dixon are sodium, chloride, and boron with respect to their effects on the agricultural beneficial use of the groundwater resources. A summary of the relevant water quality for these constituents for the WWTF is presented in the following table:

Table 1. Constituents of Concern (mg/L)

	Potable Water	Raw Wastewater	Proposed Project Discharge	Future Project Discharge[a]	Currently Proposed Site Specific Limits[b]
Sodium	55	140	170	200	190
Chloride	15	110	130	160	180
Boron	0.50	0.67	0.80	1.0	0.70[c]

a- Planning values, to account for long term degradation of water supply and mandated water conservation.
b- Based on background water quality data from a network of first recoverable groundwater monitoring wells and statistical analyses.
c- Local Background value approx. 0.6 mg/L, default agricultural WQO noted.

The receiving water of concern is the shallow groundwater including its potential to affect the deeper production aquifer. The beneficial use of the aquifer for agricultural irrigation provides the most stringent default water quality objectives for salinity related constituents. For all constituents of concern except boron, the background water quality provides a basis for a site-specific discharge limit that is attainable through BPTC. For boron there is a need to justify a higher limit than the default agricultural water quality objective to ensure compliance with a site specific discharge limit. The purpose of this work plan is to identify a study method to determine such a site specific boron objective in the vicinity affected by the WWTP's discharge.

2.0 STUDY AREA

The study area should be comprised of an area that could reasonably be expected to use groundwater affected by effluent from the WWTP. To this end, the Regional Board staff has recommended the study area encompass a 1 mile extent around the WWTP and its disposal areas. This study area is depicted in Figure 1.

> *Note: While there may be complex hydrogeologic flow paths depending on the heterogeneity of the soils and local pumping and surface water irrigation practices, it is generally expected the most likely directly affected production aquifers would be located on the down gradient (SE) direction from the WWTF,*

Excluding the area covered by the WWTF, this results in a local study area of approximately 6,800 acres, which would have an annual crop demand of approximately 10,000 million gallons based on annual average reference evapotranspiration from the Dixon CIMIS station. The amount of irrigation water applied is likely much greater than this volume due to irrigation efficiency and salinity management (i.e. leaching fraction), and the percolated volume from crop irrigation could be as high as approximately 3,000 million gallons. In contrast, the future project discharge will result in approximately 350 - 700 million gallons of effluent percolating into the groundwater, under existing and general plan build-out conditions. Since the effluent has the potential to fulfill less than 10 percent of the study area's crop demand, this local study area appears conservatively large enough to address significant impacts from the WWTF's discharge. Furthermore, local irrigation has a greater potential (i.e. more than four times that of effluent) to control groundwater quality than the WWTF's discharge.

However, to address the issue of not knowing the exact areas that the WWTF discharge will effect, the work plan, in addition to crops grown in this local study area, will also address concerns from the Dixon Resource Conservation District (RCD) regarding impacts to the "million dollar crops" listed in their Long Range Plan, that have historically been grown down gradient of the WWTF. The "million dollar crops" list is actually based on the value of crops generated in the entire County during 1999 and 2000, and some of the crops may not be grown in the RCD and/or in the vicinity down gradient of the WWTF.

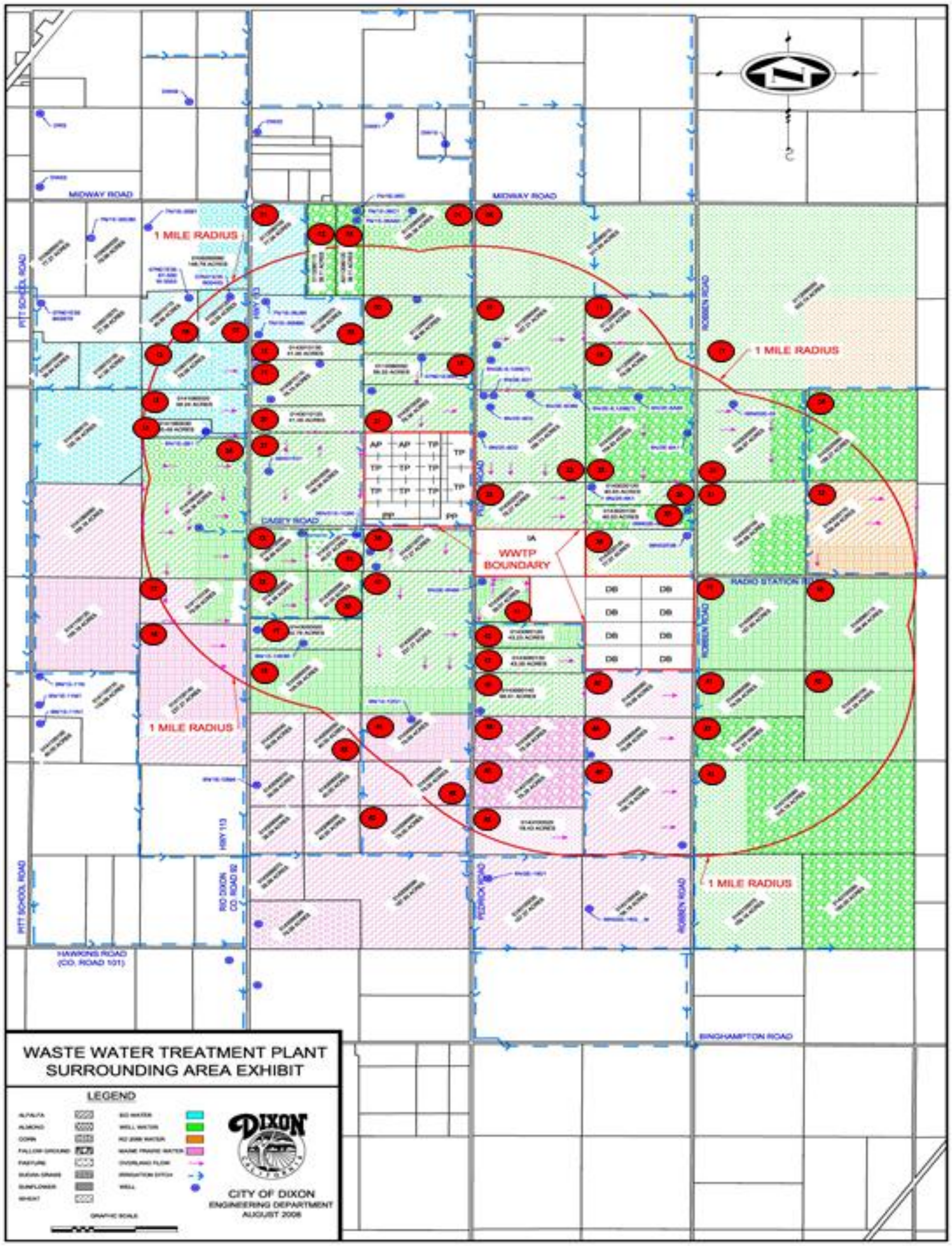

Figure 1 Study Area based on one mile buffer around wastewater treatment and disposal facilities.

3.0 AVAILABLE INFORMATION SOURCES

The site specific boron water quality objective for agricultural use should be based on agricultural practices, available irrigation source water quality, existing soil conditions, and climate. These are the same factors that have played a pivotal role in shaping the types of agriculture occurring in a region, since the crops growing in an area have been selected over time based on suitable performance in the environmental conditions given available agricultural technologies to control those environmental conditions. This section addresses sources of information that will be used to evaluate the susceptibility of crops grown in the study area to impairment from boron.

3.1 Agricultural Practices

City staff has conducted a comprehensive survey of the parcels within 1 mile of the WWTP that includes current crop(s) and planned future crops, irrigation method and source, and general drainage patterns. Additional crop types of regional significance have been compiled by the Dixon RCD and Solano County. The California Department of Water Resources (DWR) conducted land use surveys of Solano County in 1994 and 2003, which identified crops grown and irrigation methods in individual fields during those years. These sources of information will be used to document agricultural practices in the area.

Other pertinent agriculture practices which help reduce impacts from salt, and therefore boron, include artificial drainage, adjustments to leaching fraction, soil amendments, and supplemental (i.e. higher quality) irrigation water, if available. These practices are more difficult to characterize and quantify, primarily due to individual farmers experience with, and application of, these practices. Generally, the best source of this information is from discussions with local Cooperative Extension agents, resource conservation districts, and/or irrigation districts. Therefore, the study will solicit such input from the Dixon RCD.

3.2 Water Quality

The irrigation water quality is a major factor in crop selection as well as determining the extent of salinity management necessary, since long term productivity requires matching crop needs to available resources. Irrigation water in the study area appears to be a mixture of several sources. Relatively high quality surface water from Lake Berryessa is supplied by Solano Irrigation District (SID) in areas up gradient of the WWTF, this supply is augmented by local groundwater and control of previously used drainage water. In the vicinity of and down gradient from the WWTF the irrigation supply is largely individual wells and some reuse from the Dixon drainage system operated by Dixon RCD. Water in the drainage canals includes SID tail water with increasing amounts of local groundwater and previously used drainage water as one proceeds down gradient.

The average quality of the irrigation water near the WWTF is currently unknown. Most farms use groundwater for irrigation supply, although there is significant recapture of tail water in the area. Recent studies have shown the shallow groundwater to be highly variable near the WWTP, and the agricultural well water also exhibits significant variability, although they have not been as extensively characterized. Available SID reports and the available groundwater reports will be reviewed to identify irrigation water quality in the area. We will also obtain water quality information that may be provided by the local farmers.

3.3 Soils

The ability to manage salts in crop production is dependent on the types of soils found in an area. Some soils are naturally salt affected and are of limited productivity even under intense management, while others can become anthropogenically salt affected and require varying degrees of management based on individual physical and chemical properties of the soils. An understanding of natural soil conditions as well as the susceptibility of soils to degradation by the accumulation of salts is an essential component in establishing salt related water quality objectives and the associated salinity management necessary for that water quality. The Soil Survey of Solano County prepared by the Soil Conservation Service (NRCS) in 1977 provides the most comprehensive assessment of soils in the area and will be used to identify soil types and salinity management related aspects of those soils.

In addition to typical salinity management concerns, soil properties can affect the amount of boron in solution and available to plants. Boron adsorption capacity varies with soil pH, texture, mineralogy, and organic matter content, and a portion of the adsorbed boron resists desorption in some soils (Gupta et al, 1985). Additionally, the presence of calcium, nitrogen, and potassium can affect plant uptake as well as expression of boron deficiency and toxicity symptoms. Available literature will be reviewed to assess, at least qualitatively, the ability of area soils to buffer the concentration of boron in the soil solution and ameliorate detrimental effects on crops.

3.4 Climate

Similar to other salinity parameters, climatic factors affect boron toxicity, generally through the inducement of moisture stress. Ferreyra et al. (1997) partially attributed a milder climate in Chile to greater crop yields than predicted by salinity and boron thresholds developed largely at the USDA Agricultural Research Station (Salinity Lab) in Riverside, CA. In addition, the contribution of seasonal rainfall to irrigation demand and/or flushing of salts from the root zone effect the amount of applied boron that is retained in the soil. Local climatic data will be reviewed and used to assess boron loading and where applicable any discrepancies with reported tolerance studies. Average year rainfall amounts will be used to calculate loading and/or leaching of boron.

Flooding is generally tied to climate and controlled by topography. The potential for flooding in the area will be reviewed to determine if substantial volumes of stormwater are contributing to irrigation demand and/or flushing the soils.

4.0 CROP BORON TOLERANCE

Although the study will attempt to identify additional information on boron tolerance, this subject is the primary determinant of an agricultural based water quality objective and warrants further discussion. Unfortunately, there is not a multitude of crop response data for boron, and direct yield relationships have only been developed for a few crops. Most of the published boron tolerance of crops is based on research done by Frank Eaton in the 1930's and 1940's. The occurrence of boron in irrigation water and occurrence of crop toxicity in the San Joaquin Valley were presented in Eaton, 1935 along with a relative rating of various crops based on boron tolerance. The experiments consisted of growing the crops in sand columns irrigated with solutions containing various levels of boron, and primarily noting visible toxicity symptoms. Since visible symptoms of toxicity do not always correlate to a reduction in yield, Eaton's rating, which forms the basis for boron tolerance data presented by Ayers and Westcot (1976) in the FAO Irrigation and Drainage Paper 29, does not relate directly to yield. Similarly, E.V. Maas (1990) relies on Eaton's ratings for crops where additional studies have not been conducted; however, in the cases where additional studies have been conducted, several do not relate directly to yield. The available information for boron tolerance adapted from E.V. Maas (1990) for crops grown, or potentially grown, in the area is presented in Table 2.

The limiting thresholds appear to be for orchards (e.g. fruit and nuts) and grapes; however, these crops have not been typically grown in the local area historically. Of the prevalent crops identified as being grown within one (1) mile of the WWTP, sunflower and wheat appear to have limiting thresholds of 0.75 to 1 mg/l, and only the wheat yield response to boron has been studied sufficiently to allow for calculation of yield at increasing boron concentrations. Although pasture has limited information available, it is assumed that pasture would not be less tolerant than wheat, since grass species diversity in a pasture is based on adaptation to the environmental conditions, and boron concentrates in the leaf tips, which are continuously removed in a pasture.

Alongside the lack of a direct yield relationship for most crops, there is significant genetic variability in boron tolerance. This has largely played out in the selection of rootstocks for citrus and stone fruits that limit boron uptake in regions where boron toxicity is anticipated. Additionally, some wheat and sunflower cultivars are more tolerant than others and the thresholds listed in Table 2. Moreover, there are regions where boron is naturally elevated and agriculture production continues, suggesting some of these boron thresholds may be more stringent than necessary to protect the beneficial use.

Table 2. Boron Tolerance of Crops Potentially Grown Near the City of Dixon's WWTP.
(tolerance data adapted from E.V. Maas, 1990)

Crop	$Million Crop[a]	Area of Crop Survey[b] (%)	Threshold (mg/L)	Slope (% per mg/L)	95% Yield (mg/L)	Comments
Alfalfa	Y	35.5	4 to 6	NA	NA	
Almonds	N	1.7	0.5 to 0.75	NA	NA	- Based on other *Prunus* species. - Almond root stocks are more tolerant than other *Prunus* species
Beans	Y	--	0.75 to 1.0	NA	NA	- Based on Mung, Kidney and Lima. - Snap beans have a yield response with threshold of 1 mg/l and 95 % yield of 1.4 mg/l. - Based on area of field crops, beans could potentially be grown w/in 1 mile of WWTP
Corn	Y	18.4	2 to 4	NA	NA	
Grapes	Y	2.3	0.5 to 0.75	NA	NA	- Most vineyards are in North West part of Solano County.
Pasture (Range and Irrigated)	Y	20.9	no info			- Available info on pasture species indicates MT (threshold > 2mg/L).
Pears	Y	--	Not presented			- Eaton 1935, listed pears as sensitive similar to plum (0.5 to 0.75 mg/L)
Prunes	Y	--	0.5 to 0.75	NA	NA	
Safflower	Y	--	no info			
Sudan Grass	Y	5.9	7.4	4.7	8.5	- Based on Sorghum
Sunflower	N	15.1	0.75 to 1.0	NA	NA	- Eaton, 1935 listed native sunflowers as the most semi tolerant (2 to 4 mg/L)
Tomatoes	Y	14.6	5.7	3.4	7.2	
Walnuts	Y	--	0.5 to 0.75	NA	NA	
Wheat (dry and irrigated)	Y	12.3	0.75 to 1.0	3.3	2.27	- 95 % yield based on 0.75 mg/L threshold

a) Dixon RCD list of million dollar crops is based on entire Solano County data from 1999 and 2000. Nursery Stock and Livestock were excluded from this table.

b) From the City's Survey of fields within 1 mile of WWTP, includes future crop types and double cropping which causes the same acreage to be counted for multiple crops.

5.0 DETERMINATION OF SITE-SPECIFIC AGRICULTURAL WATER QUALITY OBJECTIVES AND EFFLUENT LIMITATIONS

The first step in establishing a site specific agricultural water quality goal for boron is to identify significant (e.g. greater than five percent of study area) crop types in the study area. This will largely be derived from the City's survey of the fields within one mile of wastewater treatment and disposal facilities. Crops of regional significance will be addressed primarily through a review of DWR crop survey data in the down gradient vicinity of the treatment plant. Where additional crops are identified as being significant from the crop surveys, they will be added to the list of crops. Available boron tolerance thresholds will be used to rank the significant crops by tolerance, and the most sensitive crop will be selected as the limiting crop. Based on varying agriculture practices and growing seasons, multiple crops may be selected to identify water quality objectives.

The second step includes establishing an acceptable crop productivity metric to strive for, which in recent site specific salinity objective studies has been expressed as the point on the yield response curve associated with maintaining a 95 percent yield. As discussed in Section 4, this yield metric is only directly ascertainable for a few crops given the current state of knowledge. Where a yield response curve has not been developed, other criteria will need to be used to establish an acceptable boron threshold.

One potential method would be to establish an arbitrary 95 percent yield concentration. Review of available crop response curves indicates relatively gradual slopes, where less than a five percent reduction in yield is associated with each milligram per liter (mg/L) increase in boron, suggesting an arbitrary 95 percent yield level could be established by adding 1 mg/L to the threshold. The only documented exceptions are snap beans and cowpeas, which exhibited a 12 percent yield reduction per mg/L increase in boron; therefore, for legumes the arbitrary 95 percent yield level could be established by adding 0.4 mg/L to the threshold.

Another potential method would be to determine if the limiting crop(s) is successfully grown in areas where boron concentrations are elevated and identifying boron concentration of the source water. This second method relies on the general tendency of the western flanks of the central valley and coast range valleys to have naturally elevated boron concentrations in groundwater and surface water. In particular, areas near Capay Valley, Winters, Woodland, and Patterson generally have elevated boron concentrations in their surface and/or groundwater resources, and agriculture production does not appear to be limited. Therefore, the water quality of these sources may provide a basis for demonstrating protection of the agricultural use for similar crops and soils.

Once an acceptable crop productivity based boron concentration is established, it will need to be adjusted based on site specific conditions, including climate and soils. This is generally a qualitative assessment due to complex relationships between environmental factors and crop responses to individual ions. To some extent, simple models can be used to estimate boron adsorption in soils, resulting soil solution boron, and the amount of boron needed to be applied to achieve those levels. These models can be used to assess time frames required to achieve levels above the accepted threshold, typically in the 5 to 60 year time frame depending on initial water quality and soil types. Simple equilibrium salt build up models can be applied to boron, but they do not account for the stronger adsorption of some of the boron pool, which reduces the available and exchangeable boron in the soil. However, for this study simple models will be used to assess soil solution boron concentrations to establish the boron objective that is appropriate for long term protection of the use.

The contribution of precipitation to irrigation demand and leaching fractions will be addressed using average year precipitation. Therefore, the boron objective will be based on total water applied. As with most soil salinity concerns, the time frames needed to cause deleterious effects are generally long (e.g. measured in years or decades); therefore, the boron objective will be presented as an annual average. A potential effluent limit will be derived from the water quality objective adjusted for precipitation and through consideration of the attenuation of effluent effects on the resource due to general mixing with the aquifer and other recharge sources.

6.0 TIME SCHEDULE

This study is necessary to support findings in the Waste Discharge Requirement (WDR) that will regulate the new WWTF that is being proposed to comply with a 2008 Cease and Desist Order (CDO). Under terms of the CDO the Report of Waste Discharge must be submitted to the Regional Board staff by November 30, 2013, with a Board hearing to likely to occur in April/May 2014.

In addition, as stated in a letter from the Executive Officer, the results of this proposed study must be reviewed by CV_SALTS committees who are asked to provide recommendations to Board staff on site specific objectives to support WDR findings.

Therefore, the study will be implemented concurrently with submittal of this workplan for Regional Board staff and CV_SALTS review. The study will proceed following the general framework presented in this workplan unless the City receives alternative direction from Board staff and/or CV_SALTS. A Preliminary Draft Study based on readily available information will be submitted along with the RWD to Board Staff and CV_SALTS by November 30, 2013.

It is expected additional information, if found to be necessary by Board staff, could be incorporated into the RWD Technical Support Documentation as late as March 2014 without impacting the schedule of Board consideration of the WDR.

7.0 REFERENCES

Ayers, R. S. and D. W. Westcot. 1976. Water quality for irrigation. Irrigation and Drainage Paper 29. Food and Agriculture Organization. Rome, Italy.

Eaton, F. M. 1935. Boron in soils and irrigation waters and its effect on plants: with particular reference to the San Joaquin Valley of California. Technical Bulletin No. 448. U.S. Department of Agriculture. Washington D.C.

Ferreyra, R. E., A. U. Aljaro, R. S. Ruiz, L. P. Rojas, and J. D. Oster. 1997. Behavior of 42 Crop Species grown in saline soils with high boron concentrations. Agricultural Water Management 34:111-124.

Gupta, U. C., Y. W. Jame, C.A. Campbell, A. J. Leyshon, and W. Nicholaichuk. 1985. Boron toxicity and deficiency: a review. Canadian Journal of Soil Science 65:381-409.

Maas, E. V. 1990. Crop Salt Tolerance. In: Tanji, K.K. (Ed.), Salinity Assessment and Management. American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 71. ASCE, New York. Pp.262-304.

Soil Conservation Service. 1977. Soil survey of Solano County, California. U. S. Department of Agriculture. Washington D.C.