Appendix S

Memorandum Regarding Predicted Impact on Farming from Use of Recycled Water with Higher Salinity

This Page Left Intentionally Blank

Bahman Sheikh, PhD, PE

Tech Memo

To: Mike McCullough, Monterey Regional Water Pollution Control Agency (MRWPCA)

From: Bahman Sheikh

Reviewed By: Alison Imamura, Margaret H. Nellor, Jim Crook

Date: January 15, 2015

Re: Predicted Impact on Farming from Use of Recycled Water with Higher Salinity

ABBREVIATIONS

AF	Acre-feet
AFY	Acre-feet per year
Ca	Calcium
cfs	Cubic feet per second
CSIP	Castroville Seawater Intrusion Project
dS/m	deci Siemens per meter (units of electrical conductivity)
EC	Electrical Conductivity (a measure of salinity of water)
ECe	Electrical Conductivity of Soil Solution
ECw	Electrical Conductivity of Irrigation Water
FAO	Food and Agriculture Organization of the United Nations
LF	Leaching Fraction (extra water applied to leach salts below the root zone)
LR	Leaching Requirement (a calculated LF, based on formula)
MCAC	Monterey County Agricultural Commission
Mg	Magnesium
mgd	Million gallons per day
mg/L	Milligrams per liter
meq/L	Milliequivalents per Liter
MRWPCA	Monterey Regional Water Pollution Control Agency
MWRSA	Monterey Wastewater Reclamation Study for Agriculture
Na	Sodium
RTP	Regional Treatment Plant (located in Marina, operated by MRWPCA)
S	Slope
SAR	Sodium Adsorption Ratio
SWRCB	California State Water Resources Control Board
T	Threshold
TDS	Total Dissolved Solids
TM	Technical Memorandum
US	United States

Predicted Impact on Farming from Use of Recycled Water with Higher Salinity

EXECUTIVE SUMMARY

The proposed Pure Water Monterey Groundwater Replenishment Project (proposed project) is a water supply project that will serve northern Monterey County. The project includes the collection of a variety of new source waters that would be combined with existing incoming wastewater flows for conveyance to and treatment at the Monterey Regional Water Pollution Control Agency's Regional Wastewater Treatment Plant (RTP). The effluent would be further treated at a new advanced water treatment facility to produce highly-purified recycled water for injection into the Seaside Groundwater Basin (and later extraction for replacement of existing municipal water supplies) and to provide additional tertiary recycled water for agricultural irrigation in northern Salinas Valley as part of the Castroville Seawater Intrusion Project (CISP).

Water quality guidelines critical to plant growth and development include salinity (as measured by total dissolved solids or electrical conductivity, sodicity (represented by a non-dimensional parameter called Sodium Adsorption Ratio), and specific ions (primarily sodium, chloride, and boron). Salinity is the most critical of these criteria with regard to its impact on farming under the conditions prevailing in the CSIP service area and the recycled water blend scenarios anticipated in the future as part of the proposed project.

The addition of new source waters for the proposed project is likely to increase the salinity of recycled water above that currently produced at the RTP. This change in water quality is not expected to impact the farming activities within the CSIP service area to a significant extent, mainly because of the various management tools and expertise available to the growers, some of which are already in practice. It is estimated that the increased salinity of the recycled water resulting from the blend of existing raw wastewater with the new source waters may result in a 13% reduction in total crop production value in the CSIP service area under a drought year scenario only under two conditions (1) if Salinas River water is not available for dilution with recycled water for irrigation <u>and</u> (2) if salinity control crop management practices are not implemented to maintain yield. The calculations leading up to this conclusion are based on agronomic and soil science literature combined with data from local conditions, holding all other variables constant. To maintain the integrity of these calculations, all other factors are assumed unchanged, even though in practice, that would not be the case. In practice, the potential loss of crop value would be ameliorated by the implementation of standard strategies and management practices to address higher salinity levels in irrigation water sources.

Recycled water currently is blended with Salinas River water during most parts of the year (April 1 through October 31) and in most years, except following multiple drought years, before delivery to the growers. This practice is expected to continue in the future. Therefore, few—if any—of the growers will be irrigating with a straight blend of recycled water at all times. Salinas River water has a much lower salinity than any of the new source waters that will become recycled water (except the storm water). Of the new source waters to be used for the proposed project, Agricultural Wash Water will be the highest volumetric contributor and has higher salinity than the current recycled water. Thus, timing of the Agricultural Wash Water contribution to the RTP is important when understanding the effects of blending recycled water with Salinas River water. Significantly, the greatest extent of blending with Salinas River water and with the recycled water containing Agricultural Wash Water is expected to occur during the peak summer period when plants would be growing at the highest rate and would benefit the most from a reduced salinity level.

It is the considered opinion of the author that the potential losses in crop production can and will be mitigated with irrigation management practices, such as additional leaching fraction, modified irrigation scheduling, and addition of amendments as described further below in this technical memorandum.

Predicted Impact on Farming from Use of Recycled Water with Higher Salinity

INTRODUCTION

The coastal lands in northern Monterey County are some of the most fertile agricultural areas in the State of California. Combined with an ideal climate for growing a large variety of food crops, this area is an economic powerhouse. The Monterey County Agricultural Commissioner's 2013 Crop Report (MCAC 2013) estimates that the annual value of agricultural products from the County is $4.4 billion. Growers in the Castroville Seawater Intrusion Project (CSIP) service area have been growing high value crops under a recycled water irrigation regime for the past 17 years. With the choice of crop varieties, management practices, and a sophisticated irrigation management system there have been no complaints about yield, quality of crops, or sales of crops sent to market. In fact, the availability of recycled water has ensured the continued cultivation of high-value crops in this region. Recycled water has served as a valuable regional resource to replace groundwater wells that historically provided irrigation water, but were abandoned as a result of seawater intrusion caused by overdraft of the local aquifers.

The proposed Pure Water Monterey Groundwater Replenishment Project (proposed project) is a water supply project that will serve northern Monterey County. The project includes the use of new source waters that would be combined with existing incoming wastewater flows for conveyance to, and treatment at, the Monterey Regional Water Pollution Control Agency's Regional Wastewater Treatment Plant (RTP). The effluent from the RTP would be further treated at a new advanced water treatment facility to produce highly-purified recycle water for injection into the Seaside Groundwater Basin (and later extraction for replacement of existing municipal water supplies) and treated through the SVRP to provide additional tertiary recycled water for agricultural irrigation in northern Salinas Valley. The new source waters would include the following: 1) water from the City of Salinas agricultural wash water system, 2) stormwater flows from the southwestern part of Salinas and the Lake El Estero facility in Monterey, 3) surface water and agricultural tile drain water that is captured in the Reclamation Ditch and Tembladero Slough, and 4) surface water and agricultural tile drain water that flows in the Blanco Drain.

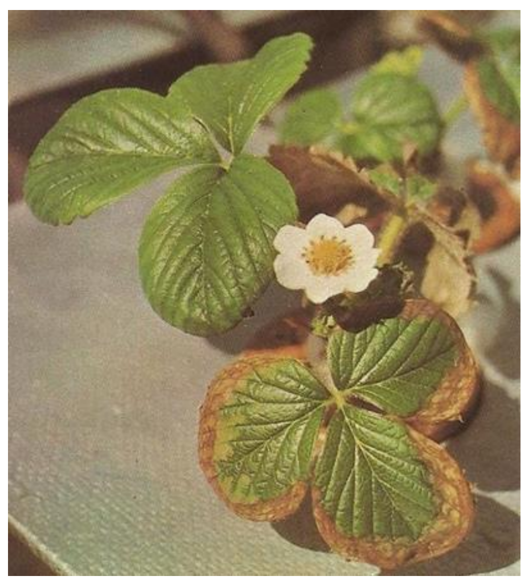
The purpose of this technical memorandum (TM) is to assess the impact of introduction of additional source waters on farming resulting from the anticipated increase in the salinity of disinfected tertiary recycled water. An increase in the salinity of recycled water could result in yield reduction of crops grown with recycled water unless specific management practices are implemented to account for the change in salinity levels in the recycled water. Such adjustments to management practices may be costly, may not be fully effective, or may have additional adverse impacts of their own. The added cost elements may include extra water application commonly applied with each irrigation to increase the leaching fraction. It may also include the material and labor costs of amendments, such as gypsum to increase soil permeability, which would allow free movement of the extra water past the plant root zone. Another cost element that may be required is additional tile drain installation.

For the purposes of calculating impacts of increased salinity on crop production, it was assumed that the current scenarios and management practices would not change in the future.

WATER QUALITY AND FARM PRODUCTIVITY

A one-year monitoring program from July 2013 to June 2014 was conducted for five of the potential source waters for the proposed project. Monthly and quarterly sampling was carried out for the RTP secondary effluent, agricultural wash water, and Blanco Drain drainage water. Limited sampling of stormwater from Lake El Estero was performed due to seasonal availability, and there was one sampling event for the Tembladero Slough drainage water.

The agronomic water quality parameters of the greatest importance with regard to sustainable soil productivity and maximum crop yield potential along with applicable guidelines are shown in first four rows of Table 1, and can be found in standard agronomic and soil science literature (e.g., FAO, 1976). Inorganic salts will not be removed during primary or secondary treatment at the RTP, or during tertiary treatment/disinfection, and thus it is possible to calculate a predicted concentration (Blended Mix) based on the volumetric contributions of each source water and their constituent concentrations. The 5th through 10th rows in Table 1 present the median concentrations for each parameter for each source water. The last row (Blended Mix) presents the calculated predicted concentration of each parameter for the blend of the source waters at a time when their impact might approach worst-case scenario. As described more fully in the section below titled "Salinity of Blended Water," the Phase B drought scenario of source water blends reflects this worst-case.



With the exception of chloride, the other parameters fall within the green zone (generally safe). Chloride, at a Blended Mix concentration of 264 mg/L falls within the red (problem) zone and would require some management on the part of the growers. However, the existing recycled water comprised of municipal wastewater has the same average chloride concentration, and thus the Blended Mix recycled water quality would be the same, not necessitating changes in management practices or impacts on crops.

Potassium chloride is used as a soil amendment in the Salinas Valley as a fertilizer to replenish the essential macronutrient, potassium. As a result of increasing levels of chloride, detected in the soil in recent years, it was recommended that growers use alternative potassium amendments, such as potassium thiosulfate or potassium sulfate. More recent monitoring in recent years has shown a steadily declining level of chloride in the CSIP area soils (Platts, 2015).

Table 1 Water Quality Parameters of Agronomic Relevance in Irrigation of Agricultural Crops

Sustainability Guidelines	Salinity (EC) dS/m[1]	Sodium Adsorption Ratio (SAR)	Sodium, mg/L[2]	Chloride, mg/L	Boron, mg/L
Generally No Problem	0.5 - 2.0	<6	< 70	<100	<0.5
Slight to Moderate Problem	2.0 - 4.0	7 - 9'	70 - 230	100 - 250	0.5 - 5
Problem	> 4.0	>9	>230	>250	>5
Source Waters	**Average Values of Parameters**				
Municipal Wastewater	1.44	4.75	174	264	0.31
Agricultural Wash Water	1.59	4.15	177	237	0.23
Blanco Drain	2.84	3.32	241	274	0.66
Lake El Estero	2.56	4.96	235	423	0.18
Tembladero Slough	2.94	4.41	333	394	0.51
Reclamation Ditch	1.17	2.45	96	130	0.51[3]
Blended Mix[4]	1.75	4.75	174	264	<0.5

1. EC – electrical conductivity; dS/m – deci Siemans per meter.
2. mg/L – milligrams per liter.
3. Reclamation Ditch boron is assumed to be equal to the concentration of boron in Tembladero Slough since they are both part of the same ditch system.
4. These water quality parameters reflect the worst-case scenarios of source water flow diversions for the purpose of assessing water quality of the treated secondary effluent/tertiary-treated water (i.e., Phase B in a drought year). Under all other Phases and scenarios, these values would be less.

As can be seen from a comparison of the value of each parameter with the corresponding guidelines in Table 1, some source waters fall in the problem range if used unblended with other sources. However, in the drought year, Phase B blended scenario (see discussion about this scenario, below), the average values, under blending scenarios considered, are in the safe range, with the exception of chloride. But as noted above, the predicted Blended Mix chloride concentration is equivalent to the current recycled water concentration.

Data for boron is provided in Table 1 because boron is an essential nutrient for plant growth and development at very low concentrations. However, at concentrations indicated to be problematic in Table 1, it can be toxic and cause severe damage to plants. While the current levels of boron in the recycled water (i.e., RTP effluent) and other potential source waters are not problematic in the blend, it may change in the future should the Monterey Peninsula Water Supply Project be implemented. It is a proposed ocean desalination project that would produce between 9.6 million gallons per day (mgd) to 6.4 mgd of water to be added to the region's water supply. The desalinated ocean water could increase the concentration of boron in recycled water by as much as 0.1 mg/L. If the increase is limited to this prediction, the blend will still be safe for irrigation. If the boron level in the blend rises to problematic ranges, additional actions would be needed to maintain the boron levels below the 0.5 mg/L guideline.

Aside from this overall evaluation of water quality parameters, there are two major additional concerns that must be addressed: (1) salinity, and (2) SAR. The impacts of salinity on crop yield are the most important consideration and are evaluated in most of the remainder of this TM.

Sodium adsorption ratio is a unitless parameter derived from the following empirical formula:

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

wherein concentrations of each of the ionic species (sodium [Na], calcium [Ca], and magnesium [Mg]) are expressed as meq/L. SAR is a measure of the potential for impact on soil permeability. A high SAR is indicative of problems in infiltrating water into the soil profile. However, the impact potential of SAR in a given irrigation water source is strictly related to the salinity of that irrigation water. This interdependence is best described by the graphic depiction[1] in Figure 1. Plotting the intersection of electrical conductivity (EC) and SAR for each source water indicates that none of the source waters (singly or in the Mixed Blend), as irrigation water, are problematic in terms of long-term potential impact on soil infiltration rate. This conclusion is consistent with findings of a long-term field study of recycled water impacts on the soils of CSIP service area (Platts, 2014A):

> "*Our analysis of study data from 2000 to 2012 supports the general conclusions of the MWRSA in the 1980s: The use of recycled water has caused an increase in soil salinity in the area; however, SAR values are not deleterious and Na has shown little accumulation in the rooting zone (1 to 12 inches).*"

Over a ten-year period of irrigation with a blend of varying proportions of recycled water and river water, moderate increases in salinity, sodium, chloride, and SAR in the soil solution were recorded. The increase in chloride was of particular interest and concern. A second paper in the same publication (Platts, 2014B) documents the critical role that annual rainfall plays in ameliorating salt impacts by leaching the salts and preventing accumulation in the root zone.

[1] This graphic depiction is commonly used in the classic agronomic literature and textbooks, such as Grattan (2002).

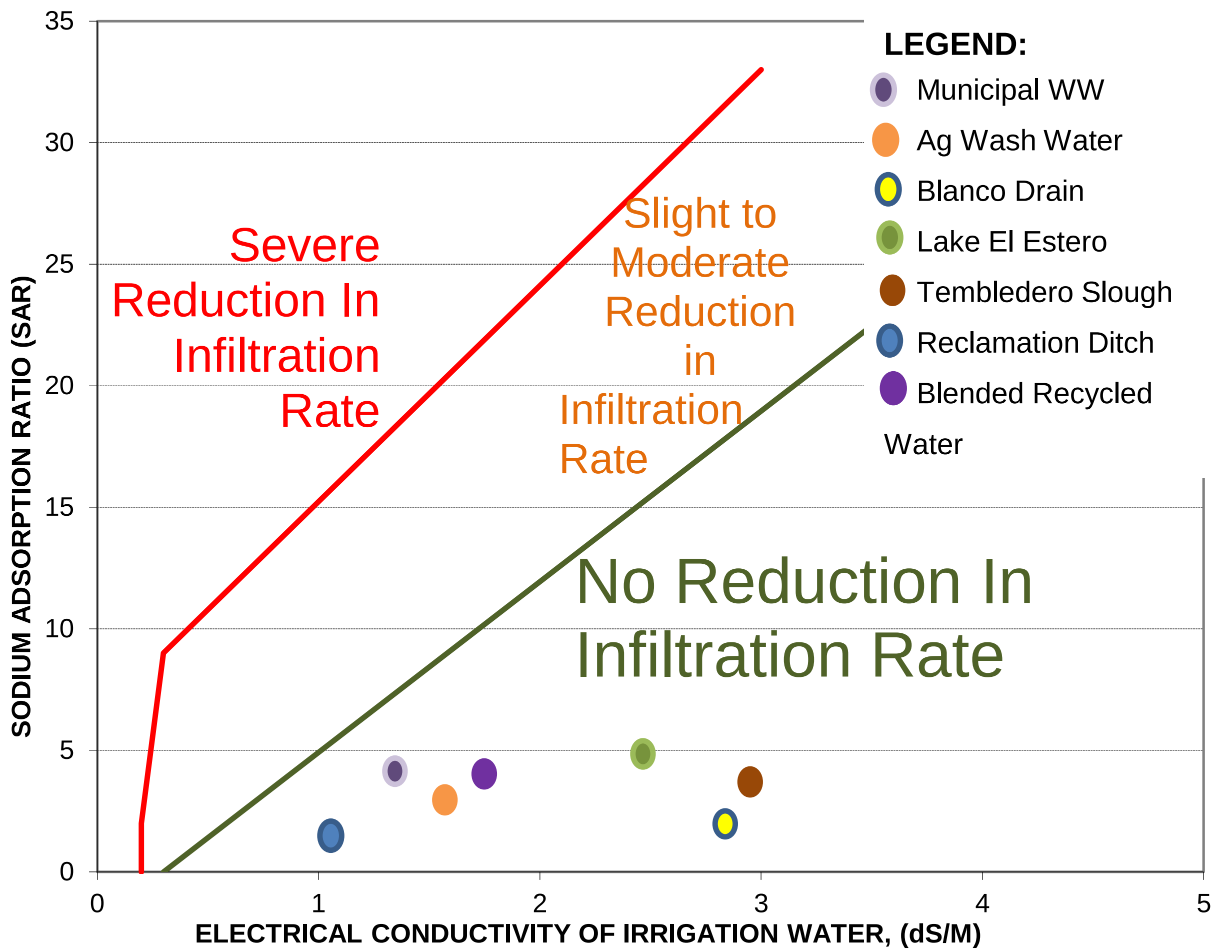


Figure 1 Potential for Impact on Soil Infiltration Rate As a Result of Irrigation with Undiluted Source Waters and Blended Mix

SALINITY OF IRRIGATION WATER

Salinity of an irrigation water source is the most important short-term and long-term predictor of farm productivity, as measured by the yield potential of crops irrigated with that water. The most common indicator of salinity is total dissolved solids (TDS). Another indicator, favored by agronomists and field practitioners is the EC of the water, since it is linearly proportional to the concentration of inorganic compounds present in the water.

IMPACT OF SALINITY ON CROP YIELD

Yield reductions occur when salts accumulate in the plant root zone, thus increasing its osmotic pressure. If the increase in salinity is to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, water stress occurs in plant tissues for a significant period of time—a condition termed physiological drought, since the symptoms are identical with those resulting from a prolonged lack of water. If water uptake is thus appreciably reduced, the plant slows its rate of growth and crop yield is proportionately reduced, as discussed in more detail below, under the heading "Salt Impact on Crop Yield".

SALT CONTENT OF SOURCE WATERS

The anticipated monthly flows of various source waters into the RTP were used to compute predicted salinity concentrations in the blended recycled water under various scenarios. The blend ratios of the various water sources are shown in tabular and graphic forms in Appendix A.

The source waters and their average salinities are shown in Table 2 based on the Source Water Analysis prepared for the proposed project dated October 17, 2014 by the Monterey Peninsula Water Management District. The last column in the table is the most likely salinity of the water at equilibrium in the root zone, relevant to each source water if used independently for irrigation (which is not the case for the proposed project). This value, known in soil science terminology as ECe (electrical conductivity of the soil saturated paste extract), would be the salinity experienced at the root zone by plant roots. Crop tolerance and yield potential are related to this parameter.

Table 2 Salinity of Source Waters and Long-Term Root Zone Soil Water

Source of Water	Salinity, TDS[1] (mg/L)	Salinity, ECw (dS/m)	Likely Root Zone Salinity, ECe (dS/m)
Municipal Wastewater	793	1.44	2.88
Agricultural Wash Water	820	1.59	3.18
Blanco Drain	2003	2.84	5.68
Lake El Estero	1226	2.56	5.12
Tembladero Slough	1963	2.94	5.88
Reclamation Ditch	641	1.17	2.34

1. Source of salinity data: Williams, 2014.

When the build-up of soluble salts in the soil becomes or is expected to become excessive, the salts can be leached by applying more water than is needed by the crop during the growing season. This extra water moves at least a portion of the salts below the root zone by deep percolation (leaching). Leaching is the key factor in controlling soluble salts brought in by the irrigation water. Over time, salt removal by leaching must equal or exceed the salt additions from the applied water or salts will build up and eventually reach damaging concentrations. The terms "leaching fraction (LF)" and "leaching requirement (LR)" are used interchangeably. They both refer to that portion of the irrigation water that should pass through the root zone to control salts at a specific level. While LF indicates that the value be expressed as a fraction, LR can be expressed either as a fraction or percentage of irrigation water.

ECe is a function of the applied irrigation water salinity (ECw) and the LR. Because variations in existing irrigation management practices among farmers are too great to generalize, a conservative 10 to 15% LR is assumed in translating the ECw to the salinity in the root zone (ECe). According to Grattan (2002), the relationship between ECw, LR, and ECe is as follows:

LR at 10% leads to ECw x 2.1 = ECe
LR at 15-20% leads to ECw x 1.5 = ECe
LR at 30% leads to ECw ~ ECe

For the purposes of this analysis, it is estimated (conservatively) that the **ECw x 2.0 = ECe**. This estimate is consistent with field observations in the CSIP service area over a ten-year period (Platts, 2014A).

Both sets of data (TDS and EC) for all source waters are presented in Table 2, in addition to the anticipated salinity in the root zone, under long-term irrigation equilibrium with moderate leaching fraction of 15% to 20%.

SALINITY—TDS or EC?

The data used in this TM for calculating the predicted impact of salinity on crop yield are derived from average measurements of electrical conductivity on the various source waters involved. The salinity of those same source waters is also often reported as total dissolved solids. While this parameter was not used in the impact analysis, it is important to note that it is directly related to EC. The linear relationship between EC and TDS is a function of the specific mix of cations, anions, and other compounds in the water.

According to the soil science/agronomy literature, the generalized conversion factor for salinity, from TDS to EC, is:

TDS in mg/L = 640 x EC in dS/m
(Grattan, 2002)

Salinity measurements on water samples from Reclamation Ditch and Blanco Drain appear to follow this equation. However, actual measurements of both TDS and EC on samples of recycled water from the RTP, over the last several years, lead to a different conversion factor:

TDS in mg/L = 550 x EC in dS/m

The agricultural wash water and Lake Estero water samples also appear to follow this equation. Because of the availability of actual data for some of the source waters, the latter conversion factor is preferred for converting salinity units from TDS to an equivalent electrical conductivity value.

SALINITY OF BLENDED WATER

Blended recycled water will have a different composition every month and under various phases and scenarios. The projected operational scenarios are described in the textbox to the right.

While Table 2 indicates that most of the new source water salinities are significantly higher than the salinity of the existing RTP recycled water, it is important to understand what the predicted blend salinity will be based on the actual composition of blends of the different source waters that will be combined with wastewater and treated to produce future recycled water (Holden, Sterbenz 2014).

The composition of blends during each month of the year, under various scenarios is provided in Appendix A. The most critical blend (flows of various sources under the drought scenario) is graphically presented in Appendix A, Figure A-1.

A detailed analysis of potential maximum salinity of the blended water sources under various scenarios was performed by Trussell Technologies, Inc. (Williams, 2014). Based on that analysis, the salinity of recycled water during the highest-salinity month for each scenario is depicted in Figure 2.

PROJECT PHASES AND OPERATIONAL SCENARIOS

Phase A: includes administrative permit applications to the State Water Resources Control Board for diverting less than 3 cubic feet per second (cfs) and less than 200 acre-feet per year (AFY) of storage of surface water from the Reclamation Ditch at Davis Road, Tembladero Slough at Castroville, and Blanco Drain.

Phase B: includes an application to the State Water Resources Control Board (SWRCB) to increase diversions to up to 6 cfs each from the Reclamation Ditch at Davis Road and from Blanco Drain.

Normal Rain–Wet; Building Reserve: Under this scenario, during normal and above-normal rainfall, only the most favorable water sources—in terms of water quality—would be utilized, avoiding the high-salinity sources (Tembladero Slough and Blanco Drain). During such periods, the system would be producing extra water to store in the ground as a “water bank”, which is 200 AFY, up to a total storage of no more than 1,000 acre-feet (AY).

Normal Rain–Wet; Full Reserve: This scenario pertains when the banked maximum 1,000 AF of storage total has been met and the system is not producing extra water for storage

Drought: Under drought conditions, water is still withdrawn from the Seaside Groundwater Basin by California American Water (i.e., water previously banked). In these scenarios, additional source waters are provided after secondary treatment to the Salinas Valley Reclamation Plant for recycling and crop irrigation, in lieu of advanced treatment for Seaside Groundwater Basin injection.

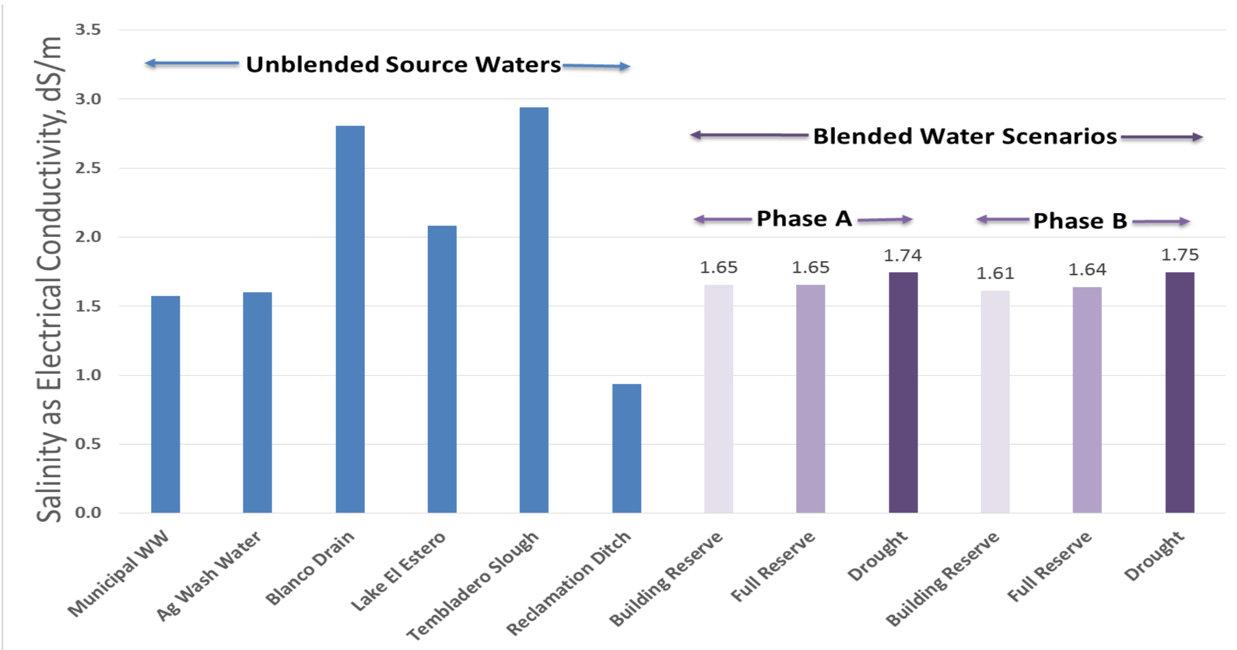


Figure 2 Highest Monthly Salinity in Source Water Blends under Various Scenarios

SALT IMPACT ON CROP YIELD

The classic salinity/yield relationship was described by Shannon (1997) in a graphic reproduced below as Figure 3.

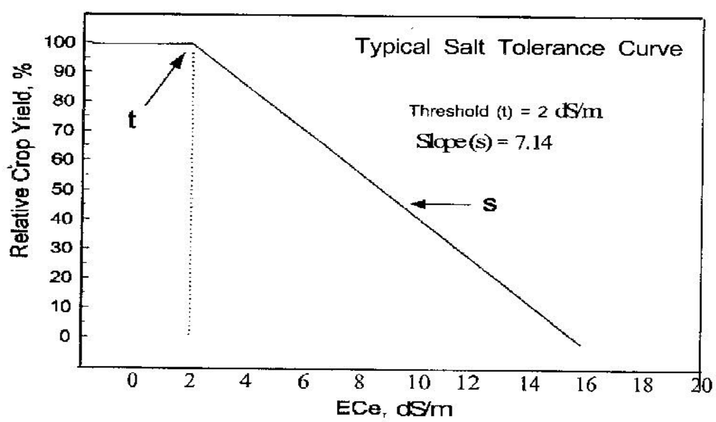


Figure 3 Relative Crop Yield (% of maximum potential) As a Function of Root Zone Salinity (ECe)

According to this model, there is a salinity threshold for each crop below which 100% yield can be obtained, assuming that there are no other limitations. Beyond that threshold, increasing salinities result in decreasing yields. For each crop, there is a different rate at which this decline takes place. For salt-tolerant crops, the threshold occurs at higher ECe and the slope is shallower. For salt-sensitive crops, the threshold occurs at lower ECe and the slope is much steeper.

CROPS GROWN IN CSIP SERVICE AREA

The typical crops grown with recycled water in the CSIP service area are presented in Table 3.

Table 3 Crops Commonly Grown in the CSIP Service Area and their Salinity-Yield Threshold[1]

Crop	Acres	Percentage of US Acreage [2]	Threshold Salinity as ECe (dS/m)
Artichoke	4,000	76	6.1
Lettuce	4,000	1.8	1.3
Cauliflower	2,000	4.8	2.8
Broccoli	800	1.1	2.8
Strawberries	1,650	2.3	1.0
Celery	270	1.0	2.4

1. Source for crop acreage: Holden, 2015 and 2005; Source for threshold salinity: Shannon, 1997
2. The percent of United States acreage may be inaccurate because of the ten-year age of the data, while acreages for the CSIP service area are estimates for current conditions.

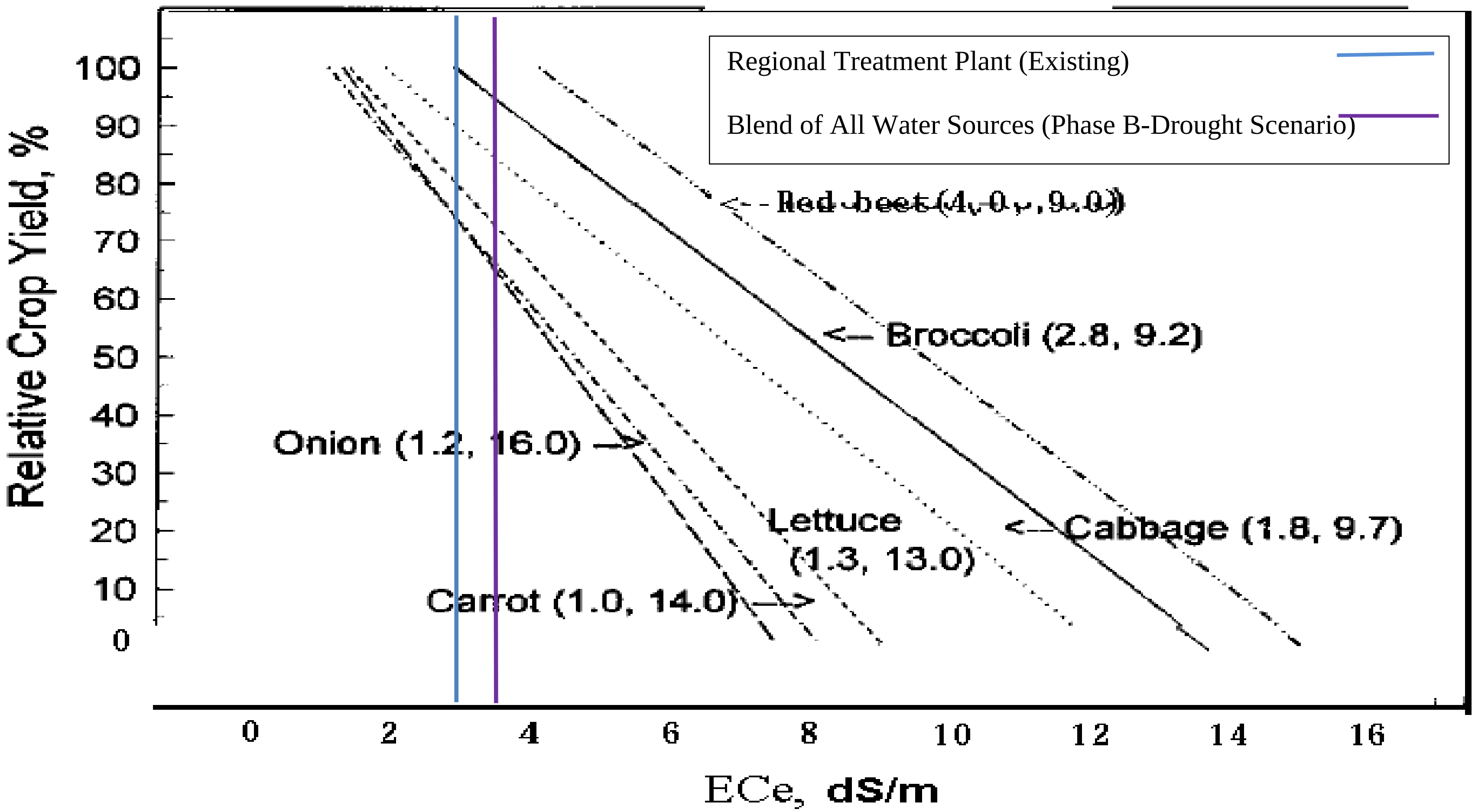
YIELD REDUCTION UNDER DIFFERENT BLEND SCENARIOS

Salinity and yield are related based on extensive field experiments at agricultural research stations managed by the University of California Agricultural Extension Service. The baseline for these graphics is an ideal growing environment where crop yield is not restricted by any environmental or artificial limitations. Under those conditions, the yield of a given crop is pegged as its 100% potential yield. Keeping all other environmental and artificial conditions constant and varying only the soil water salinity over a series of experimental plots produces the graphics similar to those on Figures 3, 4, and 5. These graphics have been published in textbooks, monographs and periodicals (Shannon, 1997, Grattan, 2002, and others).

For the purposes of this TM, the graphical representations from Shannon (1997) are reproduced in Figures 4, 5, and 6 below. Each graphic is annotated with the equilibrium root zone soil water salinities resulting from irrigation with the two recycled waters in the scenarios under discussion:

(1) the existing RTP recycled water, potentially resulting in soil water salinity of **2.88 dS/m** (1.44 x 2 = 2.88)

(2) maximum salinity in Phase B drought condition, potentially resulting in soil water salinity of **3.50 dS/m** (1.75 x 2 = 3.50)



Source: Shannon, 1997

Figure 4 Relative Yield of Lettuce, Broccoli, and Cabbage at two Root Zone Salinities

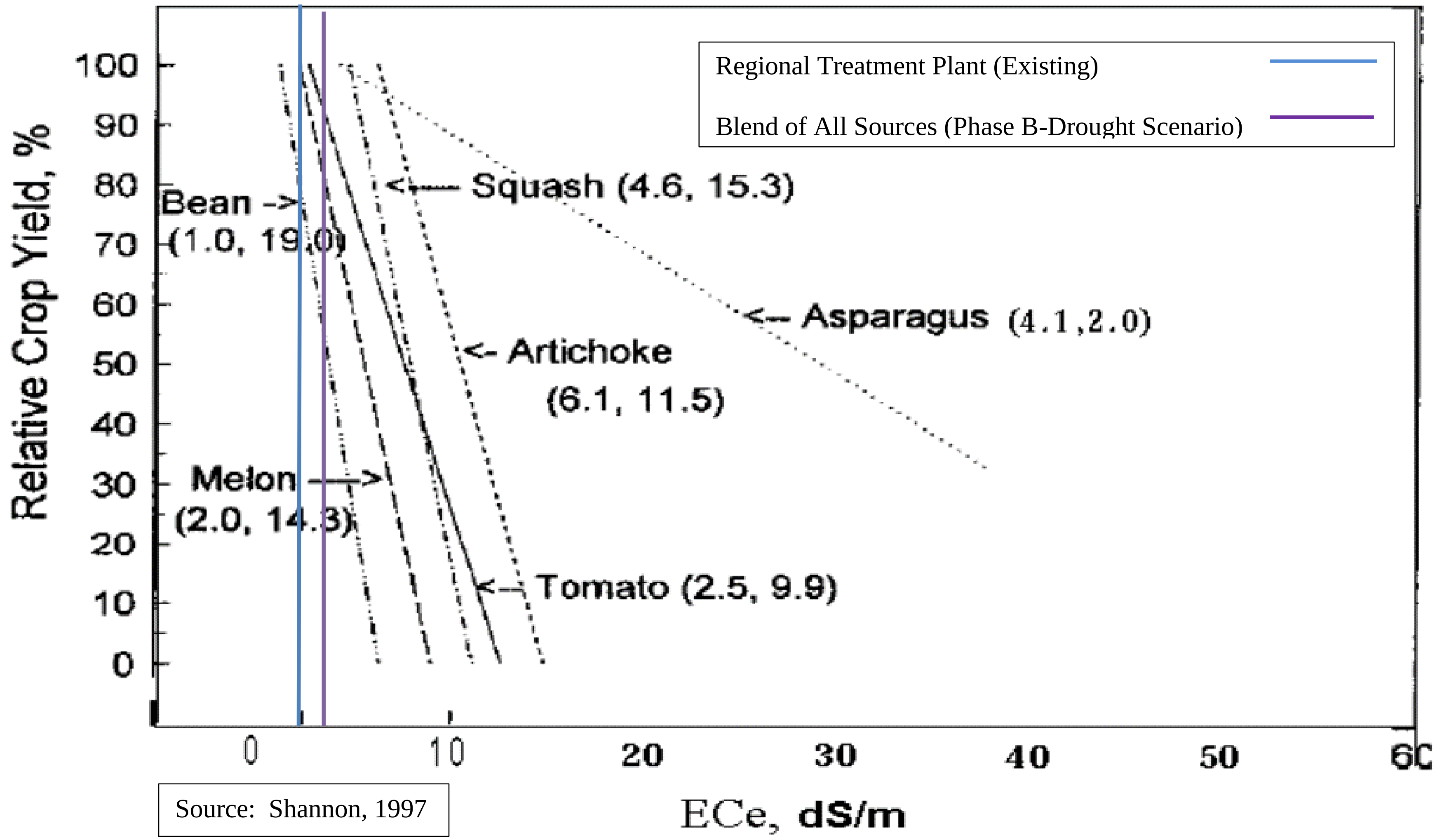


Figure 5 Relative Yield of Artichoke at two Root Zone Salinities

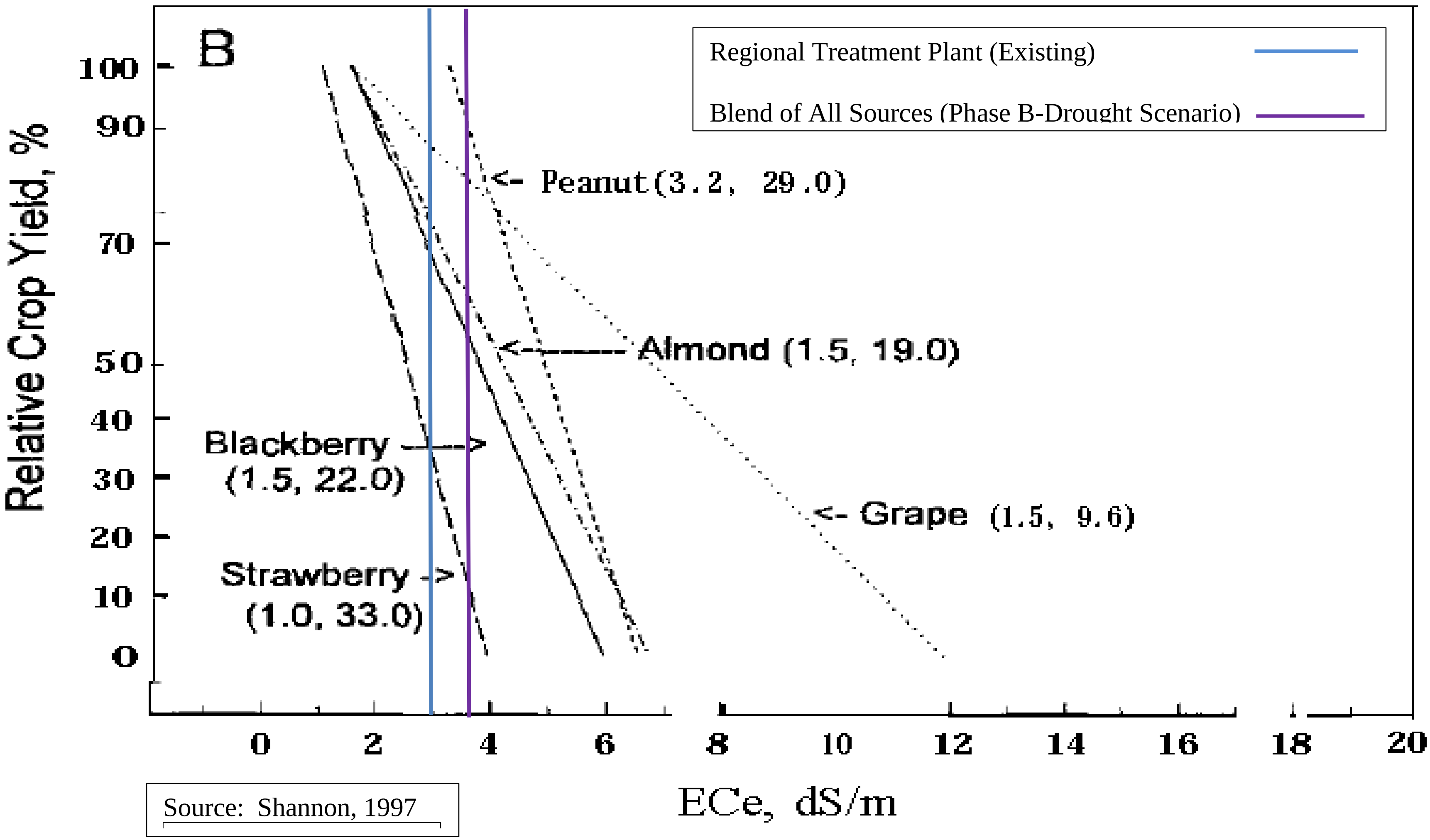


Figure 6 Relative Yield of Strawberry at two Root Zone Salinities

Intersection points of each soil water salinity (ECe) with the corresponding crop's yield graph provides the estimated percent yield potential resulting from long-term use of recycled water associated with that average salinity value. The results are summarized in Table 4.

Table 4 Estimated Crop Yield, as Percentage of Maximum Potential Yield, with Two Recycled Water Salinity Scenarios

Crop	Yield with Existing RTP Water, ECe = 2.88 (dS/m)	Yield with Blend of All Source Waters, without River Water ECe = 3.5 (dS/m)	Yield Impact, %
Artichoke	100%	100%	0
Lettuce	80%	73%	-7%
Cauliflower	100%	95%	-5%
Broccoli	100%	95%	-5%
Strawberries	35%	15%	-20%
Celery	95%	85%	-10%

PREDICTED ECONOMIC IMPACT OF YIELD REDUCTION

Subtracting percent yield obtained for each crop irrigated with the blend of source waters from the yield of that same crop irrigated with the existing RTP recycled water gives percent yield reduction for each crop as shown in the first column of Table 5. Extending the percentage yield reduction to the acreage and value of each crop provides the estimated maximum annual loss of value that would result from use of all source water blends as irrigation water.

As discussed previously, this maximum annual loss is provided for the worst-case scenario of source water diversions in a drought year without dilution with river water or implementation of any salinity management measures by farmers. The next section describes the measures that have been used in the past, and that can be used in the future by farmers to safely and profitably irrigate the land and avoid these potential losses.

Table 5 Estimated Yield Reduction for Each Crop Irrigated with Source Waters

Crop	Maximum Yield Decrease Due to Use of Blend with All Source Waters	Annual Value of Crop[1] $/Acre	Total Value of Crop In CSIP Area[2] $/Year	Loss of Value Due to Use of Blend of All Source Waters $/Year
Artichoke	0%	9,108	36,433,000	0
Lettuce	-7%	11,034	44,135,000	-3,089,000
Cauliflower	-5%	7,782	15,564,000	-778,000
Broccoli	-5%	6,510	5,208,000	-260,000
Strawberries	-20%	79,188	130,661,000	-26,132,000
Celery	-10%	16,024	4,327,000	-433,000
Total:			**236,328,000**	-30,692,000
Percent Loss:				-13%

1. Annual crop values were obtained from Monterey County Office of Agricultural Commissioner's 2013 Crop Reports (MCAC, 2014), by dividing the County-wide value of each crop by the acreage in which the crop was produced in that year.
2. Total value of each crop was calculated by multiplying the annual value of the crop by the estimated acreage of the crop in the CSIP service area, shown in Table 3.

DISCUSSION

The estimated losses of crop production value shown in Table 5 are based on simple theoretical relationships and can only be realized if the growers do nothing in response to the elevated level of salinity. Strong evidence for the ability of the currently produced recycled water to provide a safe and profitable irrigation resource has been obtained from previous research:

Monterey Wastewater Reclamation Study for Agriculture

Prior to large-scale use of recycled water in the CSIP area, a five-year field pilot project was undertaken to determine the potential impact of using recycled water for irrigation of food crops, its safety, and the potential for marketing the produce. The results of that research project, in which recycled water from the now-demolished Castroville wastewater treatment plant was used, have been published (Sheikh et al., 1998). The results provided evidence, over a five-year period, that

- soil permeability, as measured in the field on plots irrigated with recycled water and those irrigated with well water were not significantly different,
- crop yields were equal to or higher than those irrigated with well water, and
- quality and shelf-life of the crops were not significantly different from those grown with well water.

Soil Salinity Monitoring in CSIP Area

A monitoring study of soil characteristics has been underway at several test sites and control sites to track changes attributable to long-term use of recycled water in the CSIP service area. Some of the results were recently published in California Agriculture (Platts 2014A, 2014B). While some trends in increasing levels of EC, sodium, chloride, and SAR were noted, above control levels, the critical role of annual precipitation in diluting and removing accumulated salts was also observed. Overall, it was concluded that

> "In 13 years of data, the average soil salinity parameters at each site were highly correlated with the average water quality values of the recycled water. Soil salinity did increase, though not deleteriously. Of most concern was the accumulation of chloride at four of the sites, to levels above the critical threshold values for chloride-sensitive crops."

Another conclusion from this research is that

> "Increasing rainfall depths were significantly correlated with decreasing soil salinity of the shallow soil at all test sites, though this effect also diminished with increased soil depth. When applied water had high salinity levels, winter rainfall in this area was inadequate to prevent soil salinity from increasing."

Several types of management strategies are in use for salinity control and would be used to prevent any theoretically calculated reductions in yield. These strategies are listed below:

Blending with Salinas River Water

Recycled water currently is blended with Salinas River water during most parts of the year and in most years, except following the driest winters, before delivery to the farmers. This practice is expected to continue in the future. Therefore, few if any of the framers will be irrigating at all times with a straight blend of recycled water from the sources indicated above. Salinas River water has a much lower salinity than any of the source waters discussed here (except the storm water). Of the new source waters to be used for the proposed project, Agricultural Wash Water will be highest volumetric contributor and has higher EC values than those in the current recycled water. Thus, timing of the Agricultural Wash Water contribution to the RTP is important when understanding the effects of blending recycled water with Salinas River water. Significantly, the greatest extent of blending with Salinas River water and recycled water containing Agricultural Wash Water is expected to occur during the peak summer period when plants would be growing at the highest rate and would benefit the most from a reduced salinity level. The beneficial, counteracting impact of the Salinas River water cannot be readily quantified because of the variable and temporal rates at which it will be introduced as influent to the irrigation system. If the CSIP service area is expanded in the future, more Salinas River water will be required to be blended to meet the demand. This will further dilute the salt content of the blended recycled water from all sources.

Agronomic Management Practices

Growers in Salinas Valley are some of the most sophisticated and technologically advanced farmers in the world. They will, in all likelihood, respond to a higher salinity blend of recycled water by employing agronomic management practices, including the following: regular monitoring using sensors; increasing the leaching fraction; modifying irrigation scheduling; leaching during the cool seasons to improve leaching efficiency; scheduling leachings at periods of low crop water use or postponing leachings until after the cropping season; land leveling for better water distribution; installing additional tile drains to improve leaching, scheduling timing of irrigations to prevent crusting and water stress; placement of seed to avoid areas likely to be salinized; careful selection of materials, rate and placement of fertilizers; and addition of agricultural amendments, as needed.

Salt Tolerant Varietals

California's academic institutions and agricultural research services are continuing research in plant breeding for salt tolerance, higher yields, and more consumer-attractive characteristics. These efforts routinely produce varietals and cultivars that, among other beneficial traits, can tolerate higher salt levels in the soil root zone, producing near maximum potential yield. In particular, the strawberries grown in the CSIP service area are patented proprietary varietals adapted to the conditions and water quality at hand.

Trends for Crops Grown in the CSIP Service Area

Even though the calculations in this TM indicate a significant yield reduction for strawberries grown with the RTP recycled water, actual field experience of the farmers does not bear this out. In fact, over the period of recycled water delivery, much of the farmland in the CSIP service area has been shifted from growing artichoke (a salt-tolerant plant) to producing strawberries (a salt-sensitive crop), as shown in Table 6. This shift indicates that the farmers are obtaining adequate (possibly superior) yields and high-quality harvests from their investment, under the recycled water irrigation regime.

Table 6 Shifts in Crop Acreage and Corresponding Value[1] from Artichokes to Strawberries in CSIP Service Area

Crop		1998	2010-2014[2]	Change
Artichokes	Acres	4,200	3,900	-7%
	Dollars	25,262,000	35,522,000	41%
Strawberries	Acres	120	1,642	1,300%
	Dollars	3,641,000	130,027,000	3,500%

1. Crop values were obtained from Monterey County Office of Agricultural Commissioner's 2013 Crop Reports (MCAC, 2014). Crop acreages were provided by Bob Holden, MRWPCA.
2. Artichoke acreage is for 2010; strawberry acreage is for 2014.

CONCLUSION

The addition of new source waters for the proposed project is likely to increase the recycled water salinity above that currently produced at the RTP. This change in water quality is not expected to impact the farming activities within the CSIP service area to a significant extent, mainly because of the various management tools and expertise available to the growers, some of which are already in practice. It is estimated that the increased salinity of the recycled water resulting from the blend of existing raw wastewater with the new source waters may result in a 13% reduction in total crop production value in the CSIP service area during a drought year scenario only under two conditions (1) if Salinas River water is not available for dilution and (2) if salinity control crop management practices are not implemented to maintain yield. In practice, the potential loss of crop value would be ameliorated by the implementation of standard strategies and management practices to address higher salinity levels in irrigation water sources.

The farming enterprise is a dynamic industry with constant revision of policies, practices and procedures to meet changing environmental and input variables, including irrigation water quality. Over the 17-year period of using recycled water for irrigation in the CSIP service area, large tracts of salt-tolerant artichoke have been converted to growing salt-sensitive, but far more profitable, strawberries. This conversion attests to the ingenuity of local growers and their ability and willingness to adapt real-time to water quality variations and economic realities.

REFERENCES

Food and Agriculture Organization of the United Nations (FAO) 1976, Water Quality for Agriculture, Irrigation and Drainage Paper 29.

Holden, Bob, January 5, 2015, Personal Communication, and 2005, "Water Production for the 'Salad Bowl' of the USA", presented at Water & Wastewater Europe June 29, 2005, Milan, Italy.

Holden, Bob, Sterbenz, Andy, 2014. "Source Water Analysis for Augmentation of Castroville Seawater Intrusion Project Flows and Feed Water for the Pure Water Monterey Groundwater Replenishment Project", a MS Excel Spreadsheet, October 16, 2014.

Grattan, Stephen R., 2002 "Irrigation Water Salinity and Crop Productions", University of California Agriculture and Natural Resources Publication 98066 (available at http://anrcatalog.ucdavis.edu/pdf/8066.pdf)

MCAC 2013, Monterey County Office of Agricultural Commissioner, "Monterey County Crop Report 2013", Accessed December 2014 at http://ag.co.monterey.ca.us/assets/resources/assets/429/CropReport_2013.pdf?1403024356

Platts, Belinda, 2014A, "Chloride levels increase after 13 years of recycled water use in the Salinas Valley", in California Agriculture, Vol. 68. No. 3, pp. 68-74.

Platts, Belinda, 2014B, "Rainfall leaching is critical for long-term use of recycled water in the Salinas Valley", in California Agriculture, Vol. 63. No. 3, pp. 75-81.

Platts, Belinda, 2015, "Results of MRWPCA soil salinity study 2010 – 2014", presented by Belinda Platts to the Water Quality Committee, January 2015.

Shannon, Michael C. 1997 "Adaptation of Plants to Salinity", US Department of Agriculture Agricultural Research Service, US Salinity Laboratory, Riverside, California. Advances in Agronomy, Volume 60 0065-2113/97. Retrieved March 27, 2014 from website: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.30.9812&rep=rep1&type=pdf on

Sheikh, Bahman, Robin Cort, 1998. Chapter 17, "Tertiary Reclaimed Water for Irrigation of Raw-Eaten" Vegetables, in "Wastewater Reclamation and Reuse" edited by Takashi Asano, pp. 779-825.

Williams, Gordon, 2014, "Blending Calculator for Estimating Concentration in MRWPCA Raw Wastewater under GWR scenarios", MS Excel Spreadsheet, December 2, 2014.

Appendix A

Table A-1 Predicted Composition of Source Water Blends under Various Scenarios

Phase	Scenario	Source of Water	Average Flow, mgd	Percentage from Each Source	Maximim Monthly Flow, mgd	Percentage from Each Source
Phase A	Normal/Wet - Building Reserve	Municipal WW	17.8	82%	18.4	65%
		Ag Wash	2.8	13%	6.8	24%
		Blanco Drain	0.6	3%	1.9	7%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.0	0%	0.0	0%
		Rec Ditch	0.5	2%	1.2	4%
	Normal/Wet - Full Reserve	Municipal WW	17.8	82%	18.4	65%
		Ag Wash	2.8	13%	6.8	24%
		Blanco Drain	0.6	3%	1.9	7%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.0	0%	0.0	0%
		Rec Ditch	0.5	2%	1.2	4%
	Drought	Municipal WW	17.8	79%	18.4	62%
		Ag Wash	2.6	11%	6.7	22%
		Blanco Drain	1.1	5%	1.9	6%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.5	2%	1.5	5%
		Rec Ditch	0.6	3%	1.2	4%
Phase B	Normal/Wet - Building Reserve	Municipal WW	17.8	82%	18.4	64%
		Ag Wash	2.8	13%	6.8	24%
		Blanco Drain	0.4	2%	1.6	6%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.0	0%	0.0	0%
		Rec Ditch	0.8	4%	2.0	7%
	Normal/Wet - Full Reserve	Municipal WW	17.8	82%	18.4	64%
		Ag Wash	2.8	13%	6.8	23%
		Blanco Drain	0.6	3%	2.1	7%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.0	0%	0.0	0%
		Rec Ditch	0.6	3%	1.8	6%
	Drought	Municipal WW	17.8	77%	18.4	59%
		Ag Wash	2.6	11%	6.7	21%
		Blanco Drain	1.4	6%	3.0	9%
		El Estero	0.0	0%	0.0	0%
		Tembladero Slough	0.4	2%	1.5	5%
		Rec Ditch	0.8	4%	1.8	6%

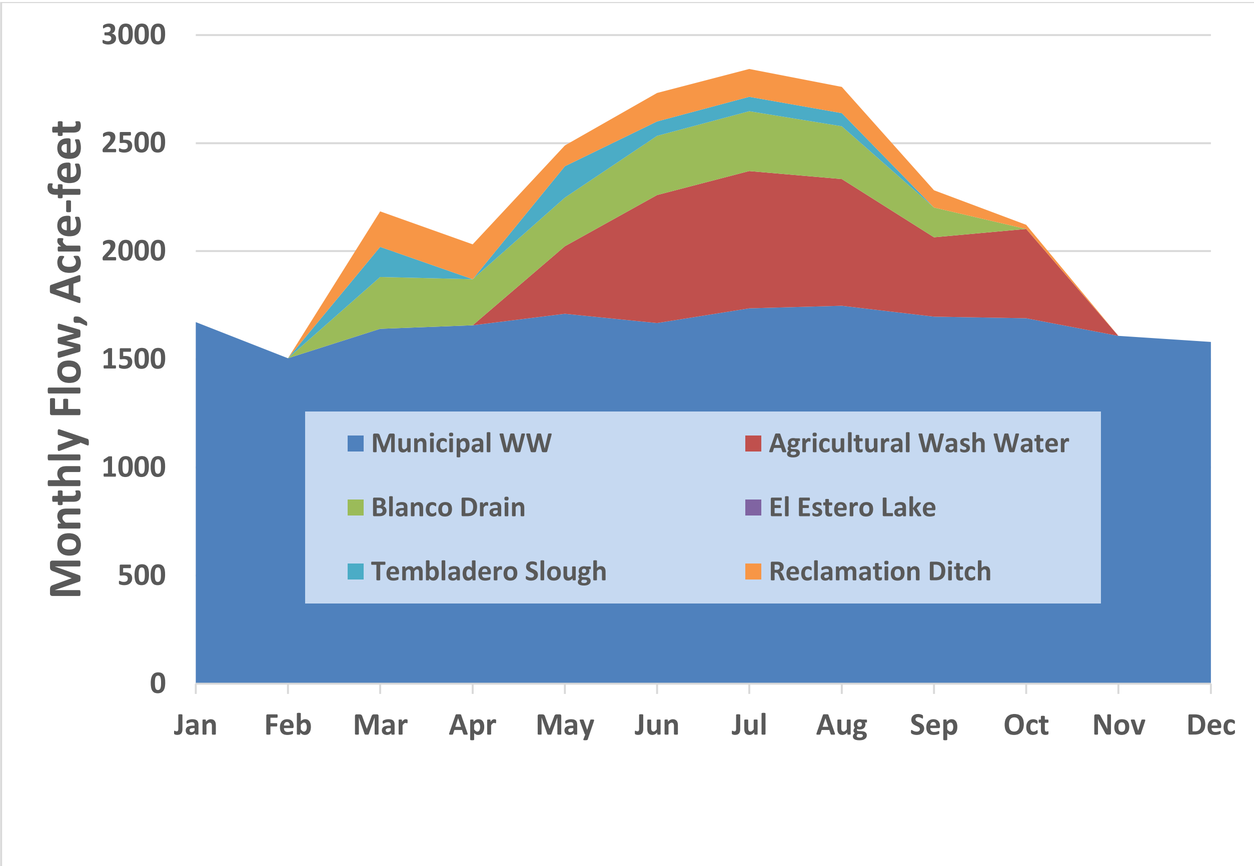


Figure A-1 Monthly Blend Composition from Various Source Waters under Phase B, Drought Scenario—Worst-Case Condition for Salinity