CONSERVATION POTENTIAL OF SALINITY MITIGATION STRATEGIES

Greater Southern California

FINAL PROJECT REPORT

AGREEMENT SCSC-11-02

Table of Contents

EXECUTIVE SUMMARY

As California's water supplies continue to be stressed, utilizing current water resources efficiently and protecting quality is crucial. Rising salinity levels and the economics of removing and preventing salt from entering potable water supply have been studied for decades. As municipalities have become more reliant on recycled water to help meet the regional water supply needs, salinity levels have become a serious water quality concern.

Multiple studies have been conducted over the past few decades that have identified salinity sources, impacts on household appliances, commercial and industrial uses, and effects on agriculture and landscape irrigation. The benefits of reducing salinity have been identified and economic factors have been applied to help quantify salinity reduction and damages in terms of dollars. However, with multiple sources of salinity, multiple impacts on water consumers, quantifiable and unquantifiable variables, developing a reasonable and defensible economic relationship is a difficult undertaking.

To continue this endeavor, URS Corporation (URS) and its Subconsultants, PlanTierra and Harvey Economics (Project Team) were retained by the National Water Research Institute to conduct an extensive literature review, estimate the water savings that may be realized when salinity levels are reduced, specifically, for large landscape irrigation applications and in the residential, commercial and industrial sectors where water softeners and reverse osmosis devices are being utilized, estimate the associated dollar savings when salinity levels are reduced, and identify potential cost effective water saving approaches and future studies. The information contained within this study may be adapted for any area, however, our focus was on Metropolitan Water District of Southern California's (MWDSC) service area.

Equations were developed for large landscapes that established the relationship between total dissolved solids (TDS) and water requirements for leaching purposes, and the water savings that may be realized. An approach and calculator tool (spreadsheet) were developed to calculate conservation potential in irrigated land due to a reduction in leaching facilitated by a change (lowering) of irrigation water supply salinity. In addition to the tool with which to develop and assess future projects, the sensitivity of conservation to a number of key factors was investigated and described. These sensitivities can serve as guiding principles when prioritizing between salinity control and irrigation management to conserve water. In addition to technical factors, it was recognized that irrigation management is strongly influenced by the behavior of irrigators. The conservation calculation tool therefore, allows the user to override leaching fractions determined by purely technical factors with those that are known to actually occur. As of this writing, mapping of large landscapes within MWDSC was underway and therefore, the potential water conservation could not be calculated. However, the water savings for a typical household in the study area was determined to be approximately 1400 to 3400 gallons per year (depending on the type of grass installed). The associated annual savings per household was calculated to be approximately $4.70 to $11.35 respectively.

To determine the water savings that could be realized from the use of household, commercial and industrial water softening/water treatment devices if the salinity in the source water were incrementally reduced, a number of assumptions had to be made. Those assumptions included: 1) type of water softeners/water treatment devices being used, 2) The percentage of residential households within the study service area that have water softeners 3) the average amount of water that is utilized to backwash the softening devices during regeneration, 4) how often regeneration occurs 5) the average number of individuals per household and water use per household and 6) human factors. Assuming the average water use per day per household was 369 gallons, the water used per regeneration cycle for a self-regenerating water softener was 50 gallons and that all water softeners were adequately sized, the volume of water that could be saved is approximately 440 to 550 gallons per year per household for every 50 mg/L reduction in salinity. These water savings were translated into equations that related to economic effects and it was found that for every 100 mg/L decrease in salinity, households would experience a savings of $3.61.

In addition to conservation potential due to changes in water supply salinity, other opportunities for water conservation were identified and include education and outreach programs for irrigators, education programs for the public and homeowners on the use of water softeners and alternatives available, providing commercial and industrial water audits, rebate programs to incentivize alternatives to water softeners and future research to identify alternative water softening devices or methods such as electromagnetic, water conditioning, or chelating devices.

1.0   INTRODUCTION

As California's water supplies continue to be stressed, utilizing current water resources efficiently and protecting quality is crucial. Rising salinity levels and the economics of removing and preventing salt from entering potable water supply have been studied for decades. As municipalities have become more reliant on recycled water to help meet the regional water supply needs, salinity levels have become a serious water quality concern.

Multiple studies have been conducted over the past few decades that have identified salinity sources, impacts on household appliances, commercial and industrial uses, and effects on agriculture and landscape irrigation. The benefits of reducing salinity have been identified and economic factors have been applied to help quantify salinity reduction and damages in terms of dollars. However, with multiple sources of salinity, multiple impacts on water consumers, quantifiable and unquantifiable variables, developing a reasonable and defensible economic relationship is a difficult undertaking.

To continue this endeavor, URS Corporation (URS) and its Subconsultants, PlanTierra and Harvey Economics (Project Team) were retained by the National Water Research Institute to conduct an extensive literature review, estimate the water savings that may be realized when salinity levels are reduced, specifically, for large landscape irrigation applications and in the residential, commercial and industrial sectors where water softeners and reverse osmosis devices are being utilized, estimate the associated dollar savings when salinity levels are reduced, and identify potential cost effective water saving approaches and future studies. The primary area of focus for this study was the Metropolitan Water District of Southern California's
Service area as shown in Figure 1-1.
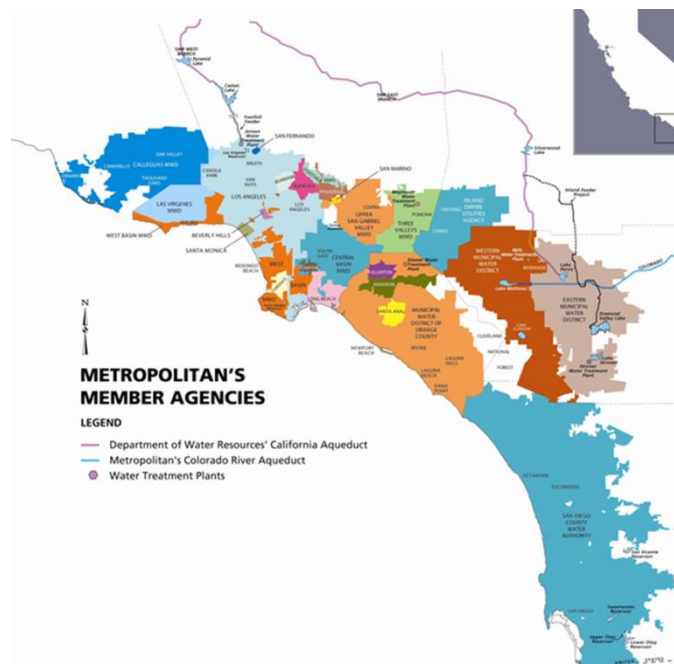
Figure 1-1. Study Area, Metropolitan Water District of Southern California's Service Area

2.0   LITERATURE REVIEW

The first step in the Scope of Work was to conduct a review of the available and relevant literature, identify additional information needed to complete this study and review the economic model that was prepared in 1999 by Bookman-Edmonston. The available literature on salinity and water use for large landscape irrigation as well as the use of water treatment devices for residential, commercial and industrial applications were reviewed and an attempt was made to identify and summarize each for its relevancy to this project and where further information was needed to complete the water savings calculations and associated dollar savings. The bibliography of the literature reviewed and the detailed summaries of each entry are included in Appendix A.

3.0   LARGE LANDSCAPE ASSESSMENT

Introduction

The scope included developing an economic formula(s) that established the relationship between total dissolved solids (TDS) and water requirements for leaching purposes, and the water savings that may be realized.

As with any study of this nature, there are multiple variables. For example, factors that affect estimating the water savings that may be realized by large landscape irrigators when the salinity is reduced may include the following primary and secondary variables:

- Defining "large" landscape irrigators
- Estimating existing acreage of irrigated turf
- Varying types of turf
- Varying types of soil
- Varying leaching requirements
- Varying salinity levels
- Varying management practices to address salts
- Varying water requirements due to weather

The assumptions to be made for the primary variables and the extent to which the secondary variables were to be included in the equation were established and are discussed in detail in the following sections. At the time of this writing, historical water use data for specific irrigation sites were not available. However, irrigation requirements are presented, as are formulae for relating reductions in water supply salinity to economic impacts of water savings and are applicable to all landscape irrigation sites utilizing the spreadsheet tool that was developed and discussed below.

An approach and calculator tool (spreadsheet) were developed to calculate conservation potential in irrigated land due to a reduction in leaching facilitated by a change (lowering) of irrigation water supply salinity. Comparisons of actual conservation were not possible, since no specific project (i.e., specific set of lands with planned changes to irrigation water salinity) has been formulated to date. Therefore, in addition to the tool with which to develop and assess future projects, the sensitivity of conservation to a number of key factors was investigated and described. These sensitivities can serve as guiding principles when prioritizing between salinity control and irrigation management to conserve water.

Conservation potential depends on several technical factors. Among these, there are three that all have a direct, linear influence on the amount of conservation that can be achieved. These include: 1) the affected acreage, 2) the degree of change in salinity in the water supply, and 3) evapotranspirative demand. This suggests, for example, that if there are options with respect to landscape areas to serve in such a project, greater conservation can be achieved by focusing on landscapes that consume the most water. A fourth technical factor, the salt sensitivity of the plants in the landscape, has a non-linear relationship, with conservation potential being much greater for more salt-sensitive species.

In addition to these technical factors, it was recognized that irrigation management is strongly influenced by the behavior of irrigators. The conservation calculation tool therefore, allows the user to override leaching fractions determined by purely technical factors with those that are known to actually occur. This should result in a more accurate estimate of achievable conservation.

Closely related actions that might also facilitate water conservation, such as education and outreach to irrigators, were also identified. Several actions of this kind are shown here.

Conservation actions agencies could take without a change in water supply quality

- Identify wasteful irrigation practices in current use, including over-irrigation
- Facilitate soil testing to improve understanding of landscape area soil salinity and to inform irrigation practices. Mobile tools for mapping soil salinity may be particularly useful for this purpose.
- Facilitate access to and use of straightforward irrigation scheduling tools and soil moisture monitoring.
- Informed use of and improve access to basic information (e.g., climate, water quality, plant sensitivity) and how they influence salinity and irrigation management.
- Facilitate shift to water-efficient and salt-tolerant complexes of plantings and irrigation technology.
- Leverage existing state and regional programs mentioned in the text for several of the above.

Calculation of Leaching Fraction

Salt is added to soils as solutes in irrigation water, as solid amendments in fertilizer, and by atmospheric deposition. Excessive soil salinity (high concentrations of salt in soil water) makes it more difficult for plants to take up the water they need to grow, and can thus reduce plant growth, vigor, and (in the case of crops) yield. Salt stress on landscape plants, like turf, can be expressed by stunting, a less desirable appearance, and, when severe, death. Leaching is used to remove excess salts that are dissolved in soil, below the root zone, so that plants will not suffer these ill effects. Leaching fractions are operational choices by irrigators, ideally chosen to manage soil salinity to levels low enough to grow the plants being irrigated, without wasting water by moving more than necessary through the root zone.

In soil and water, salinity is often expressed in units of electrical conductivity (EC), which increases with salt concentration.

The leaching requirement (LR) is the depth of water leached below the root zone divided by the depth of water applied at the land surface to attain the desired root zone salinity concentration.

Differential Leaching due to Reduced TDS of Applied Water

Detailed mapping of landscape areas by regional water agencies is currently underway. This acreage will be needed to calculate potential water savings due to changes in irrigation that might result from reductions in water supply salinity. In preparation for that work, a leaching water reduction algorithm was developed for future application to the acreage data. The calculator can be incorporated into the acreage database in the form of a series of queries and is based on the equations shown in Table 3-1.

Table 3-1. Calculator for leaching fraction differential[a, b]	
Equations:	
Conservation (acre-feet/year)	Area (acres) * Leaching differential (inches/year) / (feet/12 inches)
Leaching differential (inches/year)	Initial leaching of irrigation water (inches/year) – final leaching of irrigation water (inches/year)
Leaching of irrigation water (inches/year)	Leaching (inches/year) – Leaching by rainfall (inches/year)
Target ECe (dS/m)	(100+A*B - RY)/B
Applied water (inches/year)	Leaching + ETc - EP = (ETc-EP)/(1-LR)
Depth of leaching water (inches/year)[c]	(ETc-EP)/(1-LR)-(ETc-EP)

[a] Equations are adapted from Ayers and Westcott (1984) for this particular application.

[b] EC = electrical conductivity; RY = crop yield relative to 100% of yield potential; A = threshold ECe at which RY begins to decline; B = rate of RY decline with increases in ECe above A; Target ECe = approximate threshold, average root-zone ECe to achieve desired RY goal; ETc = plant evapotranspiration; EP = effective precipitation; LR = minimum leaching needed to maintain Target ECe, expressed as a proportion of applied water.

[c] Ignores potential influence of leaching by precipitation on soil salinity.

Relationships were employed to develop conservation program priorities that could maximize the benefits of reducing the salinity in the potable water supply. The relationship of conservation potential to a number of variables were characterized and are listed in Table 3-2. The amount of conservation that can be achieved as a result of reductions in salinity in the water supply is dependent on these variables. These variables can be divided among those due to irrigator behavior and those related to characteristics of the type of landscape being irrigated. Irrigator behavior is discussed in the "Education and Outreach" section.

Table 3-2. Sensitivity of water conservation (due to changes in leaching) to determining factors (listed in Table 3-1).

| Variable	Relationship
Irrigator information	Irrigators must know a) the nature of changes to irrigation water quality, b) implications relative to the landscape they irrigate, and c) means by which and manner in which to alter irrigation schedules.
Irrigator response	The extent to which actual irrigation scheduling changes by irrigators reflect the theoretical limits to irrigation requirements of landscapes determines whether theoretical amounts of conservation are indeed realized.
Acres affected	The greater affected acreage (by the change in irrigation water supply quality, in the presence of adequate information and effective irrigator response), the greater the amount of potential conservation. Linear relationship.
Plant evapotranspirative demand	All things equal, plants with greater rates of ET present greater potential for conservation. Linear relationship. This includes climatic effects.
Plant sensitivity to salinity	All things equal, plants with greater sensitivity to salinity present greater potential for conservation. Non-linear relationship. See Figure 3-1.
Change in applied water salinity	All things equal, plants with greater rates of ET present more potential for conservation. Linear relationship.

Climatic input data were required to run example calculations. Data used is shown in Figure 3-1. This data is only representative of areas local to the station shown; other areas should be associated with climate data appropriate to their locale.
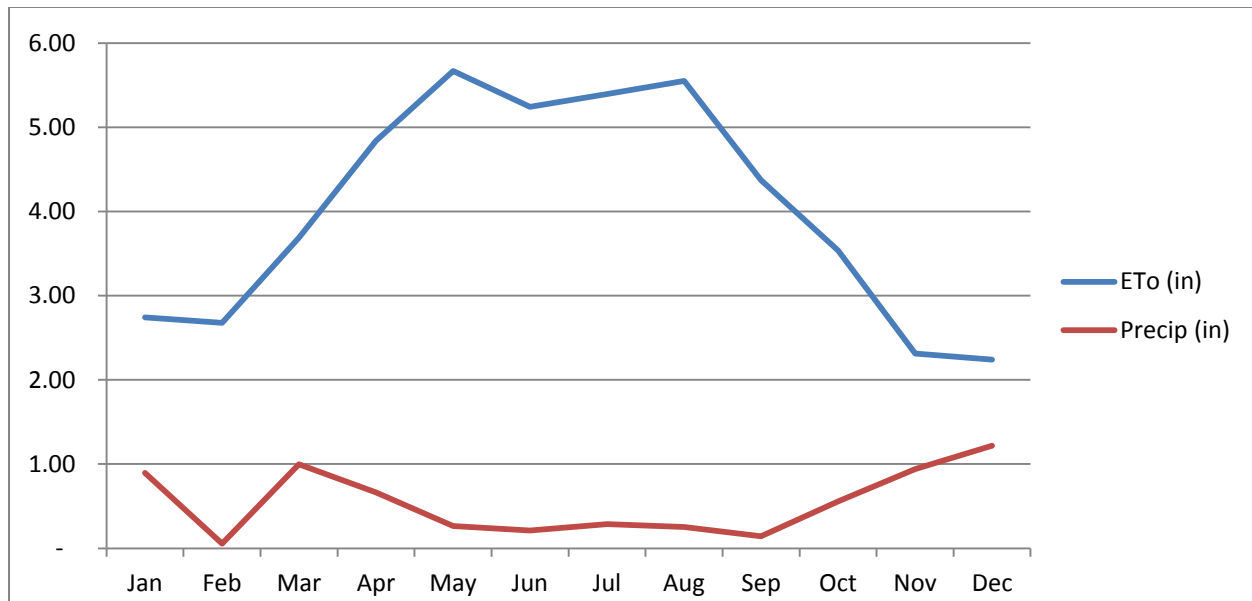
Figure 3-1. Average monthly ETo and precipitation from the Santa Monica CIMIS Station (#099). Average annual ETo = 48.3 inches, and average annual precipitation = 6.5 inches.

Sensitivity of Conservation to Various Factors

Conservation potential depends on several technical factors. Among these, there are three that all have a direct, linear influence on the amount of conservation that can be achieved: 1) affected acreage, 2) the degree of change in salinity in the water supply and 3) the evapotranspirative demand of plants. This suggests, for example, that if there are options with respect to landscape areas to serve in such a project, greater conservation can be achieved by focusing on landscapes that consume the most water. A fourth technical factor, the salt sensitivity of the plants in the landscape, has a non-linear relationship with conservation potential. This is illustrated in Figure 3-2. Based on this relationship, if there are options with respect to landscape areas to serve within a project area, greater conservation can be achieved by focusing on the most salt-sensitive landscapes.
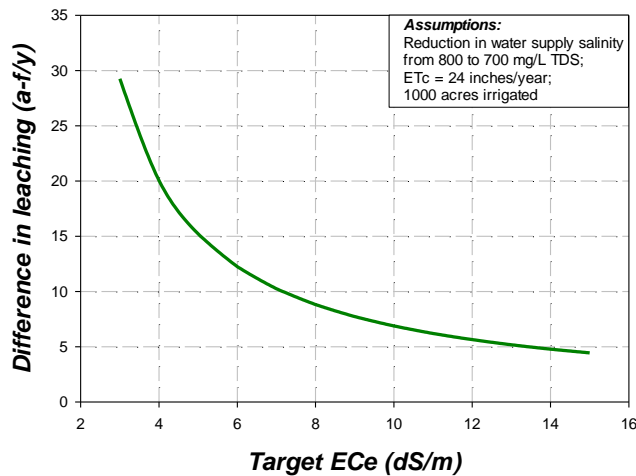
Figure 3-2. Illustration of the relationship between water conservation potential due to differences in leaching, and the target soil ECe determined by the level of landscape plant salt sensitivity. This is illustrated for hypothetical landscapes, holding the listed ETc and acreage assumptions constant. Note that, unlike ECw, ECe cannot be readily translated into a comparable value of TDS (mg/L). Therefore, no such translation is provided.

All of the factors mentioned previously in this section are accounted for in the calculation framework that has been presented. However, other factors such as behavior of irrigators and types of plants may indirectly influence the amount of conservation that may be achieved. The effects of these factors are less calculable.

The most prominent factor affecting water consumption beyond technical factors is probably the behavior of irrigators, which is related to the degree to which they are adequately informed about conditions and best practices, equipped with adequate planning and control tools and motivated to put this knowledge and tool set to use. Programs to influence these factors are discussed in a later section.

Types of plantings also affect the technical factors previously listed. Shifting to more water efficient and salt tolerant species, will greatly facilitate conservation. More efficient irrigation systems can also help to maximize irrigation efficiency.

Improvements in irrigation management and irrigation systems can also facilitate salinity management. This will have the greatest impact in a) sensitive plantings, and b) challenging (e.g., poorly drained) soils.

Several example calculations were developed for this study (see Table 3-3). Cases included landscape classes for which sensitivity coefficients have been defined. Approximate crop coefficients (Kc's) were used. Note that conservation calculations of this type can only be developed for species with sensitivity coefficients and coefficients have not been extensively developed for landscape species. This necessitates the use of similar species, often grown in a forage cropping environment, for these types of calculations. A range of species are included to represent differing levels of applied water and salt sensitivity (two of the main determinants of conservation potential). Conservation potential in the examples ranged from 47 (for a relatively tolerant species) to 117 a-f/y (for a sensitive species with relatively high water demand) on 1000 acres. Two levels of reduction in water supply salinity were

12

evaluated. Conservation potential was approximately doubled when the reduction in water supply salinity was doubled.

Table 3-3. Example theoretical conservation amounts for various landscape types with defined sensitivity thresholds.			Water Supply Salinity		Leaching			
Landscape type	ECe Threshold	ETc	Before	After	Before	After	Conservation	
(species)	(ds/m)	(in/y)	(mg/L, TDS)		(inches/year)			(a-f/y on 1000 a)
Bermuda	14.7	63	900	600	1.8	1.2	0.6	51
Fescue, tall	13.3	53	900	600	1.6	1.1	0.6	47
Ryegrass, perennial	12.2	53	900	600	1.8	1.2	0.6	52
Clover, strawberry	5.7	48	900	600	3.8	2.4	1.4	117
Strawberry	2.5	29	900	600	4.3	3.5	0.8	65
Bermuda	14.7	63	900	750	1.8	1.5	0.3	26
Fescue, tall	13.3	53	900	750	1.6	1.3	0.3	24
Ryegrass, perennial	12.2	53	900	750	1.8	1.5	0.3	26
Clover, strawberry	5.7	48	900	750	3.8	3.1	0.7	60
Strawberry	2.5	29	900	750	6.1	4.7	1.4	117

As an example of how these calculations were made, Table 3- 4 shows the equations from Table 3-1 filled in for specific values. For the first line, the numbers would fit into the equations from Table 1 as follows:

For line 1 (assuming that leaching fractions are determined by formulae, not user input and raw irrigator behavior):

EC_w before = 900 mg/L * (dS/m/(640 mg/L) = 1.4 dS/m

LF before = EC_w before/(5*EC_e target - EC_w after) = 1.4 dS/m/(5 * 9.8 dS/m -1.4 dS/m) =2.95%

Leaching depth before in/y = (ETc - EP) * LF before = (62.8 in/y - 4.9 in/y) * 2.95% = 1.8 in/y

EC_w after = 600 mg/L * (dS/m/(640 mg/L) = 0.9 dS/m

LF after = EC_w after/(5*EC_e target - EC_w after) = 0.9 dS/m/(5 * 9.8 dS/m -0.9 dS/m) =1.95%

Leaching depth after in/y = (ETc - EP) * LF after = (62.8 in/y - 4.9 in/y) * 1.95% = 1.2 in/y

Conservation in/y = 1.8 - 1.2 = 0.6 in/y

Conservation a-f/y on 1000 acres = 1000 acres * 0.6 in/y * ft/12 in = 51 a-f/y

Economic Formulae to Estimate Impacts of Reduced TDS

The price of water to agencies and to customers, multiplied by the rate of conservation, gives the financial savings in water purchase price associated with conservation and the economics are discussed in Section 6 of this Study. Other factors include:

- The cost of outreach and extension
- Cost of altering irrigation systems where this is anticipated
- Changes in landscape quality (usually positive) that result from irrigation system upgrades, along with their value
- Other costs and benefits

One example of another economic factor related to irrigation is the cost of regulatory programs that increasingly affect irrigators. Basin-level management of salinity is an increasing regulatory focus in California (SWRCB, 2009). Water management entities are now required to develop salt/nutrient management plans that describe how and where salt will be retained and tolerated within the basin, or exported in an environmentally sound manner. The cost of implementing these plans will, to some extent, depend on the salt load imported into a basin. Thus, reductions in salinity of imported water have real potential to reduce these costs.

In addition to bulk salinity, specific ions that compose salinity (e.g., sodium, chloride, boron) can affect plants. Mainly, at elevated concentrations, they (like bulk salt) tend to damage sensitive species. Although levels vary widely among different water sources, specific ion concentrations are loosely correlated with salinity. Thus, when more dilute water is delivered to irrigators, the risk of damage and loss due to specific ions declines, benefiting irrigators.

Mapping of Landscape Features

MWD is in the process of mapping large landscape areas (see Figure 3-3). When complete, this acreage will need to be classified by irrigation regime and then potential water conservation can be a calculated. The general form of the conservation calculation for individual lots is as follows:

Area (acres) * Leaching differential (inches/year) / (foot/12 inches) = Conservation (acre-feet/year)

Initial leaching of irrigation water (inches/year) – final leaching of irrigation water (inches/year) = Leaching differential (inches/year)

Leaching (inches/year) – Leaching by rainfall (inches/year) = Leaching of irrigation water (inches/year)

For example, there are approximately 40,000 acres of golf course land use identified in the land use data within MWD's service area thus far. Assuming 66% is irrigated turf and we have an irrigation requirement of 106,000 acre-feet per year (assuming the typical application rate for golf courses 4 ac-ft/ac/yr). If the leaching fraction is 15%, that equates to 16,000 acre-feet of leaching, some of which could be conserved.

Sample Large Landscapes from SCAG/SANDAG Landuses

DRAFT 3/20/14
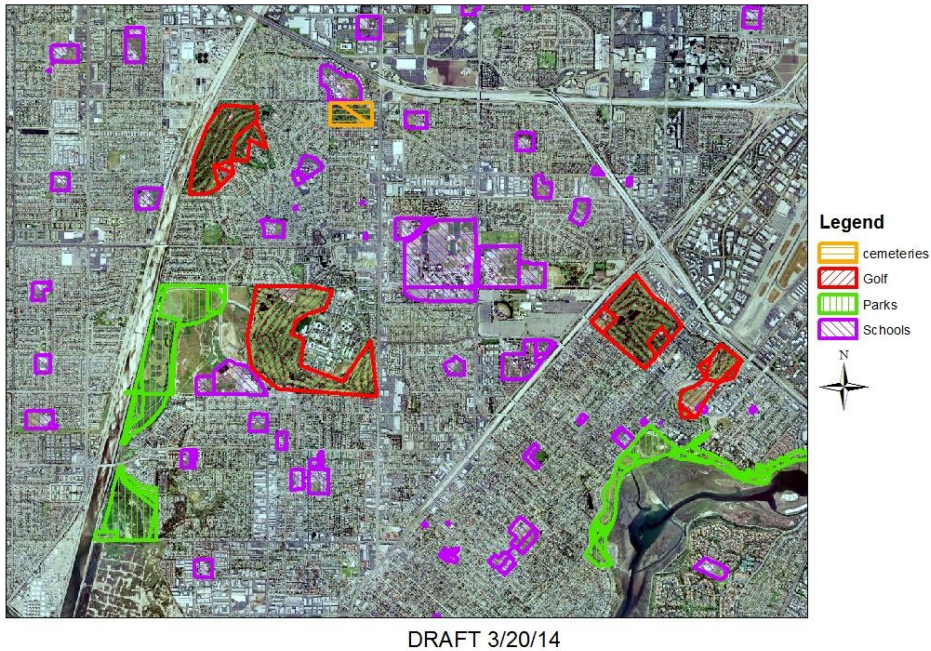
Figure 3-3. Illustration of ongoing landscape mapping.

Conclusions

The greatest potential to conserve irrigation water is in areas with the greatest demand and the most salt-sensitive landscapes. Realization of this potential depends completely on the ability of irrigation managers to respond knowledgeably to the change in water supply quality. Programs to inform irrigators might also realize latent conservation potential, where current practice is less efficient than it could be. In addition to large landscape irrigators, agricultural and small landscape irrigation may hold significant water conservation promise. Secondary benefits to recycled water and regulatory programs, where salinity is often a challenge, might be pronounced. Additional programs to conserve water have been identified and are discussed in Section 6.

4.0 WATER SOFTENER AND REVERSE OSMOSIS ASSESSMENT

Salinity is a major water quality problem in the southwestern United States. High salinity levels, typically measured as TDS, and defined as a water supply with a TDS level greater than 500 mg/l, affects the uses of water, causes pipes to corrode, spotting on dishes, increases household detergent use and causes the water to taste bitter and salty. Homeowners often respond to these challenges with the installation of water softening devices to improve the water quality. The use of high salinity water also becomes limited for many commercial and industrial applications and installation of pretreatment technologies such as water softeners and reverse osmosis units become necessary.

With the onset of drought, the potable water supply has become more stressed and California has become heavily reliant on water conservation measures. A number of studies have been conducted to help identify and better understand sources of salinity and its impacts on household appliances, commercial and industrial uses and the overall water supply. The benefits of reducing the salinity have been identified and economic factors have been applied to help better quantify the benefits of salinity reduction and damages in terms of dollars (Edmonston, 1999). However, the water savings and avoided costs by lowering salinity levels, due simply to lower rates of water consumption have not been quantified.

The primary objective of this task was to quantify the potential water savings that may be realized from the use of residential, commercial and industrial water softening devices if the salinity levels in the delivered potable water supply were lowered, identify additional water saving approaches and conservation measures, determine the potential cost savings associated with the water savings and identify, water saving approaches and recommendations for conservation.

Methods and Assumptions

A number of assumptions must be made in the variables in order to determine the water savings that could be realized from the use of household, commercial and industrial water softening/water treatment devices if the salinity in the source water were incrementally reduced. Those assumptions include: 1) type of water softeners/water treatment devices being used, 2) The percentage of residential households within the study service area that have water softeners 3) the average amount of water that is utilized to backwash the softening devices during regeneration, 4) how often regeneration occurs 5) the average number of individuals per household and water use per household and 6) human factors. Examples of human factors considered: 1) Are the water softeners programmed properly for the actual salinity in the potable water supply, and, if the salinity in the potable water is reduced, 2) will residents stop using water softening devices. The development of these assumptions and derivations are described in the paragraphs below.

Water savings where water softening and water treatment devices are being used in commercial and industrial applications are not as easily derived since water quality needs and water use varies significantly depending on the industry and developing gross assumptions on the variables with the

limited information available will not provide defendable water saving projections. Thereforean attempt was not made to quantify the water savings for commercial and industrial applications and instead make recommendations for future research and how those water savings may best be determined.

A. Residential Water Softeners

There are three types of water treatment devices that are used in the residential sector today:

1. <u>Self-regenerating water softeners</u> – Self regenerating water softeners on the market today use resin beds that consist of resin beads that exchange primarily the calcium and magnesium ions in the incoming water supply for sodium. This decreases the hardness in the water supply without increasing the overall TDS. Water is then used to rinse the resin beads and the water is discharged as a brine solution to the sanitary sewer system. The volume of water used in the rinsing process depends on a number of factors including: hardness of the drinking water supply, the volume of water being softened, age and efficiency of the water softener and whether the unit is controlled by a timer or on-demand. Timer based water softeners are no longer permitted in California and are not included in this water conservation analysis.

2. <u>Portable Exchange Units</u> - Portable exchange units operate similar to the self-regenerating units but have a removable ion exchange cartridge. When the resin beads are exhausted, the cartridge is taken to a central facility to be recharged eliminating the use of water at the home for cleaning and recharge. Therefore, these types of units are not included in this analysis.

3. <u>Reverse Osmosis</u> – Reverse osmosis (RO) systems use membrane technology to filter impurities such as minerals, calcium, chloride, sodium chloride, etc. from the incoming water supply. These systems may be whole house systems or small point of use systems. Research shows that the efficiency of these units vary depending on the RO unit but typically for every one gallon of water produced, three gallons are wasted (Aquacraft, 2011) and sent directly to the sewer with no beneficial use. The water conservation that may be realized from point of use RO systems are difficult to estimate where in the home the devices are installed and the market penetration are unknown. In addition, there are many variables that affect the efficiency of the RO units such as: water quality of the incoming water supply, how often the filters must be flushed or changed, if the homeowner changes the filters when required, etc. Therefore, for purposes of this study, the potential water savings was estimated based on whole house RO systems operating at 25% efficiency. A direct correlation specifically to changes in salinity in the potable water and its impact on filter efficiency has not been included.

The assumptions and formulae that were used to calculate the water savings from the use of self-regenerating residential water softeners are summarized in Table 4-1.

Table 4-1 - Assumptions and Variables for Determining Water Savings from Residential Self-Regenerating Water Softeners	
Assumptions and Equations:	
Average water use per day per household[a] (gallons)	369
Media capacity MC (gallons)[b]	48,000 and 60,000 prior to regeneration
Regeneration Rate R (Days)[c]	(MC *0.75)/(water hardness)/(water used per household)
Water used per regeneration cycle (gallons)[d]	50
Water used per household per year for water softener regeneration (gal/yr/household)	365/(R*water used per regeneration cycle)
[a]Awwa, 2013 Water Rate Survey, California-Nevada Section, 2014	
[b]Media capacity is sized by the water softener supplier based on household water use. Due to fouling, regeneration rates longer than 7 days is not recommended	
[c]Varies based on water hardness, media capacity and water used per household; water hardness in grains/per gallon	
[d] Salinity Characterization Study for the Carbon Canyon Water Recycling Facility, Inland Empire Utilities Agency, October 2006	

The assumptions and formulae that were used to initially calculate the water savings from the use of whole house RO systems are summarized in Table 2.

Table 4 -2 - Assumptions and Variables for Determining Water Savings from Residential Reverse Osmosis Units	
Assumptions and Equations:	
Average water use per household[a] (gallons)	369
Efficiency 25% - Water wasted per gallon of water produced (gallons) [b]	3
Water wasted per household per year to operate whole house RO System	(369*365*3) = 404,055 gal/yr/household
[a]AWWA, 2013 Water Rate Survey, California-Nevada Section, 2014 [b]California Single Family Water Use Efficiency Study, Aquacraft Water Engineering & Management, December 2011	

Findings

The amount of water that may be conserved as a result of reductions in salinity in the potable water supply when households are utilizing self-regenerating water softener devices depends on a number of variables and assumptions as listed in Table 4-1 above. Ultimately, if an assumption is made that all residential self-regenerating water softeners will be sized adequately to regenerate only every seven days based on the salinity of the source water supply (as recommended by water softener suppliers), then the variability of the media capacity is removed and the amount of water that would be used for water softener regeneration would be approximately 2,607 gallons per year per household. However, this is not a reasonable assumption as the size of the softener media capacities do not vary such that the units are regenerated exactly after seven days. The softener media capacities for a typical single family house are either 48,000 gallons or 60,000 gallons. Utilizing these media filtration capacities, the water used for softener regeneration and the potential incremental water savings are shown in Tables 4-3 and 4-4 respectively.

Table 4-3

Incremental Water Savings when Softener Media Capacity is 48,000 Gallons

Water Hardness		[1,2,3]Regeneration	Water Use per Regeneration	Water Used for Regeneration	[5]Incremental Water Savings
(grains/gal)	(mg/l)	(Days)	(gal)	(gal/yr/household)	(gal/yr/household)
29	500	3.34	50	5468	547
32	550	3.03		6015	547
35	600	2.78		6561	547
38	650	2.57		7108	547
41	700	2.38		7655	547
44	750	2.23		8202	547
47	800	2.09		8749	547
50	850	1.96		9295	547
53	900	1.85		9842	547
56	950	1.76		10389	547
58	1000	1.67		10936	

Assumptions:
[1]Average water use per household (11,220 gal/month*12/365) - 2013 Water Rate Survey, AWWA California-Nevada Section)
[2]The average household is assumed to have softener media that processes 48,000 gallons prior to regeneration;
[3]Regeneration occurs when media is 75% saturated
[4]Incremental Water Savings is the gallons of water saved per household per year when the hardness is decreased by 50 mg/l

Table 4-4

Incremental Water Savings when Softener Media Capacity is 60,000 Gallons

Water Hardness		[1,2,3]Regeneration	Water Use per Regeneration	Water Used for Regeneration	[4]Incremental Water Savings
(grains/gal)	(mg/l)	(Days)	(gal)	(gal/yr/household)	(gal/yr/household)
29	500	4.17	50	4376	438
32	550	3.79		4813	438
35	600	3.48		5251	438
38	650	3.21		5688	438
41	700	2.98		6126	438
44	750	2.78		6564	438
47	800	2.61		7001	438
50	850	2.45		7439	438
53	900	2.32		7876	438
56	950	2.20		8314	438
58	1000	2.09		8751	

Assumptions:
[1]Average water use per household (11,220 gal/month*12/365) - 2013 Water Rate Survey, AWWA California-Nevada Section)
[2]The average household is assumed to have softener media that processes 60,000 gallons prior to regeneration;
[3]Regeneration occurs when media is 75% saturated
[4]Incremental Water Savings is the gallons of water saved per household per year when the hardness is decreased by 50 mg/l

The incremental water that could be conserved if the media capacities are 48,000 and 60,000 gallons are 547 gal/year/household and 438 gal/year/household respectively for every 50 mg/L decrease in salinity (TDS) in the source supply. In addition, human factors such as altering the softener settings are difficult to quantify and are not captured in these calculations. While this amount may seem modest for a few hundred households, when multiplied by thousands of homes within MWD's service area that utilize self-regenerating water softeners, it can be a significant water savings as well as render the salinity contribution to the recycled water so high as to preclude its use for landscape irrigation.

The amount of water that may be conserved if whole house RO systems were eliminated in Southern California is approximately 404,055 gal/yr/household utilizing the assumptions and variables shown in Table 4-2.

Conclusions

This preliminary work suggests that significant amounts of potable water in Southern California may be conserved with reductions in potable water supply salinity and further reduced if whole house RO systems were eliminated. While it is not reasonable to reduce the salinity for the entire potable water supply within MWD's service area, other water saving approaches and programs to increase water conservation are discussed in Section 6. The greatest potentials to immediately conserve potable water supplies are calibrating existing self-regenerating water softeners to the salinity and the quantity of water being utilized and educating residents on the basin impacts. Another option is implementing newer water softening technologies that do not utilize salt and are less water intensive is another option.

5.0 ECONOMIC MODEL REVISIONS AND DEVELOPMENT

Introduction

The water savings projection methods were translated into equations then related to economic effects. It was found that for every 100 mg/L decrease in the salinity content of urban water supplies, households would experience a direct savings of $8.60 per year through decreased water use from water softeners and landscape irrigation. The existing Bureau of Reclamation (BOR) economic model was then supplemented with this information.

This section briefly summarizes the foundational pieces as well as the results of the BOR model. First, the BOR economic modeling, current and past, efforts are described. Secondly, the water saving projections and other results are described. The economic implications of those savings are then addressed. Finally, an approach for incorporating the collective work into the existing BOR mode was provided.

Economic Impact Model of Salinity

In 1971, the Environmental Protection Agency (EPA) released a report recommending the adoption of salinity criteria for water from the Colorado River. By 1975, the EPA had developed regulations limiting the amount of total dissolved solids at three locations; below the Hoover Dam (723 mg/L), below the Parker Dam (747 mg/L) and at the Imperial Dam (879 mg/L). As per federal regulations, these standards have been reviewed every three years.

In 1988, the BOR developed a model to estimate the economic impacts of salinity on residential, commercial, industrial and agricultural water users; and water and wastewater treatment and distribution facilities.[37]This model calculates annual replacement costs (e g. water heaters), additional costs (e.g. bottled water purchases) or loss of income (e.g. agricultural crops) attributed to a given TDS level.

In 1999, the Metropolitan Water District of Southern California and the BOR published The Economic Impact of Changes in Water Supply Salinity report and the Salinity Economic Impact Model.[7] This model is an update to the Southern California portion of the BOR's 1988 model. The 1999 model includes economic impacts of changes in water supply salinity upon residential, commercial, industrial and agricultural water users, groundwater, water recycling and water and wastewater utilities.

In 2004, the BOR produced a technical memorandum on the salinity model spreadsheet. This memorandum acted as a guidebook to describe the previous work done on the model, explain how the spreadsheet model works, its data requirements and present the most current damage estimates based on the latest water salinity levels. No changes were made to the structure of the model.

The BOR model was updated again in 2008 to reflect 2008 prices for replacement or additional costs incurred due to salinity. Again, no changes were made to the structure of the model at that time.

Potential Water Savings from Lower Salinity: Water Softeners

The water savings for self-regenerating residential water softeners as a result of declining salinity levels was examined. For self-regenerating water softeners, there is a direct correlation between the salinity of the incoming water and the amount of water used in the water softening process. Self-regenerating water softeners replace the calcium and magnesium ions in the incoming water with sodium to soften the water. After the water softener reaches its calcium and magnesium capacity, it must be rinsed with water. During this regeneration cycle, the rinsing water is discharged directly into the sewer system. With lower salinity, the regeneration cycle does not occur as often, resulting in water savings. There is a linear relationship between the amount of salinity in the water and the amount of water flushed in the softening process. The amount of flushing water required is based on the household water use, the size of the water softener tank and the water use per regeneration cycle. For example, the incremental water savings from a 50 mg/l decrease in potable water salinity is 547gallons per household per year for a household with water use of 369 gallons per day, and a water softener with a 48 thousand gallon tank capacity and a regeneration cycle that uses 50 gallons per cycle.

The project team transformed the equations discussed in Section 4 into a single equation based on the household water use, the size of the water softener tank and the water use per regeneration cycle, to facilitate incorporation into the BOR salinity model. The transformed water softener equation is presented in Table 1.

Table 5-1.
Quantified Relationship between Water Softeners, Salinity and Water Use

Water Softener Equation
Water Use for Regeneration =365 / ((Gallons per Regeneration Cycle * 0.75) / (Hardness / milligrams per liter to grains per gallon conversion) / (Water Use per Household)) * Water Use per Regeneration Cycle
Definitions:

Water Use for Regeneration:	The amount of water used to flush the water softener each year
Gallons per Regeneration Cycle:	The gallons of water that can be softened before a regeneration cycle is needed.
Hardness:	Salinity
Hardness Conversion:	The factor to convert milligrams per liter to grains per gallon (equal to 17.1)
Water Use per Household:	Gallons per household per day
Water Use per Regeneration Cycle:	The amount of water used to flush the water softener every regeneration

Source: URS Corporation, Conservation Potential of Salinity Mitigation Strategies Task 4 – Softener and RO Assessment Technical Memorandum, 2014; and HE, 2015.

Potential Water Savings from Lower Salinity: Landscapes

Increased salinity in irrigation water leads to increased salinity of soil, which makes it harder for plants to take up the water they need to grow and thrive. Excess salinity can reduce plant growth and, in the case of crops, yield. In landscape plants, excess salinity manifests itself in stunting, a less desirable appearance or even plant death if the salinity is severe enough. Landscape irrigators use leaching, the

application of more water to leach the salts down into the soil, below the plant root zone, to mitigate these harmful effects.

In addition to the salinity level, the leaching water requirements also varies by plant and soil type, as well as, local climate conditions. A model to calculate the decrease in leaching water necessary across an array of plant types for a decrease in irrigation water salinity. There is not a linear relationship between the TDS and plant growth (or leaching water required). The leaching water requirement must be calculated for the baseline water salt content conditions (plant type, soil type, evapotranspirative demand, plant condition, etc.), then recalculated for the changed content of salt in the water. The difference in the two is the water savings from reduced salinity. Equations in the model were combined into a single equation for easier inclusion into the larger BOR model and adapted to deal with changing plant species. The landscape equation is displayed in Table 5-2.

Table 5-2.
Quantified Relationship between Water Softeners, Salinity and Water Use

Landscape Equation
Leaching Water = $((ET_o * K_c) - (AP * .75)) / (1 - ((TDS / 640) / (5 * (100 + A * B - RY) / B) - (TDS / 640))) - ((ET_o * K_c) - (AP * .75))$

Definitions:

ETo	Total Evapotranspiration
Kc	Crop Coefficient for Evapotranspiration
AP	Annual Precipitation
TDS	Salinity
A	Threshold ECe at which RY begins to decline
B	Rate of Decline in RY with increase in ECe above A
RY	Crop Yield Relative to 100% Yield Potential

Source: PlanTierra, TASK 3 - Large Landscape Assessment for the Conservation Potential of Salinity Mitigation Strategies Project Technical Memorandum, 2015; and HE, 2015.

Table 5-2's equation calculates the amount of water saved, not the economic value. Utilities incur costs of treating recycled water, and in marketing it to customers. With reduced salinity in potable water supplies, recycled water salinity would also decline, rendering it more marketable and benefiting the bottom line of recycling programs.

Economic Impact of Salinity-Related Water Savings

The monetary savings associated with the water savings were then calculated. Consistent with the BOR model, only direct impacts were considered (i.e. the impacts to the household that uses less water), not the potential impacts to the overall economy if dollars saved were spent on other goods and services.

Water Softeners

Following the work completed in Section 4, a water use of 50 gallons per regeneration cycle and the amount of water used by a household per day of approximately 370 gallons was assumed for further calculations.[3] The water use equation for water softeners was applied to varying salinity levels. The water savings for a decrease of 100 mg/L is about 1,100 gallons per year for a typical household. Due to the linear relationship between water hardness and water wasted by softeners the water savings for a 100 mg/L decrease in salinity remain the same if the salinity decline is from 900 to 800 mg/L or from 400 to 300 mg/L.

To determine the value of the water saved, the amount of water saved was multiplied by the marginal cost of water to a typical household. It was determined that the marginal cost of water for Southern California was $3.30 per thousand gallons.[3] At this price, the savings of about 1,100 gallons is worth $3.61 to a household. These results are presented in Table 5-3.

Table 5-3.

Amount and Value of Water Savings for a Water Softener from a 100 mg/L Decrease in Salinity

Hardness (mg/L)	Water Use for Regeneration (gal)	Incremental Water Savings (gal)	Value of Water Savings ($)
1000	10,936	NA	NA
900	9,842	1,094	$3.61
800	8,749	1,094	$3.61
700	7,655	1,094	$3.61
600	6,561	1,094	$3.61
500	5,468	1,094	$3.61
400	4,374	1,094	$3.61
300	3,281	1,094	$3.61
200	2,187	1,094	$3.61
100	1,094	1,094	$3.61

Note: Assumes a 48,000 gallon capacity water softener

Source: URS Corporation, Conservation Potential of Salinity Mitigation Strategies Task 4 – Softener and RO Assessment Technical Memorandum, 2014; and HE, 2015.

Landscape Irrigation.

Following the work in Section 3, the amount of water saved and its value from a 100 mg/L reduction in salinity for lawn, parks and golf course irrigation water was quantified. It was determined the average lawn size for single family homes in the Los Angeles area to be approximately one quarter acre per single family housing unit.[43, 60] The parkland and golf course land per household in the Los Angeles area

was estimated to be about one twentieth of an acre per single family housing unit.[53]Overall, there is about one third of an acre of greenspace per single family housing unit in the Los Angeles area.

The main species of grass used in the project area are Bermuda grass, tall fescue, perennial ryegrass and Bentgrass. Bermuda grass is by far the most planted species, often mixed with fescue or ryegrass. The main use of these latter two grasses is principally for over-seeding Bermuda grass. Bentgrass is a specialty grass that is capable of withstanding low mowing heights. Due to the difficulty maintaining it, it is only used for putting greens and other areas where short grass is required. Bermuda grass, fescue and ryegrass have similar salinity response characteristics, while the Bentgrass is very salt intolerant. HE assumed that the mixture of grasses is 75 percent Bermuda grass, 12 percent for each of fescue and ryegrass and 1 percent Bentgrass.

Unlike a water softener, plants do not show the same response to a decrease in salinity at every level of salinity; the equation is non-linear. In general, the higher the salinity (i.e. the more stressed the plant is), the greater the impact a given level of salinity decrease will have on plant health. For the three more common grasses, the difference in water saved between a drop from 900 mg/L to 800 mg/L and a drop from 200 mg/L to 100 mg/L is about 10 percent. However, for Bentgrass, the difference in water saved for the same set of circumstances is over 20 percent. A 100 mg/L decrease from 600 mg/L to 500 mg/L for the value calculations was assumed.

The water savings were multiplied by the current marginal price of water for Southern California, $3.30. The results are shown in Table 5-4.

Table 5-4.
Amount and Value of Water Savings for Greenspace Irrigation
from a 100 mg/L Decrease in Salinity

Species	Water Saved (gal/yr)	Annual Savings per Houshold per Year	Grass Mixture Weights
Bermuda	1,435	$4.74	75%
Fescue	1,596	$5.27	12%
Ryegrass	1,760	$5.81	12%
Bentgrass	3,440	$11.35	1%
Weighted Average Annual Savings per Household per Year			
$4.99			

Note: The 100 mg/L drop in salinity was from 600 mg/L to 500 mg/L.

Source: PlanTierra, TASK 3 - Large Landscape Assessment for the Conservation Potential of Salinity Mitigation Strategies Project Technical Memorandum, 2015; and HE, 2015.

Adding the $3.61 to the $4.99 results in a total savings of $8.60 savings per household per year for a 100 mg/L decrease in salinity levels attributable to water softeners and landscaping respectively. This is a small savings for individual households, but once aggregated across all the Southern California households, the monetary savings is noteworthy.

This is a very conservative measure of the economic benefits related to lower salinity, water softeners, and landscaping:

- ✓ If potable water is saved, water utilities can reap benefits of lower costs or take advantage of additional water sales, perhaps accommodating more customers. These benefits should at least offset lower revenues from the water conservation.

- ✓ Water utilities will also be in a better position to meet water conservation goals.

- ✓ Lower salinity levels have a multiplier effect. Lower salinity return flows from landscaping and households can benefit downstream users, hence the benefits are cumulative.

- ✓ Economic benefits from an outside influence, like reduced salinity, can have economic multiplier effects as well. Not only do households have lower operating costs, they spend that money buying goods and services which are a benefit to the economy of Southern California.

- ✓ Economic effects outside the residential sector were not considered in this work. Certainly, commercial and industrial savings would also be evident.

Proposed incorporation of water softener and landscape water savings in the Existing BOR economic model

The work described in this paper can be incorporated into the existing BOR model. The equations previously described can be transformed to modules. These will require the provision of parameters either from other parts of the model or independently provided. These parameters are identified in Table 5-5.

Table 5-5.
Exogenous Parameters for the Landscape and Water Softener Modules

Landscape	Water Softeners
• Change in Salinity	• Level of Salinity
• Total Evapotranspiration	• Household Water Use
• Annual Precipitation	• Gallons per Regeneration Cycle**
• Plant Type	• Water Use per Regeneration Cycle**
• Acres Covered by Plant Type	• Proportion of Households with a Water Softener
• Yield Reduction Percentage*	
• Salinity Impact Threshold*	
• Rate of Decline*	

Note: * These parameters are plant specific and are provided in the PlanTierra work. A lookup table with the values for these parameters would be added to the BOR model as part of inserting the modules.
** These parameters depend on the size of the water softener. To aggregate across all households, an average size would likely be assumed.

Source: URS Corporation, Conservation Potential of Salinity Mitigation Strategies Task 4 – Softener and RO Assessment Technical Memorandum, 2014; PlanTierra, TASK 3 - Large Landscape Assessment for the Conservation Potential of Salinity Mitigation Strategies Project Technical Memorandum, 2015; HE, 2015.

The equations calculate the extra water required due to salinity, which should be multiplied by a price to determine the economic impact. That additional price parameter would be needed for both calculations. This parameter would have to be passed from elsewhere within the BOR model or included in the modules if it is not already included in the BOR model.

Since the existing BOR model is a spreadsheet, new tabs would be created to insert the modules. For both the water softener and landscape equations, links would be established to incorporate the proper parameters to the tab containing the relevant equation. The calculations would be performed in each tab, resulting in an estimate of the economic impact of a given salinity level (or change in salinity level) on water use in either water softeners or for landscapes. This economic impact would then be linked back into the existing section of the BOR model where the various economic impacts are aggregated into the total economic impact.

6.0   POTENTIAL COST EFFECTIVE WATER SAVING APPROACHES

In addition to conservation potential due to changes in water supply salinity, several other opportunities for water conservation were identified during the course of the study and are briefly discussed. The focus of this work was narrower.   A thorough review and/or quantification of these additional opportunities for water conservation and future studies were beyond the scope of this study but are included to make the study more complete.

Landscape Irrigation

Education and Outreach to Irrigators - Irrigator behavior and response are important to conservation. If irrigation *practices* do not change when the amount of water required to maintain soil salinity levels within the range tolerated by plants changes, then conservation is not achieved. It is also true that conservation opportunities exist where irrigators currently over-irrigate. Modification of irrigator behavior could be achieved through outreach and education programs, which are beyond the scope of this study. However, they are acknowledged to be essential to reaching water conservation goals. Some water districts have irrigator outreach programs. These can be utilized to extend information regarding changes to water supply quality, as well as, the means and methods by which irrigators ought to respond in order to realize the full benefit of the improvements (Dickey, 2014). Additional tools to assist irrigators in adapting to lower levels of salinity might include the following:

- Identify and diagnose wasteful irrigation practices. Examples of tools for this include review of water use records relative to known irrigated areas and estimated demand, remote sensing of evapotranspiration rates and surveys of irrigators.
- Facilitation of soil testing to improve understanding of landscape area soil salinity to inform irrigation practices. Mobile tools for mapping soil salinity may be particularly useful for this purpose (Rhoades et al., 1997).
- Basic information regarding changes in water quality and how they are anticipated to influence salinity and irrigation management. For example, in addition to reducing leaching, irrigators may need to take additional care to avoid impacts from sodicity in fine-textured soils. Figure 6-4 illustrates how this relates to irrigation supply water chemistry in a specific case.
- Utilization and reinforcement of existing programs to ensure that irrigators have access to, and properly employ irrigation scheduling tools and information (e.g., ITRC, 2003).
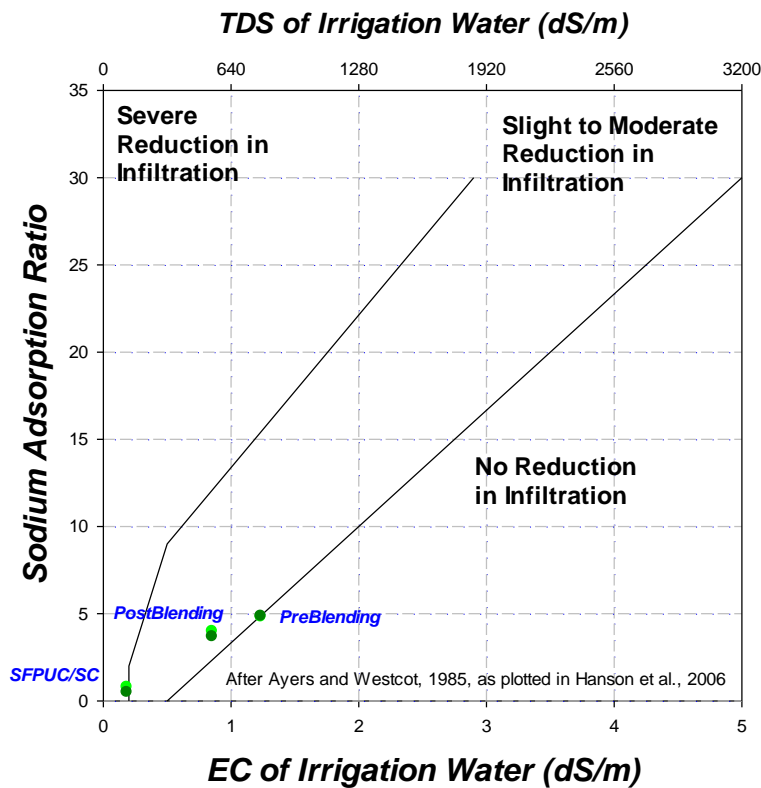
Figure 6-4. Comparison of pre- and post-project water quality, when water of extremely low salinity is blended into a recycled water supply. Sodium adsorption ratio (SAR) and adjusted SAR (light green points) values are shown. While generally beneficial (especially to salt-sensitive plants), more dilute water may require some care when irrigating fine-textured soils, to avoid reductions in infiltration, even when the SAR of the blend remains constant or declines. Comparison to San Francisco's water supply (the left-most points) illustrates that this is a problem that can arise with any dilute irrigation source water.

Agriculture and Small Landscape - The primary reason the project focuses on large landscape irrigation is the large volume of water leads to a large potential to conserve. The same can be said for agricultural customers. In addition, several of the crops grown widely in Southern California are highly sensitive to salinity (e.g., avocado, citrus, and strawberry). It has already been established that the conservation potential of sensitive crops is relatively high, other things being equal. Small landscape areas, while more fragmented than large landscapes, constitute a substantial portion of the land area and therefore water demand. Where homeowners are sensitized and subsidized, rapid changes in landscape irrigation have occurred, primarily through the planting of low-consumption species and installation of low-volume, high efficiency (e.g., drip) irrigation.

Recycled Water - Recycled water programs often struggle with supplies that are marginal (nearly too saline) for irrigation of sensitive landscape species. Salinity in recycled water supplies is directly related to salt load in wastewater, which is influenced by potable water supply salinity, along with salt load that is added by, for example, water softeners. Reductions in these salt loads would reduce salinity of

recycled water, generating secondary (landscape quality, conservation) benefits where these supplies are used for landscape irrigation.

Water Softening

Preliminary work contained in the previous sections indicates that significant quantities of potable water could be conserved in the residential sector with the elimination of self-regenerating water softeners and whole house RO systems. While immediate and complete elimination of these systems is not a reasonable undertaking, other approaches and combinations thereof that may be considered are as listed:

Education Programs – Educating the public on potable water quality, the pros and cons of water softener and RO usage and their impacts on future water supplies.

Ordinances – Encourage water agencies and municipalities to pass salinity reduction and/or water softener ordinances and offer alternatives to and incentives to remove water softeners.

Rebate Programs - Encourage water agencies and municipalities to undertake rebate programs to exchange whole house RO systems and/or self-regenerating water softeners for other less water intensive softening devices that do not introduce salinity into the sewer system. The Inland Empire Utilities Agency and The Santa Clarita Valley Sanitation District of Los Angeles County already have programs. There are new technologies coming on the market that may achieve these goals.

Commercial/Industrial Water Audits – Some water agencies provide incentives and water audit services to commercial and industrial customers utilizing water softeners and/or water filtration systems so that areas for water conservation and recycling within the facilities may be identified. These efforts should continue. This may be a collaborative effort between water and sanitation agencies since both will be benefitting. Industries to target include oil and gas, food and beverage, biomedical, carpet and fabric dying facilities, textile, etc.

Test and Identify Alternative Water Softening Devices or Methods – There are new technologies that come on the market that claim to soften water without the use of salt, addition of chemicals or increase water use. Some of the solutions that warrant additional research include:

- Chelating Devices – These types of devices do not soften the water but instead make the hard minerals soluble through chelation, preventing scaling and damage to appliances.

- Electromagnetic Devices – These devices emit low frequency electromagnetic pulses through pipes that stop scaling of mineral salts. It does not soften the water.

- Water Conditioning and Filtration Devices – Whole house filtration devices that utilize a natural technology by using a polyphosphate additive, Siliphos which inhibits scale deposits.

APPENDIX A – LITERATURE REVIEW