Study to Evaluate Long-Term Trends and Variations in the Average Total Dissolved Solids Concentration in Wastewater and Recycled Water

Funding Agency: Southern California Salinity Coalition

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Daniel B. Stephens & Associates, Inc.

3150 Bristol Street, Suite 210 • Costa Mesa, California 92626

Mission Statement

SCSC is a coalition of water and wastewater agencies in Southern California dedicated to managing salinity in our water supplies.

SCSC is administrated by the National Water Research Institute and consists of the following member agencies:

Eastern Municipal Water District

Inland Empire Utilities Agency

Metropolitan Water District of Southern California

Orange County Sanitation District

Orange County Water District

San Diego County Water Authority

Sanitation Districts of Los Angeles County

Santa Ana Watershed Project Authority

Table of Contents

Section **Page**

Table of Contents (Continued)

Section **Page**

List of Figures

List of Tables

List of Appendices

List of Acronyms and Abbreviations

ac-ft/yr	acre-feet per year
AWWARF	American Water Works Association Research Foundation
BDCP	Bay Delta Conservation Plan
CED	California Executive Department
CRA	Colorado River Aqueduct
CUWA	California Urban Water Agencies
DWR	California Department of Water Resources
DBS&A	Daniel B. Stephens & Associates, Inc.
EBMUD	East Bay Municipal Water Utilities District
EC	electrical conductivity
ENSO	El Niño Southern Oscillation
EMWD	Eastern Municipal Water District
EPA	U.S. Environmental Protection Agency
gpf	gallons per flush
gpcd	gallons per capita per day
gphd	gallons per household per day
HECW	high-efficiency clothes washer
HET	high-efficiency toilet
IEUA	Inland Empire Utilities Agency
IFU	increment from use
IGPCD	influent flow in gallons per capita per day
JOS	Joint Outfall System
JWPCP	Joint Water Pollution Control Plant
LACSD	Los Angeles County Sanitation District
mg/L	milligrams per liter
mgd	million gallons per day
MWDSC	Metropolitan Water District of Southern California
NOAA	National Oceanic and Atmospheric Administration
O&M	operation and maintenance
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
PDMWD	Padre Dam Municipal Water District
PDSI	Palmer Drought Severity Index

List of Acronyms and Abbreviations (Continued)

PMDI	Modified Palmer Drought Severity Index
POTW	publically owned treatment works
RIX	rapid infiltration and extraction facility
RPU	Riverside Public Utilities
RWQCP	Riverside Regional Water Quality Control Plant
SAWPA	Santa Ana River Watershed Project Authority
SCSC	Southern California Salinity Coalition
SCVSD	Santa Clarita Valley Sanitation District
SCVWD	Santa Clarita Valley Water District
SDCWA	San Diego County Water Authority
SML	salt mass load
SRWS	self-regenerating water softener(s)
STDS	source total dissolved solids concentration
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
ULFT	ultra-low-flow toilet
WRP	water reclamation plant
WWTP	wastewater treatment plant

Executive Summary

This report was funded by the Southern California Salinity Coalition (SCSC). SCSC and its member agencies are dedicated to managing salinity in the water supplies, wastewater, and recycled water. Member agencies include Eastern Municipal Water District (EMWD), Inland Empire Utilities Agency (IEUA), Metropolitan Water District of Southern California (MWDSC), Orange County Sanitation District (OCSD), Orange County Water District (OCWD), San Diego County Water Authority (SDCWA), Sanitation Districts of Los Angeles County (LACSD), and Santa Ana Watershed Project Authority (SAWPA). Daniel B. Stephens & Associates, Inc. (DBS&A) performed the analysis and is submitting this technical memorandum to address the research questions posed by SCSC and its member agencies.

The 2011 to 2016 drought in California, in conjunction with unprecedented statewide conservation legislation, caused several member agencies to face challenges meeting regulatory water quality standards for the salinity of discharge water from wastewater treatment plants (WWTPs). In particular, total dissolved solids (TDS) concentrations have increased, while the operation of WWTPs have remained consistent with prior years. Figure ES-1 is a typical example of TDS trends for WWTPs in Southern California.

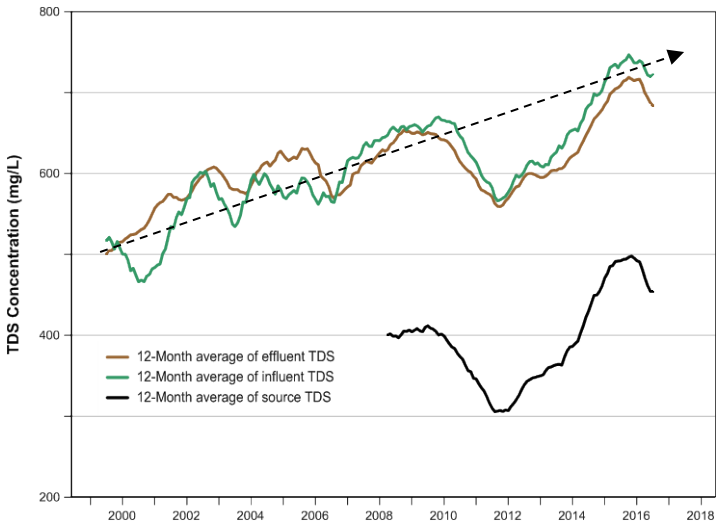

Figure ES-1. EMWD TDS Concentrations Trends

Long-term water quality trends of TDS in wastewater and wastewater effluent show an upward trend over the last several decades.

There is a growing concern among SCSC and its member agencies that long-term water quality trends of salinity in WWTPs are increasing, which would result in financial and operational burdens to the member agencies and their constituents.

This analysis considered a series of research questions, the purpose of which is to provide a quantitative understanding of the relationships among variables such as salt concentrations in municipal influent and treated effluent, drought, self-regenerating water softeners (SRWS), and the mandated implementation of water conservation practices that reduce per capita water use. The findings from this research will be of particular value to water supply and wastewater treatment and recycling agencies as they consider how changes in water quality and quantity may impact their ability to provide reliable, high-quality drinking water while complying with waste discharge requirements.

Two variables (volume-weighted source water TDS and indoor per capita water use) can predict with a high degree of statistical significance the TDS concentration of WWTP influent water use (Figure ES-2). However, the volume-weighted source water TDS concentration is the significant determiner of influent TDS. Source TDS explains more of the variability in influent/effluent TDS than any other factor, including decreased indoor water use, for the following reasons.

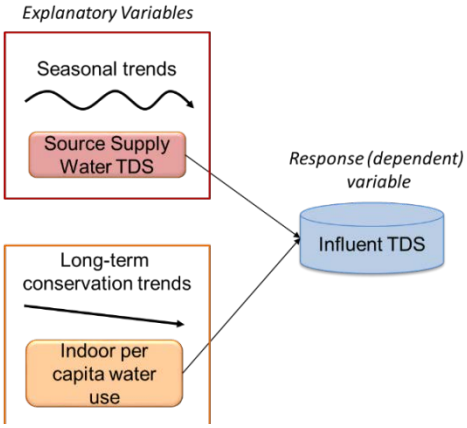

Figure ES-2. Model Variables for Influent TDS

- Source water supply trends are often cyclical, corresponding with climatic cycles such as the El Niño Southern Oscillation. Drought conditions negatively impact surface water quality and therefore imported water quality. TDS concentrations in the California State Water Project and Colorado River Aquifer can vary by 200 to 300 milligrams per liter (mg/L) from wet years to dry years.

- While this explanatory variable has a lower effect in the determination of influent TDS, long-term conservation accounts for an estimated increase of 1.2 mg/L to 1.7 mg/L in TDS for every 1.0 gallon per capita per day (gpcd) decrease in indoor per capita water use.

An unintended consequence of indoor water conservation is that for every 1 gpcd decline in indoor water use, there is a 1.2 to 1.7 mg/L increase in WWTP influent TDS.

Water Conservation in Southern California

Member agency indoor water use has decreased from 80–110 gpcd in the 1990s to 50–70 gpcd by 2016.

The population in California has doubled in the last 45 years and is expected to reach 50 million people by 2050. In the MWDSC service area alone, the population rose from 16.8 million to 18.7 million from 2000 to 2015. However, from 2000 to 2015, the potable water demands for 1.9 million additional people were met with the same total water supply. Not surprisingly, urban water use in Southern California region accounts for approximately 82 percent of the total water use, which is significantly higher than the state average of 11 percent urban use. Within the urban sector, there are five main categories of use: residential indoor, residential outdoor, commercial/institutional, industrial, and unaccounted for water (e.g., leaks). In this study, the WWTP influent flows were used to estimate indoor per capita water use for this study.

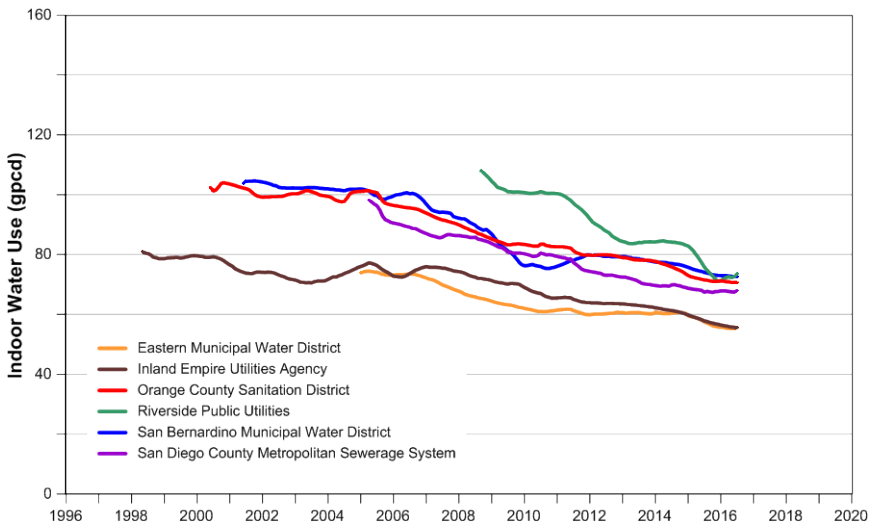

Figure ES-3. Indoor Per Capita Water Use Trends

Figure ES-3 shows the estimated indoor water use for six of the member agencies. Every member agency demonstrated a general decline in indoor per capita water use over a two-decade period. The average per capita indoor water use declined from a range of 80 to 110 gpcd in the 1990s to a range of 50 to 75 gpcd by 2016.

Other unintended consequences of water conservations measures include loss of revenue from water sales, less available recycled water, and increased infrastructure operations and maintenance costs. Unintended benefits include a reduction in energy costs and decreased greenhouse gas formation.

Under current legislation, California residences are expected to reduce per capita water use to 55 gpcd by 2025 (AB-968 Section 10608.25). Some members of SCSC have met this objective and suspect that they have reached a reasonable limit for indoor conservation measures and that it may be unrealistic to achieve lower per capita indoor water use at this time. Service areas that

have not reached this 55 gpcd goal will likely continue to see a downward trend in per capita water use. The implication for continued decrease in indoor per capita water use is that WWTP influent TDS will increase by an estimated 1.2 to 1.7 mg/L for every 1.0 gpcd decrease in indoor water use.

Climate Cycles and Source Supply Water

There is a strong inverse correlation between drought and imported water TDS concentrations - for both SWP water and CRA water. TDS concentration can vary by 300 mg/L from wet years to dry years for CRA water and by 200 mg/L for SWP water.

There is a strong inverse correlation between surface water quality and the long-term meteorological cycles, including drought cycles. One way to evaluate drought is through the Palmer Drought Severity Index (PDSI), established by the National Oceanic and Atmosphere Administration. While this study focuses on WWTPs in Southern California, a drought in Northern California can change TDS in source water supply in Southern California. Likewise, drought conditions in the Rocky Mountains affect TDS in the Colorado River. This analysis uses the drought index for the entire state of California as a generalization of drought conditions. Local drought indices will vary across hydrologic regions.

Another way to analyze long-term meteorological cycles is through the 8-Station Index. This method compares the annual precipitation of 8 key stations in Northern California to the annual average precipitation measured at these stations from 1966 to 2015. The 8-station index is used to help manage state water supplies, including how much low-salinity State Water Project (SWP) water is available to Southern California. Figure ES-4 compares the PMDI and 8-Station Index to surface supply water quality data for major reservoirs and treatment facilities operated by MWDSC. Time-series TDS concentrations are shown for Skinner Lake, Lake Mathews, Deimer WTP, and Weymouth WTP as part of the Colorado River Aqueduct, and for Mills, Silverwood Lake, Castaic Lake, and Jensen WTP as part of the SWP. Aside from Lake Mathews, which has a more gradual trend, all reservoirs show similar increases in TDS during periods of drought and decreases in TDS during wet years.

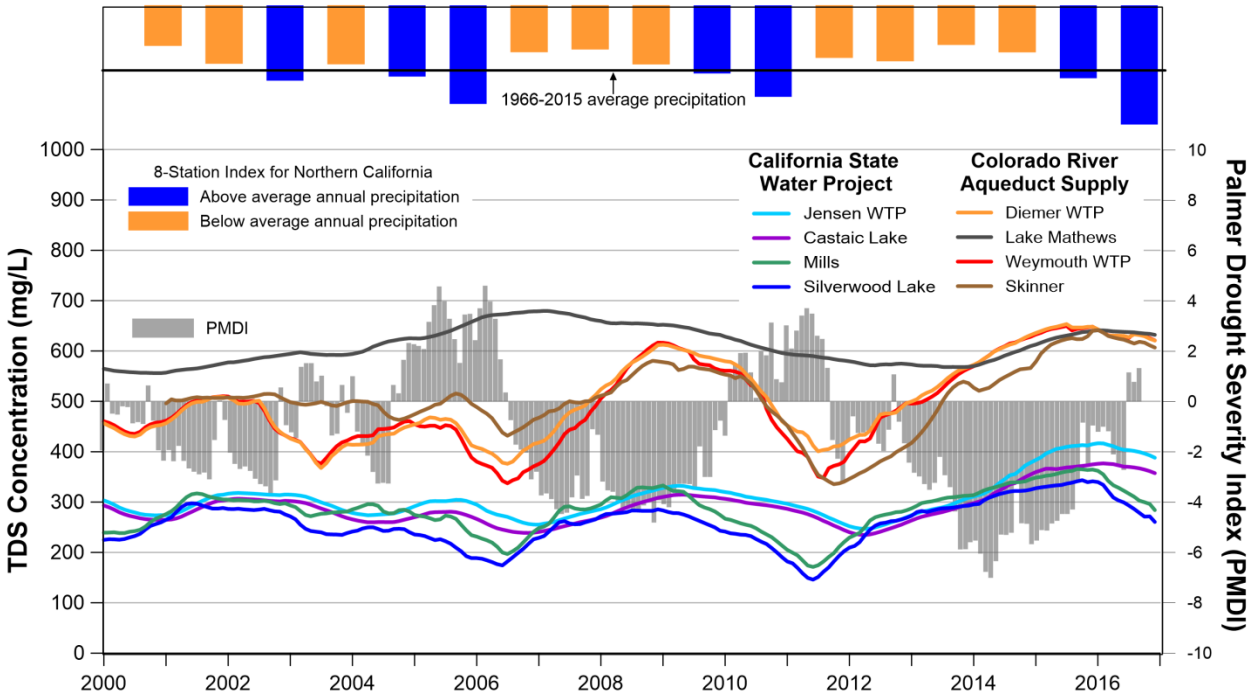

Figure ES-4. Palmer Drought Severity Index, 8-Station Index, and Surface Supply Water

Statistical Modeling of Influent TDS

> Multiple linear regression of source water TDS and indoor use can predict TDS concentrations entering WWTPs with a high degree of certainty.

A statistical model using multiple linear regression was used to assist in the interpretation of the data and to determine the degree to which variability can be attributed to one or more factors or variables. The multiple linear regression analysis included a response variable (influent TDS concentration) and explanatory variables (e.g., indoor per capita water use). The response variable is the factor or variable that is being modeled and is dependent on the explanatory variables. Changes in indoor per capita water use and source supply water quality are the variables that account for the majority of the variability in TDS concentrations and determine the influent water quality entering a WWTP. Most of the case studies found that TDS entering a WWTP nearly matched the discharge water quality from the WWTP's effluent. Therefore influent water quality is used as a proxy or surrogate to understand the WWTP effluent water quality.

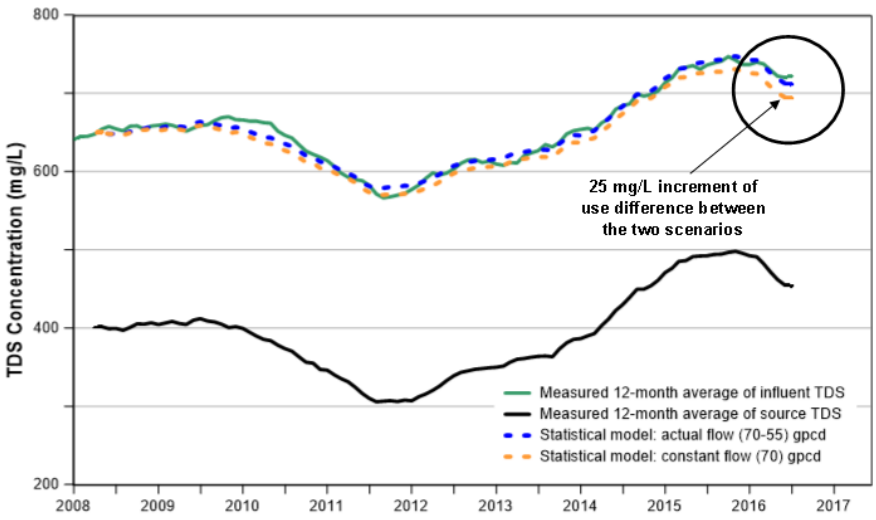

Figure ES-5. Statistical Model Results for EMWD

shows time-series TDS concentrations for the 12-month rolling average for the source water (shown as a black line) and for the wastewater that is influent to the WWTP (shown as a green line). The difference between these two lines is due to the salt added from indoor uses. The two explanatory variables—indoor per capita water use and volume-weighted source supply water TDS concentrations—were used in the multiple linear regression model. The statistical model was used to analyze the following two scenarios:

- "Statistical model actual flow" in blue. Indoor per capita water use gradually declined from 70 gpcd in 2008 to 55 gpcd in 2016.
- "Statistical model constant flow" in orange. Indoor per capita water use was held constant theoretically at 70 gpcd to represent conditions prior to statewide conservation efforts.

The difference in TDS concentrations between the two scenarios is a function of the increment from use (IFU). While the salt added from indoor uses is theoretically the same in the two scenarios, the volume of water used indoors is less, causing the influent TDS to be higher.

Self-Regenerating Water Softeners

The reduction in the number of SRWS units can significantly reduce the concentration of TDS in influent flows to the WWTPs. In a case study, SCVWD removed 8,000 SRWS units, thereby reducing the TDS in the WWTP influent flow by nearly 80 mg/L.

Beginning in 2002, the Santa Clarita Valley Sanitation District (SCVSD) imposed strict regulations to remove SRWS from use in order to reduce the chloride load entering the Santa Clarita River. It is estimated that more than 8,000 units were removed by 2014. An estimated salt load for an SRWS unit is 1.65 pounds of

salt per day per unit. The average flow for the SCVSD treatment facilities between 2002 and 2014 was 20 million gallon per day (mgd). Using the following equation (with the appropriate unit conversions), it is estimated that nearly 80 mg/L of TDS was removed from the system by removing SWRS units:

$$\text{TDS removed} = \frac{\text{Number of SWS units} \times 1.65 \text{ pounds of salt per day per unit}}{\text{Flow into the WWTP}}$$

Of the 26 WWTPs in the study that provided influent TDS data, only 4 WWTPs demonstrated a downward trend in TDS; the 2 WWTPs in the SCVSD are among those. The remaining WWTPs either demonstrated an upward trend or a flat trend. The downward trend in TDS concentrations over the study period for the WWTPs in the SCVSD service area are likely a result of the systematic removal of SRWS units.

1. Background and Understanding

This report was funded by the Southern California Salinity Coalition (SCSC). The objective of SCSC, which consists of water and wastewater agencies in southern California, is “to address the critical need to remove salt from water supplies and to preserve water resources in California” (SCSC, 2017). SCSC and its member agencies are dedicated to managing salinity in the water supplies, wastewater, and recycled water. Member agencies include Eastern Municipal Water District (EMWD), Inland Empire Utilities Agency (IEUA), Metropolitan Water District of Southern California (MWDSC), Orange County Sanitation District (OCSD), Orange County Water District (OCWD), San Diego County Water Authority (SDCWA), Sanitation Districts of Los Angeles County (LACSD), and Santa Ana Watershed Project Authority (SAWPA). Daniel B. Stephens & Associates, Inc. (DBS&A) performed the analysis and is submitting this technical memorandum to address the research questions posed by SCSC and its member agencies.

The water supply for Southern California originates from a variety of sources, both imported and local. In general, water is imported into the Southern California region from the Sacramento/ San Joaquin Delta through the State Water Project (SWP), from the Colorado River through the Colorado River Aqueduct (CRA), and from the Owens Valley/Mono Basin areas through the Los Angeles Aqueduct. Much of the imported water is then distributed to the SCSC member agencies through MWDSC. These imported sources supplement local water development projects (e.g., local surface water, groundwater [including treated and desalinated groundwater], recycled water, stormwater recharge, and desalinated seawater). Local agencies also implement conjunctive use programs (i.e., storage and recovery of imported water in groundwater basins and local surface reservoirs) to increase the reliability of local supplies during dry periods and in anticipation of interruptions in imported supply from catastrophic events. Local conservation efforts also support water supply needs by reducing the overall water demand in the region.

Water agencies routinely use a mix of imported and local water sources to meet their water supply needs at an acceptable water quality. The average water quality of these various water sources is known and can be managed to create an appropriate blend to control the level of

salinity in the delivered water and subsequent wastewater. However, changes in the blend of available sources of water, as well as fluctuations in their salinity, can alter typical expected salinity levels. For example, the 2013 California Water Plan (DWR, 2013) notes that all three key imported water sources for the southern California region will become less reliable sources of water—in terms of both quantity and quality—due to anticipated climate change impacts and requirements to address environmental concerns.

1.1 Indoor Water Use

Total water use can be separated into three main sectors of water use: urban, agricultural, and environmental—which includes the preservation of aquatic habitat and/or protection of endangered species. In 2010, the use of water in California was about 50 percent environmental, 40 percent agricultural, and 10 percent urban (Mount and Hanak, 2016). According to California Department of Water Resources (DWR), between 2001 and 2010, urban water use accounted for 9,084 acre-feet per year (ac-ft/yr), or approximately 11 percent of the total water use for the entire state of California. All of the member agencies for this study are within the South Coast DWR hydrologic region, which extends along the coast from Ventura to San Diego and eastward to San Bernardino. Urban water use in the South Coast hydrologic region accounts for approximately 82 percent of the total water use. For comparison, Table 1 shows the average water use by main sector for each of the DWR hydrologic regions for the period 2001 to 2010.

Within the urban sector, there are five main categories: residential indoor, residential outdoor, commercial/institutional, industrial, and unaccounted for water (i.e., leaks). Figure 1 is a simplified flow diagram that represents the water supplies that reach Southern California wastewater treatment plants (WWTPs). The gross water supply (source water) is split into two components: (1) water that will ultimately reach the WWTP and (2) water that reenters the environment through agriculture or irrigation, or is sent to brine lines. The component that reaches the WWTP consists of indoor residential, commercial, and industrial uses and represents the flow and quality of the WWTP influent.

Table 1. Average Water Use by Main Sectors by DWR Hydrologic Region, 2001–2010

DWR Hydrologic Region	Average Water Use (ac-ft/yr)		
	Environmental	Agricultural	Urban
North Coast	18,865	833	155
San Francisco Bay	24	123	1,192
Central Coast	101	1,066	305
South Coast	**127**	**769**	**4,162**
Sacramento River	13,690	8,664	904
San Joaquin River	3,067	7,415	674
Tulare Lake	1,560	10,832	744
North Lahontan	340	492	43
South Lahontan	81	382	278
Colorado River	30	4,001	627
Total	37,885	34,577	9,084

Source: DWR, 2013
ac-ft/yr = Acre-feet per year

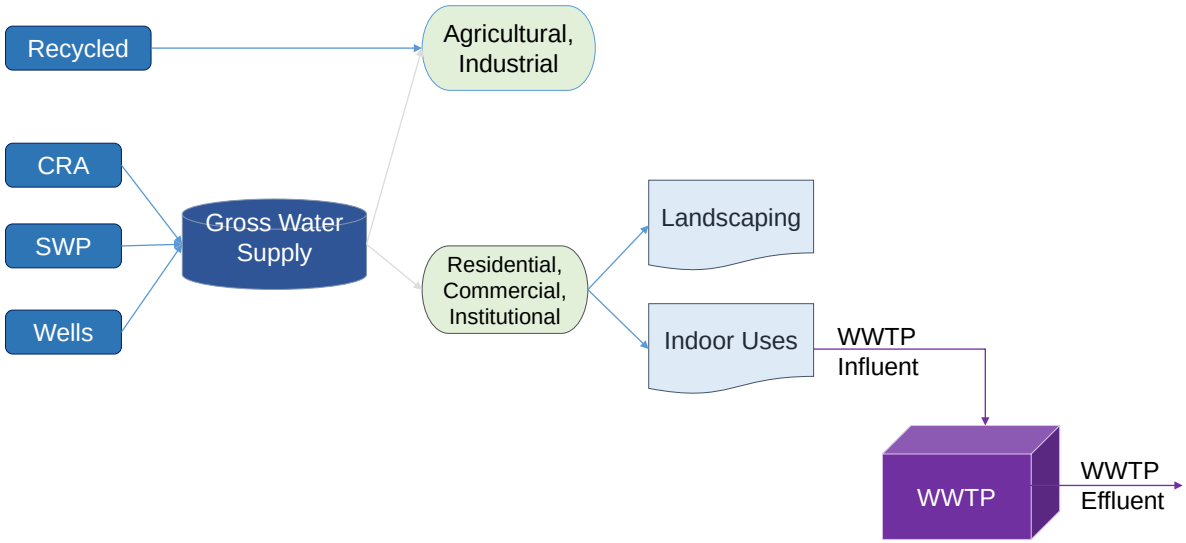

Figure 1. Flow Diagram of Water Supply and Water Uses for WWTPs

Water delivered for residential, commercial, and industrial sectors is used for both indoor and outdoor applications; in this study, indoor uses are analyzed because water used indoors becomes influent water to WWTPs (with the exception of leaks). DeOreo et al. (2017) found in their study that the split is about 53 percent outdoors and 47 percent indoors for a sample of

their study that the split is about 53 percent outdoors and 47 percent indoors for a sample of 735 single-family homes from 10 water agencies in California. In the 2017 study, the total annual water use was 362 gallons per household per day (gphd). Based on an average occupancy rate of 2.94 persons per home, the per capita total water use was 123 gallons per capita per day (gpcd); at 47 percent, the indoor use was 57.9 gpcd.

Mayer et al. (1999) described seven main indoor end uses of water, along with the per capita water use for each end use (Table 2).

Table 2. Seven Main Indoor End Uses

Indoor End Use of Water	Average Per Capita Water Use (gpcd)	Percentage of Use
Toilets	18.5	26.7%
Clothes washers	15	21.7%
Showers	11.6	16.8%
Leaks and other uses	11.1	15.9%
Faucets	10.9	15.7%
Baths	1.2	1.7%
Dishwashers	1.0	1.4%

Source: Mayer et al., 1999
gpcd = Gallons per capita per day

The total average indoor water use in Mayer et al. (1999) was 69.3 gpcd—across 1,188 study homes in 12 study sites. The range of total indoor water use was 57.1 gpcd in Seattle, Washington to 83.5 gpcd in Eugene, Oregon. In the period between the completion of the Mayer et al. (1999) study (date range from 1996 through 1998) and the DeOreo et al. (2017) study (date range 2005 through 2010), there was a 13 percent reduction in indoor water use. Toilets represent the largest indoor water use category, and DeOreo et al. (2017) report a 60 percent market penetration (i.e., by 2010, 60 percent of the units met ultra-low flow toilet [ULFT] standards of 1.6 gallons per flush [gpf]). Clothes washers using 30 gallons per load or less were installed in 30 percent of homes. Four of the categories (showers, faucets, leaks, and baths) showed increased use during this period, and dishwater and miscellaneous uses remained unchanged.

DeOreo et al. (2017) used the U.S. Environmental Protection Agency (EPA) post-retrofit study (U.S. EPA, 2005) as a water efficiency benchmark. The EPA post-retrofit study represents an analysis of homes in Seattle, Washington, Tampa, Florida, and the East Bay Municipal Water Utilities District (EBMUD) service area for the period 2000 through 2003. Two weeks of baseline water use data were collected before a subset of homes was retrofitted with high-efficiency fixtures and appliances. The average indoor use from the EPA post-retrofit study was 36.4 gpcd, although DeOreo et al. (2017) postulated that 41 gpcd was likely a more attainable benchmark. The average indoor water use in these studies is summarized in Table 3.

Table 3. Range of Indoor Water Use

Study	Study Period	Reference	Average Indoor Water Use	
			gphd	gpcd
REUWS (California)	1996–1998	Mayer et al. (1999)	186	63.3
California single-family home study	2005–2010	DeOreo et al. (2017)	175	59.5
EPA post-retrofit study	2000–2003	U.S. EPA (2005)	107	36.4

gphd = Gallons per household per day
gpcd = Gallons per capita per day

1.2 Directives to Increase Water Recycling and Conservation

Beginning in 2009, statewide government directives provided for an increase in water recycling and conservation (Recycled Water Policy of 2009 [SWRCB, 2009] and the Water Conservation Act of 2009 [Senate Bill (SB) X7-7] [DWR, 2009]). Additionally the Governor of California issued executive orders between 2014 and 2016 (B-28-14, B-29-15, and B-37-16) designed to conserve water statewide. These directives need to be considered in long-range planning of water supplies, including the potential impact that these changes have on the salinity of wastewater influent to treatment plants. The following is a brief discussion of key government directives that have influenced or are influencing water supply planning.

The State Water Resources Control Board (SWRCB) adopted Recycled Water Policy in 2009 (Resolution No. 2009-0011 [SWRCB, 2009], as amended in Resolution No. 2013-0003 [SWRCB, 2013]). The Recycled Water Policy directs the State Water Board and the Regional

Water Quality Control Boards (Regional Boards) to "exercise the authority granted to them by the state legislature to the fullest extent possible to encourage the use of recycled water, consistent with state and federal water quality laws" so that water suppliers can become independent of reliance on "the vagaries of annual precipitation and move towards sustainable management of surface water and groundwater, together with enhanced water conservation, water reuse and the use of stormwater." The Recycled Water Policy also recognizes that encouraging increased recycled water use requires increased attention to potential management of salt and nutrient impacts that may result. Accordingly, the Recycled Water Policy requires the Regional Boards to develop and implement salt and nutrient management plans to ensure attainment of water quality objectives and protection of beneficial uses.

Subsequent to the adoption of the Recycled Water Policy, the California Legislature approved the Water Conservation Act of 2009 (DWR, 2009), which established a number of water conservation requirements, including the goal to obtain a 20 percent reduction in urban per capita water use, consistent with the goals of the Recycled Water Policy (SWRCB, 2009). This 20 percent reduction goal is to be achieved by December 31, 2020.

The Governor issued a number of executive orders to address the 2011 to 2016 drought, which has resulted in significant overdraft of groundwater basins throughout the state. At the drought's peak, over 90 percent of California was classified as being in an "exceptional" drought period, which is the worst drought classification. Given the significance of this drought, Governor Edmund G. Brown Jr. declared a state of emergency on January 17, 2014, "directed state officials to take all necessary actions to prepare for these drought conditions," and called for Californians to reduce water use by 20 percent (CED, 2014a). Three months later, Governor Brown "issued an executive order to strengthen the state's ability to manage water and habitat effectively in drought conditions and called on all Californians to redouble their efforts to conserve water" (CED, 2014b). On April 1, 2015, the Governor directed the State Water Board to implement mandatory water reductions. The targeted reduction is 25 percent less potable urban water use statewide when compared to the amount of water used in 2013 (CED, 2015).

May 9, 2016, Governor Brown issued executive order B-37-16 (CED, 2016), commonly referred to as "Making Water Conservation a California Way of Life," to bolster California's climate and

drought resilience. This executive order was designed to incorporate the lessons learned from the temporary statewide emergency water restrictions and apply them to establish a long-term water conservation framework. Legislation was passed on February 16, 2017 to update the Water Code (AB-968 Section 10608.25) (CED, 2017a), wherein urban retail water suppliers shall develop a water efficiency target for 2025 that meets either 75 percent of urban retail water suppliers base daily per capita water use calculated in Section 10608.2 or establish a retail-level efficiency target that among several factors is based upon population multiplied by 55 gpcd.

Table 4 summarizes water conservation legislation in California since the passage of the Water Conservation Act of 2009.

Table 4. California Legislation on Water Conservation

Date Issued	Type of Legislation	Reference Number	Summary of Legislation
November 10, 2009	Senate Bill	SB-X7-7	Goal to obtain a 20% reduction in urban per capita water use by December 31, 2020. Commonly referred to as 20x2020 Water Conservation Plan (DWR, 2009).
January 17, 2014	Emergency Proclamation	Proclamation No. 1-17-2014	Governor proclaimed a state of emergency throughout California due to severe drought conditions, asking Californians to reduce their water usage by 20% (CED, 2014a).
April 25, 2014	Executive Order	B-26-14	Governor proclaimed a continued state of emergency throughout California due to ongoing drought. (CED, 2014b)
December 22, 2014	Executive Order	B-28-14	Extension of the emergency proclamations through May 31, 2016 (CED, 2014c).
April 1, 2015	Executive Order	B-29-15	The State Water Resources Control Board imposed restrictions to achieve statewide 25% reduction in potable water usage through February 2016 (CED, 2015).
May 9, 2016	Executive Order	B-37-16	Commonly referred to as “Making Water Conservation A California Way of Life,” this order builds upon the temporary statewide emergency water restrictions to establish a long-term water conservation framework (CED, 2016).
February 16, 2017	Assembly Bill	AB-968 Section 10608.25	An update to the California Water Code that establishes a retail-level efficiency based upon population multiplied by 55 gpcd, among several factors (CED, 2017a).
April 7, 2017	Executive Order	B-40-17	Recantation of the April 25, 2014 Emergency Proclamation and Executive Orders B-26-14, B-28-14, B-29-15, B-36-15. The continuation of B-37-15 of “Making Conservation A Way of Life” to remain in full effect with some modifications (CED, 2017b).

1.3 Impacts of Drought Water Conservation on Wastewater Conveyance Systems and WWTP Operations

The impact of indoor water conservation on wastewater flows—and, by extension, WWTP operations and discharge water quality—has been discussed for decades. Prompted by the severe drought in California in 1976 to 1977, the EPA conducted a study to quantify the effects of water conservation on the reduction of wastewater influent flows to WWTPs (U.S. EPA, 1980). The drought-induced reductions in flow were used as a surrogate for projecting the impact of conservation measures.

The study noted that "during the last 10 years, urban water conservation has attracted much attention and has widely become to be considered as an essential part of effectively managing our water resources" (U.S. EPA, 1980). Some of the indoor water conservation measures employed in the mid- to late-1970s include ". . . installing low-flow faucet aerators, low-flow shower heads or flow restrictors, and 'water dams' or plastic bottles in toilet tanks to reduce the amount of water used for flushing" (U.S. EPA, 1980).

Table 5 shows the theoretical increase in total dissolved solids (TDS) concentrations due to conservation measures. This analysis assumes an equivalent salt mass load, but with a reduction in the volume of wastewater with an initial TDS concentration of 300 milligrams per liter (mg/L).

Table 5. Incremental TDS Attributable to Reduction in Indoor Water Use

Percent Reduction in Indoor Water Use	TDS Pickup Due to Water Conservation [a] (mg/L)	Incremental TDS Increase [b] (mg/L)
10	333	33
20	375	75
30	429	129
35	462	162

Source: U.S. EPA (1980)
[a] From a source water total dissolved solids (TDS) concentration of 300 milligrams per liter (mg/L); for example: 300/0.9 = 333 mg/L
[b] For example: 333 – 300 = 33 mg/L

The California Urban Water Agencies (CUWA) published a white paper in November 2017 that summarizes the impacts of declining flows on water distribution systems, wastewater conveyance systems, wastewater treatment plant operations, and recycled water projects. The study was based on a literature review, a high-level survey, and focused interviews with individual water agencies in California. CUWA (2017) notes that, the "effluent from WWTPs is held to standards mandated by their individual National Pollutant Discharge Elimination System (NPDES) permits, including effluent quality limits for constituents like ammonia. . . Increasing influent concentrations can impact effluent quality, straining a plant's ability to meet its discharge permit requirements. To avoid exceeding permit limits, utilities may have to consider implementing costly WWTP upgrades." In the survey, 40 percent of WWTPs were impacted by increased concentrations of TDS, ammonia, or other constituents, resulting in challenges with effluent quality limits.

1.4 Salt Mass Loading

The American Water Works Association Research Foundation (AWWARF) and the WateReuse Foundation jointly funded the study *Characterizing and Managing Salinity Loadings in Reclaimed Water Systems* (Thompson et al., 2006). This study was a comprehensive review of the "problem of salinity in reclaimed water on a national level" (Thompson et al., 2006). Salinity increases in reclaimed water can limit its use on crops, landscape, golf courses, and industrial uses. According to Thompson et al. (2006), "When water passes through municipal systems, it gains salts ('salt pickup'), typically adding 200–400 mg/L TDS." This report uses the term salt mass load (SML) to define the mass of salt loaded to the system over a period of time (e.g., one day), whereas Thompson et al. (2006) use the term "TDS contribution." Likewise, this report uses the term increment from use (IFU) to express the TDS concentration (mass/volume) increases, while Thompson et al. (2006) refer to "TDS gain."

In residential use, the average person excretes between about 70 grams (Thompson et al., 2006) and 72.8 grams (Nall and Sedak, 2013) of salt each day. About 45 grams per capita per day are excreted in urine and about half of this is in the form of urea, a soluble organic compound that degrades over time (Aparicio et al., 2017). Because urea is not measured as a component of TDS, the mass of measurable salt excreted by the average individual is between

about 47.5 and 50.3 grams per capita per day. Gray water (showers, baths, clothes washing machines, and wastewater that does not contain fecal contamination) adds about 20 to 30 grams per capita per day, including about 10 grams per capita per day from detergents and 2 grams per capita per day from in-sink food disposals. Hence, the SML from indoor use is approximately 0.15 to 0.18 pound per capita per day. However, WWTPs also receive water from commercial and industrial sources, which may increase or decrease the SML values of wastewater entering a WWTPs and therefore affect the estimated per capita salt load per day.

Tran et al. (2017) note that ". . . a simple water balance thought experiment illustrates that drought, and the conservation strategies that are often enacted in response to it, both likely limit the role reuse may play in improving local water supply reliability." This study analyzed influent flow and water quality data for IEUA's Regional Plant 1 (RP1) from 2011 through 2015. Tran et al. (2017) note that "as a particular drought progresses and agencies enact water conservation measures to cope with drought, influent flows likely decrease while influent pollution concentrations increase, particularly salinity, which adversely affects wastewater treatment plant (WWTP) costs and effluent quality and flow. Consequently, downstream uses of this effluent, whether to maintain streamflow and quality, groundwater recharge, or irrigation may be impacted," leading to the conclusion that "indoor conservation can result in the generation of a more concentrated wastewater stream, with elevated concentrations of total dissolved solids (TDS), nitrogen species, and carbon."

1.5 Impact of Self-Regenerating Water Softeners

Water hardness is defined by the amount of dissolved calcium and magnesium in the water. Hard water can cause staining and scaling on dishes, appliances, plumbing fixtures, and adversely affects taste and texture of drinking water (USGS, 2016a). The scaling can reduce the useful lifespan of equipment (USGS, 2016b), clog pipes, and increase the cost of heating water. For many years, water softeners have been installed and operated in residential and commercial properties with water supplies containing higher levels of hardness, as they provide a service by reducing scale in customer appliances and fixtures.

There are two types of water softeners in residential use: self-regenerating water softeners (SRWS), also known as automatic water softeners, and exchange tank systems. SRWS use ion exchange technology, wherein the unit contains negatively charged resin with positively charged sodium ions sorbed to the surface. The calcium and magnesium ions are exchanged with the sodium ions because they have a higher charge density due to a higher valence state (+2 versus +1). When most of the sodium ions have been removed from the resin, the system is regenerated by adding a solution of sodium chloride or potassium chloride from an on-site brine tank. The high concentration of sodium or potassium ions swamp the calcium and magnesium ions sorbed to the resin surface. After regeneration, the system's brine waste, containing calcium, magnesium, and chloride, is discharged to the municipal sewer system. In exchange tank systems, a vendor replaces an exhausted tank with a newly regenerated tank; the regeneration takes place at an off-site location where the regenerated brine can be managed appropriately, minimizing impacts to publically owned treatment works (POTWs).

As discussed previously, conventional WWTPs do not remove TDS or the major ions that contribute to TDS, such as calcium, magnesium, or chloride; therefore, concentrations of these constituents in wastewater influent are higher in sewer service areas where SRWS are or used to be allowed than they would be absent the use of SRWS. Effective January 1, 2003, SB-1006 allows prospective water softener prohibitions if a WWTP is in non-compliance with permits and completes extensive studies. With the passage of AB-1366 in 2009, local agencies or cities that own or operate a community sewer system or water recycling facility have the authority to regulate SRWS.

1.6 Study to Evaluate Long-Term Trends and Variations in the Average TDS Concentration in Wastewater and Recycled Water

Given the complexity of factors that can influence the salinity of source waters and wastewater influent and effluent, the SCSC commissioned this study to analyze the relationship of the effects of drought, water conservation practices, and the quality of recycled water. Conservation measures may have unintended consequences that are beneficial, such as the electricity savings and greenhouse gas emissions reductions associated with reduced operation of urban water infrastructure (Spang et al., 2018), as well as consequences that are

undesirable, including for recycled water reuse by impacting water quality downstream uses of recycled water: irrigation, groundwater recharge, industrial uses, or releases to aquatic habitats. This analysis considered a series of research questions, the purpose of which is to provide a quantitative understanding of the relationships among variables such as salt concentrations in municipal influent and treated effluent, impact of water softener devices on salt concentrations in influent, and implementation of conservation practices that reduce per capita water use. The potential link between these various factors is important in predicting how salinity relative to water use may continue to change in the future.

The findings from this research will be of particular value to water supply and wastewater treatment and recycling agencies as they consider how changes in the future may impact their ability to provide reliable, high-quality drinking water while complying with waste discharge requirements. In addition, the findings can be evaluated in the context of the following factors that have the potential to further influence the availability of water (and associated quality) from various sources in the future:

- *Climate change:* Climate change currently has the potential to significantly alter the hydrology of the Sierra Nevada Mountains (the main source of water that flows through the Delta and SWP) and the Rocky Mountains (the main source of water for the Colorado River System). State Water Board Resolution No. 2017-0012, Comprehensive Response to Climate Change, states that "Changes in hydrology include declining snowpack and more frequent and longer droughts, more frequent and more severe flooding, changes in the timing and volume of peak runoff, and consequent impacts on water quality and water availability."

- *Bay Delta management:* Environmental regulations concerning endangered fish species or other requirements could significantly restrict Delta water exports in the future. The Bay Delta Conservation Plan (BDCP) (U.S. EPA, 2018) "was a habitat conservation plan proposed by the California Department of Water Resources, U.S. Fish & Wildlife Service, National Marine Fisheries Service, and Bureau of Reclamation, under the Endangered Species Act, to address the most critical water issues facing California by constructing new water delivery infrastructure and restoring aquatic habitat. In 2015, the

Bay Delta Conservation Plan was recast as California WaterFix, with a focus on the construction and operation of proposed new water export intakes on the Sacramento River to divert water into a proposed 40 mile twin tunnel conveyance facility" (U.S. EPA, 2018).

- *Colorado River System:* Drought and increasing water demands in the Colorado River Basin have significantly reduced Lake Mead storage levels, which could result in future shortage declarations by the U.S. Bureau of Reclamation. While MWDSC's firm entitlement of the Colorado River is protected from the first stages of Colorado River shortage declarations, it is possible that some cutbacks in deliveries could happen in the future if Lake Mead levels continue to decline. The "Department of the Interior and its bureaus to [have been directed to, "continue collaborative efforts to finalize important drought contingency actions designed to reduce the risk of water shortages in the Upper and Lower Colorado River" (U.S. DOI, 2017).

2. Data Compilation

2.1 Data Collection

The quality of analyses, especially the statistical modeling (Section 4), is dependent upon the availability, completeness, and accuracy of monthly observations, as well as the duration of the dataset. Understanding the treatment system as a whole is an important factor in determining the usability of each dataset. For example, it is common practice to have changes in volume of flow when wastewater is diverted from one plant to another within a single agency to meet the needs of everyday demands. However, it is beyond the scope of this report to capture all the nuances of the day-to-day treatment plant operations at individual facilities. This section briefly describes data requested and collected from the member agencies and some of the general characteristics of each of the agencies as they relate to this report.

Monthly flow and water quality data were requested for the following:

- Source flow: the average volume of supply water for both indoor and outdoor uses in the sewershed in million gallons per day (mgd)
- Source TDS: volume-weighted concentration of TDS in the source water supply
- Influent flow: volume of indoor water used that is influent to each WWTP in mgd
- Influent TDS: measured concentration of TDS in the WWTP influent
- Effluent flow: volume of water discharged from each WWTP in mgd
- Effluent TDS: measured concentration of TDS in the effluent discharged from each WWTP

Additionally, annual population estimates for each sewershed, a summary of conservation measures implemented at the agency level, a history of SRWS deployment and/or removal, and historical blend of source supply waters (i.e., SWP, CRA, groundwater, etc.) were requested. Table 6 summarizes the availability of data collected.

Table 6. Data Collection Summary
Page 1 of 2

Agency	Site	Date Range	Source		Influent		Effluent		Population
			Flow	TDS	Flow	TDS	Flow	TDS	
Eastern Municipal Water District	Moreno Valley Regional Water Reclamation Facility	2008–2016	X	X	X	X	X	X	X
	Perris Valley Regional Water Reclamation Facility	2008–2016	X	X	X	X	X	X	X
	San Jacinto Valley Regional Water Reclamation Facility	2008–2016	X	X	X	X	X	X	X
	Temecula Valley Regional Water Reclamation Facility	2008–2016	X	X	X	X	X	X	X
Inland Empire Utilities Agency	Regional Water Recycling Plant RP1	1997–2016	X	X	X	X	X	X	X
	Regional Water Recycling Plant RP2-RP5 [a]	1997–2016	X	X	X	X	X	X	X
	Regional Water Recycling Plant RP4	1997–2016	X	X	X	X	X	X	X
	Carbon Canyon Water Recycling Facility (CCWRF)	1997–2016	X	X	X	X	X	X	X
City of San Bernardino	San Bernardino Water Reclamation Plant (WRP)	1981–1996 (Effluent) 1995–2016 (Influent and Source)	X	X	X	X	X	X	X [b]
	Rapid Infiltration and Extraction (RIX)[b]	1996–2016					X	X	
Riverside Public Utilities	Riverside Water Quality Control Plant (RWQCP)	2003–2016	X	X	X	X	X	X	X
Orange County	Plant 1	2003–2016	X	X	X	X	X	X	X
	Plant 2	2003–2016	X	X	X	X			X

[a] In 2002 RP-5 was commissioned to handle the liquids treatment section of RP-2 and RP-2. Solid from RP-5 and CCWRF are handled at RP-2.
[b] Population provided for City of San Bernardino (San Bernardino WRP serves the City of San Bernardino, Loma Linda, East Valley, San Bernardino International Airport, Patton State Hospital, and unincorporated San Bernardino County areas)
[c] Padre Dam provided electrical conductivity data for source water quality, which were converted to total dissolved solids (TDS) using a conversion equation where TDS = EC * 0.625.
[d] The RIX facility receives approximately 33 MGD of secondary treated wastewater from the San Bernardino WRP and Colton's treatment facility.

Table 6. Data Collection Summary
Page 2 of 2

Agency	Site	Date Range	Source		Influent		Effluent		Population
			Flow	TDS	Flow	TDS	Flow	TDS	
Los Angeles Sanitation District	Saugus DMS - #4109406	2002–2016						X	
	Los Coyotes DMS - #4109410	2002–2016						X	
	Valencia DMS - #4109413	1997–2016						X	
	San Jose Creek West DSM -#4109418	1984–1992; 2004–2016						X	
	San Jose Creek East DMS -#4109429	1984-1992; 2004-2016						X	
	Whittier Narrows DMS - #4109435	1984-1992; 2004-2016				X		X	
	Pomona DMS - #4109441	1984–1992; 2002–2016				X		X	
	Long Beach DMS - #4109449	1992–2016						X	
	La Canada DMS - #410983	1984–2009					X	X	
San Diego County Water Authority	Carlsbad MWD	2006–2016	X				X	X	X
	Point Loma	1993–2016	X	X	X	X	X	X	X
	South Bay	2003–2016	X	X	X	X	X	X	X
	Olivenhain Municipal Water District - 4S Ranch	2009–2016	X				X	X	X
	Otay Water District	2010–2016	X	X	X	X	X	X	X
	Padre Dam [c]	2002–2016	X	X [d]	X	X	X	X	X
	North City WRP	2002–2016	X	X	X	X	X	X	X
	Fallbrook Public Utility District		X						X

[a] In 2002 RP-5 was commissioned to handle the liquids treatment section of RP-2 and RP-2. Solid from RP-5 and CCWRF are handled at RP-2.
[b] Population provided for City of San Bernardino (San Bernardino WRP serves the City of San Bernardino, Loma Linda, East Valley, San Bernardino International Airport, Patton State Hospital, and unincorporated San Bernardino County areas)
[c] Padre Dam provided electrical conductivity data for source water quality, which were converted to total dissolved solids (TDS) using a conversion equation where TDS = EC * 0.625.
[d] The RIX facility receives approximately 33 MGD of secondary treated wastewater from the San Bernardino WRP and Colton's treatment facility.

2.2 Eastern Municipal Water District

EMWD provides a significant portion of the water supply within their service area, and treats all wastewater for reuse for beneficial purposes at five regional water reclamation facilities that treat approximately 46 mgd of wastewater for nearly 800,000 residents. The five water reclamation facilities include Moreno Valley, Perris Valley, San Jacinto Valley, Temecula Valley, and Sun City. All flows from Sun City are diverted to Perris Valley; therefore, for this study, these two WWTPs will be treated as one WWTP. Influent and effluent water quality data were provided from 1993 to 2016, while source water quality was reported from 2008 to 2016.

A common operational practice for agencies with multiple treatment plants is to divert flows as needed to ensure compliance of discharge permit requirements. Such flow divergences affect the calculations of per capita water use. EMWD had two periods of significant construction activity where there was extensive flow diversion. In the early 2000s, flows normally allocated for Moreno Valley WWTP were diverted to Perris Valley WWTP. Beginning in 2012, flows normally directed for San Jacinto Valley WWTP were diverted to Perris Valley WWTP. In addition to the analysis of the individual sewersheds, a “combined sewershed” analysis was performed, where the flows for each WWTP are summed together for a total flow, and influent TDS concentrations are estimated using a volume-weighted average. This combined sewershed approach accounts for the variations in flow divergence and other anomalies.

2.3 Inland Empire Utilities Agency

IEUA is a wholesale imported water provider, the regional wastewater treatment agency, and the regional recycled water distributor, with nine member agencies: Chino, Chino Hills, Cucamonga Valley Water District, Fontana, Fontana Water Company, Montclair, Monte Vista Water District, Ontario, and Upland. IEUA serves 825,000 people and treats about 60 mgd of wastewater. IEUA provided data for five treatment facilities: RP1, RP2, RP4, RP5, and CCWRF. In March 2004, RP2 was taken out of service and RP5 was commissioned in its place. Therefore, in this study, RP2 and RP5 will be treated as one system.

IEUA developed a residential SRWS removal rebate program with three main objectives: (1) to achieve water savings, (2) to reduce salinity contributions to WWTPs, and (3) to raise awareness about the importance of local water supplies and the need for water conservation and reduction of salinity in recycled water (IEUA, 2012). IEUA and its member agencies determined that the best option for regulating the use of SRWS is to prohibit the future installation of these devices and to establish a voluntary rebate program for removal of existing SRWS. Between 2008 and 2012, IEUA adopted a voluntary rebate program and the results of this program are reported in a 2012 final report (IEUA, 2012).

2.4 Orange County Sanitation District/Orange County Water District

OCSD collects and treats wastewater from central and northwest Orange County from a population of approximately 2.5 million people, and treats an average of 184 mgd of wastewater. There are two treatment plants; in 2016, approximately 117 mgd was treated at Plant No. 1 and 67 mgd was treated at Plant No. 2. Influent water quality data were provided and used for Plant No. 1 only for the following reasons:

- Plant No. 2 receives approximately 30 percent of its total flow from the Inland Empire Brine Line, a gravity pipeline that receives non-reclaimable wastewater from the Santa Ana River watershed upstream of Orange County and includes flows from industrial dischargers and desalination facilities. The Inland Empire Brine Line provides the facilities for exporting salt from inland areas to the ocean (SAWPA, 2018).
- Some sewer lines in the Plant No. 2 sewershed have challenges with infiltration of brackish shallow groundwater.
- Plant No. 2 receives brine and backwash water from Plant No. 1.
- Plant No. 2 discharges to the ocean and does not have permit limits for TDS.

OCSD keeps records of permitted discharges received by Plant No. 1, and which account for approximately 2.5 percent of the total flow. The TDS concentrations listed below from the permitted discharges illustrate that there are sources of high TDS concentration that are not directly accounted for in the analysis; these include, but are not limited to, the following:

- City of Tustin Water Services (17th St): 5,500 mg/L
- City of Tustin Water Services (Main St): 9,300 mg/L
- Coca-Cola Company-Anaheim Water Plant: 1,700 mg/L
- Irvine Ranch Water District: 4,900 mg/L
- Mesa Water District: 1,700 mg/L
- Weidemann Water Conditioner, Inc.: 15,000 mg/L

To maximize OCWD's Groundwater Replenishment System, some flows are diverted from Plant No. 2 to Plant No. 1. Because of the flow diversion there is an apparent increase in the calculated per capita water use at Plant No. 1 (see Section 3.1 for the calculation used in this study for indoor per capita water), which is inconsistent with general declines in per capita water use demonstrated from both plants. To better represent per capita water use in Orange County, total influent flows for Plant No. 1 and Plant No. 2 were used in place of influent flow solely from Plant No. 1. For the water quality analysis, TDS concentrations were used only from Plant No. 1. There is a long and continuous record of effluent TDS concentration data; however, influent TDS concentration data for Plant No. 1 are limited. TDS concentration data for source water were provided on an annual basis instead of a monthly basis.

2.5 San Diego County Water Authority

SDCWA is a wholesale water supplier for 24 retail water agencies throughout San Diego County. Population data were provided for each of the 24 member agencies. There are 28 treatment facilities within the county. The largest treatment network, the Metropolitan Sewerage System, serves the greater San Diego area, has a population of approximately 2.2 million, and overlies all or portions of nine of the retail water agencies generating approximately 180 mgd of wastewater. The WWTPs in this service area include the North City Water Reclamation Plant (WRP), South Bay WRP, and Point Loma WWTP. The North City and South Bay treatment facilities are inland and send some of their effluent flow to Point Loma, which discharges to the ocean. Due to the ability to divert flows to Point Loma WWTP, these three facilities were analyzed as a combined average, similar to EMWD and IEUA. However, the influent TDS at Point Loma is nearly 1,000 mg/L greater than that at both North City WRP and South Bay WRP, which makes the apparent IFU in the combined analysis much higher than literature values.

The higher IFU can likely be attributed to the brine discharge from North City WRP and South Bay WRP, as well as the proximity to the ocean (sea water intrusion near coastal pipes and facilities).

Two of the smaller facilities—Otay and Padre Dam—were also analyzed independently. Padre Dam Municipal Water District (PDMWD) collects wastewater from Santee and parts of El Cajon and Lakeside; on average, 40 percent of the wastewater collected is processed in the Padre Dam water recycling facility, while the remainder is sent to the City of San Diego's metropolitan wastewater system, where it is treated at the Point Loma facility. Source water quality for Padre Dam was reported as electrical conductivity (EC) and was converted to TDS by PDMWD staff by multiplying the EC by 0.625. Effective January 1, 2007, Lakeside Water District detached from PDMWD, at which time the reported population in the sewershed declined by 35,500 people and continued a gradual decline through 2016. Otay Water District provides sewer services to the northern portion of the district, which represents approximately 11 percent of the total service area.

2.6 Sanitation Districts of Los Angeles County

LACSD has three major water reclamation areas, Antelope Valley WRPs (Lancaster and Palmdale facilities), Santa Clarita Valley WRPs (Saugus and Valencia facilities), and the Joint Outfall System (JOS) which include the Joint Water Pollution Control Plant (JWPCP), La Cañada, Long Beach, Los Coyotes, Pomona, San Jose Creek, and Whittier Narrows Water WRPs. The JWPCP is the only facility that discharges to the ocean. The JOS facilities are primarily reuse plants providing water for non-potable reuse and groundwater recharge. The data LACSD reported was limited to effluent TDS data for the Santa Clarita Valley WRPs and the JOS facilities. The La Cañada and Long Beach facilities have the longest continuous dataset in this study, extending back to 1984 and 1992, respectively. San Jose Creek, Whittier Narrows, and the Pomona facilities also have data extending back to 1984; however, each of these datasets has a 10-year data gap from the early 1990s to the early 2000s.

Extensive work has been done in the Santa Clarita Valley to reduce discharge chloride concentrations by removing SRWS units in the area. In 2002, LACSD produced the first

comprehensive chloride source report for the Santa Clarita Valley, which includes an estimate of the contribution from SRWS units (LACSD, 2002). LACSD provided annual chloride source identification/reduction, pollution prevention, and public outreach plans from 2005 to 2014. The 2014 report summarizes the policies in place to reduce SRWS. In short, the Santa Clarita Valley Sanitation District (SCVSD) took the following policy actions to reduce the number of SRWS in their service area:

- March 2003 SRWS installation ban ordinance takes effect
- November 2005 Voluntary Phase I Rebate Program
- May 2007 Voluntary Phase II Rebate Program
- January 2009 mandatory ordinance banning SRWS
- August 2011 Ordinance Enforcement Program

The 2014 report also provides an estimation of the number of SRWS units remaining in the system between 2002 and 2013 (LACSD, 2014), which is used to calculate the TDS contribution in Section 3.4.

2.7 City of San Bernardino

The San Bernardino Municipal Water Department operates a 33 mgd regional secondary treatment facility that provides services for City of San Bernardino, Loma Linda, East Valley, San Bernardino International Airport, Patton State Hospital, and unincorporated San Bernardino County areas. The secondary treated wastewater is then discharged to an off-site tertiary treatment system in Rialto, the rapid infiltration and extraction facility (RIX). RIX also receives treated wastewater from Colton's WRP. Data from San Bernardino accounts for the influent TDS and flows coming into the San Bernardino treatment facility and the effluent TDS and flows from RIX. The data do not account for the influent flows from Colton's WRP. Not all of the corresponding population data needed for the analysis were provided.

2.8 Riverside Public Utilities

The City of Riverside Public Works department operates and maintains a wastewater collection system for more than 300,000 people within the City of Riverside and the surrounding areas. Four main branches come to the Riverside Regional Water Quality Control Plant (RWQCP) from Riverside, Jurupa, and Rubidoux. Riverside Public Utilities (RPU) provided population data, source TDS data for the City of Riverside, and influent flow and concentration data for the two main branches that reflect the contribution from the City of Riverside.

3. Analysis and Results

This analysis considered a series of 12 research questions, the purpose of which is to provide a quantitative understanding of the relationships among variables such as salt concentrations in municipal influent and treated effluent, impact of water softener devices on salt concentrations in influent, drought, and implementation of conservation practices that reduce per capita water use. The potential link between these various factors is important in predicting how salinity relative to water use may continue to change in the future. The data presented in the body of the report were selected as the clearest examples for answering the research questions. Detailed trends and statistical analysis and can be found in Appendices A and B.

3.1 How has indoor per capita water use changed over time? What are the water quality implications if the trend continues for the next 20 years?

Population in California is on the rise; it has doubled in just the last 45 years and is expected to reach 50 million by 2050 (PPIC, 2017). Population in MWDSC's service area rose from 16.8 million to 18.7 million from 2000 to 2015 (Figure 2) (MWDSC, 2016; California Department of Finance, 2017). Note that even though the population increased significantly in this 15-year period, the total water supplied was flat or trending down; from 2000 to 2015, the potable water demands for 1.9 million additional people were met with the same total water supply, largely as a result of conservation efforts, increased stormwater capture, and increased reuse of recycled water, thereby decreasing the gross per capita water use in Southern California. This population growth for MWDSC (estimated at 180,000 per year, or about 1 percent) will continue to put significant pressure on water supplies in the region.

Indoor water use for this study is equivalent to the influent flow to a WWTP. Indoor per capita water use is calculated by dividing the influent flow by the population of the treatment plant service area. SCSC member agencies report indoor per capita water use in water master plans. While the calculations of per capita use are often very similar to those of the member agencies, there may be some discrepancies in how these numbers are calculated (such as service areas boundaries used for population data). Local agencies can often produce more precise estimates of indoor per capita water use than those generated in this report. Indoor per

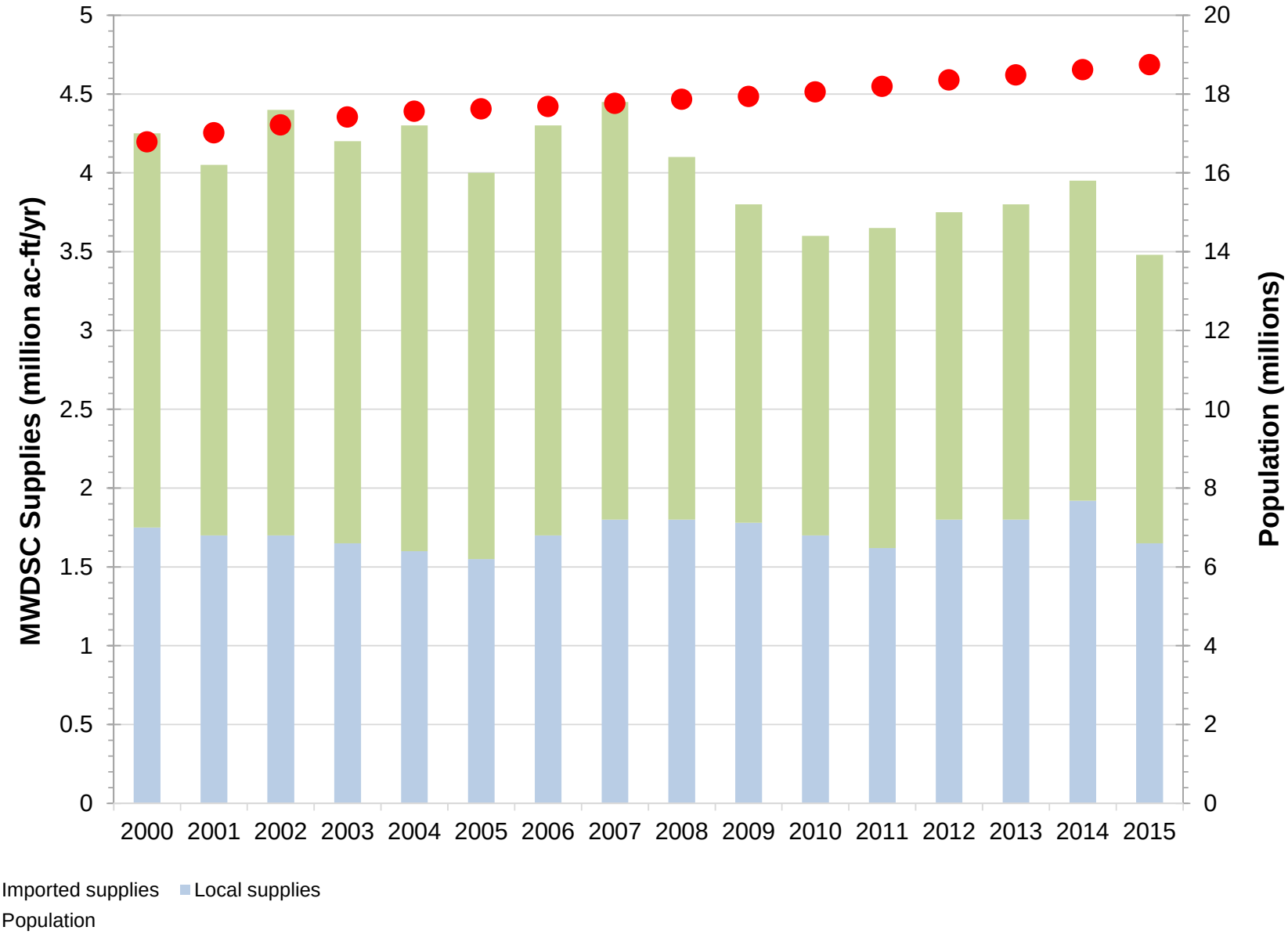

Figure 2

SOUTHERN CALIFORNIA SALINITY COALITION

Population Growth and Water Supply in MWDSC

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3/29/18

capita calculations made in this study are estimates and are primarily used to represent relative trends for each sewershed.

Using the method described above for calculating indoor per capita water, there has been a general decrease over the past decades, from a range of 80 to 110 gpcd in the 1990s to a range of 50 to 75 gpcd by 2016, as shown in Figure 3.

Under current proposed legislation, California residences are expected to reduce per capita water use to 55 gpcd by 2025 (AB-968 Section 10608.25). Some members of SCSC have met this objective and suspect that they have reached a reasonable limit for indoor conservation measures, beyond which it may be unrealistic to achieve lower per capita indoor water use. These groups will likely see a change in indoor water use from a downward trend to a flat trend. Service areas that have not reached this 55 gpcd goal will likely continue to see a downward trend in per capita water use. The implication for continued decrease in per capita water use is an estimated 1.2 to 1.7 mg/L increase in WWTP influent TDS for every 1.0 gpcd decrease in indoor water use (see Section 4 for more details).

3.2 How has the volume-weighted average concentration of TDS in municipal influent changed over time? What are the water quality implications if the trend continues for the next 20 years?

There are 14 WWTPs with influent TDS data and 26 with effluent TDS data. Of the 14 WWTPs with influent TDS data, 9 have upward trends of TDS, 4 have flat trends, and 1 has a downward trend. Influent and effluent trends are generally closely correlated as shown in Appendix A. The WWTPs that do not have influent TDS data were likely to have similar TDS trends compared to their observed effluent TDS trends. Of the 26 WWTPs that have effluent TDS data, 15 have an upward trend in TDS, 7 have no trend, and 4 have a downward trend in TDS; nearly 60 percent of the WWTPs had increasing TDS trends.

If upward TDS concentration trends continue, more wastewater agencies will approach or exceed discharge permit limits. In some cases, desalination treatment facilities may be required

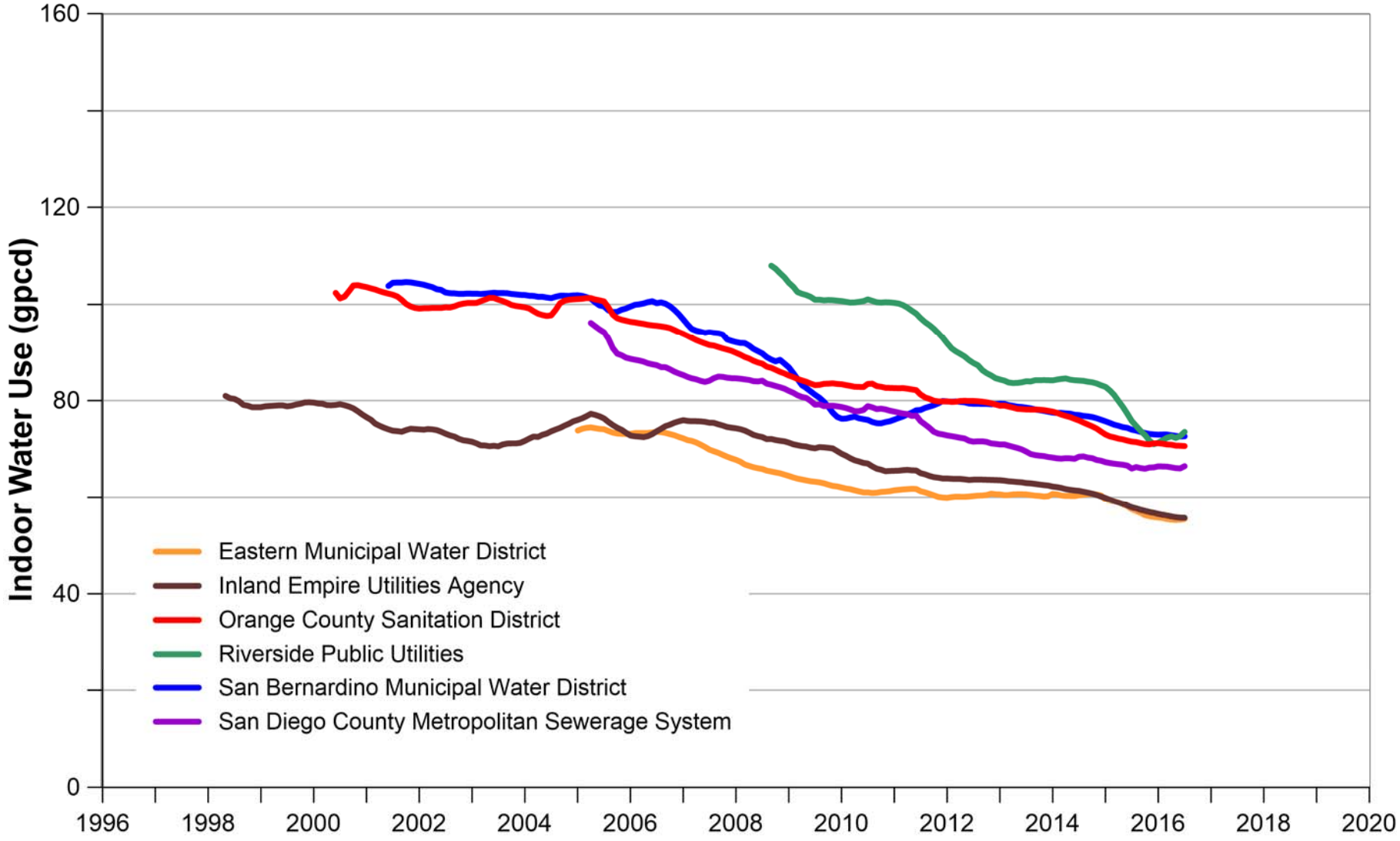

Figure 3

SOUTHERN CALIFORNIA SALINITY COALITION

Indoor Per Capita Water Use Trends

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3/29/18

to mitigate the increasing levels of TDS. As more agencies move toward the use of recycled water, the quality of the effluent water will impact the quality of the recycled water.

3.3 How has the residential/commercial per capita "increment from use" for TDS changed over time? What are the water quality implications if the trend continues for the next 20 years?

IFU is defined as the difference between influent TDS and source TDS. IFU values for the sewersheds analyzed in this study fall within the range of literature values: 200 to 400 mg/L. In other words, if the volume-weighted source water TDS concentration is 350 mg/L, the TDS concentration of WWTP influent will be between 550 and 750 mg/L, with the added salt from indoor uses. The statistical models estimate an increase in effluent TDS between 1.2 and 1.7 mg/L for every 1.0 gpcd decrease in indoor water use. A more in-depth discussion of the statistical analysis is provided in Section 4.

OCWD/OCSD and SDCWA are exceptions to the normal range of IFU, and had values that far exceeded typically literature values, with IFU values exceeding 1,000 mg/L. Both OCSD and SDCWA are coastal agencies, and sea water infiltration to sewer lines in low-elevation areas is one probable cause of higher IFU values. As described in Section 2, Orange County permits industrial discharges with high TDS concentrations that exceed the typical contribution of TDS from human excretion and gray water disposal. Similarly, the Point Loma WRP in the San Diego Metropolitan Sewerage System service area receives brine from North City and South Bay WRPs.

3.4 What proportion of the increase in average per capita increment from use can be attributed to widespread implementation of low-flow plumbing fixtures and appliances?

Urban water conservation has gained much attention since the 1976/1977 drought in California. Indoor water conservation measures employed in the mid- to late-1970s include the installation of "low-flow faucet aerators, low-flow shower heads or flow restrictors, and 'water dams' or

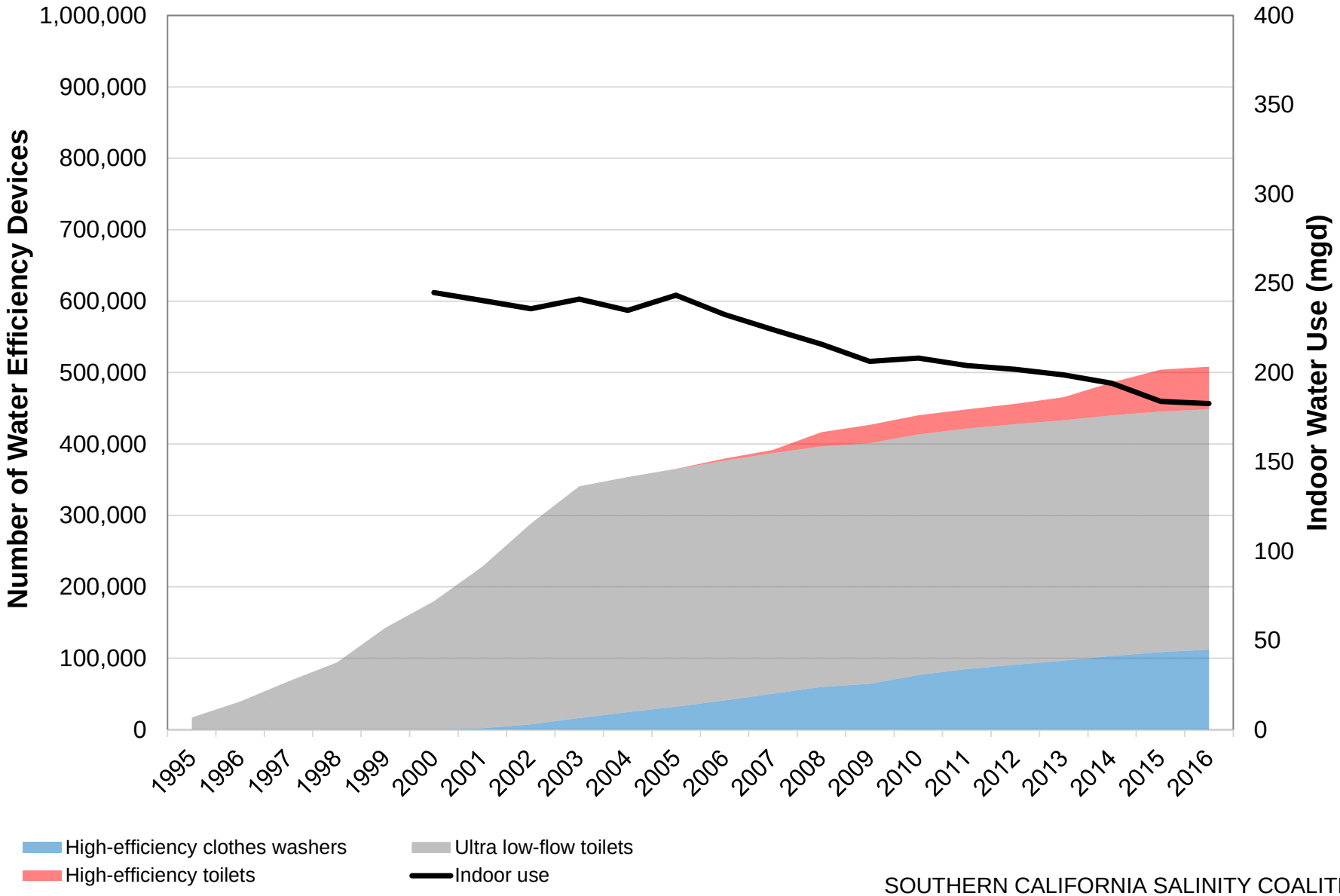
plastic bottles in toilet tanks to reduce the amount of water used for flushing" (U.S. EPA, 1980). Commonly used devises for indoor conservation currently include ultra-low flow toilets (ULFT), high efficiency toilets (HET), high-efficiency clothes washers (HECW), and low-flow showerheads.

The two primary methods for implementing low-flow plumbing fixtures are through changes to the plumbing codes (difficult to measure and keep records) and through conservation incentive programs, such as buy-back rebate programs. Estimates of conservation were reported for active installation/replacement of low-flow fixtures through incentive programs. Water saved through passive measures, (e.g., ordinances and building code changes) were not provided for this report. OCWD, SDCWA, and RPU provided records of the implementation of low-flow plumbing fixtures and appliances for both indoor and outdoor devices.

Using Orange County as an example, the impact of these devices over time can be measured. OCWD recorded the number of units installed through local conservation programs and provided the cumulative number of indoor devices installed, HECW, HET, and ULFT. The number of installed devices compared to the indoor water use (in mgd) over that time period is shown in Figure 4. This figure does not include water used for showers, as only totals were provided instead of annual records. In 2016, the amount of indoor water saved through active conservation is approximately 6.3 gpcd. Using the increase from IFU values introduced in Question 2, there would be an increase in TDS in the range of 7.6 to 10.7 mg/L.

In 2016, the annual water savings from the installation and use of HECW, HET, ULFT, and low-flow showerheads are:

- HECW: 3,800 acre-feet, or approximately 1,300 million gallons
- HET: 2,200 acre-feet, or approximately 700 million gallons
- ULFT: 13,500 acre-feet, or approximately 4,400 million gallons
- Showers: 1,700 acre-feet, or approximately 500 million gallons



SOUTHERN CALIFORNIA SALINITY COALITION

Cumulative Number of Water Efficient Plumbing Fixtures and Indoor Water Use, Orange County

Figure 4

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3.5 What proportion of the increase in average per capita IFU (for TDS, chloride, and sodium) can be attributed to incremental installation of self-regenerating water softeners?

In 1978, the California Regional Water Control Board, Los Angeles Region established a water quality objective for chloride of 100 mg/L for the Santa Clara River. The SCVSD faced significant regulatory challenges regarding the concentration of chloride being discharged to the Santa Clara River from the Saugus and Valencia WRPs. SCVSD took a hardline approach to address chloride loadings from SRWS. In 2002, LACSD completed the first comprehensive assessment of salt sources and water softener salinity impacts following the passage of SB-1006 (LACSD, 2002). On November 4, 2008, voters approved the Santa Clara River Chloride Reduction Ordinance of 2008, which mandates that, "Effective June 30, 2009, all residential automatic water softeners, also known as self-regenerating water softeners, are prohibited in the Santa Clarita Valley" to control the discharge of chloride to the Santa Clara River. The Santa Clara River Chloride Reduction Ordinance Enforcement Program began in August 2011. Letters were sent to the residences indicating that the SCVSD would conduct home inspections and sewer samplings to ensure compliance with the ordinance and that violation of the ordinance would result in a misdemeanor charge punishable with a fine up to $1,000 or by imprisonment up to 30 days. The resulting effort removed over 8,000 SRWS in the SCVSD service area through 2014. The chloride contribution from residential SRWS to WWTP effluent dropped from over 100 mg/L during its peak in 2003 to less than 40 mg/L by 2013.

Using the number of SRWS units removed from the SCVSD, this report estimates the TDS contribution from the SRWS. Estimates of the amount of salt added as brine from a typical SRWS unit range from 1 to 2.35 pounds of salt per day per unit (Thompson et al., 2006; Jessen, 2015; IEUA, 2012; LACSD 2017). Using an average value of 1.65 pounds of salt per day, the TDS salt loading from SRWS is estimated by multiplying the number of units reported by the estimated unit contribution:

$$\text{TDS removed} = \frac{\text{Number of SWS units} \times 1.65 \text{ pounds of salt per day per unit}}{\text{Flow into the WWTP}} \quad (1)$$

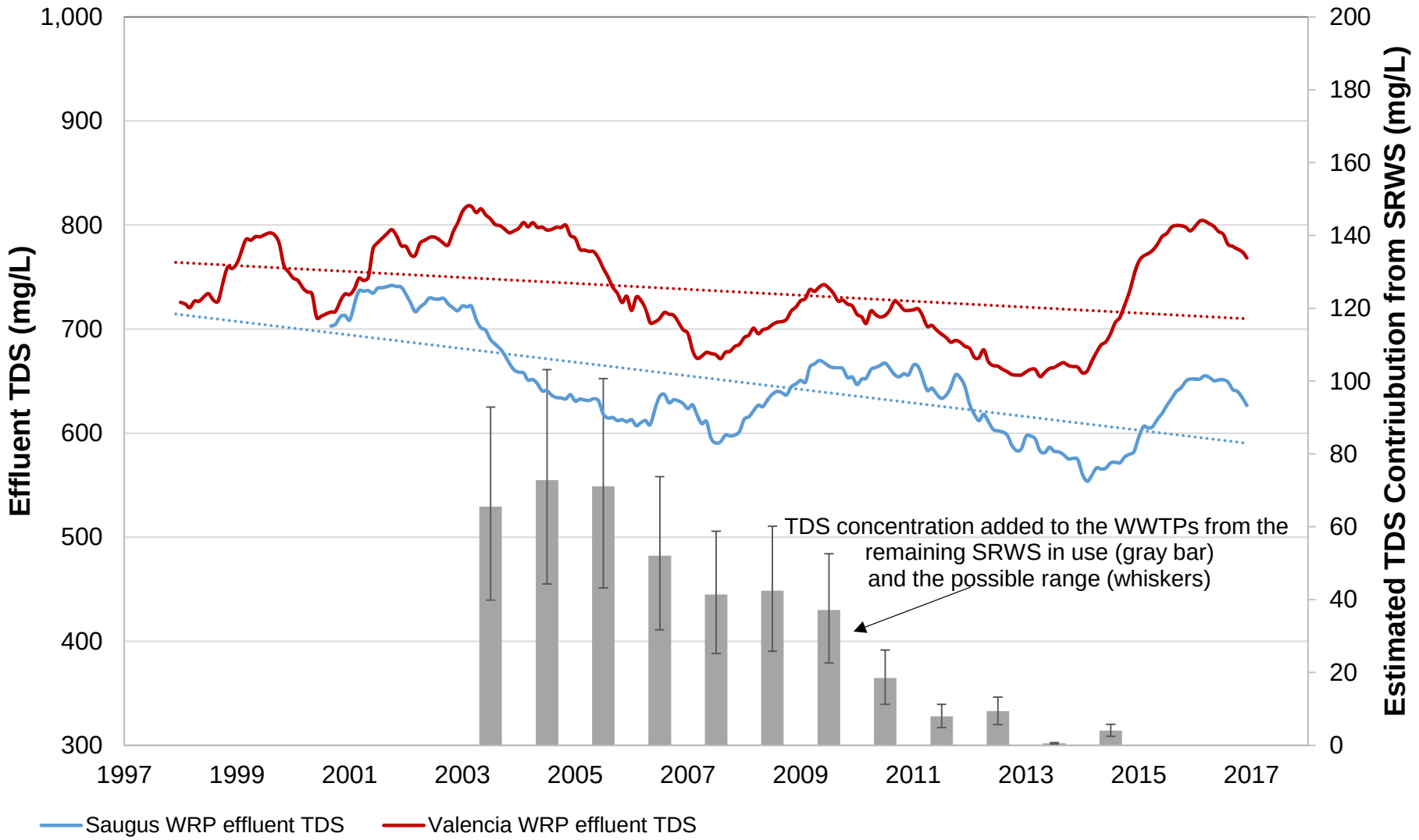
The estimated salt loading for the number of units remaining in the Santa Clarita Valley is shown in Table 7, as well as the TDS concentration that is then estimated using the combined volume of water entering the Saugus and Valencia WRPs.

Table 7. LACSD Self-Regenerating Water Softener Removal and Estimated TDS Concentrations

Year	Combined Plant (Saugus + Valencia) Influent Flow (mgd)	Estimated Number of SRWS remaining in system as reported in 2014 by LACSD [a]	Estimated Salt Load [b] (tons)	Estimated TDS Concentration in Wastewater as Result of Remaining Water Softeners (mg/L)
2002	17.98	5,983	1,382	50.5
2003	18.12	6,699	1,547	56.1
2004	18.78	6,775	1,565	54.7
2005	21.13	5,587	1,291	40.1
2006	20.83	4,384	1,013	31.9
2007	20.91	4,507	1,041	32.7
2008	20.91	3,943	911	28.6
2009	20.44	1,917	443	14.2
2010	20.19	812	188	6.1
2011	19.87	942	218	7.2
2012	19.96	54	12	0.4
2013	19.72	405[c]	94	3.1

[a] 2014 LACSD chloride report
[b] Estimated using the number of SRWS units multiplied by conversation coefficient of 1.26 pounds TDS/day/SRWS unit
[c] Values estimated by LACSD are based on several assumptions, such as source water quality and potential water softeners remaining; therefore, some fluctuation from year to year is expected.
mgd = Million gallons per day
mg/L = Milligrams per liter

Figure 5 demonstrates the correlation between the declining trends in effluent TDS at the Saugus and Valencia WRPs and the estimated TDS contribution from the remaining water softeners in the Saugus and Valencia treatment systems from 2002 to 2013. Of the treatment plants evaluated in this study, Saugus and Valencia WRPs are two of the four WWTPs to show a decline in measured effluent TDS. This is likely due to the removal of SRWS units over that period.



SOUTHERN CALIFORNIA SALINITY COALITION

Effluent TDS Concentration, Saugus and Valencia WRPs and Estimated TDS from SRWS

Figure 5

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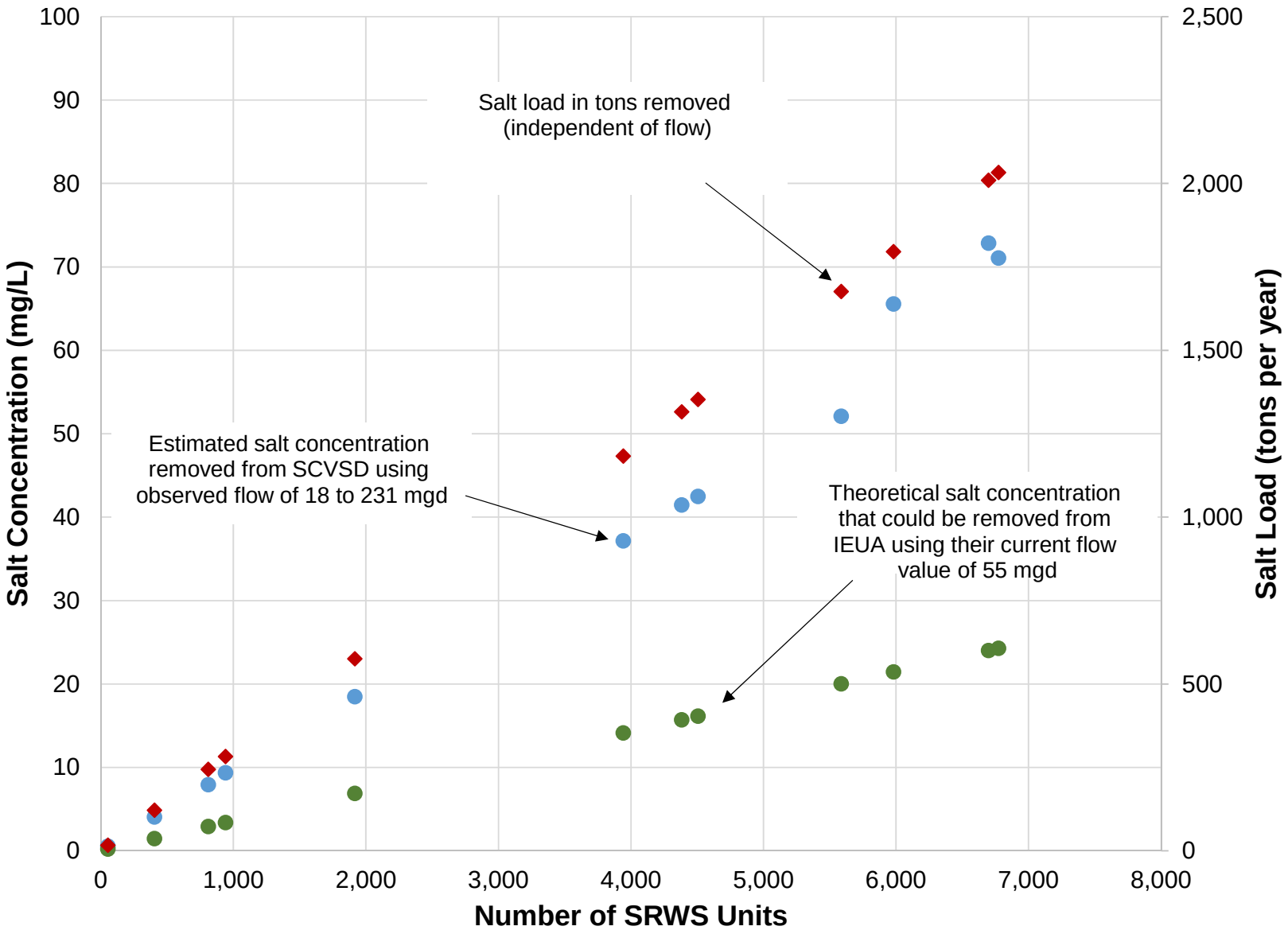
3/29/18

Following the model established by LACSD, IEUA developed a residential SRWS removal rebate program with three main objectives: (1) to achieve water savings, (2) to reduce salinity contribution to WWTPs, and (3) to raise awareness about the importance of local water supplies and the need for water conservation and reduction of salinity in recycled water (IEUA, 2012). IEUA and its member agencies determined that the best option for regulating the use of SRWS was to prohibit the future installation of these devices and to establish a voluntary rebate program. Between 2008 and 2012, IEUA successfully removed 511 residential SRWS units; as a result, it is estimated that a total of 236,000 pounds of salt was removed from the system during this time period. Multiplied by the current average influent flow to treatment system of 55 mgd, the removal of these units resulted in an estimated reduction in TDS of 1.4 mg/L.

The secondary y-axis in Figure 6 shows the hypothetical salt load removed as a function of the number of SRWS removed from the system, shown in red on the graph. For example, removing 6000 SRWS units at 1.65 pounds per day would result in the removal of a mass of salt equivalent to 1,800 tons per year. The blue data points (SCVSD) and the green data points (IEUA) show the resultant reduction of TDS concentrations (primary y-axis) based on their respective flow rates: 55 mgd for IEUA and 18 to 21 mgd for SCVSD.

For example, the indoor use for SCVSD between 2003 and 2014 was 18 to 21 mgd, and it is estimated (in blue) that due to removal of 6,000 SRWS units, the TDS concentration of water entering the WWTP was approximately 65 mg/L less than it would have been if no SRWS had been removed. On the other hand, IEUA has an indoor water use of approximately 55 mgd; if, hypothetically, the agency removed the same number of SRWS, it would only reduce the concentration by approximately 20 mg/L as shown in green.



SOUTHERN CALIFORNIA SALINITY COALITION

Contribution of Salt Loading from SRWS
Santa Clarita Valley and IEUA

Figure 6

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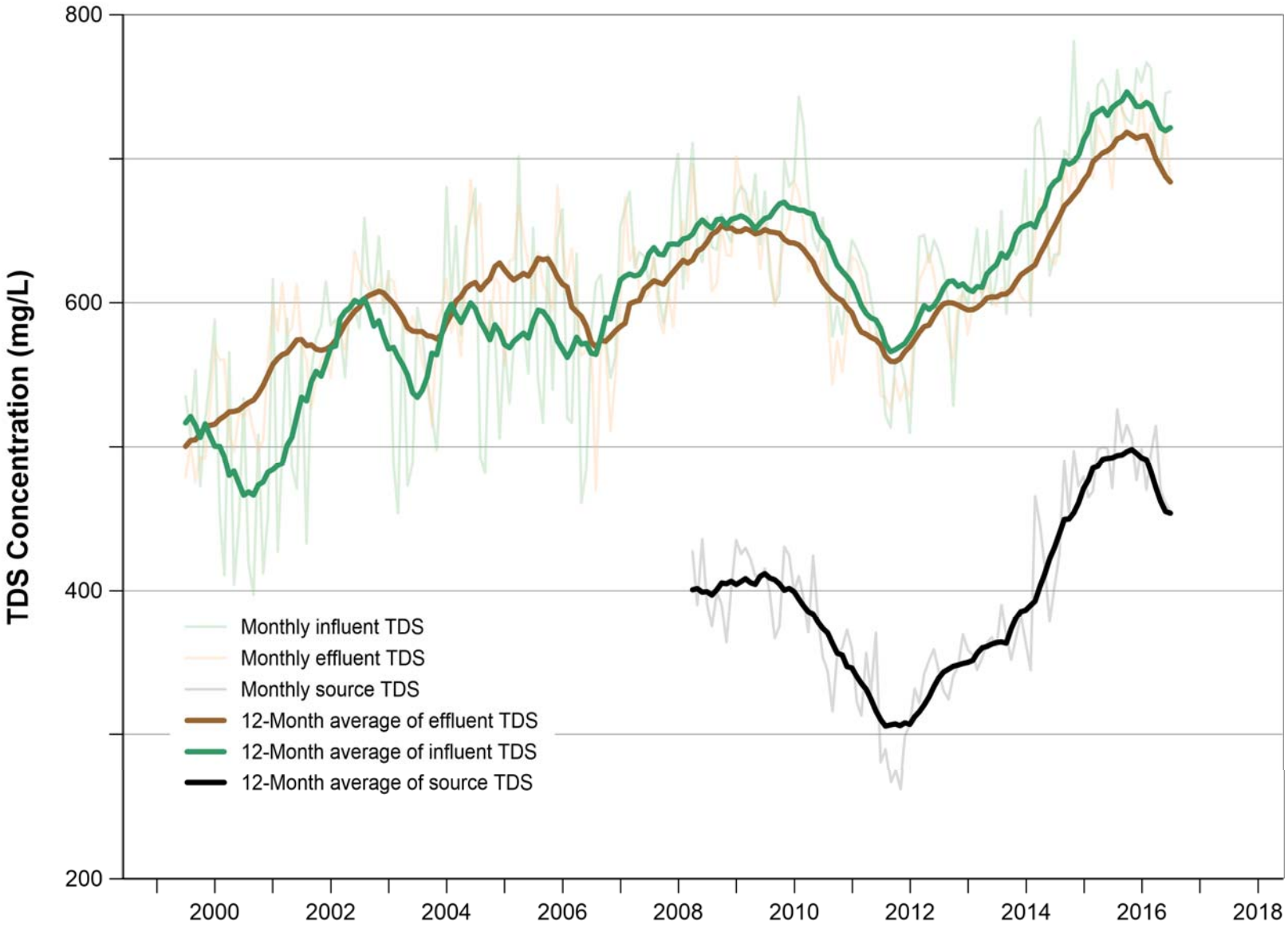
3.6 To what degree are fluctuations in the volume-weighted average concentration of TDS in recycled water correlated with variations in the volume-weighted average concentration of TDS in the wastewater influent?

This question was posed to address the concern that the treatment process itself contributes significant amounts of TDS to the system. Chemicals such as ferric chloride, sodium hypochlorite, and polymers are often added to facilitate in the wastewater treatment process. The observed relationship between influent and effluent TDS concentrations is that they are generally closely correlated and nearly equal. This suggests that there is no significant increase in TDS during the treatment process. In some situations, effluent TDS is actually less than influent TDS. Appendix C shows the correlation between influent and effluent. In Figure 7, influent, effluent, and source TDS concentrations for the EMWD combined sewershed (weighted average for the four WWTPs in the EWMD service area) are plotted to compare their relationships correlation between influent and effluent TDS concentrations.

Appendix A provides a comparison of influent and effluent TDS trends for each of the WWTPs. In addition, influent versus effluent plots were created for each individual WWTP where data are available to determine the correlation between influent and effluent TDS. These plots are available in Appendix A. Table 8 summarizes the R^2 values. The four WWTPs in EMWD have an average R^2 value of 0.81, IEUA has an average of 0.78, and SDCWA has an average of 0.70. OCSD and RPU values are lower because Plant No. 1 does not have continuous influent TDS data and RPU influent and effluent trends are flat with little variation. In general, the observed influent and effluent TDS concentrations are closely correlated and have similar trends.



SOUTHERN CALIFORNIA SALINITY COALITION

Influent, Effluent, and Source TDS Trends for EMWD (Weighted Average of All Sewersheds)

Figure 7

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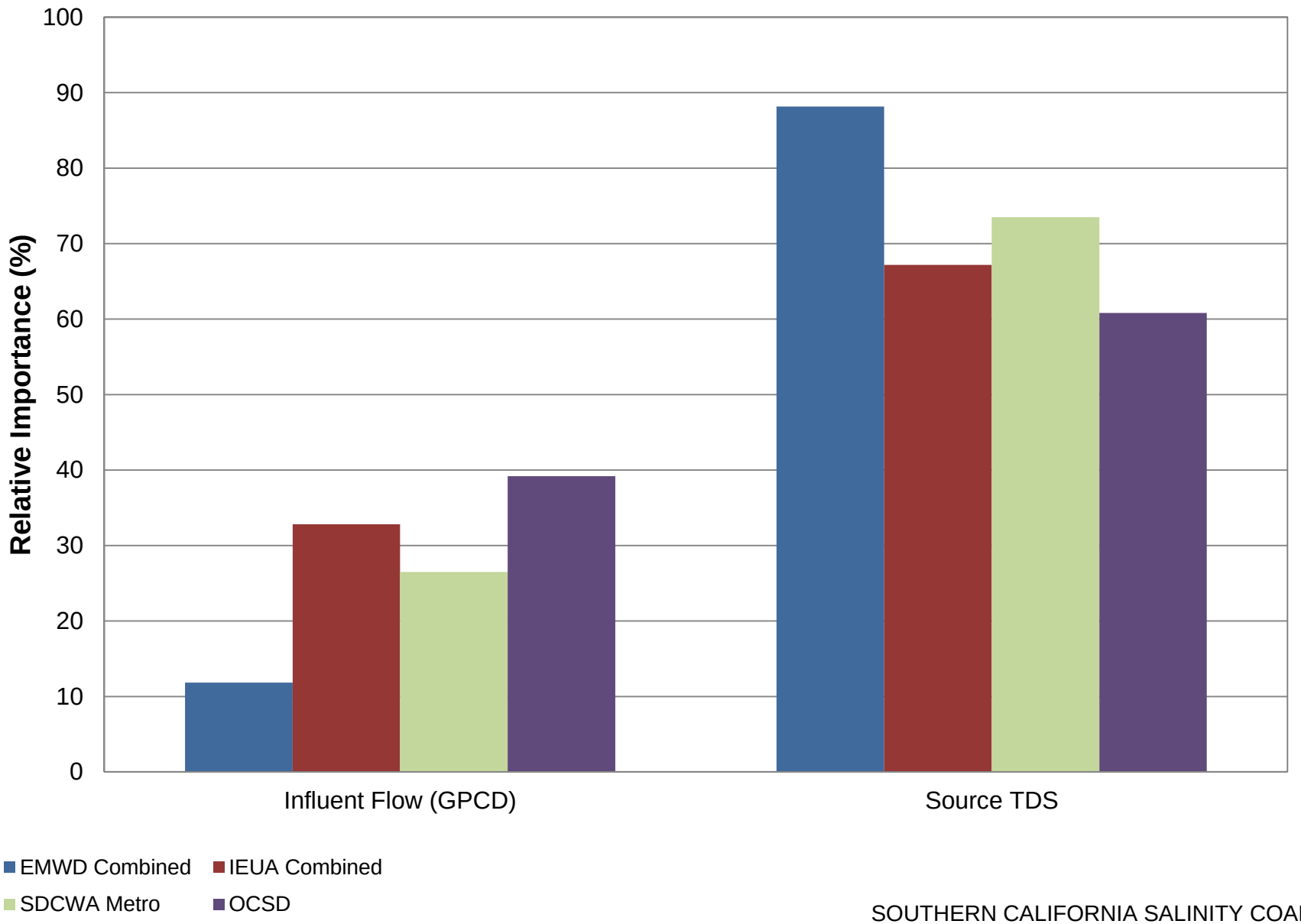
Table 8. R^2 Values of Influent vs. Effluent TDS Concentration

Agency	WWTP	R^2 Value of Influent vs. Effluent TDS Concentration
EMWD	Moreno Valley	0.87
	Temecula Valley	0.9
	Perris Valley	0.86
	San Jacinto	0.61
IEUA	RP-1	0.83
	RP-2/RP-5	0.74
	RP-4	0.68
	CCWRF	0.87
SDCWA	Padre Dam	0.73
	North City	0.63
	Point Loma	0.98
	South Bay	0.45
OCSD	OCSD Plant 1	0.46
RPU	RPU	0.41

3.7 To what degree are fluctuations in the volume-weighted average concentration of TDS in recycled water correlated with variations in the volume-weighted average concentration of TDS in the municipal water supply?

The two most important explanatory variables for influent TDS concentrations (response variable) are volume-weighted source water TDS concentrations and indoor per capita flow. There is a high degree of correlation between the fluctuations of volume-weighted source water TDS concentrations and the fluctuations of influent TDS. Figure 8 plots the relative importance for each statistical model. The majority of the statistical models developed in this study show a greater relative importance on volume-weighted source water TDS concentrations with an average of 78 percent relative importance. Sewersheds with a water supply mix that has a larger percentage of imported water—such as EMWD—exhibit a greater relative importance on source TDS.



SOUTHERN CALIFORNIA SALINITY COALITION

Relative Importance of Influent Flow and Source TDS Variables

Figure 8

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3.8 To what degree do fluctuations in the volume-weighted average concentration of TDS in recycled water correlate with long-term meteorological (drought) cycles?

As shown in the response to Question 7, there is a high degree of correlation between the volume-weighted source water TDS concentrations (explanatory variable) and the effluent discharge TDS concentrations (response variable). One of the factors influencing the quality of source water supply water is the long-term meteorological cycles including droughts. One way to evaluate drought is through the Palmer Drought Severity Index (PDSI) established by the National Oceanic and Atmosphere Administration (NOAA). According to NOAA (2017):

> The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that spans –10 (dry) to +10 (wet). It has been reasonably successful at quantifying long-term drought. As it uses temperature data and a physical water balance model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration. Monthly PDSI values do not capture droughts on time scales less than about 12 months.

This analysis uses the Modified Palmer Drought Severity Index (PMDI), which is an update to the PDSI for operational meteorological purposes (NOAA, 2017). The PMDI and PDSI have the same values during established wet periods and droughts; however, they differ slightly when the meteorological cycles transition from one to another. While this study focuses on WWTPs in Southern California, a drought in Northern California can change TDS concentrations in source water in Southern California and a drought in the Rocky Mountains can have an effect on TDS in the Colorado River. This analysis uses the drought index for the entire state of California as a general picture of drought conditions affecting imported and local water supply quality in Southern California. Local drought indices will vary region to region.

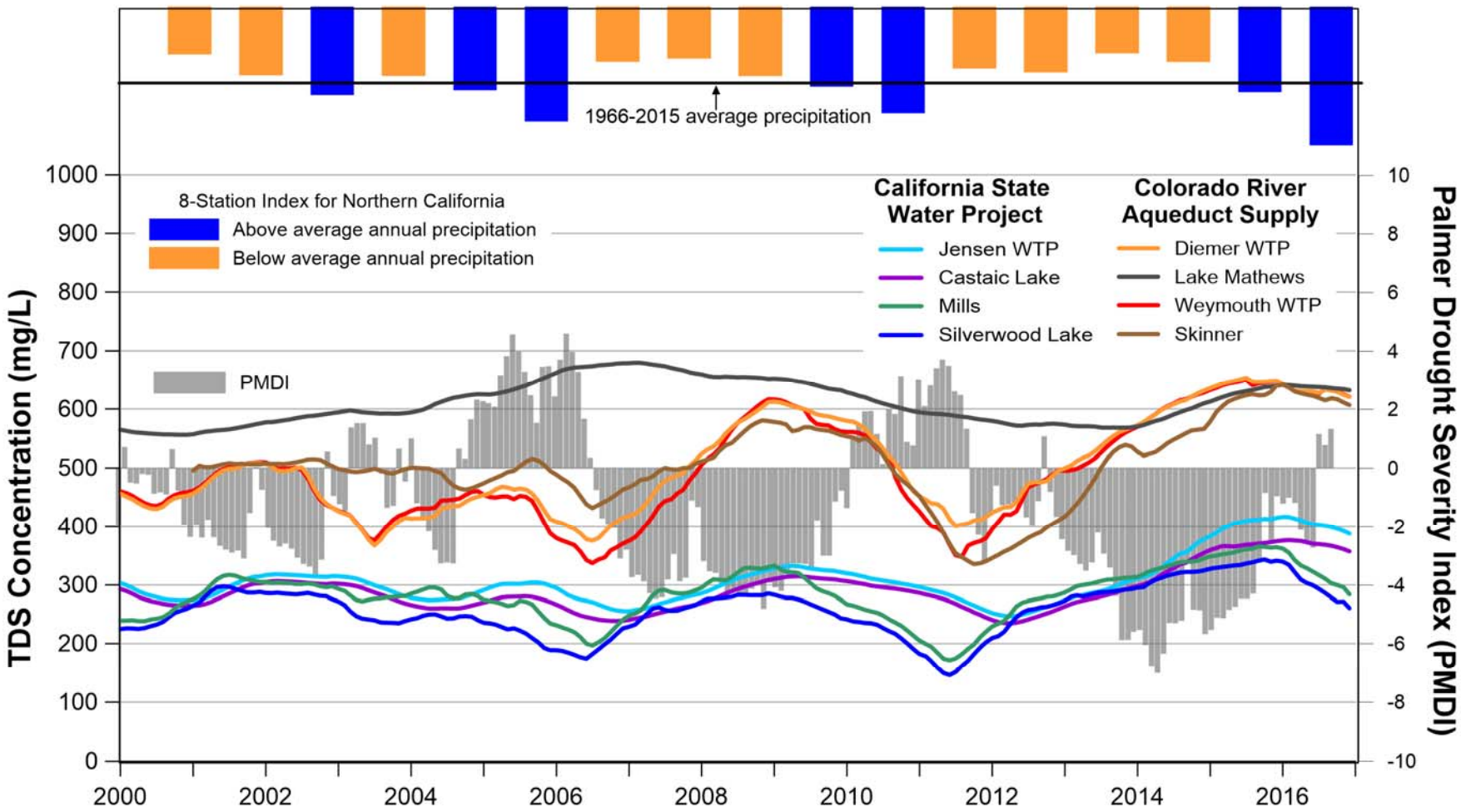
Another way to analyze climatic variations is through the 8-Station Index, which compares the annual precipitation with a 50-year average (DWR, 2018). The DWR began development of the 8-Station Index for tracking precipitation in the Northern Sierra in the 1980s. The 8-Station Index was originally designed to be a simple index of the cumulative amount of precipitation

(rainfall and snow) that fell in the watershed of the Sacramento River Basin throughout the water year. Stations were selected to record the average water year runoff: three stations for the Sacramento River above the historical Red Bluff gage (Mt. Shasta City, Shasta Dam, Mineral), three stations for the Feather-Yuba River (Brush Creek, Quincy, Sierraville), and two for the American River (Blue Canyon and Pacific House).

The original average precipitation of the 8-Station Index, starting in the 1920s and going through the 1980s, was 50 inches. DWR recently updated the 8-Station Index average precipitation for the 1966-2015 period to 51.8 inches. There will be a further update in 2021 for a new 1971-2020 50-year average).

Figure 9 compares the PMDI and 8-Station Index to surface supply water quality data for major reservoirs and treatment facilities operated by MWDSC. Time-series TDS concentrations are shown for Skinner Lake, Lake Mathews, Deimer WTP, and Weymouth WTP as part of the Colorado River Aqueduct, and for Mills, Silverwood Lake, Castaic Lake, and Jensen WTP as part of the SWP. Aside from Lake Mathews, which has a more gradual trend, all reservoirs show similar increases in TDS during periods of drought and decreases in TDS during wet years.

To meet water demands, water agencies maintain a portfolio including imported water and groundwater; this mix influences how much impact climate change has on the source supply water. For example, both EMWD and IEUA rely on a blend of groundwater and imported water; however, EMWD receives CRA water, while IEUA only receives SWP water. In addition, IEUA relies more heavily on groundwater than EMWD. These differences between the two service areas are reflected in the variability in volume-weighted source water TDS concentrations. EMWD has larger fluctuations in concentration, while IEUA is increasing only slightly and shows a relatively smooth trend compared with EMWD.



Sources: MWDSC (2017), NOAA (2017), and DWR (2018)

SOUTHERN CALIFORNIA SALINITY COALITION

Surface Supply Water TDS Concentration and Palmer Drought Severity Index for California

Figure 9

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In Figure 10, source water TDS concentrations are plotted against the PMDI values for EMWD and IEUA; there is a strong inverse correlation with the climatic drought cycles. During wet periods, PMDI values are positive and TDS concentrations are lower; during drought periods, PMDI values are negative and TDS concentrations are higher. IEUA, which relies more on local resources and groundwater, has lower TDS concentrations and variation between drought cycles; however, there appears to be a general upward trend in source TDS for IEUA. Agencies that rely more heavily on imported water may be more susceptible to TDS fluctuations caused by climate change.

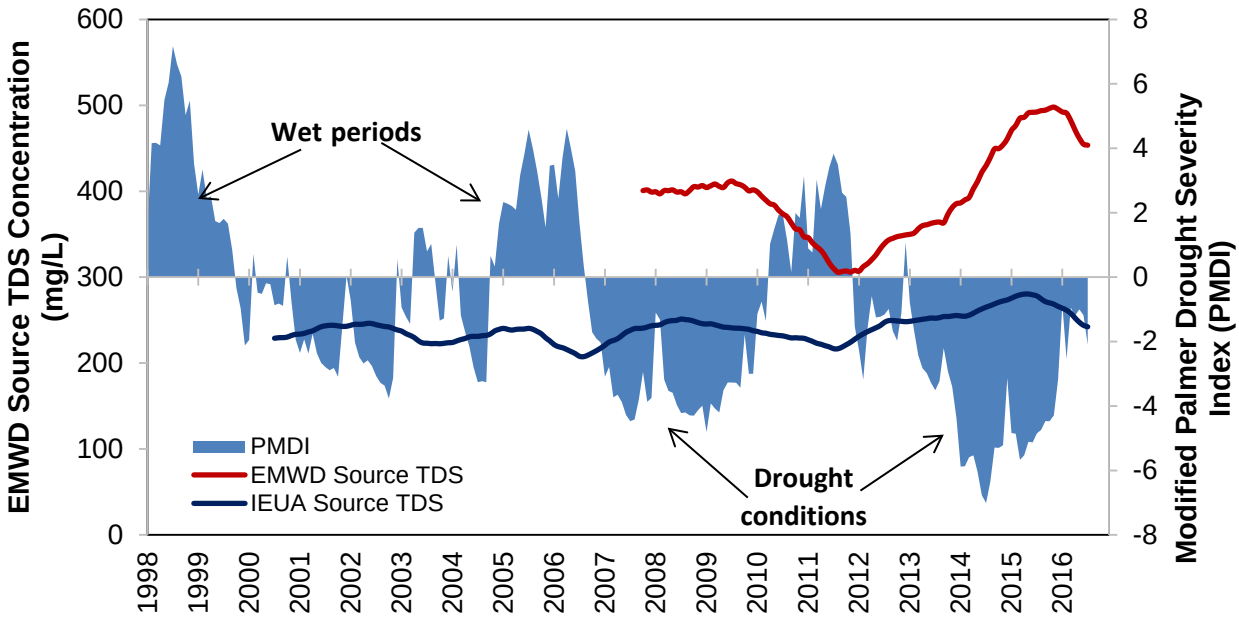
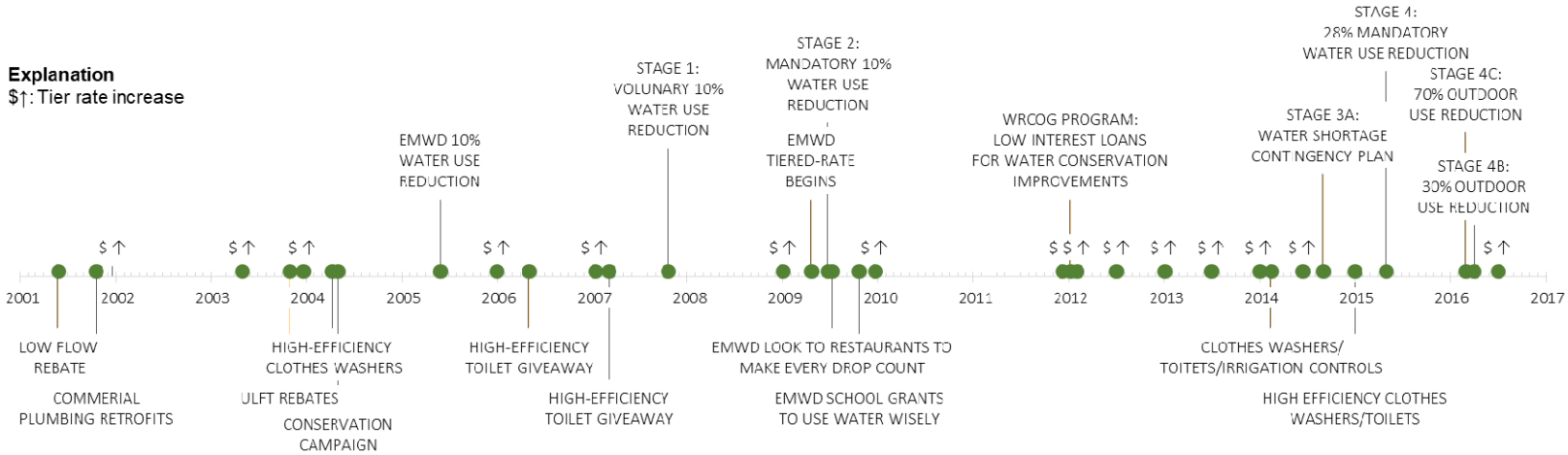
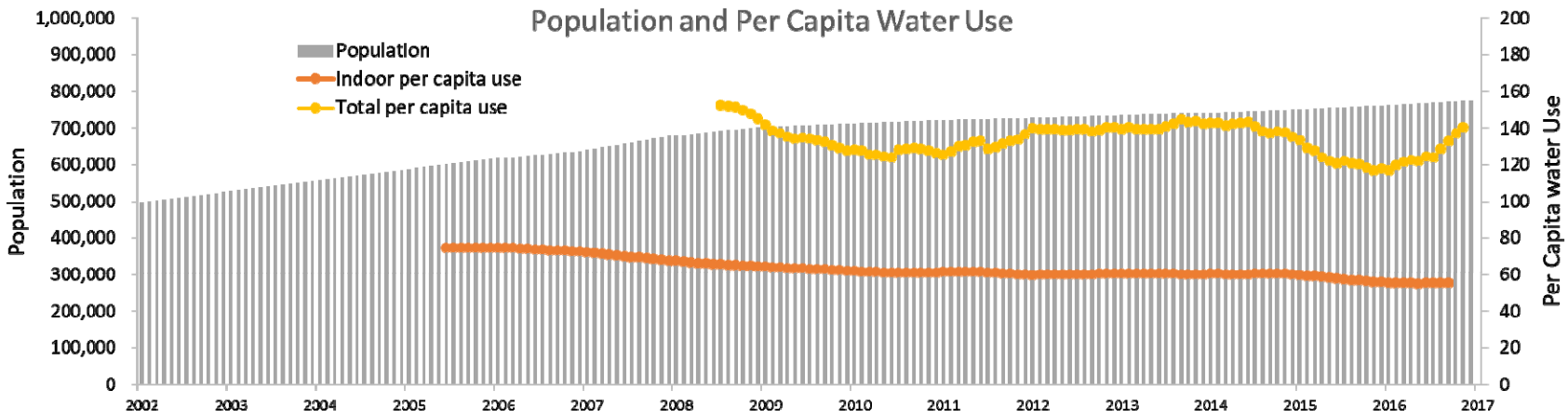


Figure 10. Modified Palmer Drought Severity Index and Source TDS, EMWD and IEUA

3.9 What effect, if any, did the state's mandatory conservation measures (2015-16) and the subsequent relaxation of these measures have on average per capita indoor and outdoor water use?

Since 2001, EMWD has been tracking their water conservation and incentive program, which promotes conservation of both indoor and outdoor water within residential, commercial, and industrial sectors. Figure 11 summarizes the indoor conservation incentive programs, ongoing rate adjustment periods, and EMWD Conservation Stages 1 through 4. Stage 4 is the





SOUTHERN CALIFORNIA SALINITY COALITION

EMWD Conservation Programs and Incentives for Indoor Water Use

Figure 11

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most aggressive in terms of water conservation, and coincided with the Governor's 2015 emergency proclamation. The timeline of conservation incentives and programs is compared to the timeline of population growth and indoor per capita water use (dark orange) and total per capita water use (light orange).

Figure 11 suggests that as policies are implemented and technology becomes more efficient, consumers become more adapted to conserving water and policies made at the state level are much more gradual than expected. There are subtle changes that occurred at certain points in time. In particular, between 2004 and 2010 there is a general decrease in per capita indoor water use. From 2010 to 2015, per capita indoor water use remained constant at around 60 gpcd, and in May 2015, per capita indoor water use began to decline again down to 55 gpcd in 2016. The response to the state's mandatory conservation measure from the 2015 executive order to reduce water use by 25 percent statewide is more evident in total per capita water use rapid declines following 2015 (Figure 11). Total water use includes both indoor uses such as residential, commercial, and industrial, as well as outdoor use such as agricultural and landscape irrigation uses.

3.10 What effect, if any, did the 2015-16 changes in average per capita indoor water use have on the average concentration of TDS in wastewater influent and recycled water?

As described in Question 1 and Question 9, there is a gradual downward trend in indoor per capita water use over time. Changes in average indoor per capita water use following the mandatory conservation measures in 2015 are minimal, especially when compared with total water use. Analysis of this particular event suggests that it was not statistically significant in modeling influent TDS concentration changes. This is, in part, because the 12-month rolling averages tend to smooth out short-term changes in monthly TDS concentrations.

3.11 Based on the results produced for Questions 8, 9, and 10, what are the implications for the trends described in Questions 1, 2, and 3 if precipitation patterns over the next 20 years are drier than normal (i.e., consistent with each agency's planning for potential climate change)?

Matrices for EMWD and IEUA (Tables 9a and 9b) were developed from the statistical models to predict the effects of conservation and changes in source water TDS. On the top row is a range of values for volume-weighted source water supply TDS concentrations. On the left axis of the matrix is a range of values for indoor per capita water use. The center of the matrix shows the model-predicted influent TDS concentrations at a given indoor per capita water use and a given source TDS value. Supply water concentrations are dependent upon the blend of imported water and local resources, as well as climatic changes.

As the indoor per capita use decreases, the resulting influent TDS concentration increases. The statistical model for EMWD predicts a 1.7 mg/L increase in WWTP influent TDS for every 1.0 gpcd decrease in indoor water use, while the statistical model for IEUA predicts a 1.2 mg/L increase in WWTP influent TDS for every 1.0 gpcd decrease in indoor water use. For example, during the peak of the 2016 drought, TDS in the volume-weighted potable supply water for EMWD reached 500 mg/L. At this time the indoor per capita water use was 55 gpcd, and the resulting influent TDS was approximately 750 mg/L. As described in the response to Question 1, there is a downward trend of indoor per capita water use, and as shown in the matrices (Tables 9a and 9b), decreasing per capita use increases TDS concentrations. The response to Question 8 predicts that source supply water will exhibit an increase in TDS concentrations during drought cycles.

Table 9a. EMWD Statistical Model Matrix for Influent TDS

Indoor Water Use (gpcd)	Supply Water Quality TDS (mg/L)																															
	200	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**	**625**	**650**	**675**	**700**	**725**	**750**	**775**	**800**	**825**	**850**	**875**	**900**	**925**	**950**	**975**	**1,000**
40	524	545	566	587	608	629	650	671	692	713	733	754	775	796	817	838	859	880	901	922	943	964	984	1,005	1,026	1,047	1,068	1,089	1,110	1,131	1,152	1,173	1,194
42	521	542	563	584	605	626	646	667	688	709	730	751	772	793	814	835	856	877	897	918	939	960	981	1,002	1,023	1,044	1,065	1,086	1,107	1,128	1,148	1,169	1,190
44	518	539	560	580	601	622	643	664	685	706	727	748	769	790	810	831	852	873	894	915	936	957	978	999	1,020	1,041	1,061	1,082	1,103	1,124	1,145	1,166	1,187
46	514	535	556	577	598	619	640	661	682	703	724	744	765	786	807	828	849	870	891	912	933	954	974	995	1,016	1,037	1,058	1,079	1,100	1,121	1,142	1,163	1,184
48	511	532	553	574	595	616	637	657	678	699	720	741	762	783	804	825	846	867	888	908	929	950	971	992	1,013	1,034	1,055	1,076	1,097	1,118	1,139	1,159	1,180
50	508	529	550	571	591	612	633	654	675	696	717	738	759	780	801	821	842	863	884	905	926	947	968	989	1,010	1,031	1,052	1,072	1,093	1,114	1,135	1,156	1,177
52	504	525	546	567	588	609	630	651	672	693	714	735	755	776	797	818	839	860	881	902	923	944	965	985	1,006	1,027	1,048	1,069	1,090	1,111	1,132	1,153	1,174
54	501	522	543	564	585	606	627	648	668	689	710	731	752	773	794	815	836	857	878	899	919	940	961	982	1,003	1,024	1,045	1,066	1,087	1,108	1,129	1,149	1,170
56	498	519	540	561	581	602	623	644	665	686	707	728	749	770	791	812	832	853	874	895	916	937	958	979	1,000	1,021	1,042	1,063	1,083	1,104	1,125	1,146	1,167
58	495	515	536	557	578	599	620	641	662	683	704	725	746	766	787	808	829	850	871	892	913	934	955	976	996	1,017	1,038	1,059	1,080	1,101	1,122	1,143	1,164
60	491	512	533	554	575	596	617	638	659	679	700	721	742	763	784	805	826	847	868	889	910	930	951	972	993	1,014	1,035	1,056	1,077	1,098	1,119	1,140	1,160
62	488	509	530	551	572	592	613	634	655	676	697	718	739	760	781	802	823	843	864	885	906	927	948	969	990	1,011	1,032	1,053	1,074	1,094	1,115	1,136	1,157
64	485	506	526	547	568	589	610	631	652	673	694	715	736	756	777	798	819	840	861	882	903	924	945	966	987	1,007	1,028	1,049	1,070	1,091	1,112	1,133	1,154
66	481	502	523	544	565	586	607	628	649	670	690	711	732	753	774	795	816	837	858	879	900	920	941	962	983	1,004	1,025	1,046	1,067	1,088	1,109	1,130	1,151
68	478	499	520	541	562	583	603	624	645	666	687	708	729	750	771	792	813	834	854	875	896	917	938	959	980	1,001	1,022	1,043	1,064	1,084	1,105	1,126	1,147
70	475	496	517	537	558	579	600	621	642	663	684	705	726	747	767	788	809	830	851	872	893	914	935	956	977	998	1,018	1,039	1,060	1,081	1,102	1,123	1,144
72	471	492	513	534	555	576	597	618	639	660	681	701	722	743	764	785	806	827	848	869	890	911	931	952	973	994	1,015	1,036	1,057	1,078	1,099	1,120	1,141
74	468	489	510	531	552	573	594	614	635	656	677	698	719	740	761	782	803	824	845	865	886	907	928	949	970	991	1,012	1,033	1,054	1,075	1,095	1,116	1,137
76	465	486	507	527	548	569	590	611	632	653	674	695	716	737	758	778	799	820	841	862	883	904	925	946	967	988	1,009	1,029	1,050	1,071	1,092	1,113	1,134
78	461	482	503	524	545	566	587	608	629	650	671	691	712	733	754	775	796	817	838	859	880	901	922	942	963	984	1,005	1,026	1,047	1,068	1,089	1,110	1,131
80	458	479	500	521	542	563	584	605	625	646	667	688	709	730	751	772	793	814	835	855	876	897	918	939	960	981	1,002	1,023	1,044	1,065	1,086	1,106	1,127

Table 9b. IEUA Statistical Model Matrix for Influent TDS

Indoor Water Use (gpcd)	Supply Water Quality TDS (mg/L)																															
	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800	825	850	875	900	925	950	975	1,000
40	479	503	527	551	574	598	622	646	669	693	717	741	764	788	812	836	859	883	907	931	955	978	1,002	1,026	1,050	1,073	1,097	1,121	1,145	1,168	1,192	1,216	1,240
42	477	501	524	548	572	596	619	643	667	691	715	738	762	786	810	833	857	881	905	928	952	976	1,000	1,023	1,047	1,071	1,095	1,118	1,142	1,166	1,190	1,213	1,237
44	475	498	522	546	570	593	617	641	665	688	712	736	760	783	807	831	855	878	902	926	950	973	997	1,021	1,045	1,068	1,092	1,116	1,140	1,163	1,187	1,211	1,235
46	472	496	520	543	567	591	615	638	662	686	710	733	757	781	805	828	852	876	900	923	947	971	995	1,018	1,042	1,066	1,090	1,114	1,137	1,161	1,185	1,209	1,232
48	470	493	517	541	565	588	612	636	660	683	707	731	755	779	802	826	850	874	897	921	945	969	992	1,016	1,040	1,064	1,087	1,111	1,135	1,159	1,182	1,206	1,230
50	467	491	515	539	562	586	610	634	657	681	705	729	752	776	800	824	847	871	895	919	942	966	990	1,014	1,037	1,061	1,085	1,109	1,132	1,156	1,180	1,204	1,227
52	465	489	512	536	560	584	607	631	655	679	702	726	750	774	797	821	845	869	892	916	940	964	987	1,011	1,035	1,059	1,082	1,106	1,130	1,154	1,178	1,201	1,225
54	462	486	510	534	557	581	605	629	652	676	700	724	747	771	795	819	842	866	890	914	938	961	985	1,009	1,033	1,056	1,080	1,104	1,128	1,151	1,175	1,199	1,223
56	460	484	507	531	555	579	602	626	650	674	698	721	745	769	793	816	840	864	888	911	935	959	983	1,006	1,030	1,054	1,078	1,101	1,125	1,149	1,173	1,196	1,220
58	458	481	505	529	553	576	600	624	648	671	695	719	743	766	790	814	838	861	885	909	933	956	980	1,004	1,028	1,051	1,075	1,099	1,123	1,146	1,170	1,194	1,218
60	455	479	503	526	550	574	598	621	645	669	693	716	740	764	788	811	835	859	883	906	930	954	978	1,001	1,025	1,049	1,073	1,097	1,120	1,144	1,168	1,192	1,215
62	453	476	500	524	548	571	595	619	643	666	690	714	738	761	785	809	833	857	880	904	928	952	975	999	1,023	1,047	1,070	1,094	1,118	1,142	1,165	1,189	1,213
64	450	474	498	521	545	569	593	617	640	664	688	712	735	759	783	807	830	854	878	902	925	949	973	997	1,020	1,044	1,068	1,092	1,115	1,139	1,163	1,187	1,210
66	448	472	495	519	543	567	590	614	638	662	685	709	733	757	780	804	828	852	875	899	923	947	970	994	1,018	1,042	1,065	1,089	1,113	1,137	1,160	1,184	1,208
68	445	469	493	517	540	564	588	612	635	659	683	707	730	754	778	802	825	849	873	897	920	944	968	992	1,016	1,039	1,063	1,087	1,111	1,134	1,158	1,182	1,206
70	443	467	490	514	538	562	585	609	633	657	680	704	728	752	776	799	823	847	871	894	918	942	966	989	1,013	1,037	1,061	1,084	1,108	1,132	1,156	1,179	1,203
72	440	464	488	512	536	559	583	607	631	654	678	702	726	749	773	797	821	844	868	892	916	939	963	987	1,011	1,034	1,058	1,082	1,106	1,129	1,153	1,177	1,201
74	438	462	486	509	533	557	581	604	628	652	676	699	723	747	771	794	818	842	866	889	913	937	961	984	1,008	1,032	1,056	1,079	1,103	1,127	1,151	1,175	1,198
76	436	459	483	507	531	554	578	602	626	649	673	697	721	744	768	792	816	839	863	887	911	935	958	982	1,006	1,030	1,053	1,077	1,101	1,125	1,148	1,172	1,196
78	433	457	481	504	528	552	576	600	623	647	671	695	718	742	766	790	813	837	861	885	908	932	956	980	1,003	1,027	1,051	1,075	1,098	1,122	1,146	1,170	1,193
80	431	455	478	502	526	550	573	597	621	645	668	692	716	740	763	787	811	835	858	882	906	930	953	977	1,001	1,025	1,048	1,072	1,096	1,120	1,143	1,167	1,191

3.12 How does the volume-weighted average TDS concentration in recycled water, and the related increment for use, vary using a range of rolling averaging periods (e.g., 1, 5, 10, and 15 years)?

Member agencies within the Santa Ana River Watershed have WWTP discharge permit limits associated with groundwater management zones of effluent TDS that are based on 12-month rolling averages. In 2014, the Perris Valley WWTP in the EMWD service area exceeded its groundwater basin discharge limit of 800 mg/L TDS based on the 12-month rolling average. The Santa Ana Regional Board has different averaging periods for different permits; for example, TDS compliance for Reach 2 of the Santa Ana River is based on a 5-year rolling average, waste load allocation permits are based on 10-year rolling averages, and maximum benefit demonstrations for the Santa Ana River Watershed values are based on 20-year rolling averages. More importantly, long-term weather cycles (El Niño Southern Oscillation [ENSO]) are about 10 to 12 years between El Niño winters. One of the objectives of this report is to present how different rolling averages vary using a range of averaging periods (e.g., 1, 5, 10, and 15 years). Figure 12 shows 1-, 3-, 5-, and 10-year rolling averages for Perris Valley WWTP effluent.

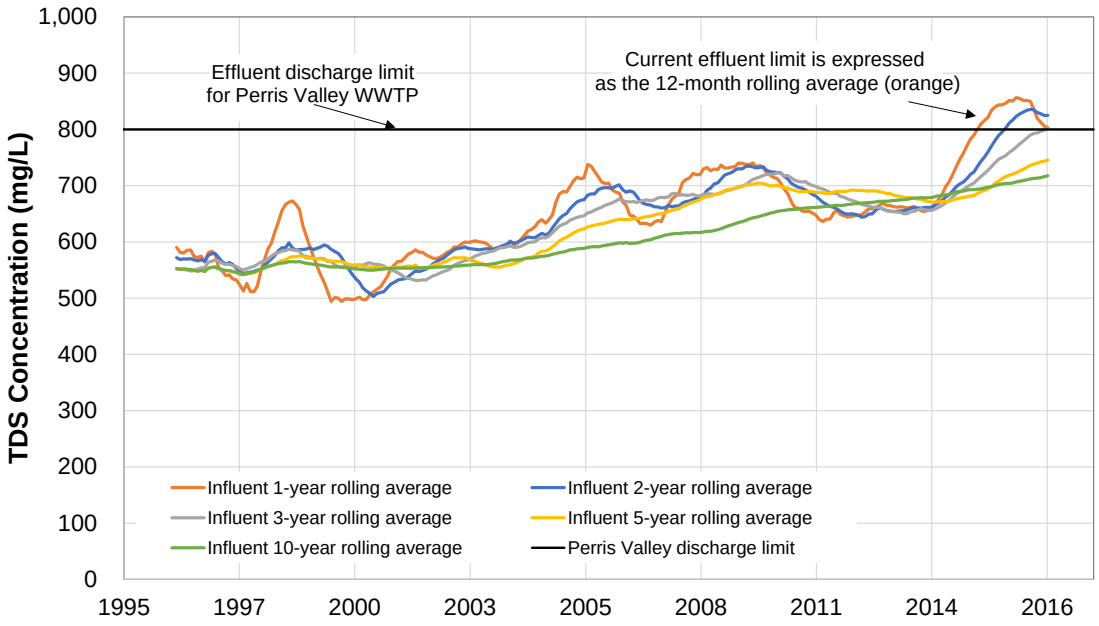

Figure 12. Perris Valley WWTP Effluent TDS Using Varied Rolling Averages

The 1-, 2-, and the 3-year rolling averages exceed the facility's permit limit; however, with a 5-year rolling average, EMWD could be under permit limits. While a 10-year rolling average would capture the effects of climate fluctuations, based upon this figure there is still an apparent upward trend in effluent TDS.

Of the datasets provided by the study participants, the La Cañada facility has the longest effluent TDS period: 1984 to 2016. In Figure 13, ranges for rolling averages include 15- and 20-year duration periods, which show the same general patterns as the Perris Valley WWTP effluent.

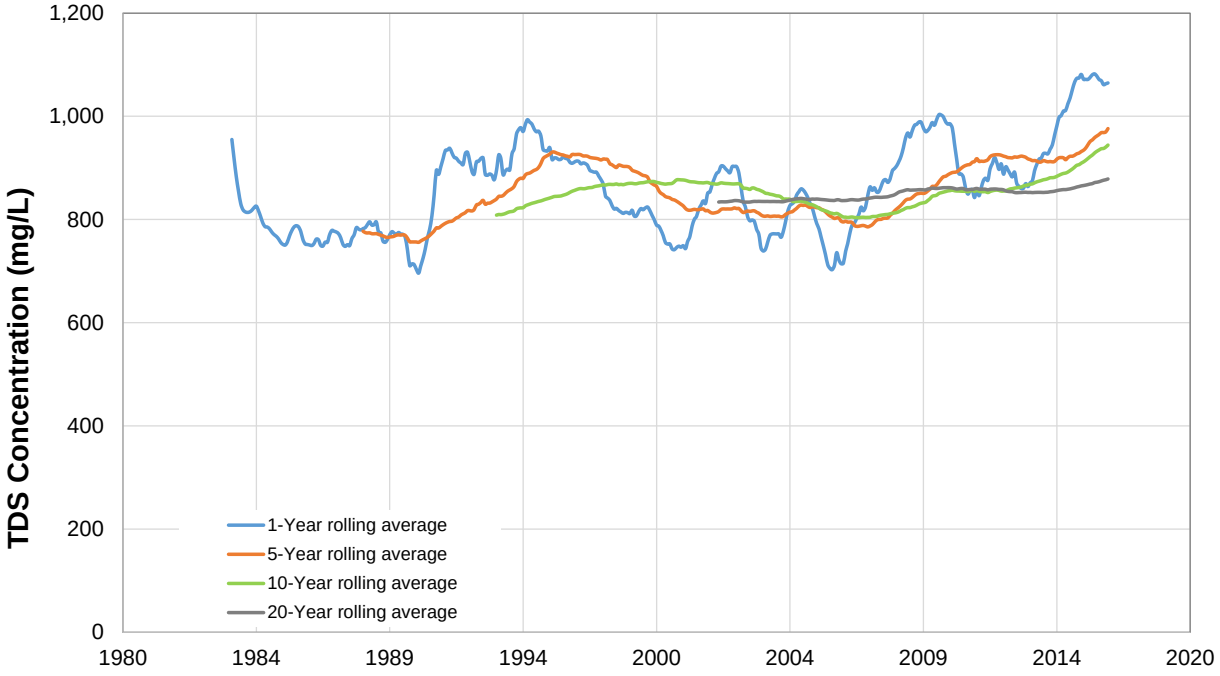

Figure 13. La Cañada WWTP Effluent TDS Using Varied Rolling Averages

4. Approaches for Evaluating TDS Trends

DBS&A employed two primary methods for modeling and evaluating long-term trends for salinity in wastewater and recycled water. The first method is a deterministic model, where the outcome of a deterministic/algebraic model is governed through relationships between a state (initial conditions) and an event (parameters). WWTP influent TDS concentrations were estimated from a measured concentration of source water and a salt load from indoor use The second method uses statistical analyses to explore the relationship between the dependent or response variable (WWTP influent TDS) and independent (explanatory) variables (e.g., source concentration, population, conservation measures, etc.). Both methods are limited to the availability of source water quality data; therefore, these analyses were performed on a subset of the total number of sewersheds provided. At a minimum, the requisite data for the trends analysis include the following:

- Monthly indoor water use flows – assumed to be equivalent to influent flow
- Monthly volume-weighted average TDS concentrations in source water
- Monthly TDS concentrations in influent and/or effluent flows
- Per capita salt mass load for the deterministic model (literature values)
- Population for each sewershed

4.1 Deterministic Approach to Evaluating TDS Trends

One of the key purposes of this study is to determine what effect conservation has on the quality of water discharged by WWTPs. As an initial step in understanding this relationship, a deterministic approach was used to model the observed influent TDS with and without conservation measures. Influent TDS is estimated from a measured concentration of source water and the per capita SML from indoor use multiplied by the population in the sewershed. Salt mass in source water and salt added from indoor uses of water (human excretion, gray water, soaps, water softeners are the two principal components of influent TDS in the deterministic model:

$$\text{Influent TDS} = \text{Source TDS} + (\text{SML}*\text{population}) / (\text{influent flow in mgd}) \qquad (2)$$

SML is relatively constant based on the characteristics of a given sewershed and, as described in Section 1.4, is approximately 0.15 to 0.18 pounds per capita per day. For this study, the SML value varies by sewershed, and is determined by calibrating the starting point of the model to the measured influent TDS. The average SML for each of the sewersheds is 0.17 pounds per capita per day, and ranged from 0.4 pound per capita per day for OCSD to 0.04 pound per capita per day for Padre Dam MWD. The wide variation is likely due to the industrial, commercial, and institutional discharges into the system and underestimates or overestimates in population or flow data provided for each sewershed.

To compare the effects of conservation, two scenarios were developed based upon influent flow:

- Scenario 1 uses the actual influent flow values which generally declined over time because of conservation measures.
- Scenario 2 adjusts the flow volume to represent a constant per capita indoor water use throughout the period represented by the dataset. The constant per capita indoor water use is assumed to be the water use at the beginning of the dataset. This scenario shows what the influent TDS concentration would have been throughout the study period without conservation.

The parameters used for the EMWD combined dataset for the two deterministic models scenarios are summarized in Table 10. Figure 14 is a graphical representation of the two scenarios for the deterministic model for the EMWD combined dataset. The black and green lines represent the observed volume-weighted source water TDS and influent TDS, respectively. Scenario 1 of the deterministic model is depicted as the blue dotted line and Scenario 2 is depicted as the orange dotted line. Deterministic models for the remaining sewersheds are provided in Appendix B. This approach is dependent on influent flow; therefore, variations or divergences of flow can impact the model results and may artificially overestimate the “with conservation” scenario.

Table 10. EMWD Deterministic Parameters

Deterministic Model	2007 Population	2016 Population	SML Multiplier	Per Capita Indoor Water Use
Scenario 1	670,000	780,000	0.135	Declines from 70 to 55 gpcd
Scenario 2	670,000	780,000	0.135	Held constant at 70 gpcd

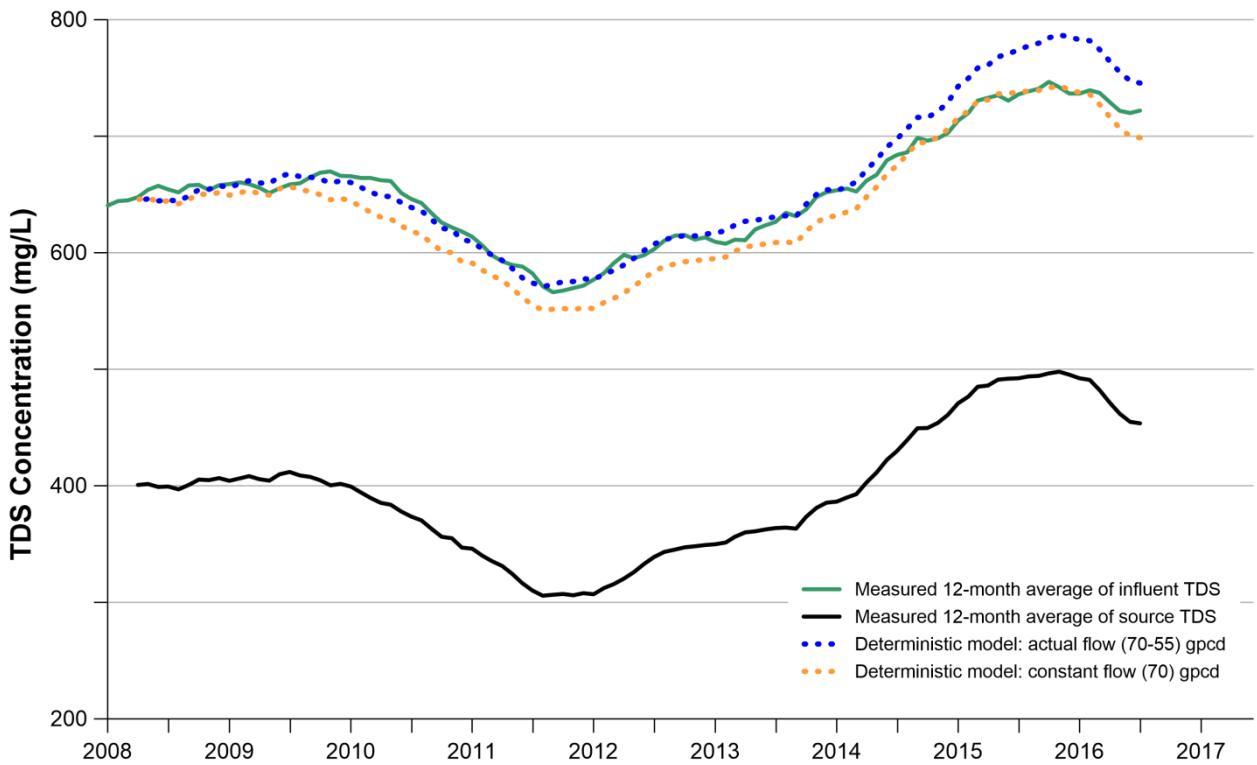

Figure 14. EMWD Combined Sewersheds Deterministic Model Approach

For the EMWD combined dataset, model Scenario 1 matches the observed influent TDS until 2014, at which point Scenario 2 matches the observed influent TDS more closely. Generally, the predicted TDS concentrations in Scenario 1 model are higher than in Scenario 2. By the end of the dataset, there is an approximately 70 mg/L separation between the two models, suggesting that conservation of indoor water does account for some increase in the increment of use for TDS. The statistical models described in Section 4.2 provide for a more rigorous method in establishing relationships between conservation and source TDS.

4.2 Statistical Analyses for Evaluating TDS Trends

Statistical analyses were used to assist in the interpretation of the data and to determine the degree to which variability can be attributed to one or more factors. Variables for the analyses were divided into response variables (e.g., influent TDS concentration) and explanatory variables (e.g., source TDS, indoor per capita water use, conservation measures). The response variable is the factor or variable that is being modeled and is dependent on the explanatory variables. The two principal sources of salt that impact the influent TDS are the source water TDS and the indoor per capita water use (Figure 15).

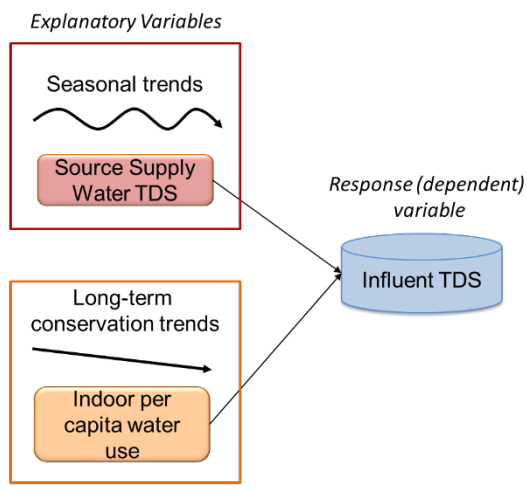

Figure 15. Statistical Model Variables

Multiple linear regression models were developed for each of the sewersheds that had the requisite data to perform the analyses; these models demonstrate the relationship between the response variable and two or more explanatory variables. The use of a multiple linear regression approach and the resulting models are discussed in Section 4.2.1. For this TDS trend study, all statistical analyses were conducted using the R program (R Development Core Team, 2017) and, where applicable, selected packages developed for the R program.

The objective of multiple linear regression analysis is to make possible a deeper understanding of the potential cause and effect relationships influencing the response variable. Generally, a multiple linear regression model is:

$$y_i = b_0 + \sum_{j=1}^{n} b_j x_{ij} + e_i \qquad (3)$$

where y_i = the predicted value of the response variable y for data point i

b_0 = the model intercept coefficient

b_j = the model slope coefficient for explanatory variable j

n = the total number of explanatory variables in the model

x_{ij} = the known value x of explanatory variable j for data point i

e_i = the residual error of data point i from the fitted model

Multiple linear regression analysis determines the coefficients b_0 and b_j for a best-fit linear model by minimizing e_i, along with the statistical significance of the explanatory variables in the model and the portion of the total variance accounted for by the model (as measured by the multiple R^2).

In addition to the basic multiple regression model (Equation 3), the R package, called "relaimpo" (Gromping, 2015), was used to determine the relative importance of the explanatory variables in the model. The package implements methods detailed in Gromping (2006), particularly the 'lmg' method, which decomposes multiple R^2 values based on both direct effects and effects adjusted for the intercorrelations of the explanatory variables in the model.

The response variable, influent TDS, was modeled as a function of the explanatory variables, source TDS and influent flow measured in gpcd. In other words, influent TDS ~ source TDS + influent per capita flow, where "~" denotes "is a function of." Results are provided in Table 11.

Figure 16 is a graphical example for the EMWD combined sewershed with influent TDS as the response variable. The black and green lines represents the observed volume-weighted source water TDS and influent TDS, respectively. As with the deterministic model, Scenario 1 is depicted as the blue dotted line and Scenario 2 is depicted as the orange dotted line.

Table 11. Multiple Linear Regression Analysis on Influent TDS

Sewershed	Multiple R^2	Intercept (b_0)	Explanatory Variable	Slope (b_1)	Significance [a]	Relative Importance (%)
EMWD Combined	0.979	423.18995	STDS	0.83656	***	88.17
			IGPCD	–1.65462	***	11.83
EMWD Temecula Valley	0.902	748.91772	STDS	0.50234	***	80.82
			IGPCD	–4.35893	***	19.18
EMWD Perris Valley	0.923	418.7358	STDS	0.85903	***	99.01
			IGPCD	–1.3862	***	0.99
EMWD San Jacinto Valley	0.644	448.25998	STDS	0.45257	***	97.13
			IGPCD	–0.10629		2.87
EMWD Moreno Valley	0.965	247.42822	STDS	0.84916	***	99.04
			IGPCD	0.23688		0.96
IEUA	0.747	316.22148	STDS	0.99689	***	67.18
			IGPCD	–0.85149	***	32.82
IEUA RP1	0.788	276.71694	STDS	1.01263	***	68.32
			IGPCD	–0.53245	***	31.68
IEUA RP2-RP5	0.299	403.19657	STDS	0.30222	***	72.07
			IGPCD	0.26596	**	27.93
IEUA RP4	0.746	52.11672	STDS	1.97405	***	94.66
			IGPCD	–0.82468	***	5.34
IEUA CCWRF	0.741	579.22115	STDS	0.22931	***	32.81
			IGPCD	–1.2801	***	67.19
OCSD	0.533	522.5264	STDS	1.1303	***	60.82
			IGPCD	–1.1934	***	39.18
SDCWA Padre Dam	0.832	384.44652	STDS	0.75329	***	97.76
			IGPCD	1.2371	.	2.24
SDCWA OTAY	0.09817	373.18296	STDS	1.04385	***	66.13
			IGPCD	–7.09841	***	33.87
SDRWP	0.7914	1302.82192	STDS	1.03088	***	73.46
			IGPCD	–3.68322	***	26.54

[a] *** $p < 0.001$
** $p < 0.01$
* $p < 0.05$
. $p < 0.1$

STDS = Source total dissolved solids (TDS) concentration (milligrams per liter [mg/L])
IGPCD = Indoor flow (gallons per capita per day [gpcd]); includes residential, commercial, industrial, and institutional flows

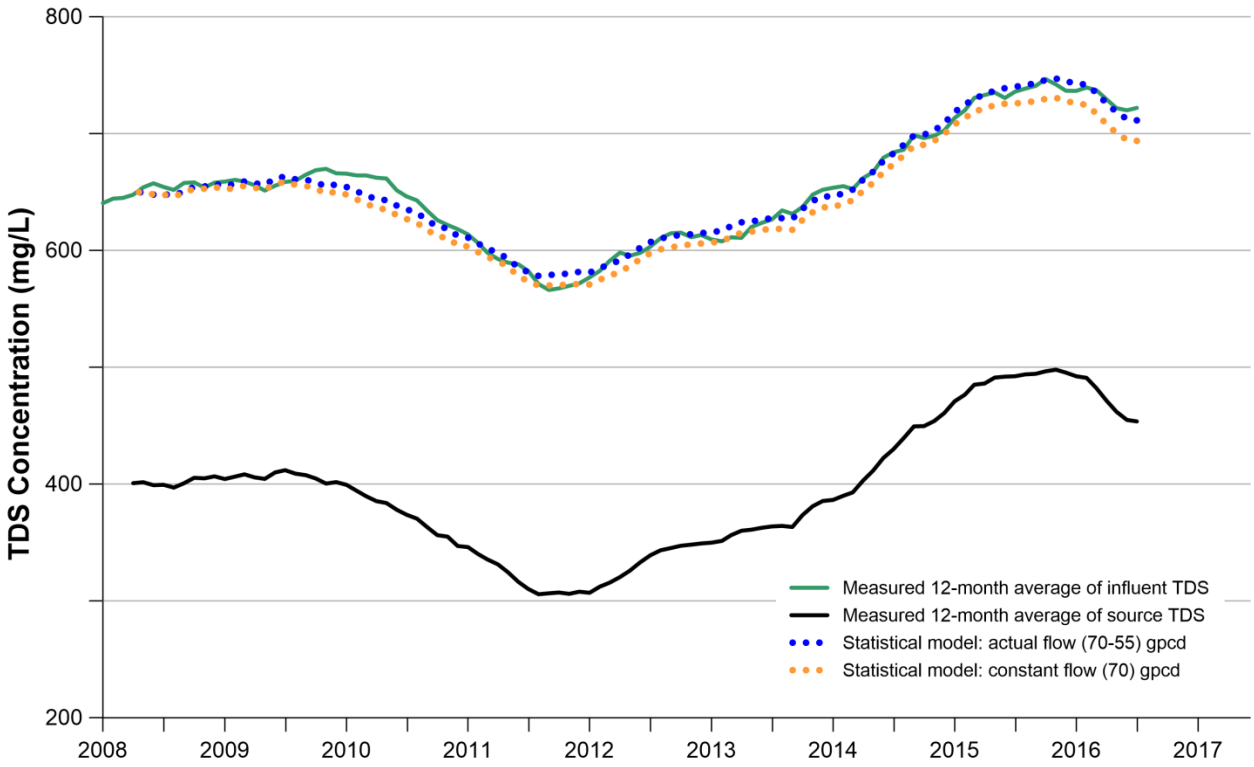

Figure 16. EMWD Combined Sewersheds Multiple Linear Regression Model on Influent TDS

In this example, the two explanatory variables, influent per capita flow and source TDS, predict influent TDS concentrations with an R^2 value of 0.98. These two variables do an excellent job of predicting the influent TDS for the combined EMWD sewershed. The relative importance of the explanatory variables is 88 percent for source TDS and 12 percent for influent per capita flow. This statistical model for the combined EMWD sewershed estimates that there is an increase of 1.7 mg/L for every 1.0 gpcd decrease in influent flow in gallons per day (IGPCD). This is apparent by the increasing gap between Scenarios 1 and 2 in Figure 16; by 2016, there is a 17 mg/L difference between the two scenarios. Appendix B provides the remainder of the statistical results.

5. Summary

A majority of WWTPs in this study exhibited an increase in influent and effluent TDS concentrations over the past few decades. This study found that the two primary contributors to increasing TDS in WWTPs are (1) volume-weighted source water quality and (2) decreased indoor water use. Source water quality is a function of temporal trends as a consequence of drought cycles and long-term climate change, among other factors. The decreased availability of reliable, high-quality potable water supplies may result in water supply agencies changing their water supply options and augmenting their portfolio to include lower quality sources, including switching from SWP water to CRA water or groundwater that may have higher TDS. Drought and climate change impact water quality directly and secondarily by changing the source of the water. Water conservation measures—in part due to recent historic drought cycles—has resulted in decreased indoor water use and a corresponding increase in TDS. This is an unintended and largely unanticipated consequence of well-intentioned water conservation measures. The salt mass added through an increment of use for indoor water uses remains about the same, while the volume of water decreases, resulting in increased TDS concentrations.

The key findings of this study include:

- Volume-weighted source water TDS concentration is *the* significant determiner of influent TDS. Source TDS explains more of the variability in influent/effluent TDS than any other factor, including decreased indoor water use.
- There is a strong inverse correlation between drought and imported water TDS concentrations for both SWP water and CRA water. TDS concentration can vary by 300 mg/L from wet years to dry years for CRA water and by 200 mg/L for SWP water.
- Long-term conservation efforts account for a smaller, but still significant, increase in TDS. IEUA and EMWD statistical models predict a 1.2 to 1.7 mg/L increase in TDS for every 1.0 gpcd decrease in indoor water use.

- Other unintended consequences of water conservation measures include loss of revenue from water sales, less available recycled water, and increased infrastructure operation and maintenance costs. Unintended benefits include a reduction in energy costs and decreased greenhouse gas formation.

- The reduction in the number of SRWS units can significantly reduce the concentration of TDS in influent flows to the WWTPs. In a case study, SCVSD removed 8,000 SRWS units, thereby reducing the TDS in the WWTP influent flow by nearly 80 mg/L.

- The duration of rolling-average periods can determine whether or not an agency is in violation of their permit limits. A compliance limit based on a 5-year rolling average instead of a 1-year rolling average for the Perris Valley WWTP would have kept the WWTP within permit limits.

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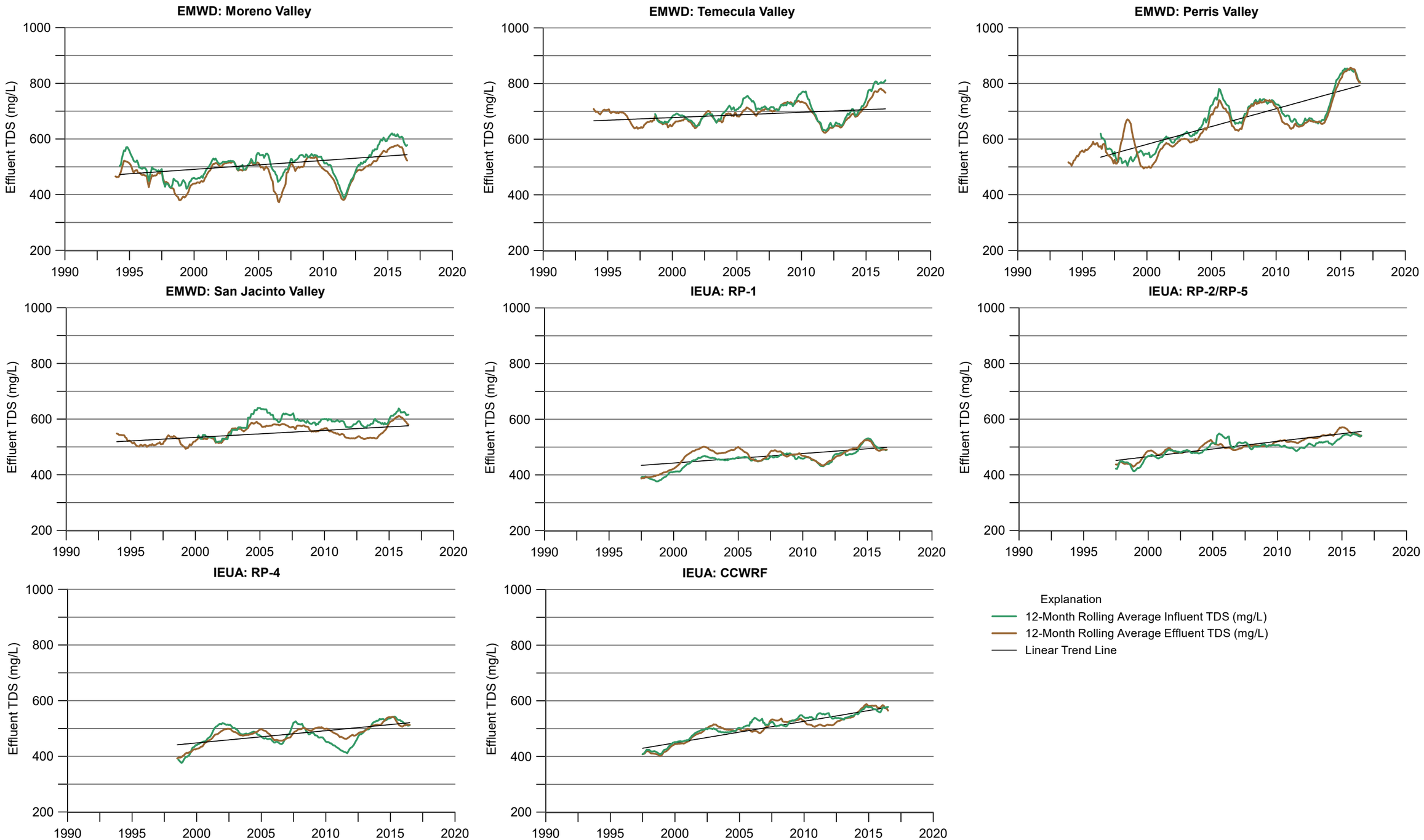
Appendix A

Influent and Effluent TDS Trends



J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX A\A1_EMWD_IEUA.MXD

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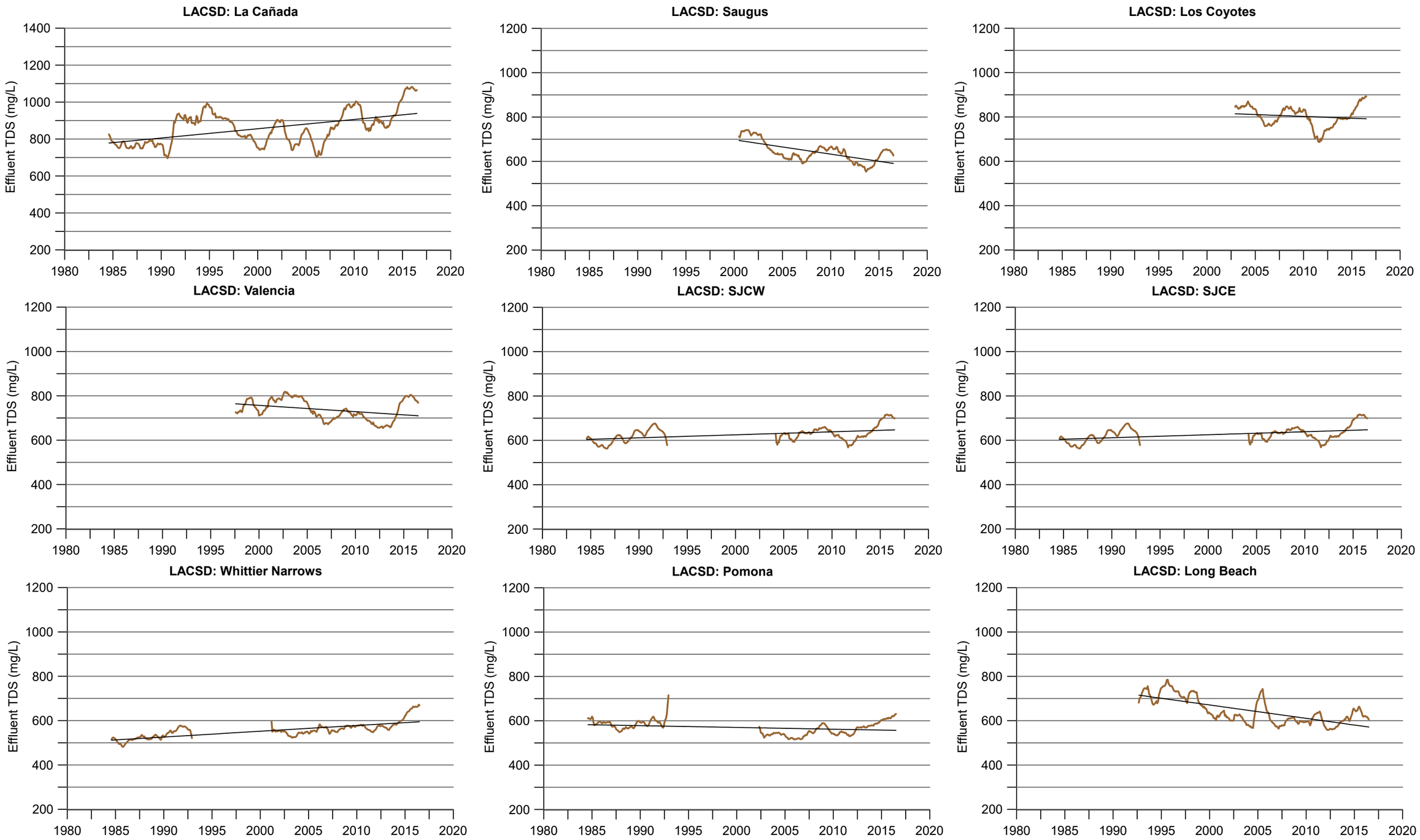
DB17.1179

SOUTHERN CALIFORNIA SALINITY COALITION

Wastewater Treatment Facility Influent and Effluent TDS Trends

Appendix A1



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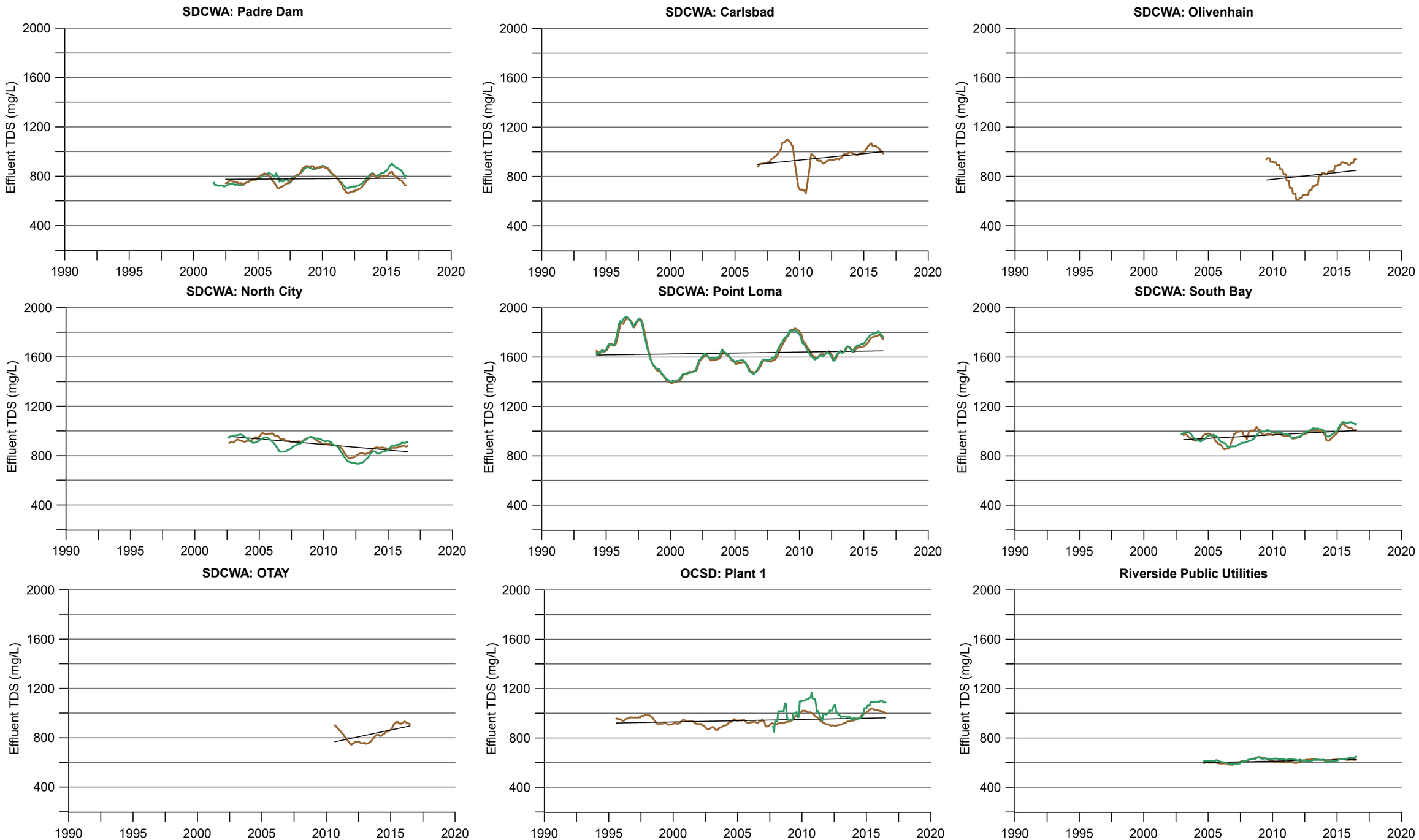
DB17.1179

SOUTHERN CALIFORNIA SALINITY COALITION

Wastewater Treatment Facility Influent and Effluent TDS Trends



J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX A\A3_SDCWA.MXD

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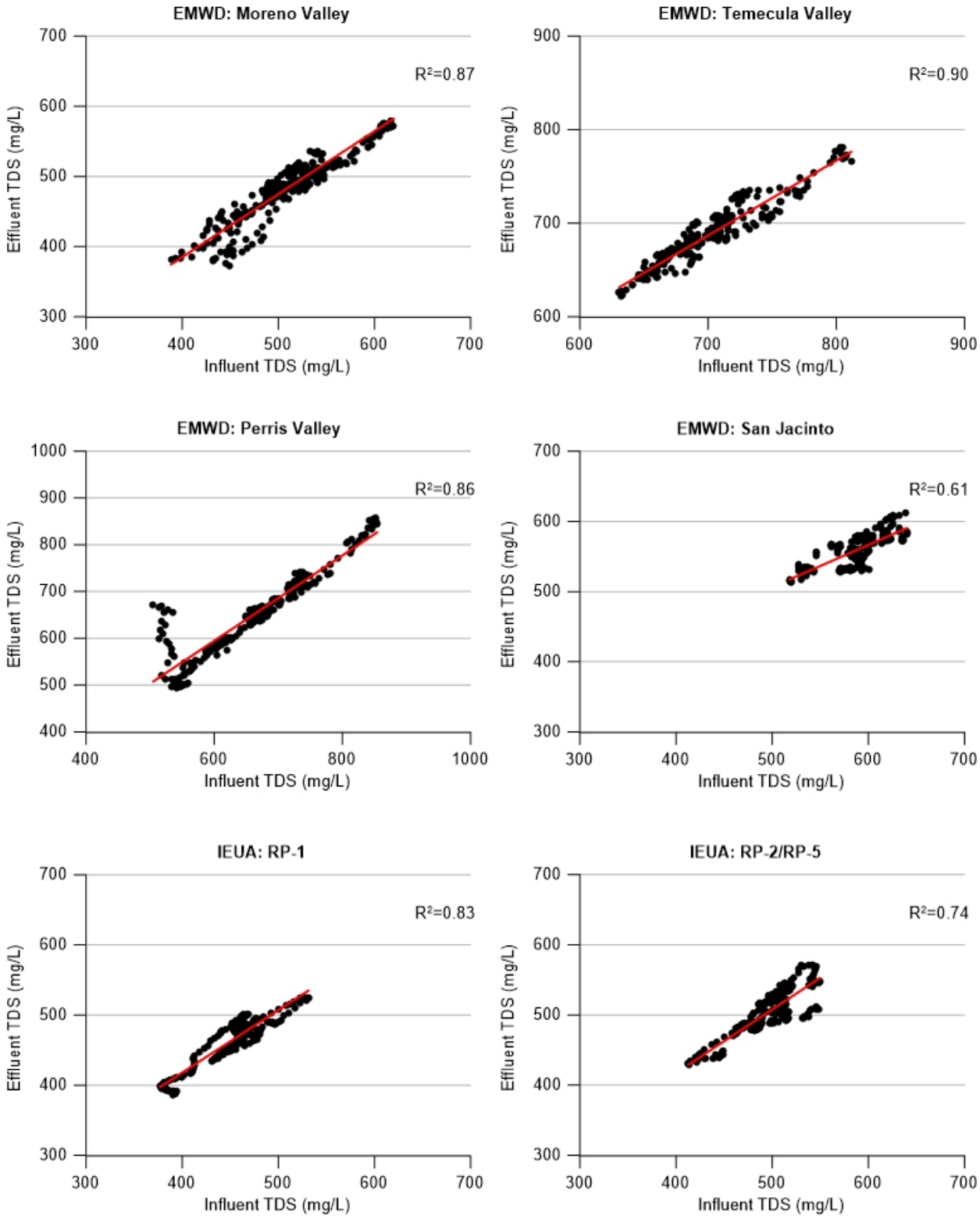
03/01/2017
DB17.1179

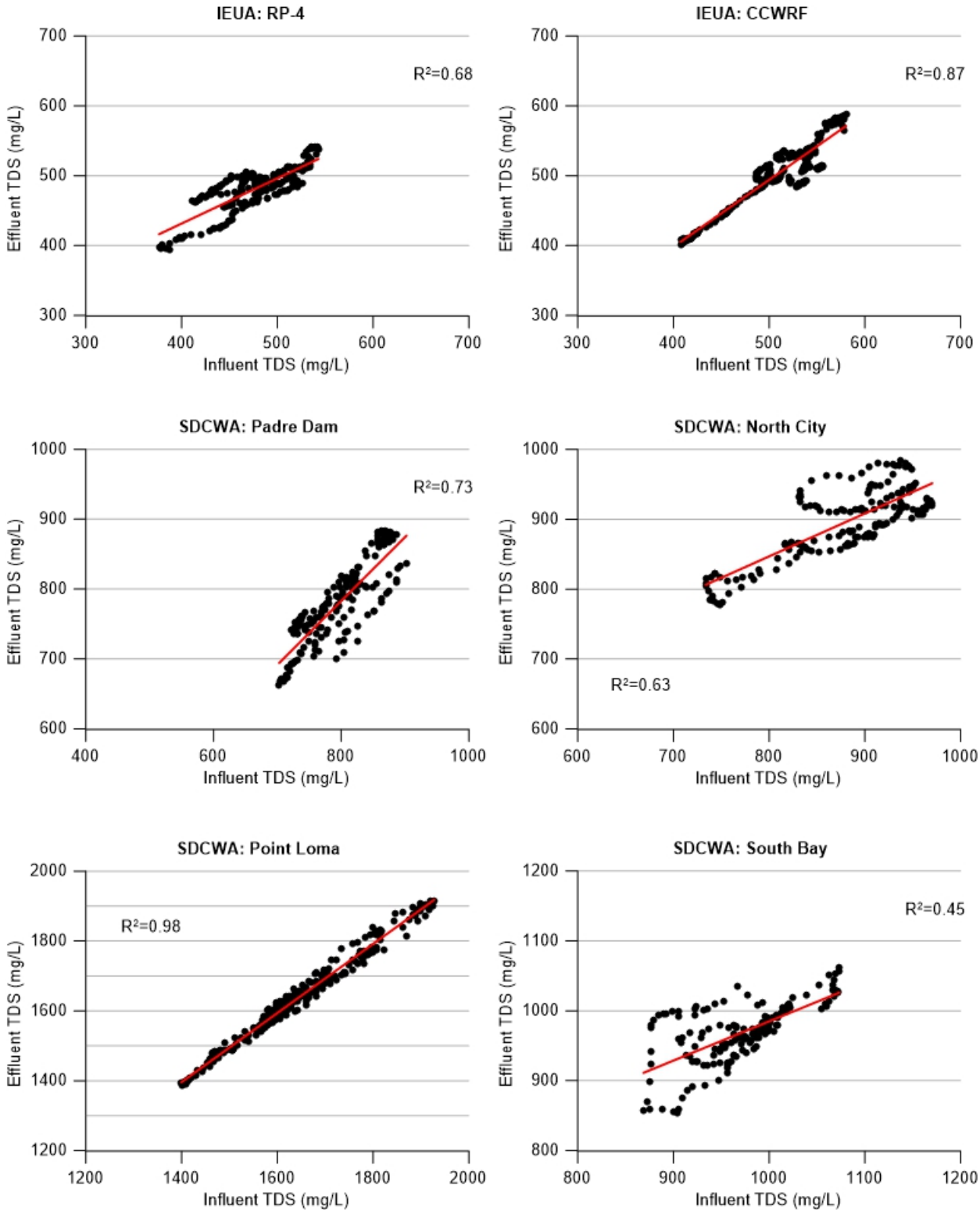
SOUTHERN CALIFORNIA SALINITY COALITION

Wastewater Treatment Facility Influent and Effluent TDS Trends



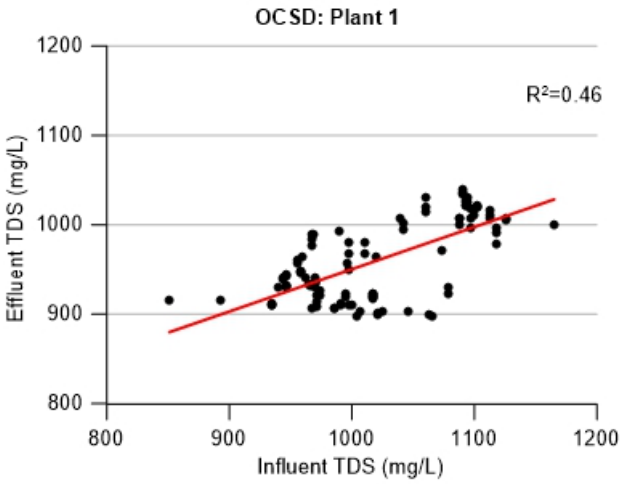
Influent TDS Vs Effluent TDS

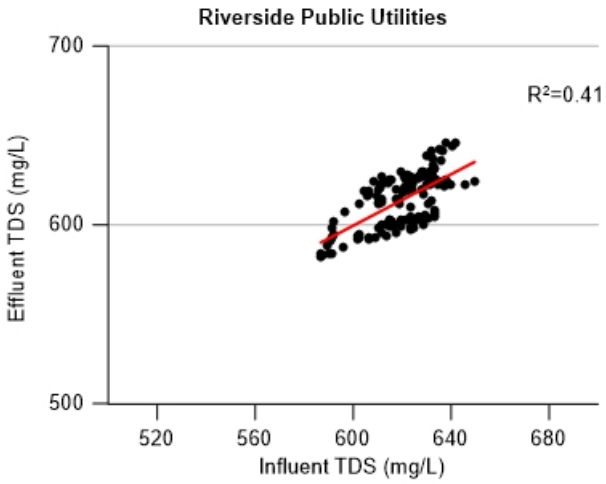
Appendix A4



Influent TDS Vs Effluent TDS

Appendix A5



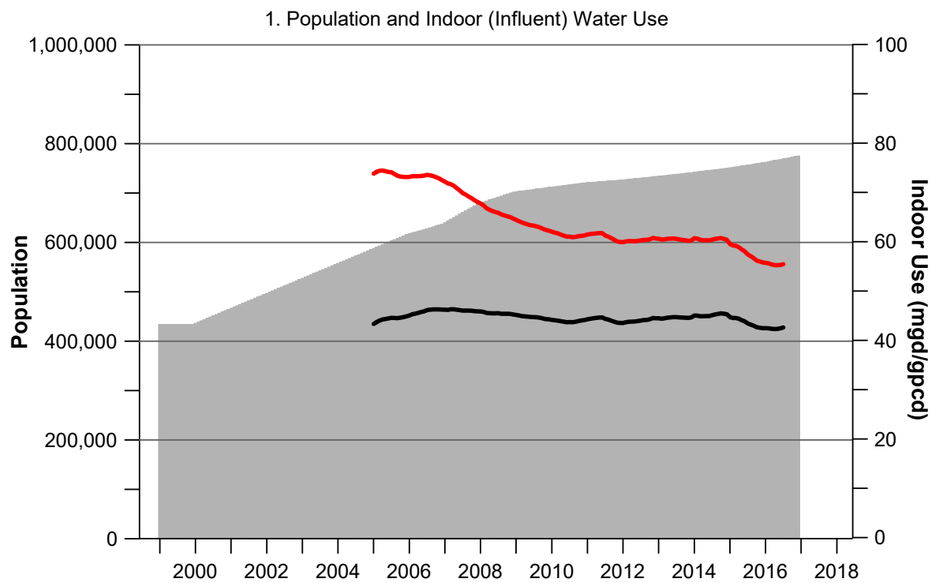


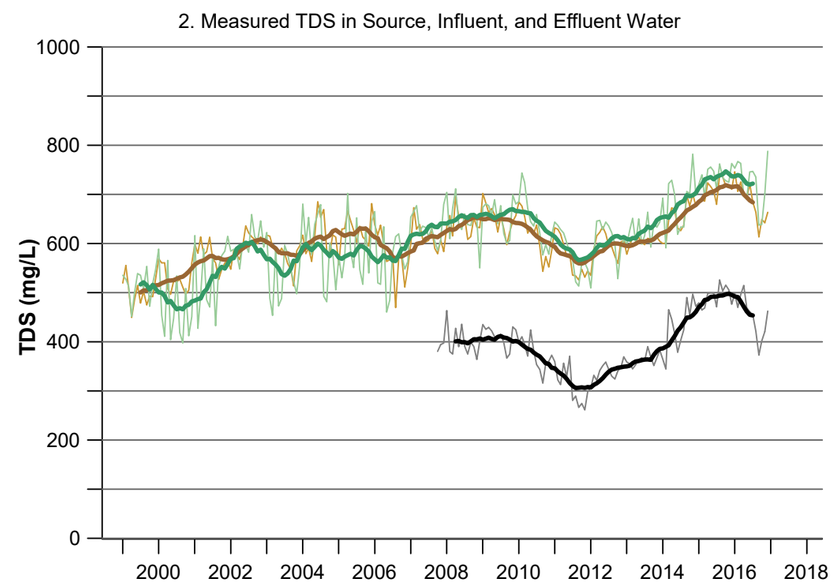
Influent TDS Vs Effluent TDS

Appendix A6

Appendix B

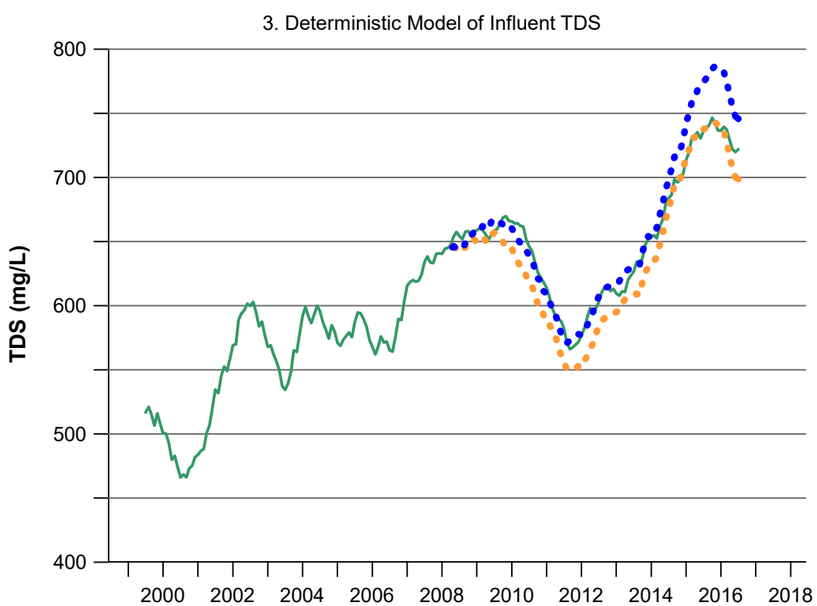
Indoor Water Use, TDS Trends, and Deterministic and Statistical Model Results

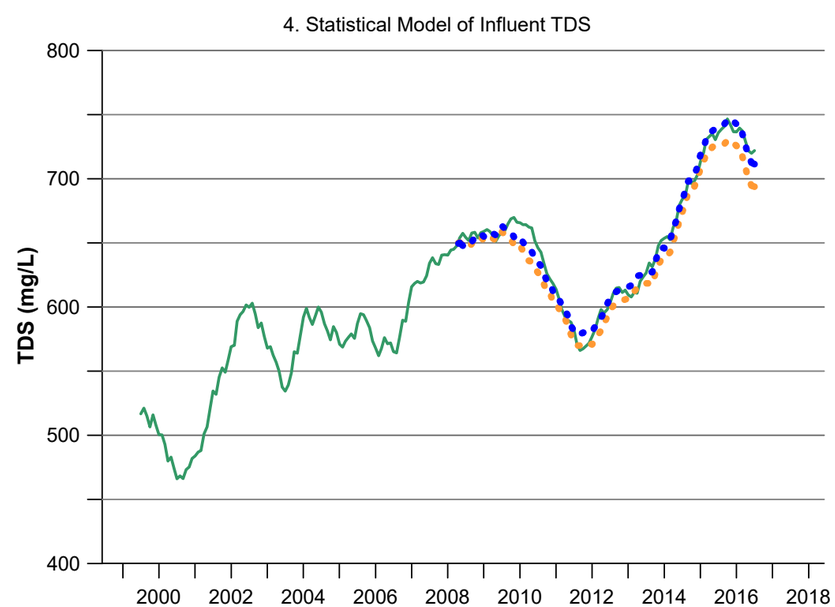




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (70-55) gpcd
   - Deterministic model: constant flow (70) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (70-55) gpcd
   - Statistical model: constant flow (70) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 423.18995   22.02622  19.213  < 2e-16 ***
STDS          0.83656    0.01419  58.971  < 2e-16 ***
IGPCD        -1.65462    0.31497  -5.253 8.85e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7.233 on 97 degrees of freedom
Multiple R-squared:  0.979,     Adjusted R-squared:  0.9786
F-statistic:  2260 on 2 and 97 DF,  p-value: < 2.2e-16
```

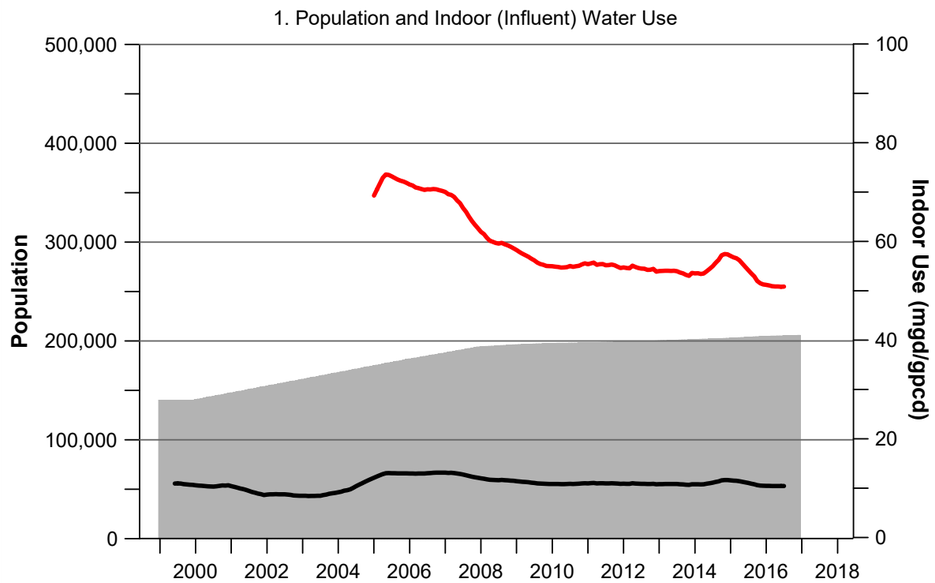
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B1 EMWD COMBO.MXD

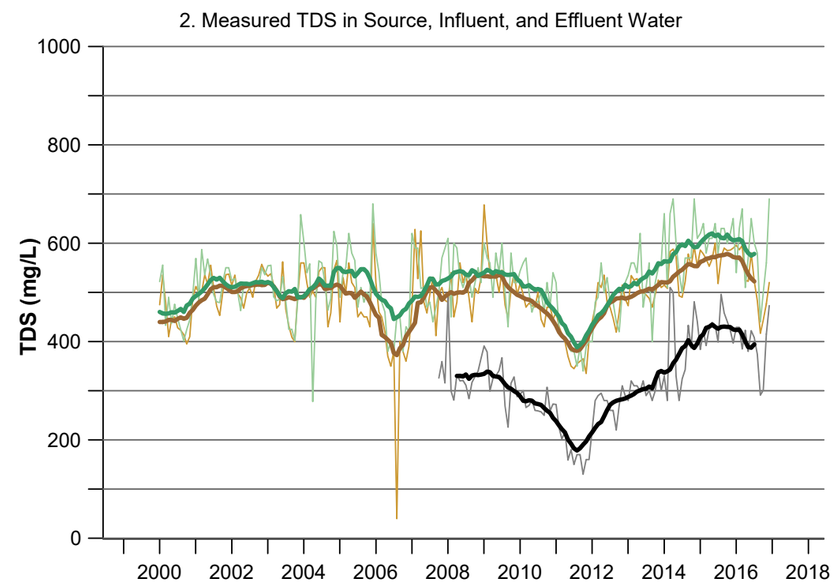
SOUTHERN CALIFORNIA SALINITY COALITION

EMWD Combined Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

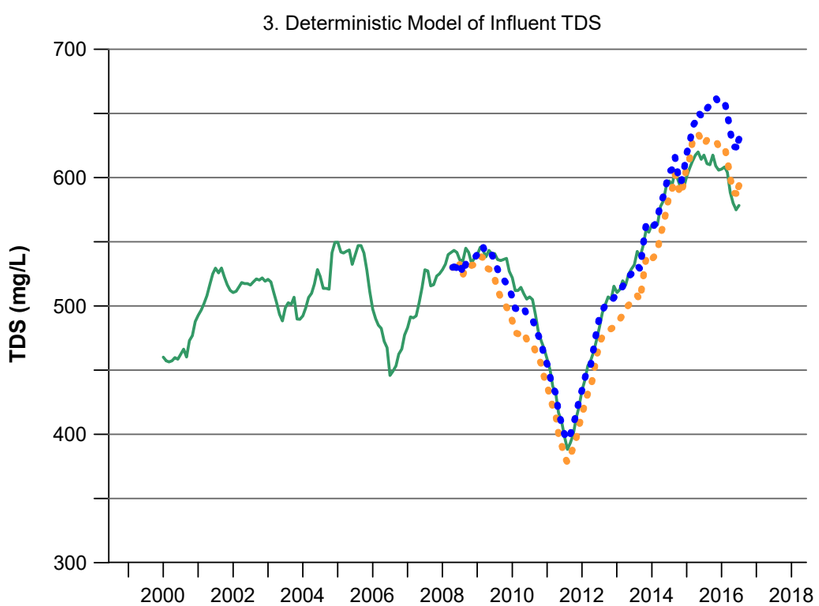
3/22/2018 DB17.1179

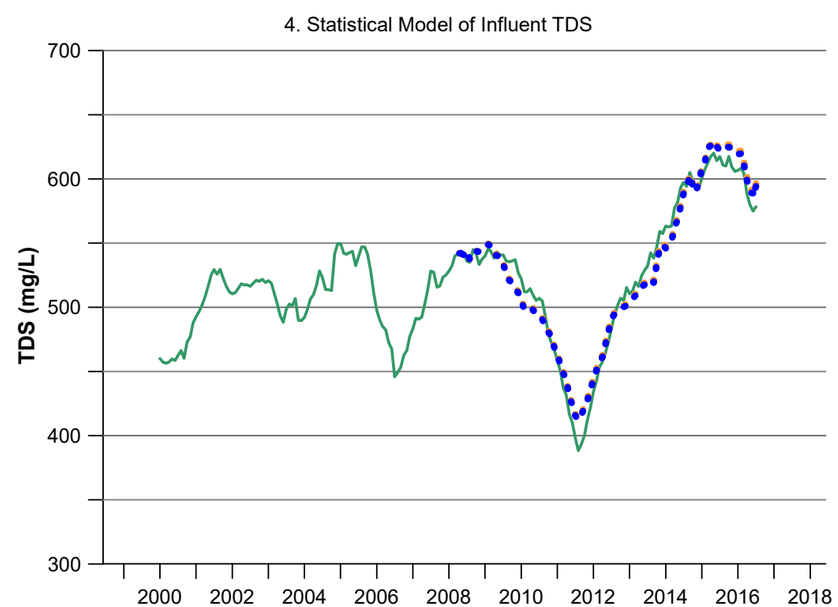




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (60-50) gpcd
   - Deterministic model: constant flow (60) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (60-50) gpcd
   - Statistical model: constant flow (60) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 247.42822   31.50080   7.855 5.46e-12 ***
STDS          0.84916    0.01656  51.285  < 2e-16 ***
IGPCD         0.23688    0.55014   0.431    0.668
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.44 on 97 degrees of freedom
  (105 observations deleted due to missingness)
Multiple R-squared:  0.9651,    Adjusted R-squared:  0.9644
F-statistic:  1341 on 2 and 97 DF,  p-value: < 2.2e-16
```

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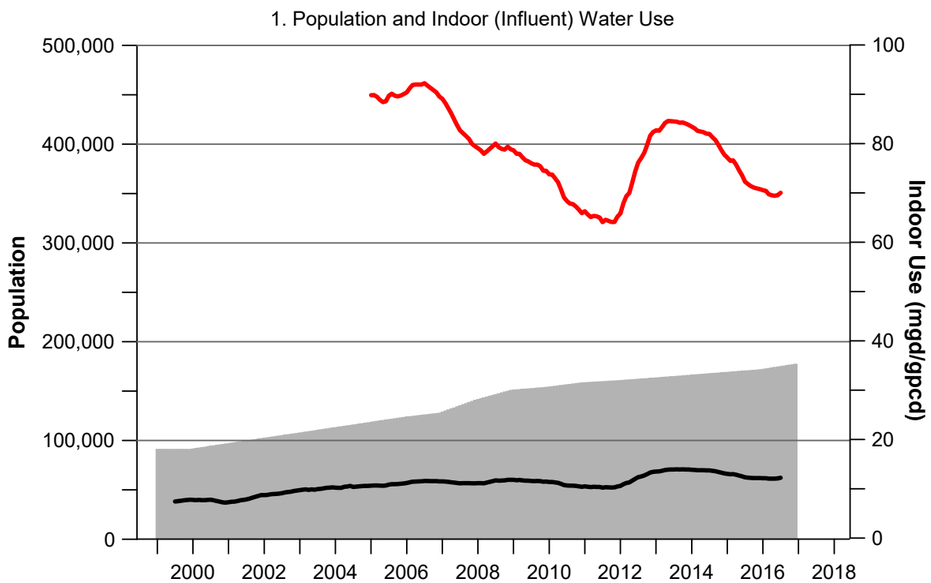
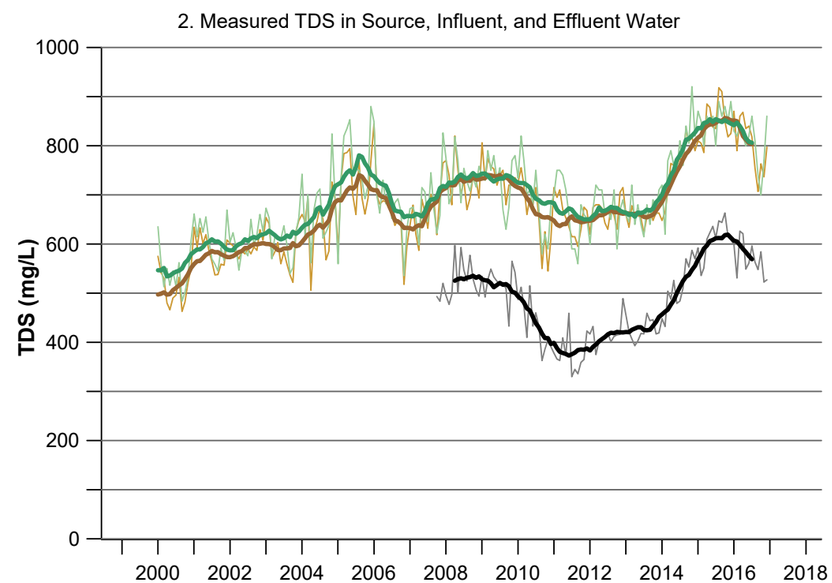
SOUTHERN CALIFORNIA SALINITY COALITION

EMWD Moreno Valley Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

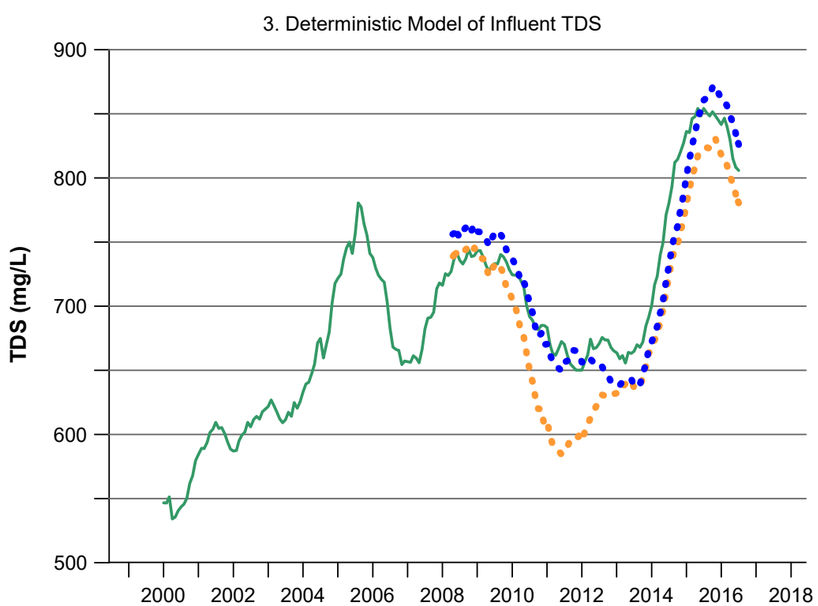
3/22/2018 DB17.1179

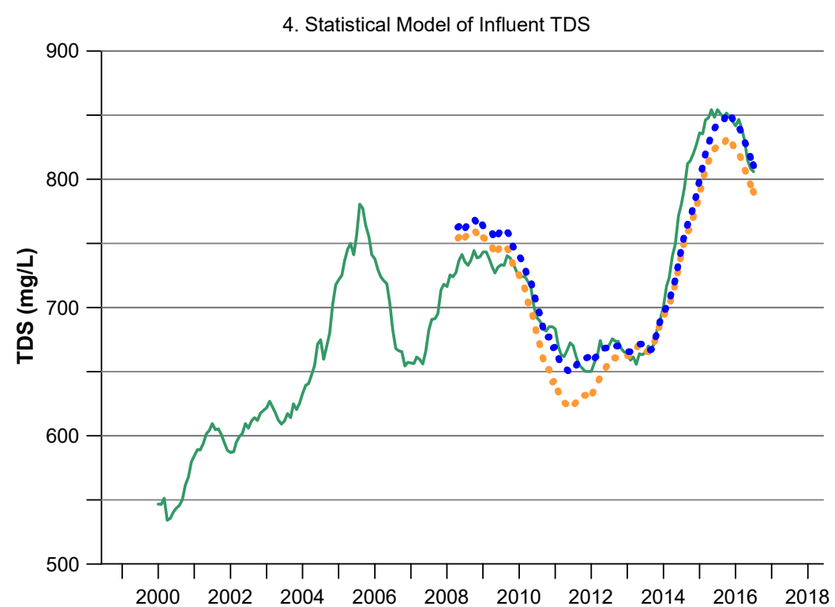




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (85-70) gpcd
   - Deterministic model: constant flow (85) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (85-70) gpcd
   - Statistical model: constant flow (85) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 418.73580   23.82338  17.577  < 2e-16 ***
STDS          0.85903    0.02524  34.032  < 2e-16 ***
IGPCD        -1.38620    0.30181  -4.593 1.31e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 18.67 on 97 degrees of freedom
  (142 observations deleted due to missingness)
Multiple R-squared:  0.9228,    Adjusted R-squared:  0.9212
F-statistic:   580 on 2 and 97 DF,  p-value: < 2.2e-16
```

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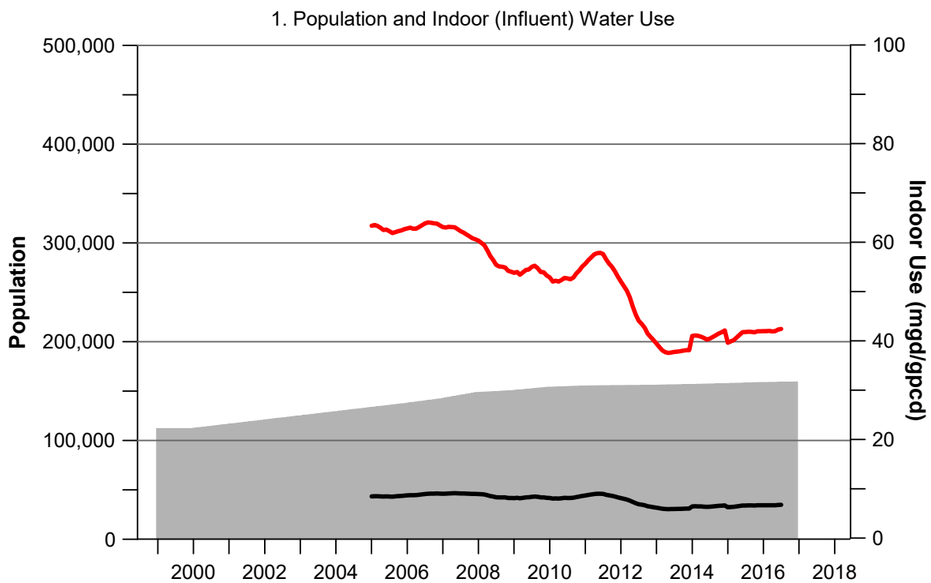
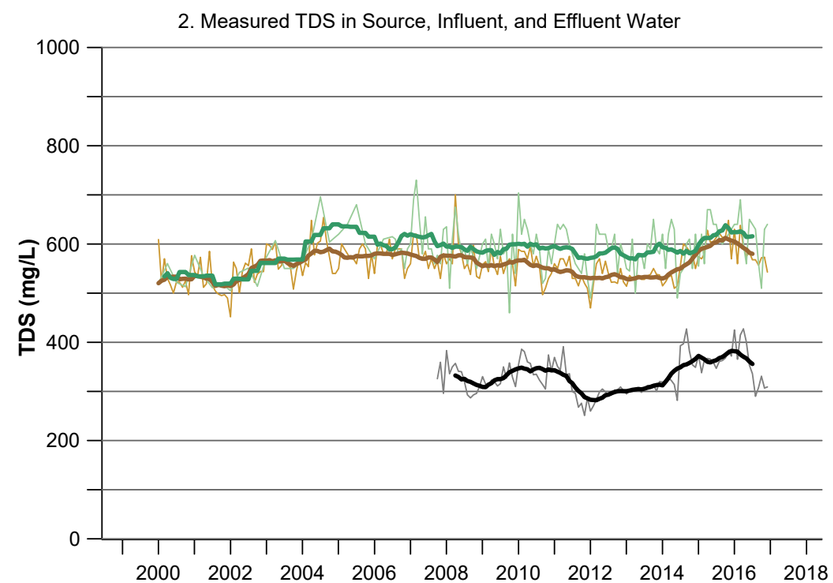
SOUTHERN CALIFORNIA SALINITY COALITION

EMWD Perris Valley Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

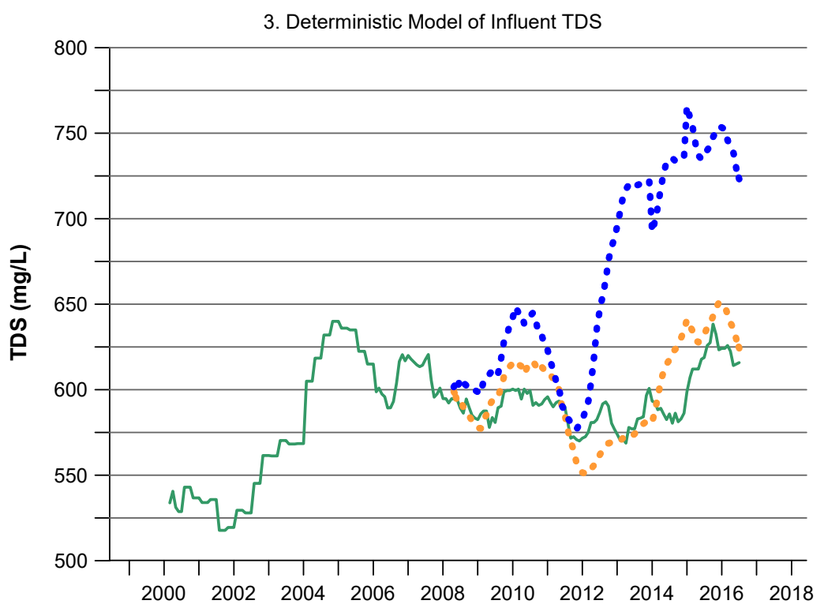
3/22/2018 DB17.1179

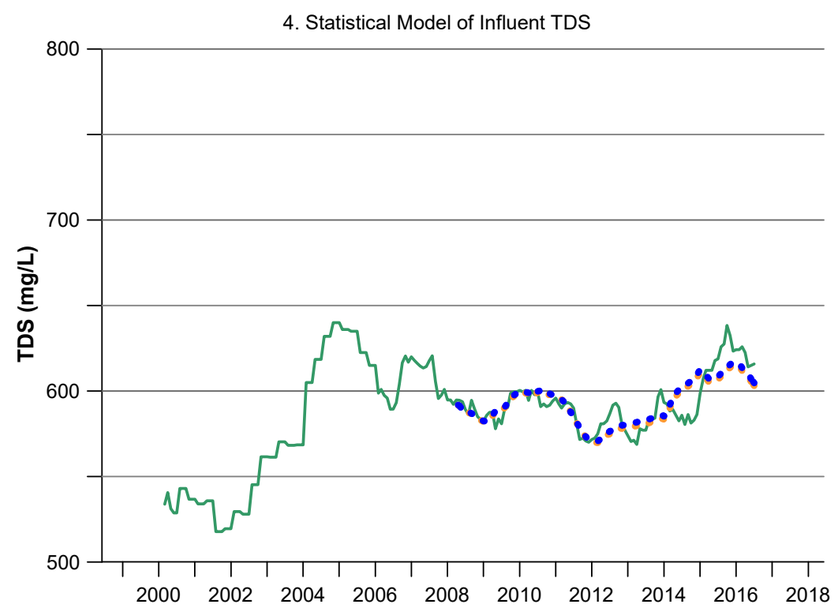




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (58-40) gpcd
   - Deterministic model: constant flow (58) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (58-40) gpcd
   - Statistical model: constant flow (58) gpcd





ITDS Multiple Linear Regression Results

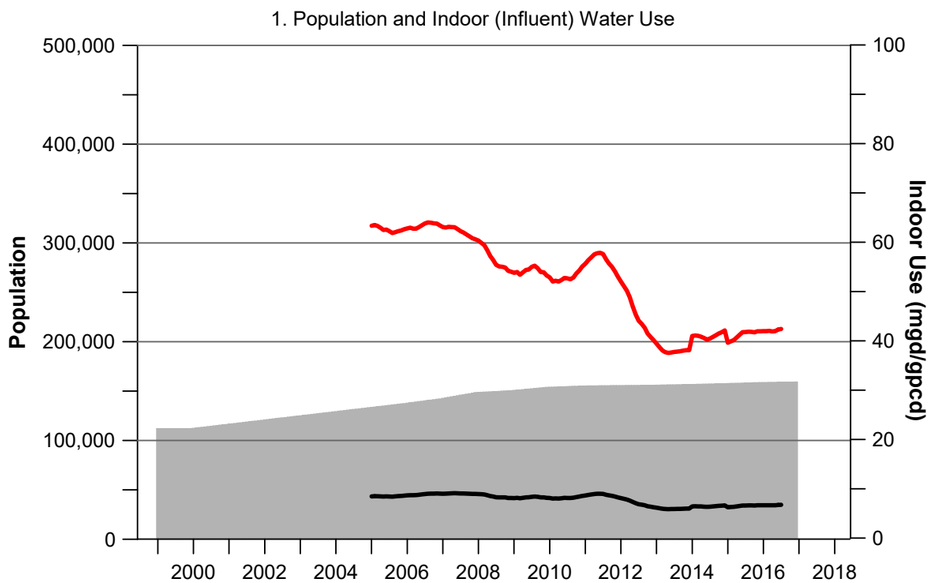
```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 448.25998   14.26102  31.433   <2e-16 ***
STDS          0.45257    0.03514  12.880   <2e-16 ***
IGPCD        -0.10629    0.13561  -0.784    0.435
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9.386 on 97 degrees of freedom
Multiple R-squared:  0.6439,    Adjusted R-squared:  0.6365
F-statistic: 87.69 on 2 and 97 DF,  p-value: < 2.2e-16
```

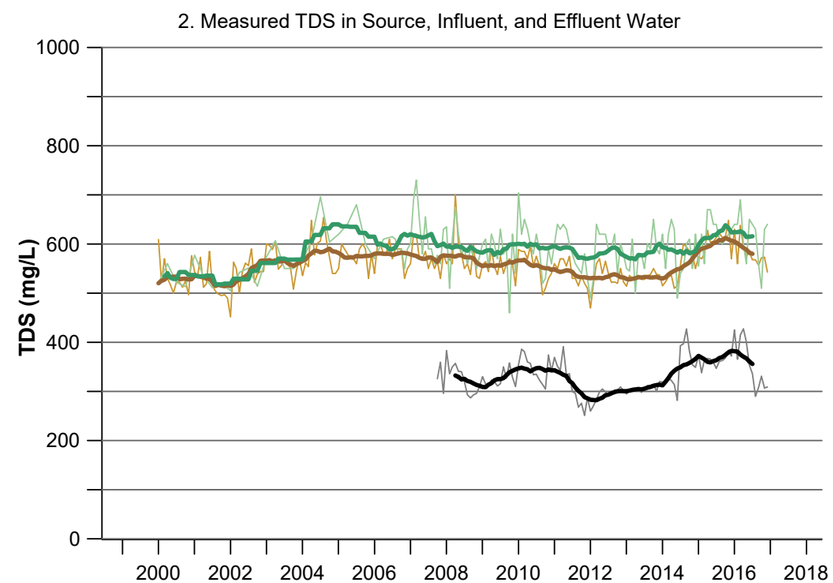
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B4 EMWD SAN JACINTO.MXD

SOUTHERN CALIFORNIA SALINITY COALITION

EMWD San Jacinto Valley Summary of Results: Indoor Water Use and TDS Trends

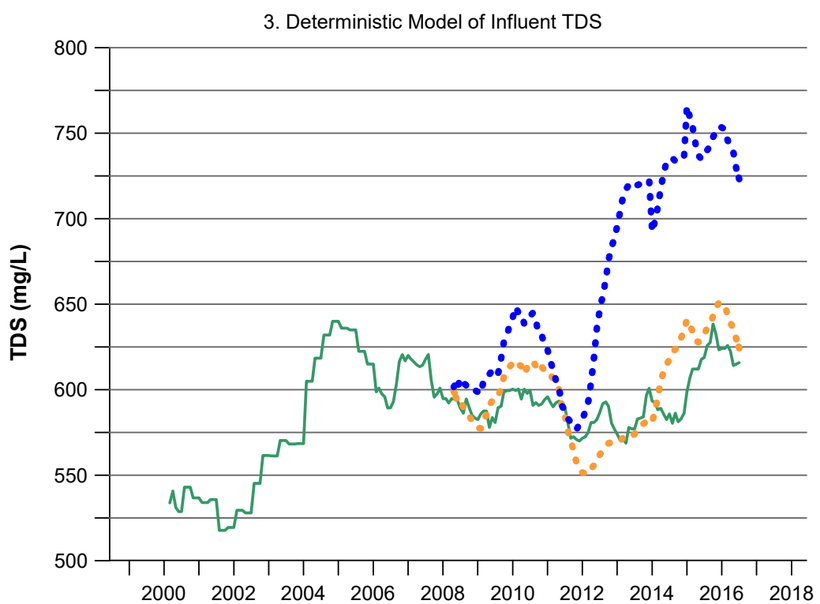
Daniel B. Stephens & Associates, Inc.
3/22/2018
DB17.1179

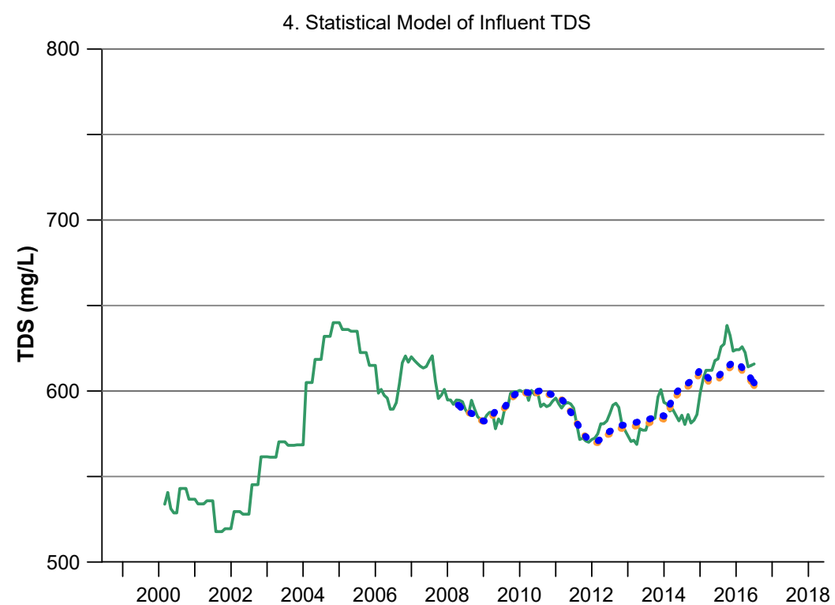




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (58-40) gpcd
   - Deterministic model: constant flow (58) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (58-40) gpcd
   - Statistical model: constant flow (58) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 748.91772   34.45491  21.736  < 2e-16 ***
STDS          0.50234    0.01931  26.019  < 2e-16 ***
IGPCD        -4.35893    0.46787  -9.317 2.26e-15 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 15.88 on 104 degrees of freedom
Multiple R-squared:  0.902,     Adjusted R-squared:  0.9001
F-statistic: 478.7 on 2 and 104 DF,  p-value: < 2.2e-16
```

J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B5 EMWD TEMECULA.MXD

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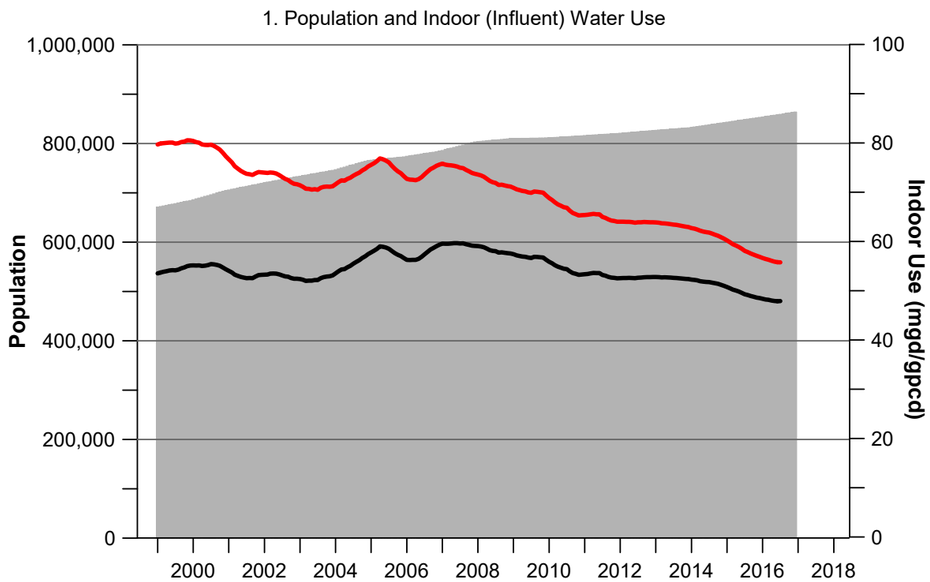
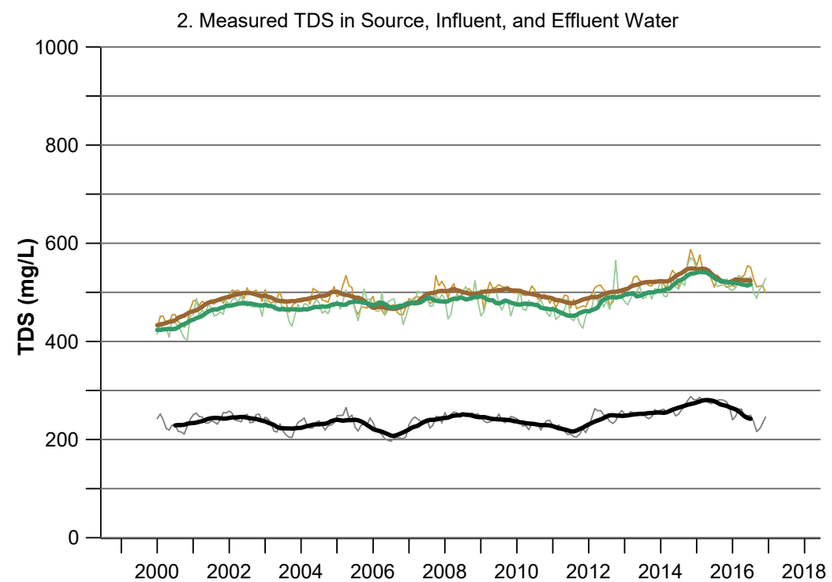
3/22/2018
DB17.1179

SOUTHERN CALIFORNIA SALINITY COALITION

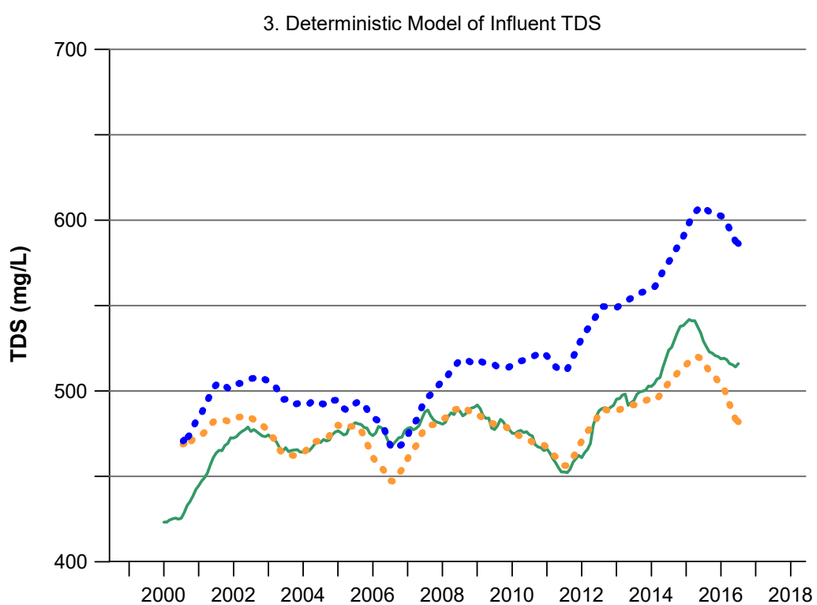
EMWD Temecula Valley Summary of Results: Indoor Water Use and TDS Trends

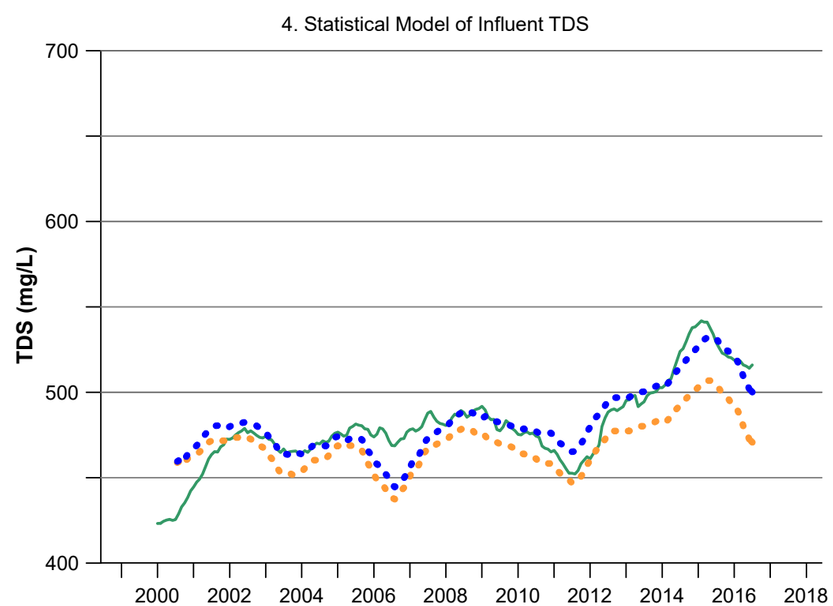




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (80-55) gpcd
   - Deterministic model: constant flow (80) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (80-55) gpcd
   - Statistical model: constant flow (80) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 337.95382   23.21138  14.560  < 2e-16 ***
STDS          0.95026    0.06194  15.342  < 2e-16 ***
IGPCD        -1.21540    0.16108  -7.545 1.82e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 10.87 on 190 degrees of freedom
Multiple R-squared:  0.773,     Adjusted R-squared:  0.7706
F-statistic: 323.4 on 2 and 190 DF,  p-value: < 2.2e-16
```

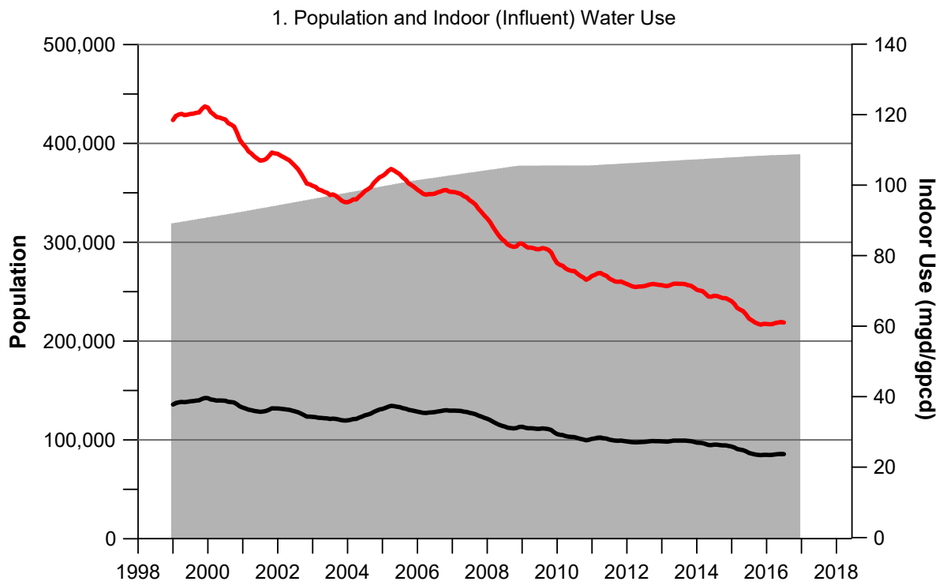
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B6 IEUA COMBO.MXD

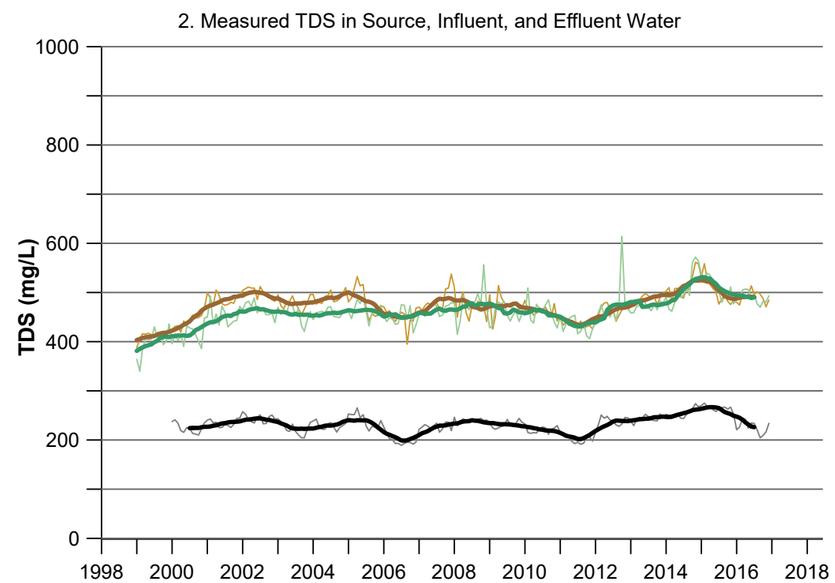
SOUTHERN CALIFORNIA SALINITY COALITION

IEUA Combined Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

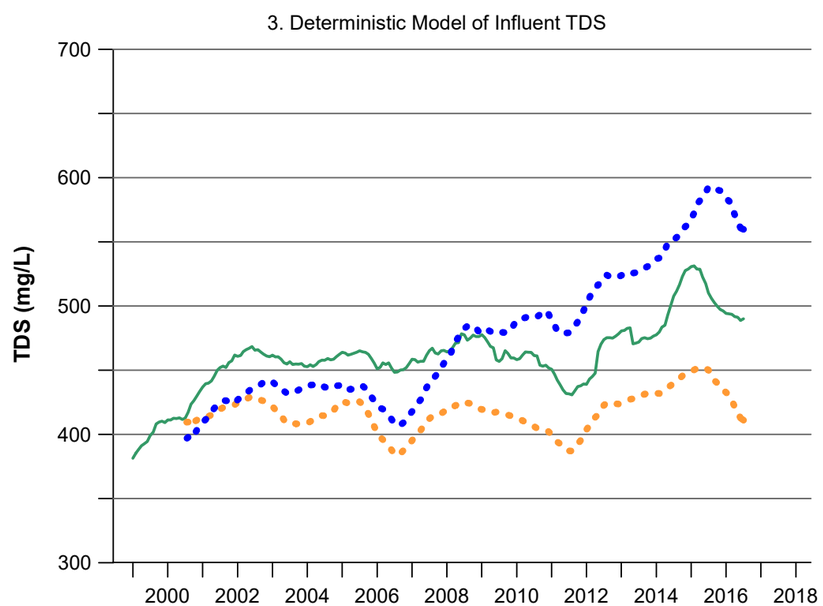
3/22/2018 DB17.1179

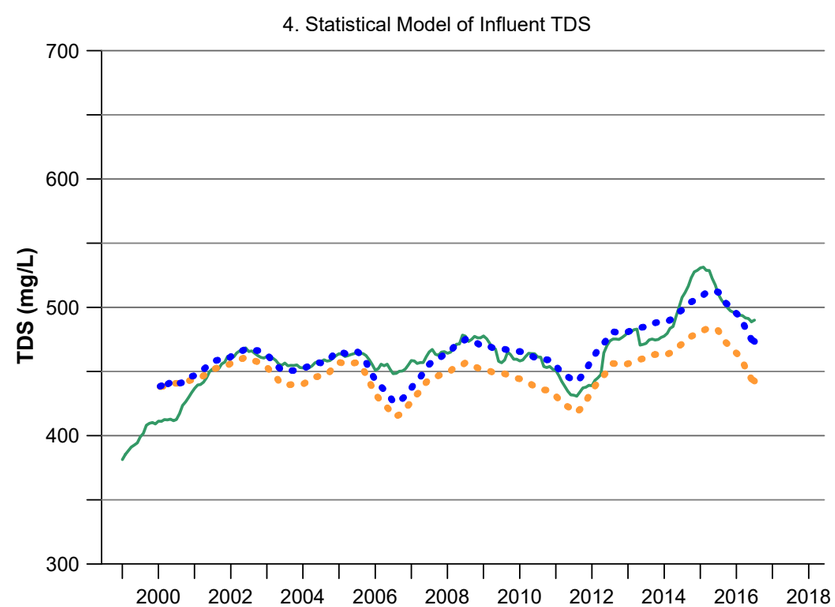




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (110-60) gpcd
   - Deterministic model: constant flow (110) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (110-60) gpcd
   - Statistical model: constant flow (110) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 276.71694   13.98997   19.78   <2e-16 ***
STDS          1.01263    0.05199   19.48   <2e-16 ***
IGPCD        -0.53245    0.04841  -11.00   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 10.13 on 190 degrees of freedom
Multiple R-squared:  0.7878,    Adjusted R-squared:  0.7856
F-statistic: 352.7 on 2 and 190 DF,  p-value: < 2.2e-16
```

J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B7 IEUA RP1.MXD

SOUTHERN CALIFORNIA SALINITY COALITION

IEUA RP1 Summary of Results: Indoor Water Use and TDS Trends

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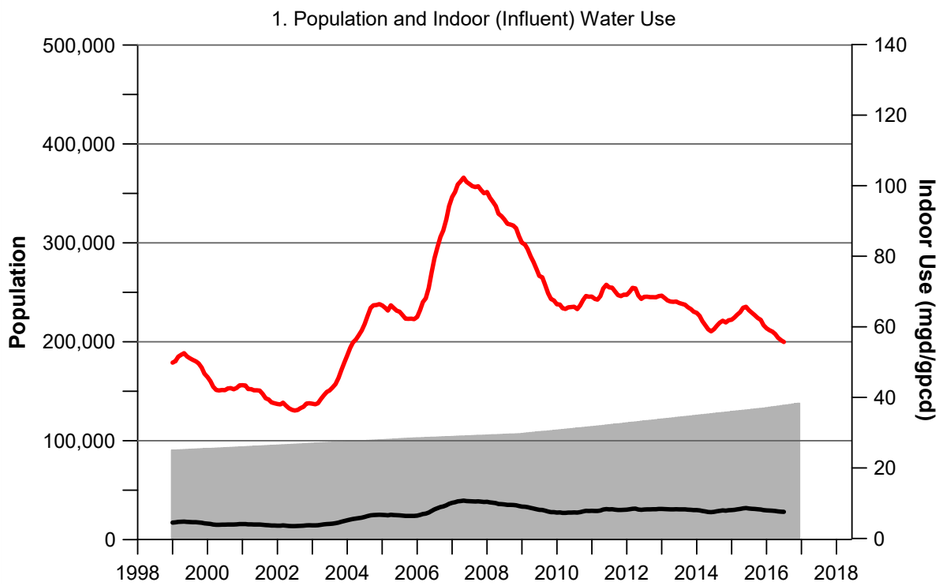
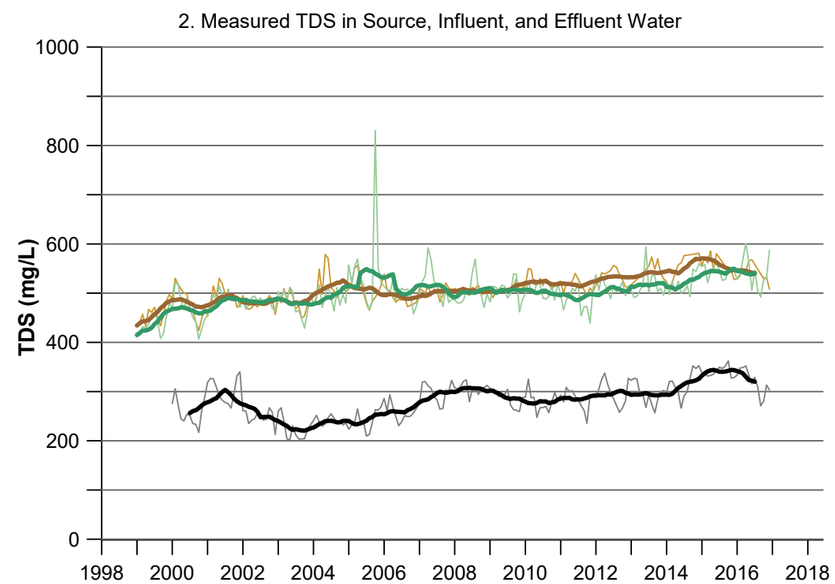
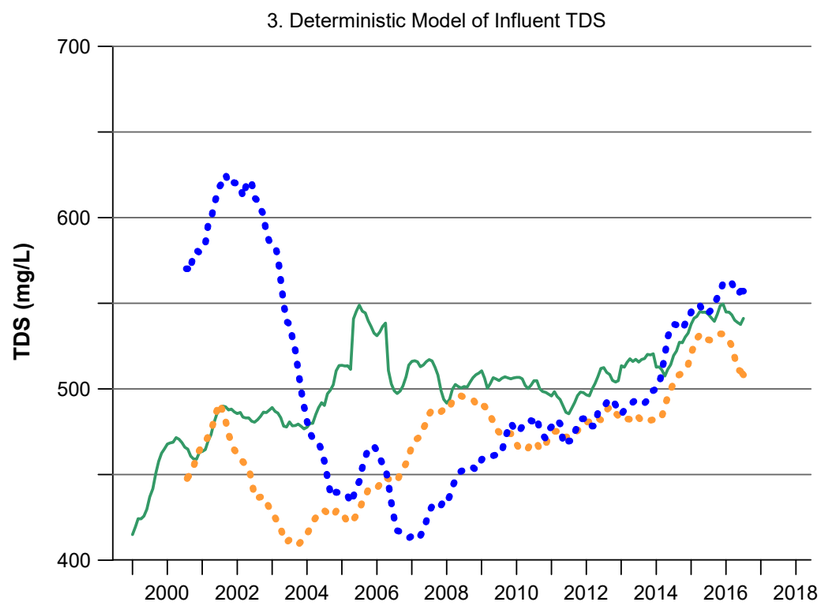
3/22/2018
DB17.1179

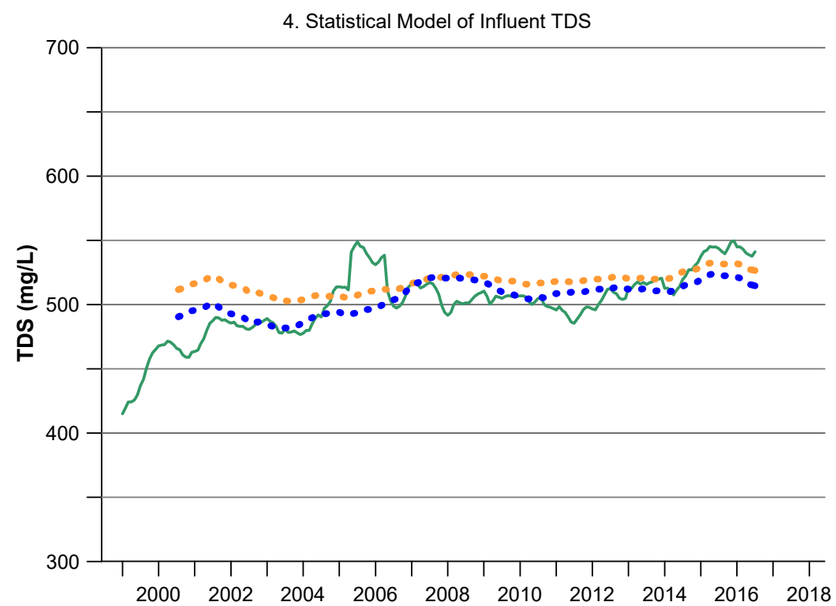




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (70-55) gpcd
   - Deterministic model: constant flow (70) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (70-55) gpcd
   - Statistical model: constant flow (70) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 403.19657   11.90105  33.879  < 2e-16 ***
STDS          0.30222    0.04423   6.833  1.1e-10 ***
IGPCD         0.26596    0.08051   3.304  0.00114 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 17.85 on 190 degrees of freedom
Multiple R-squared:  0.299,     Adjusted R-squared:  0.2916
F-statistic: 40.52 on 2 and 190 DF,  p-value: 2.205e-15
```

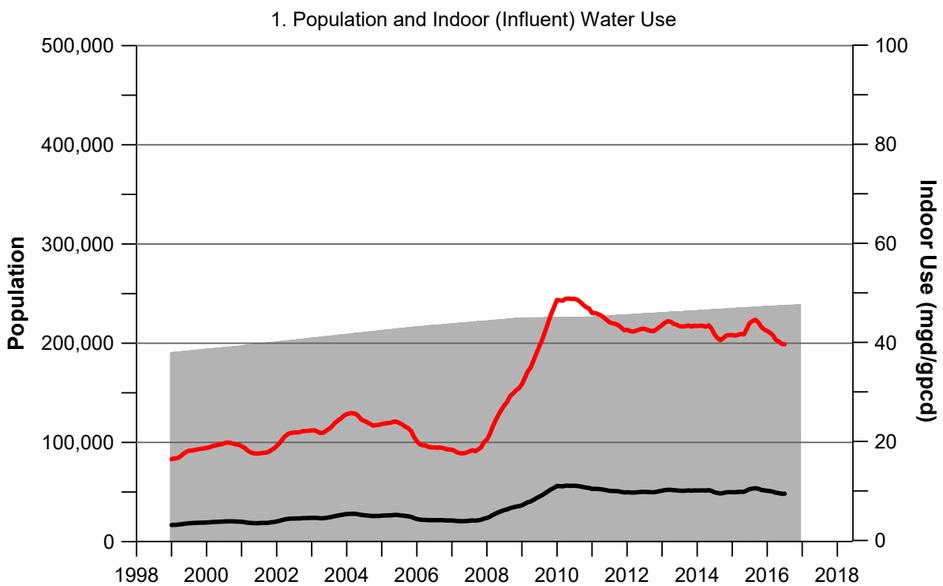
SOUTHERN CALIFORNIA SALINITY COALITION

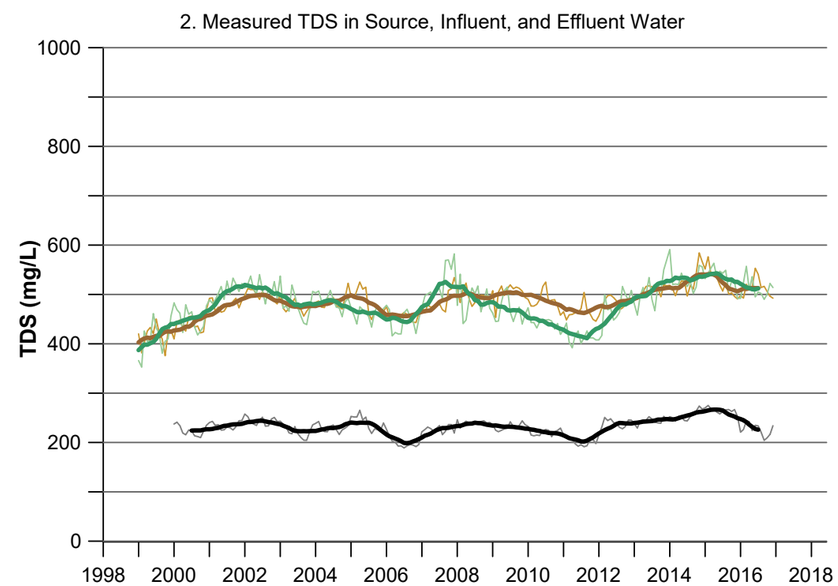
IEUA RP2/RP5 Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

3/22/2018 DB17.1179

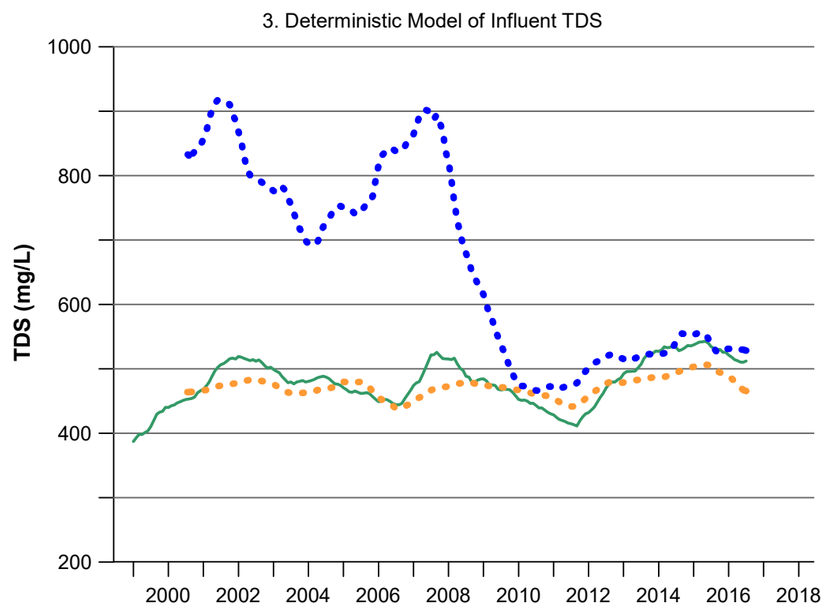
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B8 IEUA RP2-5.MXD

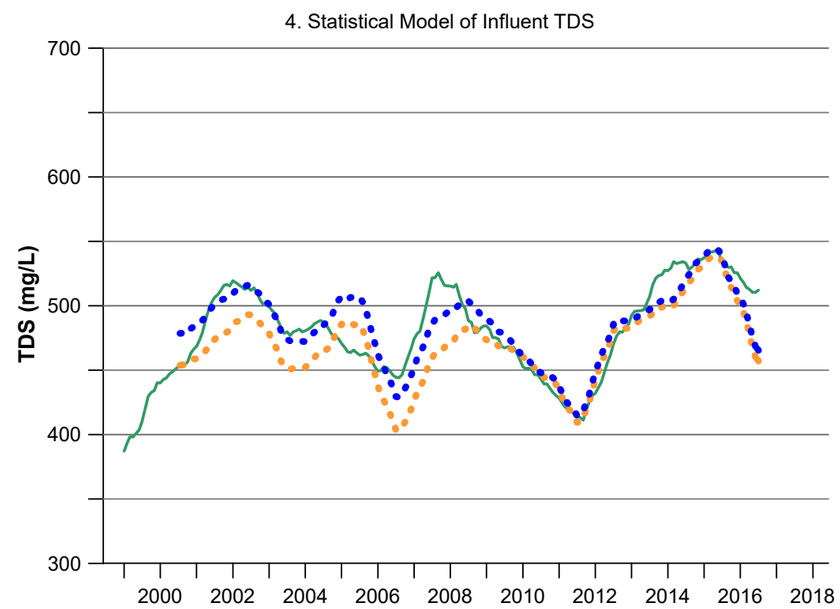




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (50-40) gpcd
   - Deterministic model: constant flow (50) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (50-40) gpcd
   - Statistical model: constant flow (50) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 52.11672   19.04372   2.737  0.00679 **
STDS         1.97405    0.08398  23.505  < 2e-16 ***
IGPCD       -0.82468    0.11093  -7.434  3.5e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 16.78 on 190 degrees of freedom
Multiple R-squared:  0.7455,    Adjusted R-squared:  0.7429
F-statistic: 278.3 on 2 and 190 DF,  p-value: < 2.2e-16
```

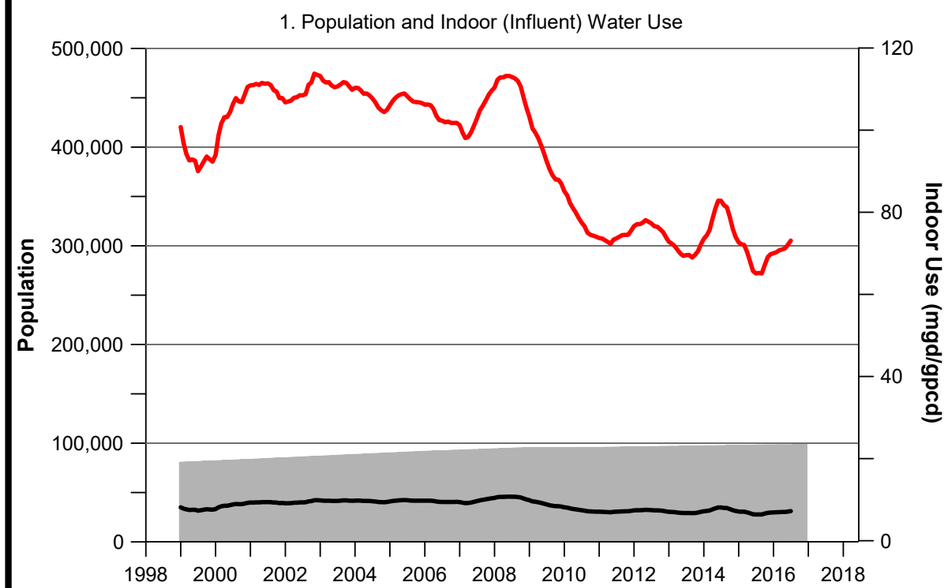
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B9 IEUA RP4.MXD

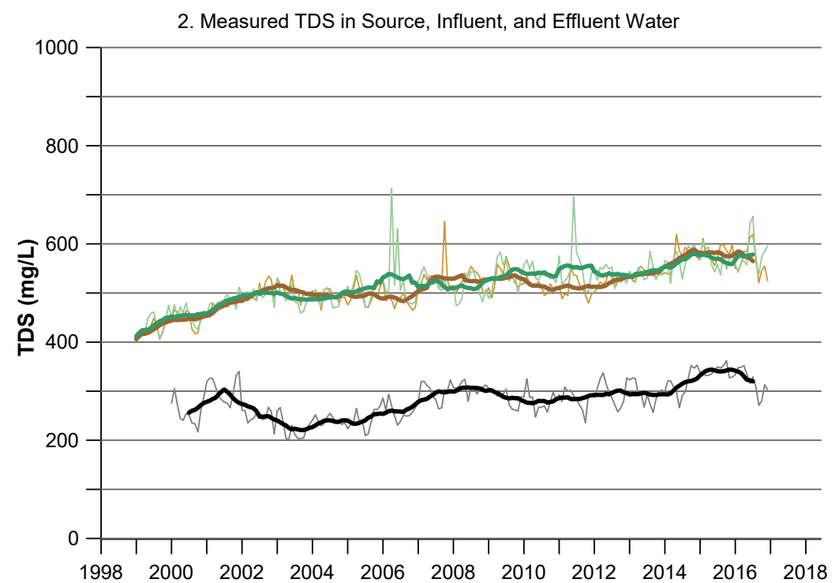
SOUTHERN CALIFORNIA SALINITY COALITION

IEUA RP4 Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

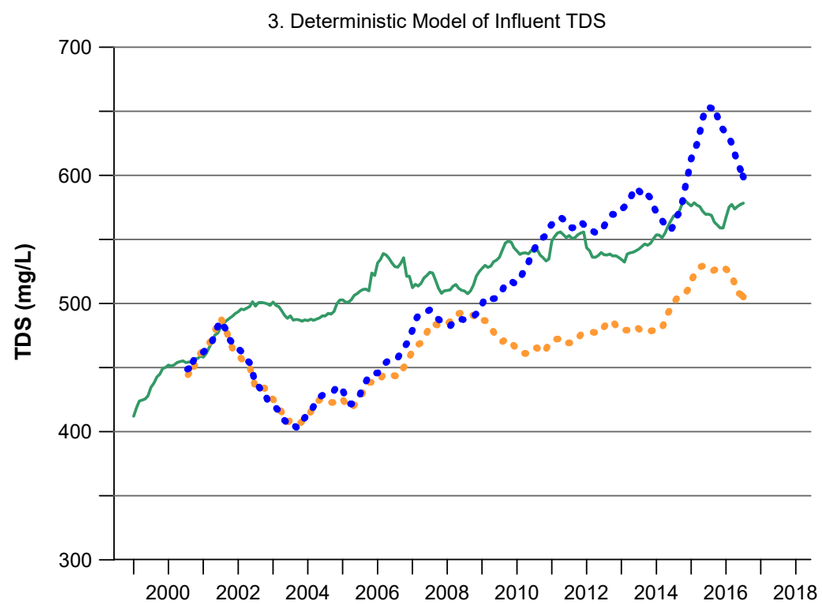
3/22/2018 DB17.1179

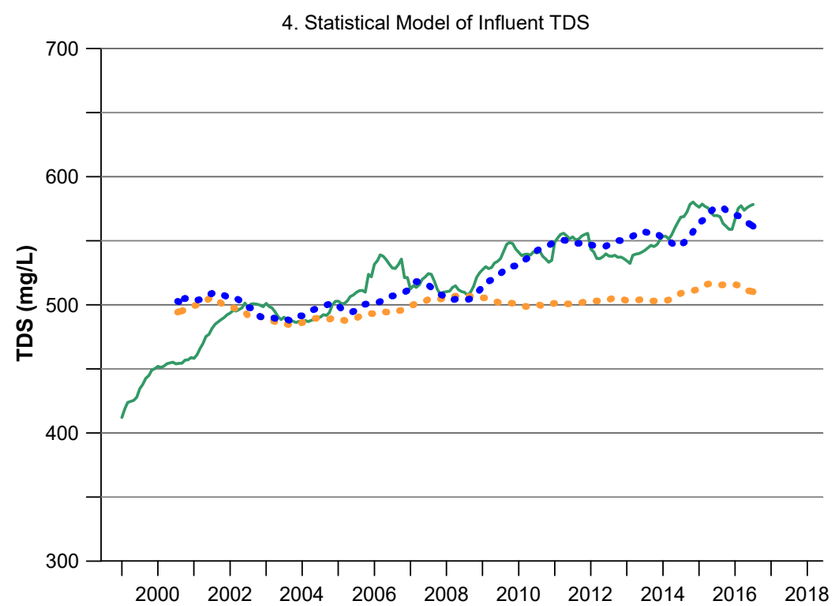




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (110-70) gpcd
   - Deterministic model: constant flow (70) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (110-70) gpcd
   - Statistical model: constant flow (70) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 579.22115   19.94242  29.045  < 2e-16 ***
STDS          0.22931    0.04824   4.754 3.93e-06 ***
IGPCD        -1.28010    0.08842 -14.477  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 15.82 on 190 degrees of freedom
  (55 observations deleted due to missingness)
Multiple R-squared:  0.7411,    Adjusted R-squared:  0.7384
F-statistic: 271.9 on 2 and 190 DF,  p-value: < 2.2e-16
```

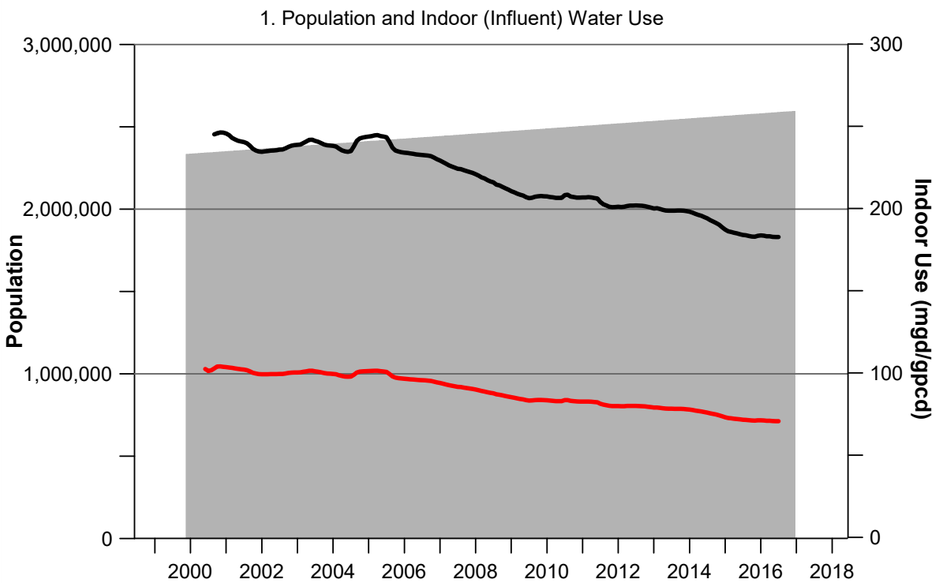
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B10 IEUA CCWRF.MXD

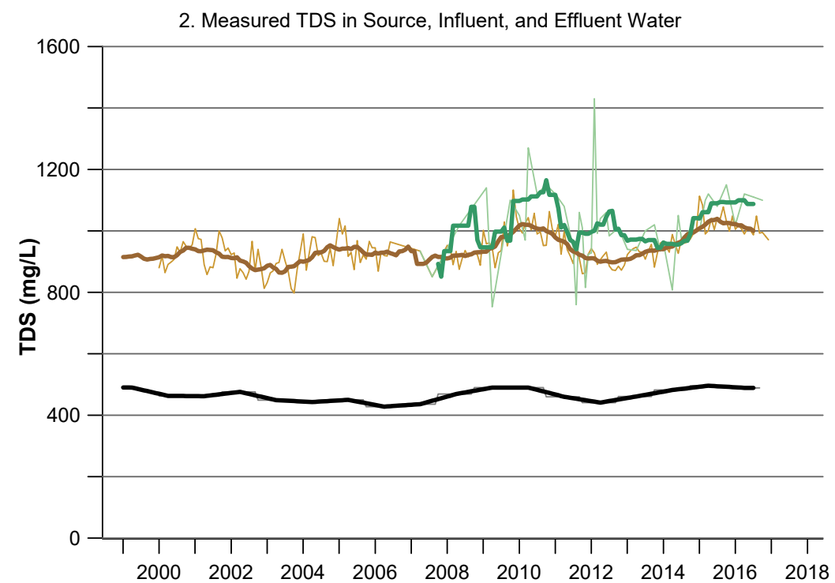
SOUTHERN CALIFORNIA SALINITY COALITION

IEUA CCWRF Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

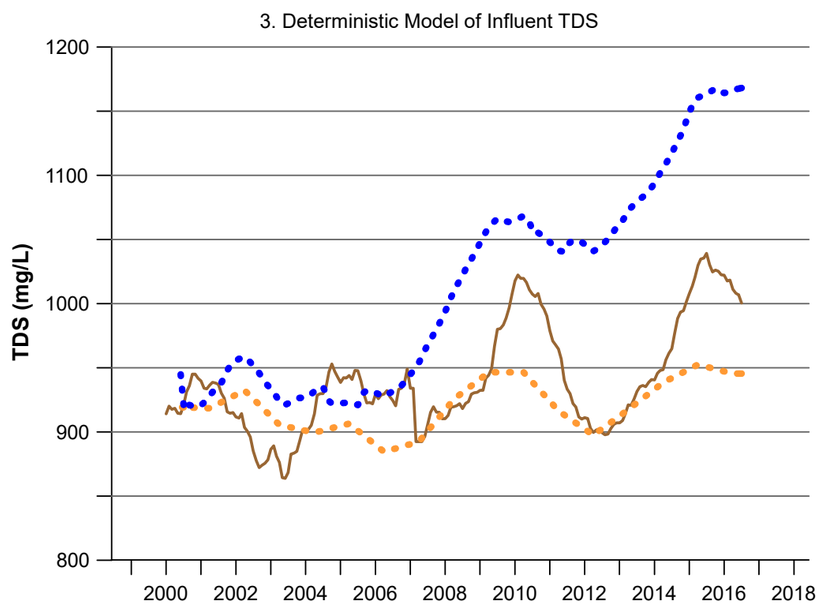
3/22/2018 DB17.1179

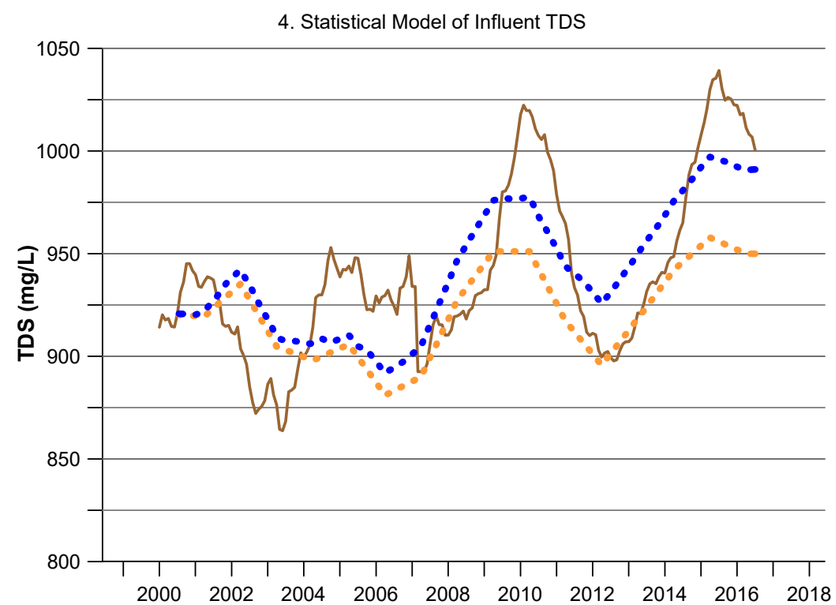




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of effluent TDS
   - Deterministic model: actual flow (105-70) gpcd
   - Deterministic model: constant flow (105) gpcd
4. Statistical Model
   - Measured 12-month average of effluent TDS
   - Statistical model: actual flow (105-70) gpcd
   - Statistical model: constant flow (105) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 522.5264    77.1171   6.776 1.51e-10 ***
STDS          1.1303     0.1345   8.405 9.90e-15 ***
IGPCD        -1.1934     0.2452  -4.868 2.37e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 29.13 on 190 degrees of freedom
Multiple R-squared:  0.5332,    Adjusted R-squared:  0.5283
F-statistic: 108.5 on 2 and 190 DF,  p-value: < 2.2e-16
```

J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B11 OCSD.MXD

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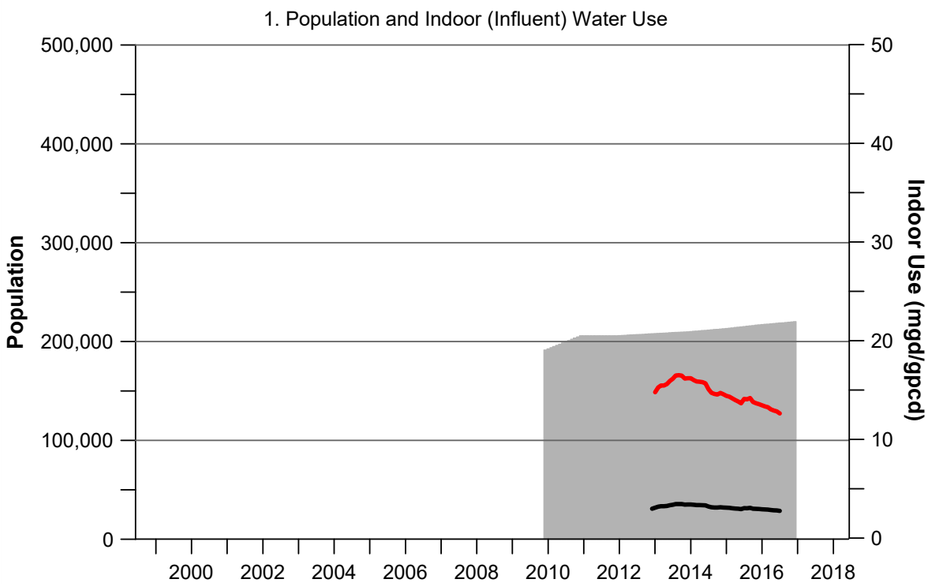
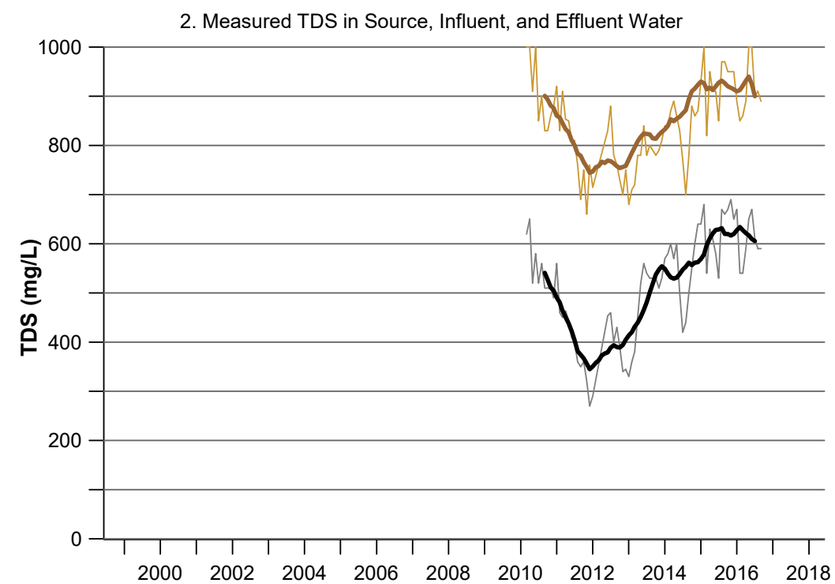
3/22/2018
DB17.1179

SOUTHERN CALIFORNIA SALINITY COALITION

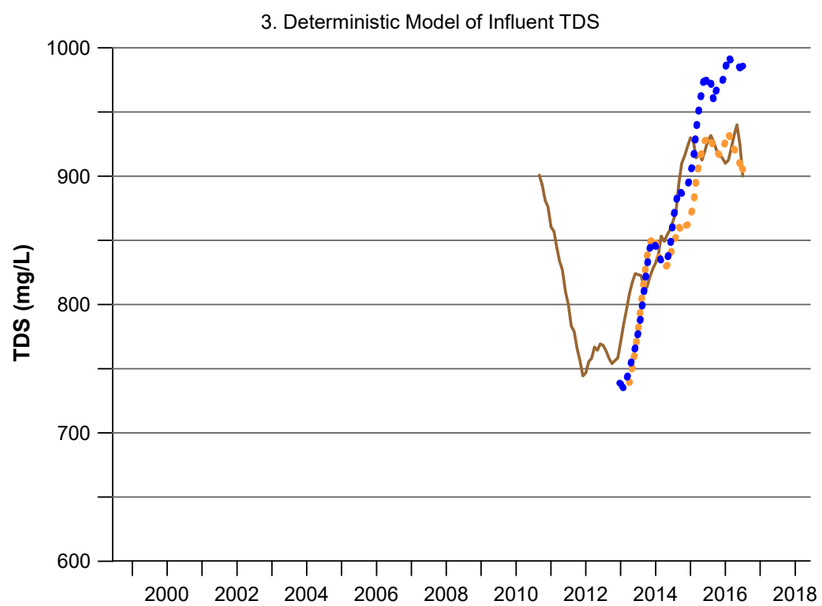
OCSD Summary of Results: Indoor Water Use and TDS Trends

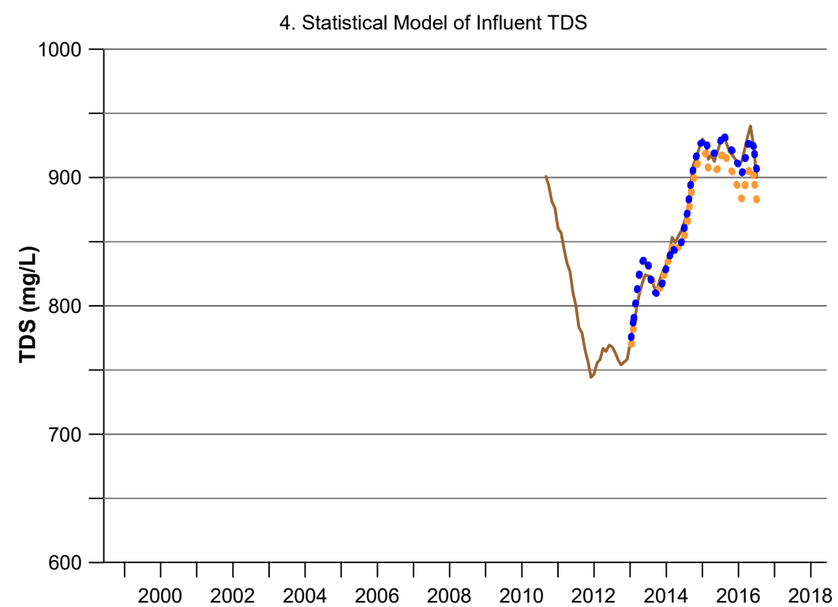




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of effluent TDS
   - Deterministic model: actual flow (16-13) gpcd
   - Deterministic model: constant flow (16) gpcd
4. Statistical Model
   - Measured 12-month average of effluent TDS
   - Statistical model: actual flow (16-13) gpcd
   - Statistical model: constant flow (16) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 373.18296   40.68536   9.172 2.19e-11 ***
STDS          1.04385    0.03893  26.815  < 2e-16 ***
IGPCD        -7.09841    1.41392  -5.020 1.11e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.946 on 40 degrees of freedom
Multiple R-squared:  0.9817,    Adjusted R-squared:  0.9808
F-statistic:  1075 on 2 and 40 DF,  p-value: < 2.2e-16
```

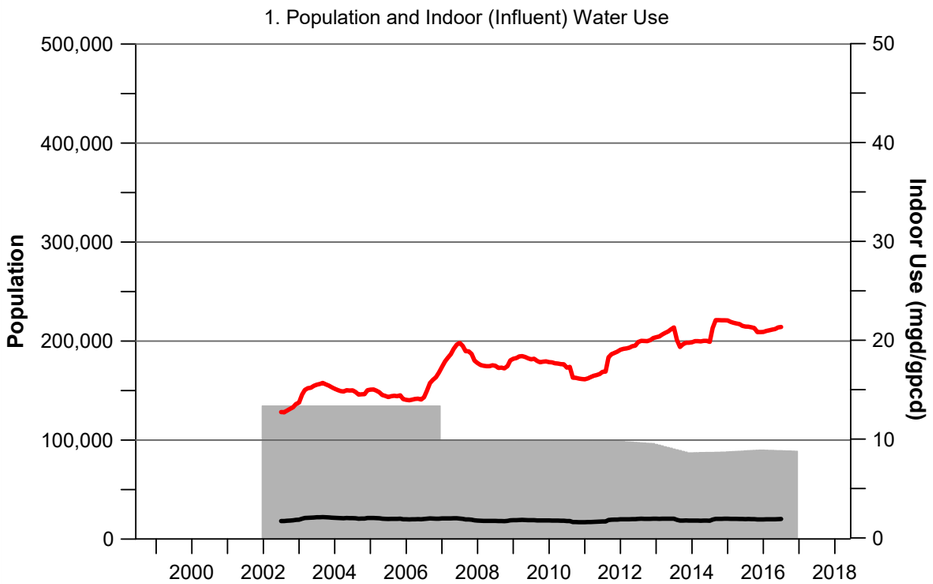
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B12 SDCWA OTAY.MXD

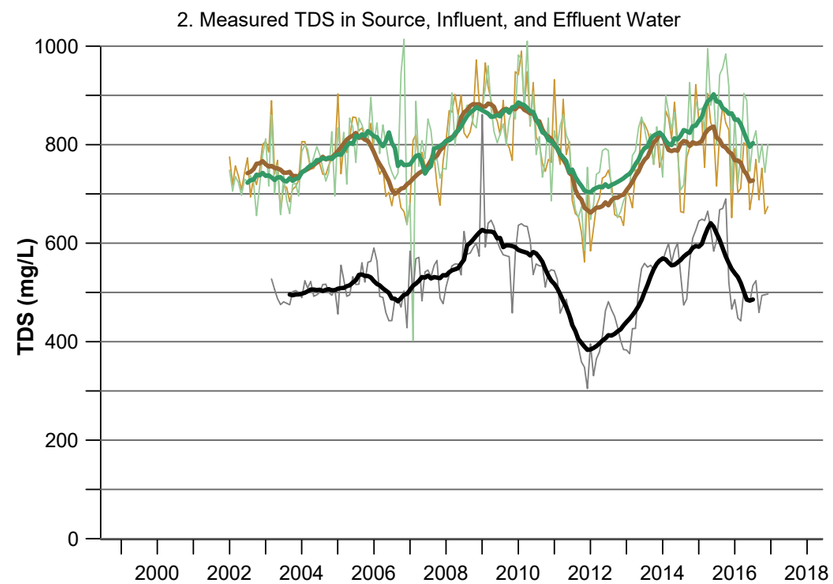
SOUTHERN CALIFORNIA SALINITY COALITION

SDCWA Otay Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

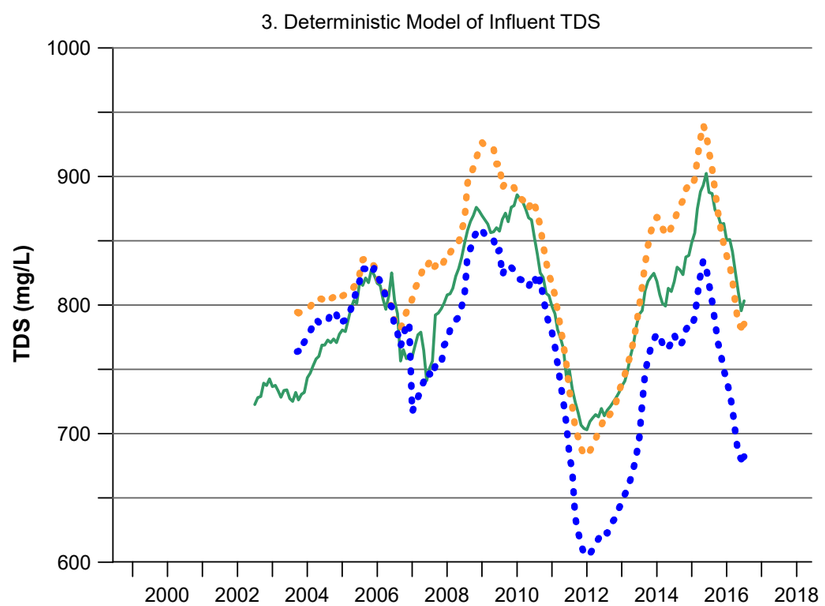
3/22/2018 DB17.1179

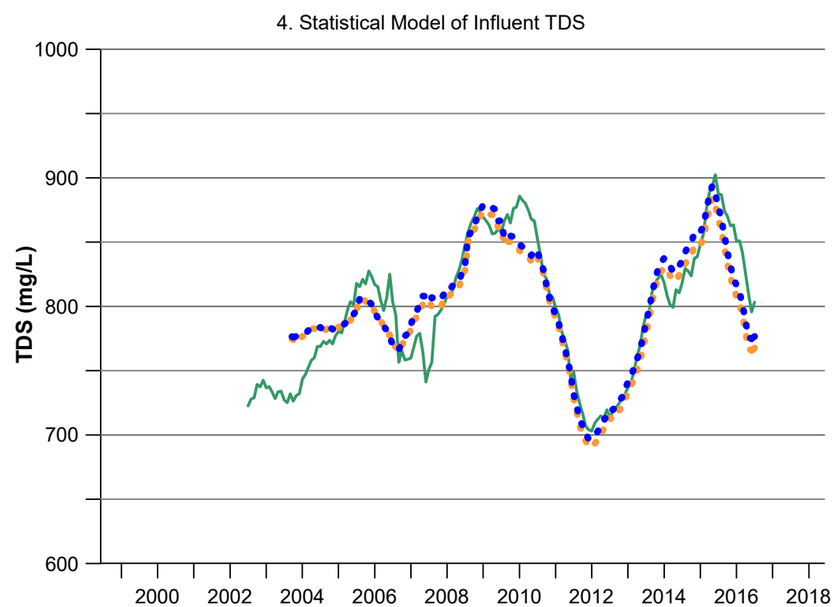




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (14-21) gpcd
   - Deterministic model: constant flow (14) gpcd
4. Statistical Model
   - Measured 12-month average of effluent TDS
   - Statistical model: actual flow (14-21) gpcd
   - Statistical model: constant flow (14) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 384.44652   18.22124  21.099   <2e-16 ***
STDS          0.75329    0.02807  26.832   <2e-16 ***
IGPCD         1.23710    0.71442   1.732   0.0854 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 21.23 on 152 degrees of freedom
Multiple R-squared:  0.8316,    Adjusted R-squared:  0.8294
F-statistic: 375.3 on 2 and 152 DF,  p-value: < 2.2e-16
```

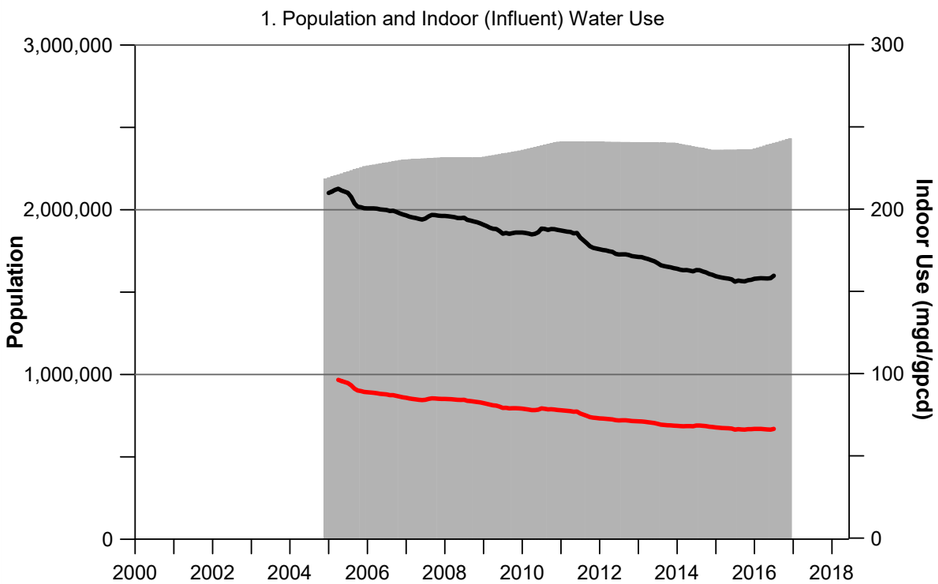
J:\PROJECTS\DB17.1179 SCSC TDS TRENDS\GIS\MXDS\APPENDIX B\B13 SDCWA PADRE DAM.MXD

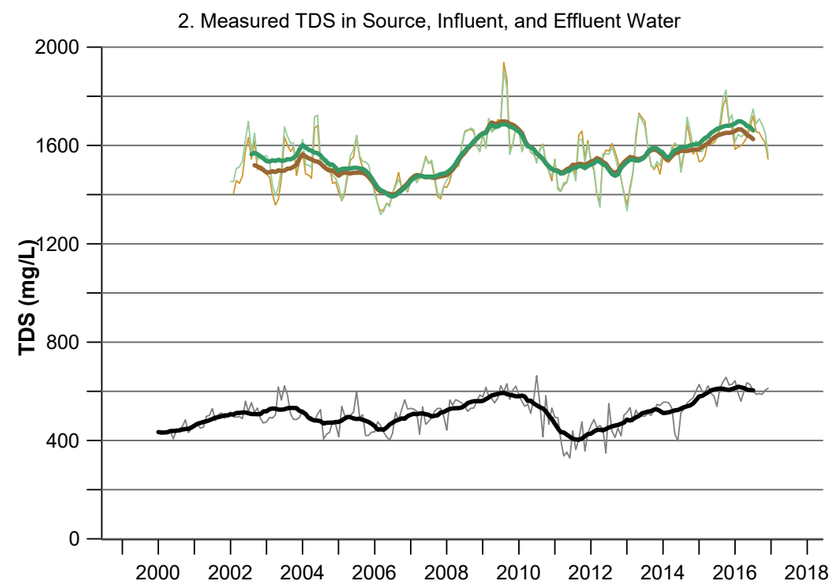
SOUTHERN CALIFORNIA SALINITY COALITION

SDCWA Padre Dam Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

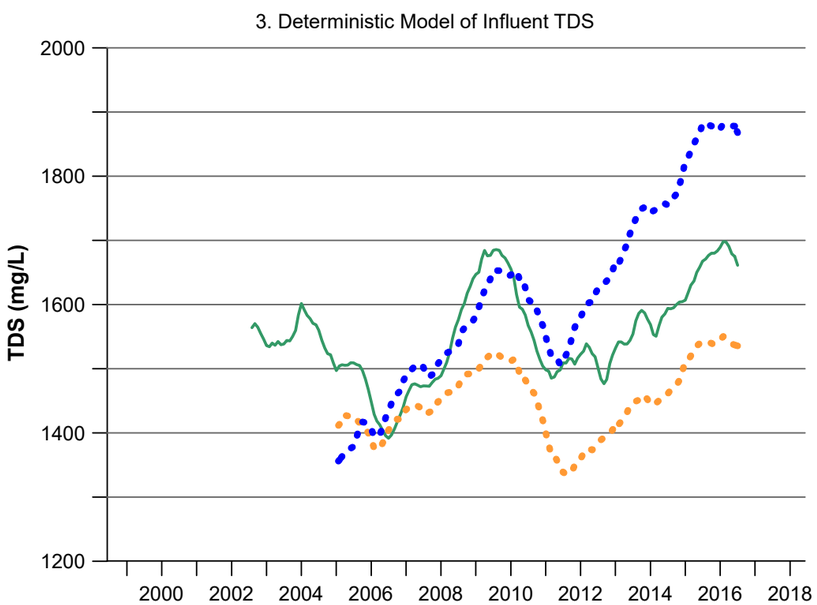
3/22/2018 DB17.1179

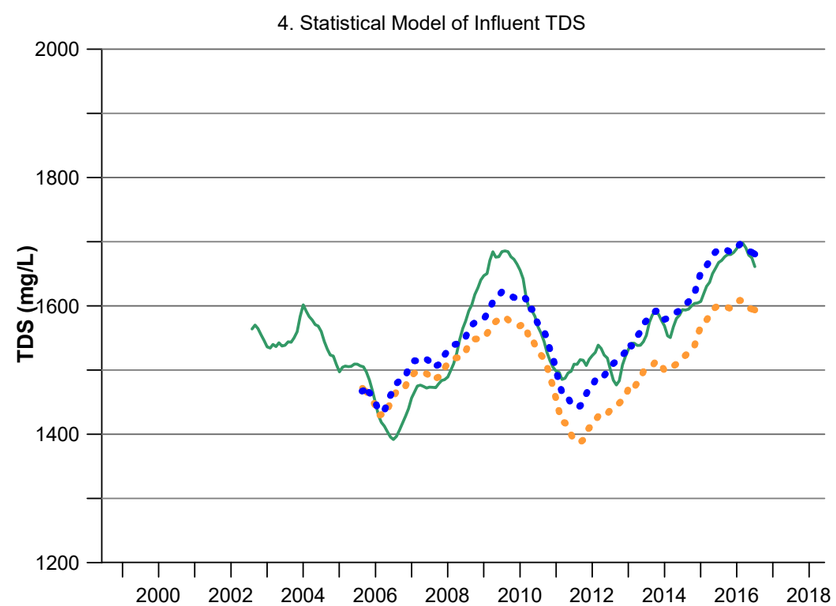




Explanation

1. Population and Indoor Water Use
   - Population
   - Per capita gallons per day (gpcd)
   - Million gallons per day (mgd)
2. Measured TDS
   - Monthly effluent TDS
   - Monthly source TDS
   - Monthly influent TDS
   - 12-Month average of effluent TDS
   - 12-Month average of source TDS
   - 12-Month average of influent TDS
3. Deterministic Model
   - Measured 12-month average of influent TDS
   - Deterministic model: actual flow (90-65) gpcd
   - Deterministic model: constant flow (90) gpcd
4. Statistical Model
   - Measured 12-month average of influent TDS
   - Statistical model: actual flow (90-65) gpcd
   - Statistical model: constant flow (90) gpcd





ITDS Multiple Linear Regression Results

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1302.82192   53.37756  24.408  < 2e-16 ***
STDS           1.03088    0.05999  17.184  < 2e-16 ***
IGPCD         -3.68322    0.45484  -8.098 3.65e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 38 on 129 degrees of freedom
Multiple R-squared:  0.7914,    Adjusted R-squared:  0.7882
F-statistic: 244.8 on 2 and 129 DF,  p-value: < 2.2e-16
```

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SOUTHERN CALIFORNIA SALINITY COALITION

SDCWA Combined North City, Point Loma, South Bay Summary of Results: Indoor Water Use and TDS Trends

Daniel B. Stephens & Associates, Inc.

3/22/2018 DB17.1179