Investigating the Role of Drought and Water Conservation Efforts on the Effluent Dominated Streams in Southern California

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Abstract

This study seeks to examine the effects of water conservation policies on flow and Total Dissolved Solids (TDS) level in wastewater treatment plants (WWTPs) and effluent-dominated water bodies. The research focuses on the Southern California region, predominantly the Los Angeles Metropolitan Area. This region once contained many natural rivers that have seen their natural base flows replaced with discharge from WWTPs. Some of these rivers, such as the Santa Ana, contain threatened and endangered species like the Santa Ana Sucker. This study takes a mixed method approach to analyze the impacts of the conservation policies enacted during the 2014-2017 drought, such as the Governor's mandate (June 2015-May 2016). A time series fixed effect analysis is conducted on a sample of 32 WWTPs in Southern California. The results demonstrate that conservation measures have adverse impacts on both effluent flow and quality, resulting in impact on downstream users as well. To illustrate, the study then examines the effects of effluent flow on streams. We focus partially on the section of the Santa Ana harboring the bulk of the Santa Ana Sucker population, as it is of critical importance. We found evidence that increases in effluent flow from WWTPs both increases flow and Total Dissolved Solids (TDS) in the Santa Ana. There is evidence that wastewater discharge has a significant effect on the flow of other streams in the region. Therefore, we can conclude that the conservation measures enacted during the drought had a significant impact on effluent-dominated streams in the area. To better understand this, we conducted a series of interviews with WWTPs environmental and regulatory compliance managers and utilized a qualitative analysis. We found that conservation policies add challenges that complicate a WWTPs ability to maintain the full viability of these streams while attempting to recycle the amount of water needed to meet residential demand. This speaks to a larger issue in which the state needs to consider the externalities that conservation policies such as the 2015 mandate will have on effluent dominated streams while considering the present constraints that WWTPs bear in the wake of imminent droughts.

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List of Acronyms and Abbreviations

CRA	Colorado River Aqueduct
DWR	Department of Water Resources
EDWs	Effluent Dependent Waterbodies
EMWD	Eastern Municipal Water District
GPCD	Gallons per capita per day
IEUA	Inland Empire Utilities Agency
Mg/L	milligrams per liter
MGD	Million Gallons Per Day
MWD	Metropolitan Water District
NPDES	National Pollutant Discharge Elimination System
OCWD	Orange County Water District
PPIC	Public Policy Institute of California
Ppm	Parts Per Million
RIX	Rapid Infiltration and Extraction Facility
RPU	Riverside Public Utilities
RWP	Recycled Water Policy
SAWPA	Santa Ana Watershed Protection Authority
SBVMWD	San Bernardino Valley Municipal Water District
SNMP	Salt and Nutrition Management Plan
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	Total Dissolved Solids
TEAM	Santa Ana River Watershed Action Team
WMWD	Western Municipal Water District
WRF	Water Reclamation Facility
WRP	Water Reclamation Plant
WTP	Wastewater Treatment Plant

1.0 Introduction

California is no stranger to drought. With its large population, Southern California is particularly sensitive to water shortages. The last drought lasted several years and pushed the state to the brink. With the onset of climate change, it is certain that there will be more. To help deal with drought and water shortages, more districts are turning towards recycling in order to augment their supply. Treated effluent from reclamation plants can be used for irrigation, golf course ponds, groundwater recharge, and stream supplementation. Recycled wastewater is quickly becoming an important resource. In 2009, the California State Water Resource Control Board developed a Recycled Water Policy(RWP) and later issued a mandate in 2013 to increase the use of recycled water in 2020 by 200,000 acre feet per year (SWRCB,2013). However, the viability of reuse depends on the quantity and quality of the treated water available.

Another byproduct of droughts are conservation measures. Indoor water concentration can reduce influent flows to treatment facilities. This can lead to less dilution of solids in the water which raises the TDS (Total Dissolved Solids) of effluent discharges. This drop in quality can reduce its usability and as well as impacting local environments. These measures can also reduce the amount of water that facilities can discharge. This is important, as much of the discharge goes into local streams and rivers. These rivers support an abundance of wildlife and unique species. As their natural flow diminishes during dry periods, these ecosystems become increasingly dependent on wastewater discharges. In fact, many of the rivers and streams in the Los Angeles region are now composed year-round of primarily effluent flow from treatment plants. We refer to these water bodies as being effluent-dominated. This could bring stability to them in drought, or adversity due to human negligence. Therefore, the health of these ecosystems is now dependent on policy.

Figure 1 below shows the main effluent-dominated rivers and tributaries in the area. The Santa Ana, San Gabriel, Los Angeles, and the Santa Clara river are the main bodies. The boundaries of the water and sanitation districts are shown to give an idea of the bureaucratic complexity of the area. Each of these districts have their own policies and practices with many of them engaged in wastewater recycling.

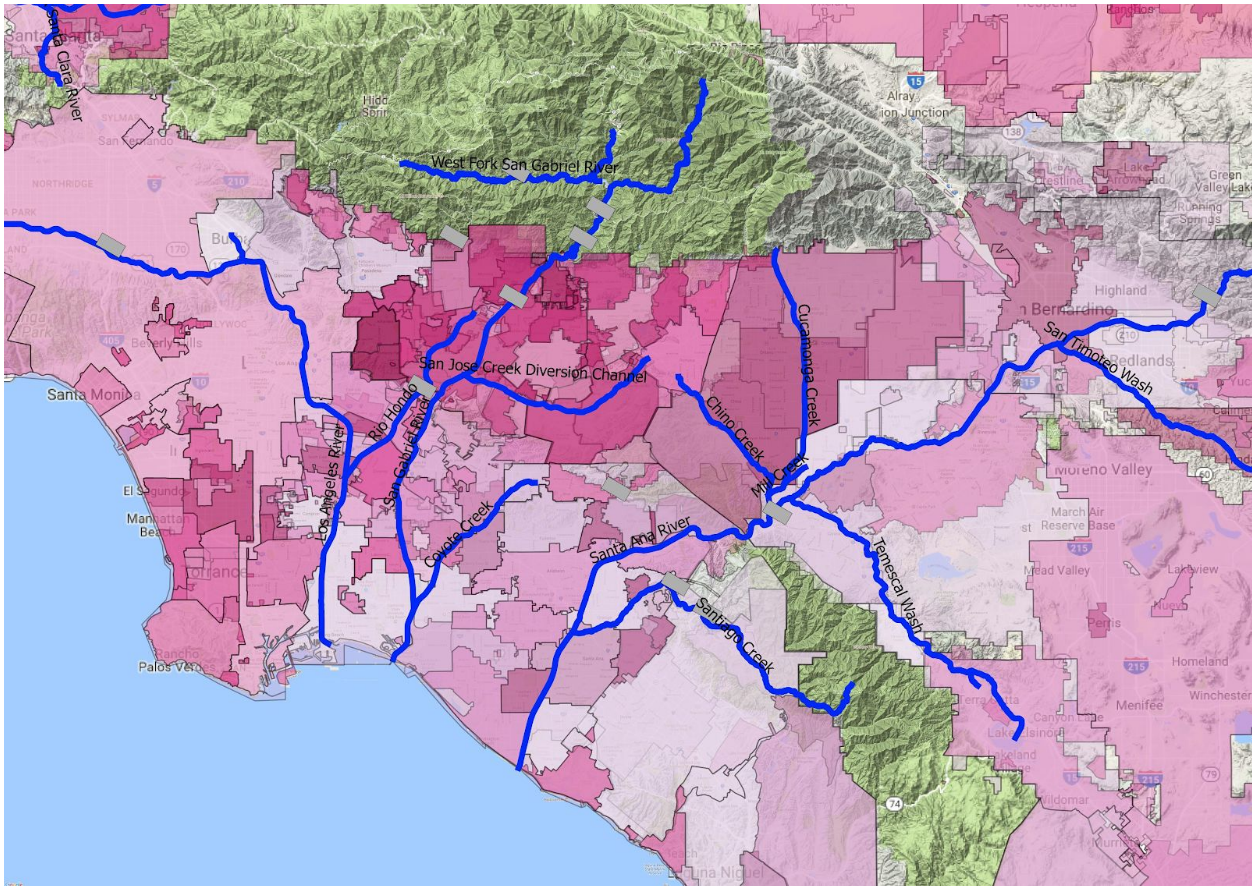

Figure 1: Effluent Streams and Water Districts in LA Metro

Our research project seeks to examine the effects of drought and water conservation policies on wastewater plants and the streams that depend on their flow in the Los Angeles region. We will use the periods of conservation policies before (voluntary conservation from June 2014 to May 2015), during(mandated conservation from June 2015 to May 2016), and after (self certification period starting from June 2016) Governor's mandate went into effect. Our units of analysis are wastewater treatment plants and several monitoring points along the Santa Ana. We will identify impacts on wastewater treatment plants, as well as investigating WWTP's response to extreme drought. In particular, our study intends to give answers to the four research questions outlined below:

1. How did drought and conservation efforts impact effluent quality and quantity?
2. How did the conservation measures and drought impact stream quality and quantity in California?
3. How are wastewater agencies responding in order to meet the requirements for discharges?
4. How are wastewater agencies preparing for anticipated future challenges related to climate variability and its impact on effluent flow, discharge and quality?

First, we will go into the background behind our research in order to help understand the issues surrounding it. We will discuss the drought and the conservation measures enacted and their impacts on WWTPs. Second, we will discuss the environmental situation in the Santa Ana River. Our third section describes our data. The fourth component of our paper contains our quantitative research and analysis. It will be broken into multiple parts. The first part of our analysis will examine the effects on conservation policies on WWTP effluent flow and Total Dissolved Solids (TDS). It will utilize a fixed effect time series regression model with data from 40 WWTPs in Southern California. The second part of the analysis focuses on the impacts on streams. We will run a multivariate regression model on the Santa Ana River, then incorporate several other rivers into a time series fixed effects model.

For the fifth section, we will discuss our qualitative analysis. The paper will break down numerous descriptive interviews held with WWTP environmental and regulatory compliance managers with the intent of providing their perspective on the potential challenges in meeting regulatory requirements during to the drought and conservation mandate. The sixth section will summarize the challenges we had obtaining data. In the seventh section we will discuss potential opportunities for future research. Our last section of the report contains our conclusion, which includes our policy recommendations. The references and appendix are located at the end of the paper as sections 9 and 10, respectively.

2.0 Background and Understanding

2.1 Water Conservation & Management in Southern California

Water conservation is the result both of the conscious effort of water agencies' policies and of individuals' behaviors (Inman and Jeffrey, 2006). California, a state with approximately 39 million of residents (US Census Bureau, 2017) has a long history of laws, policies and practices to promote water conservation. Southern California contains 54% of the state's population and therefore exhibits the most need. Agencies in Southern California have been putting in place voluntary and market-based conservation strategies since the 1980s. One of the largest large water agencies in Southern California, Metropolitan Water District (MWD), has been maintaining these programs since the beginning. Although the state has endured many droughts, the latest one from 2012-2016 was unusual in its severity. It encompassed the driest four-year stretch on record for the last 120 years . Rivers and wetland ecosystems throughout California experienced record-low flows and water quality degradation. This resulted in harm to salmon, steelhead, and other native fish in many of the watersheds.

High rates of conservation helped this region to manage limited water supplies during drought. Some agencies started to work collaboratively to mitigate the impacts of prolonged drought in this region. For example, Inland Empire Utilities Agency (IEUA), in partnership with the Orange County Water District (OCWD), San Bernardino Valley Municipal Water District (SBVMWD), Western Municipal Water District (WMWD), and Eastern Municipal Water District (EMWD), formed the Santa Ana River Watershed Action Team (TEAM) to actively identify large scale water supply and reliability projects that will provide benefits to the entire Santa Ana Watershed (IEUA,2014). In January 2014, Governor Jerry Brown proclaimed a drought emergency and requested Californians to voluntarily reduce their water usage by 20%. At first, the effort was merely voluntary. Eventually, increasing water scarcity and pressure on the water supply led to it becoming a mandatory commitment. In April 2015, after a record-low snowpack, the Governor declared mandatory conservation measures and ordered the State Water Board to impose a 25 percent reduction in potable urban water use. The State Water Board adopted emergency mandatory reduction from June 2015 to May 2016, which varied between 4 and 36 percent relative to residential per capita water use in 2013. In May 2016, a self certification period started, following a near-normal winter and improved water storage conditions (suppliers can opt out from state mandated conservation target if they could demonstrate they had supplies adequate to carry them through at least three more years of drought). Most urban water suppliers (approx 83%) elected to self certify and have no mandatory restrictions. California communities successfully reduced water use by 22 percent in between June 2015 and January 2017.

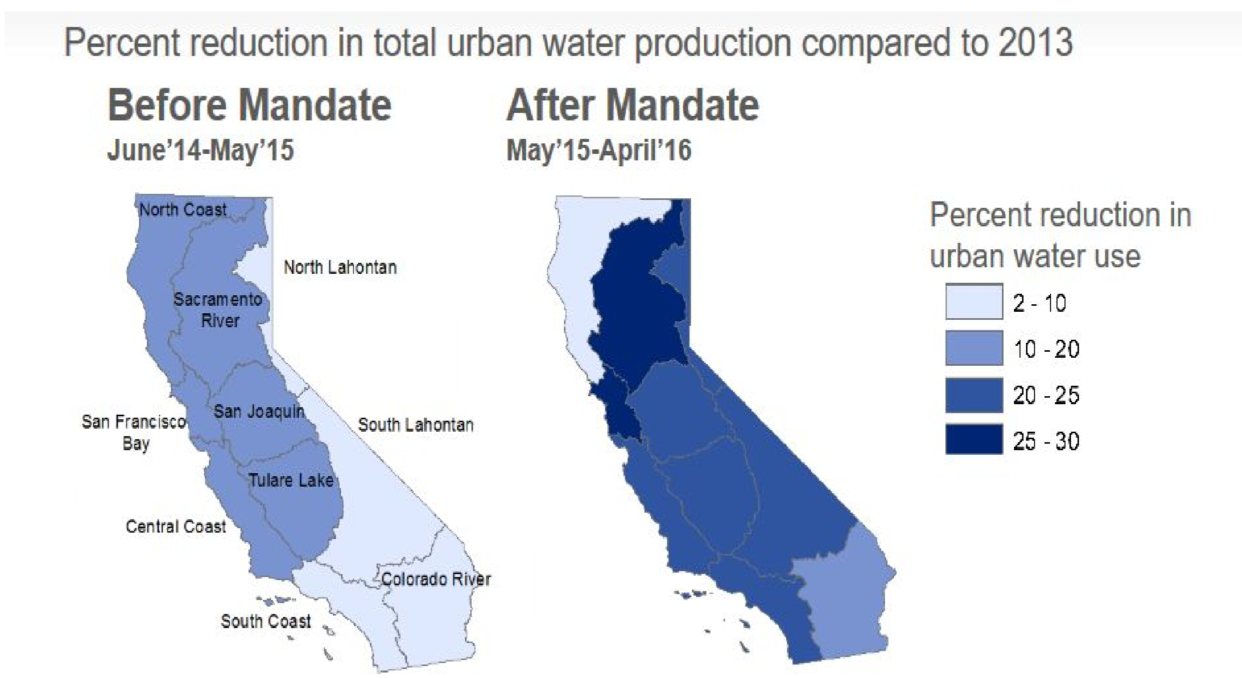

Figure 2: Percent reduction in total urban water production compared to 2013

Source: PPIC Water Policy Center

2.2 Impact of Drought Water Conservation on WWTPs Operations

High rates of conservation can have a downside as well. Unintended consequences of water conservation strategies includes water quality problems, less available water to recycle, increase in operation and maintenance costs, and infrastructure management difficulties. A PPIC report published in June 2017 shows how urban suppliers experienced additional challenges and adverse physical effects in managing wastewater service. Based on their survey report, 40% of urban water suppliers who responded faced water quality impairment and 71% mentioned reduction of available supply sources (Escriva, et. al 2017).

The consequence of consumers' efforts to reduce their water consumption has led to a lower amounts of wastewater going into the treatment system. Less wastewater flowing through sewer pipes can result in higher concentrations of solids as there is less flow to flush them down. This can lead to leakage problems and degradation of water infrastructure which imposes additional costs on WWTPs. It also leads to inefficiency as WWTPs have to treat lower amounts of wastewater in a plant designed to treat larger amounts of water. Additionally, drought leads to less inflow/infiltration into the plant. Although rainfall runoff is designed to be captured in the storm sewer, every time it rains there is a certain percentage (sometimes upwards of 50% of the peak flow) that will enter the sanitary sewer through manholes, improper connections, leaking pipes, etc. (SCSC, 2017).

Conservation measures, such as indoor conservation, can have unintended consequences that include a reduction in the quantity and quality of recycled water. This is often accompanied by revenue decreases and increases in infrastructure costs. (SCSC, 2018). This is evident in a study conducted by Tran et

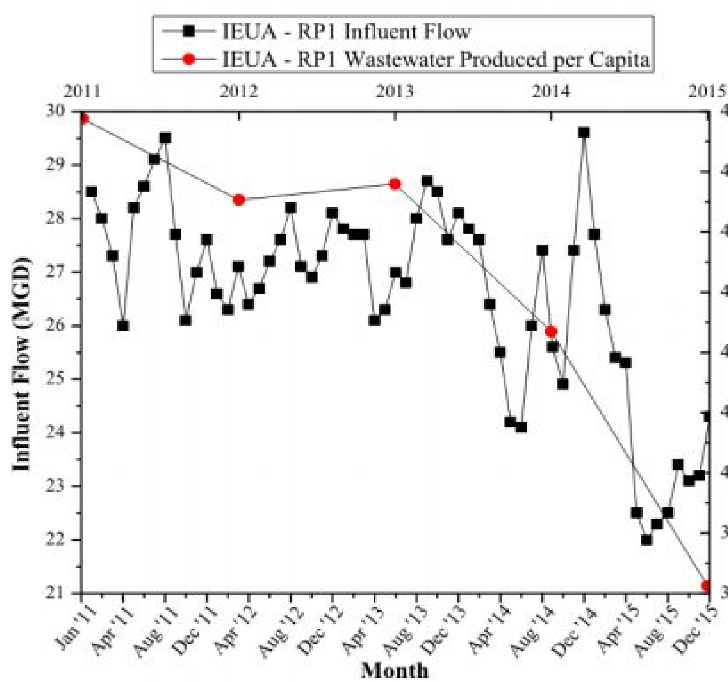

Figure **IEUA – RP1 influent flows and the wastewater produced per capita decreased from 2011 through 2015.**

Source: Tran et al. 2017.

al. (2017), where they analyzed influent flow and water quality data for IEUA's Regional Plant 1 between 2011 and 2015 as seen on the figure to the right. Results show that "indoor conservation can result in the generation of a more concentrated wastewater stream, with increased concentrations of total dissolved solids (TDS), nitrogen species, and carbon" (Tran et. al, 2017). There is a dependence between reuse on water conservation measures in terms of the recycled water supply. Therefore, they recommend that more emphasis be placed on programs that promote outdoor water conservation, as opposed to indoor conservation, since the flows of outdoor use does not enter the sewage system.

2.3 Impact of Drought Water Conservation on Recycled Water Usage

Following the lessons learned from previous drought in this region, utilities are exploring ways to diversify water supplies so as to be more drought resilient. Increased reuse of treated wastewater is a centerpiece of these effort. The Recycled Water Policy (RWP) established in 2009 required the CA Regional Water Quality control board to develop and implement salt and nutrient management plans (SNMPs) to ensure attainment of water quality objectives and protection of beneficial uses. In 2013, the State Water Board established a mandate to increase the use of recycled water in California by 200,000 afy (acre-feet per year) in 2020 and by an additional 300,000 afy in 2030 (SWRCB, 2013).

State Water Board and water suppliers hope that the increasing use of recycled water will allow them to meet rising demand, augment streamflow, replenish groundwater, and supplement irrigation. However, wastewater containing high levels of contaminant concentrations may violate discharge limitations set by state and federal regulations (i.e., National Pollutant Discharge Elimination System or NPDES permit) which can result in penalties. Generally, the Clean Water Act prohibits the discharge of pollutants from point sources to surface waters of the United States unless authorized under an NPDES permit. (33 U.S.C. §§ 1311, 1342). The major challenge arises if the wastewater contain a high load of TDS because most conventional wastewater treatment processes (primary, secondary, tertiary, disinfection process) cannot effectively remove the salts (Tran et.al. 2016). This poorer quality recycled water can negatively impact the recipients, such as the streams. Our study takes into account how conservation strategies upstream can adversely affect downstream recipients with a focusing on the effluent dependent water bodies (EDWs) in Southern California. In **Figure 4**, we visually illustrate how indoor water conservation in upstream can adversely impact downstream users. **Figure 5** graphically shows an example of one wastewater treatment plant in LA region named Tapia WWRF. The data collected is for Jan 2013 to Dec 2016 and shows how increasing indoor conservation simultaneously led to a reduction in effluent flow (calculating percent change in effluent flow relative to the same month of 2013) and an increase in effluent TDS (percent change in effluent TDS concentration relative to the same month of 2013).

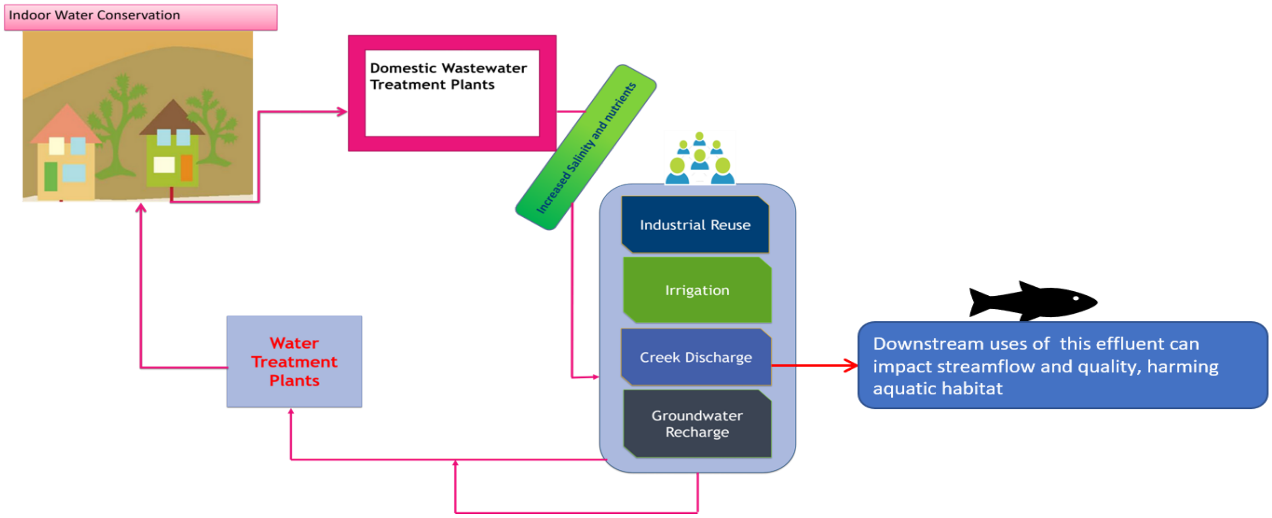

Figure 4: Flowchart showing how upstream indoor conservation can impact downstream users (such as the streams)

Source: Developed by author; (Amin, Refat et al., WSI poster session 2017)

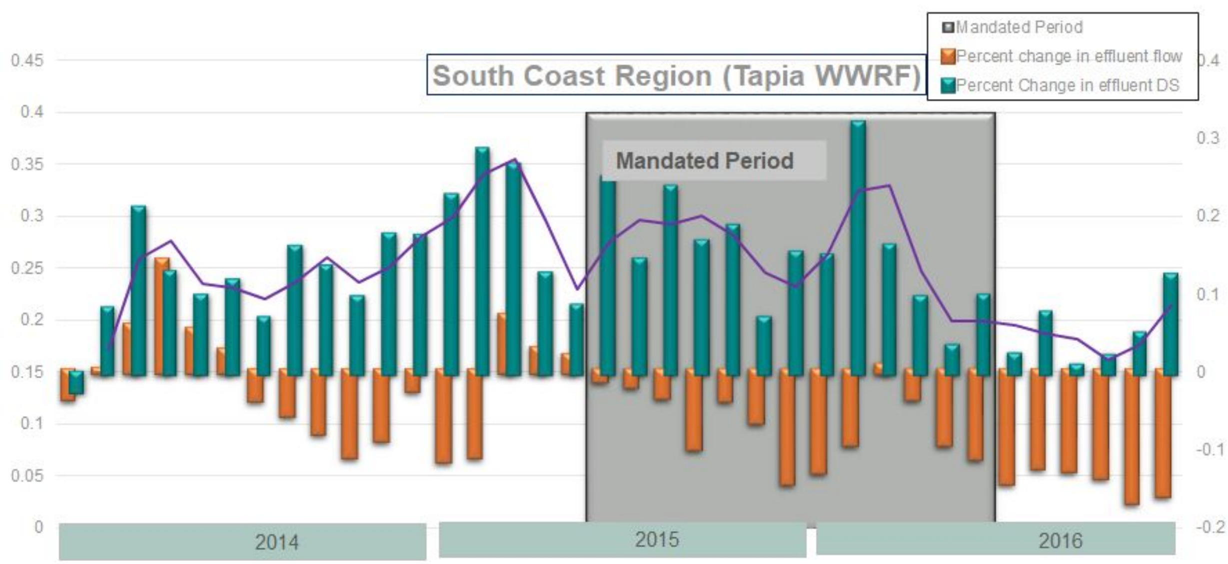

Figure 5: Developed by project author using effluent data from Tapia Wastewater Reclamation Facility. Calculated percent change in monthly effluent flow and TDS data (2014-2016) relative to the same month of 2013.

2.4 Impacts on Streams

There currently is very limited literature on the effects of conservation policies on the wildlife inhabiting effluent dominated streams. However, there is literature on the how the health of certain fish species is affected by effluent that is discharged by wastewater treatment plants. One study in Wascana Creek, Saskatchewan, Canada looked at the exposure municipal effluent affects the health and reproductive development of fish (Fathead Minnows) in an effluent dominated stream. "Exposed fish of both species exhibited delayed spawning and altered gonadal development depending on the season" (Tetreault GR, et al. 2012). Additionally, the histopathology of exposed Fathead Minnows revealed inflammation of the gill lamellae and changes in structures of the kidneys. Another study in Boulder Creek and the South Platte River looked at intersex White Suckers that resided downstream of the wastewater treatment plant effluent. Results found that "Asynchronous ovarian development was found in some female white downstream of the WWTP effluents, but not upstream" (Woodling et al., 2006). This is an important link that we find relative to our study because conservation policies may reduce the amount of effluent flow into streams due to less consumption and influent coming in. This allows more active chemicals to seep through the effluent and biologically alter the fish populations.

The USGS conducted a study in 2004 and 2005 to see if the "threatened Santa Ana sucker was *potentially* exposed to endocrine disrupting compounds (EDCs) in the SAR by using the western mosquitofish (Gambusia affinis) as a surrogate fish model." (Jenkins et al., 2009). Four Santa Ana River sites were chosen along a gradient of proximity to WWTP effluents to analyze. Analyses of the extracted samples showed that EDCs were detected in water from the Santa Ana River sites. Many of these compounds contributed to activity from an "estrogenic in-vitro assay that showed a significant potential for impacting endocrine and reproductive systems compared to the 25 organochlorine compounds detected in aquatic biota" (Jenkins et al., 2009). This means that there was an alteration of endocrine and reproductive functions in male western mosquitofish. This means that there are huge implications for hormone impairment for the threatened Santa Ana Sucker Fish. All the sites were suitable habitats for the Sucker Fish. It should be noted that there was no single causative chemical that could be attributed to the EDC's located in these Santa Ana river sites.

2.4.1 Santa Ana Sucker

One of the reasons for the Santa Ana River's importance is that it is home to the Santa Ana Sucker. The fish was designated a threatened species in 2000 under the Endangered Species Act of 1973 by the United States Department of Fish and Wildlife (USDFW). Its habitat once encompassed much of the San Gabriels and Santa Ana Basin. Population growth and developments such as the Seven Oaks Dam have reduced their habitat to a fraction of what it once was. Shortly after the sucker's designation, the Center for Biological Diversity sued the US Fish & Wildlife Service in order to establish a protected habitat and 21,000 acres was set aside. This was later slashed to 8,305 acres and the service was sued again to finally designate 9,331 acres of the Santa Ana watershed for the sucker in 2010 (CBD).

Currently, it is estimated that 90% of the SA Sucker population is located in a 3 mile stretch of river between the Rialto Channel and the Mission Inn Avenue bridge. A recent study estimated that about 6,801 suckers are living this area, as well as 11,798 Arroyo Chub, another species of concern (Steinberg 2016). The flow in this stretch of river is dependant on discharges from the Regional Tertiary Treatment Rapid Infiltration and Extraction Facility, referred to as RIX. Discharge from this facility flows into the Santa Ana River near the Rialto Channel in the city of Colton. This section is pictured below.

Figure 6: Santa Ana River Sucker Habitat Near Riverside - Generated by Authors in QGIS

As this section of river if heavily influenced by RIX facility discharge, any interruption in flow can have dramatic effects. The plant is jointly owned by the cities of San Bernardino and Colton. As the graph below shows, the effluent flow from this facility is fairly stable. However, the plant periodically must shutdown for maintenance. The shutdowns are often planned, such as replacing UV bulbs used in the final phase of treatment. Other times the shutdowns are unexpected, due to power issues. A report from the California Regional Water Quality Control Board shows that there were 69 incidences of temporary plant shutdown between January 2014 and December 2016 (SWRCB RIX Shutdowns). Plants are not allowed to discharge effluent flow during these periods without violating their NPDES permits, which leads to sections of the river going dry. After several shutdowns in 2015 resulted in dozens of fish deaths, conservation groups pressed the Fish and Wildlife service for greater protection and cooperation. Subsequent major planned shutdowns have led to organized efforts by groups to physically go to the river and save fish. Using nets and electricity to stun fish, volunteers collect fish in buckets and hold them until flow resumes (Steinberg 2016). Lobbying efforts have since led to the development of the Upper Santa Ana River Habitat Conservation Plan. The sucker is a physically sensitive fish that requires a clean gravel bottom for spawning. The quality and temperature of effluent flow matter as well. If the water becomes too warm, algae will form and reduce the fish's habitat. The plan also includes efforts to reintroduce the Santa Ana Suckers to former habitat further up stream and the removal of non-native species.

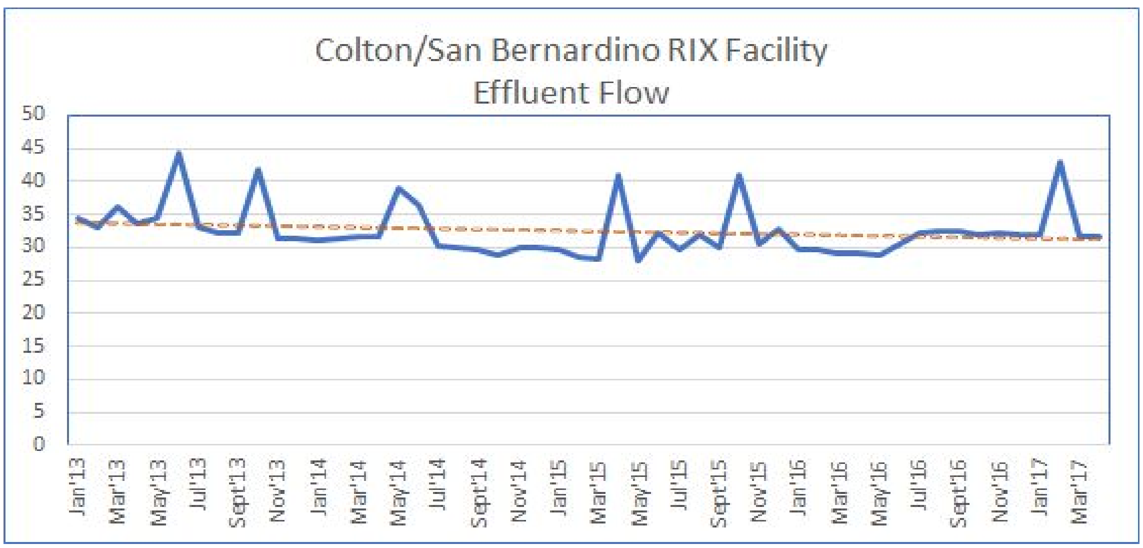

Figure 7: RIX Effluent Flow - Developed by Authors

Due to both the sensitivity and biological importance of this area, we will focus much of our analysis on the urban Santa Ana watershed. The Santa Ana River's dependence on non-natural water flow makes it much more susceptible to the effects of policy than a naturally flowing river. Water policy in the Inland Empire region is particularly complicated as it must balance both the population's growing need for water and the environment's needs. When exacerbated by a drought, the key to good policy is information. Therefore, our project hopes to identify vulnerable points in the region throughout the drought period and uncover some relationships between conservation policies and the health of effluent-dominated streams.

3.0 Data Compilation

3.1 Wastewater Quantity & Quality data

Selection Criteria

The purpose of our research is to provide both quantitative and qualitative measurement of the impact of drought and conservation measures in stream flow and quality in Southern California. We try to identify relationships among variables such as salt concentrations in municipal influent and treated effluent, drought, and mandatory water conservation. Thus, the selection criteria for agencies and wastewater treatment plants (WWTPs) were established to determine the relationship between indoor water use and wastewater flow/quality. The data on monthly flow and wastewater quality (in particular, TDS data) from 2013-2016 were requested and obtained from water agencies and WWTPs (mostly, NPDES permit holders) in Southern California. The data that we requested includes:

- ❏ **Influent flow:** Volume of indoor water used which is considered as influent for each WWTPs. Monthly influent volume of wastewater (monthly average) at each plant starting from 2013- Present. Unit - MGD (Millions Gallons per Day)
- ❏ **Influent TDS:** concentration of salt or TDS in the wastewater influent. Monthly average and/ or volume weighted average influent TDS at each plant starting from 2013- Present. Unit- mg/L or ppm (parts per million)
- ❏ **Effluent flow**: volume of wastewater discharged from the treatment plants. Monthly effluent volume of wastewater (monthly average) at each plant starting from 2013- Present. Unit - MGD (Millions Gallons per Day)
- ❏ **Effluent TDS:** concentration of salt or TDS in the wastewater effluent. Monthly average and/ or volume weighted average effluent TDS at each plant starting from 2013- Present. Unit- mg/L or ppm (parts per million).

We were able to collect the influent/effluent flow and TDS data for 37 WWTPs. However, we decided to use 32 WWTPs as some of the water suppliers did not report their conservation data through State Water Resources Control Board Monthly Conservation Reporting Portal. This prevented us from obtaining water usage data, which we felt was important to conduct our analysis. Thus, those plants were excluded.

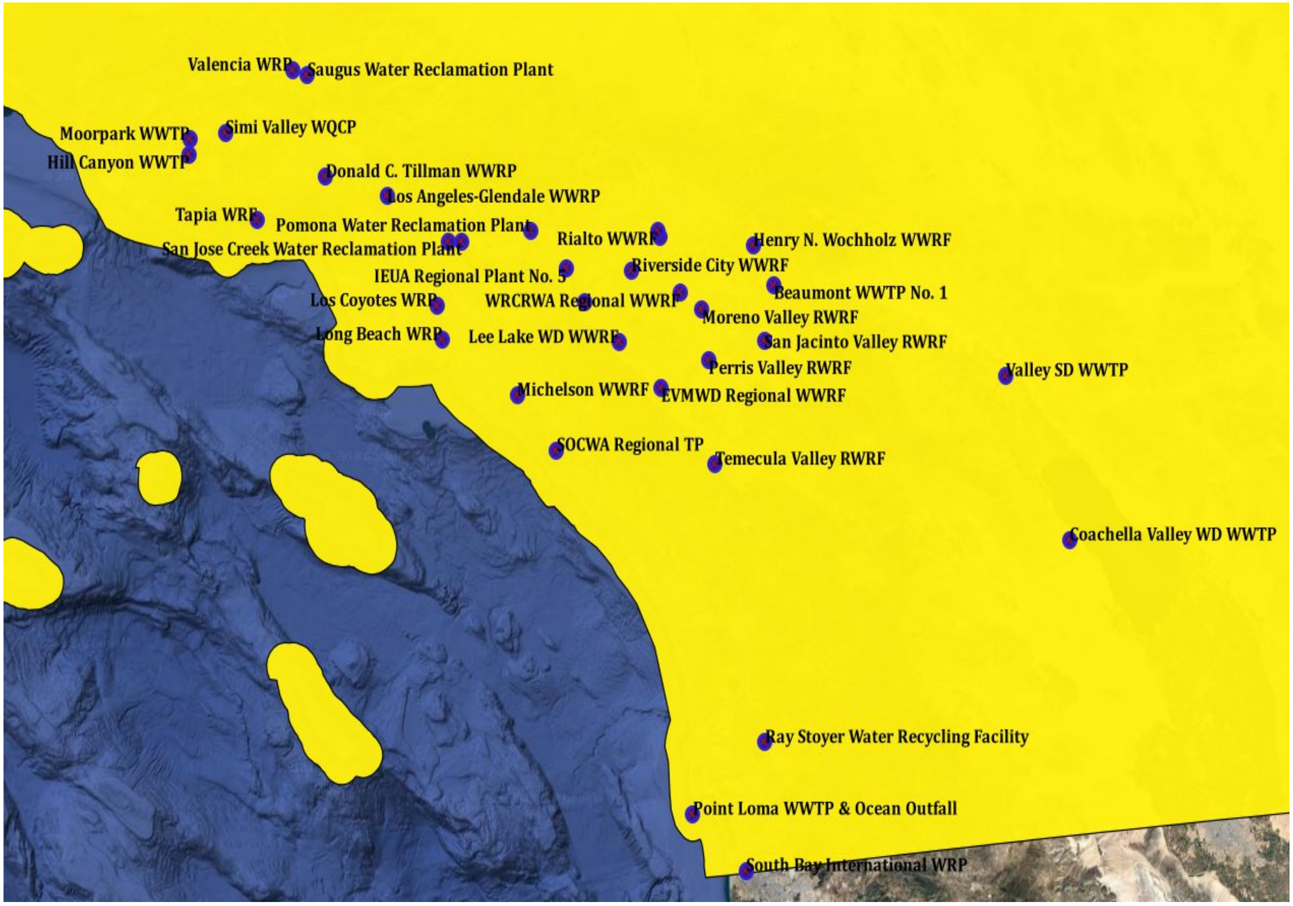

Figure 8: Wastewater Treatment Plants Represented in Effluent Quantity-Quality Analysis
Source: *Developed by authors using QGIS.*

3.2 Stream Data

The data for the Stream Analysis is summarized below.

Data:	Description:	Source
Streamflow:	USGS - Water.gov - Various Locations Monthly Averages, converted from cubic feet per second to million gallons per day; Monthly Average	USGS
Effluent Flow:	Effluent Discharge from Entire WWTP - MGD - Daily Data Averaged into Monthly	Individual WWTPs
TDS:	USGS - Water.gov - Monitoring locations for SA Riverside MWD	USGS

	Crossing - Monthly Averages of Field Measurements	
Effluent TDS:	TDS of Effluent Discharge from WWTP - Monthly Average	Individual WWTPs
Precipitation:	Precipitation Gauge USGS 340742117161701 San Bernardino & National Weather Service Locations - Monthly Totals in Inches	USGS & NWS
Temperature	Average Temperature - in Fahrenheit	NOAA/NWS
CA Streams	.shp file from Data.gov	CA Dept of Fish & Wildlife
Water District Boundaries:	.shp file for GIS	SWRCB Contact

4.0 Analysis and Results

WWTP Analysis

4.1 WWTP Effluent Quantity and Quality Analysis

Data:

Our analysis is based on water quantity and quality or effluent data from 32 wastewater treatment plants (WWTP) in Southern California. Observations are from January 2013 to December 2016. Using data from four years rather than one allows us to increase the sample size without diminishing the comparability between the plants. By using fixed effect specifications, we identify the effect of time varying variable. This panel structure of our dataset makes it possible to solve the problem of plant-level unobserved heterogeneity. To model the most important determinants behind the effluent quality and quantity, we apply regression models. Our specifications are the following:

Regression Analysis

Equations

$$(1)\ Y1_{it} = \alpha_i + \lambda_t + \beta_1 monthlypotablewater_{it} + \beta_2 vcons_{it} + \beta_3 mcons_{it} + \ldots\ldots + \beta_7 fall_{it} + \varepsilon_{it}$$

$$(2)\ Y2_{it} = \alpha_i + \lambda_t + \beta_1 effluentflow_{it} + \beta_2 vcons_{it} + \beta_3 mcons_{it} + \ldots\ \beta_8 lneffflow_{it} + \varepsilon_{it}$$

Here,
Y1= Effluent Flow
Y2= Effluent Salinity (TDS concentration)

X1= Total Monthly Potable Water use (1), effluent flow(2)
X2= Voluntary conservation
X3= Mandated Conservation
X4: Self Certification
X5: Seasonal dummy (winter)
X6: Seasonal dummy (spring)
X7: Seasonal dummy (fall)
X8: lneffflow (Natural logarithm of effluent flow)

i= plant
t= time

In equation (1), the dependent variable is effluent flow. It represents the monthly average of treated wastewater discharged from individual plant (i) in each month (t). In equation (2), the dependent variable is effluent TDS. It represents the monthly weighted average of TDS, or salt concentration, in the wastewater effluent. The coefficients of the explanatory variables can be interpreted as: how the dependent variable changes if the explanatory variable changes by 1 unit. We include a full set of seasonal 0/1 dummy variables (fall, winter,spring) in time t (Jan 2013-Dec 2016) to signify whether relative to summer, these months have a significant effect on the dependent variables. Here, dependent variable effluent flow, effluent TDS and independent variable, total monthly potable water use are continuous variables. We use 0/1 dummy variables to signify whether the voluntary conservation period (June 2014-May 2015), the Mandatory Conservation period (June 2015-May 2016), and Self-Certification period following the end of the mandate (June 2016-May 2017) had specifically captured the effluent flow and TDS, relative to 2013 (considered as the baseline). Instead of putting a unique error term, we include a bunch of error terms (α_{i}) to represent the unobserved attribute of each plant(i), which do not change in time (t). To identify if there is anything happening all over the plants during a specific time period, we include error term λ_t so that each time receives its own intercept, like each plant's. $\boldsymbol{\varepsilon}_{it}$ stands for fixed error term, which is different for each individual plant (i) at each point in time (t).

The table below summarizes the variables and provides the basic statistics of the continuous variables.

Variable	Description	Data type	Units	obs	Mean	StDev	Min	Max
Effluent Flow	Volume of wastewater discharged from individual WWTPs	; Monthly average (2013-2016)	MGD	1376	16.25	23.692	16.25	155.4
Effluent TDS	Measured concentration of TDS(salinity) in WWTP effluent	Monthly average (2013-2016)	ppm or mg/L	1376	725.8	274.56	280	1939
Total Monthly Potable Water Use	Total monthly potable water production from individual urban water suppliers	Monthly average (2013-2016)	MG	1376	5424	5147.8	44.74	17957
Vol_Cons	Voluntary Conservation Period	Dummy Variable (0/1)						
Mand_Cons	Mandatory Conservation Period	Dummy Variable (0/1)						
Self_Cert	Self-Certification Period	Dummy Variable (0/1)						
winter	Seasonal Variable for Winter	Dummy Variable (0/1)						
spring	Seasonal Variable for Spring	Dummy Variable (0/1)						
fall	Seasonal Variable for Fall	Dummy Variable (0/1)						
ln	"ln" Preceeding a Variable Indicates it is a Logged		All continuous variables are monthly observation					

Predictions:

The predictions for the relationships in the model are summarized in the charts below. We will discuss the predictions more in the analysis section.

Dependent: effluent flow	
Variable	**Prediction**
Monthly potable water use	Positive Correlation
winter	Positive Relative to Summer
fall	Positive Relative to Summer
spring	Positive Relative to Summer
vcons	Negative Correlation
mcons	Negative Correlation
scons (Self Certification)	Negative Correlation

Dependent: effluent tds	
Variable	**Prediction**
effflow	negative Correlation
winter	negative Relative to Summer
fall	negative Relative to Summer
spring	negative Relative to Summer
vcons	Positive Correlation
mcons	Positive Correlation
scons (Self Certification)	Positive Correlation
lneffflow	negative Correlation

To see the robustness of our results, we estimate our effluent flow model in four different ways and effluent TDS model in five different ways. The results for the effluent flow and TDS regressions are discussed in the next section.

Effluent Flow Results and Discussion:

We began data analysis by using the effluent flow as the dependent variable. The result of the regression model using a fixed effect analysis is presented in the following table. Model 1 tests the relationship between monthly potable water use and effluent flow. The result shows the monthly potable water use has a significant positive association with effluent flow. The second model incorporate three seasonal dummy variables winter, spring and fall representing the variation relative to summer. The results show that relative to summer time, winter months have statistically significant positive effect on effluent flow. For the third model, we introduce three dummy variables representing before(voluntary conservation), during (mandated conservation), and after(self certification) the governor's mandatory conservation. Results show that all three periods have a statistically significant negative association with effluent flow relative to the period before conservation measures were enacted. Finally, the response variable, effluent flow, is modeled as a function of all explanatory variables, monthly potable water use measured in MGD, three conservation periods and three seasonal models. Taken together, effluent flow ~ potable water use + winter+ fall+ spring+ vcons+ mcons+ scons. The conservation variables have a strong negative association with effluent flow relative to 2013 and all are significant. Seasonal variables remain to have a positive effect on effluent flow relative to summer months. Finally, monthly potable water use has a positive effect on effluent flow, but narrowly misses being significant. The result shows all our predictions are correct.

Dependent effluent flow	Model 1	Model 2	Model 3	Model 4
Monthly potable water use	0.000138*	0.000447***	-0.0000738	0.000138
	(2.19)	(6.01)	(-1.05)	(1.60)
fall		0.288		0.118
		(1.52)		(0.61)
winter		1.644***		0.966***
		(7.09)		(3.98)
spring		0.928***		0.470*
		(4.37)		(2.10)
mcons			-1.288***	-1.098***
			(-6.54)	(-5.46)
vcons			-0.594**	-0.503**
			(-3.14)	(-2.66)
scons			-1.668***	-1.362***
			(-7.57)	(-5.82)
_cons	15.50***	13.17***	16.60***	15.09***
	(44.51)	(27.52)	(42.05)	(27.10)
N	1376	1376	1290	1290

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Taken together, our regression models demonstrate clearly that conservation efforts have an effect on wastewater effluent flow. The positive association between monthly potable water use and effluent flow demonstrates that reductions in potable water use (meaning more conservation efforts) results in a reduction in the volume of generated wastewater. Thus, it reflects unintended consequences associated with high rates of conservation. Accounting for conservation variable before and after mandated conservation helps us understand the changes undergone during drought. Using the method described above, our results indicate that water conservation measures over the last few years have resulted in reduction in wastewater going into the treatment plants, essentially reduced treated wastewater as well. This is an unintended consequence of water conservation efforts. Conservation measures may pose additional problems for recycled water reuse as well by impacting the water quality of downstream users. The next section will discuss the implications on effluent water quality.

Effluent TDS Results and Discussion:

In this section, we used effluent TDS (Total Dissolved Solids) as the dependent variable. We included the monthly weighted average of effluent TDS of 32 WWTPs in Southern California. Here, we used effluent flow (monthly average) data from 2013-2016 as our explanatory variable. Our assumption is that higher flow will dilute TDS, therefore the relationship will be negative. The results from the fixed effects times series model is provided in the following table. Model 5 tests the relationship between the monthly averages of effluent flow and TDS. The result shows that effluent flow has a significant and strong negative association with effluent TDS. Model 6 includes three seasonal dummy variables (winter, spring, fall) that represent the variation relative to summer. The results show that relative to summer time, winter months have negative effect on effluent TDS. Although they are not significant, the relationship is negative as expected. In model 7, we incorporate three conservation periods. (voluntary, mandatory and self certification). We use 0/1 dummy variables to signify these three conservation variables. Results show that all three periods have a strong positive association with effluent TDS relative to 2013 and all are statistically significant. In Model 8, the response variable is effluent TDS. It is modeled as a function of all our explanatory variables; effluent flow, three seasonal variables, and three conservation periods. The results indicate that all our predictions were correct. In the full and final Model 9, we use logged effluent flow and logged effluent TDS. The estimate shows that a 1% increase in effluent flow leads to 7.13% decrease in effluent TDS. In other words, more water will dilute the salt loads in the effluent.

Dependent effluent TDS	Model 5	Model 6	Model 7	Model 8	Model 9
efflow	-5.643***	-5.509***	-3.713***	-3.573***	
	(-9.24)	(-8.93)	(-5.98)	(-5.72)	
fall		-2.291		-2.256	-0.00258
		(-0.54)		(-0.55)	(-0.47)
winter		-7.342		-8.674*	-0.00966
		(-1.64)		(-1.98)	(-1.65)
spring		-3.087		-1.477	-0.00304
		(-0.67)		(-0.32)	(-0.50)
mcons			57.85***	58.02***	0.0929***
			(13.85)	(13.89)	(16.86)
vcons			37.73***	37.81***	0.0640***
			(9.15)	(9.18)	(11.73)
scons			35.34***	34.67***	0.0654***
			(7.23)	(6.91)	(9.87)
lnefflow					-0.0713***
					(-5.05)
_cons	817.5***	818.3***	758.0***	758.8***	6.666***
	(81.38)	(79.65)	(72.41)	(71.02)	(208.18)
N	1376	1376	1290	1290	1247

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Our results found that reduction in effluent flow can increase the salt concentration in the generated wastewater (aka effluent TDS). Almost all of the WWTPs in our study exhibited an increase in effluent TDS over the past few years. Increased TDS concentration in the generated wastewater can impact the downstream users who rely on it. Since most wastewater treatment plants are not designed to treat high salinity, these conventional facilities may have to invest in upgrading their technologies and processes to meet their discharge requirements. The decreased availability of reliable and high-quality potable water supplies may result in water supply agencies changing their water supply options and augmenting their portfolio to include lower quality source including switching from SWP(State Water Project) water to CRA(Colorado River Aqueduct) water or groundwater that may have higher TDS (SCSC, 2018). Therefore, our study focuses on how upstream conservation measures can impact the downstream users, such as impact on the water bodies that depend on these effluent. Our next section analyzes the impact on stream flow and quality over the years of drought.

4.2 Stream Analysis

4.2.1 Santa Ana at MWD Crossing:

The Santa Ana is arguably the most important of the effluent-dominated water bodies due to its harboring of the threatened Santa Ana Sucker. Because of this, our streamflow analysis will be carried out on the section of the Santa Ana closest to the sucker's current population. The point is located near the border of the Metropolitan Water District and is known as the MWD Crossing. This is approximately 8 miles downstream from the RIX facility and the Rialto Channel. Four wastewater plants operate upstream of this area. The largest is the RIX Facility, followed by Rialto WRF, Colton WRF, and San Bernardino WWTP. We have the effluent data for the first two. According to NPDES documents, the City of Colton WRF does not discharge into the Santa Ana except under extreme high flows. Instead, it sends its effluent to the RIX facility for additional treatment. Therefore, this plant is excluded. The Santa Ana generally has little to no flow above San Bernardino due to the Seven Oaks dam, which does not let much water pass through. There are also several small tributary streams that can run into the Santa Ana near San Bernardino. Examining their flow shows that most of the streams average less than 1 MGD at their gauge locations and typically are dry. Based on the flow data from downstream, it is certain that a large portion of flow in Riverside is coming from unnatural sources. The map below shows the location.

For the analysis, we will examine both flow and TDS at the MWD Crossing location. We will start by looking at long-term trends since 2000. After that, we will run regression models on flow and TDS to discern any correlations.

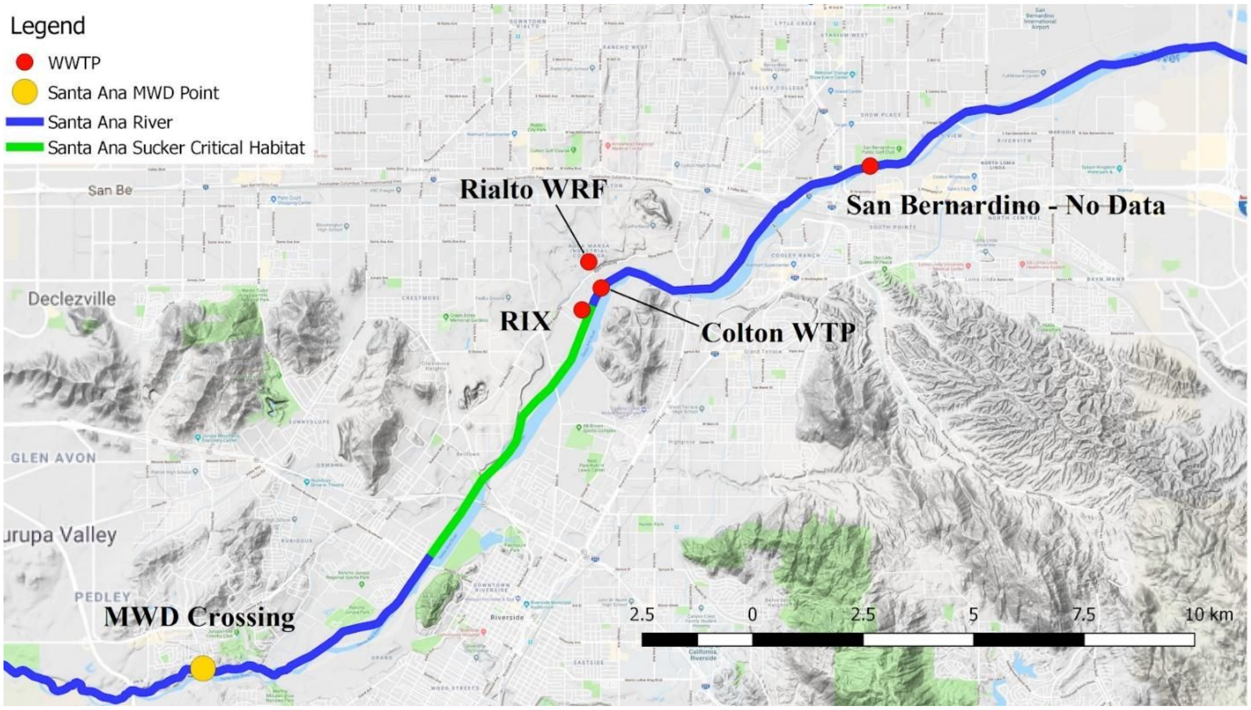

Figure 10: Santa Ana Regression Area Map - Created by Authors

Long-Term Trends:

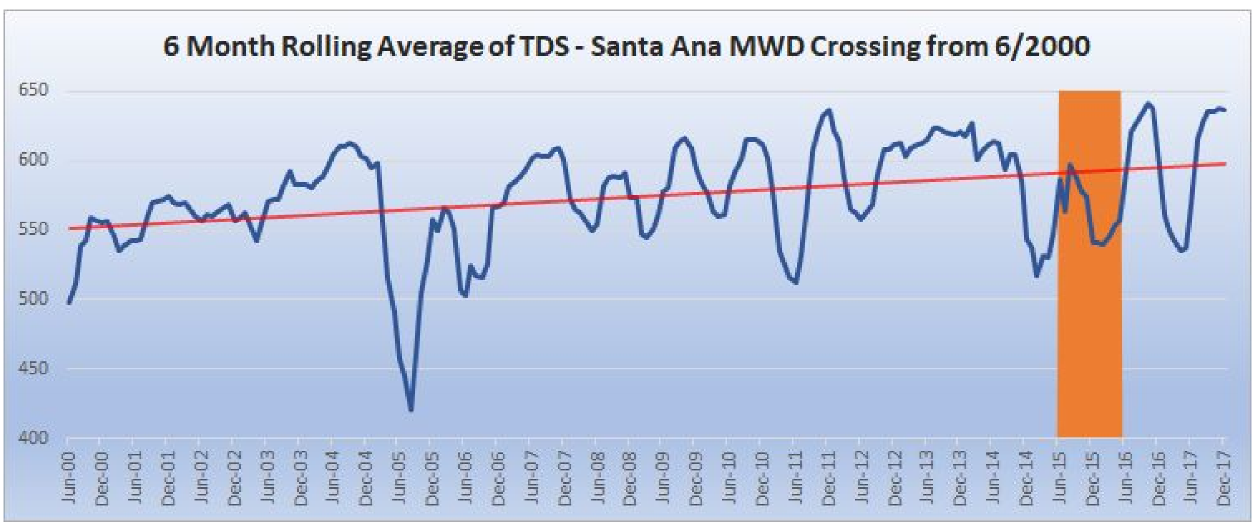

Figure 4.2.3: 6 Month Averages TDS for Santa Ana

We begin the stream analysis by looking for long term TDS (Salinity) trends. Above is a 6-month rolling average of TDS levels in the Santa Ana River from June 2000 to December 2017. The 6-month average is used to smooth out the data visually. Although there are significant fluctuations, there seems to be an upward trend in TDS at this location. The increase over the last ~17 years looks to be only about 10%. During the Mandatory Conservation period the TDS fluctuated a lot and does not appear to have been directly affected by the mandate.

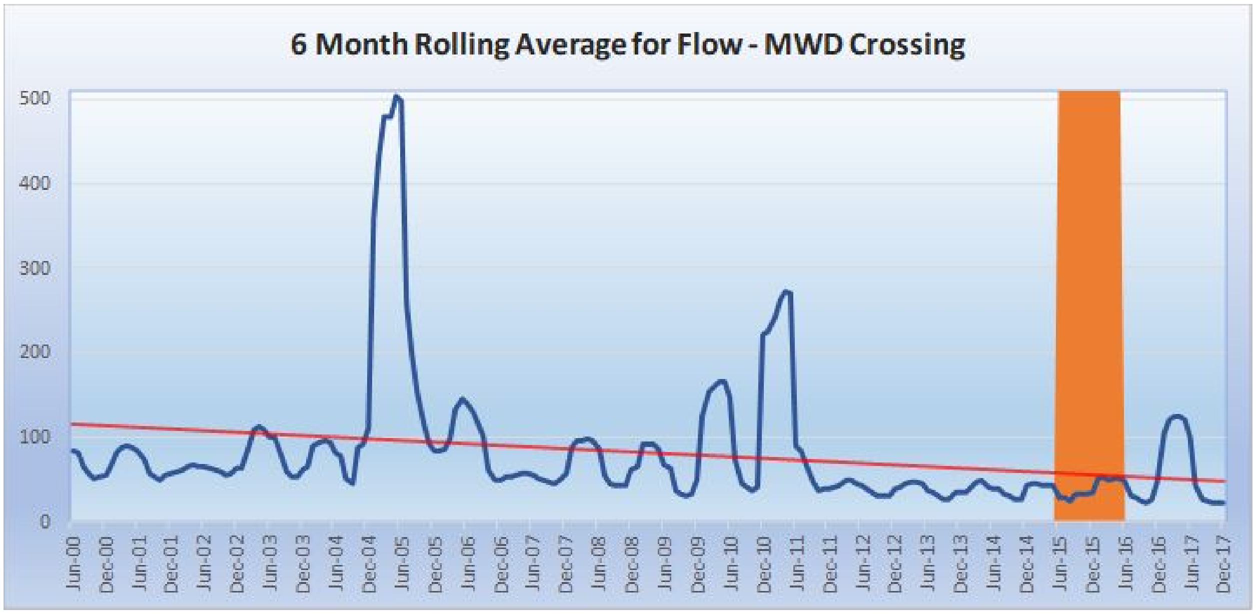

Figure 4.2.4: 6 Month Average Flow at Santa Ana MWD Crossing

The chart above shows a six-month rolling average of streamflow. The trend line shows a small and gradual decline in average flow over the last 18 years. One can clearly see several years of low flow, with the mandated conservation period looking like the final dry year in a series. Even after the drought subsided in 2017, the flow did not look to be very high compared to prior years. To better ascertain if there is any linkage to conservation measures, we will run a regression analysis on TDS and streamflow at the MWD crossing point in the next section.

4.2.3 Santa Ana Analysis

Data:

The table below summarizes the variables and their basic statistics. The data for the regression uses monthly data and runs from January 2013 to April 2017. All continuous variables in these regressions are natural logged except for the Time and Precipitation variables. The Time Variable is a series of sequential whole numbers 1-53. It is used as a time series variable to pick up any longitudinal trends. The precipitation data contains many zero values and so we leave it in real values. The temperature is in degrees Fahrenheit, logged. We use 0/1 dummy variables to signify the voluntary conservation period (June 2014-May 2015), the Mandatory Conservation period (June 2015-May 2016), and Self-Certification period following the end of the mandate (June 2016-May 2017).

Variable	Description	Units	obs	Mean	StDev	Min	Max
SA_Flow_MWD	Santa Ana Flow at MWD Crossing	MGD	53	46.17	52.8	16.61	365.75
SA_tds_MWD	Santa Ana TDS at MWD Crossing	ppm	53	586.79	75.03	360	668
Precip	Monthly Total Precipitation USGS Gauge - San Bernardino	Total Inches	53	1.08	1.61	0	8.59
Temp	Temperature for Riverside Area	Degrees F	53	67.8	8.58	53.3	81.5
RIX_eFlow	Effluent Flow for RIX WTP	MGD	52	32.51	3.84	27.94	44.4
RIX_eTDS	Effluent TDS for RIX WTP	ppm	52	497.65	12.18	478	540
Rlto_eFlow	Effluent Flow for Rialto WTP	MGD	52	5.82	0.33	5.17	6.61
Rlto_eTDS	Effluent TDS for Rialto WTP	ppm	52	505.05	23.65	476.7	542.1
Time_Var	Check for Time Correlation	1-53	53	27	15.4	1	53
Vol_Cons	Voluntary Conservation Period	0,1 Dummy	53	0.23	0.42	0	1
Mand_Cons	Mandatory Conservation Period	0,1 Dummy	53	0.23	0.42	0	1
Self_Cert	Self-Certification Period	0,1 Dummy	53	0.23	0.42	0	1
ln	"ln" Preceeding a Variable Indicates it is a Logged	All Observations Are Monthly					
lln	"lln" Preceeding a Variable Indicates it is Logged & Lagged 1 Month						
lag	A "lag" Preceeding a Variable Indicates it is Lagged 1 Month						

Predictions:

The predictions for the relationships in the model are summarized in the charts below. We will discuss the predictions more in the analysis section.

Dependent: SA_Flow_MWD	
Variable	**Prediction**
Precip	A Strong Positive Correlation
Temp	Negative Correlation
RIX_eFlow	Positive Correlation
Rlto_eFlow	Positive Correlation
Time_Var	Unsure
Vol_Cons	Negative Correlation
Mand_Cons	Negative Correlation
Self_Cert	Negative Correlation

Dependent: SA_tds_MWD	
Variable	**Prediction**
SA_Flow_MWD	Negative Relationship
Precip	Negative Relationship
Temp	Positive Correlation
RIX_eTDS	Positive Correlation
Rlto_eTDS	Positive Correlation
RIX_eFlow	Negative Relationship
Rlto_eFlow	Negative Relationship
Time_Var	Unsure
Vol_Cons	Positive Correlation
Mand_Cons	Positive Correlation
Self_Cert	Positive Correlation

Both the TDS and Flow models incorporate robust estimators to account for heteroskedasticity. Durbin Watson D-Statistics were also estimated to check for serial dependence of the error terms over time. Both were over 2, so there is no evidence of serial dependence. The time variable probably accounts for any time dependence. The results for the flow and TDS regressions are discussed in the next section.

TDS Analysis:

The results from the TDS (Total Dissolved Solids) model are shown in the table below. The table displays the coefficient estimates with the p-values in parentheses. Our method utilizes a multivariate regression model with a time variable. The analysis starts off simple and then proceeds to add in additional variables. The first model is just a simple bivariate estimate between Santa Ana River TDS and Flow at the Metropolitan Water District Crossing Point. We assume that higher flow will dilute TDS levels, and therefore the relationship will be negative. Precipitation and temperature changes are likely picked up in this flow variable. As expected, it is highly significant and the relationship is negative.

Model 2 introduces the effluent discharge flow volume from both the RIX and Rialto WWTPs. Contrary to our prediction, we found that there was a positive correlation between flow and TDS. On reflection, this makes sense, as the effluent flow will always have a higher level of TDS than the natural flow. Therefore, the plants are effectively introducing more salts into the river, which would raise TDS. The Rialto flow sees more variation than the RIX has become significant. Model 3 adds the TDS levels for both the Rialto and RIX plants. There are positive signs on these, as predicted. The fourth and final model adds a time variable to check if there is a stochastic component. It is significant at 5%, but the coefficient is very small. The adjusted R-Squared for this model is .473, so it explains a fair amount of the variation in TDS levels. We will go over the implications more in the results section. The next section will discuss the model results for streamflow.

	(1) lnSA_tdsMWD	(2) lnSA_tdsMWD	(3) lnSA_tdsMWD	(4) lnSA_tdsMWD
lnSA_FlowMWD	-0.159***	-0.173***	-0.178***	-0.174***
	(0.000)	(0.000)	(0.000)	(0.000)
lnRIX_eFlow		0.171	0.152	0.121
		(0.091)	(0.157)	(0.239)
lnRlto_eFlow		0.610*	0.699*	0.797**
		(0.035)	(0.022)	(0.010)
lnRIX_eTDS			0.667	0.638
			(0.182)	(0.209)
lnRlto_eTDS			0.105	0.864
			(0.773)	(0.138)
Time_Var				-0.00275*
				(0.044)
_cons	6.936***	5.319***	0.448	-4.101
	(0.000)	(0.000)	(0.921)	(0.435)
N	53	52	52	52
adj. R-sq	0.420	0.477	0.465	0.473

p-values in parentheses   Durbin-Watson d-statistic(7, 52) = 2.167163
* p<0.05, ** p<0.01, *** p<0.001

Flow Analysis:

The next regression set examines the relationship between effluent flow and streamflow using a multivariate regression with a time variable. The P-values are in the parentheses. We start by establishing the relationship between Precipitation and Streamflow. Model 1 shows the relationship as positive and highly significant. The coefficient is .343, which mean that an increase of monthly precipitation by 1" results in an increase in streamflow of 34.3%. This coefficient is fairly robust and does not change very much throughout the models. The second model incorporate the logged effluent flow from both the RIX and Rialto plants. The relationship is positive, but not significant. In model 3, the temperature and time variables are introduced. Temperature is logged and is significant. It has a negative correlation, as expected. The time variable is not significant.

	(1) lnSA_FlowMWD	(2) lnSA_FlowMWD	(3) lnSA_FlowMWD	(4) lnSA_FlowMWD
Precip	0.343***	0.338***	0.307***	0.320***
	(0.000)	(0.000)	(0.000)	(0.000)
lnRIX_eFlow		0.146	0.146	0.0491
		(0.552)	(0.569)	(0.864)
lnRlto_eFlow		0.817	0.444	1.328
		(0.229)	(0.560)	(0.105)
lnTemp			-0.790*	-0.435
			(0.042)	(0.294)
Time_Var			-0.000317	0.00863
			(0.883)	(0.296)
Vol_Cons				-0.307*
				(0.023)
Mand_Cons				-0.162
				(0.479)
Self_Cert				-0.477
				(0.148)
_cons	3.212***	1.274	5.295*	2.540
	(0.000)	(0.405)	(0.039)	(0.387)
N	53	52	52	52
adj. R-sq	0.856	0.857	0.871	0.889

For the fourth and final model, we introduce three dummy variables representing the three stages of conservation. All three show a decrease in flow relative to the period before conservation measures were enacted, January 2013-June 2015. Only the voluntary measure displays significance. The Adjusted R^2 for all models are very high at more than .85. This shows that a large portion of the variation of streamflow is captured. For this series of models, all of our predictions about the relationships were correct. Next, we will discuss the overall implications of the findings.

Discussion:

The TDS model shows us that flow has the largest effect on TDS levels. In this scenario, the flow variable likely encompasses both precipitation and temperature. However, the positive relationship between effluent flow and TDS is an interesting find. Our focus is on the importance of effluent discharge for the Santa Ana, but it should be noted that increasing reliance on effluent discharge will raise TDS levels. This undermines the importance of maintaining high treatment standards regarding effluent water quality. The effluent flow models support our predictions. The relationships stay the same except for the time variable. Unsurprisingly, precipitation has the largest effect. The coefficient does not change substantially, so it is very robust.

The lack of significance in the RIX and Rialto effluent flow variables are mostly due to their lack of variation. If one examines the data summary, you will see that the standard deviation of the Rialto plant is .33 MGD with a maximum discharge of 6.61. Compared to the actual flow of the Santa Ana, which averages 46 MGD monthly, it is a small contribution. On the other hand, the RIX facility has an average discharge of 32.51 MGD. We also know from the literature that when the facility ceases discharging, critical sections of the Santa Ana River run dry. Therefore, we can surmise that the RIX facility makes up a significant portion of the flow in the vicinity. When looking at the variation, the RIX has a standard variation of only 3.84, while the river itself has a standard deviation of 52.8. From this we can infer that the facility provides a stable base flow which appears to be less affected by environmental factors. Therefore, our conclusion is that the facility is well-managed. As for the Voluntary conservation, it could be capturing some of the variance in the San Bernardino WWTP discharge. However, it is more likely capturing some other external factors that were resulting from the drought and conservation measures.

This study shows that effluent flow and TDS can affect the TDS levels of effluent-dominated streams. There is also evidence that effluent flow fluctuations can influence the streamflow. As the previous analysis on wastewater treatment plants shows, conservation measures do affect the effluent TDS and discharge amounts from the actual wastewater treatment facilities. Therefore, we can conclude that water conservation measures do affect the quantity and quality of flow in effluent-dominated streams. To further expand our analysis of flow, we will add three additional locations and run a time series fixed effects model. This analysis will be explained in more detail in the next section.

4.3.1 Regional Flow Analysis

In our last section we analyzed a specific location due to its importance. The flow model we used reflected most of our relationships predictions. Now we will expand our regression to include three more locations in addition to the MWD Crossing Point on the Santa Ana. Doing so will further test the relationships. If the relationships hold up when other locations are included, then future research could apply the model over a larger region. We will utilize a fixed effects model with time series variable. The panel data is arranged by streamflow monitoring points. The three new locations are described below.

Locations:

The three additional locations are displayed in GIS maps generated by the authors and located in the ***Annex***, Figures **4.3.1**, **4.3.2**, **4.3.3**. The first new location is the Los Angeles River in the Hollywood area. The flow point is measured near Sepulveda Boulevard below the Sepulveda Dam. There is only one WWTP, the Donald Tillman facility located immediately upstream. It discharges both directly into the LA River and indirectly via Woodley Creek. The precipitation and temperature data for this point is measured in Woodland Hills.

The second location added is a Flow monitoring point on the Santa Clara river between Santa Clarita and the town of Piru. There are two WWTPs upstream, Saugus and Valencia. Valencia is the larger plant and both discharge into the Santa Clara. The precipitation and temperature data for this point is also measured in Woodland Hills.

The third location is on the San Gabriel River near Spring Street in the city of Long Beach. The Los Coyotes is a large plant that discharges into the San Gabriel several miles upstream. Further upriver, is the Whittier Narrows WRP. This plant is smaller and discharges into both the Rio Hondo and San Gabriel. Unfortunately, our effluent data does not differentiate between discharge points, so it is not known how much of the effluent data went into the San Gabriel versus the Rio Hondo. Nonetheless, we are including this plant’s effluent. The precipitation and temperature data for this point is measured in Long Beach.

Data:

The summary for the all of the data used in this model is shown below along with our predictions. All observations for explanatory variables are monthly averages or totals. The PointNo variable functions as the cluster number for the panels. The timevar is to check for temporal correlation, denoted in sequential integers. The streamflow is the dependent variable. The effluent1 and effluent2 variables are for wastewater treatments plant flow. The system is set so that the larger plant is always set as effluent1. The flow from the second plant (if there is one) is effluent2. AllEff is the sum of both effluent1 and effluent2. For all flow variables in the model we take the natural log. The precipitation data contains many zero values and so is left in real values. The temperature is in degrees Fahrenheit, logged. We use 0/1 dummy variables to signify the voluntary conservation period (June 2014-May 2015), the Mandatory Conservation period (June 2015-May 2016), and Self-Certification period following the end of the mandate (June 2016-May 2017).

Variable	Description	Units	obs	Mean	StDev	Min	Max
streamflow	Streamflow at Monitoring Location	MG/D	208	43.82	45.41	3.13	365.75
PointNo	Cluster Numbering for each Streamflow Point	1-4	208	N/A	N/A	1	4
timevar	Check for Time Correlation	1-52	208	N/A	N/A	1	52
precip	Monthly Total Precipitation - National Weather Service & USGS	Total Inches	208	0.9	1.56	0	9.33
temp	Temperature - NWS	Degrees F	208	67.08	8.01	53.3	81.5
effluent1	Effluent Flow for Largest/Closest WTP to Streamflow Point - RIX, Valencia, Tilman, Coyotes	MG/D	208	26.19	7.41	14.62	45.86
effluent2	Effluent Flow for Smaller WTP - Rialto, Whittier, Saugus	MG/D	156	6.39	1.29	4.41	9.87
AllEff	effluent1 + effluent2 Aggregated	MG/D	156	30.88	7.97	19.88	50.12
Vol_Cons	Voluntary Conservation Period	0,1 Dummy	208	0.23	0.42	0	1
Mand_Cons	Mandatory Conservation Period	0,1 Dummy	208	0.23	0.42	0	1
Self_Cert	Self-Certification Period	0,1 Dummy	208	0.23	0.42	0	1
ln	"ln" Preceeding a Variable Indicates it is a Logged	All Observations Are Monthly					

Predictions:

The predictions for this model are the same as the predictions for the Santa Ana Flow model. We expect positive relationships between all flow variables and precipitation. Negative signs are expected for temperature and conservation measures.

Dependent: streamflow	
Variable	**Prediction**
Precip	A Strong Positive Correlation
Temp	Negative Correlation
effluent1	Positive Correlation
effluent2	Positive Correlation
AllEff	Positive Correlation
Vol_Cons	Negative Correlation
Mand_Cons	Negative Correlation
Self_Cert	Negative Correlation

Regional Analysis:

The table below shows the results from the panel series. The model we are running is a fixed effects time series model. The panel variable is PointNo and the time variable is timevar. We start in Model 1 by regressing precipitation and temperature on streamflow. The model displays a strong positive relationship between precipitation and streamflow. Temperature has a negative correlation. These are in line with expectations. Model 2 adds in the effluent (effluent1) flow from the largest plant for each location and a time variable. The effluent1 variable is positive and significant with a coefficient around one percent. The time variable has no significance. This echoes our predictions. The third model introduces our conservation dummy variables. The all negative, but not significant.

One important detail to address in modeling for streamflow is how to account for multiple wastewater treatment plants. Accounting for only one plant would leave out important data. However, having separate variables for each treatment plant could muddle the effects depending on each individual plant's variance. We also assume that effluent flow discharges into the stream does not diminish much. To test this, we continue the analysis in Model 4 by adding the additional WWTPs as a separate variable, effluent2. We find that the second effluent has a negative correlation with streamflow. However, it is not significant. In model 5, we aggregate the effluent flows together to make the AllEff variable and take the natural log. The resulting coefficient is both positive and significant. The model estimates that a 1% increase in the aggregate discharge leads to a .948% increase in streamflow. For the final model, we add in the conservation variables. This gives us the fixed effects model below:

$$\mathbf{\ln(Streamflow) = B_1(Precipitation) + B_2\ln(Temp) + B_3\ln(AllEff) + B_4(Time\ Variable) + B_5(VolCon) + B_6(MandCon) + B_7(SelfCert) + a_i + u_i}$$

With the conservation variables added, we find that streamflow decreased during the conservation periods relative to 2013. The AllEff variable remains positive, but misses being significant by a small margin. Temperature remains negative and is not significant. The time variable is not significant either. Precipitation remains positive and highly significant. These results bring us to our conclusions, which we will discuss in the next section.

	(1) lnstreamflow	(2) lnstreamflow	(3) lnstreamflow	(4) lnstreamflow	(5) lnstreamflow	(6) lnstreamflow
precip	0.236*	0.279**	0.286**	0.277**	0.260*	0.270*
	(0.026)	(0.002)	(0.002)	(0.008)	(0.015)	(0.016)
lntemp	-1.644	-1.336	-1.190	-1.534	-1.635	-1.456
	(0.087)	(0.108)	(0.099)	(0.125)	(0.160)	(0.138)
lneffluent1		1.021*	0.980*	1.264*		
		(0.028)	(0.015)	(0.035)		
timevar		-0.00792	0.00315	0.00311	-0.0111	0.00348
		(0.275)	(0.809)	(0.870)	(0.364)	(0.844)
volcon			-0.0965	-0.101		-0.122
			(0.667)	(0.730)		(0.684)
mandcon			-0.263	-0.334		-0.319
			(0.369)	(0.414)		(0.430)
selfcert			-0.482	-0.579		-0.644
			(0.199)	(0.277)		(0.210)
lneffluent2				-0.542		
				(0.352)		
lnAllEff					0.948**	0.921
					(0.006)	(0.054)
_cons	10.16*	5.753	5.160	6.670	7.028	6.207
	(0.035)	(0.076)	(0.063)	(0.123)	(0.138)	(0.174)
N	208	208	208	156	156	156

p-values in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Discussion:

Upon reviewing the set of flow models, we see that the coefficient for precipitation remains fairly consistent throughout. The models estimate that a 1 inch increase in local precipitation results in a 23.6-28.6% increase in streamflow. The time variable shows no signs of significance at any time. Temperature maintains a negative relationship with flow, but never reaches significance. The models all estimate that flow decreased during conservation relative to the 1/2013-6/2014 pre-conservation period.

When looking at the effluent variables, we see that assigning plants to separate variables presents several issues. One issue that arises is the method of deciding which effluent plant is assigned which effluent variable. If we had a very large number of WTPs we could theoretically randomly assign them to variables. However, with the limited number of location involved in a regional study, there needs to be a solid methodology for assigning plants to variables. Even with a sound method, having two separate variables can result in conflicting relationships, as Model 4 shows. The 5th and 6th model show that aggregating effluent discharge together results in a more consistent model. With a coefficient around 1, is seems that effluent discharge does not diminish into the environment quickly. We can conclude from this that effluent flow is an important component of many of these streams. This concludes our stream analysis.

5.0 Qualitative Analysis

The purpose of this qualitative study is to attain an on-the-ground perspective from four WWTPs regulatory managers regarding common and unique challenges that WWTPs are facing due to impacts of drought and conservation policies. The purpose of these questions is to gain a more direct understanding from the key informant experts within the WWTP's of any regulatory requirement challenges they may be facing and how they are addressing them in the short-term and long-term. Their input also gives us great insight as to how the reductions in flow have impacted the plant's capacity to treat wastewater with a higher TDS content and what that means in terms of increasing the resiliency for these plants in a climate that is making the amount of source water increasingly variable. Additionally, these questions help assess the role that WWTP's play in maintaining the health of effluent dominated streams such as the Santa Ana watershed. This analysis explores how these underlying factors currently present challenges of maintaining the long-term health of the stream but also sheds light on the policy gaps that need to be addressed.

5.1 Methodology

5.1.1 Study Design:

The study design is a descriptive research design with a short descriptive survey. We asked five open-ended questions in consistent order with questions one and three having two and three sub-questions, respectively. Each interview lasted between twenty to thirty minutes. The full survey is included in the Appendix, **Figure 5.1.1** for reference.

5.1.2 Sampling Method:

In order to identify which WWTPs we were going to interview, we decided to conduct a snowball sample technique. Our point of entry was through a fellow colleagues connection with board members of the Santa Ana Watershed Project Authority (SAWPA). He connected us to their Senior Watershed Manager, who we conducted an interview to provide initial thoughts on the 2015 conservation mandate. He then connected us to the President of the Southern California Salinity Coalition (SCSC) who helped us hone in on the issue of TDS. Four WWTPs agencies in the Inland Empire and within the SAWPA network were selected with a total of 8 participants:

1. San Bernardino Valley Municipal Water District (SBMWD): 2 Participants
2. Inland Empire Utilities Agency (IEUA): 4 Participants
3. Riverside Department of Public Works (RPW): 1 Participant
4. Eastern Municipal Water District (EWMD): 1 Participant

Figure 5.1.2: Graphic developed by author
Above are the sampled agencies with the key interview informant for each WWTP

These four WWTPs were chosen due to the proximity of the source of the Santa Ana stream, which is the San Bernardino Mountains. More importantly, we chose these specific plants because they hold NPDES discharge permits. Four treatment plants were decided because they are intricate enough to make a statistical analysis practical but also because the sample is small enough to make clear quantitative comparisons.

5.1.3 Data Collection Method:

We held two preliminary phone interviews with SAWPA and the SCSC to gather regional expertise on the topics of state conservation mandates and their impacts on the level of TDS. It should be noted that the five questions asked to the WWTPs were not asked to them. The SCSC, who has conducted recent research on the effects of TDS in wastewater and recycled water were able to adequately provide four WWTPs in which they collaborated with. Through this, we were able to attain exact names and contacts of Regulatory and Compliance managers. Our questions centered around these 5 main points, respectively:

1. The trend in stream quality and quantity in recent years in the specified WWTP.

2. Reason why the quality and quantity of flow has changed, if at all.

3. Regulations or policies that specify flow or quality levels surrounding effluent in a specified WWTP. Any present challenges to meet NPDES permit requirements to maintain quality based on the surface water quality standards.

4. Opinion on role that effluent plays in maintaining the viability of streams in Southern California. Especially in times drought, where effluent may be reliable source of water flow as opposed to runoff.

5. WWTP's role to protect the streams before discharging the effluent into them. (i.e., Greater investments in increased treatment, collaboration with other stakeholders)

5.2 Results

5.2.1 San Bernardino Valley Municipal Water District

Trends in Stream Quality and Quantity	Flows reduced from 33 million gallons/ day in early 2000's to 22 million gallons per/day currently. No major change in water quality.
Reasons for Change in Quality and Quantity	Changes in industry and the absence of a former military facility severely reduced flow which was then followed by housing crash in 2007. No major change in water quality. TDS has stayed constant with less influent to dilute it. Their water table is dropping lower and lower, which is their primary source.
Regulations Specifying Effluent Standards/Challenges Meeting Requirements	Follow NPDES discharge permit requirements. Have not exceeded them. "Challenge is keeping the facility running due to lower flows and attaining any usable water they can treat and recycle."
Role of Effluent Discharge in Southern California Streams	If the RIX facility goes dry, water from the water table is pumped into the river to prevent it from going dry. The natural habitat relies on effluent and Orange County relies on wastewater to infiltrate their drinking water.

WWTPs measures to protect streams before discharge	More pressure is put on WWTP, there is a lack of understanding from regulators of other discharges such as street city chemical runoff and homeless settlements along the river contribute to bacteria discharged along the river. Regulators need to consider these other types of non-WWTP discharges.

5.2.2 Inland Empire Utilities Agency

Trend in Stream Quality and Quantity	Quantity has been reduced. Quality has not.
Reasons for Change in Quality and Quantity	High water use in 07-08, flows reduced after the housing crash. Plumbing codes and landscape ordinances was main contributor to flow change. Changed source water from Colorado River to State Water Project.
Regulations Specifying Effluent/Challenges Meeting Requirements	NPDES permits, state plumbing codes, and landscape ordinances. TDS continues to rise as a long-term challenge, yet due to change in source water. Agency has to pump more groundwater to dilute it. Area is unique for having low TDS compared to surrounding agencies.
Role of effluent flow in Southern California Streams	Agency needs to discharge for WWTPs downstream. Santa Ana River Habitat Conservation plan makes efforts to protect various habitat along the Santa Ana.
WWTPs measures to protect streams before discharge	Only incentive to keep viability of the Santa Ana is their legal requirement to discharge a certain amount of water into the stream. Which is a challenge for agencies to balance this stream.

5.2.3 Riverside Public Works (RPW)

Trend in Stream Quality and Quantity	Quality of influent has been reduced. Quality has not.

Reasons for Change in Quality and Quantity	Water conservation began in 2008 after the crash and the implementation of low flow toilets. Gov. Brown mandate accelerated conservation.
Regulations Specifying Effluent/Challenges Meeting Requirements	Follow NPDES permit requirements. Always remain compliant: “It is our job!” 60% of TDS comes from source water: “Where it gets difficult.” Prime water is less available in time of drought. Have to draw from saltier sources such as Colorado River. Plants are not designed to treat TDS. Drought and water conservation is increasing the strength of TDS. Upgrade to treatment plant to support an additional 6 million gallons of treatment capacity with price tag of $200 million.
Role of effluent flow in Southern California Streams	“100% of water flowing into the Santa Ana is effluent mixed with a little groundwater. The water is pretty clean. It is Rec 1 water and you can do full body contact.”
WWTPs measures to protect streams before discharge	SAWPA focuses on collaboration efforts to protect streams.

5.2.4 Eastern Municipal Water District

Trend in Stream Quality and Quantity	Reduction in flow and decrease in water quality.
Reasons for Change in Quality and Quantity	The 2008 housing crash brought water consumption use down.The concentration of BOD organic mass is the same but the volume of water has changed, which has increased the concentration. TDS has increased and there is less water to dilute it.
Regulations Specifying Effluent/Challenges Meeting Requirements	Follow NPDES permit requirements. Did have issues meeting them in 2014. The plant relies more on imported water from State Water Project and Colorado which has higher fluctuations of TDS.
Role of effluent flow in Southern California Streams	Without the Santa Ana, there is not enough flow going to the OC. It is a water rights issue because they rely on stream flows to recharge their groundwater system. Limited coordination between plants and

	conservation groups. SAWPA is the main hub of collaboration when it comes to protecting aquatic life.
WWTPs measures to protect streams before discharge	Will have membrane filters but not yet, will continue to operate the same way for now. There is no study of aquatic life in the river as yet. Feels that is something that needs to be looked at.

5.3 Themes

Figure 5.3: Key Findings and Common Themes
Graphic developed by author

There are four themes that our analysis decided to highlight: 1) Prior Reduction of Flow pre-drought and conservation mandate, 2) Lack of understanding from state regulators of specific WWTP constraints, 3) Increase in technological investment, and 4) Balancing recycled water and stream discharge. These points illustrate a timeline of prior challenges, current dilemmas, and forward-looking initiatives as to how improve the reliability and resiliency of WWTPs.

Prior Reduction of Flow Pre 2012-2017 Drought and Conservation Mandate:

One consistent event that caused a reduction in flows amongst all treatment plants was the 2008 financial collapse. The large-scale development of homes occurring in the Inland Empire at the time was brought to halt, which also brought a significant reduction of water consumption amongst indoor residents with it (IEUA, 2018). This was also in conjunction with efforts that the state had already taken in terms of incentivizing the use of low flow toilets and other energy and water saving appliances. The trends in increasing TDS were already increasing due to prior voluntary conservation. According to RPW, “Governor Brown’s mandate accelerated conservation” which only increased the strength of TDS flowing into the system.

WWTPs did face their own unique individual situations that reduced their flow prior the drought and the 2015 mandate. For example, SBMWD faced significant decreases in influent after the Norton Air Force Base was shut down in 1994 due to the Base Realignment Closure action. According to their compliance manager, that is the first event that led to a significant reduction in flows in the plant previous to the 2008 crash. Their plant is designed to treat “33 million gallons/day and now flows are 22 million gallons per/day” (SBMWD, 2018). This shows that plants such as SBMWD have been operating below their designed capacity for years even decades. Conservation measures only make a stringent situation increasingly dire by inadvertently reducing wastewater flowing through needed to dilute TDS concentrations.

Lack of Understanding from State Regulators of Specific WWTP Constraints

This transitions us to our next theme which is the sentiment that state regulators do not take into full account the specific challenges and limitations that WWTPs may face in meeting conservation mandates. For example, the IEUA serves an area that “is unique for having relatively low levels of TDS compared to other surrounding agencies” (IEUA, 2018). The situation is inverted when it comes to EMWD who exceeded their NPDES permit requirements due to their high salinity source water. “The plant relies more on imported water from State Water Project and Colorado which has higher fluctuations of TDS” (EMWD, 2018). It is interesting to note that despite the fact that these plants are both located in the Inland Empire and their proximity is only 40 miles-their situations are drastically different. They both pull from different source waters which is correlated with their levels of TDS and their ability or inability to meet water quality standards. It is pertinent to understand how similar and/or how different the state is approaching these two agencies. We cannot not infer based on our data, yet it evident that the degree of difficulty in meeting state regulatory requirements varies among agencies-even those close to each other.

When it came to discussing the role of WWTPS in maintaining the viability of effluent streams, SBMWD states that their role only goes insofar as to ensuring that discharged water meets state quality standards. However, they do not have any control over what happens within the stream. “There is more focus on the WWTP to ensure that the streams remain clean and keep flowing, yet regulators do not take into account other discharge points such as street chemical runoff or bacteria discharge from homeless camps” (SBMWD, 2018) WWTP do not have legal jurisdictions to remove homeless settlements or regulate street runoff. However, the state does and it seems that they are placing most of the responsibility unto the plants to maintain the viability of these streams with limited resources and ever-increasing constraints.

Increase in Technological Investment

The rise in strength of TDS has only accelerated due to drought and conservation. RPW mentions that "treatment plants are not designed to treat TDS, it is only a pass through." RPW has taken the option to "upgrade the plant by increasing capacity by an additional 6 million gallons/day which will come at a price tag of $200 million." This is to ensure that the plant is able to bring the levels of TDS down to an appropriate level as its strength increases over time. The plant is always assessing 20 years ahead through its Master Plan in how the plant can remain resilient. For example, RPW gives the hypothetical that if they "need to install a desalter in 20 years," they have to implement "a program to temporarily address TDS levels while this project is under way." RPW adds that investing in cost-effective TDS treatment technologies is something that is possible in the future for them because the strength will only continue to increase. While other agencies are installing Membrane Bioreactors to adjust for the de-rating of their plants, RPW is one of the compliant plants making technology upgrades to foster future resiliency. If they are considering making technological investments, then it is deduced that other fully compliant plants will follow suit.

Balancing Recycled Water and Stream Discharge

The increase in frequency of droughts and the widening impacts of climate change have led to the reduction of fresh natural source water. The need to recycle as much water as possible is the rational conclusion, yet requirements to discharge effluent into streams is also call for protecting local ecosystems and ensuring a fresh water supply to downstream users. WWTPs face a dilemma in discharging the potential reusable water into a stream while also recycling every drop of water available for societal use. Plants have had no other option but to get creative. For example, EMWD has included recycled water into their "water portfolio and have converted parks into a zone for recycled water use."

Lower amounts of available source water have shown to create an air of desperation and anxiety for WWTPs to recycle as much water as possible. This often conflicts with other mandated priorities. IEUA expresses that their only incentive to maintain the viability of the Santa Ana is their legal requirement to discharge into the stream. This is not just an environmental issue but it is a water rights issue as "Orange County relies on the flows of the Santa Ana to recharge their groundwater system" (EMWD, 2018). SBMWD concretely synthesizes this dilemma "because water is so scarce, people are looking into how they can hold more water at their agency to recycle. It is rarer for water to be discharged into the river due to drought conditions because water is valuable."

6.0 Data Challenges

For effluent quantity-quality data, WWTP effluent flow rates usually vary throughout the year, depending on seasonal storm runoff and infiltration. Along the California coast, the lowest flow rates (or dry weather flow rates) typically occur from July through September. Therefore, the daily flow rates collected from State Water Resources Control Board (SWRCB) website and WWTPs were converted to monthly average to understand the variations. Almost all of the wastewater treatment plants measure volume of wastewater for both influent and effluent on a daily basis. However, there are sometimes data gaps due to seasonal monitoring or alterations to permits throughout 2013-2017.

The major challenge was obtaining the TDS data. During data collection, some of the treatment plants mentioned that they are not required to test for TDS. For example, one of the WWTP administrators in Santa Barbara mentioned that they discharge their treated wastewater into the ocean. Because of this, TDS is not one of the compounds they are required to analyze. Furthermore, some of the WWTPs only started to measure their salinity level after the governor adopted mandated conservation in June 2015, but for the purpose of the study we needed to include the data for flow and TDS from 2013- 2016 (before and after conversation policies went into effect) to measure the difference over the drought period. We included the treatment plants that measure at least one flow (influent and/or effluent as flow data should be relatively close to each other) and TDS data (in particular, effluent TDS). The table summarizing the availability of data is attached in the ***Appendix***.

For stream data, there is a dearth of points continuously monitored for TDS. This means that there are very few decent locations where you can run time series models for correlation. Most water districts only do occasional field grabs to monitor TDS and contaminants. For example, Los Angeles County Flood Control only does 6 TDS measurements per year, 3 after a dry event and 3 after a wet event. It was not adequate for our regression analysis. Choosing matching streamflow points was also difficult as they had to line up cleanly with plants whose effluent data is in our possession.

The main challenge in acquiring the qualitative data was being able to secure an interview time with the proper personnel. Environmental and Regulatory Compliance managers are busy plant operators that work behind the scenes and are not readily accessible to the public. Therefore, using SCSC's name upon initial contact served as a credible reference to expedite response rates. However, setting a time slot proved to be difficult due to their busy schedules or time conflicts that we as interviewers had. RPW's compliance manager did not respond until a month after our initial outreach due to a time consuming project they were involved with. Additionally, a couple of our first point of contacts for SBWMD and IEUA wanted to include other members of their department who could adequately speak on specific issues such as compliance or conservation. Our initial contact for EMWD was the Assistant General Manager of Planning and therefore, connected me to his Director of Environmental and Regulatory Compliance. On average, it took between one and two weeks after their first response to schedule an interview with the key informants.

7.0 Future Research

Future research would have us expand the model to incorporate more locations. TDS in streams is not monitored as frequently as flow. Therefore, it would be valuable to find a way to do a large scale evaluation of TDS levels. It would also be worthwhile to incorporate other important constituents such as Biochemical oxygen demand (BOD) and ammonia.

For wastewater treatment plants, future studies could include the TDS of the source water supply. Most plants utilize water from the water table directly surrounding them. However, during drought they are often forced start to incorporating water from alternate sources, such as the Colorado River. It would be a very worthwhile study to research the conditions that cause plants to adjust their water sources and the resulting impacts of these changes.

For the qualitative part of the study, future research could include interviews with environmental and conservation groups. For example, members of the Upper Santa Ana River Habitat Conservation Team could be included. Larger activist organizations such as the Sierra Club could also be included to gain their perspective on whether they deem these streams worthy of protection.

8.0 Policy Recommendations

In this region, treated wastewater makes up a significant portion of flows in the major watersheds, as well as Southern California's waterways. During drought, effluent flow plays a more important role due to decreases in precipitation and snowmelt. Therefore, it is important for us to consider how deterioration in effluent flow, particularly elevated salinity levels, can adversely impact the downstream users. There are several recommendations that can be extracted from our analysis.

1.) **More consideration of the impacts on downstream users while implementing conservation strategies.**

First, urban water suppliers, cities, municipalities need to consider the impact on downstream users while promoting conservation. Just assigning the conservation mandates to cities (4% to 36%) based on their previous year water use per-capita will not fully address this issue. The state water board needs to consider other issues, such as challenges to downstream users and impacts to wildlife. For example, how it will impact rivers such as the Santa Ana, which as our analysis has shown, is highly dependent on effluent flow. Agencies can also take more steps to promote outdoor conservation rather than indoor conservation.

2.) Treatment plants should invest in upgrading their treatment technology to reduce the concentration of salts in the wastewater.

Second, water conservation strategies along with drought can result in poorer quality water, particularly with respect to salinity. Given that conventional treatment process are not designed to treat the higher concentration of constituents, the wastewater treatment plants need to upgrade their technology. It can be costly, but our study can help to recognize the relationship between how a reduction in flow could cause increases in salinity. Our analysis can help these wastewater treatment plants better plan for such outcomes and can help them to adopt cost-effective adaptation.

3.) Streamflow augmentation projects needs to consider impact on habitats and endangered species when developing restoration projects on effluent dominated streams.

Streamflow augmentation projects in this region needs to account for the full impact on the ecosystems, including threatened and endangered species. Agencies need to make informed decisions when attempting to restore effluent-dominated streams. Planners of restoration projects often fail to consider all of the externalities and social benefits that may derive from flow augmentation with wastewater effluent. They also lack the tools and informations that can identify the value of effluent for streamflow augmentation. Our study take an initiative to inform agencies that scientists, engineers, and planners must work toward developing metrics and models that inform a decision-making process that recognizes the realities of how best to meet urban water demands while considering the impacts on aquatic habitats.

4.) Collaboration among the State, water agencies and WWTPs is essential.

We propose that the SWRCB, water agencies and wastewater treatment plants need to coordinate and collaborate more effectively in order to fully understand consequences of drought and conservation policies at the micro level not just at the macro level. The State needs to consider a holistic assessment of the agency if there any external barriers from meeting benchmark standards set upon them. Additionally, they need to identify low cost options/treatment technologies and the degree of treatment that provides the greatest benefit to our society.

5.) Standardize the Terminology

We recommend standardizing the nomenclature. The official term for these streams is “effluent dependant water body”, or EDW. However, most of the literature does not utilize this term. When reading through NPDES permits and other paperwork in the environmental bureaucracy, you mostly see effluent-dominated or ephemeral streams. There is also no set percentage of streamflow that must be effluent for it to be classified as “effluent-dependant”. Therefore, we recommend establishing concise definitions for the terminology and ensuring their appropriate usage.

6.) Increased Focus on TDS

As out data collection process revealed, TDS is one of the more neglected constituents in regards to monitoring. We recommend increasing the frequency of measurements in streams and rivers so that more accurate assessments about water quality can be made. The research also found wastewater treatment plants to be lacking in terms of TDS. TDS is considered a pass-through constituent that they do not treat. This is mainly due to the lack of effective technology which makes it uneconomical to remove salts from effluent. Therefore, we recommend more state investment into R&D for TDS controls.

9.0 Conclusion

As we conclude our project, we reflect on what we have done. This report discussed the background of recent conservation policies and some of the potential impacts to the area. We then described our data collection process. Following that, we conducted an analysis on wastewater treatment plants and effluent-dominated streams in Southern California. We then expanded our analysis with a qualitative interview study. Our next sections described our data challenges and noted possible future research topics. This led us to the final part of our project, comprised of our policy recommendations. While there are always more avenues of research to pursue, we feel that our study is an important step in a new area of research involving effluent-dominated streams. We hope our project provides awareness of the issues facing effluent-dominated streams and helps further the research in this field. This concludes our Capstone project.

10.0 References

Amin, Refat., Schwabe, Kurt., Tran, Quynh., and Jassby,David (2017, October). Investigating the role of drought and water conservation efforts on the reuse of treated municipal wastewater. Poster session presented at the Water Smart Innovations Conference, Las Vegas. Retrieve from https://ceregportal.com/wsi/documents/poster_sessions/2017/P-32.pdf

Andersen, C. B., Lewis, G. P., & Sargent, K. A. (2004). Influence of wastewater-treatment effluent on concentrations and fluxes of solutes in the Bush River, South Carolina, during extreme drought conditions. *Environmental Geosciences*, *11*(1), 28-41.

Belby, B. & Lentsch, L. & Fleury, S. (2015, May 4) IFC International. Memorandum to Upper Santa Ana River HCP Hydrology Technical Advisory Committee. Retrieved from https://static1.squarespace.com/static/53920f34e4b05366f07d971c/t/588a2a5603596e8d03aff3ac/1485449856966/SAR+HCP+baseline+hydrology+period+selection+012517.pdf

Bergamaschi, B. A., Kalve, E., Guenther, L., Mendez, G. O., & Belitz, K. (2005). *An assessment of optical properties of dissolved organic material as quantitative source indicators in the Santa Ana River Basin, Southern California*.

Center for Biological Diversity (nd) Santa ana Sucker. Action Timeline. Retrieved from https://www.biologicaldiversity.org/species/fish/Santa_Ana_sucker/

CSWRCB (2016, December 16) RIX Shutdowns. State of California. Water Resource Control Board. Retrieved from file:///D:/WWTP_Shutdowns_2014-2016_for_RIX.pdf

Escriva-Bou, A., Mitchell, D., Baerenklau, K., Hanak, E., McCann, H., Pérez-Urdiales, M., & Schwabe, K. (2017). Building Drought Resilience in California's Cities and Suburbs.

IEUA. (2014, June). Inland Empire Utilities Agency Comprehensive Annual Financial Report. Retrieved from http://www.sbcounty.gov/uploads/LAFCO/AgendaNotices/20150520/Item_9_1_3b.pdf

Inman, D., and P. Jeffrey (2006), A review of residential water conservation tool performance and influences on implementation effectiveness, Urban Water J., 3(3), 127– 143, doi:10.1080/15730620600961288.

Jenkins et al. (2009). Effects of Wastewater Discharges on Endocrine and Reproductive Function of Western Mosquito fish and Implications for the Threatened Santa Ana Sucker . *USGS*. Retrieved from https://pubs.usgs.gov/of/2009/1097/pdf/OF2009-1097.pdf.

Mitchell, D., Hanak, E., Baerenklau, K., Escriva-Bou, A., McCann, H., Pérez-Urdiales, M., & Schwabe, K. (2017). Building Drought Resilience in California's Cities and Suburbs. *Public Policy Institute of California*.

Mount, Jeffrey, Caitrin Chappelle, Brian Gray, Ellen Hanak, Richard Howitt,Jay Lund, Richard Frank, Greg Gartrell, Ted Grantham,Josué Medellín-Azuara, Peter Moyle, Barton "Buzz" Thompson, and Joshua Viers. 2016.California's Water: Managing Droughts. Public Policy Institute of California

Onnis-Hayden et al.,. (2006). Effluent Dominated Rivers . Retrieved from https://repository.library.northeastern.edu/files/neu:329755/fulltext.pdf.

Rodman, K. E., Cervania, A. A., Budig-Markin, V., Schermesser, C. F., Rogers, O. W., Martinez, J. M., ... & Folkerts, A. (2018). Coastal California Wastewater Effluent as a Resource for Seawater Desalination Brine Commingling. *Water*, *10*(3), 322.

Southern California Salinity Coalition. (2018). Retrieved from http://static1.1.sqspcdn.com/static/f/947398/27829727/1518587848670/2018+LeClaire+Presentation.pdf?token=tMYFy8PGz8lASWn7j3xcIn1LITA%3D

Steinberg, J. (2016, September 23) How the Santa Ana Sucker Preservation Effort is Being Improved. The Press-Enterprise. Retrieved from https://www.pe.com/2016/09/23/how-the-santa-ana-sucker-preservation-effort-is-being-improved/

Steinberg, J. (2016, November 16) Santa Ana River Sucker Rescue Saves Hundreds of Endangered Fish. The Sun. Retrieved from https://www.sbsun.com/2016/11/16/santa-ana-river-sucker-rescue-saves-hundreds-of-endangered-fish/

SWRCB (2018, March) California State Water Resource Control Board. Gov't Website. Retrieved from https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.shtml

SWRCB. (2013, April). Policy for Water Quality Control for Recycled Water (Recycled Water Policy). Retrieved from https://www.waterboards.ca.gov/water_issues/programs/water_recycling_policy/docs/rwp_revtoc.pdf

SWRCB RIX Shutdowns (2016, December 16) Sata of California. Retrieved from file:///D:/WWTP_Shutdowns_2014-2016_for_RIX.pdf

Tetreault GR et al., (2012, January 13). Reproductive and histopathological effects in wild fish inhabiting an effluent-dominated stream, Wascana Creek, SK, Canada. Retrieved March 14, 2018, from https://www.sciencedirect.com/science/article/pii/S0166445X1200015X

Tran, Q. K., Schwabe, K. A., & Jassby, D. (2016). Wastewater reuse for agriculture: development of a regional water reuse decision-support model (RWRM) for cost-effective irrigation sources. *Environmental science & technology*, *50*(17), 9390-9399

Tran, Q. K., Jassby, D., & Schwabe, K. A. (2017). The implications of drought and water conservation on the reuse of municipal wastewater: Recognizing impacts and identifying mitigation possibilities. *Water research*, *124*, 472-481.

Urban Water Conservation and Efficiency Potential In California. (June 2014). Issue Brief: Pacific Institute. Retrieved from https://pacinst.org/wp-content/uploads/2014/06/ca-water-urban.pdf.

US Fish and Wildlife (nd) Species Profile: Santa Ana Sucker. Environmental Conservation Online System. Retrieved from https://ecos.fws.gov/ecp0/profile/speciesProfile?spcode=E07W

U.S. Geological Survey, 2013. Santa Ana Basin, U.S. Geological Survey, San Diego, CA.

U.S. Census Bureau (2017). Quick Facts California. Available online: https://www.census.gov/quickfacts/table/PST045215/06,00&sa=D&ust=1491193250609000&usg=AFQjCNHREy8h2MAoBN6nW9TZc7u5EWOWMA (accessed on 3 April 2017).

Woodling et al. (2006, July 28). Intersex and other reproductive disruption of fish in wastewater effluent dominated Colorado streams. Retrieved March 14, 2018, from https://www.sciencedirect.com/science/article/pii/S1532045606001682

11.0 Appendix

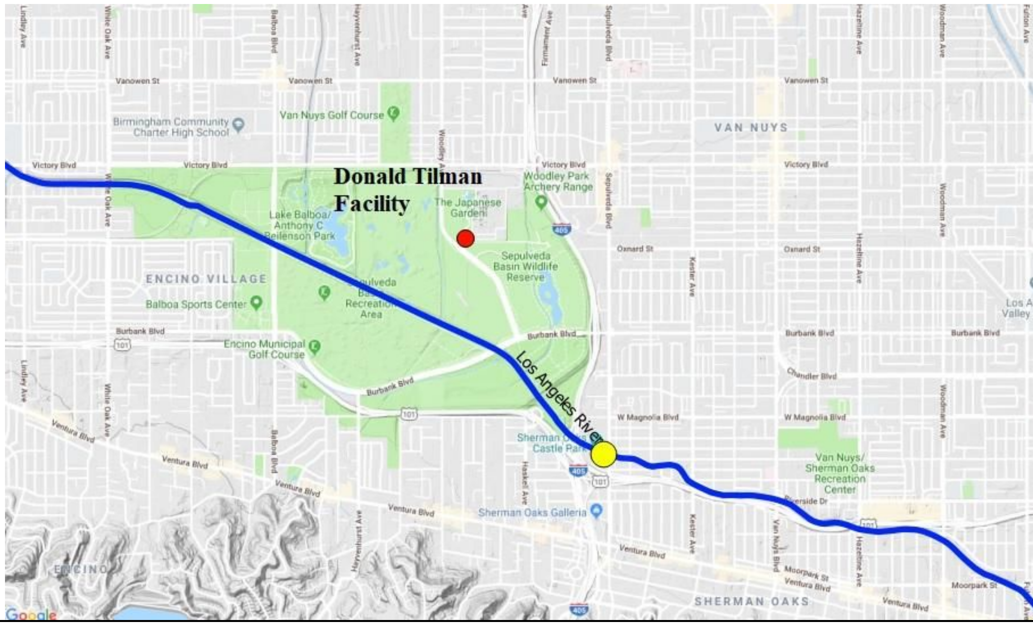

Figure 4.3.1 Los Angeles River: Donald Tillman - Developed by Authors

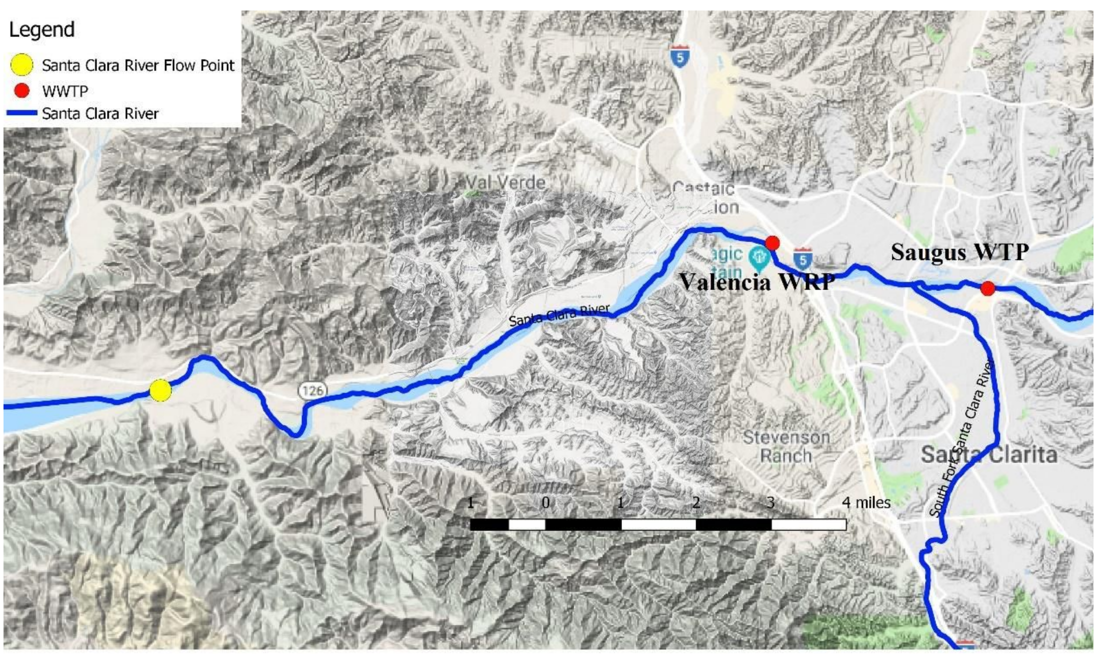

Figure 4.3.2 Santa Clara River: Saugus & Valencia - Developed by Authors

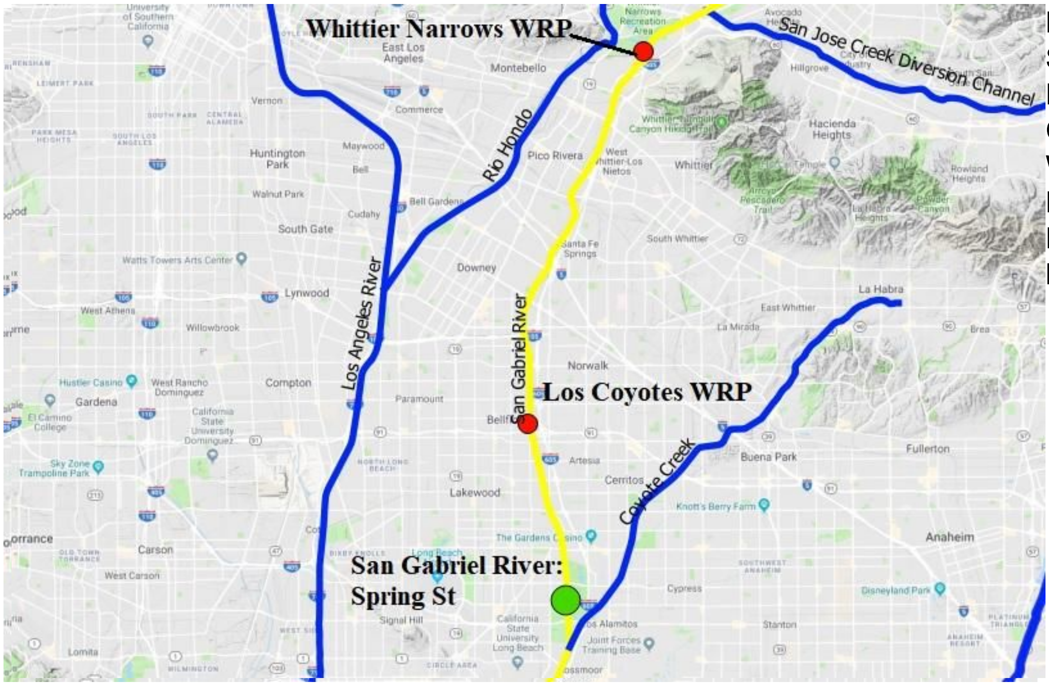

Figure 4.3.3 San Gabriel River: Los Coyotes & Whittier Narrows - Developed by Authors

DATA COLLECTION SUMMARY								
					Influent		Effluent	
Hydrologic Region	Plant	Time range	Agency	Wastewater Treatment Plants	Flow	TDS	Flow	TDS
South Coast	1	2013(Jan)-2017(July)	Riverside City	Riverside City WWRF	☑	☑	☑	☑
South Coast	2	2013 (Jan)-2017(Jun)	Western Riverside County Regiona	WRCRWA Regional WWRF	☑	☑	☑	☑
South Coast	3	2013(Jan)-2017(Apr)	Colton/San Bernardino RTT&WRA	Colton/San Bernadino STP, RIX	☑	☑	☑	☑
South Coast	4	2013(Jan)-2017(Dec)	Yucaipa Valley Water District	Henry N. Wochholz WWRF	☑		☑	☑
South Coast	5	2013(Jan)-2017(Apr)	Rialto City	Rialto WWRF	☑	☑	☑	☑
South Coast	6	2013(Jan)-2017(Apr)	Las Virgenes MWD	Tapia WRF	☑			☑
South Coast	7	2013(Jan)-2017(July)	Thousand Oaks City	Hill Canyon WWTP			☑	☑
South Coast	8	2013(Jan)-2017(May)	Los Angeles City Bureau of Sanitati	Donald C. Tillman WWRP	☑		☑	☑
South Coast	9	2013(Jan)-2017(May)	Los Angeles City Bureau of Sanitati	Los Angeles-Glendale WWRP	☑		☑	☑
South Coast	10	2013(Jan)-2017(Dec)	Joint Outfall System	Long Beach WRP	☑		☑	☑
South Coast	11	2013(Jan)-2017(Dec)	Joint Outfall System	Los Coyotes WRP	☑		☑	☑
South Coast	12	2013(Jan)-2017(Dec)	Joint Outfall System	Pomona WWTP			☑	☑
South Coast	13	2013(Jan)-2017(Dec)	Joint Outfall System	Whittier Narrows Water Reclamation Plant	☑		☑	☑
South Coast	14	2013(Jan)-2017(Dec)	Joint Outfall System	San Jose Creek East WRP	☑		☑	☑
South Coast	15	2013(Jan)-2017(Dec)	Joint Outfall System	San Jose Creek East WRP	☑		☑	☑
South Coast	16	2013(Jan)-2017(Dec)	Santa Clarita Valley SD of Los Ange	Saugus Water Reclamation Plant	☑		☑	☑
South Coast	17	2013(Jan)-2017(Dec)	Santa Clarita Valley SD of Los Ange	Valencia WRP	☑		☑	☑
South Coast	18	2013(Jan)-2017(Nov)	Eastern Municipal Water District	Moreno Valley RWRF			☑	☑
South Coast	19	2013(Jan)-2017(Nov)	Eastern Municipal Water District	Perris Valley RWRF			☑	☑
South Coast	20	2013(Jan)-2017(Nov)	Eastern Municipal Water District	San Jacinto Valley RWRF			☑	☑
South Coast	21	2013(Jan)-2017(Nov)	Eastern Municipal Water District	Temecula Valley RWRF			☑	☑
South Coast	22	2013 (Jan)-2017(Jun)	Irvine Ranch Water District	Michelson WWRF	☑	☑		☑
South Coast	23	2013(Jan)-2017(July)	Beaumont City	Beaumont WWTP no.1	☑	☑	☑	☑
South Coast	24	2013(Jan)-2016(Dec)	Simi Valley City	Simi Valley WWTP	☑		☑	☑
South Coast	25	2013(Jan)-2016(Dec)	Ventura County Special Districts	Moorpark WWTP	☑		☑	☑
South Coast	26	2013(Jan)-2017(Dec)	Encina Wastewater Authority	Encina Water Pollution Control Facility	☑	☑	☑	☑
South Coast	27	2013(Jan)-2016(Dec)	San Diego City Metropolitan Waste	Point Loma WWTP	☑	☑	☑	☑
South Coast	28	2013(Jan)-2017(May)	San Diego City Metropolitan Waste	South Bay WRP	☑	☑		
South Coast	29	2013(Jan)-2016(Dec)	Padre Dam Municipal Water Distric	Ray Stoyer WRP	☑	☑	☑	☑
South Coast	30	2013(Jan)-2016(Dec)	San Diego City Metropolitan Waste	South Bay International WTP	☑	☑		☑
South Coast	31	2013 (Jan)-2017(Jun)	San Juan Capistrano City	San Juan Capistrano GW TP			☑	☑
South Coast	32	2013 (Jan)-2017(Jun)	Coachella Valley WD	Coachella Valley WD	☑		☑	☑
South Coast	33	2013 (Jan)-2017(Jun)	Elsinore Valley Municipal Water Di	EVMWD Regional WWRF	☑	☑	☑	☑
South Coast	34	2013 (Jan)-2017(Jun)	Corona City DWP	Corona WWRF No.1	☑	☑	☑	☑
South Coast	35	2013(Jan)-2016(Dec)	Corona City DWP	Corona WWRF No.3	☑			☑
South Coast	36	2013(Jan)-2017(July)	Lee Lake/ Temescal Valley WD	Lee Lake/ Temescal Valley WD WWRF	☑			☑
South Coast	37	2013(Jan)-2017(May)	Colton City	Colton WRF	☑	☑		

Table: Data collection summary of influent and effluent flow and quality data.

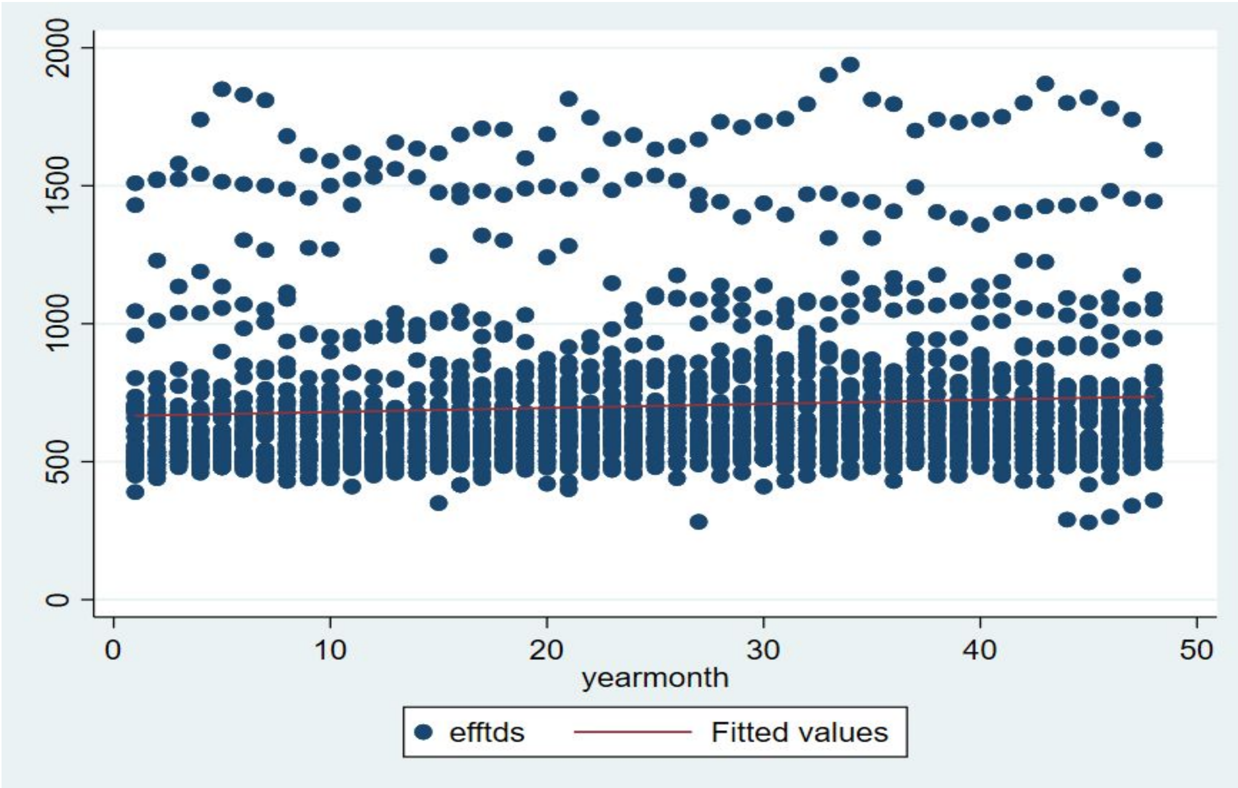

Figure: twoway scatter plot showing effluent TDS results from 2013-2016.

Operator Managers Survey Questions

1. What has been the trend in stream quality and quantity in recent years in your WWTP?

   a) What has been the pattern for both influent and effluent flow? Have they increased or decreased?
   b) Also, what has been the trends in terms of quality (TDS)? Has the quality increased or decreased?
   c) If available, can you provide me with data or tables that illustrate how influent and effluent quality and quantity have changed over time?

2. If the quality and quantity of flow has changed, why has this trend been occurring?

3. Are there any regulations or policies that specify flow or quality levels surrounding effluent in your WWTP?

   a) If not answered above: Do you think treatment plants are facing any challenges to meet NPDES permit requirements to maintain quality based on the surface water quality standards?

   b) What role, if any, did the drought or recent conservation policies mandated by Governor Brown due to the drought play in changes in influent flow and/or quality to make meeting your NPDES requirements? Were they more difficult?

   c) If they were more difficult to meet, what measures did your WWTP or others plants in general take during the drought? What is within your control?

4. What role do you think effluent plays in maintaining the viability of streams in Southern California? Especially in times drought, where effluent may be reliable source of water flow as opposed to runoff?

5. Do you think WWTP s should do more to protect the streams before discharging the effluent into them? (i.e., Greater investments in increased treatment) Why?

Figure 5.1.1: Qualitative Survey Questionnaire