

Submitted to

County of San Diego Watershed Protection Program



Detecting Groundwater in Dry Weather MS4 Discharges

County of San Diego, CA

Submitted by

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SECTION 1. OVERVIEW OF MANUAL

1.1 Introduction

Dry weather discharges into municipal separate storm sewer systems (MS4) can occur due to a variety of sources and may contribute or mobilize pollutants such as bacteria and nutrients to receiving waters. These discharges may be attributed to one or more of the following sources: sewage (e.g., overflows, exfiltration from sanitary sewers, illicit connections), industrial wastewater illicit discharges, liquid waste (e.g., oil, paint), recycled water (e.g., distribution system leaks, landscape/agricultural irrigation, water features), potable water (e.g., distribution system leaks, wash water, landscape/agricultural irrigation, draining of swimming pools), and natural waters (e.g., groundwater, spring water). The MS4 National Pollutant Discharge Elimination System (NPDES) permit (Order No. R9-2013-0001) (SDRWQCB, 2015) requires permittees to eliminate most dry weather MS4 discharges (i.e., illicit discharges). To comply with the NPDES Permit and Waste Discharge Requirements for Discharges from the MS4s Draining the Watersheds within the San Diego Region (MS4 Permit) (NPDES No. CAS109266) (SDRWQCB, 2015), the County of San Diego (County) implements an illicit discharge detection and elimination (IDDE) program to identify and abate anthropogenic discharges including sewage and liquid waste. Recycled (reclaimed) water and potable water are also considered illicit discharges and must be eliminated as well. However, groundwater seepage is a permitted discharge and does not require management action.

Groundwater can contribute to dry weather flow in the MS4 when the water table rises above the level of storm drains and enters through cracks/joints or where the MS4 intercepts seeps and springs. Groundwater and spring water may also enter the MS4 by surface flow from upstream areas. Groundwater flow may vary seasonally due to fluctuations in water table elevations and precipitation. Dry weather flows from potable water and groundwater are relatively clean and do not generally contribute a significant load of pollutants to receiving waters. The MS4 Permit specifies that naturally occurring groundwater seepage via a storm drain is an allowable non-stormwater discharge (Section I.A.1.e.2.e). However, discharges caused by anthropogenic sources are required to be eliminated through the County's IDDE program. Thus, differentiation of groundwater MS4 discharges from anthropogenic discharges (e.g., recycled water and potable water) is critical to MS4 agencies.

This manual presents an approach for distinguishing groundwater discharges from other anthropogenic sources including potable and recycled water. Other sources that may contribute to dry weather MS4 discharges such as sanitary sewage, industrial water and liquid waste, are not addressed herein, as these sources are being addressed through the County's current IDDE and pollutant source tracking programs.

1.2 Area of Interest

This manual was developed to be applicable to County unincorporated areas within water district service areas¹ (under the San Diego County Water Authority). This area is referred to herein as the “area of interest” and is shown in Figure 1.

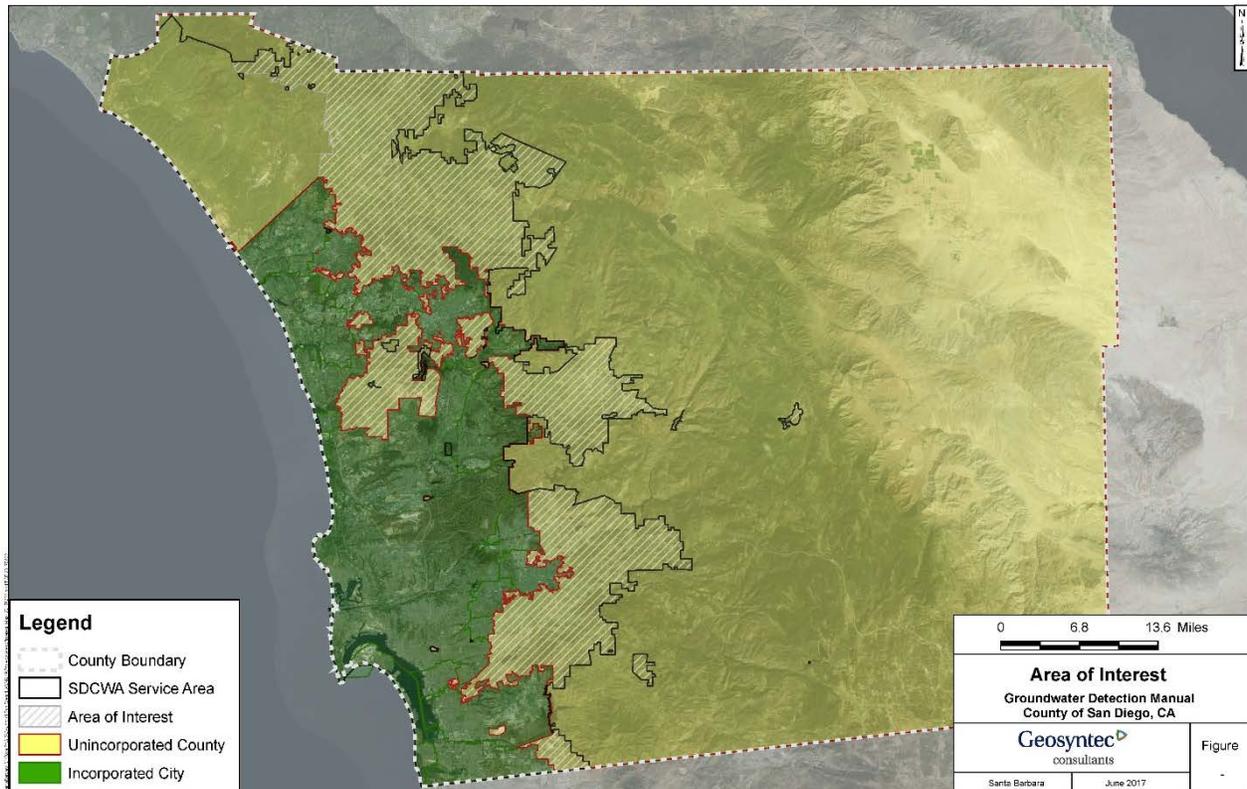


Figure 1. Area of Interest Map

1.3 Potential Sources of Dry Weather Discharge

1.3.1 Potable Water

The San Diego County Water Authority (SDCWA) provides water to 24 agencies in the County, serving approximately 90 percent of the County’s population. This includes six cities, five water districts, three irrigation districts, eight municipal districts, one public utility district, and one military base. SDCWA has been purchasing water from the Metropolitan Water District of Southern California (MWD) since joining MWD in 1946. MWD imports water from the Colorado

¹ Excluding Marine Corps Base Camp Pendleton.

River (through the Colorado River Aqueduct) and from Northern California Rivers through the State Water Project. Based on data from 2012 through 2016, the County receives an approximate average of 17 percent of total water supply from the State Water Project and 68 percent from the Colorado River, representing a total of approximately 85 percent of the County’s water supply from SCDWA (purchased from MWD). The remaining 15 percent is primarily acquired from local supplies including groundwater and lakes/reservoirs. The Claude Lewis Carlsbad Desalination Plant, which has been operating since December 2015 and utilizes water from the Pacific Ocean, also has an agreement to supply water to the SDCWA. According to projections from SDCWA, seawater desalination is expected to be eight percent of the County’s water supply by 2020.

SDCWA receives both treated and untreated water from MWD. Water is treated at the Lake Skinner Treatment Plant in Riverside County (MWD) or the Twin Oaks Valley Water Treatment Plant in San Marcos (SDCWA). Untreated water received by MWD may also be treated by one of the other agencies that own and operate treatment plants within the County. Therefore, potable drinking water across the County may be treated by MWD, the SDCWA, or one of the aforementioned local agencies. The water agencies within the area of interest are shown in Figure 2.

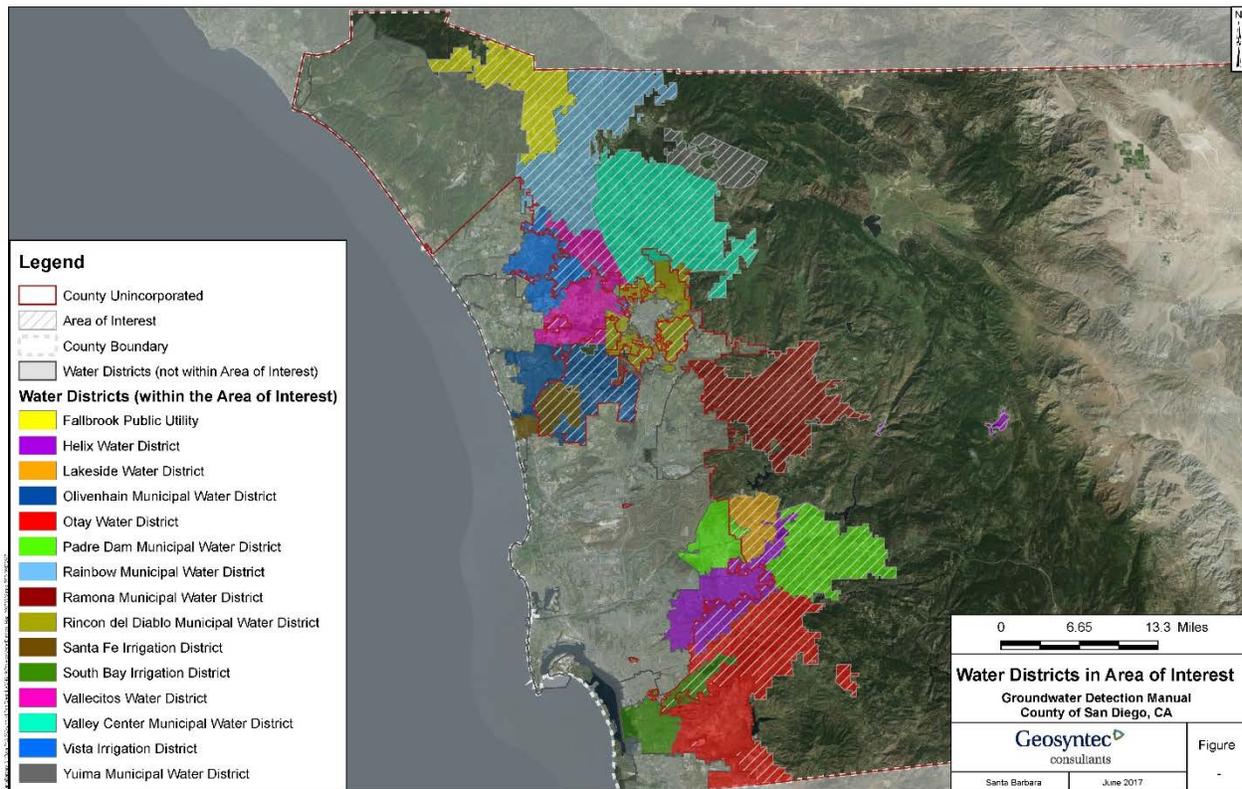


Figure 2. Water Districts within the Area of Interest

Potable drinking water may enter the MS4 through leaks and losses in the drinking water distribution system. Average drinking water system losses for water districts in the San Diego region² were approximately five percent, with a range of approximately two to 14 percent³, according to the Center for Sustainable Energy (Taylor, 2016). This water is generally free from harmful contaminants, but it is still important to distinguish so that leaks in the distribution system may be repaired and discharges may be prevented. Another potentially significant source of potable water in the MS4 is from over-irrigation and misdirected or broken sprinklers. This includes runoff from watering of lawns, gardens, parks, and other vegetated areas that flows into storm drain inlets. Although potable water used for irrigation is generally clean, flows can mobilize pollutants that have built up on the ground surface such as pet waste and pesticides/fertilizers (Urban Water Resources Research Council, 2014). Typical dry weather runoff volumes from residential areas (predominately from over-irrigation but can also include other sources such as wash water, pool draining, etc.) based on various sources are listed below and range from 2,000 to 16,000 cubic feet per acre per year (cu ft/acre/yr):

- 8,760 to 11,700 cu ft/acre/yr (Robinson, T.H., 2005)
- 12,600 to 16,000 cu ft/acre/yr (Geosyntec Consultants, 2011)
- 9,270 to 15,600 cu ft/acre/yr (CH:CDM, 2006)
- 1,980 to 6,300 cu ft/acre/yr (Municipal Water District of Orange County, 2004)

Potable water may also be a source of dry weather MS4 discharges when used as wash water. Wash waters may include washing of vehicles in residential areas, window washing, power washing of equipment and buildings, sidewalk cleaning, dumpster wash downs, and commercial car washes (Urban Water Resources Research Council, 2014). These wash water sources may enter the MS4 through surface flow that enters storm drain inlets.

In this manual, tap water, wash waters, and irrigation water (from potable water sources) will be referred to together as potable water. However, portions of the manual may also address tap water (drinking water directly from the drinking water system), wash waters, and irrigation water independently, when needed to address specific sources.

1.3.2 Recycled Water

According to SDCWA, approximately 30,000 acre-feet of recycled water is used within SDCWA's service area annually, and this number is expected to increase in the coming years (projected to

² Includes self-reported data in the 2010 Urban Water Management Plans for retail water districts in the San Diego region that produce annual urban water management plans.

³ The approximate maximum loss rate reported was for the City of San Diego. The maximum loss rate in drinking water systems within the area of interest was approximately 10%.

provide seven percent of the water supply by 2020). Recycled water consists of municipal wastewater that has been treated and disinfected to provide a non-potable water source. Recycled water can be used to fill lakes/ponds and for irrigation of public parks, campgrounds, golf courses, freeway medians, community greenbelts, and athletic fields. Other applications of recycled water also include cooling water for power plants/refineries, industrial process waters, toilet flushing, or construction activities. Although most applications of recycled water are for non-potable water demands, it can also be used for indirect potable purposes such as recharging groundwater aquifers (for augmentation of water supply or to prevent salt water intrusion) or augmenting surface water reservoirs.

Permits are required from the California Regional Water Quality Control Board (Regional Board) for water recycling operations, and recycled water must not exceed ground and surface water quality objectives defined in the Water Quality Control Plan for the San Diego Basin (SDRWQCB, 2016). The California Department of Public Health (DPH) established statewide effluent treatment standards for recycled water in Title 22 of the California Administrative Code. These standards are based on the potential for human contact and vary for each type of general use.

Utilizing recycled water for certain applications is a beneficial use of water supply, but it can also contribute to dry weather flows in the MS4 through over-irrigation of landscaped areas, runoff from construction or industrial areas, draining of fountains or other decorative water features that use recycled water, or leaks in the distribution system. Regulations specify that recycled water should not leave the site where it is used, and the County of San Diego Department of Environmental Health (DEH) and water purveyors conduct coverage test site inspections in order to prevent over-irrigation of recycled water. Therefore, dry weather discharge of recycled water should be minimal but still considered a potential source.

1.3.3 Groundwater

Aquifers within the area of interest are shown in Figure 3. Groundwater basins are approximately represented by the alluvial areas in Figure 3. Outside of the main alluvial aquifers, groundwater is predominately in fractured crystalline bedrock and semi-consolidated sedimentary deposits, so groundwater use in these areas is only adequate for lower-yielding domestic water supply wells. There are only three SDCWA water districts that obtain 30 percent or greater of their water supply from local sources (i.e., groundwater and surface water/reservoirs) (County of San Diego, 2017)⁴. However, there are 14 water districts that serve small County unincorporated areas and are dependent on groundwater supplies (i.e., do not receive imported water from SDCWA).

⁴ These include Sweetwater Authority/South Bay Irrigation District (30%), Vista Irrigation District (30%), and Yuima Municipal Water District (58%).

Additionally, there are many groundwater-dependent properties that are served by private wells onsite or a small community water system.

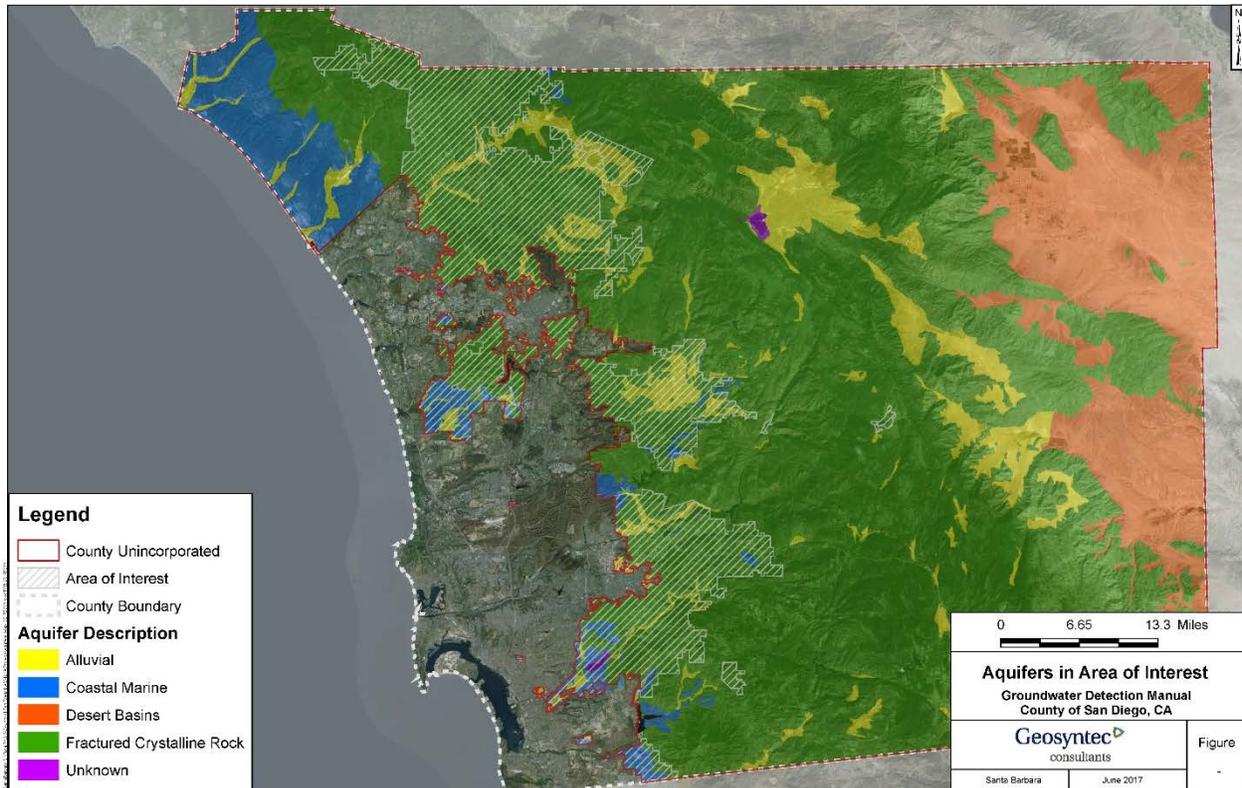


Figure 3. Aquifers in the Area of Interest

Groundwater can enter the MS4 when the local water table rises above the MS4 and enters through cracks/joints in the storm drains, or where open channels intercept seeps/springs (Center for Watershed Protection and Pitt, 2004). Groundwater and spring water may also enter the MS4 by surface flow from upstream areas. Groundwater flow may vary seasonally due to fluctuations in water table levels and precipitation.

1.4 Local Data Sources

Various data sources were investigated to characterize area-specific water quality within the area of interest. Data are used to determine expected levels of certain parameters for the potential sources evaluated in this manual. Details regarding the investigation into these data sources is presented in the following subsections.

1.4.1 Potable Water

Water districts are required to publish annual water quality reports, also known as Consumer Confidence Reports. These reports inform the public where their drinking water comes from and provide a summary of water quality, including how it compares to state and federal standards. For most parameters, a range of measured values (in a calendar year) is presented (minimum and maximum), in addition to a calculated average value. These reported values for the parameters recommended to be sampled herein, for each water district within the area of interest, are included in Appendix A. In general, with the exception of fluoride (because of the variability throughout the area of interest), service area-weighted values of the relevant parameters (from the most recent available water quality report) were calculated for use in this manual (i.e., a weighted average was calculated based on the acreage of the service area for each water district within the County unincorporated area).

Some water districts within the area of interest have multiple sources for their drinking water supply and/or multiple treatment facilities or methods. Annual water quality reports typically present water quality data separately for each source/treatment system, since it can vary significantly. If information was available regarding the approximate portion of the district's total water supply attributed to each source or treatment facility, a weighted average was calculated for the relevant water quality parameters (to determine approximate expected values for the entire water district). If this information was not readily available, it was assumed that equal proportions could be attributed to each source/treatment system⁵.

1.4.2 Recycled Water

Information from several water reclamation facilities (WRFs) was used to aid in characterizing water quality of recycled water. These facilities treat wastewater for use as recycled water. For example, the Woods Valley Ranch WRF treats wastewater for use as irrigation on the Woods Valley Ranch Golf Course. Water quality data from the following sources were used to characterize recycled water:

- Woods Valley Ranch WRF (Valley Center Municipal Water District, 2015)

⁵ If a water district provided a portion of their water supply from the Carlsbad Desalination Plant, and no other information was provided regarding the portion treated at the desalination plant, it was assumed that seven percent of the given district's total water supply came from the Carlsbad Desalination Plant, which reflects the approximate percentage of San Diego County's total water supply treated by the desalination plant. The remaining 93 percent was assumed to be from the other source/treatment system(s) included in the water quality report.

- Carlsbad WRF⁶ (CRWQCB San Diego Region, 2016)
- Meadowlark WRP and Hale Avenue Resource Recovery Facility⁶ (CRWQCB, 2012)

1.4.3 Groundwater Data

The Groundwater Ambient Monitoring and Assessment (GAMA) Program was established by the State Water Resources Control Board (State Board) in 2000 to serve as a comprehensive groundwater quality monitoring program. It was later expanded through Assembly Bill 599 (Groundwater Quality Monitoring Act of 2001) to integrate existing monitoring programs and implement new program elements in order to monitor groundwater quality in basins that combined account for 95 percent of California's groundwater use. The GeoTracker GAMA groundwater information system presents groundwater data from a variety of sources. For use herein, groundwater data for San Diego County was downloaded from the following sources⁷:

- Department of Drinking Water (DDW)
- Department of Pesticide Regulation (DPR)
- Department of Water Resources (DWR)
- Domestic Well Project (Water Board GAMA)
- Lawrence Livermore National Laboratory (LLNL)
- U.S. Geological Survey (USGS)
- USGS National Water Information System (USGS NWIS)

The resulting dataset contained data throughout the County, ranging from September 1925 through November 2016. In order to utilize an adequate amount of data that represent a variety of climate conditions but also closely represent current conditions, it was decided to use a period of record (POR) of approximately 25 years. Therefore, data was filtered to include results from January 1, 1992 to present. The dataset was then filtered for wells located within the area of interest⁸. Because the resulting dataset contained many results, summary statistics were generally determined using the 10th percentile, 90th percentile, and median value to represent the low, high, and typical expected concentration of a given parameter. The data contained many high outliers, which skewed

⁶ Not within the area of interest.

⁷ Data was also available for Water Board groundwater monitoring from cleanup sites (EDF). However, this data was not used herein because the data were likely significantly different from other portions of the County.

⁸ It should be noted that well locations provided in the GAMA dataset represent approximate locations, estimated to be within half a mile of the actual well location.

the average concentrations reported, and thus the median was used. The locations of GAMA wells from GAMA GeoTracker are shown in Figure 4.

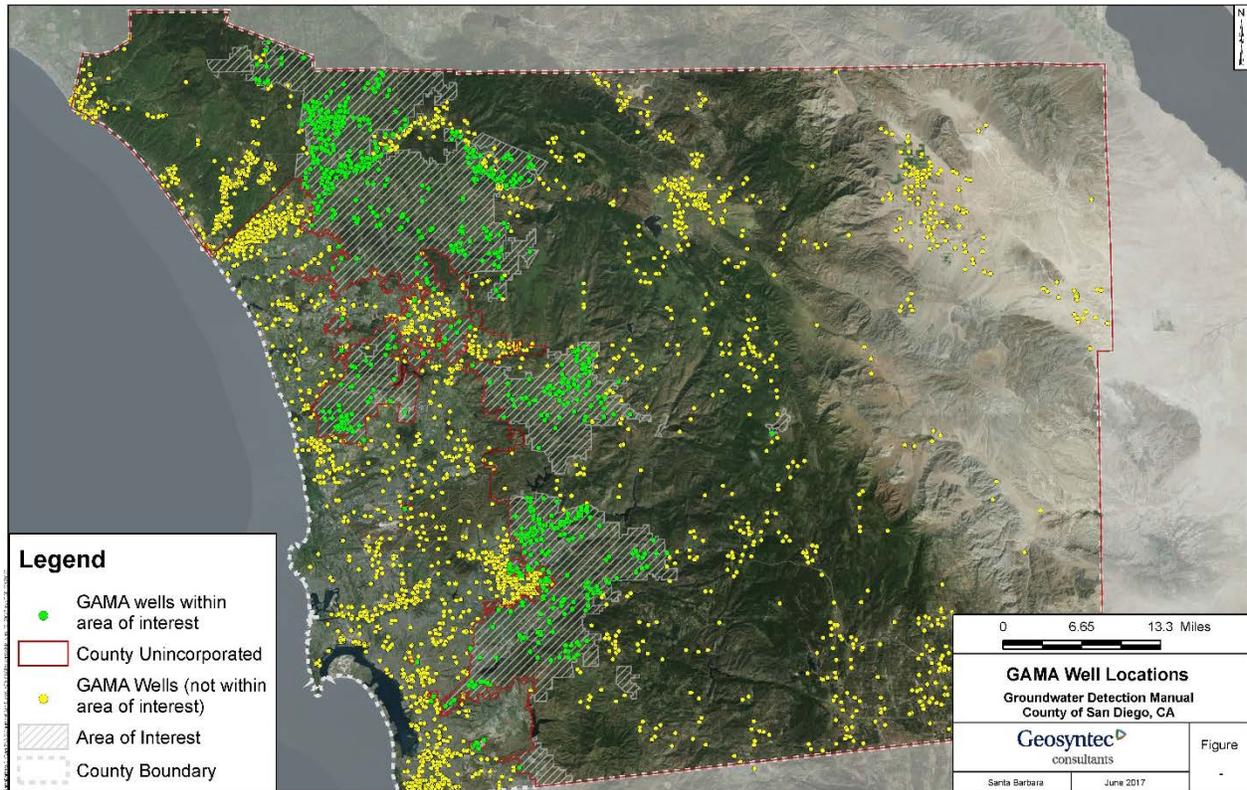


Figure 4. GAMA Well Locations

SECTION 2. APPROACH

This section describes a recommended approach to distinguish dry weather MS4 discharges caused by groundwater from anthropogenic sources such as potable and recycled water. This recommended methodology uses a tiered approach of analysis methods to provide the information needed to identify the source of MS4 discharges. In general, the approach starts with low cost indicator monitoring and transitions to more expensive analyses if initial results are inconclusive or do not provide enough information to identify the predominant source of flow. This approach is outlined in the following general descriptions of the steps to be executed and illustrated in Figure 5 and Figure 6. Detailed explanations of each step and relevant data are included in the subsequent sections (Section 3 for Tier 1 analyses and Section 4 for Tier 2 analyses).

- 1) Determine the potential sources of the dry weather discharge based on an above-ground visual assessment of area-specific conditions (i.e., surrounding land uses/activities, nearby use of recycled water, etc.). This step aids in determining which analyses will be most informative using the outlined approach. If potential sources are unable to be determined based on area-specific conditions, it should be assumed that all potential sources may be applicable. All potential sources for an observed activity or land use should be considered. For example, agricultural runoff could be from potable water, groundwater, or recycled water. The potential sources covered by this manual include the following⁹:
 - a. Potable water (tap water, irrigation water, and/or wash water)
 - b. Groundwater
 - c. Recycled water
- 2) Proceed to the tiered approach outlined below. If the first tier is not conclusive (i.e., the source of discharge could not be determined), proceed to the subsequent tier. It is important to select the parameters for monitoring based on the potential sources identified in Step 1, as described in each section. Each parameter contains information regarding which potential sources it is applicable to. Alternatively, all of Tier 1 (Tier 1a through 1c) can be executed simultaneously; the breakdown of Tier 1 into three tiers was meant to provide low cost options initially, if desired.

⁹ Other sources such as sewage, industrial discharges, etc. should be ruled out using conventional IDDE methodologies.

Tier 1: Indicator Monitoring and Ion Analysis

Tier 1a: Sample the discharge and perform analyses using conventional parameters. Compare the results to expected concentrations from each potential source of discharge. The expected ranges for all Tier 1a parameters are shown in Table 2 through Table 7. The supplemental kmz file(s) may be used in Google Earth to aid in identifying the appropriate expected concentrations based on the location of the discharge¹⁰ (to be discussed further in Section 3.1). If the measured concentration is within the range of expected values for a potential source, and the expected range does not overlap with the range for another potential source (or the overlap in ranges is very minimal¹¹), it can be assumed that at least a portion of the discharge can be attributed to the particular source. In order to increase confidence in results, it is recommended to perform this analysis for all Tier 1a parameters that are applicable after determining the potential sources for the particular discharge (see list below).

If all parameters analyzed for Tier 1a provide conclusive results (i.e., the measured value of a certain parameter falls within the expected range for a potential source and the range does not overlap with the range of another potential source), then it may be concluded that the given source is the primary source of discharge and analysis may cease. If one or all of the parameters analyzed provide inconclusive results (i.e., the measured value of a certain parameter does not fall within the expected range for a potential source or the overlap in expected ranges is too significant), then Tier 1a is inconclusive and the next step should be to proceed to Tier 1b. Tier 1a is outlined in detail in Section 3.1. Step 1 included determining the potential sources of the discharge based on area-specific conditions surrounding the discharge. The parameters listed below should only be analyzed if they are applicable to the identified potential sources. If all potential sources are identified for a given discharge, or area-specific information does not aid in narrowing down the potential sources, analyze the discharge for all parameters.

¹⁰ To use the kmz files, download Google Earth and double-click on the kmz file name to load them into Google Earth. The kmz files contain a layer for each parameter recommended for indicator monitoring (in addition to other supplemental files such as the MS4 infrastructure), and all layers will initially be visible. To investigate the expected ranges for the different sources for a given parameter, turn “off” all other parameters by un-checking the checkbox next to the layer name. Once the parameter in question is the only layer checked, click on the location of the discharge in the map interface, and the expected range of values for that parameter, for the various sources, will appear on the screen. Turn layers on and off to investigate different parameters, as information for the top layer that is turned on will always appear.

¹¹ If there is slight overlap in the expected ranges from multiple sources, comparison of the measured result to the reported “typical” value from each source may aid in determining which source the discharge most closely reflects.

- i. Fluoride
 - Applicable to potable water (and recycled water) and groundwater
 - Most effective in detecting the presence of tap water
- ii. Chlorine (total residual)
 - Applicable to potable water/recycled water and groundwater
 - Most effective in detecting the presence of potable water or reclaimed water but not effective in concluding the presence of groundwater
- iii. Nitrate
 - Applicable to potable water, groundwater, and recycled water
 - Most effective in detecting the presence of reclaimed water or groundwater (in certain areas only)
- iv. Boron
 - Applicable to wash water (subset of potable water), tap water (subset of potable water), groundwater, and recycled water
 - Most effective in detecting the presence of wash water or recycled water
- v. Detergents – surfactants
 - Applicable to wash water (subset of potable water), tap water (subset of potable water), and groundwater
 - Most effective in detecting the presence of wash water
- vi. Total Dissolved Solids (TDS)
 - Applicable to potable water, groundwater, and recycled water
 - Most effective in detecting the presence of reclaimed water or groundwater (in certain areas only)

Tier 1b: Sample the discharge and perform analyses using trihalomethanes. As outlined in Tier 1a, compare the results to expected ranges from the various sources and make decisions accordingly. The expected ranges for trihalomethanes are shown in Table 8. The supplemental kmz file(s) may also be used in Google Earth to aid in Tier 1b. This tier is outlined in Section 3.2. If this tier is not conclusive, proceed to Tier 1c. The parameters to be sampled include:

- i. Trihalomethanes (THMs)
 - Applicable to potable water and groundwater
 - Most effective in detecting the presence of tap water

Tier 1c: Sample the discharge and perform an ion analysis. Develop Piper diagrams first. If points plotted on the diagrams are in close proximity to each other (i.e., the results from the discharge are in close proximity to an expected value from one of the potential sources), it can be assumed that this is the primary source of discharge. If further confirmation is

desired or results are inconclusive, Stiff diagrams should then be developed and visual observation used to determine which potential source the discharge is most similar to. Some local data from the potential sources that could be used for comparison are included herein. The remainder of data needed to characterize the baseline representation from each source should be collected and analyzed. This tier is outlined in Section 3.3. If this tier is not conclusive, proceed to Tier 2.

Tier 2: Isotope Analysis

Tier 2: Sample the discharge and perform isotope analysis. Compare the results to the expected range of concentrations from each potential source (as described in Tier 1). For this approach to be effective, samples need to be collected and analyzed from each potential source of discharge to setup an accurate baseline representation of sources (representing all areas that are of interest spatially). It will also need to be confirmed that differences among the various sources are significant and reproducible before moving forward. This tier is outlined in Section 4.1.

If it is determined that groundwater is a source of the dry weather discharge, further investigation may be needed to determine the source of groundwater (i.e., groundwater intrusion or sump pump/dewatering discharge). Closed-circuit television (CCTV) surveys may be utilized, and records of permissible discharge may also be investigated to identify sump pump or dewatering discharges. If the outlined approach concludes that potable water or reclaimed water is the source of the discharge, the illicit discharge should be identified and eliminated. This may require further investigation of the network such as visual observation, CCTV, dye testing, etc.

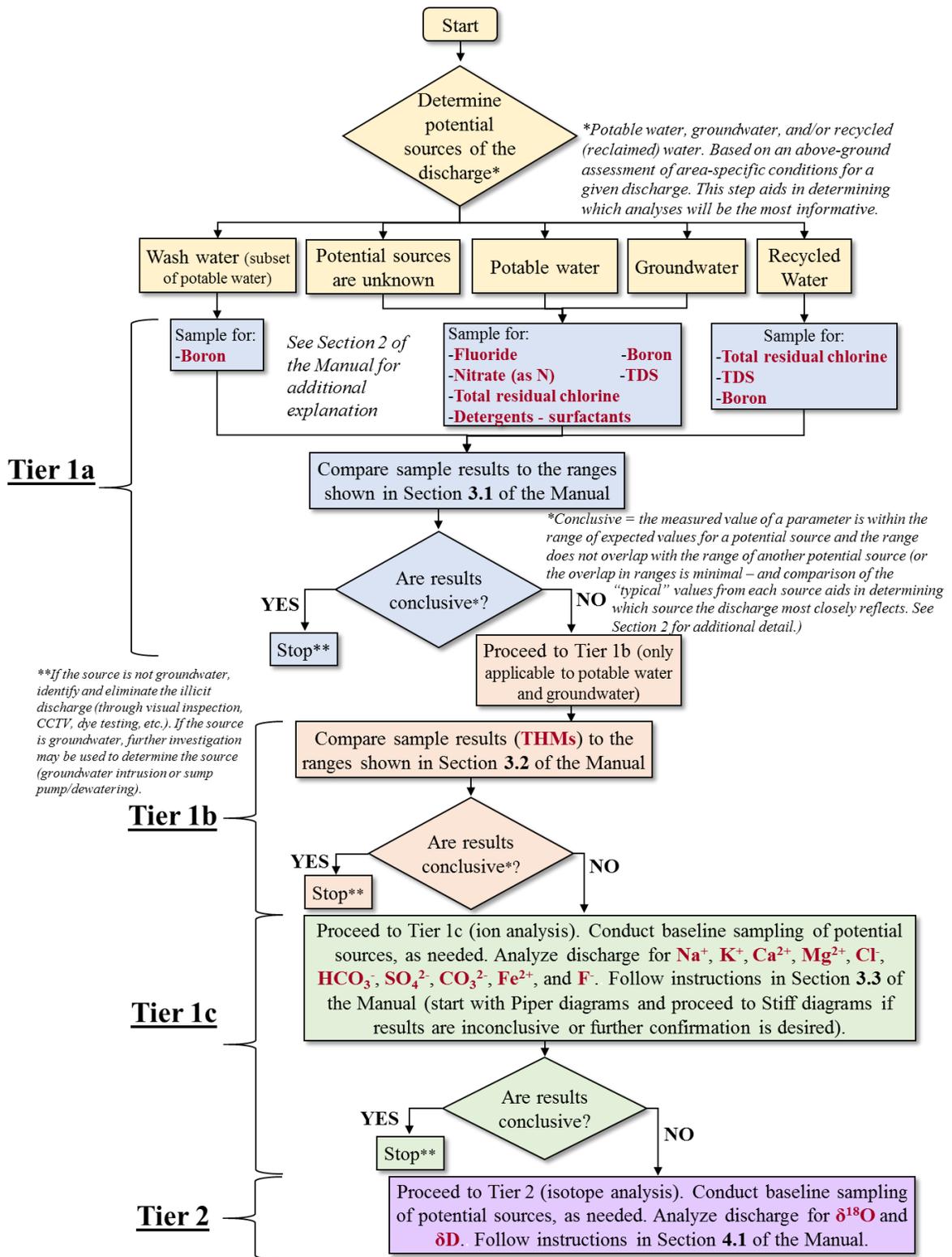


Figure 5. Overall Tiered Approach (part 1)

Potential Source	Fluoride Concentration (mg/L)		
	Low	High	Typical
Tap Water			
Entire Water Supply is Fluoridated	0.56	0.94	0.72
Portion of the Water Supply is Fluoridated			
Lakeside Water District	0.59	0.92	0.78
Yuima Municipal Water District	0.36	0.58	0.44
Vallecitos Water District	0.37	0.60	0.49
Water Supply is Not Fluoridated			
Santa Fe Irrigation District	0.23	0.30	0.28
South Bay Irrigation District (Sweetwater Authority)	ND	0.60	0.30
Groundwater	0.16	0.54	0.28

Source	Total Residual Chlorine Concentration (mg/L)		
	Low	High	Typical
Tap water	1.1	2.8	2.2
Reclaimed water	0	5	
Groundwater	Close to 0		

Source	Nitrate (as N) Concentration (mg/L)		
	Low	High	Typical
Tap water	ND	0.46	0.11
Groundwater			
Alluvial aquifer and urban area	6.1	14	12
Alluvial aquifer and non-urban area	2.7	8.7	6.4
Non-alluvial aquifer	0.88	14 ¹	2.5
Reclaimed water	4.3	6.8	5.8

Source	Boron Concentration (mg/L)		
	Low	High	Typical
Potable Water			
Tap water	0.11	0.15	0.13
Wash water	> 0.35		
Groundwater	0	0.23	0.10
Reclaimed Water	0.31	0.66	0.38

Source	MBAS Concentration (mg/L)		
	Low	High	Typical
Potable Water			
Tap water	Close to 0		
Wash water	> 0.25		
Groundwater	Close to 0		

Source	Total Dissolved Solids (mg/L)		
	Low	High	Typical
Tap water	560	650	630
Reclaimed water	770	1,200	1,000
Groundwater			
Alluvial aquifer and urban	810	1,800	1,300
Alluvial aquifer and non-urban	290	1,200	830
Non-alluvial aquifer and urban	490	1,400	710
Non-alluvial aquifer and non-urban	350	1,000	500

Source	THMs Concentration (µg/L)		
	Low	High	Typical
Tap water	14	35	29
Groundwater	0	4.6	0.50

Source	Units	Tap Water			Groundwater			Reclaimed Water		
		Low	High	Typical	Low	High	Typical	Low	High	Typical
Sodium	mg/L	88	103	99	42	217	71	Data not available		
Potassium	mg/L	4.3	4.8	4.7	2.1	7.4	4.6	Data not available		
Calcium	mg/L	62	73	71	42	159	80	42	94	70
Magnesium	mg/L	22	26	25	13	86	29	13	38	27
Iron	µg/L	Data not available			0	342	20	20	1,000	166
Chloride	mg/L	95	106	103	51	328	117	189	342	245
Bicarbonate	mg/L	Data not available			129	371	180	Data not available		
Sulfate	mg/L	184	214	217	58	346	131	147	288	195
Carbonate	-	Data not available			Data not available			Data not available		
Fluoride	mg/L	See Table 2								

**Additional baseline data should be collected*

Source	δ ¹⁸ O (‰, VSMOW)			δD (‰, VSMOW)		
	Low	High	Typical	Low	High	Typical
Potable water				-9.5		-78
Colorado River	-17.07	-14.61	-15.86	-125.20	-113.00	-118.79
Groundwater	-9.7	-5.4	-7.1	-72.7	-34.7	-46.5

**Additional baseline data should be collected*

Figure 6. Overall Tiered Approach (part 2)

SECTION 3. TIER 1 INDICATOR MONITORING AND ION ANALYSIS

3.1 Tier 1a Indicator Monitoring

3.1.1 Fluoride

Fluoride is commonly added to drinking water to provide protection against tooth decay, significantly aiding in dental health. California Assembly Bill 733 authorized the California Department of Health Services to require water suppliers with 10,000 or more service connections or customers to fluoridate their water supply. These regulations were added to the California Code of Regulations in April 1998. The MWD, which supplies drinking water to a significant portion of San Diego County, began adding fluoride to drinking water in October 2007¹².

According to SDCWA, naturally occurring fluoride concentrations in MWD's water sources typically range from 0.1 to 0.4 parts per million (ppm) (equivalent to mg/L). The optimal fluoride concentration for dental improvement is between 0.7 and 0.8 ppm. The State Board requires fluoride levels to be maintained within the range of 0.7 and 1.3 mg/L. A large portion of the County receives water from SDCWA, who purchases water from MWD. Water treated by SDCWA or MWD has fluoride added, so any agency that relies on SDCWA for its supply receives fluoridated water.

In addition, other water agencies either receive untreated water from SDCWA/MWD and treat locally or utilize local water supplies (and treat locally). The majority of these agencies (that do not rely 100% on treated water supply from SDCWA/MWD) fluoridate their water supply, based on California Assembly Bill 733 or the desire to aid in protection of public health. There are several water districts that provide drinking water from multiple different sources and/or treatment plants, such that a portion of drinking water is treated with fluoride and a portion does not have additional fluoride added for dental health (and only contains natural levels). Table 1 and Figure 7 show the water districts within the area of interest and a general description of their fluoridation practices.

¹² MWD was exempt from the law requiring water suppliers with 10,000 or more service connections or customers to fluoridate their water supply.

Table 1. Water Districts Fluoridation Information

Fluoridation Practice	Water District (in Area of Interest)
Entire Water Supply is Fluoridated	Fallbrook Public Utility District
	Helix Water District
	Ramona Municipal Water District
	Rainbow Municipal Water District
	Rincon Del Diablo Municipal Water District
	Valley Center Municipal Water District
	Padre Dam Municipal Water District
	Otay Water District
	Olivenhain Municipal Water District
	Vista Irrigation District
Portion of the Water Supply is Fluoridated	Lakeside Water District
	Yuima Municipal Water District
	Vallecitos Water District
Water Supply is Not Fluoridated	Santa Fe Irrigation District
	South Bay Irrigation District (member of Sweetwater Authority)

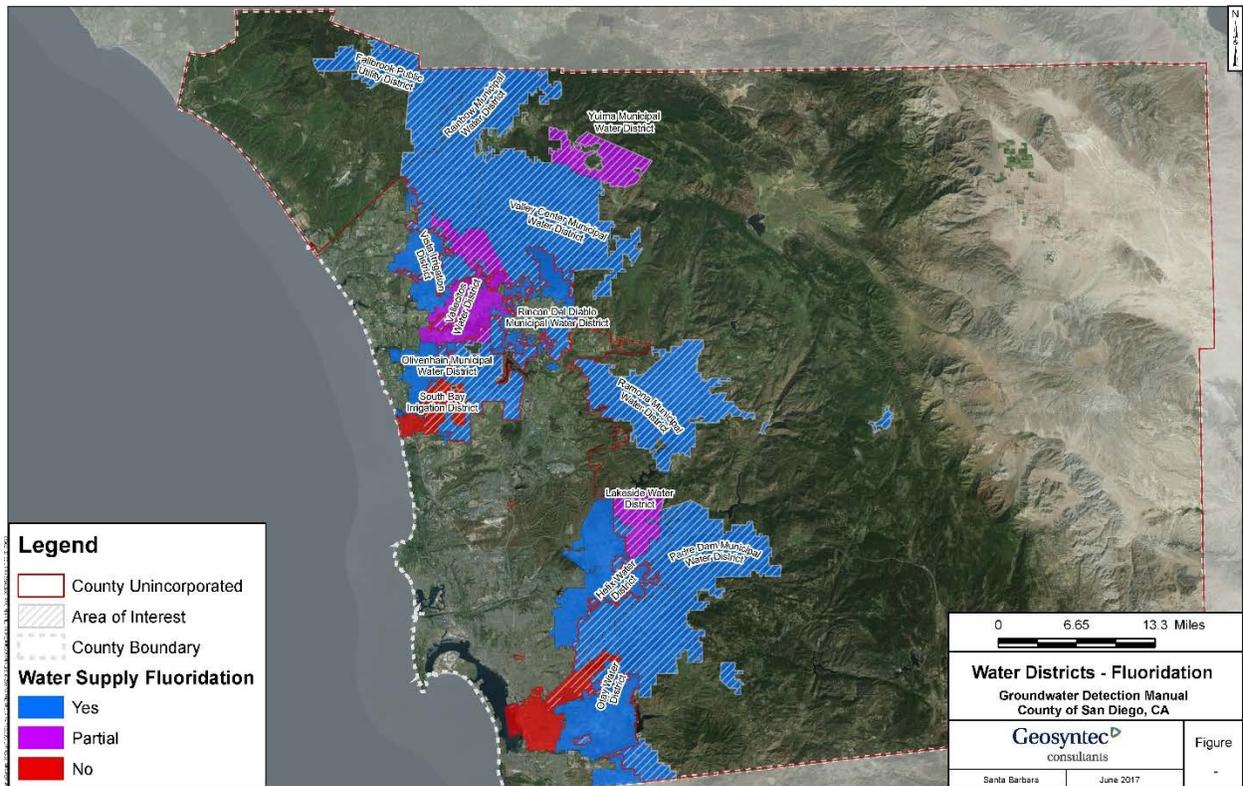


Figure 7. Water Districts Fluoridation Map

For water districts that fluoridate the entire water supply, measured fluoride concentrations are compared to a range of expected values that are representative of all districts with a fully fluoridated drinking water supply¹³. For water districts that either provide a blended (i.e., partially fluoridated) water supply or a water supply with no additional fluoride added for dental health, measured fluoride concentrations are compared to a range of expected values specific to the water district. Local sources used in these areas (i.e., groundwater wells) have some levels of natural fluoride due to erosion of natural deposits. Therefore, some fluoride is expected to be measured even if the tap water does not contain any added fluoride, although at lower levels than fluoridated water.

Table 2 shows the expected ranges of fluoride concentrations throughout the area of interest for both potable water and groundwater. Although it is not shown in Table 2, levels of fluoride in recycled water are expected to be similar to tap water. The measured concentration of fluoride from the discharge should be compared to the appropriate range for tap water based on location of the discharge (i.e., which water district the discharge is located within). If the measured concentration falls within a range specified in Table 2, it can be assumed that at least a portion of the discharge can be attributed to the given source. Fluoride will likely not be effective in distinguishing groundwater from tap water within water districts that do not fluoridate the water supply.

¹³ Calculated by area-weighting (based on service area within County unincorporated area) fluoride concentrations reported in the most recent annual water quality reports of all districts with fully fluoridated water supplies.

Table 2. Expected Fluoride Concentrations in Drinking Water and Groundwater

Potential Source	Fluoride Concentration (mg/L)		
	Low	High	Typical
Tap Water^{1, 2}			
Entire Water Supply is Fluoridated ³	0.56	0.94	0.72
Portion of the Water Supply is Fluoridated			
<i>Lakeside Water District⁴</i>	0.59	0.92	0.78
<i>Yuima Municipal Water District⁵</i>	0.36	0.58	0.44
<i>Vallecitos Water District⁶</i>	0.37	0.60	0.49
Water Supply is Not Fluoridated			
<i>Santa Fe Irrigation District⁷</i>	0.23	0.30	0.28
<i>South Bay Irrigation District (Sweetwater Authority)⁸</i>	ND	0.60	0.30
Groundwater⁹	0.16	0.54	0.28

¹ The data shown are based on the measured minimum, maximum, and average for the low, high, and typical concentrations shown, respectively.

² Values for reclaimed water are not shown herein. However, they are expected to be similar to tap water.

³ See Table 1 for list of water districts included in this category.

⁴ Estimated that approximately 17% of the total water supply is not fluoridated.

⁵ Estimated that approximately 54% of the total water supply is not fluoridated.

⁶ Estimated that approximately 44% of the total water supply is not fluoridated.

⁷ Water supply is from Lake Hodges and is treated at the R.E. Badger Filtration Plant.

⁸ Water supply is from Sweetwater River, deep freshwater wells in National City, and brackish wells in Chula Vista, and treated at Reynolds Groundwater Desalination facility or Robert A. Perdue WTP. Freshwater wells are disinfected with chloramine.

⁹ The data shown are based on the measured 10th percentile, 90th percentile, and median (from 290 sampled results in the GAMA database) for the low, high, and typical concentrations shown, respectively.

3.1.2 Total Residual Chlorine

Chlorination of public drinking water supplies is widespread (except where private wells provide the water supply). However, chlorine is very reactive and volatile and even moderate organic materials can cause chlorine levels to decrease dramatically after short periods of time. In an example study by Pitt (2001), sheetflow samples from irrigated lawns had undetectable chlorine concentrations, even after concentrations in tap water were measured at 1.5 mg/L and sheetflow traveled very short flow paths of 10 feet. Pitt (2001) also tested clean potable water in Birmingham, Alabama and found that total available chlorine decreased by 25 percent in 24 hours during an aerated bench-scale test. Therefore, chlorine is often not recommended as an indicator parameter as it is not considered reliable to eliminate the possibility of potable water due to its instability. However, in the case where high levels of residual chlorine are detected, it may help identify potable water (Center for Watershed Protection and Pitt, 2004).

California Title 22 regulates recycled water and requires that wastewater be treated to a tertiary level for use as recycled water. The disinfection process is required to meet either a chlorine residual that provides 450 milligram-minutes per liter under a minimal contact time of 90 minutes (which corresponds to a residual of 5 mg/L or less) or any process that achieves 5-log virus removal. Chlorine disinfection is one method that may be used for disinfection, or another method, such as ultraviolet disinfection at a certain dose, can also achieve the 5-log virus removal requirement. Because UV disinfection can be used as a standalone disinfection process for recycled wastewater without any addition of chlorine, total residual chlorine may or may not be present in recycled water.

Because drinking water is treated with chlorine, high levels of total residual chlorine may indicate that a dry weather discharge is potable water. Reclaimed water may be disinfected with chlorine, or alternatively UV disinfection may be used, so total residual chlorine in reclaimed water could potentially range from very low to higher than typical levels in potable water. Therefore, high levels of total residual chlorine would be able to indicate the presence of either potable water or reclaimed water. However, chlorine is very volatile and may easily decrease to undetectable levels. As a result, it is very important to note that a very low or undetectable level of total residual chlorine is not conclusive in making any determinations. Table 3 show the expected levels of total residual chlorine for potable water, reclaimed water, and groundwater.

Table 3. Expected Total Residual Chlorine Concentrations

Source	Total Residual Chlorine Concentration (mg/L)		
	Low	High	Typical
Tap water ¹	1.1	2.8	2.2
Reclaimed water	0 ²	5 ³	
Groundwater	Close to 0 ⁴		

¹ The data shown are based on the measured minimum, maximum, and average for the low, high, and typical concentrations shown, respectively.

² If UV disinfection is used to treat wastewater for use as recycled water, without any addition of chlorine.

³ If chlorine disinfection is used to treat wastewater for use as recycled water.

⁴ No data available for total residual chlorine in the GAMA database.

3.1.3 Nitrate

Nitrate may aid in differentiating potable water, groundwater, and reclaimed water. Nitrate-impacted groundwater is common in the following areas of the County: small parcels¹⁴ and areas

¹⁴ Clustered residences located on parcels less than four acres in size and on individual septic systems could result in localized nitrate impacts.

of shallow groundwater influenced by septic systems, agricultural areas, or feed lots where nitrate is used in agricultural applications. Some areas known to have elevated nitrate include Alpine along Route 8, Cameron Corners area of Campo, Crest, Escondido, Jamul, Morena Village, Rainbow, Ramona, San Marcos, and Valley Center (County of San Diego, 2017).

Nitrate data are reported for many of the annual drinking water quality reports produced by the water districts, which shows that nitrate levels in tap water are very low. In addition, GAMA groundwater data contains results for nitrate. However, it was found that groundwater near urban land uses, and within alluvial aquifers, was significantly higher (based on a t-test at the 95% confidence level) than groundwater within non-urban, alluvial areas and groundwater not within an alluvial aquifer. Therefore, it is necessary to distinguish these areas when sampling discharges for nitrate. Alluvial vs. non-alluvial and urban areas within the area of interest are shown in Figure 8.

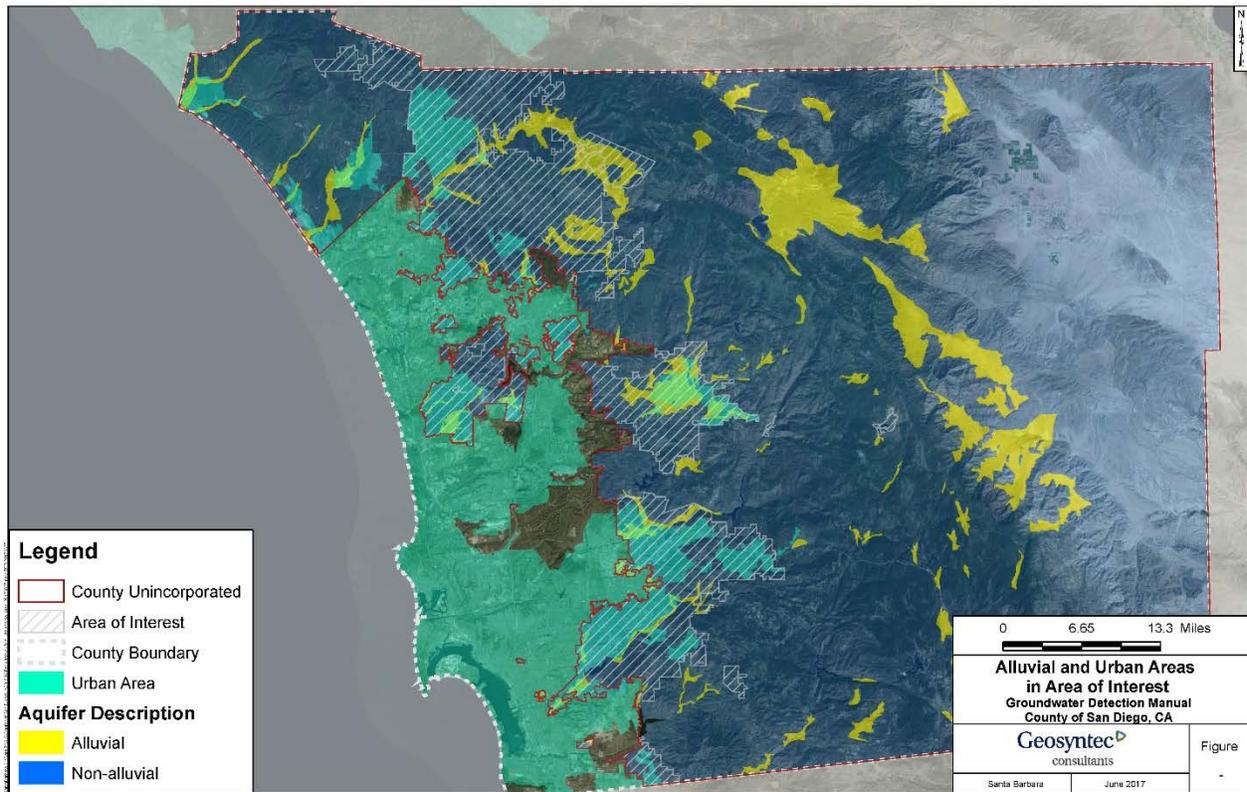


Figure 8. Alluvial and Urban Areas within the Area of Interest

Recycled water (or reclaimed water) may also be distinguished by sampling for nitrate. A study of the Upper Malibu Creek Watershed in Ventura County, CA investigated sources of dry weather flow that were contributing high levels of fecal pollution (Sercu et al., 2014). Samples of reclaimed water compared to samples at receiving water locations showed that reclaimed water had consistently high concentrations of inorganic nitrogen (nitrate + nitrite as N). In general, drinking

water has very low concentrations of nitrate, groundwater in non-alluvial areas have low/moderate levels of nitrate, groundwater in alluvial and non-urban areas, in addition to reclaimed water, have moderate levels of nitrate, and groundwater in alluvial and urban areas exhibits higher levels of nitrate. Therefore, nitrate may be useful in distinguishing between tap water, groundwater (in alluvial and urban areas, in addition to non-alluvial areas), and reclaimed water. However, if the area in question is within an alluvial aquifer and within a non-urban area, nitrate will likely not be a good differentiator between groundwater and reclaimed water (but still able to differentiate between tap water and groundwater). Expected nitrate concentrations are shown in Table 4.

Table 4. Expected Nitrate (as N) Concentrations

Source	Nitrate (as N) Concentration (mg/L)		
	Low	High	Typical
Tap water ¹	ND	0.46	0.11
Groundwater ²			
Alluvial aquifer <u>and</u> urban area ⁴	6.1	14	12
Alluvial aquifer <u>and</u> non-urban area ⁵	2.7	8.7	6.4
Non-alluvial aquifer ⁶	0.88	14 ³	2.5
Reclaimed water ⁷	4.3	6.8	5.8

¹ Non-detect (ND) results reported in annual water quality reports from water districts were assumed to be 0 mg/L (when calculating area-weighted concentrations based on water district service area within the area of interest), which matches how NDs were reported in the GAMA dataset.

² The data shown are based on the measured 10th percentile, 90th percentile, and median for the low, high, and typical concentrations shown, respectively.

³ It should be noted that this data were significantly positively skewed. The 75th percentile value was 6.2 mg/L, which may be used as the high value, but with a lower level of confidence in the conclusion.

⁴ Based on 679 sampled results in the GAMA database.

⁵ Based on 321 sampled results in the GAMA database.

⁶ Based on 1,310 sampled results in the GAMA database.

⁷ Data reflects nitrate + nitrite (as N). It was assumed that nitrite is very small compared to nitrate, such that these values can be compared to nitrate (as N) reported for tap water and groundwater (where nitrite [as N] data was not available).

3.1.4 Boron

Boron may be useful in distinguishing wash water or recycled water from other potable water (i.e., tap water) or groundwater because boron is typically high in wash water and recycled water and low in other potable water sources and groundwater. Values of boron that exceed 0.35 mg/L generally indicate that a discharge contains wash water or sewage. Additionally, recycled water generally has high levels of boron, similar to wash water. Table 5 shows expected levels of boron from tap water, wash water, groundwater, and recycled water. Boron will likely not be as useful in differentiating tap water from groundwater or reclaimed water from wash water.

Table 5. Expected Boron Concentrations

Source	Boron Concentration (mg/L)		
	Low	High	Typical
Potable Water			
Tap water ¹	0.11	0.15	0.13
Wash water ²	> 0.35		
Groundwater³	0	0.23	0.10
Reclaimed Water⁴	0.31	0.66	0.38

¹ The data shown are based on the measured minimum, maximum, and average for the low, high, and typical concentrations shown, respectively.

² Based on Center for Watershed Protection and Pitt, 2004.

³ The data shown are based on the measured 10th percentile, 90th percentile, and median (based on 263 sample results in the GAMA database) for the high, low, and typical concentrations shown, respectively.

⁴ The low and typical concentrations are based on the minimum and average, respectively, of the yearly average concentrations at the Carlsbad WRF (2010-2015), Woods Valley Ranch WRF (2014), Meadowlark WRF, and the Hale Ave. Resource Recovery Facility. It should be noted that because average annual concentrations were used to determine the low value, the actual low concentration may be lower than reported. The high concentration is based on the maximum of the yearly maximum concentrations at the Carlsbad WRF from 2010-2015 and the yearly average concentrations at the Woods Valley Ranch WRF (2014), Meadowlark WRF, and the Hale Ave. Resource Recovery Facility. Because the maximum of these values was actually the annual average at the Woods Valley Ranch WRF (in 2014), the actual maximum concentration may be higher than reported.

3.1.5 Detergents – surfactants

Detergents (surfactants) can be used to identify wash water from tap water or groundwater. Values of surfactants (as methylene blue active substances [MBAS]) that exceed 0.25 mg/L generally indicate that a discharge contains wash water or sewage (Center for Watershed Protection and Pitt, 2004).

Typical tap water is expected to have very low levels of MBAS, less than 0.01 mg/L (Pitt, 2001). MBAS in groundwater is also expected to be very low as well (close to 0 mg/L). Local data (for both tap water and groundwater) was not available for MBAS. Expected levels of MBAS are shown in Table 6.

Table 6. Expected Detergents-surfactants Concentrations

Source	MBAS Concentration (mg/L)		
	Low	High	Typical
Potable Water			
Tap water	Close to 0		
Wash water ¹	> 0.25		
Groundwater	Close to 0		

¹ Based on (Center for Watershed Protection and Pitt, 2004).

3.1.6 Total Dissolved Solids (TDS)

TDS is identified as one of the most commonly elevated parameters in groundwater within the County. TDS originate naturally due to the dissolution of rocks and minerals and can also occur as a result of septic systems, agricultural irrigation, and urban stormwater runoff (County of San Diego, 2017). Elevated TDS levels within the County are found in coastal sedimentary formations and deeper connate water in desert basins¹⁵ (County of San Diego, 2010). A study by USGS (2004) in the San Diego drainages hydrogeologic province showed that TDS concentrations were highest in shallow wells and modern (less than 50 years) groundwater. This indicates that there has been a greater loading of dissolved solids recently, likely caused by anthropogenic activities such as agricultural or urban irrigation and changes in land use that result in changing soil chemistry. The 2004 USGS study reported that high relative concentrations of TDS were most commonly detected in the alluvial basins and also were found to be highest in the coastal areas¹⁶.

Based on information above regarding TDS in groundwater within the County of San Diego, GAMA groundwater data was investigated spatially based on aquifer type, agricultural use, and urban activity. It was found that TDS levels were higher in alluvial aquifers and in urban areas compared to non-alluvial aquifers and non-urban areas (with statistical significance based on a t-test at the 95% confidence level). While there were statistically significant differences in the two aforementioned classifications compared to both alluvial/non-urban areas and non-alluvial urban areas, the difference in TDS levels between alluvial/non-urban areas and non-alluvial urban areas was not found to be statistically significant.

TDS is also reported in annual drinking water quality reports and have a smaller range of measured values compared to groundwater. Regarding TDS in recycled water, residential use of water typically adds 200 to 300 mg/L of TDS to wastewater¹⁷. The SDCWA reported average effluent TDS concentrations at several water recycling treatment facilities. The concentrations ranged from 768 to 1,200 mg/L, with an average of approximately 1,030 mg/L (SDCWA, 2011). It should be noted that TDS concentrations greater than 1,000 mg/L limits the use of recycled water, especially for agricultural purposes and industrial reuse.

As shown in Table 7, some expected ranges in TDS for various sources and spatial descriptions overlap. This is because TDS in groundwater is highly variable, even when differentiated spatially based on aquifer type and land use. Therefore, caution should be used if measured values fall

¹⁵ Neither coastal formations nor deeper fossil water in desert basins are predominant in the area of interest.

¹⁶ However, studies have indicated that seawater intrusion is not a significant factor contributing to TDS levels (USGS, 2004).

¹⁷ Self-regenerating water softeners can add even more TDS (if their use is allowed).

within overlapping expected ranges and TDS may not be useful for distinguishing the source of discharge in these cases. To distinguish between alluvial and non-alluvial aquifers and urban and non-urban areas within the area of interest, refer to Figure 8.

Table 7. Expected TDS Concentrations

Source	Total Dissolved Solids (mg/L)		
	Low	High	Typical
Tap water ¹	560	650	630
Reclaimed water ²	770	1,200	1,000
Groundwater³			
Alluvial aquifer and urban ⁴	810	1,800	1,300
Alluvial aquifer and non-urban ⁵	290	1,200	830
Non-alluvial aquifer and urban ⁶	490	1,400	710
Non-alluvial aquifer and non-urban ⁷	350	1,000	500

¹ The data shown are based on the measured minimum, maximum, and average for the low, high, and typical concentrations shown, respectively.

² SDCWA, 2011

³ The data shown are based on the measured 10th percentile, 90th percentile, and median results in the GAMA database for the high, low, and typical concentrations shown, respectively.

⁴ Based on 204 sample results in the GAMA database.

⁵ Based on 68 sample results in the GAMA database. The differences in expected value with this category and "non-alluvial aquifers and urban" are not statistically significant (and are therefore shown in gray).

⁶ Based on 42 sample results in the GAMA database. The differences in expected value with this category and "Alluvial aquifers and non-urban" are not statistically significant (and are therefore shown in gray).

⁷ Based on 209 sample results in the GAMA database.

3.2 Tier 1b Indicator Monitoring

3.2.1 Trihalomethanes (THMs)

THMs are disinfection by-products that form when chlorine and/or bromine reacts with certain natural organics (such as decaying leaves and vegetation) present in many water sources. Because THMs are commonly present after drinking water is treated with chlorine (as a disinfection by-product), they may be used to identify potable water. Low levels of THMs in groundwater are reported to be correlated with urban areas and alluvial areas (due to infiltration of treated water through landscape irrigation or leakage from distribution systems) (USGS, 2004). However, statistically significant differences in data were not found when examining data in alluvial vs. non-alluvial and urban vs. non-urban areas.

THM levels in groundwater are significantly smaller compared to potable water (in addition to recycled water, since it also undergoes treatment) such that it may be used to differentiate these sources. Expected levels of THMs in tap water and groundwater are shown in Table 8.

Table 8. Expected THMs Concentrations

Source	THMs Concentration (µg/L)		
	Low	High	Typical
Tap water ¹	14	35	29
Groundwater ²	0	4.6	0.50

¹ The data shown are based on the measured minimum, maximum, and average for the low, high, and typical concentrations shown, respectively.

² The data shown are based on the measured 10th percentile, 90th percentile, and median (based on 213 samples) for the low, high, and typical concentrations shown, respectively.

3.3 Tier 1c Ion Analysis

The ionic composition of water can also be used to identify its sources. Groundwater chemistry varies spatially depending on local geology. Similarly, recycled, wash water, and other potable water will contain different combinations of major ions based on treatment and use. Plotting the concentrations of major ions, for example, Piper and Stiff diagrams, can be used to facilitate source analysis (Zapozec, 1972). Table 9 summarizes the constituents needed for ion analyses for the Piper and Stiff diagram methods described below. It should be noted that many different cations and anions could be used in the Stiff diagram, as long as the constituents remain consistent for the samples being compared. Table 9 shows the conventional constituents used.

Table 9. Required Constituents for Ion Analysis

Cations	Piper Diagram ¹	Stiff Diagram	Anions	Piper Diagram ¹	Stiff Diagram
Sodium Na ⁺	X	X	Chloride Cl ⁻	X	X
Potassium K ⁺	X	X	Bicarbonate HCO ₃ ⁻	X	X
Calcium Ca ²⁺	X	X	Sulfate SO ₄ ²⁻	X	X
Magnesium Mg ²⁺	X	X	Carbonate CO ₃ ²⁻	X	X (optional) ²
Iron Fe ²⁺		X (optional)	Fluoride F ⁻	X (optional) ³	

¹TDS can optionally be plotted on the Piper diagram as well. It may be plotted as rings (of varying sizes according to TDS concentration) around each point in the upper diamond portion of the plot and represents the combined total of all of the cations and anions for that sample.

²Carbonate can optionally be combined with bicarbonate and the total concentration used as the vertex point.

³F⁻ can optionally be combined with Cl⁻ in the lower right ternary plot.

To perform an ion analysis, the following steps should be executed:

- 1) Step 1 of the overall approach (prior to Tier 1 analyses) includes identifying the potential sources (i.e., potable water, groundwater, or reclaimed water) of the discharge based on area-specific conditions. Similar to the previously discussed methods, identifying the potential sources for the given discharge aids in narrowing down the additional information needed to execute the method. If potential sources are unable to be determined based on area-specific conditions, it should be assumed that all potential sources may be applicable.

Table 9 shows the constituents needed for an ion analysis. Additional samples from each of the potential sources should be collected in order to establish a robust baseline dataset for each source. Local data characterizing tap water and groundwater were available for the majority of constituents listed in Table 9, and data were available for reclaimed water for some constituents. For the remainder of constituents without available data, additional samples should be collected and analyzed to develop the baseline dataset used for comparison. Local data for tap water, groundwater, and reclaimed water are shown in Table 10.

- 2) Based on available information, Piper diagrams and/or Stiff diagrams should be developed in order to determine the source of discharge, as described in Section 3.3.1 and 3.3.2, respectively. It is recommended to first develop Piper diagrams, as they are able to plot many discharge and potential source samples together to easily visualize groupings. If further confirmation of results is desired or if results are inconclusive, Stiff diagrams may also be developed. It should be noted that Piper and Stiff diagrams are similar, but Stiff diagrams also incorporate iron and carbonate, which may aid in differentiating between the sources if Piper diagrams are inconclusive.

Table 10. Local Data for Ion Analyses

Source	Units	Tap Water ¹			Groundwater ²			Reclaimed Water		
		Low	High	Typical	Low	High	Typical	Low	High	Typical
Sodium ³	mg/L	88	103	99	42	217	71	Data not available		
Potassium ⁴	mg/L	4.3	4.8	4.7	2.1	7.4	4.6	Data not available		
Calcium ^{5, 11}	mg/L	62	73	71	42	159	80	42	94	70
Magnesium ^{6, 11}	mg/L	22	26	25	13	86	29	13	38	27
Iron ^{7, 12}	µg/L	Data not available			0	342	20	20	1,000	166
Chloride ^{8, 12}	mg/L	95	106	103	51	328	117	189	342	245
Bicarbonate ⁹	mg/L	Data not available			129	371	180	Data not available		
Sulfate ^{10, 12}	mg/L	184	214	217	58	346	131	147	288	195
Carbonate	-	Data not available			Data not available			Data not available		
Fluoride	mg/L	See Table 2								

¹ The data shown are based on the measured minimum, maximum, and average values reported in annual drinking water quality reports (area-weighted based on water district service area in County unincorporated area) for the low, high, and typical concentrations shown, respectively.

² The data shown are based on the measured 10th percentile, 90th percentile, and median for the low, high, and typical concentrations shown, respectively.

³ Based on 303 sampled results in the GAMA database (for groundwater).

⁴ Based on 258 sampled results in the GAMA database (for groundwater).

⁵ Based on 304 sampled results in the GAMA database (for groundwater).

⁶ Based on 301 sampled results in the GAMA database (for groundwater).

⁷ Based on 512 sampled results in the GAMA database (for groundwater).

⁸ Based on 339 sampled results in the GAMA database (for groundwater).

⁹ Based on 284 sampled results in the GAMA database (for groundwater).

¹⁰ Based on 299 sampled results in the GAMA database (for groundwater).

¹¹ The low and typical concentrations for reclaimed water are based on the minimum and average, respectively, of the yearly average concentrations at the Carlsbad WRF (2010-2015). It should be noted that because average annual concentrations were used to determine the low value, the actual low concentration may be lower than reported. The high concentration is based on the maximum of the yearly maximum concentrations at the Carlsbad WRF (2010-2015).

¹² The low and typical concentrations for reclaimed water are based on the minimum and average, respectively, of the yearly average concentrations at the Carlsbad WRF (2010-2015), Woods Valley Ranch WRF (2014), Meadowlark WRP, and the Hale Ave. Resource Recovery Facility. It should be noted that because average annual concentrations were used to determine the low value, the actual low concentration may be lower than reported. The high concentration is based on the maximum of the yearly maximum concentrations at the Carlsbad WRF from 2010-2015.

3.3.1 Piper Diagram

Piper diagrams may be used to display the ionic composition of water samples, allowing for a visual comparison that can help determine the water source. Piper diagrams graphically show the chemistry of a water sample, with the percent composition of major cations and anions on separate axes. Calcium, magnesium, and sodium plus potassium make up the apexes of the cation plot, while sulfate, chloride, and carbonate plus bicarbonate make up the anion plot (Figure 9). These two ternary plots are then projected onto a diamond, which is a matrix transformation of the anions

and cations, reducing each sample result to a single point. Regions of the diagram represent different hydrochemical facies and many samples can be plotted on the same Piper diagram for comparison. Samples that group more closely together are more likely to be from a similar source.

To utilize this method, representative samples from local sources would be collected, analyzed, and plotted on a Piper diagram. Samples from dry weather MS4 discharges would then be analyzed and plotted on the same Piper diagram. The most likely source of the discharge could then be determined visually based on what sources the discharge samples grouped most closely to on the Piper diagram. If points plotted on the diagrams are in close proximity to each other (i.e., the results from the discharge are in close proximity to an expected value from one of the potential sources), it can be assumed that this is the primary source of discharge. An example Piper diagram is shown in Figure 9.

All three portions of the Piper diagram should be considered when comparing the discharge to the potential sources. For instance, the lower left anion ternary plot in Figure 9 is able to distinguish between the Ca-HCO₃ and Ca, Mg-HCO₃ samples, but not as effective for distinguishing the Ca, Mg-HCO₃, CO₄ samples. If there is no distinction between each of the possible sources based on the ion combinations used for the Piper Diagram, the next step would be to create Stiff Diagrams, which also utilize iron and carbonate.

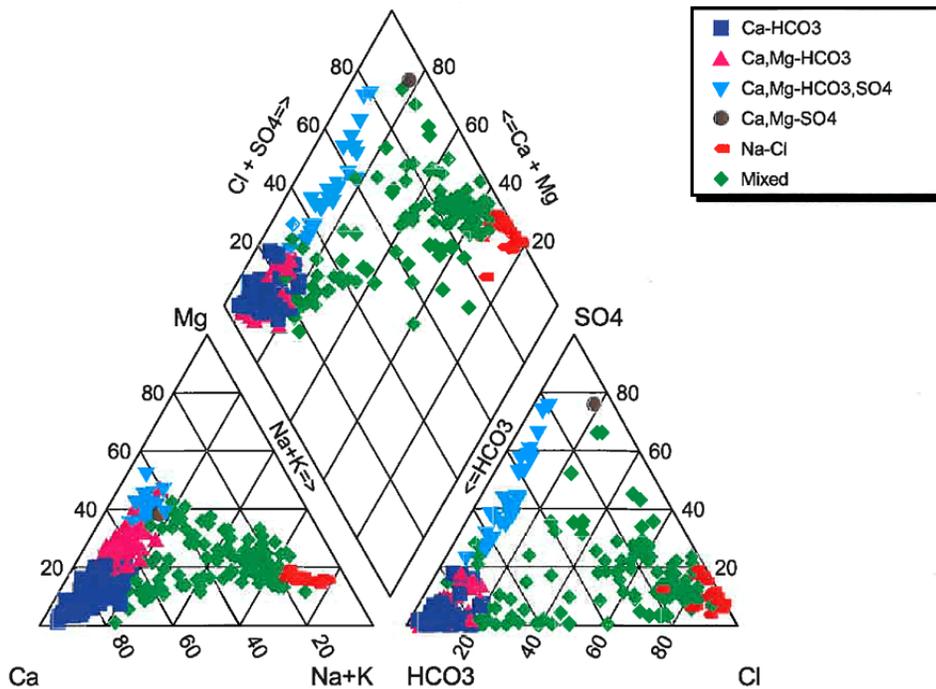


Figure 9. Example of Piper Diagram (St. Johns River Water Management District)

3.3.2 Stiff Diagram

The Stiff diagram is a polygon that results from plotting the concentrations of ions for a single sample on three to four horizontal parallel axes. Cations are on the left and include sodium, potassium, calcium, magnesium, and optionally, iron. Anions are on the right and include chloride, bicarbonate, sulfate, and optionally, carbonate. The points are connected to create an irregular polygon that is unique to a particular chemical composition. By plotting these resulting shapes for multiple sample locations, similarities or differences in water samples can be visually observed. The discharge should be plotted and compared visually to plots of each potential source; similarities in the plots should aid in determining which source(s) the discharge can likely be attributed to.

Similar to a Piper diagram, representative samples may also be collected directly from each potential source of dry weather MS4 discharge and plotted as a Stiff diagram. The discharges may then be sampled and plotted similarly, and visual observation of the Stiff diagrams for discharges compared to the potential sources may help identify the source. One benefit of the Stiff diagram is the shape each sample generates can be used as a marker on a map to identify any spatial trends. Examples of Stiff diagrams are shown in Figure 10.

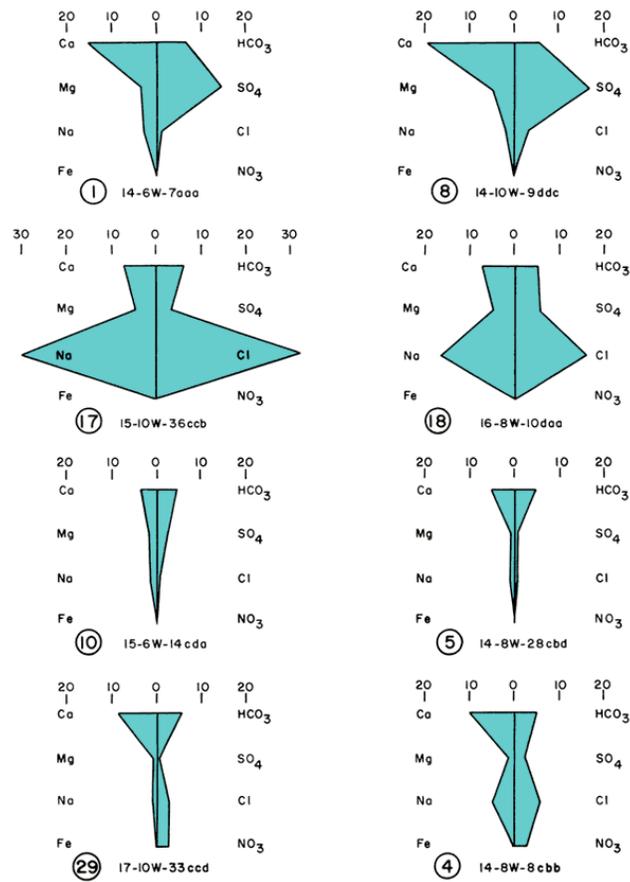


Figure 10. Example Stiff Diagrams (Kansas Geological Survey)

SECTION 4. TIER 2 ANALYSIS

4.1 Tier 2 Isotope Analysis

Analysis of oxygen and hydrogen isotopes of water may be used to distinguish sources of MS4 discharges. Isotopes are forms of the same element that have a varying number of neutrons. The relevant isotopes in water are Oxygen-16 and Oxygen-18, and Hydrogen and Deuterium. The isotopic ratios can be measured more accurately than absolute amounts so the delta notation (δD or δ^2H for hydrogen and $\delta^{18}O$ for oxygen) is used to define the per mil (‰) difference relative to Vienna Standard Mean Ocean Water (SMOW) (Harmon, 1967).

These ratios provide information on the climatological source and history of water. Most precipitation originates from seawater evaporation and therefore starts out with the same δD and $\delta^{18}O$ ratios as SMOW. As the moisture moves through different environments and temperatures, atmospheric and hydrologic processes affect the isotopic ratios. The δD and $\delta^{18}O$ composition of precipitation is linearly correlated and follows what is known as the global meteoric water line. Precipitation in tropical areas and along the coast are most similar to ocean water, while samples further inland or away from the equator are more depleted in the heavy isotopes and have more negative δD and $\delta^{18}O$ values (Harmon, 1961). The spatial distribution of these values varies depending on location, climate, and elevation. This variability allows individual sources of water to remain distinguishable even after mixing with other sources.

Groundwater and surface water isotopic ratios correspond to the local meteoric precipitation. Chemical interaction with minerals in soil/rocks may potentially modify stable isotopic ratios in water (Bowen et al.). The isotopic ratios in reclaimed water are reported to be similar to sewage, suggesting these ratios are conserved through wastewater treatment (Lee et al., 2015). In addition, groundwater measurements showed values of $\delta^{18}O$ distinct from the values found in tap, sewage, and reclaimed water.

To perform an isotope analysis, the steps outlined below should be executed. Step 1 of the overall approach (prior to Tier 1 analyses) includes identifying the potential sources of the discharge based on area-specific conditions (i.e., surrounding land uses/activities, nearby use of recycled water, etc.) This step aids in determining what baseline data are needed to execute the outlined approach. If potential sources are unable to be determined based on area-specific conditions, it should be assumed that all potential sources may be applicable.

1. The potential sources include:
 - a. Potable water: samples of potable water should be collected and analyzed at a certified lab for their δD and $\delta^{18}O$ values. Since only 15 percent of potable water in San Diego County comes from local supplies, it should be distinguishable from

local groundwater based on these isotopic ratios. The majority of San Diego County’s potable water supply is imported from the Colorado River which has much more depleted delta values for oxygen and hydrogen compared to local groundwater (Coplen, 2000). Some expected ranges are provided in Table 11; however, in order to have a more robust analysis, potable water in the area of interest should be measured since the tap water values presented here are based on only two locations within the county and they likely vary across districts.

- b. Groundwater: the State Board collected groundwater samples in San Diego County from the GAMA Domestic Wells Project from March through June 2008 and December 2008 through January 2009. 137 samples were analyzed for water isotopic composition of both oxygen and hydrogen (Singleton et al., 2012). These results could potentially be used for comparison with a sampled discharge to aid in identifying groundwater. Alternatively, new samples in the area of interest may be collected and analyzed for their oxygen and hydrogen isotopes as a representation of groundwater.
 - c. Recycled water: samples of recycled water should also be collected and analyzed at a certified lab for their δD and $\delta^{18}O$ values. Isotopic ratios in reclaimed water have been reported to be similar to sewage, however collection of new samples would provide the most accurate comparison.
2. Based on results of the δD and $\delta^{18}O$ values, the ranges of each potential source should be substantially different so that the contribution of each can be identified in the discharge. For instance, in Table 11 the difference between potable water and groundwater is substantial for the hydrogen isotopes, but not as much for the oxygen isotopes.

Table 11. Example Isotope Ratios

Source	$\delta^{18}O$ (‰, VSMOW)			δD (‰, VSMOW)		
	Low	High	Typical	Low	High	Typical
Potable water ¹			-9.5			-78
Colorado River ²	-17.07	-14.61	-15.86	-125.20	-113.00	-118.79
Groundwater ³	-9.7	-5.4	-7.1	-72.7	-34.7	-46.5

¹ The data shown are based on samples from two locations within San Diego that were collected between December 2002 and August 2003 by Bowen et. al.

² The Colorado River is included here since a portion of the tap water in San Diego comes from Colorado River Aqueduct. The data shown is based on locations between the Utah-Colorado border and northern Arizona. The composition where the Colorado River aqueduct begins near Lake Havasu likely has slightly higher values.

³ The data shown are based on the measured minimum, maximum, and average of 138 GAMA groundwater samples for the low, high, and typical concentrations shown, respectively.

SECTION 5. REFERENCES

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APPENDIX A – TAP WATER QUALITY DATA

Table 12. Tap Water Quality Reports

Water District	Water Quality report	Service Area (County Un.) (sq mi)	Sources of Water		Treatment		If multiple sources/treatment, approx. %	Fluoride Added?	Fluoride (mg/L)			THMs (µg/L)			Nitrate (as N) (mg/L)			Boron (mg/L)			Chloride (mg/L)			Sulfate (mg/L)			Sodium (mg/L)			Calcium (mg/L)			Magnesium (mg/L)			Potassium (mg/L)			Total Chlorine Residual (mg/L)			TDS (mg/L)			
			% from SDCWA/MWD	Other sources	SDCWA / MWD	Local			Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	
Fallbrook Public Utility District	2016	44	99%	Capra well (1%)	Lake Skinner WTP	UV disinfection (Red Mountain Reservoir)	N/A	Yes	0.6	0.9	0.7	14.7	44.6	31	-	-	-	0.14	0.17	0.14	102	110	103	229	260	234	101	110	102	70	80	72	24	28	25	4.8	5.5	4.9	0.4	3	2.47	14.7	44.6	31	
Helix Water District	2015	24	Some	Lake Jennings, Lake Cuyamaca, El Capitan Reservoir	<1%	R.M. Levy WTP in Lakeside (>99%)	N/A	Yes	0.6	0.7	0.7	15	41	27	-	-	-	-	-	0.1	89	100	95	240	260	250	82	94	90	61	74	69	23	27	26	4.3	4.7	4.5				15	41	27	
Lakeside Water District	2012	16	Some	All-American and Coachella channels, and local wells	Lake Skinner WTP (63% [33-84%])	Helix Plant (R.M. Levy WTP) (20% [6-52%])	N/A	N/A	0.59	0.92	0.78	14	34	25	0.0009	0.13	0.045	0.069	0.091	0.12	96	117	105	123	160	142	73	83	79	49	61	55	22	27	25	3.5	3.8	3.7	0.70	2.5	1.7	14	34	25	
Lake Skinner Plant (MWD)							63%	Yes	0.7	0.9	0.8	10	19	14	ND	ND	ND	-	-	0.13	75	77	76	96	120	110	65	66	66	34	41	38	15	17	16	3.4	3.6	3.5				10	19	14	
Helix Plant							20%	Yes	0.7	0.9	0.8	20	51	46.5	ND	0.21	0.21	-	-	0.14	75	95	87	130	180	160	70	86	78	47	54	51	19	24	22	3.8	4.6	4.3	0.1	3	1.8	20	51	46.5	
Lakeside Wells							17%	No	0.06	1.0	0.7	19	69	38.8	0.005	0.5	0.016	0.069	0.091	0.075	197	291	236	213	285	237	109	141	129	105	144	123	54	66	61				1.4	1.9	1.68	19	69	38.8	
Ramona Municipal Water District	2015	72	100%	N/A	Lake Skinner & Twin Oaks WTP, Carlsbad Desal. Plant	N/A	N/A	N/A	0.41	0.72	0.57	21	32	28.8	ND	0	ND	0.11	0.11	0.13	94	98	103	44	48	141	88	102	105	67	71	73	22	24	25	4.2	4.6	4.7				21	32	28.8	
Lake Skinner Plant (MWD) ¹							47%		0.2	0.4	0.3	-	-	-	-	-	-	0.13	0.13	0.13	102	105	104	15.3	17.9	16.7	96.0	103	100	75	78	77	25	27	26	4.7	5.1	4.9							
SDCWA ¹							47%	Yes	0.6	1	0.8	-	-	-	ND	0.3	ND	-	-	0.14			110			250			120			77			28			4.9							
Carlsbad Desalination Plant ²							7%	Yes	0.5	1	0.8	-	-	-	-	-	-	0.0003	0.0007	0.0004	40	54	44	237	249	243	32.1	94.1	39.9	15.3	23.3	19.8	0.29	0.57	0.4	1.0	1.6	1.4							
Santa Fe Irrigation District	2015	12	Some	Lake Hodges		R.E. Badger Filtration Plant	N/A	No	0.23	0.3	0.28	10	44	33.4	-	-	-	-	-		90	140	120	150	260	227	75	130	106	47	77	65				4	6.3	5.3				10	44	33.4	
South Bay Irrigation District (member of Sweetwater Authority)	2016	9.4	Some	Sweetwater River, deep freshwater wells in National City, and brackish		Reynolds GW Desal. facility, Robert A. Perdue WTP, (freshwater	N/A	No	ND	0.6	0.3	4.1	30.9	24.1	-	-	-	0.15	0.34	0.23	73	250	158	29	203	87	57	120	91	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	30.9	24.1

Water District	Water Quality report	Service Area (County Un.) (sq mi)	Sources of Water		Treatment		If multiple sources/treatment, approx. %	Fluoride Added?	Fluoride (mg/L)			THMs (µg/L)			Nitrate (as N) (mg/L)			Boron (mg/L)			Chloride (mg/L)			Sulfate (mg/L)			Sodium (mg/L)			Calcium (mg/L)			Magnesium (mg/L)			Potassium (mg/L)			Total Chlorine Residual (mg/L)			TDS (mg/L)		
			% from SDCWA/MWD	Other sources	SDCWA / MWD	Local			Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
			<i>Carlsbad Desalination Plant²</i>									7%	Yes	0.5	1.0	0.8	-	-	-	0.7	0.9	0.8	0.0003	0.0007	0.0004	40	54	44	15.3	17.9	16.7	32.1	94.1	39.9	15.3	23.3	19.8	0.29	0.57	0.4	1	1.6	1.4	
Otay Water District	2016	68	87%	Helix Water District	Lake Skinner and Twin Oaks WTPs, and Carlsbad Desal. Plant	Levy WTP (Helix Water District)	N/A	N/A	0.60	1.2	0.70	18	41	33	0.04	0.05	0.05	-	-	0.12	93	99	102	215	228	233	86	100	103	66	72	72	22	24	25	4.2	4.7	4.6	ND	3.6	2.4	18	41	33
<i>Twin Oaks WTP (SDCWA)¹</i>							40%	Yes	0.6	1.2	0.7	-	-	-	ND	ND	ND	-	-	0.14			110			250			120			77			28			4.9						
<i>Carlsbad Desalination Plant²</i>							6%	Yes	0.6	1.2	0.7	-	-	-	0.7	0.9	0.9	-	-	ND	44	54	44	15	18	17	32	94	40	15	23	20	0.3	0.6	0.4	1	1.6	1.4						
<i>Levy WTP (Helix)¹</i>							13%	Yes	0.6	1.2	0.7	-	-	-	ND	ND	ND	-	-	0.1	89	100	95	240	260	250	82	94	90	61	74	69	23	27	26	4.3	4.7	4.5						
<i>Lake Skinner Plant (MWD)¹</i>							40%	Yes	0.6	1.2	0.7	-	-	-	ND	ND	ND	-	-	0.13	102	105	104	237	249	243	96	103	100	75	78	77	25	27	26	4.7	5.1	4.9						
Olivenhain Municipal Water District	2015	31	100%	N/A	Lake Skinner and Twin Oaks WTPs, and Carlsbad Desal. Plant (<1%)	David C. McCollom WTP (>99%)	N/A	N/A	0.52	0.94	0.75	26	45	33	-	-	ND	-	-	0.15			100			240			110			73			29			5.3	1.93	3.93	3.09	26	45	33
<i>David C. McCollom WTP³</i>							100%	Yes	0.52	0.94	0.75	26	45	33	-	-	ND	-	-	0.15			100			240			110			73			29			5.3	1.93	3.93	3.09	26	45	33
Yuima Municipal Water District	2016	21	Some (46.2% [0-100%])	Local GW - deep wells in Pauma Valley (Pauma GW basin)	Lake Skinner WTP	Sodium hypochlorite	N/A	N/A	0.36	0.58	0.44	12	38	27	ND	5.8	1.5	0.06	0.12	0.09	78	104	89	29	262	162	41	119	73	17	79	72	5.2	44	24	4.2	6.8	5.0				12	38	27
<i>Local (Yuima,IDA)</i>							54%	No	0.15	0.31	0.21	8.6	18	14.65	ND	9.8	2.06	ND	ND	ND			82.3	89	200	147.1	23	130	55.14			84.8	1.2	58	26.6	5.5	8.32	5.64				8.6	18	14.65
<i>Lake Skinner Plant (MWD)</i>							46%	Yes	0.6	0.9	0.7	16	62	42	ND	1.1	0.8	0.14	0.27	0.19	78	104	97.2	29	262	179.4	62	107	93.4	17	79	56	10	27	20	2.7	5.1	4.2				16	62	42
Vallecitos Water District	2015	17	100%		Lake Skinner (3% [0-6%]) and Twin	Weese and Olivenhain (3% [0-6%]) WTP	N/A	N/A	0.37	0.60	0.49	16	31	27	0.05	0.21	0.06	0.0003	0.0007	0.12	80	90	97	171	240	233	51	97	105	45	74	70	17	26	25	2.1	2.7	4.5	0.50	3.3	2.4	16	31	27

