A WHITE PAPER

Adapting to Change: Utility Systems and Declining Flows

NOVEMBER 2017

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California Urban Water Agencies

SECTION 1

Executive Summary

Drought is a recurring phenomenon in California, and dry periods are increasing in intensity and duration because of climate change, as demonstrated by the extreme and unprecedented drought over the past 5 years that has largely redefined the driest period on record. As the state's population continues to grow, there is a greater awareness of the need to maintain water supplies for both human consumption and wildlife habitats. Wise water use is a critical part of addressing California's new realities in a sustainable manner. At the same time, declining flows also create ancillary system impacts worthy of consideration.

During the recent historic drought, Californians responded to the call for emergency statewide water use reductions, which the state has recognized as a highly successful outcome. However, this significant reduction in water demands has brought to light some unintended consequences of declining flows that ripple throughout the interconnected urban water cycle. These observations offer a preview into the potential impact of establishing permanent indoor water use targets at or below the thresholds achieved as a result of the governor's emergency conservation mandate.

California's water industry leaders, including regulators and purveyors, are working to understand the system-wide impacts of increased conservation so that decision makers are better informed as they address California's current and future water challenges.

Through a partnership with California Association of Sanitation Agencies (CASA), Water Research Foundation (WRF), WateReuse California, and California Water Environment Association (CWEA), California Water Urban Agencies (CUWA) has developed this white paper to provide decision makers, water/wastewater system managers, and other stakeholders an understanding of the impacts of declining flows resulting from substantial reductions in indoor water use and how utilities are adapting to these circumstances.

Working to understand the impacts of declining flows

270 survey responses received

8 utilities interviewed

50% of survey respondents experienced an impact on their drinking water, wastewater, or recycled-water infrastructure

This white paper has been informed by the following activities:

- Conducting a literature review to gain a foundational understanding of what impacts utilities may be experiencing because of declining flows
- Distributing a high-level survey to determine the level and range of observed impacts in California
- Holding one-on-one interviews and developing case studies to illustrate the broad range of issues agencies are experiencing and their associated impact

Wisely managing demands is foundational to ensuring reliable water supply in years to come. California water agencies continue to prioritize wise water use through both short-term conservation (i.e., in response to a drought or emergency) and long-term efficiencies for lasting, sustainable effects. While some people use the term "conservation" to describe both short-term and long-term strategies, this white paper distinguishes between conservation as an emergency response to drought and water use efficiency (WUE) as a long-term strategy for lasting demand reductions. Our objective is to leverage the recent observations of utilities impacted by emergency conservation measures in 2015 and 2016 to inform the state's long-term WUE policies.

Conservation

Short-term, emergency response for demand reductions during a drought

Water use efficiency

Long-term strategy for more sustained demand management

Efficient use of our water resources can have major environmental, public-health, and economic benefits by helping to improve water quality, maintain aquatic ecosystems, and protect drinking water resources. Potential benefits of demand management include:

- Improved drought resilience
- Sustained instream flows to support water quality and wildlife
- Reduced, deferred, or avoided costs of new infrastructure or additional supply
- Reduced energy costs due to decreased pumping of wastewater

Demand management consequently decreases flows within the interconnected urban water cycle impacting drinking water distribution and water quality, wastewater conveyance and treatment, and recycled water production and quality (Figure ES-1).

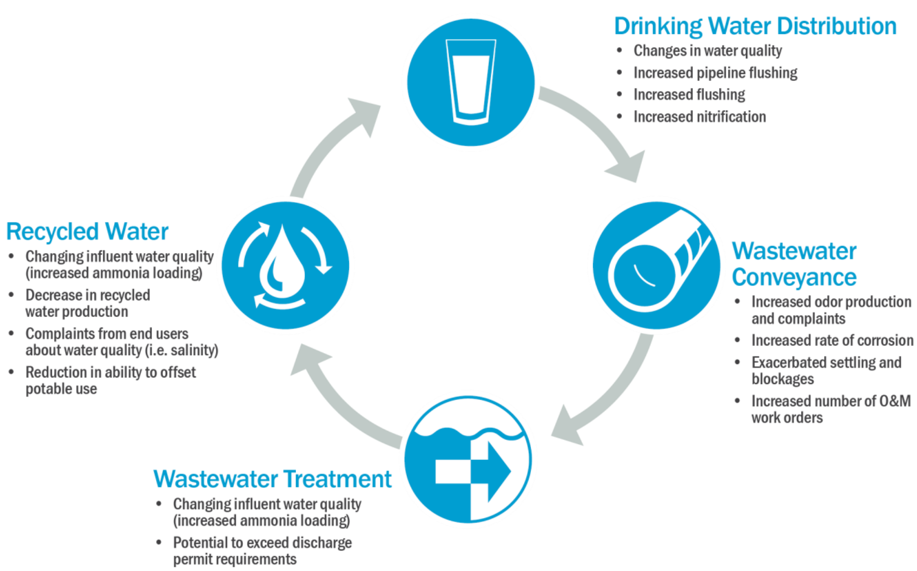


Figure ES-1. Declining flows in the urban water cycle can potentially impact all areas of the cycle.

Impacts on Water Distribution Systems

With declining water system flows, drinking water has a longer residence time in pipes, leading to chemical, biological, and physical water quality issues and potentially compromising public health and compliance with the Safe Drinking Water Act, particularly for disinfection by-products (DBPs), coliform bacteria, chlorine residual, and lead and copper action levels.

A great deal of work has been done to address these concerns. Best management practices include improving the hydraulics in storage facilities and managing water chemistry. Improvements in storage facilities include installing baffling systems and increasing the turnover rate through deep cycling pumping and tank mixing. Many water systems have implemented aggressive nitrification control and disinfection residual and DBP control practices. Water suppliers also increase pipeline flushing and discharge water from distribution system reservoirs as necessary. These mitigation methods are certainly feasible, though some system improvements and operational changes can take years to plan and implement, thus highlighting the importance of allowing sufficient time to adapt to declining flows with future WUE objectives.

Of the impacted water system respondents, 49% reported operational challenges in water distribution systems due to low flows.

Impacts on Wastewater Conveyance Systems

Declining system flows decrease wastewater flows and may increase pollutant and solids concentrations, which increase blockages, odors, and corrosion in pipes. This leads to increases in operation and maintenance (O&M) costs, odor complaints, and an accelerated degradation of infrastructure.

Preventive measures are in place to mitigate blockages, including the use of garbage disposals that break up food waste and installing grease traps/interceptors as necessary. However, declining flow can exacerbate blockages. Furthermore, the increased concentration of organics and solids can lead to elevated levels of hydrogen sulfide (H_2S) production. In addition to an increase in odors, higher levels of H_2S can accelerate the rate of corrosion within the wastewater infrastructure.

Of the impacted wastewater conveyance respondents, 50% indicated increased solids deposition, odor problems, and O&M challenges.

Impacts on Wastewater Treatment Plant Operation

Declining flows change the characteristics of wastewater, including the quantity and quality of wastewater treatment plant (WWTP) influent, causing impacts and stressing treatment processes as s salinity, ammonia, and biochemical oxygen demand (BOD) concentrations increase beyond design specifications.

Of the impacted wastewater treatment respondents, 68% indicated changes in wastewater influent quality.

The effluent from WWTPs is held to standards mandated by their individual National Pollutant Discharge Elimination System (NPDES) permits, including effluent quality limits for constituents like ammonia. Increasing influent concentrations can impact effluent quality, straining a plant's ability to meet its discharge permit requirements. To avoid exceeding permit limits, utilities may have to consider implementing costly WWTP upgrades.

In addition to the noted changes in influent water quality, more than 40 percent of impacted survey respondents are facing subsequent challenges in meeting compliance requirements with respect to effluent quality.

Impacts on Recycled Water Projects

Declining flows can alter treatment and cost-effectiveness of recycled-water infrastructure by altering factors considered in system design, like anticipated flow and water quality. In California, the desire to improve water supply reliability has motivated water utilities to expand water reuse through non-potable applications such as irrigation as well as potable reuse through groundwater or surface water augmentation and eventually raw or treated water augmentation. To expand water reuse statewide, California utilities are designing and constructing new infrastructure to treat and distribute the recycled and/or purified water. Thus, declining flows could lead to underutilized assets and could limit the ability to meet the state's water reuse goals of at least 1.5 million acre-feet per year (MAF/year) by 2020 and 2.5 MAF/year by 2030.

Of the impacted recycled water respondents, 70% indicated a decrease in recycled water production.

As indoor residential water use decreases, the availability of treated wastewater for water reuse decreases, thus decreasing production potential. Declining flows can also result in generation of more concentrated wastewater streams, with elevated concentrations of total dissolved solids (TDS), nitrogen species, and organics.

Informing Policy on Long-Term Water Use Efficiency

Long-term WUE can produce many benefits as well as some ancillary effects on the water, wastewater, and recycled water systems. These impacts can be balanced through informed policy and achievable time frames. Regulators and utilities have been leading the charge in tackling California's ever-growing water challenges. When developing long-term WUE policy, the significantly interconnected nature of the system must be considered, and a holistic, one-water view can benefit smart policy and provide better solutions in managing California's water resources.

SECTION 2

Supporting a Holistic Strategy for Water Supply Reliability

Drought is a recurring phenomenon in California, and dry periods are increasing in intensity and duration because of climate change. Meanwhile, our population continues to grow and there is a greater awareness of our need to maintain water supplies for both human consumption and wildlife habitats. Wise water use is critical to supporting water supply reliability and resilience, and understanding its impacts on the interconnected water system supports a holistic approach to addressing California's water supply challenges.

Utilities have been leading the charge in tackling California's water supply challenges, implementing innovative programs and infrastructure to develop drought-resilient water systems. Part of this strategy is reducing California's overall demand on this finite resource. During the recent historic drought, Californians responded to the call for emergency statewide water use reductions, reducing their use by as much as 31 percent in July 2015, which the State has recognized as a highly successful outcome. However, this significant reduction in water demands brought to light some unintended consequences of declining flows that ripple throughout the interconnected water supply system. These observations offer a preview into the potential impact of establishing permanent indoor water use targets at or below the thresholds achieved as a result of the governor's emergency conservation mandate.

California's water industry leaders are working to understand how declining flows can impact the interconnected water system to help utilities most effectively address current and future water supply challenges.

Through a partnership with California Association of Sanitation Agencies (CASA), Water Research Foundation (WRF), WateReuse California, and California Water Environment Association (CWEA), California Water Urban Agencies (CUWA) has developed this white paper to provide decision makers, water/wastewater system managers, and other stakeholders an understanding of the impacts of declining flows resulting from substantial reductions in indoor water use and how utilities are adapting to these circumstances. This research is intended to support long-term water use efficiency (WUE) planning and inform its development within the context of the entire urban water cycle to maximize the inherent benefits while mitigating negative impacts on our interconnected water systems.

Distinguishing between Conservation and Water Use Efficiency

Wisely managing demands is foundational to ensuring reliable water supply in years to come. California water agencies continue to prioritize wise water use through both short-term conservation efforts (i.e., in response to drought or emergency) and long-term WUE for lasting, sustainable effects. While some people use the term “conservation” to describe both short-term and long-term strategies, this white paper distinguishes between conservation as an emergency response to drought and WUE as a long-term strategy for lasting demand reductions.

Our objective is to leverage the recent observations of utilities impacted by emergency conservation measures in 2015 and 2016 to inform the State’s long-term WUE policies. Given the interconnected nature of our water system (Figure 1), and that many decision makers and stakeholders have expressed strong interest in keeping water demands at emergency reduction levels, it is critical to review the lessons learned from this recent experience to inform how to optimize future water management.

Conservation

Short-term, emergency response for demand reductions during a drought

Water use efficiency

Long-term strategy for more sustained demand management

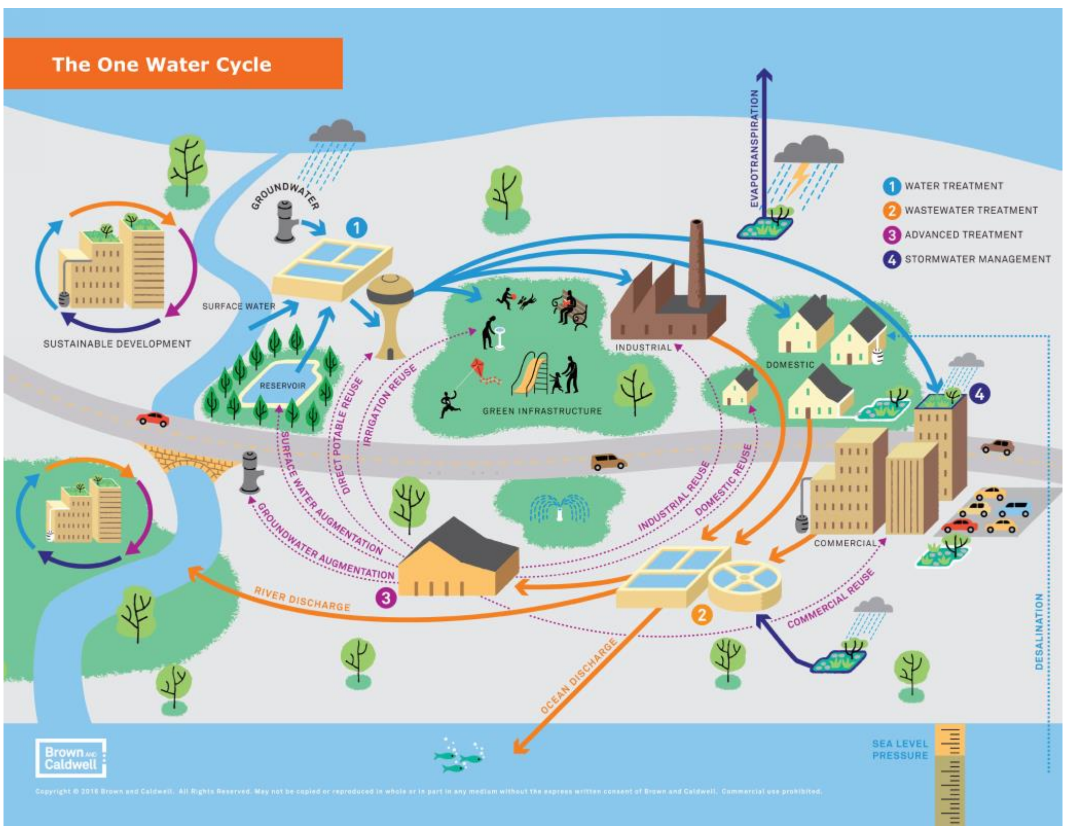


Figure 1. Understanding how the WUE strategies can affect an interconnected water supply system is critical to optimizing future water management.

Source: Brown and Caldwell, 2017

Working to Understand the Impacts of Declining Flows

This white paper was informed by the following:

- A literature review to gain a foundational understanding of what impacts utilities may be experiencing because of declining flows
- A high-level survey to determine the level and range of observed impacts in California
- In-depth interviews and developing case studies to illustrate the broad range of issues agencies are experiencing and their associated impact

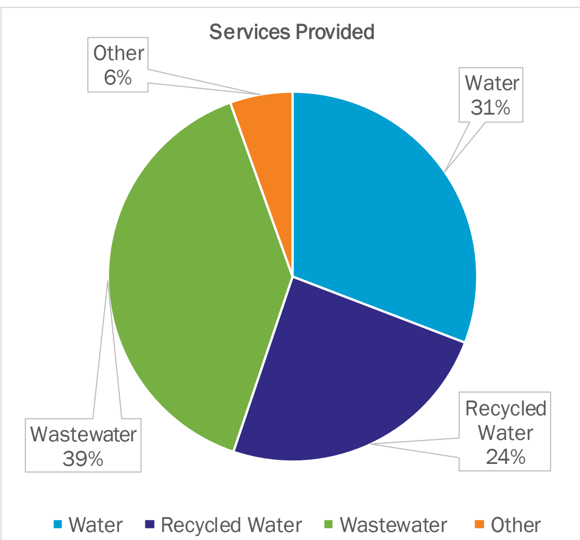
270 survey responses received

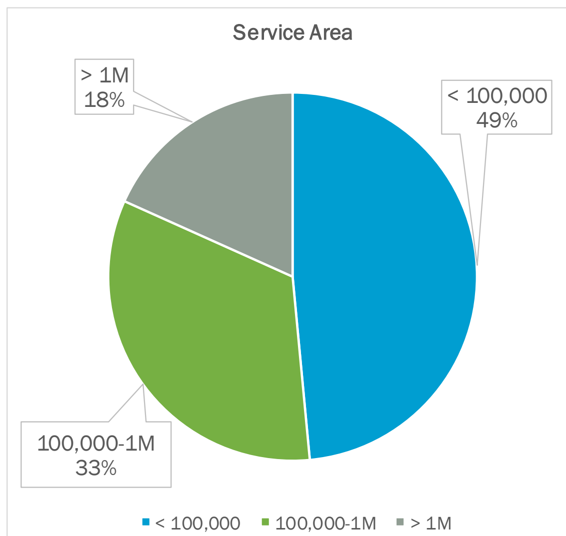
8 utilities interviewed

50% of survey respondents experienced an impact on their drinking water, wastewater, or recycled-water infrastructure

Through their collective membership, CASA, CWEA, and the Association of California Water Agencies (ACWA) distributed a high-level survey to determine how widespread the impacts of declining flows had been felt in California during the drought. The survey sought input from respondents regarding their experience with the impacts identified during the literature review, namely the "key indicators of impacts" highlighted in each section.

A total of 270 distinct responses were received, representing agencies throughout California. Respondents represented an array of services and service area sizes, as indicated in Figures 2 and 3, respectively. Given that agencies often provide multiple services, the survey was designed to give utilities the ability to address impacts on each part of their system.





Figures 2 (left) and 3 (right). Survey respondents represented wastewater, water, and recycled water service providers that served service areas ranging from less than 100,000 to more than 1 million.

The nature of the survey allowed respondents to choose whether to identify themselves or remain anonymous. Out of the 270 responses, 74 distinct utilities shared their information and are listed in Appendix B. As illustrated in Figure 4, 70 out of the 74 identified utilities indicated that they experienced some kind of impact on their system.

From the list of 65 impacted utilities, 9 utilities were selected to interview further to demonstrate the broad range of issues that utilities were experiencing, and to understand what adaptation strategies were already being implemented to address those impacts. A visual representation of the 65 utilities that indicated that they had experienced impacts is shown in Figure 4.

Tuolumne Utilities District

Service Area Size: < 100,000

- Increased settling in sewer lines
- Increased potential for sanitary sewer overflows and blockages
- Increase in work order calls
- Increased odors and odor complaints
- Increased root intrusion in collection system

Alameda County Water District

Service Area Size: 100,000 – 1,000,000

- Distribution system nitrification
- Occurrences of low chlorine residual
- Operational challenges due to water age and reduced flows
- Intermittent idling and operational adjustments at treatment facilities

Santa Clara Valley Water District

Service Area Size: > 1,000,000

- Increased THM formation
- Increased taste and odor issues
- Operational challenges due to water quality changes and reduced flows

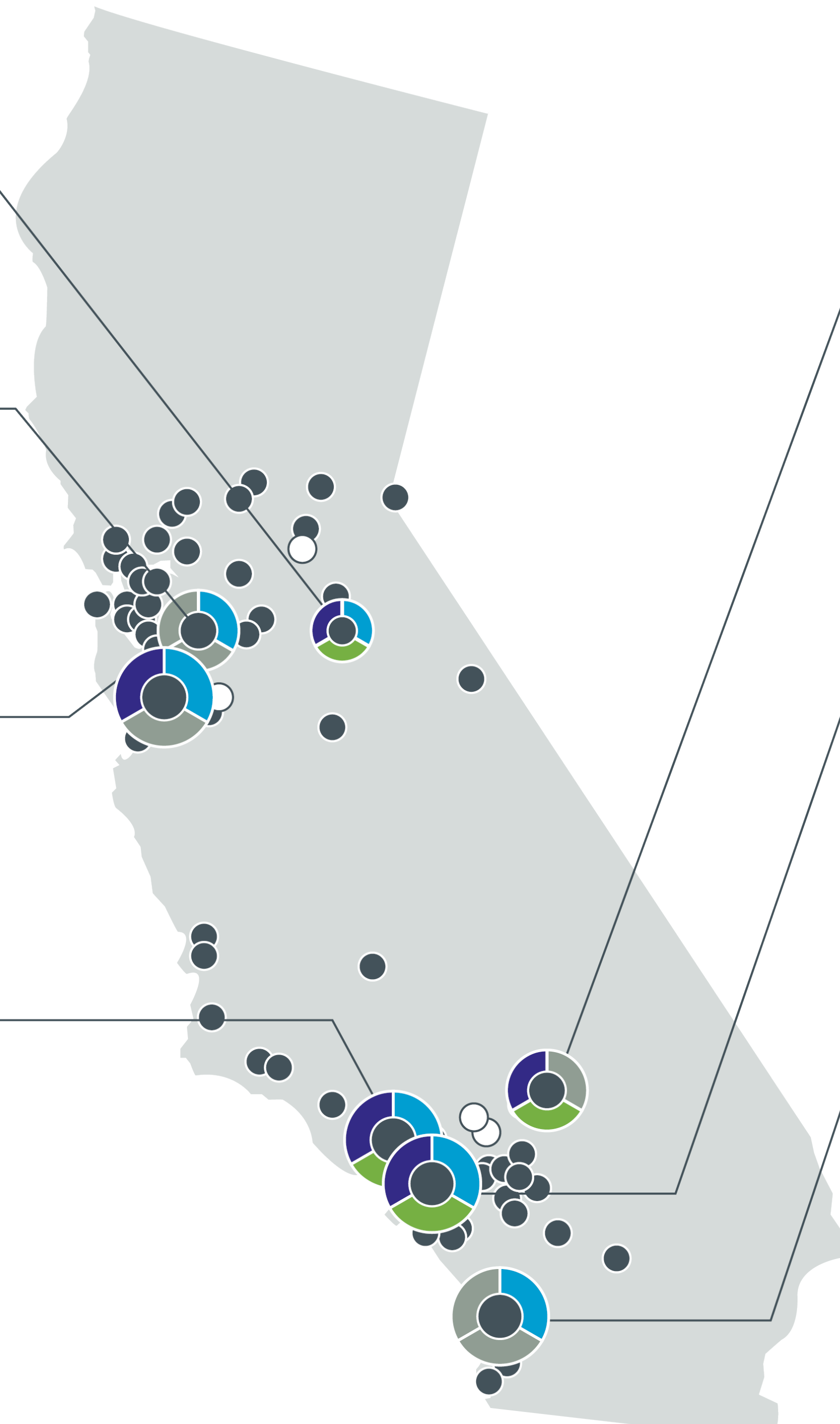
LA Department of Water and Power/City of LA, Bureau of Sanitation

Service Area Size: > 1,000,000

- Increased THM formation
- Increased taste and odor issues on wastewater
- Increased taste and odor issues
- Operational challenges due to water quality changes and reduced flows

■ Water ■ Wastewater ■ Recycled Water ■ N/A for Utility

● Agencies that observed impacts ○ Agencies with no impact



Victor Valley Reclamation Authority

Service Area Size: 100,000 – 1,000,000

- Increased ammonia concentrations in wastewater influent
- Increased H_2S in the collection system
- Increased odors and odor complaints
- Accelerated rate of corrosion and degradation of infrastructure

Orange County Water District/ Orange County Sanitation District

Service Area Size: > 1,000,000

- Increased detention time of wastewater in conveyance system leading to deposition and septic conditions.
- Increased grease build up and settling at Plant 2
- Increased salinity due to RO concentrate from upstream facilities treating more challenging water supplies

San Diego County Water Authority

Service Area Size: > 1,000,000

- Reduced distribution system residuals
- Distribution system nitrification
- Increased flushing to maintain water quality

Figure 4. Utilities throughout California indicated that they had experienced impacts due to declining flows in the high-level survey, and nine utilities were selected for in-depth interviews.

SECTION 3

Supporting Conservation as a California Way of Life

As a response to the recent extreme drought, Governor Jerry Brown issued an Executive Order (EO) directing State agencies to develop a long-term WUE framework, as specified in the report *Making Conservation a California Way of Life.* This white paper highlights observations and experiences of California utilities during the drought, which provide a preview into the potential impact of establishing permanent indoor water use targets at or below the thresholds achieved as a result of the governor's emergency conservation mandate.

During the recent drought, Governor Brown issued an EO in April 2015 directing the State Water Board to issue emergency drought regulations that mandated a statewide urban water use reduction of 25 percent. Water agencies rose to the occasion, meeting or exceeding the State-mandated set point. Before lifting the emergency drought regulations in April 2017, the governor issued a subsequent EO reinforcing key strategies addressed in the California Water Action Plan—namely, *Making Water Conservation a California Way of Life* (B-37-16, May 2016). Through this EO, the governor directed State agencies to develop a long-term WUE framework and to improve planning to support California's water supply reliability and resiliency.

Water Use Efficiency Guidelines Set Water Use Targets

The Department of Water Resources' (DWR's) *Making Water Conservation a California Way of Life* report specifies the process for the State's urban water suppliers to meet new, long-term water use targets (DWR 2016). Each agency's target is an aggregate total of per capita water use budgets in three categories: residential indoor use, outdoor irrigation use, and distribution system water loss.

Supplier water use target =

(indoor water use budget)
+
(outdoor water use budget)
+
(water loss budget)

While the water use target equation includes the three considerations, this white paper focuses on the indoor residential water use standard, because the aim is to evaluate the impact of WUE levels on engineered water systems. After residential water is used within the home, it is conveyed as sewage to a wastewater treatment plant (WWTP) and treated for discharge or reclaimed for non-potable or potable uses. Thus, water used in the outdoor irrigation or lost via the distribution system is less relevant to the focus of this white paper.

Establishing Residential Indoor Water Use Standards

The "residential indoor standard" is defined as "the volume of residential indoor water used by each person per day, expressed in gpcd" (DWR 2016). It is used to calculate a water supplier's "indoor water use budget," which is a function of the total service area population, i.e.:

***Residential indoor water use budget** = (service area population)*

x (residential indoor standard) x (number of days in a year)

Senate Bill (SB) x7-7 established 55 gallons per capita per day (gpcd) as a provisional standard for residential water use per California Water Code (CWC) 19608.20(b)(2)(A). Until a new standard for residential indoor water use is established, that existing standard will apply. As these standards are being developed, the impact of reduced indoor water use on wastewater and water systems is a critical consideration to inform policy decisions.

Effects of Reduced Demand on an Interconnected Water System

The interconnected nature of the water system means that change in one part of the cycle will inevitably have impacts, both positive and negative, on other parts of the system. For example, increased WUE can have environmental, public-health, and economic benefits by helping to improve water quality and maintaining aquatic ecosystems. It also improves drought resiliency and can defer the cost of building new infrastructure for additional water supply.

While there are many benefits to conservation, it is also important to understand how conservation may impact the rest of the water system. With reduced water demands both drinking water and wastewater flows decline and quality change. The potential impacts of declining flows on the interconnected water system is shown in Figure 5.

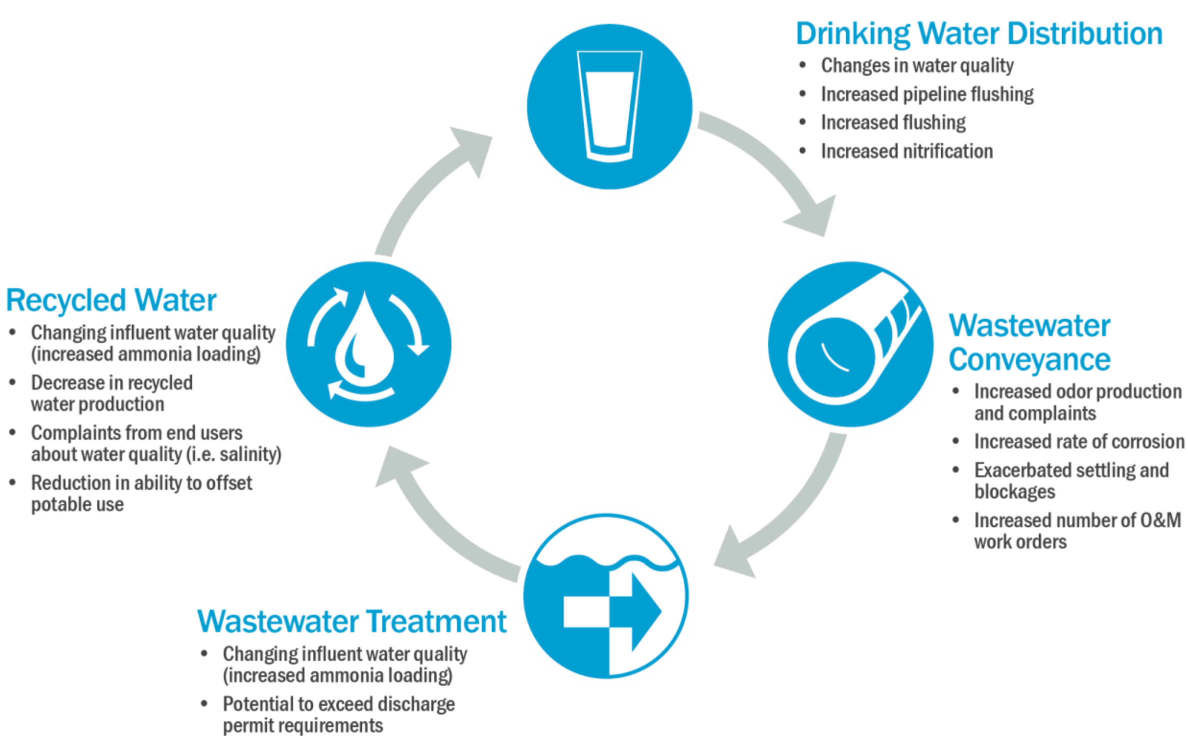


Figure 5. Declining flows can impact the interconnected water system in several ways.

Impacts Are Widespread across the State

As seen in Figure 6, impacts were experienced in every type of system interviewed. They were experienced most often in water distribution systems, where 60 percent of survey respondents indicated that they were having to manage the effects of declining flows. Additionally, 52 percent of wastewater conveyance systems, 48 percent of WWTPs, and 43 percent of recycled water projects indicated that they experienced impacts due to declining flows.

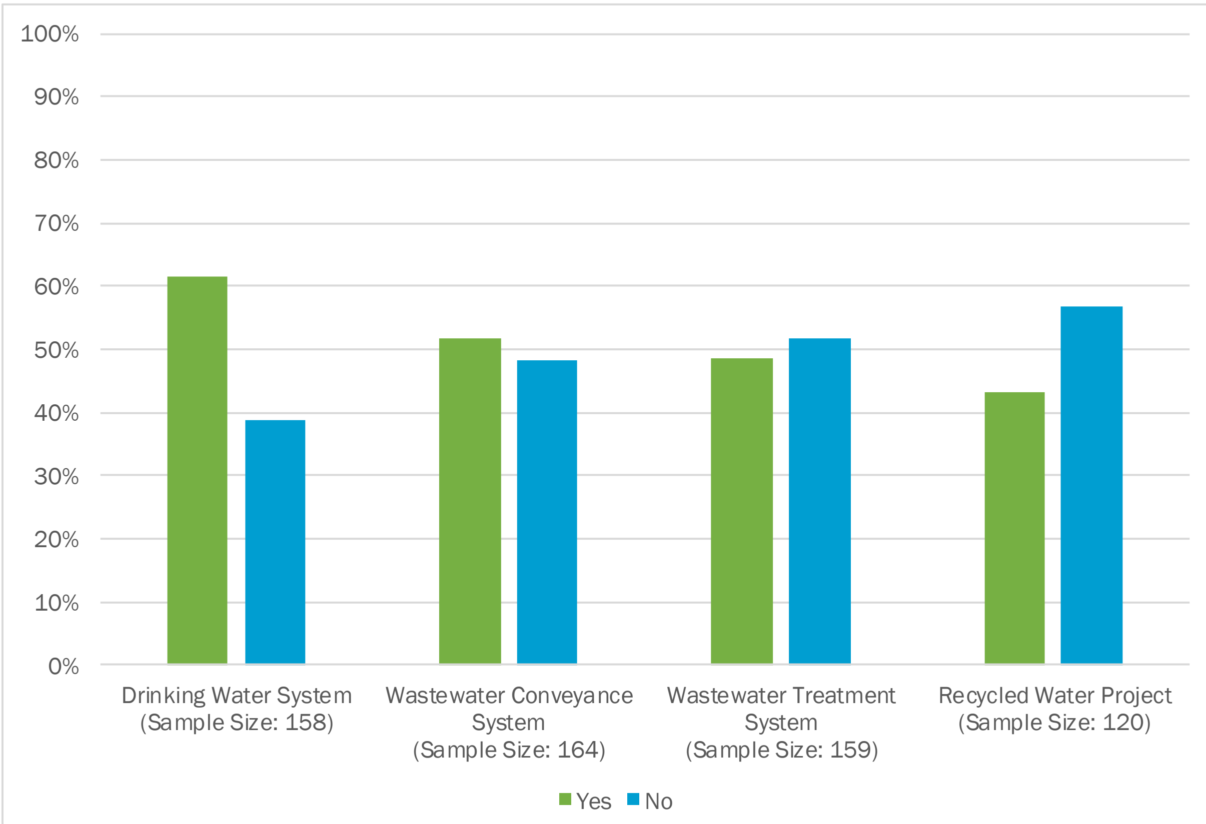


Figure 6. Survey respondents experienced impacts of water conservation in all system types, most often in water distribution systems.

The following sections dig deeper into impacts on each type of system based on the literature review, high-level survey results, and case studies with utilities that have experienced the most significant impacts and have already implemented adaptation strategies.

SECTION 4

Impacts of Declining Flows on Water Distribution Systems

With declining water system flows, drinking water has a longer residence time in pipes, leading to chemical, biological, and physical issues that may have a potential impact on public health and compliance with the Safe Drinking Water Act.

Decreased Potable Water Demand Increases Residence Time in Water Distribution Systems

As water in the distribution system declines, residence time increases in reservoirs and pipes. While reduced consumption has its benefits (e.g., decreased groundwater overdraft), it also has potential ancillary impacts.

WRF conducted two studies focused on indoor residential water use in select study sites throughout North America, once in 1999 and the next in 2016. During that time, indoor water use decreased 15% from 69.3 to 58.6 gallons per capita per day (Figure 7).

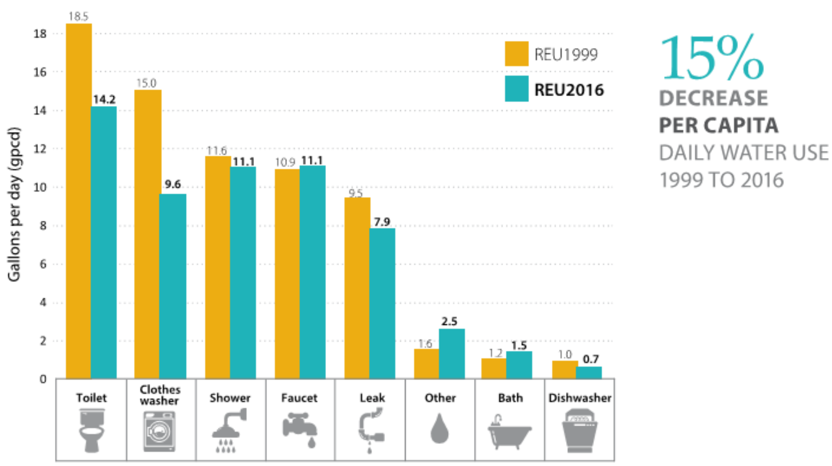


Figure 7. Two WRF studies showed a 15 percent decrease in average daily indoor per capita water use from 1999 to 2016.

Source: DeOreo et al., 2016

Key indicators of impacts:

- Lower-than-expected water use
- Changes in water quality within the distribution system
  - Increased disinfection by-product (DBP) formation
  - Increased nitrification
  - Changes in physical characteristics
- Increased flushing to maintain safe water quality
- Failure to comply with drinking water standards

In 2002, the U.S. Environmental Protection Agency (EPA) published a report titled *Effects of Water Age on Distribution System Water Quality.* It discusses the impacts that increased "water age," i.e., residence time in pipes, can have on distribution water quality, leading to potential public-health implications. Water age is a function primarily of water demand, system operation, and system design.

Table 1 lists water quality problems that can be caused or worsened by increased residence time in the distribution system. The items that are marked with an asterisk are identified as having direct potential health impacts. Water quality problems like discoloration or changes in other water aesthetics (taste, odor) are secondary though still important, as they directly impact customers' perception of the quality of their water.

Table 1. Summary of Water Quality Problems Associated with Water Age

Chemical Issues	Biological Issues	Physical Issues
DBP formation *	DBP biodegradation *	Temperature increases
Disinfectant decay	Nitrification *	Sediment deposition
Corrosion control effectiveness *	Microbial regrowth, recovery, or shielding *	Color
Taste and odor	Taste and odor	

Source: EPA 2002

**Denotes water quality problem with direct potential public-health impact.*

Increased water age exacerbates chemical, biological, and physical issues for water quality, leading to potential direct impacts on public health. This decline in water quality also puts water suppliers at risk of failing primary drinking water standards and being out of compliance with the Safe Drinking Water Act, particularly for DBPs, coliform bacteria, chlorine residual, and lead and copper action levels.

Since the EPA report was published in 2002, a lot of work has been done to address these concerns. Modifications in best management practices include improving the hydraulics in storage facilities and managing water chemistry. Improvements in storage facilities include installing baffling systems, increasing the turnover rate through deep cycling pumping, and tank mixing. Many water systems have implemented aggressive nitrification control and disinfection residual and DBP control practices. Water suppliers also increase pipeline flushing and discharge water from distribution system reservoirs as necessary. These mitigation methods will be important as declining flows continue to increase the water age within the distribution system.

47 Percent of Impacted Water Distribution Systems Indicated Operational Challenges due to Low Flows

The key indicators of impacts to water distribution systems identified during the literature review were indeed observed by California utilities during the recent drought. Of water distribution respondents surveyed, 61 percent indicated that they had experienced some kind of impact during the period of mandated conservation. Of them, 49 percent of respondents experienced operational challenges due to low flows, 47 percent experienced changes in water quality, and 17 percent indicated another impact not included in the survey (Figure 8). Other impacts included items like lower revenue, increasing rates, and stranded storage assets.

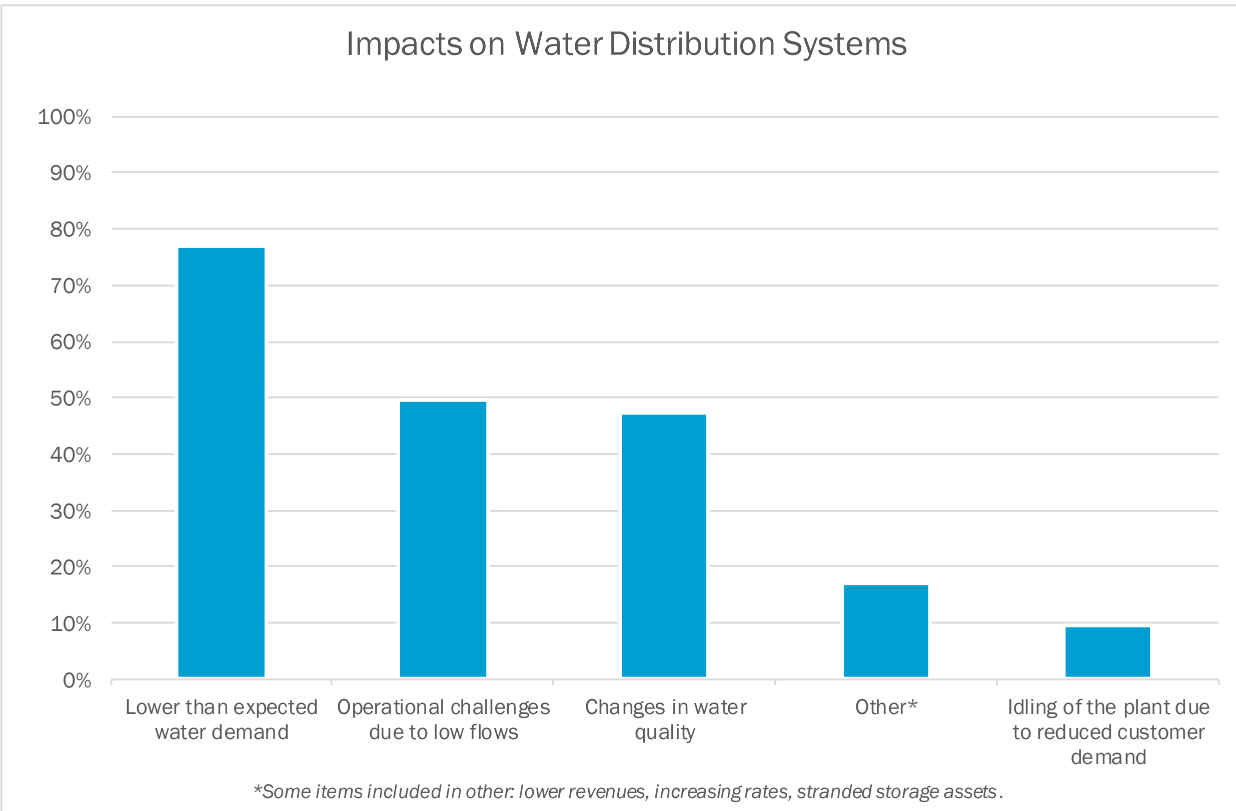


Figure 8. Operational challenges and changes in water quality were the most significant impacts on water distribution systems.

San Diego County Water Authority (SDCWA) and Santa Clara Valley Water District (SCVWD) were interviewed in greater detail as they had experienced most of the impacts identified during the literature review and survey. A snapshot of some of the impacts they observed along with how the utilities have adapted are included in the case studies below.

Case Study: San Diego County Water Authority

SDCWA is a wholesale water agency serving 24-member retail agencies, with a population of 3.3 million people and a service area of 1500 square miles. SDCWA's conveyance system delivers treated water from the Twin Oaks Water Treatment Plant and Lewis Carlsbad Desalination Plant and both treated and untreated imported water sources through 300 miles of large-diameter pipelines in two aqueducts.

Impacts experienced

- **Reduced conveyance system residuals:** As detention time through the system has increased, chlorine residuals consequently degrade. At the extremities of the aqueduct system, up to a 1-milligram per liter (mg/L) loss in residual chlorine has been experienced.
- **Conveyance system nitrification:** Nitrification has likewise increased within the aqueduct system as a result of increased detention time, resulting in the unwanted production of nitrites in the drinking water.

Adaptation strategies/financial impacts

- **Increased flushing:** To manage water quality issues, SDCWA will occasionally flush water from its treated water system into its raw water system, where it is stored for treatment again at a later date. Due to increased detention times in the aqueduct, the rate of flushing has been increased as much as ten times. The cost associated with flushing and re-treating the water have increased from $200,000 a year to over $2 million per year.
- **Investment in online monitoring equipment:** SDCWA has invested in the installation of multiple online water quality analyzers, which has been upwards of $250,000 in new equipment.

Case Study: Santa Clara Valley Water District

SCVWD provides Silicon Valley with safe, clean water for a healthy life, environment, and economy. SCVWD provides wholesale water and groundwater management services to 15 cities in Santa Clara County. On the wholesale water side, SCVWD operates three drinking water treatment plants (WTPs) that deliver wholesale drinking water to seven retailers through 39 miles of large-diameter distribution mains.

Impacts experienced

- **Changes in water quality:** SCVWD saw poorer-quality source water in the recent drought from water imported through the Delta. Two out of SCVWD's three WTPs were converted to ozonation prior to the drought. During the period of mandated conservation, the remaining WTP not previously retrofitted to ozonation experienced increased trihalomethanes (THMs) and some taste and odor issues.
- **Operational challenges because of water quality and reduced flows:** Because of conservation, demand for water production was reduced, and thus flows declined within the water distribution system. Retailers located the farthest downstream of the WTP had the potential to sustain the greatest impact due to increased water age and THM formation.

Adaptation strategies/financial impacts

- **Coagulant changes to address higher total organic carbon (TOC):** SCVWD used coagulants from aluminum sulfate to ferric chloride ($FeCl_3$) for 3 months in 2016, and also applied a much higher dose to remove TOC.
  - **Cost of ferric chloride:** $FeCl_3$ use resulted in an additional cost of $150,000.
- **Established minimum flow rates in the Rinconada distribution system:** To ensure that the most downstream retailer was not disproportionately impacted by the reduced flow rates, SCVWD established minimum required flow rates with each of its retailers.

Case Study: Alameda County Water District

Alameda County Water District (ACWD) provides a reliable source of high quality water to over 351,000 people in the cities of Fremont, Newark and Union City. ACWD is a water retailer and manages over 900 miles of distribution pipelines, 83,000 service connections, 13 water storage tanks, and numerous pumping and regulating facilities in its 100-square mile service area. ACWD also currently operates three water treatment facilities.

Impacts experienced

- **Water quality challenges:** Reduced water demands increased overall water age in the system, and changed system dynamics. As a result, ACWD experienced nitrification conditions in a greater number of storage facilities. Additionally, some outlying areas of the distribution system with low water use experienced low chlorine residuals, which had not previously occurred in ACWD's system.
- **Operational challenges:** In order to exercise distribution system storage and reduce water age, treatment facilities had to be operated at lower-than-typical and/or variable rates and water storage facilities had to be operated at lower levels. Less water in storage meant less water available in the event of an unexpected emergency or extended outage. Additional water quality monitoring, storage facility management and flushing operations were also required.

Adaptation strategies/financial impacts

- **Supplemental flushing operations:** To address unusually low chlorine residuals at outlying ends of the distribution system, supplemental flushing events were required to bring fresh water into those areas. This required significant staff time.
- **Treatment facility idling and adjustments:** Due to reduced water demands, ACWD elected to shut down its smallest treatment facility for 10 years or more. Additionally, operation of ACWD's Blending Facility was adapted to an intermittent on/off operation to cycle water system storage and reduce water age. At the Newark Desalination Facility, the recovery rate on the reverse osmosis (RO) process was reduced in order to keep it online at lower flows. Although less efficient, this adjustment was preferable to going off-line entirely, which would have impacted the life of the RO membranes and limited ACWD's ability to use local groundwater.
- **Water storage cycling and targets:** To reduce water age, operational strategies were adapted to increase and intensify water storage cycling, and storage volume targets were reduced.

SECTION 5

Impacts of Declining Flows on Wastewater Conveyance Systems

Declining system flows decrease wastewater flows and may increase pollutant and solids concentrations, which increase blockages, odors, and corrosion in pipes. This leads to increases in operation and maintenance (O&M) costs, odor complaints, and an accelerated degradation of infrastructure.

Reduced Wastewater Flows Increase Blockages

Standards used for hydraulic design include requirements of minimum slopes for various pipe diameters to achieve scouring velocities that minimize debris accumulation. However, external conditions could exacerbate debris accumulation, including root intrusion; increase in fats, oils, and grease (FOG); and pipe sags (Feeney et al. 2009). This debris accumulation results in sewer blockages, which is the number one cause of loss in sewer serviceability (Ashley 2004).

Reduced water usage and wastewater production and constant solids loading leads to an increase in solids concentration within the sewer system, which increases debris accumulation and exacerbates blockages in sewer networks.

A study conducted by a water retailer in Australia correlated the water consumption per household with the number of sewer blockages (Figure 9), indicating that lower water consumption gives rise to a higher rate of sewer blockages (Yarra Valley Water 2011). This subsequently leads to clogged pipes, loss of sewer serviceability, and an increase in operation and maintenance.

Key indicators of impacts:

- **Lower-than-expected wastewater flows**
- **Increased rate of odor complaints**
- **Accelerated rate of corrosion**
- **Increased operation and maintenance (work orders) of sewer lines and pumps**
- **Pumps operating outside of their preferred operating range (POR)**
  - **Signs of cavitation**
  - **Increased vibration and noise**

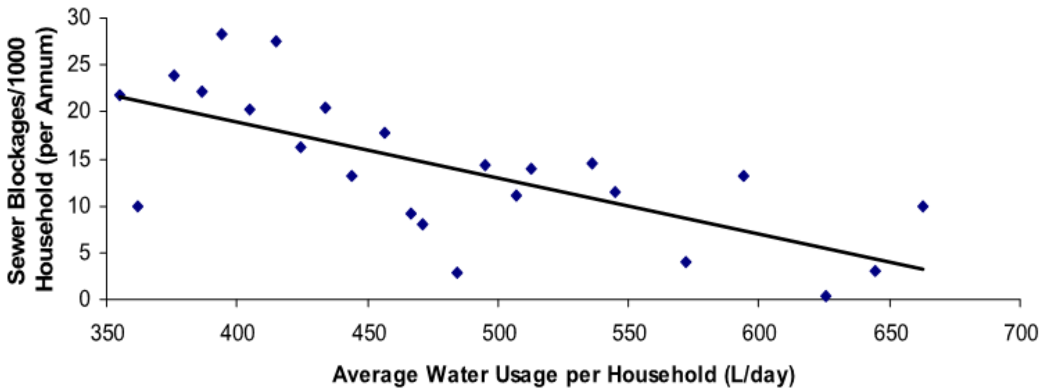


Figure 9. Lower water consumption gives rise to a higher rate of sewer blockages.

Source: Yarra Valley Water 2011.

Structural Condition Failures from Accelerated Corrosion

Corrosion in the conveyance system occurs when the free water surface releases hydrogen sulfide (H_2S) to the atmosphere during anaerobic conditions and is adsorbed by moist sewer pipe. On the pipe surface, H_2S is converted to sulfuric acid (H_2SO_4), which corrodes the pipe. The changing characteristics of wastewater from declining flows can accelerate corrosion through two methods:

- **Increased concentration of organic material and sulfate:** As wastewater flows decrease and organic and solids concentrations increase, concentrations of sulfate in sewage increase. This increase in sulfate generates additional corrosive sulfides.
- **Increased residence time:** Longer flow residence enables more time for the high organic content in wastewater to consume oxygen, leading to anaerobic conditions. This accelerates the rate of corrosive sulfide production.

Accelerated corrosion in pipes leads to a faster rate of structural failure. The primary failure mode for metal pipes is internal or external corrosion, which leads to holes in the pipe wall. Cast iron is particularly brittle, making it susceptible to cracking and subsequent collapse. Corrosion is also often a major factor in the failure of reinforced concrete pipe (RCP), which typically fails after the interior surface of the pipe wall has deteriorated to a point where the reinforcing steel is exposed. As the reinforcing steel corrodes, it swells, breaking up surrounding concrete and causing failure (Feeney et al. 2009).

This increase in the rate of structural failure because of accelerated corrosion results in increased O&M costs and accelerated aging of the infrastructure. Initiated by the National Association of Corrosion Engineers (NACE), the U.S. Federal Highway Administration (FHWA) released a 2-year study in 2002 on the direct costs associated with metallic corrosion in nearly every U.S. industry sector. It stated that the total annual cost of corrosion for drinking water and sewer systems is $36 billion, which included the costs of “replacing aging infrastructure, lost water from unaccounted-for leaks, corrosion inhibitors, internal mortar linings, external coatings, and cathodic protection” (NACE 2002). These costs will only be exacerbated as declining flows accelerate the rate of corrosion within wastewater infrastructure.

Increase in Odor Production, Leading to Increased Odor Complaints

Odors in sewers are dominated by H_2S, which can be recognized by its characteristic rotten-egg odor. It is detectable by the human sense of smell at a concentration level of 0.001 part per million (ppm) and has sub-lethal effects (nausea and eye, nose, and throat irritation) at 10 to 50 ppm (ASCE 1989). Like corrosion, the production rate of odors in sewers is exacerbated by declining flows, which increases the concentrations of sulfate (leading to an increased production of H_2S).

This increase in odor production impacts quality of life. An article in the *Los Angeles Times* stated, "In San Francisco, officials also say foul odors have become noticeable in low-lying and flat areas of the city where gravity cannot help push solids through the system" (Stevens 2015). Increased odor production requires an investment of additional O&M budget to address.

58 Percent of Impacted Wastewater Conveyance Respondents Indicated Increased Odor Problems

As seen in Figure 10, a variety of the impacts described were experienced by wastewater conveyance utilities. Of wastewater conveyance respondents surveyed, 52 percent indicated that they had experienced some kind of impact during the period of mandated conservation. Of them, more than 50 percent experienced increased solids deposition, odor problems, and O&M needs. Other issues observed included increased corrosion, root intrusion, and pH changes.

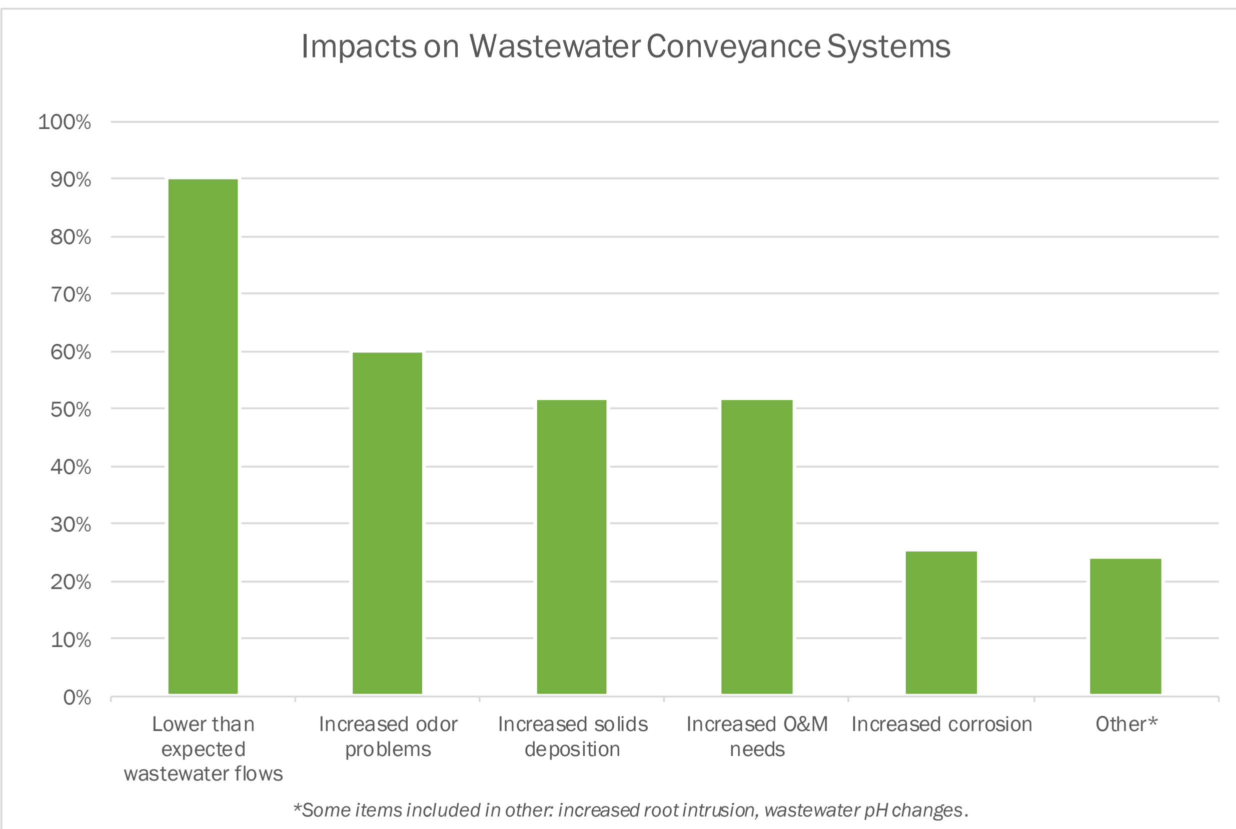


Figure 10. Lower-than-expected wastewater flows and increased odor problems were most significant in wastewater conveyance systems.

Case Study: Tuolumne Utilities District

Tuolumne Utilities District (TUD) is a water and wastewater utility that serves nearly 44,000 residents in northern California's Tuolumne County. TUD operates 14 drinking water treatment plants and a wastewater system that treats 1.2 million gallons per day (mgd) of sewage at the Sonoma Regional WTP.

Impacts experienced

- **Increased sanitary sewer overflows and blockages:** 65 percent of TUD's conveyance system is 4 to 6 inches in diameter, which makes them prone to blockages. The reduced flows exacerbate this issue, leading to an increase in required maintenance.
- **Increased root intrusion:** When there is a blockage in a gravity system, any crack has the potential to leach moisture. TUD has observed increased root intrusion in these locations, causing further separation and cracks.

Adaptation strategies/financial impacts

- **Increased maintenance of the collection system:** TUD has always maintained a hot spot list of areas that staff would routinely check. As flows have declined, that list has increased. Trucks are being sent out more often to monitor those locations.
- **Proactive pipe patching:** TUD has implemented a pipe patching system to counter the increased root intrusion. TUD cleans the pipe and cures a fiberglass material as an internal liner, which both patches the pipe and, given that it's a smoother material, moves sewage more effectively.

Case Study: Victor Valley Water Reclamation Authority

The Victor Valley Water Reclamation Authority (VVWRA) operates as a Joint Powers Authority serving four member agencies. It provides wastewater treatment services through 42 miles of wastewater conveyance and a treatment facility that treats roughly 10.7 mgd.

Impacts experienced

- **Increased odors and odor complaints:** As flows have declined in its conveyance system, solids remain in the system longer, leading to an increase in H_2S. The increased H_2S produces more odors and more odor complaints.
- **Accelerated rate of corrosion and degradation of infrastructure:** Because of the increased H_2S, VVWRA has witnessed an acceleration of corrosion in its collection system, primarily at its manholes.

Adaptation strategies/financial impacts

- **Operational improvements and increased rehabilitation and maintenance of manholes:** To combat the increased odors and accelerated rate of corrosion, VVWRA has implemented operational improvements and begun coating its manholes in epoxy. To proactively mitigate future corrosion, VVWRA has also updated its specifications for manhole coatings to include epoxy coatings while exploring alternative materials to concrete for manholes.
  - **Investment in epoxy coating:** VVWRA has spent $300,000 per year over the past 5 years to address increased corrosion.

SECTION 6

Impacts of Declining Flows on Wastewater Treatment Plant Operations

Declining flows change the characteristics of wastewater, including the quantity and quality of WWTP influent, causing impacts and stressing treatment processes as it pushes ammonia, total dissolved solids (TDS), and phosphorus concentrations beyond design specifications. This may require WWTPs to invest in improvements or expansions earlier than planned.

Increasing Wastewater Influent Concentrations May Impact Effluent Quality

The effluent from WWTPs is held to standards mandated by their individual National Pollutant Discharge Elimination System (NPDES) permits, including effluent quality limits for constituents like ammonia and nutrients.

Increasing influent concentrations that trend upward because of declining flows can reduce effluent quality, potentially impacting a plant's ability to meet its discharge permit requirements. This increase in concentration may require the WWTP to invest in upgrades earlier than expected, resulting in additional cost. This is of particular importance for plants that have discharge limits for ammonia. The following example describes a case of increased ammonia concentration in the influent flow, which subsequently increases ammonia concentrations in the effluent.

Key indicators of impacts:

- **Lower-than-expected wastewater flows**
- **Changing influent water quality**
  - **Increased ammonia and nutrient loading**
- **Exceeding discharge permit requirements**

Ammonia Concentration Increasing in Silicon Valley

Silicon Valley Clean Water (SVCW) has experienced an increase in ammonia in its influent, and subsequently, its effluent (as seen in the drought period in Figure 11 and Figure 12). SVCW's NPDES wastewater permit has a monthly average ammonia limit of 173 mg/L, and effluent concentrations are consistently below this value. With mandatory water rationing, ammonia concentrations entering the WWTP increased (Figure 11). Effluent concentrations of ammonia followed this trend (Figure 12). While still below their reporting limit, this raises the flag on potential problems further down the road.

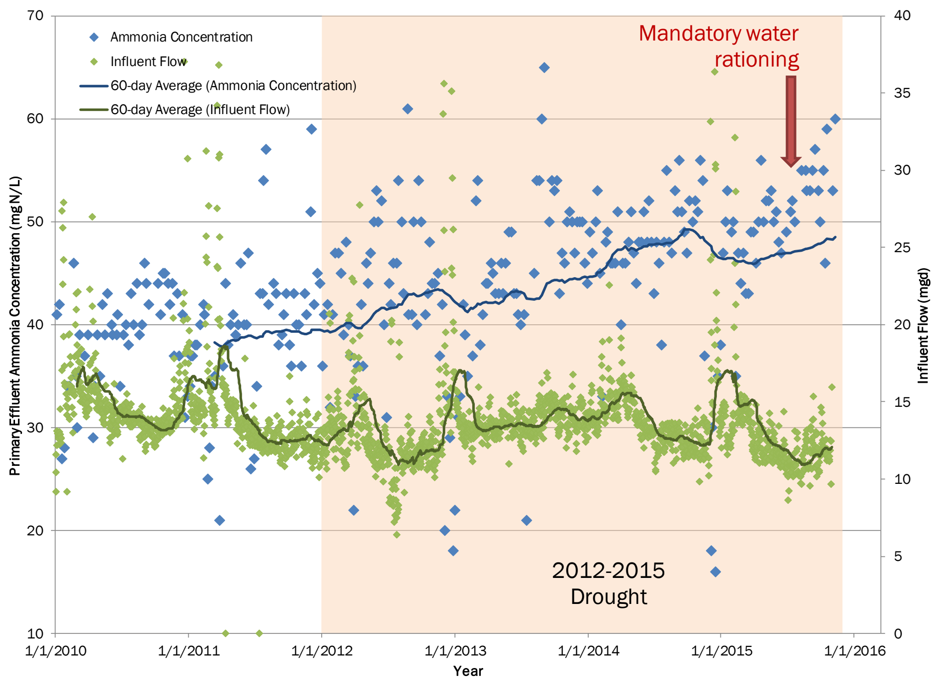


Figure 11. Primary influent ammonia concentrations for SVCW increased during the period of mandatory water rationing.

Source: Sawyer et al. 2016.

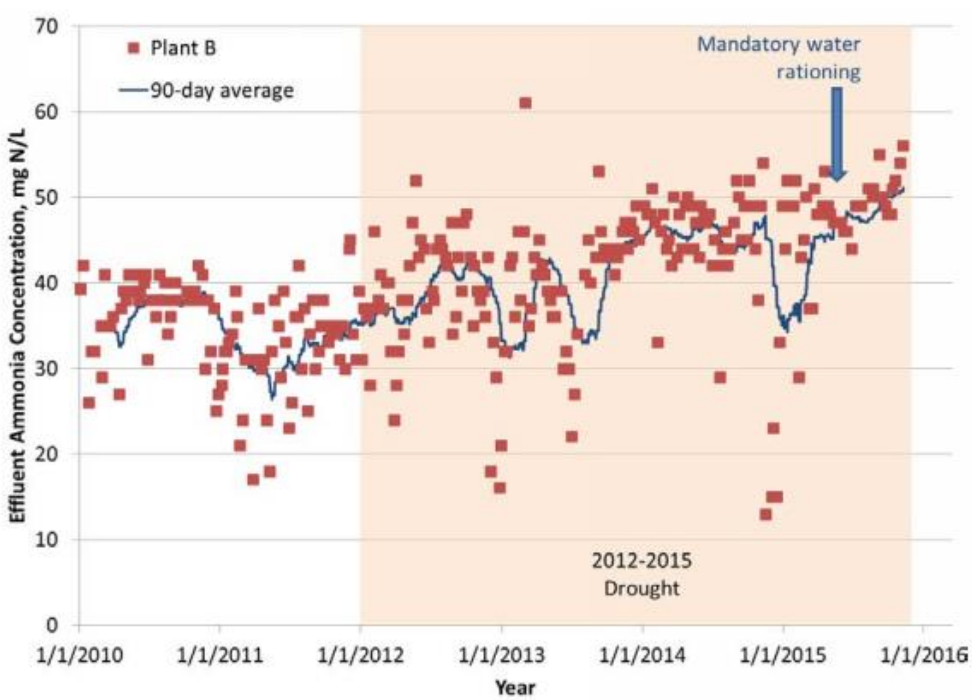


Figure 12. Plant effluent ammonia concentrations for SVCW increased during the period of mandatory water rationing.

Source: Sawyer et al. 2016.

Santa Barbara Experiences Alkalinity Limitations

When declining flows change the characteristics of that flow, treatment processes may become strained. For example, nitrification is a common process to remove ammonia, and it requires a ratio of alkalinity to stabilize the water's pH. As ammonia concentrations increase, as previously demonstrated, alkalinity must also increase to support nitrification.

However, during the period of mandatory water rationing, alkalinity has remained relatively constant. That is because much of the alkalinity in water originates from the source water and is not added by the user. Thus, there may not be enough alkalinity to balance out the increase in ammonia. The following example describes a WWTP that has had to proactively address this potential limitation.

El Estero WWTP in Santa Barbara has experienced a strain on its current wastewater treatment processes based on alkalinity limitations. The plant is currently converting to nitrification, and a residual alkalinity of 80 to 100 mg/L is required to maintain the pH in the nitrified effluent. A marked decrease in flow and increase in ammonia concentration was observed from 2012 to 2014 (Figure 13). Influent ammonia concentrations increased by 32 percent, but influent alkalinity increased by only 4 percent. The amount of alkalinity available was predicted to be insufficient to meet the alkalinity demand for nitrification, indicating an alkalinity limitation. Based on process modeling, it was calculated that supplemental alkalinity would be required at times to maintain a pH above 6.0 for nitrification, which is necessary for effluent compliance. Based on those 2014 data, chemical facilities for alkalinity addition were added to the design.

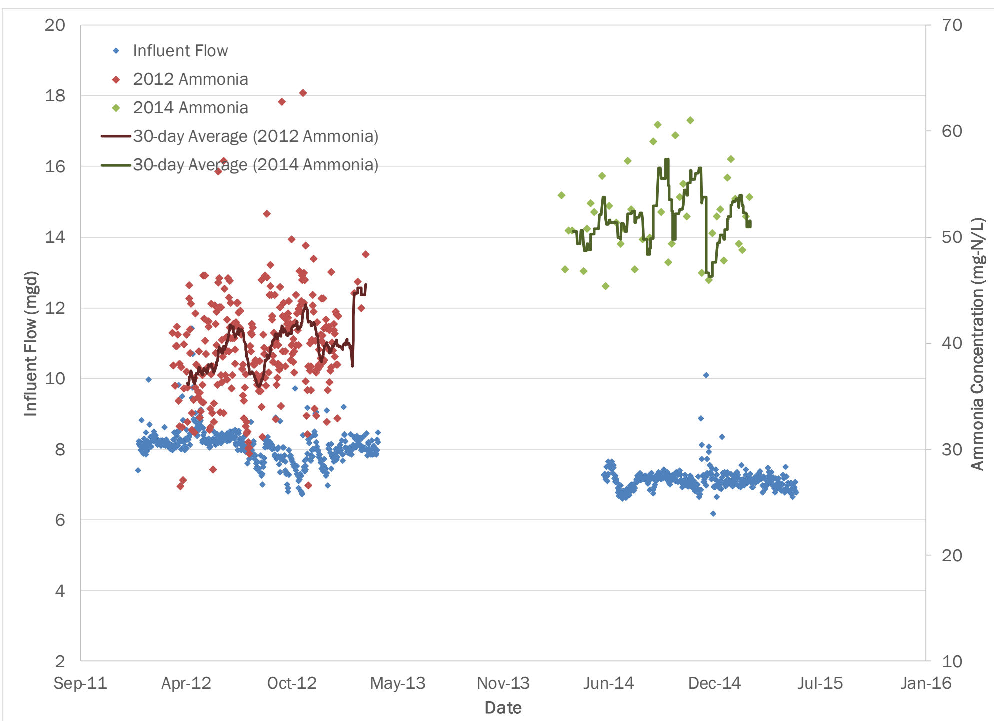


Figure 13. At the El Estero WWTP, Influent flows decreased from 2012 to 2014, and ammonia concentrations increased.

Source: Sawyer et al. 2016.

Impacts to Plant Capacity Ratings

WWTPs are typically rated based on average dry weather flows (ADWF), but the key criterion for biological processes (e.g., activated sludge) is often organic and nutrient loading. For processes that are governed by organic loading, a plant may reach loading capacity at a much lower flow than the rated design flow (Figure 14). Thus, a plant expansion for treatment processes governed by organic loading would need to occur at flows well below the original design flow capacity.

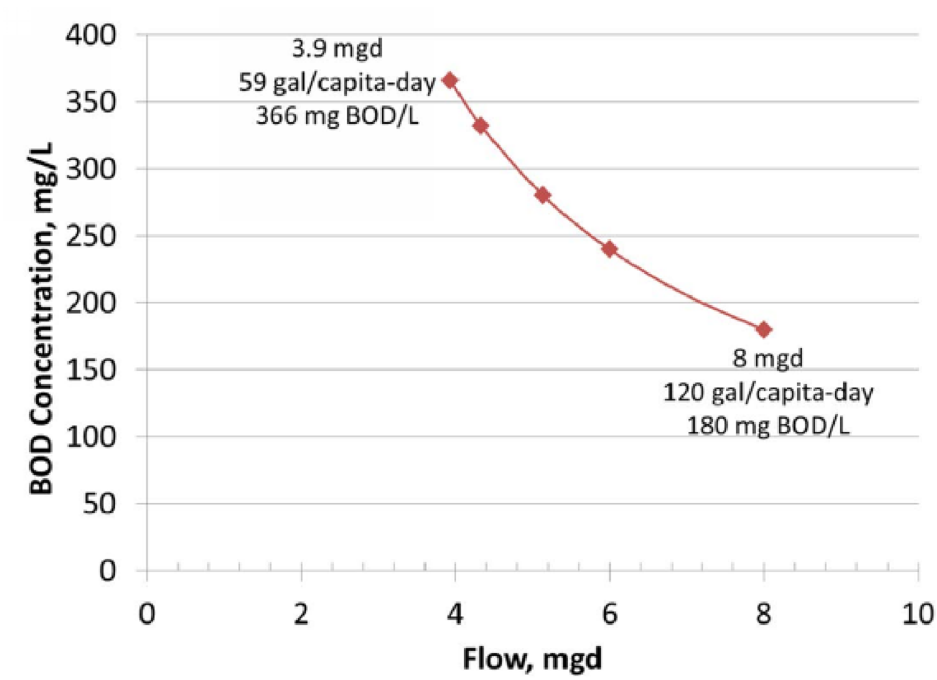


Figure 14. Declining flows may accelerate the need for investment in expansion of treatment processes governed by organic loading, as loading capacity could be reached at a much lower flow.

Source: Sawyer et al. 2016.

40 Percent of Impacted Survey Respondents indicated Changes in Wastewater Influent Quality

As seen in Figure 15, a variety of the impacts described were experienced by utilities providing wastewater treatment services. Of wastewater treatment respondents surveyed, 48 percent indicated that they had experienced some kind of impact during the period of mandated conservation. Of those impacted, more than 60 percent of respondents noted changes in influent water quality, and 40 percent faced subsequent challenges in meeting compliance requirements with respect to effluent quality (see Figure 15). Other issues experienced included plant upsets and staffing adjustments to manage the new conditions.

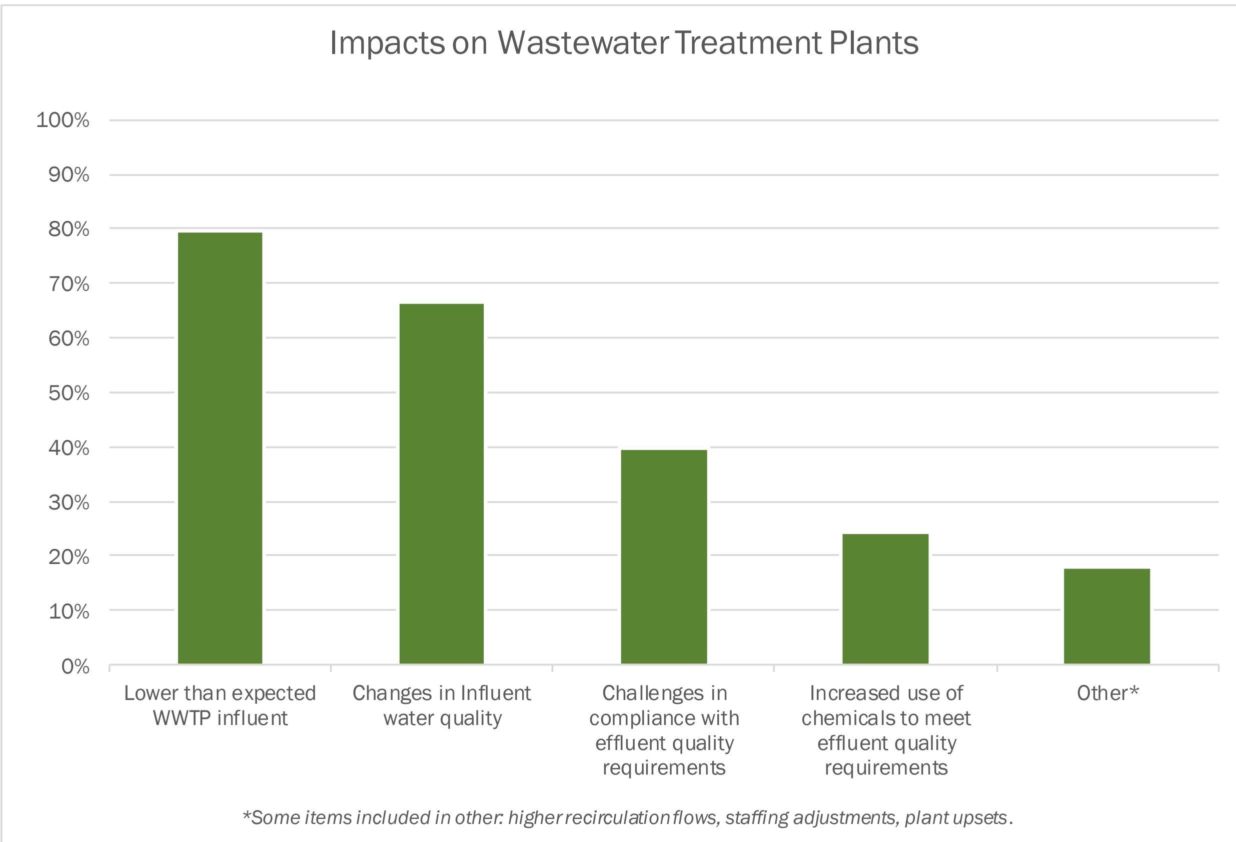


Figure 15. Lower-than-expected WWTP influent and changes in influent quality were the most significant impacts in wastewater treatment plants.

Case Study: Victor Valley Water Reclamation Authority

Introduced in the wastewater conveyance section, VVWRA provides wastewater treatment through a treatment facility that treats roughly 10.7 mgd. This plant discharges into a terminal river, which doesn't flow to the ocean. The facility is thus bound by strict regulatory requirements that require the entire wastewater effluent to be treated to Title 22 standards.

Impacts experienced

- **Increased ammonia concentrations in the wastewater influent:** Current ammonia levels in the wastewater influent are much higher than those recorded before 2010. Influent ammonia concentrations prior to 2010 averaged in the mid to high 20s mg/L. Concentrations are now between 30 and 40 mg/L.
- **Declining wastewater influent reduces wastewater effluent volumes:** This is significant for VVWRA as it is required to discharge a base flow of 8.2 mgd per day to the river.

Adaptation strategies/financial impacts

- **Changes to operations for the aeration basins:** To meet strict discharge requirements, the VVWRA treatment plant nitrifies and denitrifies its wastewater. Changing ammonia concentrations impact operations, as it reduces the dilution of the ammonia and makes it harder to treat.
- **Delivering less recycled water to customers:** To meet the base flow requirements set by CA Fish and Wildlife, VVWRA is required to discharge the 8.2 mgd first before sending its effluent to reuse. However, the less recycled water is available for reuse, the more customers will need to rely on potable resources (groundwater).

Case Study: City of Los Angeles, Bureau of Sanitation

The City of Los Angeles, Bureau of Sanitation (LASAN) provides wastewater services to more than 4 million customers through more than 6,700 miles of public sewers that convey about 400 mgd of flow from residences aed businesses.

Impacts experienced

- **Large and bulky influx of trash associated with wet weather events:** Because of declining flows, food waste and sanitary-type trash is getting stuck in the collection system. Then, when a large wet weather event occurs, all of that trash is suddenly swept to the WWTP, overloading its automatic raking system.

Adaptation strategies/financial impacts

- **Managed large influx of trash through manual labor:** When the automatic raking systems are overwhelmed by the sudden and large influx of trash, LASAN has to manually pull trash out. This is accomplished through manual rakes or a Bobcat.

SECTION 7

Impacts of Declining Flows on Recycled Water Projects

To expand water reuse statewide, California utilities are designing and constructing new infrastructure to treat and distribute the recycled and/or purified water. Declining flows can alter treatment and cost-effectiveness of recycled-water infrastructure by altering factors considered in system design, like anticipated flow and water quality. Thus, declining flows could lead to stranded community assets and could limit the ability to meet the State's water reuse goals.

Changes in Wastewater Effluent Have Impacts on Recycled Water Effluent Quantity and Quality

In California, the desire to improve water supply reliability has motivated water utilities to expand their recycled water use by designing and constructing new infrastructure to treat and distribute the recycled water. Specifically, indoor conservation can result in generation of a more concentrated wastewater stream, with elevated concentrations of TDS, nitrogen species, and carbon (Stevens 2015).

A paper published on July 27, 2017, explores how drought and water conservation strategies combine to reduce influent and flow, and subsequently, effluent flow and quality (Tran et al. 2017). The authors analyzed water quantity and quality data at the Inland Empire Utilities Agency (IEUA) Regional Water Recycling Plant 1 (RP1) during drought and pre-drought periods (2011 to 2015) to investigate the impacts during this time. Their analysis showed that the combination of poorer-quality water supplies coupled with conservation activities resulted in a decrease in wastewater influent flow and an increase in pollutants in the influent of IEUA – RP1 from 2011 and 2015 (Tran et al. 2017), as shown in Figure 16. This reduction in overall treated volumes resulted in lower discharge into surface water by approximately 38 percent, which impacts downstream agencies that rely on that surface water as their influent.

Key indicators of impacts:

- **Lower-than-expected wastewater flows**
- **Changing influent water quality**
  - **Increased ammonia loading**
  - **Increased nutrient loading**
  - **Increase in pathogens and contaminants of emerging concern (CECs)**
  - **Increased salinity**
- **Decreased recycled water production**
- **Complaints from recycled water end users about water quality**
- **Exceeding permit requirements**

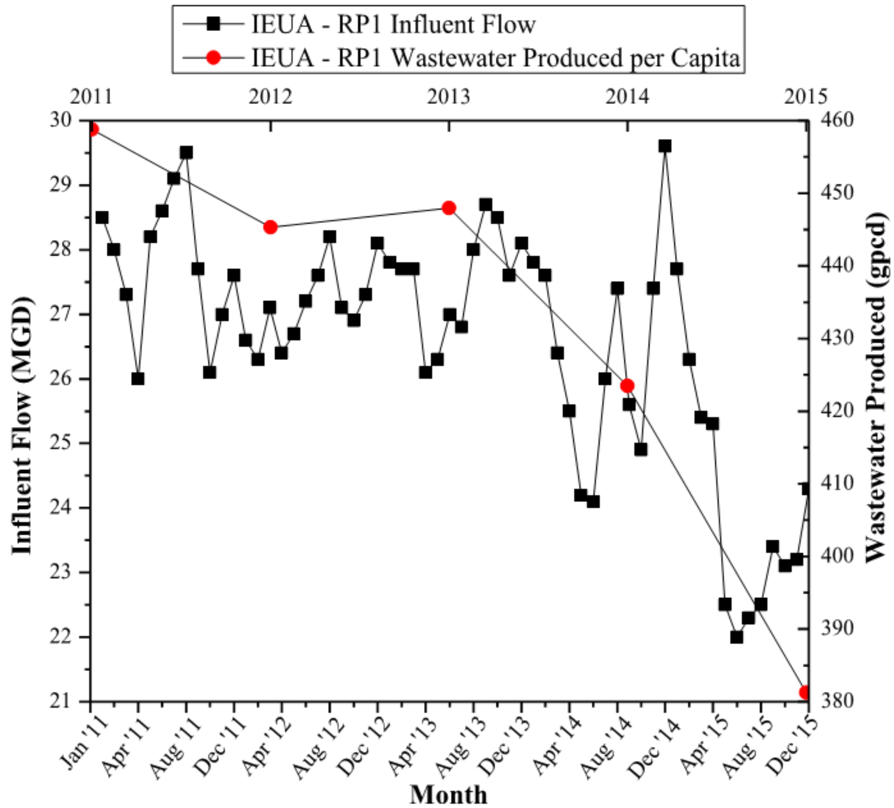


Figure 16. IEUA – RP1 influent flows and the wastewater produced per capita decreased from 2011 through 2015.

Source: Tran et al. 2017.

The paper also analyzed wastewater quality and observed increases in certain constituents, including TDS, electrical conductivity (EC_w) ions (sodium [Na^+], chloride [Cl^-], calcium [Ca^{2+}], and bicarbonate [HCO_3^-]), and nutrients (see Figures 17 and 18). Between 2011 and 2015, an 8 to 16 percent increase in many of the constituent concentrations at IEUA – RP1 led to potential discharge violations and fines. Thus, drought and water conservation measures combined to decrease both the quantity and quality of recycled water effluent.

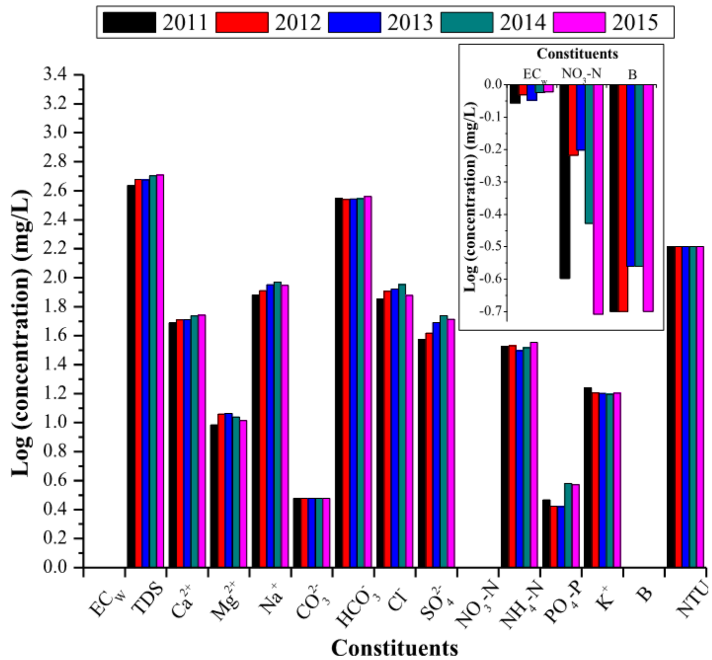


Figure 17. Certain constituents in the IEUA – RP1 influent, like TDS, ions, and EC_w, increased from 2011 to 2015.

Source: Tran et al. 2017.

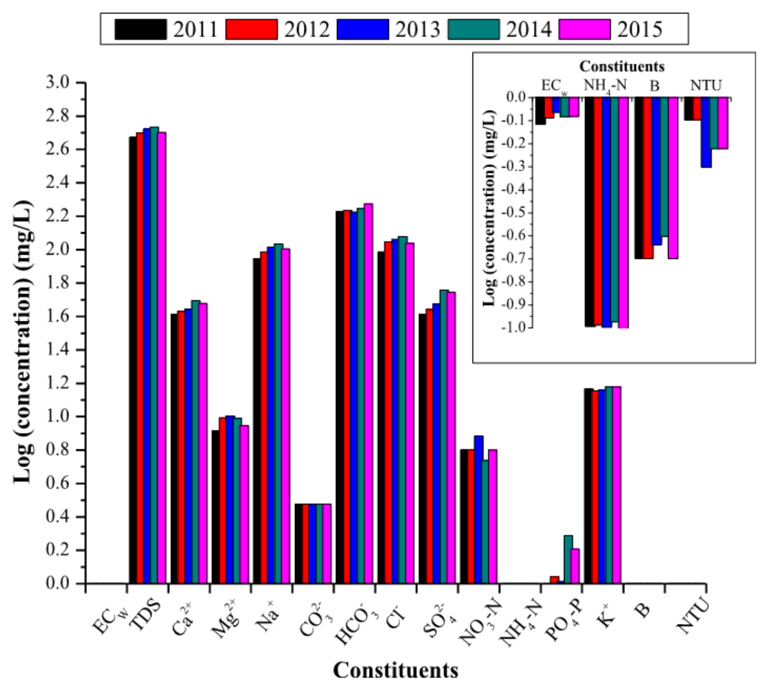


Figure 18. Constituents that increased in the IEUA – RP 1 influent also increased in the effluent from 2011 to 2015.

Source: Tran et al. 2017.

Recycled water projects are expected to produce effluent of a specific quality per their intended end-use (e.g., non-potable reuse [NPR] and potable reuse [PR]), as regulated by the Division of Drinking Water (DDW). Some of the water quality requirements for PR through groundwater replenishment are listed in Table 2. As plant influent and effluent concentrations potentially increase because of declining flows, additional treatment processes may need to be built earlier than planned to meet effluent water quality requirements.

Table 2. Water Quality Requirements for Recycled Water for Groundwater Replenishment

Constituent	Regulatory Level	Frequency of Monitoring
Inorganic chemicals	MCL (Table 64431-A)	Quarterly
Radionuclide chemicals	MCL (Table 64442, 64443)	Quarterly
Organic chemicals	MCL (Table 6444-A)	Quarterly
Disinfection by-products	MCL (Table 64533-A)	Quarterly
Lead and copper	Action levels	Quarterly
Secondary drinking water contaminants	SMCL (Table 64449-A, 64449-B)	Yearly
Chemicals with NLs	NL	Quarterly
Priority toxic pollutants	40 CFR Section 131.38	Quarterly
Any other chemical DDW specifies on a case-by-case basis	TBD	Quarterly

Impacts on Recycled Water Planning Assumptions

The changes in influent quality coming into water recycling plants also have an impact on infrastructure that is currently in design. As with all infrastructure, facilities are designed to specific design criteria, including anticipated flow and water quality. For projects that are currently in design, changing wastewater effluent quantity and quality can push the limits of those criteria.

For example, the Pure Water Program for the City of San Diego is currently designing a comprehensive surface water augmentation program that includes expanding San Diego's existing WWTP and building a full-scale advanced water purification facility and a pipeline to transport the water to Lake Miramar. The design currently assumes wastewater flows, total suspended solids (TSS), and biochemical oxygen demand (BOD) values for the wastewater influent entering the soon-to-be expanded North City Water Reclamation Plant (NCWRP). Projections were performed to understand the potential impacts that decreased indoor residential use could have on these assumptions. These projections showed that concentrations for TSS and BOD increased by 16 percent, which would substantially impact the design of aeration basins and other wastewater treatment processes.

70 Percent of Impacted Recycled Water Respondents Indicated a Decrease in Recycled Water Production

Out of all the survey respondents that provide recycled water services, 51 percent indicated some kind of impact due to declining flows resulting from the emergency mandate. As seen in Figure 19, the biggest challenge facing recycled water systems was the decline in recycled water produced. While influent and effluent recycled water quality is a concern because of increased concentrations of salt, organics, and other contaminants of concern, less than 30 percent of respondents observed significant impacts in this way.

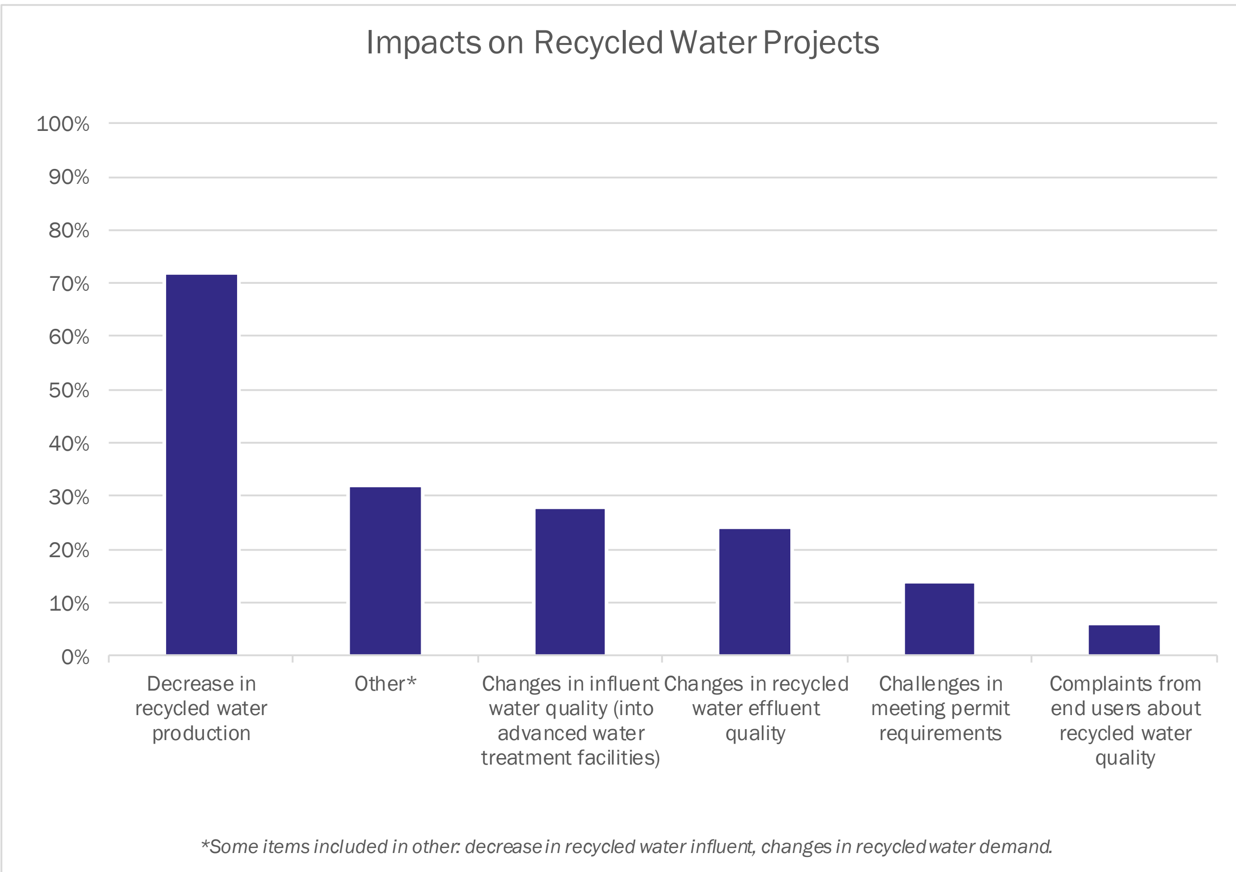


Figure 19. Decreased in recycled water production and changes in influent water quality were the most significant impacts in recycled water projects.

OCWD and OCSD

Orange County Water District (OCWD) and Orange County Sanitation District (OCSD) collaborate to provide water supply reliability in the Orange County service area. OCSD manages a 6-mile stretch of the Santa Ana River and also operates the Groundwater Replenishment System (GWRS). OCSD provides wastewater services for 2.6 million people and manages two WWTPs: Plants 1 and 2. Plant 1 produces the effluent that feeds GWRS.

Impacts experienced

- **Reduced flows at the WWTPs:** The total combined flow of Plants 1 and 2 has decreased from 240 mgd in the 2000s to 180 mgd currently. This decline in flows reduces the wastewater effluent available for groundwater recharge through GWRS.
- **Increasing salinity in discharge effluent from upstream utilities:** OCSD treats the reverse-osmosis concentrate discharge of upstream utilities. As inland water agencies seek out and treat more challenging local water supply, the increased TDS is observed downstream at OCSD.

Adaptation strategies/financial impacts

- **Supplementing GWRS feed water flows with Plant 2 effluent:** With the substantial decline in OCSD influent wastewater flows, the upcoming GWRS final expansion to 130 mgd will require flow to be diverted from Plant 2 to Plant 1 GWRS for purification.
- **Segregation of high-salinity flows:** Higher-TDS flow is currently being processed at Plant 2, which is destined for purification at GWRS as part of the final expansion. To prevent this highly saline flow from negatively impacting the GWRS, OCSD has invested $60 million to segregate these non-reclaimable flows from the water conveyed to GWRS.

City of San Diego, Public Utilities Dept.

The City of San Diego's Public Utilities Department provides water services to 1.3 million customers, wastewater services to a greater metropolitan community of 2.4 million customers and recycled water services. San Diego is a pioneer in potable reuse, promoting sustainable water use technologies through its Pure Water San Diego program. Pure Water San Diego is designed to provide one-third of San Diego's future water demands through advanced water purification, thereby effectively reducing its reliance on imported water and permanently reducing discharges of treated wastewater to the ocean.

Potential impacts

- **Insufficient influent flow at the North City Water Reclamation Plant (NCWRP):** The NCWRP serves as the first step for Phase I of Pure Water, which aims to deliver 42 mgd of recycled and purified water by the end of 2021, which requires approximately 52 mgd of influent. Since the City of San Diego's project is still in design, significant future declines in influent flow below current design specifications could:
    - limit the City's ability to meet Pure Water supply diversification goals and commitments
    - partially strand an important new asset
    - reduce regional drought resilience capabilities

SECTION 8

Policy Recommendations

Increasing water use efficiency results in both benefits and potential impacts on the water, wastewater, and recycled water systems, and these can be balanced through informed policy. Regulators and utilities have been leading the charge in tackling California's ever-growing water challenges. When developing policy associated with long term water use efficiency and indoor water use, the significantly interconnected nature of the system must be considered. A holistic, one-water approach can benefit smart policy and provide better solutions in managing California's water resources.

Based on our research on the impacts of declining flows, CUWA offers the following policy recommendations to inform the currently developing standards for WUE:

- **The entire interconnected urban water cycle as well as public health and safety must be considered in long-term WUE policies.** The existing urban water cycle is challenged by ancillary impacts of declining flows on water, wastewater, and recycled water systems. Such low flows can bring complications, and adaptations may not be straightforward or without significant costs. For example, water systems are typically designed to carry fire flows and cannot be downsized to carry lower flows without adverse effects. Policies addressing long-term WUE must account for costs required to adapt to new flow expectations. The State should provide flexibility for utilities to adjust or offer variances to account for local impacts and investments in water supply reliability measures including increased use of recycled and purified water as recommended by the California Water Action Plan.
- **Actions appropriate for sustainable long-term WUE differ significantly from those for short-term, emergency water use reductions.** Actions taken to address water shortage emergencies are intended to achieve short-term water use reductions through behavior change and sacrifice by water customers. Though some behavioral changes precipitated by emergency conditions may lead to positive lasting changes (e.g., California friendly landscapes), other extreme measures (e.g., insufficient tree watering) carry adverse impacts and are not sustainable for extended periods. When properly designed and implemented based on a holistic analysis of the urban water cycle, long-term WUE programs can result in sustainable potable demand offsets that support the economy, environment, and communities.
- **Greater flexibility, enabled by more diverse supply and storage options, will better position urban utilities to address future uncertainties.** While WUE is an important element of water management programs, it is not in itself sufficient to manage all future water demands. The California Water Action Plan acknowledges the need for more comprehensive water management and supports "making regions more self-reliant by reducing water demand and by

developing new or underused water resources locally" and expanding storage "to deal with the effects of drought and climate change on water supplies for both human and ecosystem needs." Acknowledging that declining flows have the potential to reduce the production of local, drought-resistant water supplies through water reuse, California policy on long-term WUE should prioritize outdoor water use restrictions, which will have a lower impact on interconnected water systems, to achieve statewide demand management goals.

- **An iterative and flexible approach is critical for the implementation and refinement of long-term WUE targets.** Once long-term water use targets are established, water agencies should be provided sufficient time and full flexibility for implementing local and/or regional programs in the context of the entire interconnected water cycle. Customers' water rates will increase to address costs associated with adapting to potential impacts in the midst of reduced revenues. To lessen the financial impact on customers, particularly those in disadvantaged communities, water agencies need adequate time to fully achieve targets to allow for incremental rate increases. Given the long-term nature of WUE targets, the State should evaluate compliance through longer-term planning efforts such as UWMPs, and not on a monthly basis.

SECTION 9

References

American Society of Civil Engineers (ASCE), 1989. *Sulfide in Wastewater Collection and Treatment Systems, ASCE Manuals and Reports on Engineering Practice*, American Society of Civil Engineers.

Ashley, R.M., 2004. *Solids in Sewers: Characteristics, Effects, and Control of Sewer Solids and Associated Pollutants*, IWA Publishing.

Brown and Caldwell, 2017. *Blueprint for One Water,* Used with permission in WRF Project #4660, State of California.

California Code of Regulations (CCR), 2016. *Title 22. Social Security*, "Division 4. Environmental Health, Chapter 3 Water Recycling Criteria, Article 1, 5," California Code of Regulations, https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I38842B20D60511DE88AEDDE29ED1DC0A&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default)&bhcp=1.

California Department of Water Resources (DWR), State Water Resources Control Board, California Public Utilities Commission, California Department of Food and Agriculture, and California Energy Commission, 2016. *Making Water Conservation a California Way of Life, Implementing Executive Order B-37-16,* State of California.

California Department of Water Resources (DWR), 2015. *California's Most Significant Droughts: Comparing Historical and Recent Conditions*, State of California.

DeOreo, W. B., P. Mayer, B. Dziegelewski, and J. Kiefer. 2016. *Residential End Uses of Water, Version 2: Executive Report*. Project #4309A. Denver, Colo.: Water Research Foundation.

Environmental Protection Agency (EPA), 2002. *Effects of Water Age on Distribution System Water Quality*, American Water Works Association, Economic and Engineering Services, Inc.

Feeney, C. S., Thayer, S., Bonomo, M., & Martel, K., 2009. *White Paper on Assessment of Wastewater Collection Systems,* EPA.

National Association of Corrosion Engineers (NACE) International, 2002. *Corrosion Costs and Preventive Strategies in the United States*.

San Francisco Bay Regional Water Quality Control Board, 2012. *Order R2-2012-0062, NPDES CA0038369*.

Sawyer, L.K., Hamamoto, M., Merlo, R., Henneman, S., & Arroyo, L., 2016. *Planning for Future Droughts – Lessons Learned at Water Resource Recovery Facilities*, Brown and Caldwell, Silicon Valley Clean Water, City of Santa Barbara.

Stevens, M., 2015. *Unintended Consequences of Conserving Water: Leaky Pipes, Less Revenue, Bad Odors*, Los Angeles Times.

Sydney, R., Esfandi, E., et al., 1996. *Control Concrete Sewer Corrosion via the Crown Spray Process*, Water Environment Research.

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.

Yarra Valley Water, 2011. *Data Sewer Blockages vs Average Water Usage per Household,* Melbourne.

SECTION 10

Abbreviations

ACWA	Association of California Water Agencies
ACWD	Alameda County Water District
ADWF	average dry weather flows
BOD	biochemical oxygen demand
Ca^{2+}	calcium
CASA	California Association of Sanitation Agencies
CEC	contaminant of emerging concern
CFR	Code of Federal Regulations
Cl^{-}	chloride
CUWA	California Water Urban Agencies
CWC	California Water Code
CWEA	California Water Environment Association
DBP	disinfection by-product
DDW	Division of Drinking Water
DWR	Department of Water Resources
EC_w	electrical conductivity
EO	Executive Order
EPA	U.S. Environmental Protection Agency
FeCl3	ferric chloride
FHWA	Federal Highway Administration
FOG	fats, oils, and grease
gpcd	gallon(s) per capita per day
GWRS	Groundwater Replenishment System
HCO^{3-}	bicarbonate
H_2S	hydrogen sulfide
H_2SO_4	sulfuric acid
IEUA	Inland Empire Utilities Agency
L	liter(s)
LASAN	City of Los Angeles, Bureau of Sanitation
MCL	maximum contaminant level
mg	milligram(s)
mgd	million gallons per day

Na^+	sodium
NACE	National Association of Corrosion Engineers
NCWRP	North City Water Reclamation Plant
NL	notification level
NPDES	National Pollutant Discharge Elimination System
NPR	non-potable reuse
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
O&M	operation and maintenance
POR	preferred operating range
ppm	part(s) per million
PR	potable reuse
RCP	reinforced concrete pipe
REU	residential end use
RP1	Regional Water Recycling Plant 1
SB	Senate Bill
SCVWD	Santa Clara Valley Water District
SDCWA	San Diego County Water Authority
SMCL	secondary maximum contaminant level
SVCW	Silicon Valley Clean Water
TDS	total dissolved solids
THM	trihalomethane
TOC	total organic carbon
TSS	total suspended solids
TUD	Tuolumne Utilities District
VVWRA	Victor Valley Water Reclamation Authority
WRF	Water Research Foundation
WTP	water treatment plant
WUE	water use efficiency
WWTP	wastewater treatment plant

Appendix A: Case Studies

Appendix A

Case Studies

Nine geographically diverse agencies were selected from the list of respondents, collectively experiencing a broad range of impacts resulting from declining flows. Representing a combination of water, wastewater, and recycled water systems, the agencies interviewed revealed not only the range of impacts experienced, but their technical, operational, and financial significance.

The case studies are presented in the order they appear in the main report.

San Diego County Water Authority

San Diego County Water Authority (SDCWA) is a wholesale water agency serving 24-member retail agencies, with a population of 3.3 million people and a service area of 1500 square miles. SDCWA operates and maintains the San Diego region's aqueduct delivery system, which includes 300 miles of large-diameter pipeline in two aqueducts, 1,600 aqueduct-related structures, and 100 flow-control facilities.

Major Impacts

- **More than $2 million lost to re-treat flushed water**
- **$250,000 invested in new water quality monitoring equipment**

Other major facilities in the SDCWA system include the Olivenhain Dam, its 24,000-acre-foot reservoir, and the 100 mgd Twin Oaks Valley Water Treatment Plant (Twin Oaks WTP). In December 2015, the Lewis Carlsbad Desalination Plant began commercial operation and currently provides a highly reliable local supply of up to 56,000-acre-feet per year for the San Diego region. A Water Purchase Agreement between SDCWA and Poseidon provides the terms whereby SDCWA purchases the supply and includes assurances that all water quality regulations are satisfied before deliveries are taken by SDCWA. The Water Authority also entered into long-term agreements for the transfer of conserved Colorado River supplies, which currently totals approximately 180,000-acre-feet per year. The remainder of the Water Authority's supplies are purchased as supplemental supplies from the Metropolitan Water District, which receives water from the Colorado River and the State Water Project. The water flows into San Diego through five large-diameter pipelines, which range in diameter from 48 to 108 inches. These pipelines carry either fully treated potable water or untreated water (raw water).

Impacts Experienced

Declining flows have had a variety of impacts on SDCWA, including:

- **Reduced flows in aqueducts:** Because of reduced demand from their member agencies, flows in the aqueducts have dropped from 50 to 80 percent of capacity of the pipeline (prior to 2014) to just 10 percent. Flows with historical velocities of 10 feet per second (ft/s) have declined to 1 ft/s. The decline in flow naturally increases detention time in the aqueduct, which results in increased water age and degradation of water quality.
- **Reduced conveyance system residuals:** Detention time has increased from several hours to up to 6 days in certain places within the conveyance system. Due to this increase, chlorine residuals consequently degrade. At the extremities of the aqueduct system, up to a 1 mg/L loss in residual chlorine has been experienced. The water quality continues to degrade in the member agencies' distribution systems.

- **Conveyance system nitrification:** As detention time has increased, nitrification has likewise increased within the aqueduct system, resulting in the unwanted production of nitrites in the drinking water.

Adaptation Strategies and Financial Impacts

SDCWA has proactively taken action to address the impacts described. These adaptation strategies demonstrate SDCWA's commitment to water supply reliability and water quality, but they do have a financial impact, as described below:

- **Increased flushing:** SDCWA has increased its rate of flushing to address water quality issues from increased detention time in the aqueduct. When SDCWA flushes the pipeline with treated water, it is discharged into one of two locations. It either cascades into the untreated raw water pipeline and is then purchased by agencies at the raw water rate, or the flushing water is discharged into the Terminal Reservoir. This water must be treated again before it can be used. Previously, SDCWA was flushing only 5 to 10 cubic feet per second (cfs) two to three times per year. Now, 20 to 30 cfs is flushed on average daily. The costs associated with flushing and re-treating the water have increased from $200,000 a year to over $2 million per year.
- **Investment in online monitoring equipment:** To address changing water quality in the pipeline because of loss of residual and increased nitrification activity, SDCWA has invested in the installation of multiple online water quality analyzers. These analyzers provide real-time data to control room staff to make better operating decisions.
  - **Cost of new equipment:** SDCWA has made an investment of upwards of $250,000 in new equipment to ensure water quality throughout its system.
- **Additional sampling in the field:** Operational staff members are responsible for not only controlling the water, but also managing water quality. The percentage of staff time spent performing water quality monitoring and management duties has increased from 15 percent to 35–40 percent as a result of the water quality changes observed within the system.

Santa Clara Valley Water District

The Santa Clara Valley Water District (District) provides Silicon Valley safe, clean water for a healthy life, environment and economy. That includes managing an integrated water resources system that not only provides clean water, but is dedicated to keeping residents and businesses safe through its flood protection programs and that is committed to protecting our environment through habitat restoration, cleaning toxins from water and ensuring the efficient use of water throughout our community.

The District manages 10 dams and surface water reservoirs, three water treatment plants with a total capacity of 220 mgd, an advanced recycled water purification center, a state-of-the-art water quality laboratory, nearly 400 acres of groundwater recharge ponds and more than 275 miles of streams. It provides wholesale water and groundwater management services to local municipalities and private water retailers who deliver drinking water directly to homes and businesses in Santa Clara County.

Major Impacts

- **$1.63 million in powdered activated carbon (PAC) purchased to remove total organic carbon (TOC) and taste and odor compounds**
- **An additional $150,000 from $FeCl_3$ use**
- **$350,000 in increased staff time for water quality monitoring and testing**

The District's water sources include water imported through the Sacramento-San Joaquin Delta, local surface water, groundwater and purified water produced by its Silicon Valley Advanced Water Purification Center. Imported water accounts for half of the water used in the county. The District manages the groundwater basin with local and imported water through percolation ponds and stream beds and the water purification facility produces up to 8 mgd of near-distilled-quality water.

Impacts Experienced

During the drought years, lower water volumes flowing through the Sacramento-San Joaquin Delta resulted in higher total organic carbon (TOC), higher salinity, and more taste and odor (T&O) production in the water flowing through the Delta, which made up most of the water treated at the District's three WTPs. Combined with declining flows, SCVWD's operations sustained a variety of impacts, including reduced water production from all three WTPs, changes in water quality, and subsequent operational challenges:

- **Reduced water production in the three WTPs:** During the recent extreme drought and subsequent emergency mandates, water demand decreased and water production was well below capacity. In 2013, the maximum daily water production was 161.7 mgd. In 2014, the maximum daily production was 119.8 mgd, and in 2015 the maximum daily water production was 128.4 mgd.
- **Changes in water quality:** Two of the three WTPs operated by SCVWD were converted to use ozonation for primary disinfection in 2007. These WTPs experienced fewer water quality impacts than the third plant, which is now undergoing a major overhaul. The main driver for conversion of SCVWD's WTPs to ozonation was to improve their ability to treat poor-quality source water such as that experienced in the recent drought. The ozone plants produced lower trihalomethanes (THMs) and removed T&O compounds more effectively. During the period of mandated water reduction, the third WTP (Rinconada) experienced increased THM production and some T&O issues.
- **Operational challenges because of water quality and reduced flows:** Due to reduced demand, flows declined in the water distribution system. This created the potential for the retailers located the furthest downstream to be adversely affected by abnormally high residences times.

Adaptation Strategies and Financial Impacts

SCVWD has proactively taken actions to address the impacts of declining flows. The implemented adaptation strategies included:

- **Use of PAC to remove TOC:** SCVWD was already using PAC to deal with T&O issues at the Rinconada Plant. However, in 2014 and 2015, it also used PAC to remove TOC, which came at a cost.
    - **Cost of PAC:** PAC use from 2014 to 2016 came in at $1.63 million, most of which was associated with high-TOC source water which required more TOC removal.
- **Changed chlorine injection point for WTP:** To handle changing water quality, SCVWD's Rinconada plant eliminated its chlorine injection point halfway through the clarification process. The plant instead relied on a lower chlorine dose to the filter influent, and boosted the residual post-filtration. This change was driven by drought conditions, as the original injection point had served Rinconada well prior to that time.
- **Coagulant Changes to address higher TOC:** SCVWD switched coagulants from aluminum sulfate (alum) to ferric chloride ($FeCl_3$) for approximately 3 months in 2016, and also applied a higher dose of $FeCl_3$ to achieve TOC-removal goals.
    - **Cost of ferric chloride:** $FeCl_3$ use resulted in an additional cost of $150,000 for both chemical and associated sludge disposal.
- **Increased laboratory monitoring of water quality parameters:** Due to changing source water quality, SCVWD stepped up its water quality testing frequency. The agency conducted additional THM testing, and reduced analytical turnaround times, so the results could be used to adjust operational strategies. The THM data were shared with SCVWD's retailers, increasing reporting frequency from monthly to weekly, and sometimes semi-weekly.
    - **Increased staff time:** The increased staff time to manage treatment strategies and conduct additional testing cost approximately $350,000 from 2014 to 2016.
- **Reduced distribution residual to mitigate for THMs:** SCVWD's internal goal for THMs is to remain below 80 percent of the MCL, which equates to 64 μg/L (MCL is 80 μg/L). To mitigate the production of THMs, SCVWD lowered its in-plant and effluent chlorine residuals at two WTPs. The Penitencia plant also operated with a lower clearwell level in order to reduce free chlorine contact time within the plant.
- **Established minimum flow rates in the Rinconada distribution system:** To minimize the impact of reduced flow rates on the most downstream retailer, SCVWD established minimum required flow rates with each of its retailers. This minimized detention times and maximized turnover of water despite reduced demands.

Alameda County Water District

Major Impacts

- Supplemental flushing operations was necessary to address unusually low chlorine residuals
- Suspension of the main flushing program during the drought resulted in increased sediment accumulation
- Idling of the PT Blending Facility

Alameda County Water District (ACWD) provides a reliable source of high quality drinking water to over 351,000 people in the cities of Fremont, Newark and Union City. ACWD's water system consists of nearly 900 miles of distribution pipelines, 13 water storage tanks, and numerous water pumping and regulating facilities spread out over a 100-square mile service area. As a retail water provider, ACWD is responsible for all aspects of local water service for over 83,000 direct customer service connections.

ACWD also operates 3 water treatment facilities: Water Treatment Plant 2 (WTP2) treats surface water imported from the Sacramento-San Joaquin Delta; Newark Desalination Facility uses reverse osmosis membrane technology to treat brackish groundwater from the Niles Cone Groundwater Basin; and the Peralta-Tyson (PT) Blending Facility blends imported Hetch Hetchy water with local groundwater from the Niles Cone. A fourth treatment facility, the Mission San Jose Water Treatment Plant (MSJWTP) was taken out of service in 2015. About 40% of ACWD's water is from local sources; the balance of ACWD's water supplies are imported.

Impacts Experienced

During the drought, ACWD experienced operational challenges due to conservation, reduced flows in the local water system, and degraded source water quality.

- **Lower water demand**: Due to significant conservation by ACWD customers, average daily water production decreased from 43.6 MGD prior to the drought (FY12-13) to 34.8 MGD following the drought (FY16-17). At the height of the drought, ACWD customers had reduced water demands by 27% in comparison to pre-drought levels.
- **Distribution system nitrification and areas of low chlorine residual:** Reduced water demands increased overall water age in the system. Fluctuating flow rates from ACWD's three water treatment facilities to adjust to the low demands resulted in reversals of normal flow directions and changed areas of influence for certain treatment facilities at times. As a result, ACWD experienced nitrification conditions in a greater number of water storage facilities than in the past, and to a greater extent. Additionally, some outlying areas of the distribution system with low water use and high water age experienced low chlorine residuals, which had not previously occurred.
- **Operational challenges due to reduced flows:** With reduced demands, the water treatment facilities had to be operated at lower-than-typical seasonal rates, and at variable flow rates to exercise distribution system storage and reduce water age in the system. Water storage facilities also had to be operated at lower levels to help reduce water age, which meant that less water remained in storage for use during unexpected emergencies or extended outages. These challenges increased attention to water quality monitoring, storage facility management and flushing operations which resulted in impacts on staff time and other operational needs.
- **Intermittent idling of the PT Blending Facility**: During periods of very low flows, the PT Blending Facility had to be used in an atypical low flow mode or even shut off for a few days at a time to effect turnover in the system's water storage facilities

Adaptation Strategies and Financial Impacts

ACWD took a proactive approach during and after the drought to address the impacts described above and continue to provide high-quality water under all conditions. Although not specifically quantified, many of these actions did have some level of financial impact in increased operational, monitoring, staff time or other costs as noted below.

- **Modified water storage strategies:** To address increased nitrification in the water storage facilities and reduce water age in the distribution system, ACWD's operational strategies were adapted to increase and intensify water storage cycling. This included changes in seasonal and day-to-day flow rates from water treatment facilities and adapting targets for water storage volume to the lower water demands and storage needs. However, this also resulted in less water remaining in storage for use in the event of an extended outage or emergency.
- **Increased water quality monitoring and storage facility treatments**: Due to high water age and issues with nitrification, water storage facilities were monitored more proactively to identify when supplemental chlorination treatments were needed. The frequency of supplemental chlorination treatment at the storage facilities (tanks and reservoirs) also increased, which can have potential water quality impacts. These adjustments resulted in additional staff time and overtime needs.
- **Supplemented flushing operations:** To address unusually low chlorine residuals at outlying ends of the distribution system, supplemental flushing events were required to bring fresh water into a few areas.
- **Adjusted pumping and regulating operations:** To address high water age and low chlorine residual at the end of one smaller residential zone with extremely reduced demands, adjustments were made to pumping and regulating operations to allow fresher water to pass more quickly through the zone. While this was an adjustment in only a small zone, it provides an example of how changes due to reduced demands can result in additional energy use and associated costs.
- **Shut down PT Blending Facility intermittently**: Prior to the drought, the PT Blending Facility had never been turned off for much longer than a day, and only in very rare circumstances. As a result of low flows and the need to create flow variations in the system to cycle water storage levels, the facility had to be shut down intermittently, requiring operational adjustments and extra staff time and attention.
- **Reduced RO recovery rates at Newark Desalination Facility:** To avoid overfilling the distribution system and balance the use of available water supplies while maintaining operation of facilities under low flow conditions, the recovery rate on the reverse osmosis process at the Newark Desalination Facility was reduced. Although this operation is less efficient, it allowed the plant to remain online during these periods rather than go off-line entirely, which would have impacted the life of the reverse osmosis membranes and limited ACWD's ability to use local groundwater.
- **Shutdown of Mission San Jose Water Treatment Plant (MSJWTP):** Due to significantly reduced water demands, in lieu of making needed upgrades to the 3.5-MGD MSJWTP, ACWD elected to shut down the facility for 10 or more years. This has resulted in a stranded asset and requires heavier reliance on pumping operations to higher elevation zones that were formerly served by the facility.

Tuolumne Utilities District

Tuolumne Utilities District (TUD) is a water and wastewater utility that serves nearly 44,000 residents in northern California's Tuolumne County. Ninety-five percent of its source water is snow from the Sierra Nevada, which runs through the South Fork Stanislaus River and fills the Pinecrest and Lyons reservoirs. The last 5 percent of its supply is from 30 groundwater wells.

Major Impacts:

- **Purchase of Persnickety lids to mitigate increased odors**
- **Costs of pipe patching to address increased root intrusion**

TUD's main source water is the Lyons reservoir, which flows through canals, pipes, and open ditches until it reaches the WTPs, at which point it goes through a rigorous treatment process to turn it from raw water into drinking water. TUD currently owns and operates 14 WTPs, 9 of which intake water directly from the ditch system, and the rest draw raw water from small reservoirs.

TUD also operates a wastewater management system and treats 1.2 mgd of sewage at the Sonoma Regional WWTP. TUD uses approximately 140 miles of a gravity collection system and 20 miles of force main to collect between 400 and 500 million gallons of sewage per year. There are 29 individual pump stations at various locations throughout the collection system, and 1 satellite treatment plant discharges effluent overnight into the main Sonoma Regional WWTP.

Impacts Experienced

Declining flows have had a variety of impacts on TUD, including reduced dry weather flow, decreased flows in the collection system, and increased root intrusion:

- **Reduced dry weather flow:** TUD has experienced a decline in dry weather flow over time. It has decreased to 1.2 mgd of wastewater influent at the Sonoma Regional WWTP, which is well below its design capacity.
- **Reduced flows in the collection system:** TUD's collection system was designed over a 100 years ago on typical specifications for toilets, washing machines, and other indoor residential appliances at the time of its inception. With increased water efficiency standards for indoor plumbing and appliances, pipes are not getting flushed out as effectively. Yet for gravity collection systems, water is the power that pushes the debris. Reduced flows have therefore had several impacts such as:
  - **Increased settling in the larger-diameter lines:** As flows have decreased in the collection system, there is less water to flush the debris. Thus, settling has increased in the larger-diameter pipelines.
  - **Increased sanitary sewer overflow:** The TUD collection system is mostly small-diameter pipelines (i.e., 15 inches or smaller). In fact, 65 percent of the system is 4- and 6-inch-diameter pipe. Such small pipes are prone to blockages, which are only exacerbated by reduced flows. In these situations, any amount of debris leads to sewer sanitary overflows and blockages.
  - **Significant increase in work order calls for lateral pipelines:** The increased settling and blockages have manifested in an increase in work order calls, especially for lateral pipelines.
  - **Increased odors:** The declining flows have also resulted in an increase in H_2S, which generates additional odors.

- **Increased root intrusion:** Gravity collection systems are not designed to have debris and wastewater sitting in a single location. When there is a blockage, any crack or pinhole has the potential to leach moisture. TUD has observed increased root intrusion in these locations, causing further separation and cracks.

Adaptation Strategies and Financial Impacts

TUD has proactively taken action to address the impacts described above. These adaptation strategies include:

- **Increased maintenance of the collection system:** TUD has always maintained a hot spot list that TUD staff would routinely check. As flows have declined, TUD has added locations to that hot spot list. It has also increased collection system surveys, and smaller service trucks are being sent out more often to monitor the manholes.
- **Proactive pipe patching:** TUD has implemented a pipe patching system to counter the increased root intrusion. When there is a root intrusion, TUD cleans the inside of the pipe and then cures a fiberglass material as an internal liner. The benefits are twofold: (1) it patches the pipe and reduces leakage, and (2) given that the fiberglass is smoother than the traditional gravity collection pipe, it helps to move the wastewater.
- **Installed Persnickety lids to address odor problems:** To address the increase in odors, TUD has installed about 20 PERSNICKETY lids, which are oxidizing filters that sit under the manhole cover. The gravity collection system naturally breathes air in and out of the system, and the filter cleans the odors as it passes through.

Victor Valley Water Reclamation Authority

The Victor Valley Water Reclamation Authority (VVWRA) operates as a Joint Powers Authority and serves four member agencies, including San Bernardino County Service Areas 42 (Oro Grande) and 64 (Spring Valley Lake), City of Hesperia, Town of Apple Valley, and City of Victorville. It provides wastewater treatment services through 42 miles of wastewater conveyance systems and a treatment facility that treats roughly 10.7 mgd.

Major Impacts

- More than $300,000 per year over the last 5 years in mitigating corrosion in the wastewater collection system

Its WWTP is a conventional activated sludge facility that discharges into the Mojave River, which is a terminal river that does not flow to the ocean. Thus, the facility is bound by stringent regulatory water quality requirements. In addition, due to the value of water in the Mojave area, VVWRA decided to treat all wastewater effluent to Title 22 standards to maximize its reuse potential. This is done through the addition of tertiary filtration and ultraviolet (UV) disinfection. After being purified, the reclaimed water is sent to percolation ponds, reused, or discharged into the Mojave River.

Impacts Experienced

Being in the Mojave region, water use efficiency as a water supply reliability measure was already being emphasized prior to the governor's mandate in 2014. VVWRA started experiencing reductions in flows as early as 2010, as local wholesalers went to extensive means to implement water use efficiency. By the time the governor enacted the mandatory reductions, local water use had already been reduced significantly, even beyond the 20 to 30 percent mandated by the State. Thus, VVWRA has seen the impacts of declining flows for several years. Because of the stringent nature of its discharge requirements, the impacts of declining flows, including increased ammonia concentrations in the wastewater influent and increased H_2S in its collection system, are acute, as indicated below:

- **Declining wastewater influent reduces wastewater effluent volumes**: Given its inland location, VVWRA relies on river discharge rather than an ocean outfall. Based on base flow requirements set by CA Fish and Wildlife, VVWRA is required to discharge 8.2 mgd per day to the river. The declining wastewater influent therefore reduces the amount of water available for recycling. The less recycled water is available for end-users, the more customers must rely on potable resources (groundwater).
- **Increased ammonia concentrations in wastewater influent:** Current ammonia concentrations in the wastewater influent are much higher than those recorded prior to 2010. While influent ammonia concentrations averaged in the mid to high 20s mg/L prior to 2010, VVWRA currently sees concentrations between 30 and 40 mg/L. Low-flow shower heads, low-flow toilets, and sink aerators have all decreased the amount of flow going into the wastewater system, subsequently increasing concentrations.
- **Increased H_2S in the collection system:** Much of the gravity collection system was designed to handle flows consistent with design standards of the 1980's, which would convey the solids to the WWTP. However, as flows entering the wastewater conveyance system have decreased, the solids have lost their transport medium. Thus, solids remain in the wastewater conveyance system for longer periods, producing an increased amount of H_2S. This results in:
    - **Increased odors and odor complaints:** The increase of H_2S produces more odors, which subsequently generates more odor complaints.
    - **Accelerated rate of corrosion and degradation of infrastructure:** Because of the increased H_2S, VVWRA has witnessed an acceleration of corrosion in its collection system, primarily at its manholes.

Adaptation Strategies and Financial Impacts

VVWRA has proactively taken the following steps to address the impacts it has experienced as a result of declining flows:

- **Increased rehabilitation and maintenance of collection system manholes:** To combat the accelerated rate of corrosion in the manholes, VVWRA has begun coating its manholes in epoxy. To proactively mitigate future corrosion, VVWRA has also updated its specifications for manhole coatings and is exploring alternative materials to concrete for manholes to mitigate the accelerated corrosion.
    - **Investment in the epoxy coating:** VVWRA has spent $300,000 per year over the past 5 years to address increased corrosion in its collection system.
- **Increased maintenance frequency of the collection system:** VVWRA has a third-party maintenance contract that services the locations that need to be cleaned. The entire collection system is cleaned once every three years, and areas of low flow are being cleaned more regularly to prevent the buildup of H_2S and reduce the potential for sanitary sewer blockages and overflows.
- **Coordinating with member entities to operate pump stations to reduce H_2S:** Initially, VVWRA had to use more bioxide to overcome system deficiencies. However, due to their investment in lining their manholes, VVWRA has been able to decrease their annual bioxide use. Another part of the strategy to combating odor was also coordinating closely with their member entities to train them on how to operate their pump stations to reduce H_2S.

Los Angeles Department of Water & Power and the Los Angeles Bureau of Sanitation

The Los Angeles Department of Water and Power (LADWP) was established in 1902 to deliver water to the City of Los Angeles (LA). It serves over 4 million residents through 96 pump stations and 7,300 miles of pipe.

The Los Angeles Bureau of Sanitation (LASAN) provides wastewater services through the operation of sewers, water reclamation plants, and biosolids management. LASAN operates more than 6,700 miles of sewers that convey about 400 MGD of flow to the City's four wastewater treatment and water reclamation plants.

Major Impacts

- **Additional manual labor necessary to remove large influxes of trash that buildup in the sewer system**
- **Designing new infrastructure to divert flows to the DC Tillman Water Reclamation Plant**

Impacts Experienced

Declining flows has had a variety of impacts on the urban water cycle in LA, including:

- **Reduced flows in the WWTPs:** Hyperion is designed to accommodate a flow of 450 MGD. In the summer of 2012, the average flow going to the Hyperion Water Reclamation plant was 285 MGD. Now, average flows going to Hyperion are around 250 MGD.
- **Declining flows for future groundwater recharge projects:** LASAN and LADWP are currently designing an expansion of the treatment process at the DC Tillman Water Reclamation Plant to implement groundwater recharge. The reduced flows going to WWTPs has required LASAN to divert flows from other locations to supplement the reduced flows.
- **Lower flows lead to an increase in nitrogen concentrations:** Due to declining flows, the nitrogen concentration in the influent wastewater at Hyperion has increased from 35 to 45 mg/L over the past decade. Higher nitrogen levels require additional nitrification. While Hyperion does not nitrify, it does convey 15 percent of its effluent to partner agencies, who then treats the water to different water quality standards depending on the reuse application. Wherever nitrification is necessary for the application, the increase in ammonia can present a significant challenge to meeting end-user water quality requirements.
- **Large and bulky influx of trash associated with wet weather events:** Due to declining flows, food waste and sanitary-type trash is getting stuck in the collection system. Then, when a large wet weather event occurs, the built-up debris is suddenly swept to the water reclamation plant, overloading its automatic raking system.
- **Increase in H_2S production:** As described in the white paper, declining flows in the wastewater conveyance system leads to an increase in H_2S production. This exacerbates odor production, leading to an increase in odor mitigation methods.

Adaptation Strategies and Financial Impacts

Due to the robustness of the LADWP and LASAN water and wastewater systems, they have been able to handle the impacts to the system effectively without too many changes. However, adaptation strategies have been implemented, including:

- **New infrastructure to supplement declining flows at DC Tillman:** Due to declining flows going to WWTPs, LASAN has been proactively and creatively looking for ways to divert supplemental flow to DC Tillman. The East/West Valley Interceptor is one of those projects, and other potential projects are being evaluated.

- **Managing large influxes of trash through manual labor:** When the automatic raking systems are overwhelmed by the sudden and large influx of trash, LASAN must manually pull trash out using manual rakes or a Bobcat.
- **Increasing chemical injection and potential upsizing of existing carbon scrubbers**: The increase in H_2S production has resulted in an increase in chemical injection and recommendations to upsize 3 of the 7 existing carbon scrubbers.

LASAN has also experienced *beneficial* financial impacts due to declining flows. For example, the treated effluent at Hyperion is pumped 5 miles to the ocean outfall with discharge pumps. Since wastewater influent has decreased, the energy required to pump the wastewater has also decreased. 15 years ago, the treated effluent pumps were operated daily. Now, the treated effluent flows by gravity, and the pumps are only necessary when it rains, resulting in significant energy savings.

Orange County Water District and Orange County Sanitation District

Orange County Water District (OCWD) and Orange County Sanitation District (OCSD) collaborate to provide water supply reliability in their Orange County service area.

Major Impacts

$60 million to segregate non-reclaimable flows from the water conveyed to GWRS

OCWD owns and manages 6 miles of the Santa Ana River, and the approximately 500,000 acre-feet Orange County Groundwater Basin. It also co-manages the Groundwater Water Replenishment System (GWRS) with OCSD, which is the world's largest advanced water purification system for PR through groundwater augmentation.

OCSD provides wastewater collection, treatment, and disposal services for approximately 2.6 million residents in northwest and central Orange County. It operates two facilities, Plant 1 in Fountain Valley and Plant 2 in Huntington Beach, which treat wastewater from residential, commercial, and industrial sources. GWRS currently receives reclaimable water effluent from Plant 1 alone. The balance of flows, including non-reclaimable flows from the Santa Ana River Interceptor, which carries industrial inputs and RO concentrate from inland brackish water desalters, are treated at Plant 2. To meet the flow requirements of the initial expansion of GWRS to 100 mgd of purified water production, OCSD diverts flows within its system to increase the flow through Plant 1 for reclamation at GWRS.

Impacts Experienced

Given that flow otherwise destined for Plant 2 is currently diverted to Plant 1 to maximize reuse through GWRS, the effects of declining flows are experienced more acutely at Plant 2. The impacts are described below:

- **Reduced flows in the WWTPs:** In the 2000s, the total combined flow of Plant 1 and Plant 2 was 240 mgd. Now, the combined flow of both plants is approximately 185 mgd. The decline in flows reduces the wastewater effluent available to be purified and used for groundwater augmentation.
- **Increased detention time of wastewater in conveyance system:** Because of declining flows, wastewater remains in the conveyance system for longer periods. With that extended time comes the danger of the wastewater going septic. OCSD has also noticed increased deposition as a result of lower flows.
- **Increased grease buildup and settlement at Plant 2:** With the flow diversions implemented to purposefully redirect flow to GWRS, Plant 2 consequently experiences lower flows, which leads to grease buildup and settling within the treatment process at Plant 2.

Adaptation Strategies and Financial Impacts

OCSD and OCWD have proactively taken action to address the impacts described above. These adaptations are described below:

- **Increased chemical addition in the conveyance system:** To counteract the wastewater from going septic, OCSD has increased the amount of chemicals it has dosed into its system.
- **Change in conveyance operations to mitigate impacts from low flows:** The flows to Plant 2 have been impacted both by declining flows and the increased diversion of wastewater to Plant 1. To mitigate the impacts of increased settling at Plant 2, OCSD leverages its diversion structures to channel flows into fewer pipelines. For example, instead of having four pipelines with low velocity, OCSD diverts the flows into two pipelines to regain that scouring velocity. Then every couple of months, it changes the pipelines to flush them out.

- **Supplementing GWRS feed water flows with Plant 2 effluent:** With the substantial decline in OCSD's influent flows, the upcoming GWRS final expansion to 130 mgd will require flow to be conveyed from Plant 2 to GWRS for purification. The Plant 2 effluent requires additional investment by OCSD and OCWD to segregate non-reclaimable flows and to purify effluent with a more challenging water quality.
- **Segregation of high-salinity flows to maximize reclamation:** The flow received at Plant 2 contains industrial discharge as well as RO concentrate from inland desalters. As California prepares for increased frequency, intensity, and duration of future droughts, inland water agencies seek out and treat more challenging local water supplies like brackish groundwater to improve supply reliability. This high-TDS flow is currently processed at Plant 2, the effluent from which is destined for purification at GWRS as part of the final expansion. To prevent this highly saline flow from negatively impacting the purified water produced at GWRS, OCSD has invested $60 million to segregate these non-reclaimable flows from the water conveyed to GWRS.

Appendix B: Table of Utilities

Appendix B

List of Agencies that Responded to the Survey

Table B-1. List of Agencies that Responded to the Survey and Experienced Impacts					
	Services Provided				
Agency Name	Water	Recycled Water	Wastewater	Service Area	Experienced Impacts
Alameda County Water District	✓			100,001 – 1M	✓
Amador Water Agency	✓		✓	<100,000	✓
Central Marin Sanitation Agency			✓	100,001 – 1M	✓
City of Camarillo/Camarillo Sanitation District	✓	✓	✓	<100,000	✓
City of Fairfield	✓			100,001 – 1M	✓
City of Fontana	✓		✓	<100,000	
City of Fresno	✓	✓	✓	100,001 – 1M	✓
City of Los Angeles, Bureau of Sanitation		✓	✓	> 1M	✓
City of Modesto	✓	✓	✓	100,001 – 1M	✓
City of Pacifica			✓	<100,000	✓
City of Palo Alto		✓	✓	100,001 – 1M	✓
City of Patterson	✓		✓	<100,000	✓
City of Pismo Beach	✓		✓	<100,000	✓
City of Rialto	✓	✓	✓	<100,000	✓
City of San Diego	✓	✓	✓	>1M	✓
City of San Juan Capistrano	✓	✓	✓	<100,000	✓
City of San Luis Obispo	✓	✓	✓	<100,000	✓
City of Santa Barbara		✓	✓	<100,000	✓
City of Santa Clara	✓	✓	✓	100,001 – 1M	✓
City of Scotts Valley		✓	✓	<100,000	✓
City of Stockton			✓	<100,000	✓
City of Vacaville	✓	✓	✓	<100,000	✓
Coachella Valley Water District	✓	✓	✓	100,001 – 1M	✓
Contra Costa Water District	✓			100,001 – 1M	✓
Delta Diablo Sanitation District		✓	✓	100,001 – 1M	✓
East Bay Municipal Utility District	✓	✓	✓	> 1M	✓
East Orange County Water District	✓		✓	<100,000	✓
Eastern Municipal Water District	✓	✓	✓	100,001 – 1M	✓
El Dorado Irrigation District	✓	✓	✓	100,001 – 1M	✓
Goleta Sanitary District		✓	✓	<100,000	✓
Idyllwild Water District	✓		✓	<100,000	✓
Jurupa Community Services District	✓		✓	100,001 – 1M	✓
Kern County Water Agency	✓			100,001 – 1M	✓
Kinneloa Irrigation District	✓			<100,000	✓

Table B-1. List of Agencies that Responded to the Survey and Experienced Impacts

	Services Provided				
Agency Name	Water	Recycled Water	Wastewater	Service Area	Experienced Impacts
Lake Arrowhead Community Services District	✓	✓	✓	<100,000	✓
Los Angeles Department of Water and Power	✓	✓		>1M	✓
Mammoth Community Water District	✓	✓	✓	<100,000	✓
Metropolitan Water District of Southern California	✓			>1M	✓
Mission Hills Community Services District	✓		✓	<100,000	✓
Monterey Regional Water Pollution Control Agency		✓	✓	100,001 – 1M	✓
Mt. View Sanitary District			✓	<100,000	✓
Municipal Water District of Orange County	✓			> 1M	✓
Orange County Sanitation District			✓	> 1M	✓
Orange County Water District		✓		> 1M	✓
Oro Loma Sanitary District			✓	100,001 – 1M	✓
Otay Water District	✓	✓	✓	100,001 – 1M	✓
Padre Dam Municipal Water District	✓	✓	✓	100,001 – 1M	✓
Rincon del Diablo Municipal Water District	✓	✓		<100,000	✓
Sacremento Regional County Sanitation District			✓	<100,000	✓
Sacremento Suburban Water District	✓			100,001 – 1M	✓
San Bernadino Valley Water Conservation District	✓			100,001 – 1M	
San Diego County Water Authority	✓			> 1M	✓
San Francisco Public Utilities Commission	✓	✓	✓	> 1M	✓
Santa Clara Valley Water District	✓	✓		> 1M	✓
Santa Margarita Water District	✓	✓	✓	100,001 – 1M	✓
Sausalito Marin City Sanitary District			✓	> 1M	✓
Scotts Valley Water District	✓	✓		<100,000	✓
Silicon Valley Clean Water		✓	✓	100,001 – 1M	✓
South Coast Water District	✓	✓	✓	<100,000	✓
South Orange County Wastewater Authority	✓	✓	✓	> 1M	✓
South Tahoe Public Utility District	✓	✓	✓	<100,000	✓
Sunnyslope County Water District	✓		✓	<100,000	
Tuolumne Utilities District	✓	✓	✓	<100,000	✓
Union Sanitary District			✓	100,001 – 1M	✓
Valley Center Municipal Water District	✓	✓	✓	<100,000	✓
Valley County Water District	✓			<100,000	✓
Veolia Water			✓	<100,000	✓
Victor Valley Wastewater Reclamation Authority		✓	✓	100,001 – 1M	✓
Vista Irrigation District	✓			100,001 – 1M	✓
West Bay Sanitary District		✓	✓	<100,000	✓
Western Municipal Water District	✓	✓	✓	100,001 – 1M	✓
Yucaipa Valley Water District	✓	✓	✓	<100,000	✓
Zone 7 Water Agency	✓			100,001 – 1M	✓

Per data collected on October 13, 2017.