California State Water Resources Control Board

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Summary of Environmental Effects

Evaluating effects of urban water use efficiency standards (AB 1668-SB 606) on urban retail water suppliers, wastewater management agencies, and urban landscapes (trees and urban parklands)*

** The report, as shared on May 9, 2022, only contains the evaluation of the urban water use efficiency standards on wastewater management. The work on urban retail water suppliers and urban landscapes (trees and urban parklands will be incorporated at a later date).*

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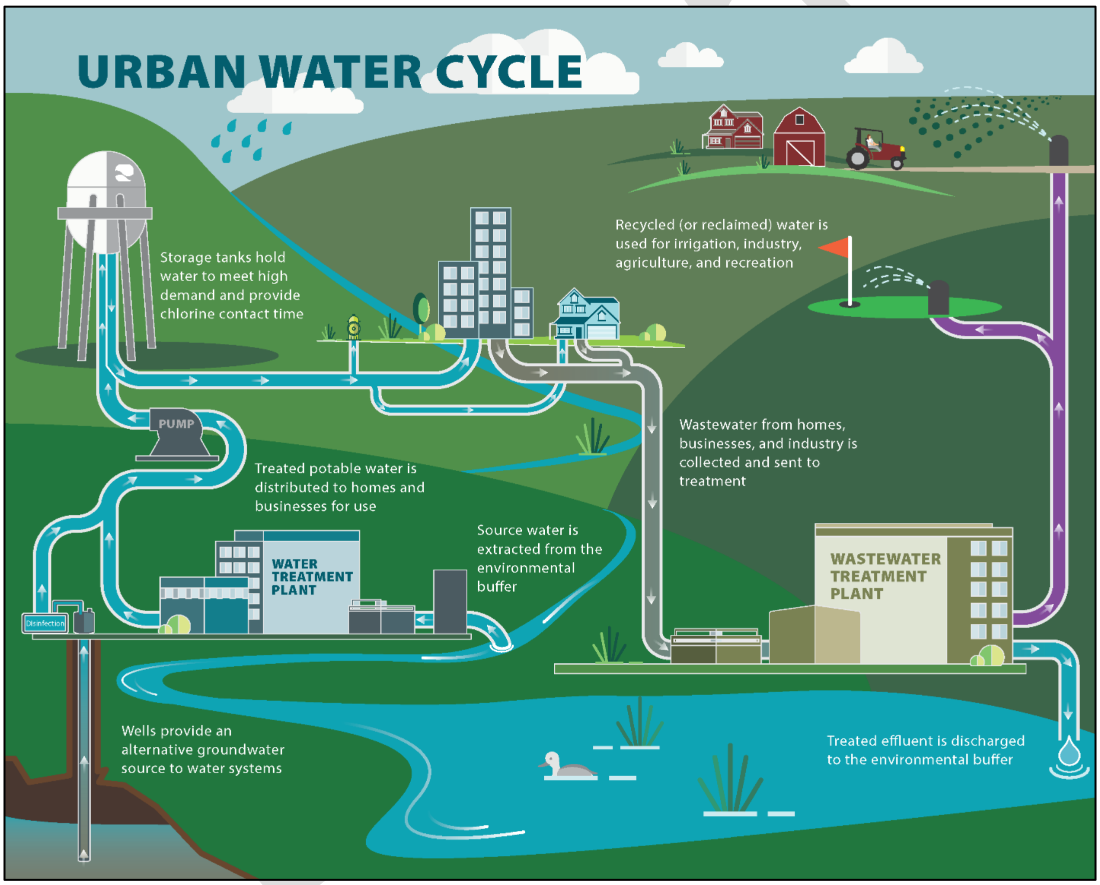
Wastewater Management

Wastewater management systems provide critical services to modern industrial societies. Pipe networks span cities, removing sewage from buildings and conveying it to wastewater treatment and recycling plants. Treatment plants process the sewage through multiple steps to meet increasingly stringent standards of environmental quality. Treatment processes remove many types of pollutants, from suspended solids and bacteria to nitrates and ammonia. Effluent and residual solids from wastewater treatment are discharged to local waterways, the ocean, and sometimes land. Within the urban water management cycle, collection and treatment systems are a critical link to ensuring continual water of sufficient quality and quantity for environmental needs and supply (Figure 6-1).

Figure 6-1: Visualizing the urban water cycle



Note: Source: Office of Water Programs at Sacramento State.

The sections below describe the steps used to identify potential effects of lower flows for wastewater management, evaluate mitigation and adaptation options, assemble available data sources, model potential impacts on wastewater management systems related to AB 1668-SB 606, and estimate effects. Findings from outreach, which were used to calibrate and interpret results from modeling and analysis, are also described.

1.1. Potential Effects of Lower Flows on Wastewater Management Systems

Reductions in water use from conservation and long-term efficiency can directly affect the volume of influent that reaches wastewater treatment plants (DeZellar and Maier 1980; Koyasako 1980). Federal, state, and local policies and incentive programs have emphasized efficient indoor fixtures for several decades (DeOreo et al. 2011; Diringer et al. 2018). When water supply agencies make investments to reduce consumption in homes, businesses, and industrial facilities, it reduces the base flow of wastewater that is generated and sent to collection systems. The rate of change in water use reductions interacts with population growth, climate factors, and system characteristics to yield a cumulative effect on flows, which may range from negligible to significant.

Beyond conservation actions, a broader series of potential changes in urban water use habits and infrastructure also affects existing wastewater operations (Table 6-1). For instance, controlling the introduction of constituents to wastewater streams at the source within industrial or commercial facilities can help reduce constituent loading. Additionally, implementing reuse of greywater from sinks and dishwashers can reduce potable water demand, but also decrease input flows that reach wastewater facilities. Decentralized reuse technologies for treating wastewater to meet nonpotable local needs can save energy when small reuse plants serve urban areas that are distant from an existing centralized treatment facility (Kavvada et al. 2016). The effects of various actions such as low-flow toilets are not evenly dispersed throughout the day, but may provide sufficiently consistent flows to reduce risk of sewer blockages and other adverse effects (Penn et al. 2013).

Household actions that do not involve water use can also significantly affect wastewater collection and treatment systems. Using garbage disposals can increase solids accumulation in conveyance systems and the concentration of suspended solids in wastewater influent, but composting can help decrease constituent concentrations in influent and mass loading. Water softeners, which are frequently used to reduce salinity levels in drinking water in homes, can significantly increase Total Dissolved Solids (TDS) in wastewater influent when the waste streams of such devices are diverted to the sewer system (SCSC 2018).

Table 6-1: Summary of factors that can impact wastewater systems

		Expected impact on wastewater management					
Strategy or activity	**Examples**	Water demand outdoor [a]	Water demand indoor [a]	Wastewater concentration	Wastewater flowrate	Wastewater mass loading	Wastewater toxicity / salinity
Reduced flow appliances and fixtures	Waterless urinals Low-flow toilets & shower heads Point of use water heating	No Change	Decrease	Increase	Decrease	No Change	Increase
Greywater use outdoors	Laundry to landscape irrigation	Decrease	No Change	Increase	Decrease	Decrease	Decrease
Greywater use indoors	Greywater treatment and reuse for indoor usage	No Change	Decrease	Increase	Decrease	No Change	Increase
Rainwater supply	Roof runoff for toilet flushing	Decrease	Decrease	No Change	No Change	No Change	Decrease
Outdoor recycled water	Recycled water to landscape	Decrease	No Change	No Change	No Change	No Change	No Change
Indoor recycled water	Recycled water for toilet flushing	No Change	Decrease	Increase	No Change	Increase	Increase
Food waste grinders	In-sink garbage disposal	No Change	No Change	Increase	No Change	Increase	No Change
Home composting	Onsite food waste management	No Change	No Change	Decrease	No Change	Decrease	Decrease
Source control	Product reformulation Onsite pretreatment Food waste diversion Urine diversion Water softeners (salt based)	No Change No Change No Change No Change No Change	No Change No Change No Change Decrease No Change	No Change Decrease Decrease Decrease Decrease	No Change No Change No Change Decrease Increase	No Change Decrease Decrease Decrease No Change	Decrease Decrease No Change Decrease Increase
Satellite systems for outdoor reuse	Onsite wastewater treatment and recycle to outdoor usage	Decrease	No Change	Increase	Decrease	Decrease	No Change
Satellite systems for indoor reuse	Onsite wastewater treatment for indoor toilet flushing	No Change	Decrease	Increase	Decrease	Decrease	Increase
Reactions during transport	Hydrolysis and anaerobic decay	No Change	No Change	Decrease	No Change	Decrease	No Change

Notes: Created by authors. [a] indicates factors from water supply from an outside provider.

Drought can exacerbate the effects of ongoing changes in behavior and water use. During the recent 2012–2016 drought, many wastewater agencies reported noticeable changes in wastewater influent that required changes. For instance, through a survey of 133 wastewater agencies conducted by the Public Policy Institute of California, agencies reported many effects of the drought and water conservation on systems. Over 80 percent witnessed declines in influent flows, and over 60 percent observed changes in influent quality. One-third had to take adaptive actions to maintain water quality from changes in influent quality. The survey elicited ranked (ordinal) responses, but did not include quantifications of effects (Chappelle et al. 2019).

Similarly, the California Association of Urban Water Agencies (CUWA) surveyed agencies to understand the effects of reduced flows on many types of urban water systems, including wastewater collection and treatment. Correlations in reduced sewage influent flows and conveyance system blockages were reported. This potentially points to the need for more adaptive actions such as system flushing, but may also indicate older ill-maintained systems with existing blockages or root intrusion issues that were exacerbated by low flows.

1.1.1. Effects on Wastewater Collection Systems

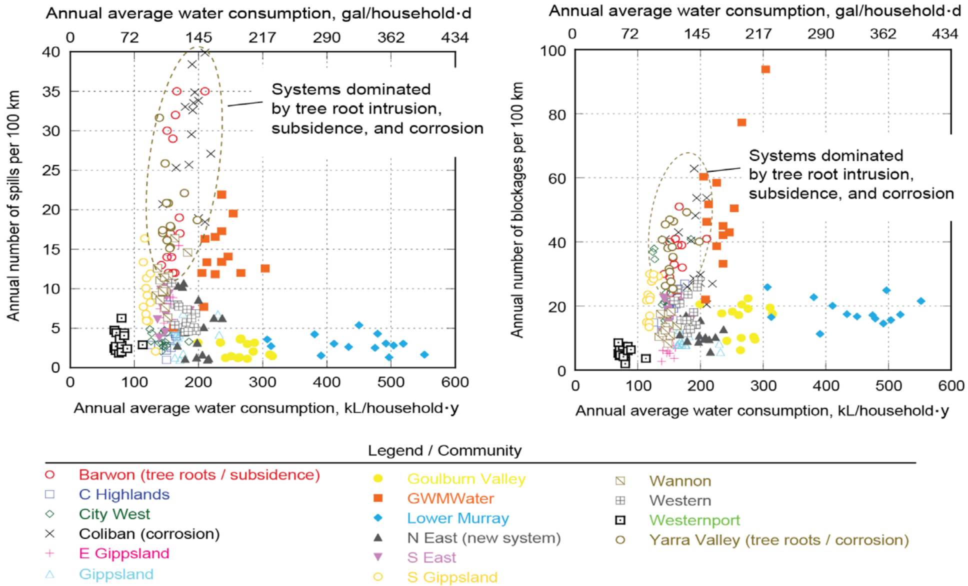
When evaluating the impacts of reduced flows on conveyance systems, two major phenomena must be considered: (1) solids accumulations, and (2) biochemical reactions leading to septic conditions. Accumulated solids lead to pipe blockages.

Sewer systems depend on the flow of wastewater to transport solids to a treatment plant. For a given pipe size, lower flows lead to increased sediment settling and decreased bedload transport, resulting in an accumulation of wastewater solids. A historic study in California identified that typical sanitary sewers would not maintain sufficient flows to ensure flushing when flow velocities fell to 40% or less of full capacity (DeZellar and Maier 1980). During the 2011–2016 drought, 27% of respondents reported increased frequency of blockages as flows declined (Chappelle et al. 2019).

Tree root damage to sewer lines is another potential outcome from lower flows. Case studies from other global regions indicate that tree root intrusion issues can correspond with effects of drought and lower flows, but effects are not consistent and system characteristics are important contributors that can mitigate or exacerbate effects. For instance, in Figure 6-2 showing data from Australia, several systems with lower influent flow rates had higher rates of root intrusion, but many systems with similar influent flow rates did not.

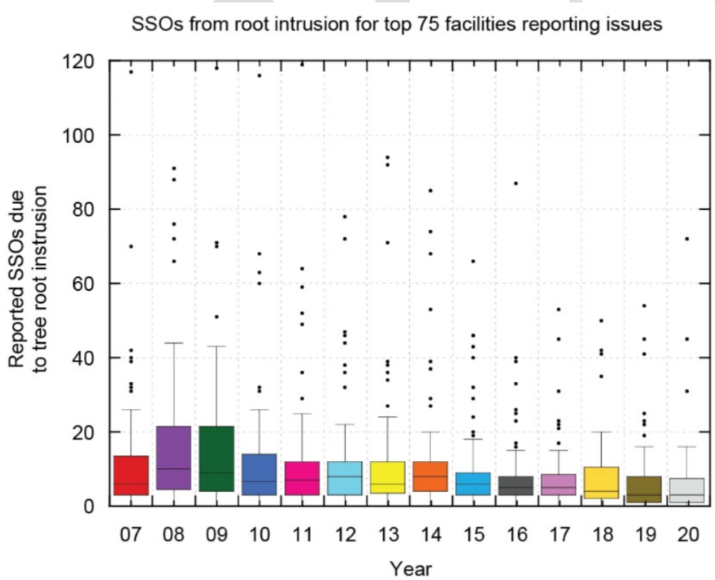
In California, sewer systems report tree root intrusion and blockage issues as a cause of Sewer System Overflow (SSO) events. This is the only source of centralized data on such effects in the state. From reported events, there is a decreasing trend in the number of reported SSO events related to tree root intrusion over time (Figure 6-3). However, SSO reports only capture a portion of actual tree root intrusion issues, and variations in regulatory enforcement across Regional Water Boards in California may lead to different outcomes for reported events.

Figure 6-2: Summary of 2005 to 2019 data from the Victoria Essential Services Commission (ESC) on the Normalized incidence of spills (left) and blockages (right) for each year as a function of the annual average water usage rates for sewer agencies in Victoria, Australia



Notes: Data obtained by authors. Source: Victoria Essential Services Commission, 2020. A diversity of factors can affect the prevalence of spills, with certain agencies particularly prone to sewer system failures.

Figure 6-3: Reported Sewer System Overflow (SSO) events in California from 2007 through 2020



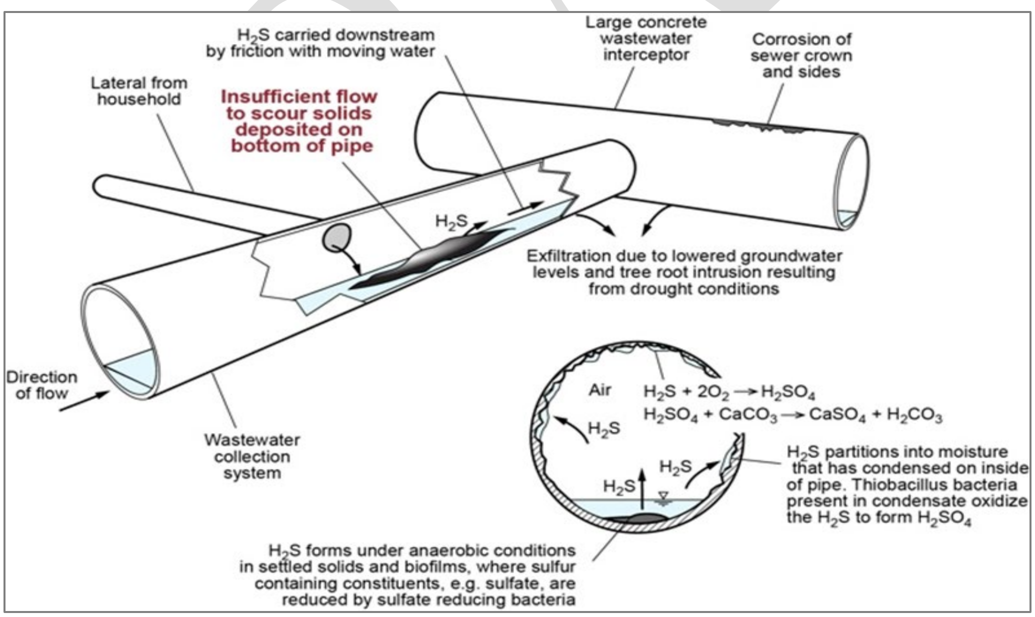
Note: Author calculations and graph based on data from the State Water Board's Sewer System Overflow database.

Low flows lead to slower velocities and longer hydraulic residence times in pipe system. With lower rates of indoor water use, wastewater influent is more likely to be become septic or fermented under anaerobic conditions from low flow velocities in the collection system. Septic influent wastewater can have a variety of impacts, including odors at primary and secondary clarifiers, odors at wet wells and thickeners, bulking in thickeners, and sludge bulking in clarifiers (Koyasako 1980).

In addition, efficient plumbing fixtures dilute the same pollutant mass load into smaller volumes, leading to higher concentrations. Solids deposits also result in elevated pollutant concentrations. Higher concentrations promote faster biochemical reactions in the wastewater. In particular, aerobic degradation of organic compounds depletes the wastewater of oxygen, leading to septic (anaerobic) conditions (Figure 6-4). Under anaerobic conditions, microorganisms chemically reduce sulfate ion (SO^{-2}_4) to hydrogen sulfide (H_2S). For instance, during the 2012–2016 drought, over half of wastewater agency respondents reported increased odor problems and more operations and maintenance costs for conveyance systems, according to a survey by the California Association of Urban Water Agencies (CUWA) (WRF 2017).

Energy savings may be associated with pumping less water. Even though wastewater treatment plants are located at the lower end of gravity conveyance systems, pumping costs can be substantial. Most collection systems including pumping operations, while nearly all treatment facilities include a pumping station to bring the wastewater from the sewer up to ground-level. In flat areas, pumps must periodically raise water from deep sewers to shallow sewers so that gravity flow can be maintained.

Figure 6-4: Creation of septic conditions and generation of hydrogen sulfide in collection systems with lower flows



Note: Figure courtesy of George Tchobanoglous.

1.1.2. Effects on Wastewater Treatment Systems

Wastewater Treatment Facilities (WWTFs) face multiple current challenges that result from the combined effects of aging systems, changing influent characteristics, topography, and climate change. Changes in influent flow rates from water use efficiency and conservation exacerbate operational challenges. Facilities are designed to operate within particular specifications of influent flow and concentrations to meet treatment efficiency requirement.

Lower influent flow rates can result in higher concentrations of constituents, which instigates mitigation actions such as increased use of chemicals in wastewater treatment facilities (WRF 2017). Lower flows can also affect effluent water quality. For instance, during the 2012–2016 drought, analysis of data from case study facilities noted found that a) effluent ammonium increased from 35 to 55 mg/L from 2010 to 2016, respectively, b) effluent ammonia toxicity also increased during the same time period, and c) effluent nitrate and total phosphate increased from 10 to 15 mg N/L and 2 to 4 mg P/L, respectively, for the period from 2005 to 2015 (Sawyer 2017).

Salinity is a significant management challenge for wastewater treatment. For thirty-four WWTFs within the Inland Empire Utility Agency, reductions in per capita use were correlated with increased salinity in wastewater influent. Additionally, mandated water conservation during the drought was correlated with a measurable contribution to the increases in salinity (Schwabe et al. 2020). However, the quality of influent water supply to the wholesale or retail agency has a significant impact on wastewater influent quality. A study commissioned by the Southern California Salinity Coalition (SCSC) used statistical analysis to identify measurable salinity increases associated with long-term flow reductions associated with water use efficiency. A 1 gpd unit decrease in consumption results in a 1–2 mg/L increase in salinity. This change was significantly smaller than the salinity contributions of the water supply influent, along with local influences of household water softeners that measurably contribute to TDS in wastewater.

1.1.3. Effects on Wastewater Reuse

Effects on recycled water production may result from volumetric and composition changes of influent associated with water use efficiency and conservation. For instance, reduced influent flows may affect current or future expected recycled water production and planned deliveries to end-users. Of the centralized wastewater systems in California, about 37 percent produce recycled water. A quarter of these facilities (54) distribute nearly all of the effluent produced to end-users throughout the entire year

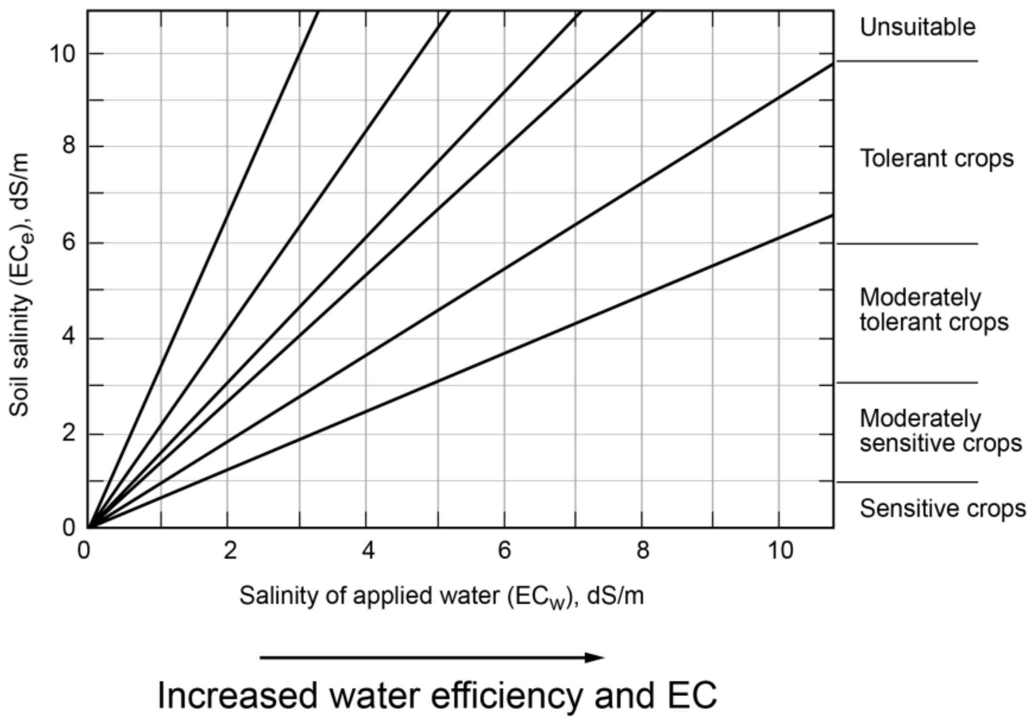
Water quality impacts also result from lower flows. Reduced rates of indoor water use may increase the concentration of constituents not typically removed with a municipal WWTF, including dissolved salts and organics. High concentrations of Total Dissolved Solids (TDS) in recycled water effluent can limit the potential for some types of water reuse. Constituents such as iron and humic acids can interfere with UV disinfection as concentrations increase.

Finally, the concentration of trace constituents in effluent and receiving water will likely increase. For example, pharmaceutical residues in effluent contributes to the potential for development of antibiotic resistant genes (ARGs) in recycled water and in the environment (Barker-Reid et al. 2010).

Such impacts may generally increase costs to produce recycled water, but the quality of recycled water is unlikely to change significantly if reuse managers undertake mitigation and adaptation actions to address process changes. There may also be the potential for an increase in demand for recycled water with increased variability of current supplies and declining groundwater levels in some regions.

Irrigation end-uses may be sensitive to changes in effluent salinity. Irrigation, which is the largest end-use of recycled water, is seasonally-driven, with demand for recycled water greatest in dry weather periods with reduced infiltration and inflow to boost influent. As shown on Figure 6-5, higher salinity of irrigation water from indoor water conservation and improved irrigation efficiency can increase soil salinity. The presence of certain constituents in recycled water, such as boron, can make recycled water unsuitable for irrigation of some crops.

Figure 6-5: Summary of the relationship between recycled water, soil EC, and crop sensitivity (adapted from Asano (2007))



1.2. Baseline Conditions

Multiple datasets collected by state agencies were evaluated to estimate baseline conditions in California, including parameters for the number of systems, locations, sizes, and water flow and quality values.

1.2.1. Collection Systems

In California, there are 1,239 identified collection systems as reported within the SSO database. From available data, average sewer system age was measured as the percentage of sewer miles constructed before a given year. Sewer maintenance was assessed by looking at the percentage of miles a collection system had inspected or cleaned in the year prior to reporting, as well as the percentage of sewer miles that were inaccessible for maintenance. Sewer system flow characteristics were determined by the percentage of sewer system miles that were gravity sewer, pressure sewer, or lateral lines. Sewer systems with a higher percentage of lateral lines would have more small pipes distributed throughout the service territory, while systems with a greater percentage of gravity sewers would be more centralized. Summary statistics (averages) for all sewer systems are reported in Table 6-2.

Table 6-2. Comparison of infrastructure age, system maintenance, flow characteristics, and spending for all collection systems in the SSO database and those with reported violations. All values are averages with the exception of the average change ratios; all values are reported as the percentage of total sewer miles

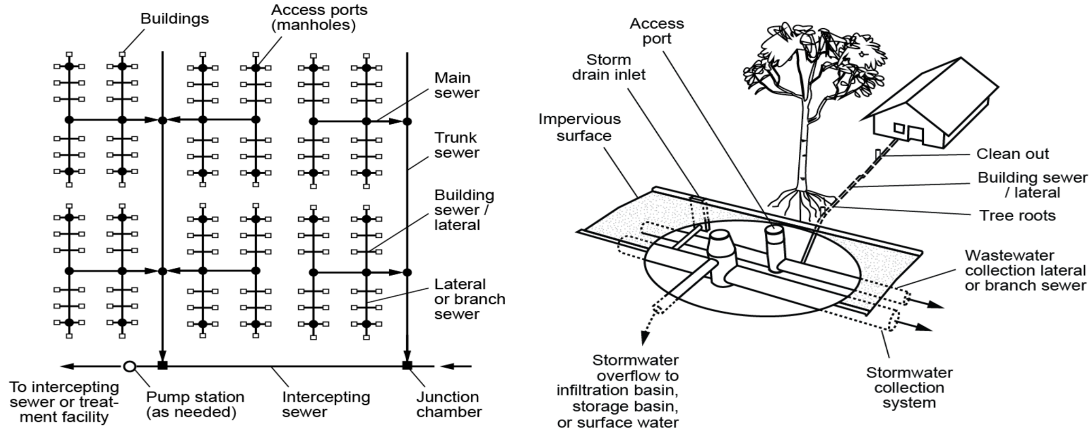
Sewer System Characteristics		Average Value for All Collection Systems
Average Infrastructure Age	Miles Constructed Before 1959 (%)	20.3%
	Miles Constructed Before 1979 (%)	52.1%
Average System Maintenance Factors	Miles Cleaned Prior Year (%)	43.0%
	Miles Inspected Prior Year (%)	12.0%
Flow Characteristics	Average Miles as Pressure Sewer (%)	8.54%
	Average Miles as Gravity Sewer (%)	60.5%
	Average Miles as Laterals (%)	31.0%
	Median ratio of current and future wastewater generation influent flow considering reductions from AB 1668-SB 606 (Water Use Objective Impact Factor, see Chapter 6.3)	1.03
	Pump Stations Per Sewer Mile	0.42
Budget	Annual Capital Expenditure per Sewer Mile	$54,030
	Annual Capital Expenditure per Capita	$204
	Annual O&M Budget per Sewer Mile	$32,035
	Annual O&M Expenditure per Capita	$ 239

Note: Author calculations based on data from the State Water Board's Sewer System Overflow survey.

Wastewater Collection System Design

While many water quality impacts focus on the operation of wastewater treatment systems, wastewater collection systems are a critical component that influences wastewater treatment and effluent quality. Conveyance systems are often arrayed in a grid pattern, with branches of the sewer extending out to remote or distinct areas. Sewer lines from individual buildings are collected together in branch sewers, which lead to main sewers. Main sewers may lead to a local treatment facility or tie into an intercepting sewer as part of a regional infrastructure system (Figure 6-6).

Figure 6-6: Definition sketch for components of wastewater collection systems: (a) grid or tree layout for wastewater collection pipes and (b) building sewer connection



Note: Figure courtesy of George Tchobanoglous.

Pipe construction materials significantly influence risk associated with effects of lower flows, but no systematic data is available on the pipe material compositions for sewer systems across California. The primary materials used for the construction of wastewater collection pipes have evolved over time in response to the availability of new materials. Traditionally small diameter building and lateral sewers were constructed of vitrified clay pipe (VCP) with various joint materials to seal individual lengths of pipe together. More recently, materials like PVC (polyvinyl chloride) and HDPE (high density polyethylene) have come into common use as well. Larger pipes (trunk sewers and interceptors) have usually, though not exclusively, been constructed of concrete. Older concrete pipes are susceptible to cracks and root intrusion, but also allow for infiltration that can boost self-flushing. Alternatively, PVC pipes are less susceptible to cracking, but this also reduces infiltration inflows and self-flushing.

The design of wastewater collection systems has also traditionally facilitated routine maintenance of such systems based on design parameters. To facilitate the transport of solids, pipe diameters and slopes are chosen to provide a scouring velocity greater than 2 ft/s. The slope is a function of pipe diameter and roughness. For pipe diameters of 8, 15, and 24 in., approximate minimum recommended slopes are 0.35, 0.17, and 0.08 percent, respectively (Tchobanoglous 1982). Pipes are not usually designed to provide scouring velocities under all flow conditions because providing the slopes needed to do this would force pipelines deep into the ground, especially for long stretches of pipeline.

Some of the oldest wastewater collection systems, installed before the 1950s and some still in operation, were largely brick and mortar and ran along surface drainages. In the last half of the 20th century, RCP and VCP were used extensively. While PVC was first used in the US for wastewater drainage in the 1950s, it became common in the late 1970s, resulting in more watertight designs. Systems installed before the 1980s are more likely to have unprotected concrete pipe. Unprotected concrete is susceptible to corrosion caused by H2S. In the 1970s, wastewater systems were typically designed based on an indoor water use of approximately 100 gal/cap-d (M&E 1972). Early sewers had sufficient flow to be self-flushing on a daily basis.

During the 1977 drought, flows reduced about 25%, and there were many documented effects on many wastewater treatment facilities (DeZellar and Maier, 1980). The impacts associated with reduced flows on wastewater treatment facilities at the time were relatively minor and did not cause significant concerns about meeting water quality goals. However, this was before the implementation of most modern biological nutrient removal (BNR) processes, which can be more challenging to adapt to changing wastewater concentrations. After the 1977 period, flows generally returned to the 100 gal/cap-d range in most locations (Table 6-3). In general, the 1977 drought did not have a lasting impact on wastewater generation rates or sewerage practice because of technological limitations.

Table 6-3: An example of historic values of water use from indoor fixtures incorporated into historic wastewater design manuals and textbooks

End Use	Normal Water Consumption
Toilet	4-6 gallon/use
Bathtub	30 gallons/use
Shower head	25-30 gallons/use
Automatic home laundry machine	30-50 gallons/load
Dishwashing machine, home	6 gallons/load
Dishwashing machine, commercial (stationary rack)	6-9 gallons/minute

Notes: Recreated by authors based on Metcalf & Eddy (1972).

Many municipal codes, which dictate how wastewater collection laterals and other pipes are to be sized and installed, were based on these flows. While municipal codes do evolve over time, they define the applicable standards at the time of construction. Therefore, the governing municipal code relevant when most WW systems were installed is based on indoor water use rates of 100 gal/cap-d, typically with peak flows around 400 percent of the average. It is important to note that concrete pipe and older standards based on higher water use rates are still in use in some areas. However, pipes installed before about 1980 are more likely to be oversized and not watertight.

Thresholds of flow can be developed for the purposes of grouping potential effects in relation to historical design parameters. Following the 1976–1977 severe drought in California, a significant amount of analysis led to some design changes, but the gradual reduction in flows across decades has presented a continual set of new challenges for increasingly aging systems.

Table 6-4: Effects of reduced flow rates on wastewater collection systems

Normalized influent flowrate, gal/cap-d	Challenges associated with basis of design year	
	<1980	1980 - 2020
>100	No issues, baseline cost	
100 – 70	Flushing O&M Odor control chem Reduced pipe life Reduced pumping Tree root service Headworks	No issues, baseline cost
70 – 50	Solids accumulation Accelerated corrosion Lift station issues (pump cycling, clogging) Tree root intrusion (possible in dry areas)	Newer pipe materials used, corrosion resistant materials, water tight joints but still subject to lift station issues and some corrosion.
< 50	Accelerated corrosion, lift station problems, deposition, routine flushing, clogging/overflows, persistent odor	Odors, lift station redesign, relatively free from tree roots and pipe corrosion. More watertight systems require extra flushing

Note: Created by authors based on multiple sources.

1.2.2. Wastewater Treatment

There are approximately 1,300 wastewater treatment facilities in California based on records within CIWQS databases (Table 6-5). The majority of WWTFs in California discharge effluent that is treated to secondary standards, with the next largest group of facilities treating to tertiary standards (Figure 6-7). Most WWTFs have flow rates less than 1 million gallons per day (Mgal/d, or MGD).

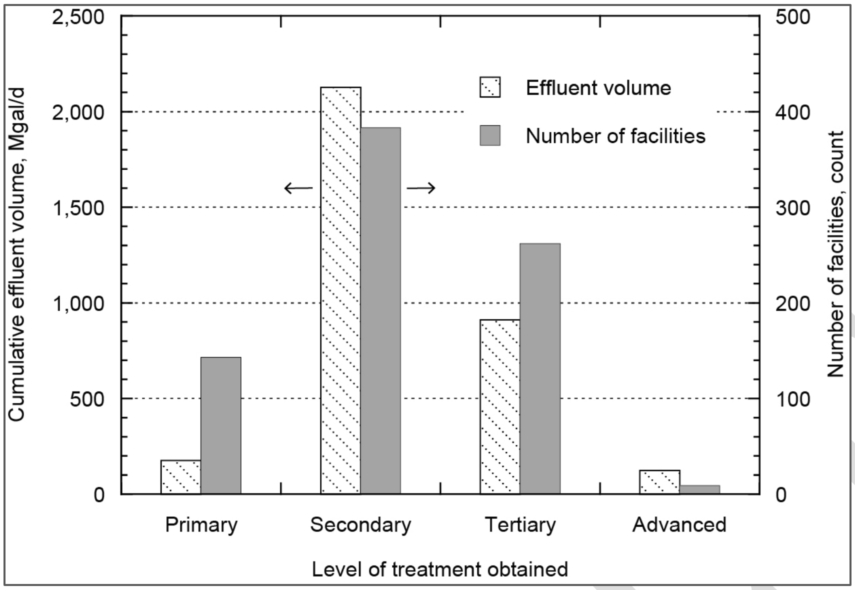
Recent trends are testing systems designed based on past assumptions of water use. In the design of wastewater treatment systems, standard industry metrics for historical flow rates, combined with studies that evaluate the characteristics of a particular service territory, are generally used as key factors in sizing facilities and systems (Table 6-6). In California, prior to the 2012–2016 drought, designs were largely based on historical precedent. When water use reductions occur, they yield lower flows to wastewater treatment plants that can result in an increase in loading. Recent observed water use rates since the 2012–2016 drought are often at or below the midpoint of standards that inform WWTF designs.

Table 6-5. Registered wastewater treatment facilities by capacity and Regional Water Board

	Design Capacity (MGD)									
Region	**<0.2**	**0.2 - 0.99**	**1.0 - 4.99**	**5.0 - 9.99**	**10.0 - 14.99**	**15.0 - 19.99**	**20.0 - 49.99**	**50.0 - 100.0**	**>100.0**	**No Data**	**Total**
North Coast (1)	66	15	11	1	0	0	1	0	0	8	102
San Francisco Bay (2)	54	8	14	5	1	2	4	0	1	36	125
Central Coast (3)	44	18	23	7	2	2	2	0	0	2	100
Los Angeles (4)	17	6	12	4	5	1	5	2	1	6	59
Central Valley, Fresno/San Joaquin (5F)	187	60	34	9	1	3	1	1	0	8	304
Central Valley, Redding/North (5R)	39	16	10	2	1	0	0	0	0	1	69
Central Valley, Sacramento/ Delta (5S)	107	35	30	6	5	2	2	1	1	9	198
Lahontan North (6SLT)	7	1	2	2	0	0	0	0	0	1	13
Lahontan South (6V)	14	7	15	0	2	0	0	0	0	2	40
Colorado River (7)	8	10	11	3	1	1	0	0	0	4	38
Santa Ana (8)	15	3	11	3	4	0	6	9	2	0	53
San Diego (9)	18	9	7	9	0	3	14	0	1	11	72
Total	**576**	**188**	**180**	**51**	**22**	**14**	**35**	**13**	**6**	**88**	**1,173**

Note: Created by authors based on data from the California Integrated Water Quality Systems (CIWQS).

Figure 6-7: Approximate distribution of centralized wastewater treatment level in CA (2019)



Note: Created by authors based on data from the State Water Board's Annual Volumetric Report survey.

Table 6-6: Typical distribution of sources comprising municipal wastewater influent

Year	2015	2015	2020	2020	2030	2030
Use	*Range*	*Typical*	*Range*	*Typical*	*Range*	*Typical*
Domestic						
Indoor	40 – 80	60	35 – 65	50	30 – 60	35
Outdoor	16 – 50	35	16 – 50	35	16 – 80	35
Commercial	10 – 75	40	10 – 70	35	10 – 65	30
Public	15 – 25	20	15 – 25	18	15 – 25	15
Inflow / other	15 - 25	20	15 - 25	18	15 - 25	15
Total	96 - 255	175		161		130

Note: Created by authors, adapted from Tchobanoglous (2021).

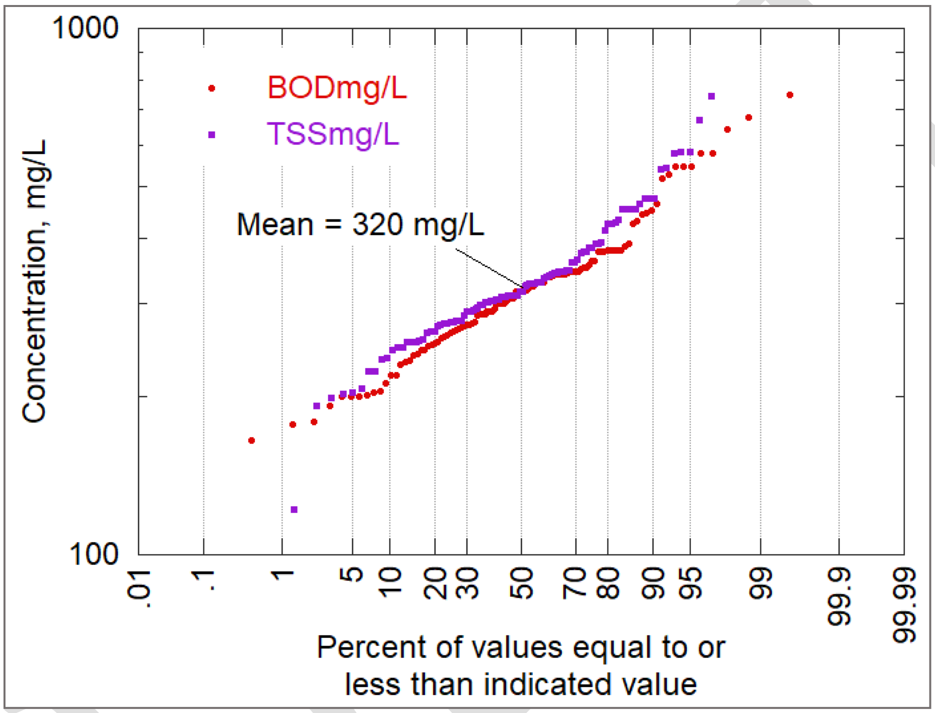
Effluent water quality is highly related to flow rates and the configuration of the treatment train processes in facilities. Two general levels of treatment govern the wastewater treatment process:

1) Removal of organics (Biochemical Oxygen Demand, or BOD) only. Such facilities may discharge to ocean waters or land surfaces and have less stringent effluent criteria.
2) Removal or conversion of nitrogen (N). Such facilities often have more stringent effluent quality requirements, such as Biological Nutrient Removal processes for discharging to inland surface waters.

Changes in influent flow rates can affect influent water quality (Table 6-7). This may occur directly if constituents are diluted in less influent flow or secondarily through changes that occur in the collection system. Even if the volumetric flows are the same to the wastewater treatment facility, the process may not have enough treatment capacity for the applied loading of wastewater effluent with constituent concentrations that are higher than designed value.

Past designs influence the effectiveness of treatment processes. For wastewater treatment facilities historically designed for average influent flows of at least 100 gpcd, the associated influent concentrations for BOD and TSS are typically near 200mg/L. Analysis of recent monitoring data for over 100 WWTFs across the state, however, indicates that mean influent values of BOD and TSS are near 320 mg/L (Figure 6-8). These concentrations are approaching levels outside of design scope for some facilities.

Figure 6-8: Cumulative distribution of constituent concentrations in wastewater influent at wastewater treatment facilities in California



Note: Created by authors based on data from the California Integrated Water Quality System.

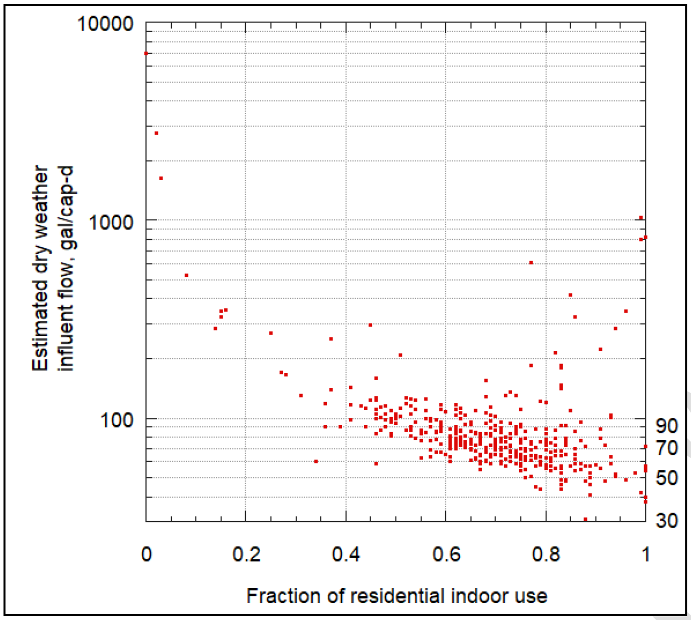
Finally, wastewater treatment facilities across the state receive varying fractions of influent from either indoor residential or indoor CII sources. Facilities that receive a greater percentage of influent from indoor residential sources would be at higher risk of effects from water demand reductions by Suppliers. The regulatory framework especially focuses on residential demand and excludes CII indoor sources. Examining recent data, wastewater facilities that collect influent from a greater percentage of residential indoor sources also have lower dry weather influent flow (Figure 6-9).

Table 6-7: Wastewater management challenges associated with various thresholds of normalized influent flow rate

Normalized influent flowrate, gal/cap-d	**Challenges associated with basis of design/upgrade year**		
	<1980	<2020	Current
>100	Large volumetric flow projections used for design		
100 – 70	Headworks corrosion, intermittent solids loading, aeration control issues Ex. Contra Costa	Improved process technologies, better corrosion resistance	
70 – 50	Elevated headworks corrosion, larger solids mass loading events, Aeration system upgrades, Energy recovery limitations Disinfection transmittance/ chlorine demand	Some headworks corrosion. For BNR systems, chemistry related issues, alkalinity addition for low alk water supply, carbon addition, aeration process modifications (e.g., recirculation). Energy recovery issues Ex: Sac Regional Volumetric limitations in providing recycled water Salinity related issues for irrigation (high TDS water supply, high TDS blowdown flows)	Reconsidering designs and mass loading approach. Industry needs a design setpoint that will not change for 50 y.
< 50	Accelerated corrosion, Upgrade aeration system, Energy recovery limitations Disinfection UV transmittance/ chlorine demand increased	New biological process designs needed, chemical addition, TDS increase can make water unsuitable for irrigation Upgrade aeration systems, Energy recovery limitations Disinfection transmittance/ chlorine demand increase Increased cost	Incorporating reduced flows and increased drought to designs. Adapting existing infrastructure. Complicated by demand to divert organics from landfills to WWTF-AD processes because food waste loading increases TDS/N and process/disinfection issues

Note: Created by authors.

Figure 6-9: Estimated dry weather influent flow vs. fraction of wastewater influent originating from residential indoor sources



Note: Created by authors based on multiple data sources.

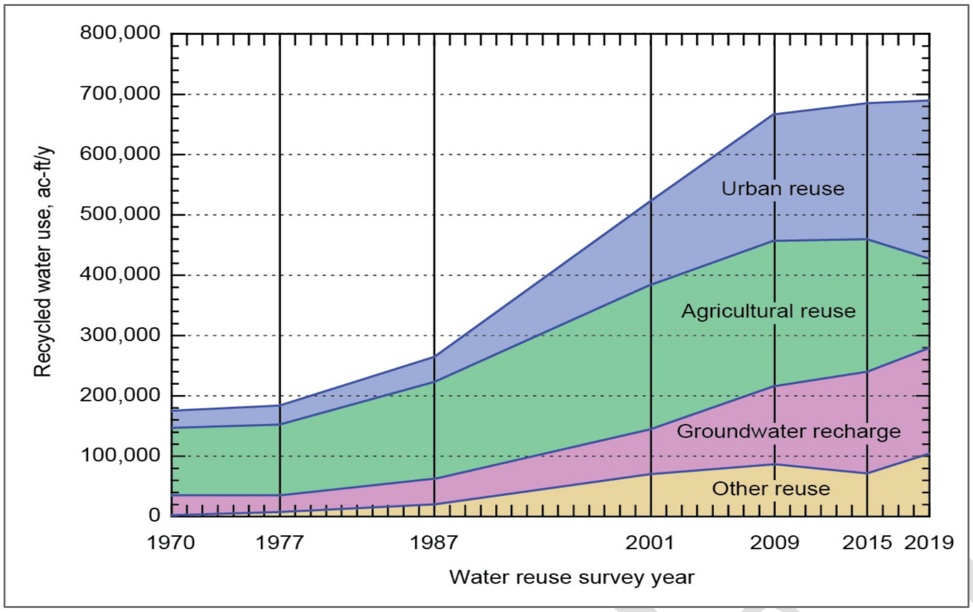
1.2.3. Water Reuse

Water reuse has been practiced in California since the late 1800s with agricultural and landscape irrigation projects. Due to the relatively low regulatory requirements to produce effluent quality suitable for application to crops, turf grass, and landscapes, recycled water is predominantly used for irrigation across the state. Over the last 100 years, significant advances in technology for wastewater treatment and reuse have made water reuse feasible for nearly any application including purification for potable use (Figure 6-10). A summary of water reuse operations in California in 2015 is shown in Figure 6-11.

At present, about 18 percent of municipal wastewater collected is reused in California. This rate of water reuse is lower than some other regions around the world similarly prone to recurring drought. Typical end-uses of recycled water include agricultural irrigation, landscape irrigation, groundwater recharge, industrial use, golf course irrigation, and sea water intrusion barriers.

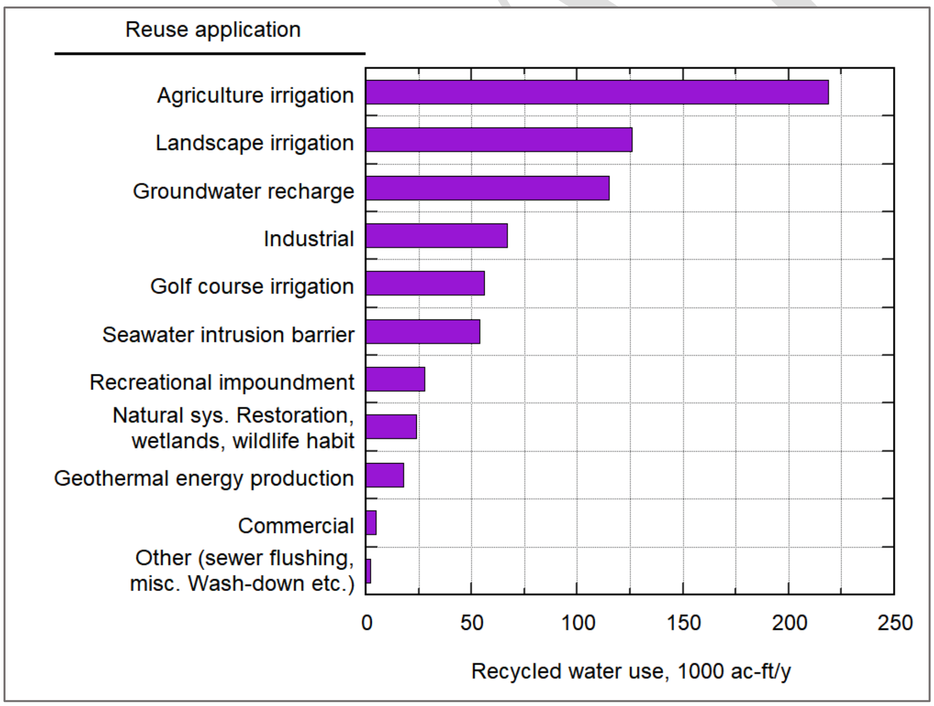
Title 22 Article 3 of the California Water Code identifies recycled water uses and specifies levels of treatment for nonpotable applications. Within section 60304, three basic types of use are outlined: nonpotable reuse, indirect potable reuse, and direct potable reuse. Urban, agricultural, environmental, and industrial end-uses may be associated with each type of recycled water operation. Title 22 specifies water quality standards associated with each type of reuse and end-use of the recycled water. The statute was amended in 2018.

Figure 6-10: Summary of water reuse activity in California from 1970 to 2019



Note: Originally published in Crites et al (2021).

Figure 6-11: Summary of water reuse in California in 2015



Note: Created by authors.

1.3. Mitigation and Adaptation Strategies

Wastewater managers and system designers pursue numerous mitigation and adaptation actions in response to seasonal and long-term changes in flow. Such actions are necessary, as many collection and treatment systems are design, built, and funded over decades. During this time, significant changes in water use habits, climate and drought, and consumer products occur that require proactive managerial actions to maintain system operations. Short-term actions focus on mitigating undesired effects and are necessary to respond to fast changes to maintain flow and effluent water quality. Long-term actions focus on adapting systems to meet future conditions, including changes in flow and more stringent water quality requirements.

Predicting future conditions is a recognizable challenge. Systems designed in recent decades may have often used assumptions of indoor urban water consumption that are higher than recently observed values. Thus, wastewater collection, treatment, and reuse systems will continue to face the need for mitigation and adaptation actions to respond to changing conditions.

1.3.1. Wastewater Collection Systems

Collection system managers have various responses they can undertake to deal with undesired effects of lower influent flows (Table 6-8). For instance, to control odors, managerial and operational responses may include the following:

- Odor control facilities: In large facilities such as pump stations, odor control equipment can be installed. Odor scrubber technologies include activated carbon adsorbers, biofilters, and chemical scrubbers (Tchobanoglous et al. 2003). In gas phase, odorous compounds are dissolved into solutions containing chemicals such as sodium hypochlorite, potassium permanganate, and hydrogen peroxide. Technology-intensive facilities such as these are not appropriate for small sources such as individual manholes. Manhole covers fitted with canisters filled with activated carbon or compost-like biological media are available commercially.
- Chemical feeds to wastewater: Various chemicals are used to suppress the production of odors in wastewater. These include sodium and magnesium hydroxide (NaOH and $Mg(OH)_2$), calcium nitrate ($Ca(NO_3)_2$), and iron salts (Abdikheibari et al. 2016; Park et al. 2014). Chemical feed facilities may be distributed at various locations throughout the conveyance network.

Similarly, to control corrosion in wastewater, managerial and operational responses may include the following:

- Chemical feeds to wastewater: Suppressing H_2S production by chemical means also addressing the associated corrosion problem.
- Coating pipes and appurtenances (manholes): For existing infrastructure, corrosion-resistant epoxy and other erosion-resistant coatings are available (WRF 2017). These are especially useful in manholes and pump stations. Coating the interior of pipes is not generally practical.
- Pipe replacement and slip-lining: Replacing pipes is one of the most expensive management responses. Pipes that remain intact, however, can be slip-lined with plastic materials that shield corrosion-prone pipe material and establish a smooth interior. Slip-lining pipes is an established technology, but because of costs, it is mainly used to prolong the life of older

pipes that are subject to corrosive conditions. It is not widely used as a preventative measure on young pipe.

Table 6-8: Summary of effects of lower flows on collection systems and mitigation responses

Low flow effects	Responses
Deposition of solids in wastewater collection system	Increased labor to flush solids, equipment purchases
Increased sulfide generation causing corrosion of pipes	Replace or upgrade collection pipes
Increased sulfide generation causing odor complaints	Increased chemical usage, equipment needs
Root intrusion and blockages in small diameter laterals	Increased labor and chemical usage, equipment purchases
Generation of methane gas	No response
Increased cycling of lift station pumps, reduced pumping efficiency	Lift station upgrades to address reduced pipe life
Blockages of lift station pumps	Increased labor
Lift station corrosion from increasing sulfide causing	Lift station upgrades to address reduced lifespan of equipment

Note: Developed by authors.

1.3.2. Wastewater Treatment Systems

Facilities that process and manage wastewater are constructed using relatively mature technologies that are available at the time when the facility is being designed. The systems are designed, constructed, operated, and financed over decades. Recent decades have seen significant changes in long-term water use habits in California's cities. As such, many WWTF operators and managers have been adept at updating and optimizing processes to address changes in flow and influent quality over time.

Mitigation and adaptation actions in wastewater treatment facilities to deal with future conditions will likely involve adapting and updating treatment processes. For instance, in a study from Southern California, planning models identified cost-effective mitigation actions to deal with influent flow and concentration changes. Across scenarios of climate and water use, cost-effective adaptation actions included blending influent combined with advanced treatment (Tran et al. 2017). New technologies that facilitate greater flexibility in operational parameters across flow rates are likely to be highly useful. These can include monitoring technologies, strategies to equalize changes in influent flows, and upgrading facilities with corrosion-resistant materials. Table 6-9 describes multiple strategies that wastewater agencies can consider for adapting systems to future conditions with lower influent flow rates.

Table 6-9: Strategies for managing reduced flows, increased concentrations, and mass loading at wastewater treatment facilities

Strategy	Description
Continuous monitoring	Monitoring is used to track and respond to process changes. Technology is available for the continuous monitoring of nearly any parameter, including toxicity, specific constituents, flowrates, concentration. Sensors can be placed throughout the wastewater management system for real time feedback on process performance.
Source control	Working with the public to eliminate certain materials from the wastewater flow. For example, it was common to dispose of expired pharmaceuticals by flushing them down a toilet. Modern wipes are an example of an incompatible material that is best controlled at the source.
Flow equalization	Because wastewater processes operate better at constant flowrate and loading, incorporating equalization facilities into the flow diagram is common. Reductions in flow and operation below design capacity may create tankage that is no longer required, e.g., extra clarifiers. These facilities can then be converted for use in flow and load equalization devices.
Corrosion resistant materials	Higher levels of hydrogen sulfide and TDS increase rates of corrosion. Using materials resistant to attack from the increasing salts, organic acid, and sulfide concentrations in wastewater can help reduce undesirable effects. The use of epoxy coatings, stainless steel, and plastic piping can last longer than traditional materials.
Pumping and metering systems with high turn-down capability	Facilities used for pumping wastewater or metering flows, such as chemical injection systems, can be specified to operate reliably over a wide range of conditions. The ability to adapt to low flows should be considered in all future designs.
Ability to take process units out of service to accommodate reduced flows	Many wastewater facilities are operating far below their design capacity. Modifications can be made to improve opportunities for taking processes in or out of service. For example, the addition of pumping or distribution piping could improve process flexibility.
Odor control structures and covered basins	As processes become more compact, enclosures are more feasible. Enclosed headworks and other facilities that cover open-air WWTF devices make it possible to contain and treat odors associated with septic conditions.
Influent filtration	Primary clarifiers use gravity separation to segregate settleable materials and may become less effective with septic wastewater. Influent filtration will make it possible achieve high level of influent treatment under variable loading conditions.
New Biological Nutrient Removal (BNR) processes	A variety of biological processes are now available to remove residual nitrogen and phosphorus from municipal wastewater. The changes in wastewater characteristics need to be considered for any potential impacts on new biological process.
Enhanced side-stream treatment	As more food waste and other organic commercial and municipal solid and liquid wastes are imported for processing by anaerobic digestion and energy recovery, there will be a greater need for side-stream treatment to remove nutrients and specific constituents.

Note: Developed by authors.

In additional to new technologies and processes, innovative management strategies are also essential for adapting to future conditions that WWTFs in California will likely face (Table 6-10). Such strategies include the following:

- Working with local water supply retailers to update collection and treatment facility upgrades that align with demand forecasts and projected water use efficiency that considers past observed changes, including drought effects.
- Evaluating thresholds of changes in water use and wastewater influent changes that would instigate significant effects that require significant investments in adaptation actions. Such studies must consider site-specific factors of collection system layout, the portion of influent from resident and CII sources, and existing treatment processes.
- Facilitating collaboration and coordination between water and wastewater agencies on implementation of adaptation and mitigation actions to changes in the managed urban water cycle (Chappelle et al. 2019).
- Supporting specialized operator training in adapting to low flows and updating operations and maintenance guidance.
- Developing a long-term strategy for investments, upgrades, and funding sources to modernize WWTFs for changes in wastewater influent.
- Changing ratings for WWTFs to be based on mass loading rather than flow.
- Compiling regional and statewide data on reported problems during a period of a water conservation "stress-test" such as drought. These systems may require upgrades to better manage future declines expected in flow and changes in wastewater characteristics.
- Preparing WWTFs to manage concurrent impacts from climate change, such as sea level rise, sea water intrusion into wastewater collection systems, flooding of coastal and inland treatment facilities, drought, and wildfire.
- Implementing continuous and cloud-based monitoring systems to improve reliability.

Table 6-10: Effects of lower flows and associated management responses

Low flow effects	Response
Management of solids scouring events at headworks	Increased labor
Increased sulfide at headworks	Increased chemical cost, upgrade structures
Grit removal less effective	Process upgrades
WWTFs with conventional trickling filter and activated sludge technology process performance deterioration	Increased energy and chemical usage, upgrade process, increased labor/consulting needs
WWTFs with nitrogen removal at or near discharge limits due to increasing ammonia concentrations	Increased energy and chemical usage, upgrade process, increased labor/consulting needs
Increased cost for disinfection	Increased energy (UV) and chemical (chlorine) use
Capacity limitations for increased loading and codigestion	Process upgrades, increased chemical and energy use, increased labor/consulting needs
Increasing dissolved solids (salts) and volumetric limitations impacting recycled water	Revenue losses, increased treatment costs
Wastewater fermentation and transformation	Process & operational modifications, energy

Note: Developed by authors.

1.3.3. Water Reuse Systems

A range of responses have been considered for managing effects of lower flows on recycled water systems (Table 6-11).

Table 6-11: Summary of strategies to improve recycled water management

Strategy	Description
Need for side-stream reverse osmosis or some other method to control TDS	Given the challenges associated with attempting for source control of TDS, applying advanced treatment, including reverse osmosis, to a portion of the effluent flow which can then be blended to lower the overall effluent TDS is becoming more feasible.
Eliminate salt-based water softeners	The removal of salt-based water softeners has been shown to reduce chloride concentrations in wastewater (SCSA 2018)
Reduce TDS of water supply; Partial demineralization of water supply	In a study of wastewater discharges in Southern California, the Total Dissolved Solids (TDS) of the influent water supply was the dominant factor in controlling the wastewater TDS (SCSC 2018). Changes in water supply can have a direct and significant impact on WWTF TDS. Within the study that controlled for multiple factors, a decrease of 1 gpd in consumption resulted in a 1-2 mg/L increase in salinity.
Increased use of rainwater for indoor nonpotable uses	Roof runoff has a very low TDS content, and if used for indoor water supply, would not contribute to overall wastewater TDS.
Flow equalization	Supplement wastewater influent with available fresh water sources. This may conflict with goals of water conservation. Opportunities to use alternative water supply sources such as commercial and industrial wastewater, groundwater that requires pumping and treating, or other sources can be explored to the extent feasible.
Upgrade treatment processes	Advanced treatment processes designed to remove dissolved constituents, such as adsorption and reverse osmosis, can be used to upgrade effluent quality prior to it entering the reuse system. Designing combined systems of tertiary and advanced wastewater treatment with reuse that are designed for lower influent flow rates may make it possible to better manage future droughts by offsetting demands on potable water systems.
Ozonation and other advanced oxidation processes	Advanced oxidation processes should be considered to control the discharge of trace constituents to water systems.

Note: Developed by authors.

1.4. Results: Effects on Wastewater Management Systems

Given the diversity of size and location in wastewater management systems across California, varying impacts from potential flow reductions from indoor water use efficiency with site-specific factors influencing potential impacts are expected. The condition of existing wastewater systems throughout the state varies significantly, with some being upgraded with new technology to meet advanced water quality standards, while others still relying on systems that may be decades old. Population growth, region-specific regulatory requirements, and facility size are key drivers in evaluating the extent to which older systems may have undergone upgrades. Additionally, WWTFs are often designed to deal with the characteristics of local influent and incorporate assumptions of future growth that can influence susceptibility to influent flow rate changes from AB 1668-SB 606. Retrofitting facilities with additional infrastructure to upgrade effluent quality can present design challenges.

The following sections describe the analysis and results associated with effects from AB 1668-SB 606 on collection, treatment, and reuse systems.

1.4.1. Overall Approach

A multistep procedure was used to evaluate effects on wastewater management systems, which included the following steps that:

1) linked wastewater management systems with upstream Suppliers;
2) conducted outreach with wastewater managers to refine and calibrate modeling and shape interpretation of model results;
3) estimated future baseline and objective-based wastewater generation and identify wastewater systems at risk of lower influent flows;
4) evaluated effects on collection systems using process modeling with clustering analysis for statewide extrapolation;
5) evaluated effects on wastewater treatment systems using process and simulation modeling with clustering analysis for statewide extrapolation;
6) estimated the potential reduction in influent flow available for recycled water production available to current and planned reuse facilities.

1.4.2. Linking Suppliers with Wastewater Management Systems

Many sources of data are available for wastewater management in California, but they are not integrated and are not exploited for systems analysis. A first step of the analysis of effects from AB 1668-SB 606 required identifying, cleaning, and merging data sources for purposes of estimating baseline operating conditions in recent years and projecting future effects.

Assembling Data Sources

Table 6-12 describes the origins, parameters, and timeframes associated with key data sources used for the analysis:

- The **California Integrated Water Quality Systems (CIWQS)** includes a table of attributes with design flow for many facilities. Such attributes are available for a majority of the 1,300 facilities. The SWB collects CIWQS data.
- For a subset of facilities, CIWQS also includes historic monitoring data for flow and water quality, which can be used to assess trends in recent operations. For instance, the data can be used to examine changes in flow and water quality before, during, and after the 2011–2016 drought for facilities with available data. Historic monitoring data is available for over 200 facilities, but not all of these serve URWSs, and CIWQS provides no data to identify WWTFs of interest for effects from AB 1668-SB 606.
- **Volumetric Annual Reporting (AVR)** data includes reporting on wastewater influent, effluent, and reuse for approximately 700 wastewater treatment facilities in the state. Data is reported monthly. While the data is standardized for more facilities, it does not include key parameters such as design flow and cannot capture acute daily observations that impact treatment processes. The SWB collects AVR data.
- **Tables 6-2, 6-3, and 6-4 in Urban Water Management Plan**s provide corroborative information on the managing agency for a WWTF, as well as connected collection systems

and URWSs. Table 6-2 identifies approximately 470 WWTFs of interest that serve URWSs. Completed tables from 2015 UWMPs were available in the time frame of this project. Operations data from 2015 is provided at an annual time step. DWR collects and compiles data for Tables 6-2 through 6-4.

- The **Sewer System Overflow (SSO) database** provides a rich source of information on collection systems attributes throughout the state, including design, layout, operations, annual spending, operator certifications and expertise, and other factors. The SWB collects SSO data.

Table 6-12: Key data sources used to evaluate recent trends in wastewater treatment across the state

Name	Source	Parameters	Timeframe
2017 Wastewater User Charge Survey	State Water Resources Control Board (file was given)	-Agency Information -Service Area -Name(s) and location(s) of the treatment facilities	06/22/2020 – 07/31/2020
California Integrated Water Quality System Project (CIWQS) eSMR Flat File	State Water Resources Control Board (file was given)	-Region -Location -Location_Place_ID -Location_Place_Type -Parameter -Result -Units -Sampling_Date -Facility_Name -Facility_Place_ID -Latitude/Longitude	02/14/2020 – 06/22/2020
California Integrated Water Quality System Project (CIWQS) eSMR Facility Export	State Water Resources Control Board (file was downloaded from the website)	-Agency/Address -Facility Name/Address -Latitude/Longitude -County -Region -WDID -Design Flow	06/22/2020 – 07/31/2020

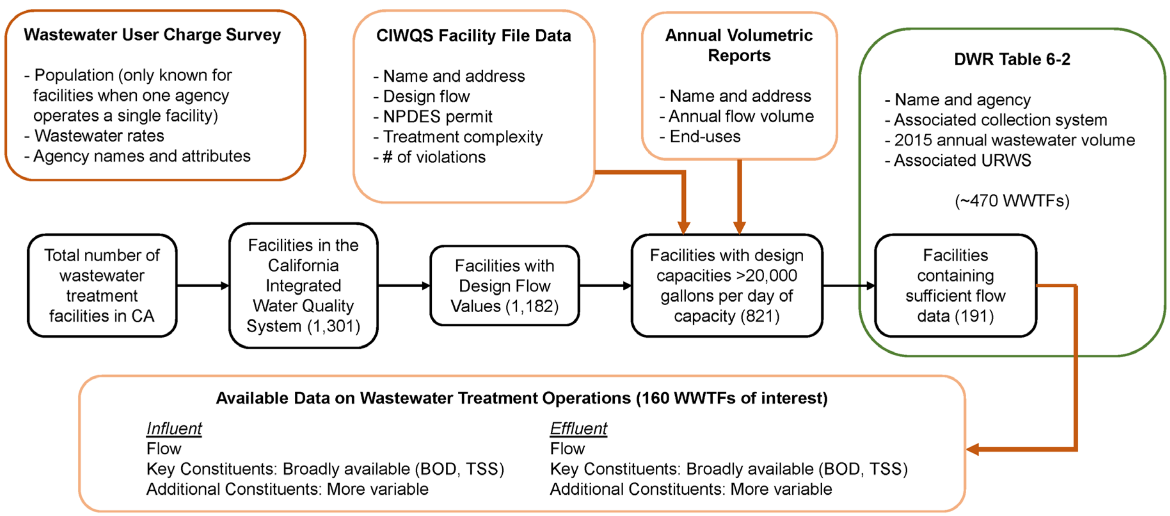
Table 6-2 Retail: Wastewater Collected Within Service Area in 2015, and Table 6-3 Retail: Wastewater Treatment and Discharge Within Service Area in 2015 (compiled data associated with urban water management plans)	California Department of Water Resources (DWR)	-DWR URWS Org ID -Water Supplier Name -Wastewater Collection Agency -Volume of Wastewater Collected (2015) -Volume of Wastewater Treated (2015) -Volume of Wastewater Discharged (2015) -Wastewater Treatment Agency -Treatment Plant Name	2015
Volumetric Annual Report (AVR)	California State Water Resources Control Board	-Facility name -Facility location -Volume of influent (monthly) -Volume of treated effluent (monthly) -Level of treatment -Volume of water reuse production	2019 (data may be available for some facilities as early as 2017)
Sewer System Overflow (SSO) database	California State Water Resources Control Board	-System name -System location -Length of pipes by type of pipe (gravity main, lateral line) -Number of pumps -Number of operators -Operator training levels -Operator certifications -Violation reports (Sewer System Overflows) and reported causes	various, based on last year of available reporting

Network Modeling to Connect Suppliers with Wastewater Management Systems

No existing database identifies relationships or estimates flows between Suppliers and wastewater management systems. The only sources of data for this purpose are Tables 6-2 through 6-4 of DWR's Urban Water Management Plans (UWMPs). These tables compile self-reported data from the UWMPs and link between water sector systems. Table 6-2 describes connections between urban water supply retailers, wastewater collection systems, and wastewater treatment facilities. The tables, however, are based on self-reported data and include errors. Further, the reported names do not match names in other state databases such as CIWQS, and common identifiers are not included. For this project, the database in Table 6-2 was converted into a network model representation to connect water supply agencies, collection systems, and wastewater treatment facilities.

A multistep procedure was used to link Suppliers with wastewater management systems and identify systems of interest. First, we rectified name discrepancies between DWR's Table 6-2, CIWQS, and the AVR. Second, after identifying wastewater systems and facilities of interest, characteristics (attributes) of those systems and facilities were collected and compiled to create a database of attributes associated with both collection systems and treatment systems. Third, historical records for operations and monitoring were collected from CIWQS and DWR's Table 6-2 for collection systems and WWTFs with available data (Figure 6-12). Fourth, using the AVR and data from DWR's Urban Water Management Plans, the volume of recycled water produced by a WWTF was estimated and linked to receiving Suppliers.

Figure 6-12: Summarizing the process to develop time series records of operations and monitoring for WWTFs with available data in the California Integrated Water Quality System (CIWQS)



1.4.3. Outreach

In 2021, as part of this project, outreach was conducted with wastewater collection, treatment, and reuse facilities to learn more about each facility type's operational challenges; this outreach produced completed responses from 69, 81, and 76 individuals, respectively. The findings for each facility or system type are summarized below. Results are aggregated to preserve anonymity. If a particular category had 4 or fewer responses, the cells were censored.

The questionnaire resulted in completed responses from managers of collection systems (69 respondents), treatment facilities (81 respondents), and reuse facilities (76 respondents). Results were summarized for each facility type and aggregated to preserve anonymity. If a particular category had four or fewer responses, the cells are censored.

Wastewater Collection System Respondents

Slightly less than half of wastewater collection system respondents reported experiencing challenges due to low flow since 2011 (Table 6-13).

Table 6-13: Number of wastewater collection system respondents and associated identification of reported challenges

Waste Water Collection System		
Outreach Summary Statistics		
Total Responses	77	
Number of completed responses	69	
	Yes	No
Since 2011, has your wastewater collection system experienced any challenges related to low wastewater flow that required operational changes or modifications to your system?	34	37
	48%	52%

Next, wastewater collection facilities that reported challenges were considered. Respondents were surveyed on several major challenge categories, including system blockages, equipment and infrastructure challenges, and operating challenges. For pipe blockages, "Solids accumulation/settling in the pipes" and "Flow patterns (e.g. surges, more variability)" were the primary reported challenges. Most collection system respondents reported experiencing equipment and infrastructure challenges. For operating challenges, results were mixed, but a large percent of collection facility respondents that did experience challenges reported experiencing "major" challenges (Table 6-14).

Table 6-14: Collection systems—reported lower-influent-flow challenges, by category and severity

If an item listed below was not a challenge, mark "none". For "major" or "minor", we are interested in your general assessment. A challenge that was widespread or happened frequently or required significant changes in your workload/costs is "major". A "minor" challenge is one that could not be ignored, but could be mostly handled as a normal part of your operations.	None	Minor	Major
Challenges involving blockage and/or overflows			
Solids accumulation/settling in the pipes	*	27	*
		100%	
Flow patterns (e.g. surges, more variability)	9	17	5
	29%	55%	16%
Root intrusion	20	8	*
	71%	29%	
Biological growth	22	6	*
	79%	21%	
Methane generation	12	*	*
	100%		
Challenges involving equipment and/or physical infrastructure			
Solids accumulating in pumping facilities	11	15	*
	42%	58%	
Solids blocking or restricting pumps and valves	12	16	*
	43%	57%	
Increased corrosion of equipment (e.g., pumps, sensors)	14	16	*
	47%	53%	
Increased corrosion of structures (e.g. pipes, manholes)	12	14	*
	46%	54%	
Pipe fractures or breaks	17	10	*
	63%	37%	
Operating challenges			
Odors	5	6	19
	17%	20%	63%
Production of methane or other gases (non-odor)	21	*	7
	75%		25%
High mass loading events (i.e. surges in solids loading)	12	*	16
	43%		57%
Restriction of pipe capacity (not enough to cause a blockage)	11	*	19
	37%		63%
Increased power requirements or energy use	21	*	8
	72%		28%
**** Asterick denotes four or fewer responses***			

Of collection system respondents that experienced challenges, most experienced increased need for clean-outs, inspections, and labor. Looking to the future, most collection system respondents were not sure about what range of future flow reduction would require remediation actions (Table 6-15).

Table 6-15: Collection systems—reported mitigation and adaptation actions used to address collection system operational challenges related to lower influent flow

For the challenges your system experienced related to lower influent flows (or higher influent concentrations), please answer the following questions.		
What changes in operations and maintenance did you take to address the challenges? Select all that apply.	Responses	30
Used more labor – increased hours, additional staff, more hours of contracted cleaning services	16	53%
Employed more outside technical help (engineering consultants or specialized services)	11	37%
Increased frequency of inspections	20	67%
Increased frequency of preventative clean-outs (i.e., sewer flushing, pipe routing)	24	80%
Purchased more or different chemicals	8	27%
In the future, given current capacity of your systems, over what range would low influent flows require remediation actions?	Responses	65
Less than 5% flow reduction	*	
Between 5% and 10% flow reduction	7	11%
Between 10% and 20% flow reduction	7	11%
Greater than 20% flow reduction	13	20%
Not Sure	37	57%
Asterick denotes four or fewer responses		

Wastewater Treatment System Respondents

More than half of wastewater treatment system respondents experienced challenges due to low flow since 2011 (Table 6-16)

Table 6-16: Treatment systems—number of wastewater treatment system respondents and associated identification of reported challenges

Waste Water Treatment Facilities		
Outreach Summary Statistics		
Total Responses	93	
Number of completed responses	81	
	Yes	No
Since 2011, has your wastewater treatment facility experienced any challenges related to low influent flows or high influent concentrations that required operational changes or modification to your system?	54	32
	63%	37%

Next, wastewater treatment facilities that reported challenges were considered. Respondents were surveyed on several major challenge categories, including constituent concentrations, biological process stability or efficiency, and operating challenges. "Constituent concentrations" was the biggest reported challenge associated with lower influent flows. "Biological process stability or efficiency" was the most significant reported challenge for treatment processes. Most reported minor or no challenges with one exception. Over half of treatment facility respondents reported major challenges meeting discharge permit requirements (Table 6-17).

Table 6-17: Treatment systems—reported system challenges associated with lower influent flows by category and severity

If an item listed below was not a challenge, mark "none". For "major" or "minor", we are interested in your general assessment. A challenge that was widespread or happened frequently or required significant changes in your workload/costs is "major". A "minor" challenge is one that could not be ignored, but could be mostly handled as a normal part of your operations.	None	Minor	Major
Challenges associated with the following influent conditions			
Constituent concentrations	*	34	14
		71%	29%
Flow patterns (e.g. surges, more variability)	17	30	*
	36%	64%	
Load patterns (e.g. surges, more variability)	18	22	9
	37%	45%	18%
Odor	25	18	7
	50%	36%	14%
Pumping trouble (at the plant, not the collection system)	37	12	*
	76%	24%	
Increased corrosion	23	22	5
	46%	44%	10%
Challenges involving treatment processes			
Grit inflows or accumulation	29	18	*
	62%	38%	
Primary settling efficiency	28	18	*
	61%	39%	
Aeration requirements	15	23	11
	31%	47%	22%
Biological process stability or efficiency	6	32	12
	12%	64%	24%
Biosolids processing or biogas production.	20	30	*
	40%	60%	
Filtration	36	10	*
	78%	22%	
Disinfection	35	11	*
	76%	24%	
Nutrient Removal	20	5	24
	41%	10%	49%
Challenges associated with meeting regulatory requirements?			
Difficulty meeting discharge permit requirements	18	5	27
	36%	10%	54%
**** Asterick denotes four or fewer responses***			

Considering wastewater treatment facilities that experienced challenges, most reported using more electricity and needing capital improvements for "Biological system and/or secondary sedimentation." Looking to the future, almost half of wastewater treatment facility respondents were not sure about what range of future flow reduction would require remediation actions (Table 6-18).

Table 6-18: Treatment systems—reported mitigation and adaptation actions used to address operational challenges related to lower influent flow

For the challenges your system experienced related to lower influent flows (or higher influent concentrations), please answer the following questions.		
What changes in operations and maintenance did you make to address the challenges? Select all that apply.	Responses	41
Purchased more or different chemicals	17	41%
Used more electricity (or other energy sources)	25	61%
Used more staff/ hired labor	7	17%
Employed more outside technical consultants or specialized services	14	34%
Purchased replacement equipment sooner than expected	11	27%
In what processes were capital improvements implemented (or planned) to address the challenges? Select all that apply.	Responses	42
Headworks/pretreatment	19	45%
Primary sedimentation	6	14%
Biological system and/or secondary sedimentation	27	64%
Disinfection system	8	19%
Filtration System	6	14%
Blower/Diffuser	21	50%
In the future, given current capacity of your systems, over what range would low influent flows require remediation actions?	Responses	79
Less than 5% flow reduction	*	
Between 5% and 10% flow reduction	*	
Between 10% and 20% flow reduction	6	8%
Greater than 20% flow reduction	29	37%
Not Sure	39	49%
**** Asterick denotes four or fewer responses***		

Wastewater Reuse System Respondents

Half of wastewater reuse systems experienced challenges due to low flow since 2011 (Table 6-19).

Table 6-19: Reuse systems—number of respondents and reported challenges

Recycled Water Facility		
Outreach Summary Statistics		
Total Responses	83	
Number of completed responses	76	
	Yes	No
Since 2011, has your recycled water facility experienced any challenges related to low influent flows (or higher concentrations of salt or pollutants) that required operational changes or modification to your system?	38	38
	50%	50%

We next considered wastewater reuse facilities that reported challenges. Over half of reuse facility respondents reported challenges supplying needed flows (Table 6-20).

Table 6-20: Reuse systems—reported challenges associated with lower influent flows by category and severity

	None	Minor	Major
Have you experienced challenges with the reclaimed water system related to low wastewater flows?			
For recycled water systems - difficulty supplying needed flows	6	14	18
	16%	37%	47%
For recycled water systems - difficulty supplying needed water quality	15	15	8
	39%	39%	21%
Difficulty meeting permit requirements	25	8	5
	66%	21%	13%
Blending with potable water to meet demand/water quality requirements	23	8	7
	61%	21%	18%

Looking to the future, almost half of wastewater reuse facility respondents were not sure about what range of future flow reduction would require remediation action (Table 6-21).

Table 6-21: Reuse systems—reported correlation between flow reductions and mitigation actions to manage lower influent flow rates

In the future, given current capacity of your systems, over what range would low influent flows require remediation actions?	Responses	66
Less than 5% flow reduction	9	14%
Between 5% and 10% flow reduction	*	
Between 10% and 20% flow reduction	9	14%
Greater than 20% flow reduction	14	21%
Not Sure	31	47%
*** Asterick denotes four or fewer responses**		

Through interviews and outreach, many respondents indicated that their systems and facilities experienced only moderate or no effects from lower flows since 2011. However, sizeable percentages of collection system respondents did indicate experiencing major operating challenges, especially odor control from septic conditions in collection systems, higher mass loading, and deposited sludge in pipes. Some wastewater facility respondents indicated major challenges, but at lower comparative rates. For reuse respondents, just under half indicated challenges to provide sufficient inflow to maintain recycled water production operations. The results were used to scope the quantitative effects analysis and refine modeling and extrapolation procedures.

1.4.4. Baseline and Objective-Based Reductions in Wastewater Generation

WEO Impact Factors were calculated for wastewater collection and treatment systems. To apply the WEO Impact Factor to wastewater management, several adjustments were incorporated. The impact factor incorporated future baseline conditions by calculating the portion of influent reductions associated with AB 1668-SB 606 after removing a baseline of reductions associated with future efficient water use efficiency from ongoing water use efficiency programs for indoor fixtures. Also, while the WEO Impact Factor estimates the maximal potential change for influent to a collection system or treatment facility if all needed reductions came from indoor use, a significant portion of reductions will likely come from noninfluent generating sources such as outdoor water use efficiency and leak loss detection. It was assumed that only 15% of reductions made by a Supplier would result from indoor water use efficiency. The economic modeling to estimate benefits and costs from Supplier actions to reduce demand for compliance will estimate water use efficiency portfolios for Suppliers with reductions from various actions, but the portfolio values were not available at the time of drafting the Task 5 Summary report.

For collection systems, the WEO Impact Factor is equal to:

$$WEO_{cs} = \frac{\sum_r^R V_{cs,future,AB\ 1668-SB\ 606}}{\sum_r^R V_{cs,actual}} \qquad (8)$$

The WEO_{cs} impact factor was estimated for collection systems across the scenarios of objectives (Table 3-1).

At-risk wastewater treatment facilities were similarly identified by estimating Water Use Efficiency Objective (WEO) impact factors using network modeling, where:

$$WEO_{WWTF} = \frac{\sum_{r}^{R} V_{WWTF,future,AB\ 1668-SB\ 606}}{\sum_{r}^{R} V_{WWTF,actual}} \tag{9}$$

Finally, the WEO Impact Factor could be estimated for wastewater facilities known to generate recycled water (WRFs):

$$WEO_{WRF} = \frac{\sum_{r}^{R} V_{WRF,future,AB\ 1668-SB\ 606}}{\sum_{r}^{R} V_{WRF,actual}} \tag{10}$$

Results from the network modeling of WEO Impact Factors indicate an increasing number of affected facilities from Scenarios 1 through 3, but the magnitude of impacts changes only slightly.

In Scenario 1, 198 treatment facilities and 230 collection systems have adjusted WEO Impact Factors less than 1, indicating less future influent flow related to AB 1668-SB 606. For affected facilities with likely lower flows due to AB 1668-SB 606 demand changes, the magnitude of reduction attributable to AB 1668-SB 606 is, on average, 12–13% lower. This value represents the estimated drop in wastewater influent that affected facilities would experience below the future baseline estimate of influent. The average percent change is larger than the average WEO Impact Factor because the percent change includes estimates of baseline future wastewater influent generation. Thus, the network modeling suggests that many of the affected wastewater collection and treatment systems would see slight increases in baseline influent flow in the absence of AB 1668-SB 606. The WEO Impact Factor suggests that aggregate projected decline in influent for affected facilities would be on average about 5%.

For Scenario 2, 263 treatment facilities and 310 collection systems are estimated to be at risk of future lower influent flows, while for Scenario 3, 288 treatment facilities and 352 collection systems are at risk (Table 6-22).

Potentially affected facilities were also evaluated by region, design capacity, and level of treatment (Table 6-23 and Figure 6-13). For the example of Scenario 2 with an indoor standard of 42 gpd and an outdoor standard of 0.62, the percent of affected facilities in a region ranges from 2% (North Coast) to 17% (Middle Central Valley), as shown in Table 6-23. The greater number of affected facilities are those with design capacities over 100 MGD. Facilities in Los Angeles (Region 4), the Southern Central Valley (Region 5F), the Colorado River (Region 7), and Santa Ana (Region 8) are affected at rates greater than the percent of facilities they comprise statewide. Table 6-23 does not include facilities without available design capacities in CIWQS.

Table 6-22: Results for the number of wastewater treatment facilities and collection systems at risk of effects of reduced flows from AB 1668-ASB 606 by scenario

Scenario	Sector	Wastewater Treatment Facilities	Collection Systems
Scenario 1	Count	198	230
	Avg. WEO Impact Factor*	0.953	0.955
	Avg. % Reduction in Flow from Future Baseline	-12%	-13%
Scenario 2	Count	263	310
	Avg. WEO Impact Factor*	0.953	0.955
	Avg. % Reduction in Flow from Future Baseline	-12%	-13%
Scenario 3	Count	288	352
	Avg. WEO Impact Factor*	0.949	0.952
	Avg. % Reduction in Flow from Future Baseline	-14%	-15%

Notes: Author calculations. The totals include wastewater treatment facilities with no available design capacity data, while Table 6-23 reports results only for facilities with design capacity data.

Table 6-23: Number of affected wastewater treatment facilities in a region by design capacity for Scenario 2 (indoor standard =42 gpd, outdoor standard = 0.62)

Region	0-5 MGD	5-20 MGD	20-50 MGD	50-100 MGD	>100 MGD	Total	% in Region
n/a	5	5	2	3	1	16	8%
North Coast	4	0	1	0	0	5	3%
Bay Area	4	5	5	2	0	16	8%
Central Coast	9	3	1	0	0	13	7%
Los Angeles	9	7	5	1	8	30	15%
Southern Central Valley (Fresno)	11	8	0	2	0	21	11%
Northern Central Valley (Redding)	2	1	0	0	0	3	2%
Middle Central Valley (Sacramento)	20	9	0	1	1	31	16%
Sierra Mountains (Lahontan/South Lake Tahoe)	1	1	0	0	0	2	1%
Sierra Mountains (Lahontan/Visalia)	4	4	0	0	0	8	4%
Colorado River	6	4	0	0	0	10	5%
Santa Ana	5	3	3	4	1	16	8%
San Diego	7	10	6	0	1	24	12%
Total	87	60	23	13	12	195	100%

Note: Author calculations.

For collection systems, the largest percentage of affected systems are located in the Bay Area and Los Angeles regions. The distribution of affected systems by size again follows the distribution of collection system sizes throughout the state. Most affected systems serve populations of 50,000 to 100,000 people (Table 6-24).

Table 6-24: Number of affected wastewater collection facilities in a region by design capacity

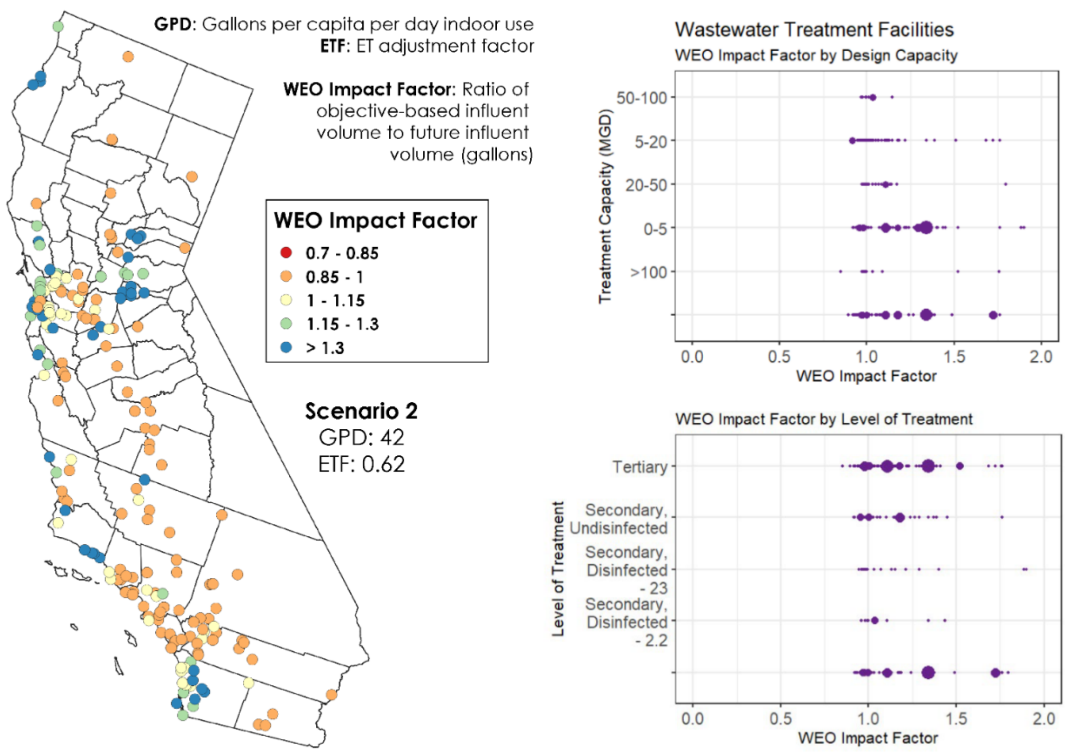
Region	<10,000	10,000 to 50,000	50,000 to 100,000	100,000 to 500,000	>500,000	Total	% in Region
n/a	6	31	23	14	0	74	33%
North Coast	2	0	0	1	0	3	1%
Bay Area	1	9	4	10	1	25	11%
Central Coast	3	6	1	1	0	11	5%
Los Angeles	2	11	2	7	3	25	11%
Southern Central Valley (Fresno)	4	10	5	2	1	22	10%
Northern Central Valley (Redding)	1	0	2	0	0	3	1%
Middle Central Valley (Sacramento)	3	9	4	1	2	19	8%
Sierra Mountains (Lahontan/South Lake Tahoe)	0	0	0	0	0	0	0%
Sierra Mountains (Lahontan/Visalia)	0	3	2	3	0	8	4%
Colorado River	0	6	1	0	0	7	3%
Santa Ana	0	4	3	7	2	16	7%
San Diego	3	6	2	2	0	13	6%
Total	25	95	49	48	9	226	

Note: Author calculations.

Limited noticeable differences in the magnitude of impact across facilities of varying levels of treatment and design capacities do exist. For instance, as shown in the boxplot, the distribution of WEO Impact Factors varies little across facilities of varying levels of treatment (Figure 6-12). The average values for each category are similar, centered around 0.95. Similar trends are evident across facilities of varying design capacities (Figure 6-13).

Figure 6-13 illustrates the geographic distribution of potentially-affected facilities for Scenario 2. Facilities in the North Coast (Region 2), Los Angeles (Region 4), Northern Central Valley (Region 5R), Southern Sierra (Region 6V), and Region 9 (San Diego) have negative WEO Impact Factors, but most affected facilities have values between 0.85 and 1.0, indicating less than 15% reductions in flow attributable to AB 1668-SB 606 based on the assumptions from network modeling. Values greater than 1.0 indicate facilities that would not experience reductions based on future values of baseline influent volume.

Figure 6-13: Visualizing impacts to wastewater treatment facilities based on the Water Use Efficiency Objective Impact Factor by location, level of treatment, and design capacity. Results are shown for Scenario 2 (indoor standard = 42 gpd, outdoor standard = 0.62)



Note: Figures and calculations created by authors based on estimates for approximately 309 facilities with sufficient information for use in network model.

1.4.5. Effects on Collection System Operations

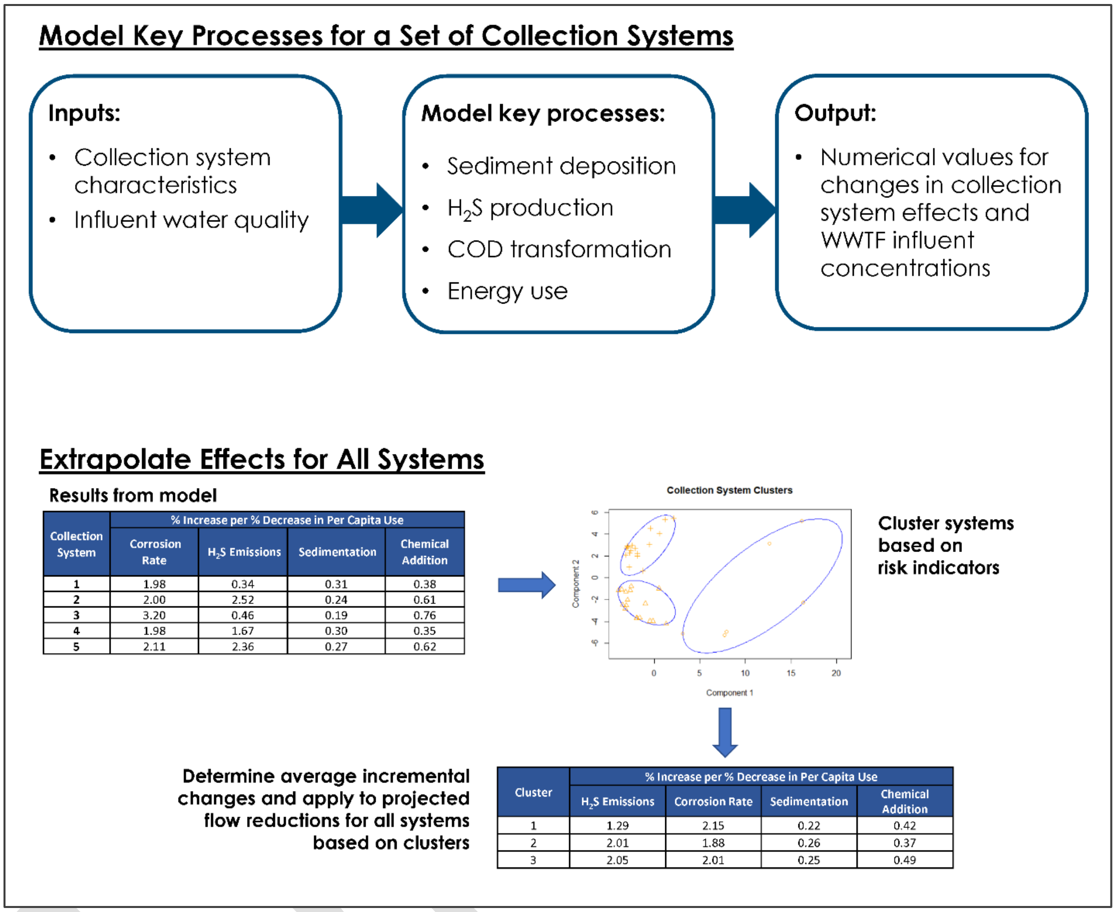
A combination of risk indicators, process modeling, field validation through outreach, and clustering of systems based on common characteristics was used to estimate the magnitude of impacts to wastewater collection system operations.

Collection System Modeling

An Excel-based model of collection system processes was developed to evaluate the effects of changes in flow and other parameters on collection system operations based on modeling key processes and extrapolating effects by clustering of common attributes (Figure 6-14).

Reductions in flow volume can lead to negative impacts on collection systems, including accelerated corrosion, odor complaints, and increased settling of solids. The underlying physical, chemical, and biological processes that contribute to these effects are heavily dependent on each other. While studies and models examine the impact of reduced flow on one or some of these processes, nothing that predicted their combined effects on the collection system was found in literature. Further, this model of collection system processes was needed to translate the effects of reduced flows—corrosion, odor, and sedimentation—into estimated costs of mitigation efforts. Using scholarly literature on general collection system influent characteristics and internal processes, an Excel-based model was created to predict the effects and cost of mitigation actions based on the characteristics of a sewer system.

Figure 6-14: Procedure used to quantify operational effects on collection systems from AB 1668-SB 606, including first modeling key processes for a set of systems, then extrapolating effects across systems based on clustering with important attributes



Note: Developed by authors.

A detailed description of the literature and calculations associated with the model is included as Technical Appendix-5 to this report. The model inputs can be categorized as either characteristics of the collection system or the influent flow. The collection system characteristics are user-inputs based on data available in the SWB's Sewer System Overflow Survey database as well as from data reported by Suppliers to DWR as part of Urban Water Management Plans**.**

Collection system characteristics used in the model include the following:

- Population served
- Indoor per capita use (gal/cap-d)
- Average flow (MGD)
- Total length of network (miles)
- Pipe size distribution

- Time between widespread flushing events (days)

Based on the population served and flow rate, the influent flow characteristics could be predicted using general values for mass loadings of common wastewater constituents (Tchobanoglous et al. 2003 Table 3-13).

Influent Flow Characteristics used in the mode include the following:

- Temperature (°C)
- Total suspended solids (TSS) (mg/L)
- Total Chemical Oxygen Demand (COD) (mg/L)
- Readily Biodegradable COD (mg/L)
- Slowly Biodegradable COD (mg/L)
- Inert COD (mg/L)
- Biological Oxygen Demand (BOD) (mg/L)
- Total Kjeldahl Nitrogen (TKN) (mg/L)
- Ammonia (mg/L)
- Total Sulfur (mg/L)
- Sulfate Concentration (mg/L)
- Sulfide Concentration (mg/L)

The model outputs can be categorized as either effects on the collection system, mitigation costs, or wastewater treatment plant influent characteristics. Modeled effects on the collection system include the following:

- Average flow velocities by pipe size (ft/s)
- Average depth of accumulated sediment (in)
- Hydrogen sulfide (H_2S) gas emissions (lb/day)
- Methane (CH4) gas emissions (lb/day)
- Average corrosion rate (in/year)
- Pipe life expectancies (year)

The estimated fiscal impact of mitigation actions calculated by the model include costs for the following:

- Chemical addition cost ($/year)
- Pumping energy costs ($/year)
- Pipe replacement cost ($/year)

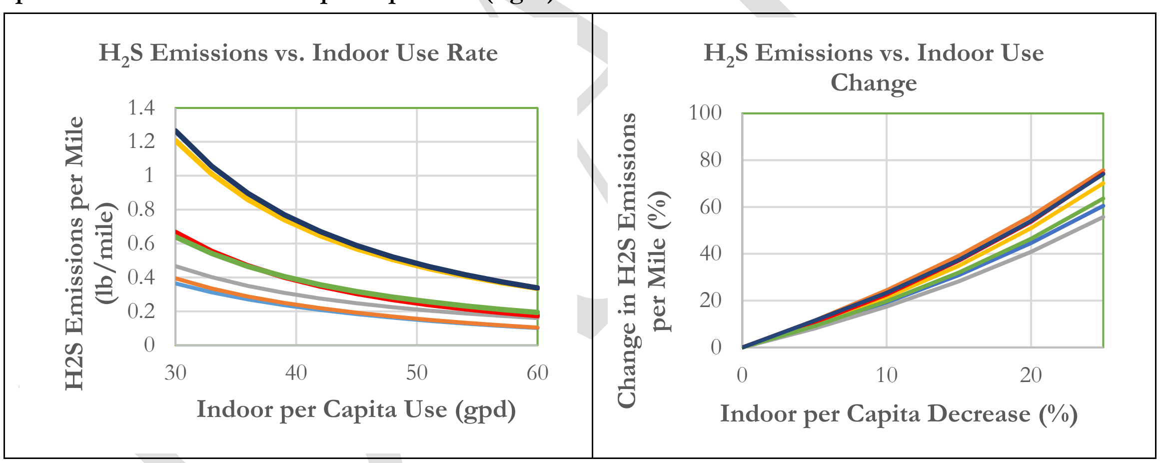
The estimated changes in influent constituent loadings to a WWTF estimated by the model include the following:

- Total suspended solids (TSS) (mg/L)
- Total Chemical Oxygen Demand (COD) (mg/L)
- Readily Biodegradable COD (mg/L)
- Slowly Biodegradable COD (mg/L)

- Inert COD (mg/L)
- Biological Oxygen Demand (BOD) (mg/L)
- Total Kjeldahl Nitrogen (TKN) (mg/L)
- Ammonia (mg/L)
- Total Sulfur (mg/L)
- Sulfate Concentration (mg/L)
- Sulfide Concentration (mg/L)

For a subset of 50 example collection systems, the model was run over a series of scenarios of per capita influent flow, starting with current per capita flow and reducing influent flow by 25% in increments of 5%. Other model inputs of system attributes were held constant. The model yielded output curves of changes in estimated effects for chemical addition, pumping energy, and pipe replacement, which were either normalized based on factors such as system size—for example, the annual cost of chemical addition per mile of sewer system—or compared to estimated annual baseline replacement rates, such as the percent change in annual pipe replacement costs (Figure 6-15).

Figure 6-15: Example model output curves for modeled systems with system with system-specific attributes, which compare a) Hydrogen sulfide emissions (pounds per mile) with changes in indoor per capita use rate (left), and b) Percent change in hydrogen sulfide emissions with percent decrease in indoor per capita use (right)



Note: Figures developed by authors based on modeling.

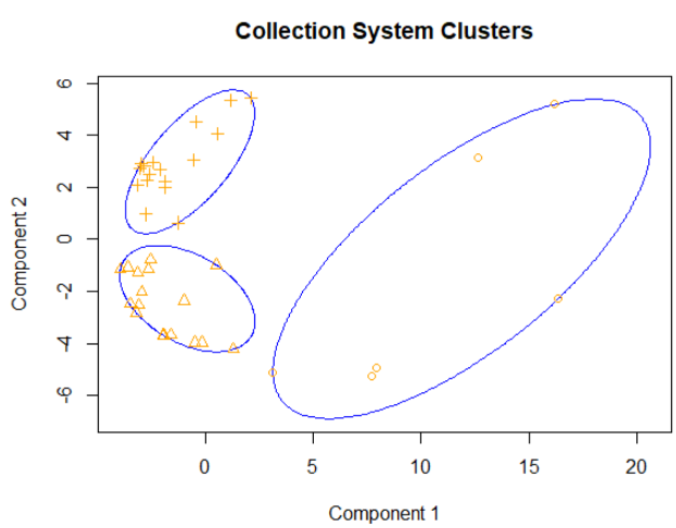
Clustering Analysis

After implementing the process modeling for the 50 example collection systems, clustering analysis was used to extrapolate effects to all systems. First, a list of key attributes of collection systems that could explain differences in the modeled effects of low flows was created based on existing literature, results from industry outreach (Chapter 6.4.3), and investigations with multivariate linear regression. Attributes with sufficient data for all collection systems were identified as significant explanatory factors of model results for four key model outcomes, including changes in corrosion rates, changes in hydrogen sulfide emissions, changes in chemical additions, and changes in sedimentation that could lead increased loading. Technical Appendix-3 provides further details on the analysis. The attributes used for clustering that correlated with modeled outcomes were the following:

1) *Current per capita influent flow for a collection system*. The metric was estimated as the total volume of annual influent divided by the population and number of days in a year.
2) *Climate zone risk score based on an ordinal indicator (1–5)*. Lower risk scores were associated with cool, wet areas where precipitation runoff can induce self-flushing of pipes. Higher risk scores were associated with hot, dry areas where lack of precipitation could lead to limited self-flushing and higher root intrusion risk, while hotter temperatures could lead to more septic wastewater in systems and hydrogen sulfide production.
3) *Percent of the sewer system constructed before 1979*, which is reported by systems through the SSO database.
4) *Percent of 6"–8" pipes in the system,* which is reported by systems through the SSO database. These pipes are smaller lateral lines that could be more susceptible to blockages and other effects.

Second, an unsupervised clustering analysis based on principal components was implemented to extrapolate effects for all collection systems based on the subset of modeled systems. For 41 systems with results from the process modeling, the attributes of current per capita influent flow, climate zone risk score, construction age (percent of pre-1979 construction), and pipe size (percent of 6"–8" pipes) were used as explanatory factors to group systems. Three distinct clusters were identified as part of two components that explained 85% of the variability (Figure 6-16). Results indicated that the explanatory factors could be used to group and extrapolate effects for all systems based on the modeled results for the subset of systems. All 446 collection systems of interest were grouped based on the explanatory factors to extrapolate statewide effects.

Figure 6-16: Results from clustering of collection systems to extrapolate effects



Note: Created by authors based using a clustering algorithm with data from the State Water Board's Sanitary Sewer Overflow survey database and network modeling of influent flow.

The clusters corresponded with ranges of the key explanatory factors, which were used as the basis for clustering all systems to extrapolate effects statewide (Table 6-25).

Table 6-25: Ranges of attributes for sewer systems in each of three clusters used to extrapolate statewide effects

Cluster	% 6"–8" Sewers	Climate Zone Risk Score	Estimated Total Per Capita Influent Flow (GPD)	Avg. Summer Temp (degrees C)
1	1%–63%	0-2.5	>95	<24
2	63%–73%	2.5-3.5	<75	>34
3	74%–100%	>3.5	75–95	24–34

Note: Author calculations based on analysis of clustering algorithm with attribute data.

Summary statistics of model outputs for each cluster were calculated (Table 6-26). Model outputs were normalized for extrapolation by estimating the percent change in model outputs associated with a 1% decrease in per capita flow that yields reductions in wastewater influent. The largest differences in model outputs across clusters corresponded with percent changes in hydrogen sulfide emissions, corrosion rate, and chemical addition requirements. The percent change in pumping energy did not vary across clusters. A change in flow was assumed to directly correlate with a change in pumping energy.

Table 6-26: Average percent change in model outputs associated with a 1% decrease in per capita flow across collection systems within clusters based on modeling 50 collection systems

Cluster	Average System Characteristics	H_2S Emissions	Corrosion Rate	Sediment Rate	Chemical Addition	Replacing Pipes	Pumping Energy
1	• Percent Pipes < 8”: 63.2% • Climate Zone Score: 2.3 • Estimated Flow: 139.7 gpd • Avg. Summer Temp: 22.7°C	1.29%	2.15%	0.22%	0.68%	2.13%	-1%
2	• Percent Pipes < 8”: 73.3% • Climate Zone Score: 2.9 • Estimated Flow: 74.2 gpd • Avg. Summer Temp: 27.4°C	2.01%	1.88%	0.26%	1.82%	2.12%	-1%
3	• Percent Pipes < 8”: 74.9% • Climate Zone Score: 4.1 • Estimated Flow: 84.6 gpd • Avg. Summer Temp: 36.8°C	2.05%	2.01%	0.25%	2.13%	2.13%	-1%

Note: Author calculations based on applying clusters to attributes of all collection systems.

Estimated Impacts

Based on the extrapolations and clustering, wastewater influent to collection systems is expected to decrease by an average of 2% (+/-5%) to 5% (+/-5%) across the Scenarios (Table 6-27). In Scenario 1 (indoor standard = 50 gpd, outdoor standard = 0.7), the clustering identified average decreases in influent flow for a collection system ranging from 0.4% (+/-4%) to 2.6% (+/-3%). The decreases have larger magnitudes in the scenarios with lower indoor and outdoor standard values. While clustering analysis used to extrapolate effects across the modeled systems based on system-specific attributes did result in noticeable differences in average influent flow rates, the ranges based on standard deviation values show overlap between distributions of clusters.

Table 6-27: Average percent decrease in flow by cluster

	Average Percent Decrease in Influent Flow		
Cluster	*Scenario 1*	*Scenario 2*	*Scenario 3*
1	-0.4% (+/-4%)	-2.6% (+/-3%)	-3.9% (+/-3%)
2	-1.7% (+/-6%)	-3.5% (+/-5%)	-4.5% (+/-4%)
3	-2.6% (+/-3%)	-4.3% (+/-3%)	-5.1% (+/-3%)
All	-2.1% (+/-5%)	-3.9% (+/-5%)	-4.9% (+/-5%)

Note: Author calculations based on applying modeling outputs to all systems based on clusters.

Based on the input assumptions and available data, results from extrapolating model results to all systems indicate average annual increases in a system from lower flows for pipe replacement costs (9.0%), hydrogen sulfide emissions (8.7%), rates of pipe corrosion (8.5%), sedimentation (1.0%), and chemical additions (2.1%). Pumping costs decrease by 4.3% on average (Table 6-28).

Table 6-28: Average modeled outputs by cluster for objectives values based on parameters for Scenario 2 (indoor standard = 42 gpd, outdoor standard = 0.62)

	Cluster			
Model Output (% Increase: Average)	*1*	*2*	*3*	*All*
Pipe Replacement Costs	7.5%	8.9%	9.5%	9.0%
H_2S Emissions	7.3%	8.6%	9.2%	8.7%
Corrosion Rate	7.1%	8.5%	9.0%	8.5%
Sedimentation	0.9%	1.0%	1.1%	1.0%
Chemical Addition	1.7%	2.0%	2.2%	2.1%
Pumping Costs	-3.5%	-4.2%	-4.5%	-4.3%

Note: Author calculations based on applying modeling outputs to all systems based on clusters.

These values are percent changes based on assumed existing rates of operations and maintenance activities typical of collection system operations. The values also assume that 15% of the demand reductions needed for AB 1668-SB 606 compliance originate from indoor water use efficiency that reduces wastewater generation. The model results could be greater in areas where Suppliers invest more aggressively in indoor water use conservation for compliance. The modeled results consider the fraction of influent coming from residential sources that fall under the AB 1668-SB 606 regulatory framework.

1.4.6. Effects on Wastewater Treatment Operations

Wastewater treatment systems with a WEO Impact Factor of less than 1 were deemed at risk of potential effects of lower flows originating from AB 1668-AB 606 demand reductions. However, the magnitude and likelihood of such effects are functions of not only flows, but also many site-specific factors including current influent flow rates, facility design, existing system conditions, location, constitution of the upstream effluent, and other factors.

To better evaluate quantitative effects and describe qualitative outcomes for wastewater treatment facilities that serve Suppliers, modeling with industry-standard software was used to identify key factors that would influence the magnitude of effects on operations associated with facilities of varying design and influent flow levels.

Modeling Summary

Wastewater treatment process impacts were evaluated using *Biowin* v 6.2. *Biowin* is a standard process model used in the analysis and design of wastewater treatment facilities. It simulates water flow, water quality, and treatment efficiency outcomes for varying configurations of wastewater treatment facilities based on input parameters. The model directly simulates changes in process outcomes such as constituent concentrations, but can also evaluate changes in secondary outcomes such as energy use and cost.

A modeling framework was developed to evaluate key outcomes for treatment process affected by changing influent flow rates, including changes within the headworks (processes such as grit screening and removal), changes in wastewater treatment processes that remove contaminants and nutrients, and effects on effluent such as reduced volumes for reuse or increased dissolved solids (Table 6-29).

Potential effects of lower flows on water quality outcomes are closely related to a facility's design flow rate and the rate of per capita wastewater generation in the sewershed. Wastewater facilities are designed to operate within a range of operational parameters that link flow rates with water quality processes and outcomes.

Two parameters influence outcomes. First, the volume of flow reaching a treatment facility in a day is the total volume of wastewater that must be treated. The total daily volume is used to calculate an influent flow rate. Second, the rate of per capita wastewater generation in the sewershed influences the concentrations of contaminants in the wastewater that reach the facility. Current per capita influent flow for a treatment facility was estimated as the total volume of annual influent divided by the population and number of days in a year. The concentrations used to simulate the influent characteristics under various per capita values (average values) are given in Table 6-30. The influent values were based on typical wastewater mass loading and adjusted for conversions taking place within the collection system (see 6.4.5, subsection Collection System Modeling).

Table 6-29: Modeling approach to evaluate how changes in flow rate affect key wastewater treatment process outcomes

Component	Identified challenges	Model approach
Headworks	Increased capital cost for headworks redesign/rebuild/lining	Scale design and costs based on outputs of collection systems process modeling for increased levels of hydrogen sulfide H_2S
	Increased operational cost for headworks odor control and additional chemicals	Scale design and costs based on outputs of collection systems process modeling for increased levels of H2S
	Increased cost for managing solids flushed from WWCS	Scale from collection system process modeling outputs for solids deposition, with increased risk for old collection systems that are stormwater-flushed
Treatment process	BOD removal	Increased energy use associated with increased constituent loading (pumping, process operations)
	Nitrogen conversion or removal	Increased energy use associated with increased loading; special cases may require alkalinity or carbon chemical additions
	Increased cost for periodic upgrades for many mechanical treatment works	Upgrades may be assumed to occur after a recognized threshold of change. The study assumes that upgrades are necessary with changes from 100 to 70 gpcd of influent flow and with a change from 70 to 50 gpcd influent flow)
Effluent	Reduced volumes for reuse	Facilities that are currently or planning to reuse full effluent volume may need to (1) blend with make-up water, (2) de-rate capacity of existing RW system, or (3) cancel or postpone new RW projects
	Increased recycled water Total Dissolved Solids	Facilities that have a high effluent TDS (e.g., > 1000 mg/L) may face limitations with irrigation of some crops. May require blending with low-TDS water or partial desalination. Mostly applies to communities using elevated TDS water supplies, e.g., groundwater.

Note: Compiled by authors.

Table 6-30: Influent data used for process modeling

Parameter	Influent concentration (mg/L) at given gpcd		
Influent Per Capita Water Use	100 gpd	70 gpd	50 gpd
TSS Concentration	210	294	404
Total COD Concentration	492	699	971
Biodegradable COD	441	626	869
Readily Biodegradable	293	416	577
Slowly Biodegradable	150	214	299
Inert COD	51	73	102
BOD Concentration	230	331	467
Total Kjeldahl Nitrogen as N	34	49	68
Ammonia as N	20	28	39
Total Sulfur	10	14	20

Note: Estimated by authors based on literature and modeling.

Generic wastewater process models were developed in *Biowin* to simulate operations and evaluate impacts associated with changing influent flow rates and associated conditions. The reference condition for simulations assumes a facility operating at or near the volumetric design flow rate and an effective per capita influent flow rate of 100 gpcd, which represents a rate of wastewater generation associated with historic design parameters during the era of initial construction for many facilities in California. The initial conditions of the volumetric flow rate for each facility, however, were not readily available. To benchmark the reference condition, an index was developed to relate current volumetric influent flow rates to the facility design capacity, which is called the *Dry Weather Capacity Index* (DWCI). The DWCI is defined as the ratio of the average dry weather flow ($Q_{dry\ weather}$) to the facility's design flow $\left(Q_{design}\right)$ over time:

$$DWCI = \frac{Q_{dry\ weather}}{Q_{design}} \quad (6)$$

The index evaluates if dry weather base flow for a facility is above, near, or significantly below the facility's design capacity. Relating volumetric influent flow to design capacity allows for benchmarking the volumetric flow rate against a parameter that is known for most facilities (design capacity). Technical Appendix 3 provides further information on the DWCI and other indices developed to estimate effects of lower flows. The per capita influent flow rate was then used to vary scenarios of constituent loading for wastewater treatment facilities that yield outcomes.

Each process model was evaluated for the following two loading scenarios at the reference condition and decreased flow rates. The two loading scenarios are defined as the following:

1) Total volume of influent flow to a facility stays the same, while the per capita influent rate decreases. Under this scenario, a facility operating at design flow capacity would have a DWCI value of 1 at all gpcd values.
2) Total volume of influent decreases as per capita influent flow rate also decreases. In this scenario, a facility operating at design capacity would have a DWCI value.

For each influent loading condition and loading scenario, energy use was used to normalize effects, which could then be related to changes in cost. The energy associated with process recycle flows and aeration demands were estimated using the model output.

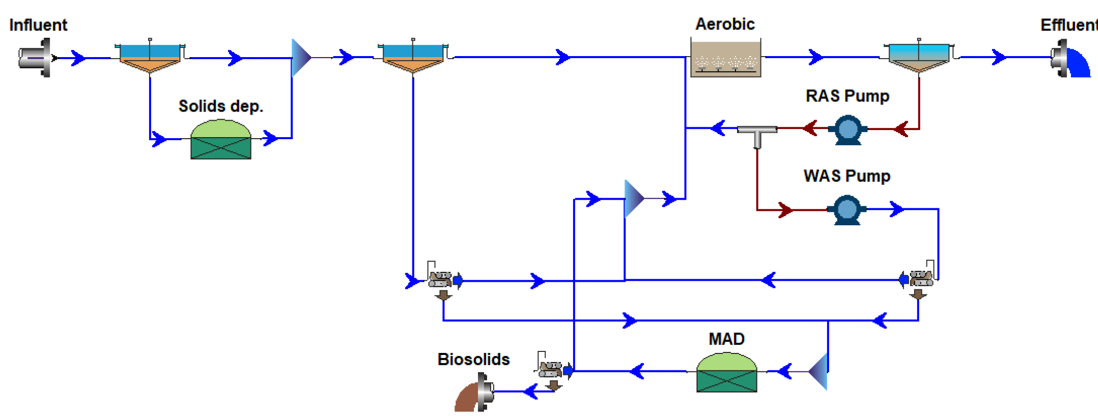
Biodegradable Organics Reduction

Some WWTFs treat influent to remove biodegradable organics from municipal wastewater prior to discharge, which typically occurs when discharging to coastal waters. These WWTFs were modeled in *Biowin* based on achieving an effluent biochemical oxygen demand (BOD) of 10 mg/L. Facilities with a higher effluent limit would be expected to use less power to accomplish treatment. A diagram of the process model used to simulate a treatment process for BOD reduction is shown in Figure 6-17.

BOD and Ammonium Removal

Some WWTFs treat influent to remove biodegradable organics and nitrification of ammonium in municipal wastewater prior to discharge, which typically flow to inland waters with sensitive aquatic species. These WWTFs were modeled in *Biowin* based on achieving an effluent biochemical oxygen demand (BOD) of 10 mg/L and ammonium less than 1 mg/L. Facilities with a higher effluent limit would be expected to use less power to accomplish treatment. A diagram of the process model used to simulate a treatment process for BOD and ammonium reduction is shown on Figure 6-17.

Figure 6-17: Process diagram of the model used for simulating both BOD and ammonium reduction

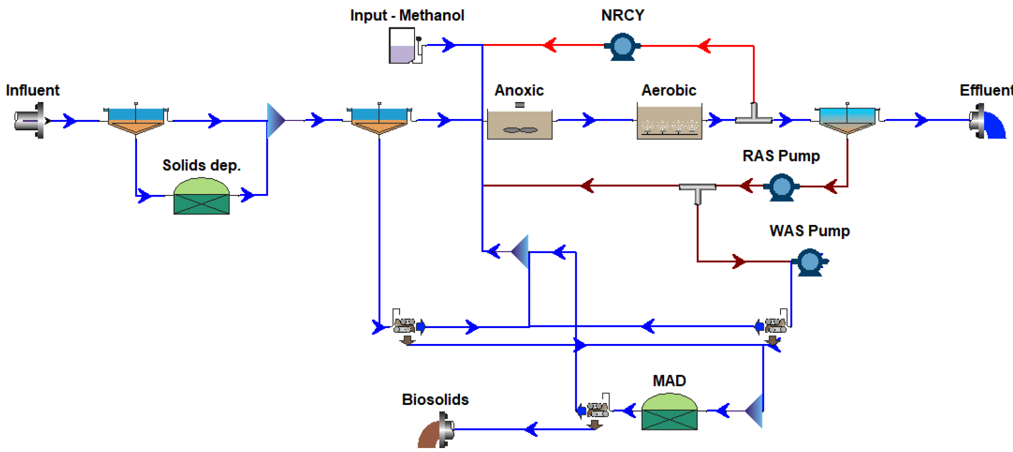


Note: Developed by authors based on visualizations in software.

BOD and Total Nitrogen Removal

Some WWTFs treat wastewater to remove both biodegadable organics and total nitrogen in municipal wastewater prior to discharge, which typically flow to inland waters used subsequently as water supply. These WWTFs were modeled in *Biowin* based on achieving an effluent biochemical oxygen demand (BOD) and total nitrogen (TN) of less than 10 mg/L. A diagram of the process model used to simulate a treatment process for BOD and TN reduction is shown on Figure 6-18.

Figure 6-18: Process diagram used for simulation of both BOD and total nitrogen reduction



Note: Developed by authors based on visualizations in software.

Operational Impacts: Process Energy

Model outputs were normalized as a single value of energy change associated with the sum of effects that could include chemical addition, pumping, and others. The results for the change in operational energy under each loading condition for each of the wastewater process simulations are shown in Figure 6-19, including models for treatment facilities with a) biodegradable organics reductions, b) biodegradable organics reduction and ammonium reduction, and c) biodegradable organics reduction and total nitrogen reduction. Generally, results for each process have similar characteristics. For purposes of estimating process energy changes, Figure 6-19(b) was used and provides a somewhat conservative estimate for any type of WWTF. Modeled scenarios yielded output curves that related per capita influent flow rates with changes in energy use to maintain water quality within a range of operational parameters for the Dry Weather Capacity Index that relates volumetric flow with the design capacity (Table 6-31).

Table 6-31: Estimated change in energy use per unit reduction of gpcd, based on benchmarking reference conditions to the estimated Dry Weather Capacity Index

Modeled/estimated parameter	Change in energy use per unit reduction in gpcd
Change in energy compared to reference condition (DWCI = 1)	$99.35 * x^{-0.997}$
Change in energy compared to reference condition for (DWCI = current gpcd)	$0.6693 * x^{0.0892}$

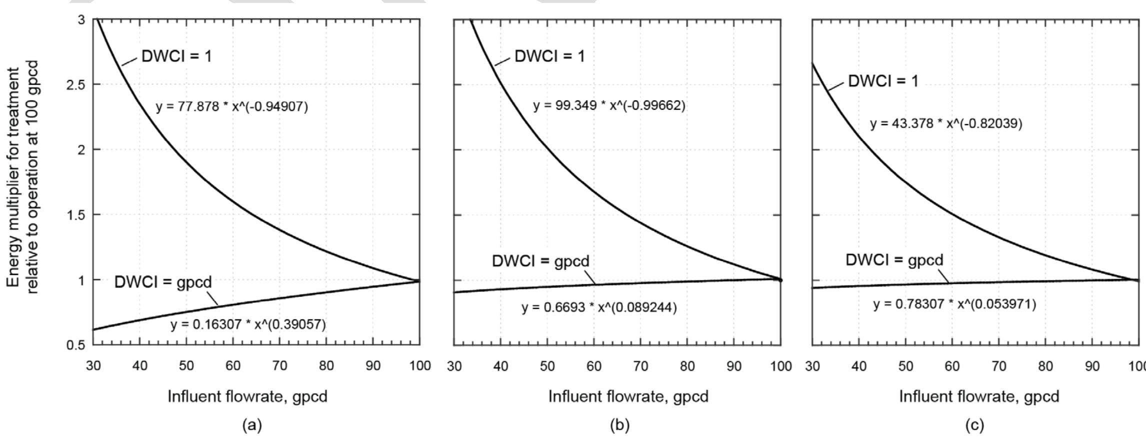
Note: Author calculations based on modeling.

The output curves were used to evaluate facility-specific changes in energy use as a quantitative effect of lower per capita influent flows using a multistep procedure:

1) Estimate the current per capita influent flow rate by dividing the total volume of influent by the estimated population. The total influent volume was estimated for a recent year based on available self-reported data sources, either from the 2015 Urban Water Management Plans (UWMP's Table 6-3) or the SWB's 2019 Annual Volumetric Survey (AVS). Current populations were estimated based on linking collection and treatment systems and using reported collection system populations and network modeling to estimate the residential population served by a WWTF.
2) Estimate the future per capita influent flow rate by dividing the total projected volumetric flow by the future population. The future total projected volumetric flow includes baseline and AB 1668-SB 606-related demand reductions, the WEO Impact Factors, and network modeling.
3) Estimate current and future Dry Weather Capacity Index values by comparing estimated or reported total influent flow with the facility's design capacity.
4) Estimate a scaling factor to identify the value of energy use change between the upper and lower modeled curves, which quantifies the energy use change associated with a facility operating at a DWCI value that represents initial conditions with accumulated changes in population growth and influent flow rate since the facility's construction;
5) Estimate the value of the normalized energy use coefficient (Figure 6-19, y-axis) for current operations based on the estimated values of current per capita influent flow rate and DWCI.
6) Estimate the value of the normalized energy use coefficient (Figure 6-19, y-axis) for future operations based on the estimated values of future per capita influent flow rate and DWCI.
7) Calculate the percent change in energy use for each facility as a proxy for operational impacts to maintain water quality.

In the systems exemplified in Figure 6-19, indoor water conservation drives a change in influent flow rate that yields increases in energy use.

Figure 6-19: Estimated change in energy use based on reference condition of 100 gpcd for (a) biodegradable organics reduction, (b) biodegradable organics and ammonium reduction, and (c) biodegradable organics and total nitrogen reduction



Note: Author calculations based on modeling.

As shown in Figure 6-19, the curves are valid within the modeled range of per capita influent flow from a baseline value of 100 gpcd down to approximately 40 gpcd. Results were quantified for

Scenario 2 (indoor standard = 42 gpcd, outdoor standard = 0.62 in 2030). Of the 204 potentially-affected WWTFs identified through network modeling (Table 6-22) in Scenario 2, 92 WWTFs had sufficient data for modeling operational effects.

Applying the model to these WWTFs within the range of 30 to 100 gpcd yielded an average increase of 0.8% in annual energy use and a median decrease of 1.8%. Of the 92, 36 had increases in energy use, and 56 had decreases. Of those with estimated increases, the nonweighted average increase in energy use was approximately 11.9%, while of those with estimated decreases, the average decrease was 6.8%. Weighting the model outputs by estimated population served by a WWTF, statewide energy use for wastewater treatment is estimated to increase by 1.4% across all WWTFs with available data. Results are summarized in Table 6-32.

Table 6-32: Changes in energy use for future flows with population growth, baseline water use efficiency improvements, and reductions from AB 1668-SB 606. Energy use in the modeling was used as a surrogate for all operational requirements

Facilities	Number	Average Change	Median Change	Population Weighted Average Change
All	92	0.8%	-1.8%	1.4%
WWTFs with energy use increases	36	11.9%	6.4%	5.2%
WWTFs with energy use decreases	56	-6.8%	-6.3%	-5.6%

Note: Author calculations based on modeling.

Capital Impacts: Facility Upgrades and Improvements

In addition to process changes modeled through *Biowin*, influent flow reductions from AB 1668-SB 606 will potentially instigate required major capital improvements to upgrade facilities adapting to future lower flows. During this project's industry outreach phase (Section 6.4.3), facility managers and sanitation district staff often discussed how incremental changes over time, such as lower flow reductions, would lead to an impact threshold, after which significant process improvements or capital investments were needed to meet effluent quality requirements. Designs for WWTFs were bounded by the expected influent loading and treatment goals. When the actual operation moves outside of the design boundary, the treatment process becomes unstable and creates challenges in meeting effluent water quality goals, thus process upgrades are required. These thresholds occur when the influent flowrate, loading, or concentration changes by approximately 30%.

Based on analysis of existing literature, modeling, and input from outreach, a threshold framework was developed for estimating the potential for capital improvements related to influent flow changes from AB 1668-AB 606. A binning approach was developed with per capita influent flow in ranges of

- greater than 100 gpcd,
- 70 to 100 gpcd,
- 50 to 70 gpcd, and
- less than 50 gpcd.

Using the binning approach with influent flow thresholds, capital improvements to processes would be needed for 43 of the 92 affected WWTFs. Such effects would be related to upgrades in headworks, aeration systems, and pumping systems. Most systems crossed thresholds of 70 gpcd or 50 gpcd of estimated future per capita influent flow.

Operational Impacts: Adapting and Upgrading Processes

The need for process upgrades and improvements is driven primarily by the integrity of the structures and the suitability of the process to meet water quality objectives. It is common for WWTFs to be upgraded about every 20 years, in response to growth and development in the community. Historically, as the influent flowrate approached the design capacity, plans for facility expansion would be developed. The rate of community growth was proportional to the influent flowrate, and the influent flowrate was the design basis for WWTFs. With the implementation of modern water usage, populations have increased in many areas while the influent flowrate has stayed the same or declined. Therefore, the standard flow-based method used for design of WWTFs is no longer applicable. Further, shifts in population for a given municipality generally occur slowly and allow adequate time for changes to and adaptation of critical wastewater infrastructure, which must continue to operate and meet effluent quality requirements on a continuous basis regardless of construction projects. The changes in influent wastewater strength due to changes in indoor water usage practices, such as in response to water shortages and conservation mandates, can occur rapidly. Rapid increases in influent concentrations or mass loading are particularly difficult to manage due to the long planning horizon generally required for modification of WWTFs.

When most WWTFs were originally built, unprotected concrete was commonly used because the wastewater was relatively dilute and the rate of sulfide production was low. In the case of headworks, increases in influent hydrogen sulfide will increase the corrosion rate of any unprotected concrete or steel structures. The required upgrade consists of replacement or relining of concrete, and, in some cases, replacement of influent pumps. Step increases in influent hydrogen sulfide can be used as an indicator of increased rate of headworks corrosion. The particular point when this upgrade takes place depends on a condition assessment as well as sufficient budget.

Similarly, the biological processes used for wastewater treatment must be adapted to changes in wastewater constituent concentration and mass loading. Due to scale effects, smaller facilities (i.e., lower influent flow rates) have greater risk because the peak concentration and loading events have a greater magnitude and frequency than on larger WWTFs. However, changes in the mean influent concentration can impact all WWTFs that have not already been adapted to current and expected influent wastewater characteristics. The areas that present the greatest challenge include legacy aeration system and pumps.

The aeration demand at a given WWTF is a function of the influent wastewater generated with the collection network and wastewater constituent transformations that take place within the collection system as well as transformations that take place at the WWTF. For example, longer retention times in primary treatment results in hydrolysis of wastewater solids and increased soluble organic and nitrogen loading on the aeration system. Imported organics for codigestion also increase the process loading. In reality, the systems used to supply oxygen to the biological treatment process have a certain range of operation and capacity. As the influent concentration and loading increase, legacy aeration systems, which were adequate previously, can no longer meet the treatment goals. The limitations are associated typically with low efficiency coarse-bubble diffusers, antiquated or manual process controls, and blowers that are not sized correctly. It is estimated that a change in the biodegradable organic concentration or loading of 30 percent could require a process upgrade.

Internal flow recirculation is a fundamental operation in modern wastewater treatment processes. Recirculated flows are used to return concentrated biomass to the biological process. These flows are also used as the principle method for nitrogen removal. Changes in wastewater concentration and strength can have a significant impact on the rate of internal flow recirculation required. While all WWTFs are subject to upgraded aeration systems, nitrogen removal type WWTFs in particular rely on internal flow recirculation to achieve process performance goals. The pumps and systems used for internal flow recirculation have a relatively narrow window of optimum performance. Increases in the ammonium nitrogen concentration and loading cause the internal recirculation of flows to increase to meet the same effluent concentration. It is estimated that a change in the ammonium concentration or loading of 30 percent could require a process upgrade. Alternately, a chemical feed system can be used to compensate for some process limitations. In such instances, increased chemical use could postpone the need for major process upgrades.

1.4.7. Effects on Water Reuse

From the network modeling of objective scenarios, a majority of wastewater treatment facilities that produce recycled water would be affected at increasing rates across scenarios (Table 6-33). For Scenario 1, the rates of affected facilities are equal across facilities identified as producing recycled water based on reporting from the SWB's Annual Volumetric Report. In Scenarios 2 and 3, the rate of affected facilities producing recycled water increases.

Table 6-33: Summary of affected wastewater treatment facilities from AB 1668-SB 606 by status as a recycled water producer

		Percent of Affected Systems, by Scenario		
Recycled Water Producer?	Total Number of Systems in State	Scenario 1	Scenario 2	Scenario 3
Yes	162	54%	79%	87%
No	101	55%	70%	79%

The estimated statewide volume of wastewater influent across all facilities increases for each scenario, but for reuse facilities, the influent volume decreases for Scenarios 2 and 3. In these scenarios, after considering ongoing efficiency, there is a 7% and 11% decline in wastewater influent available for recycled water production as a result of AB 1668-SB 606 (Table 6-34).

Table 6-34: Changes in annual influent flow volume to wastewater reuse facilities based on impacts from AB 1668-SB 606

	Estimated Change in Influent Flow		
Category	**Scenario 1**	**Scenario 2**	**Scenario 3**
All wastewater facilities	39,027 ac-ft	30,249 ac-ft	30,237 ac-ft
Recycled water producers	21,700 ac-ft	-51,402 ac-ft	-73,243 ac-ft

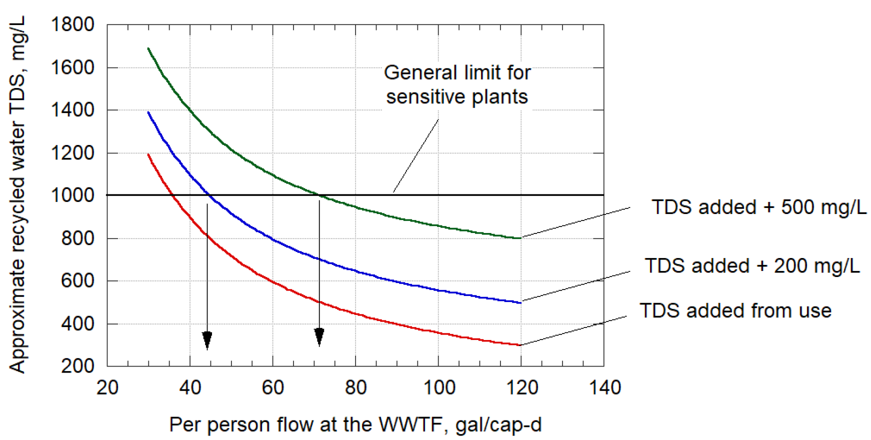
Percent Decline in Recycled Water Production	-	-7%	-11%

Notes: Author calculations based on network modeling. Values account for changes in population growth and baseline water use efficiency.

Of the recycled water producers that serve Suppliers, facilities that currently send 80% or more of recycled effluent to reuse applications would be most at risk for lost sales of recycled water. Across scenarios, 40–50 recycled water producers across the state currently send 80% or more of effluent to reuse applications during at least one month of the year. This represents 36%–45% of the affected recycled water producers in the state.

Because water supply of high quality is used for urban areas, the quality of recycled water is high relative to most other available water supply sources for irrigation. Across regions, recycled water Electrical Conductivity (EC) ranges from about 0.7 to 1.8 mS/cm. While the EC value of recycled water is not a specific concern, where there is a low leaching fraction, soil salinity can build up to inhibitory levels (Ayers and Westcot 1985). Thus, there is greater concern about increasing recycled water EC in areas that also practice high efficiency irrigation. The EC / TDS can be estimated based on the TDS of the water supply and the average per person influent flowrate (see Fig. 6-20).

Figure 6-20: Approximate Total Dissolved Solids of recycled water effluent for various levels of per capita influent flow



Notes: Figure created by the authors. The horizontal line indicates the upper limit of TDS concentration for sensitive vegetation.

In addition to reduced wastewater dilution, there is an increased use of reverse osmosis systems and evaporative cooling towers discharging wastewater with elevated levels of TDS to municipal wastewater treatment systems, further increasing the EC of wastewater effluent.

As indoor water use declines, the quality of recycled water declines. While the EC of recycled water is generally in a usable range, there may be concerns with sensitive crops. In most cases, shifts in irrigation practices and shifting to salt tolerant plant varieties can mitigate the increased salt concentrations.