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<u>Technical Appendix 3 (TA-3)</u>
Analysis of Environmental Effects on Urban Wastewater Collection, Treatment, and Reuse Systems: Literature, Methods, and Results

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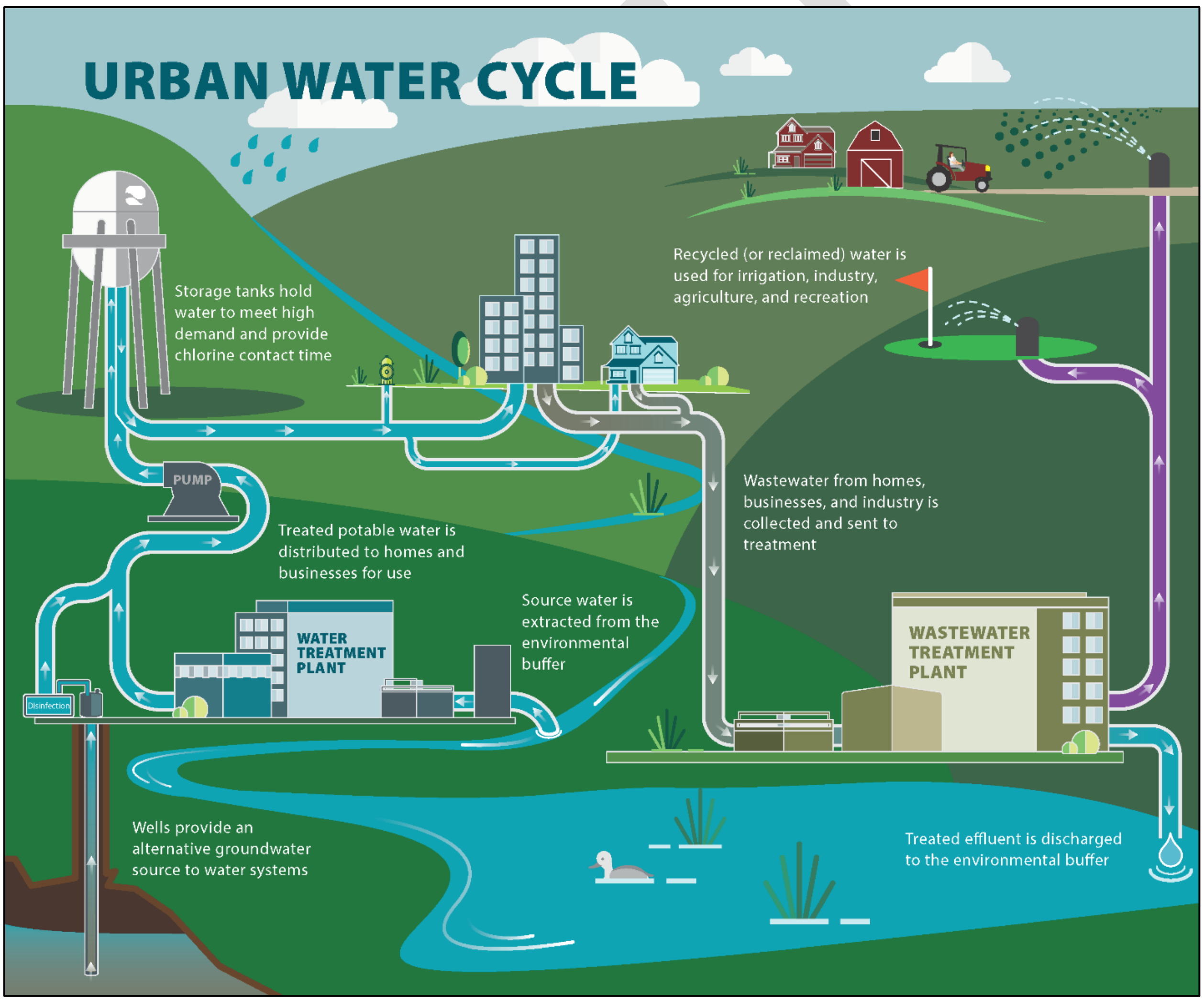
1. Introduction

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. Together, the networks of sanitary sewer pipes that move, treat, and dispose of wastewater make up modern wastewater treatment systems. 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 TA-3.1).

Figure TA-3.1: Visualizing the urban water cycle.



Notes: Figure courtesy of Office of Water Programs (OWP) at Sacramento State

Wastewater systems are one type of critical infrastructure that allow modern cities to support healthy residents. In the twentieth century, the development of expanding water and wastewater treatment systems spurred huge gains in public health. Annual bouts of disease in cities were tackled. Later in the twentieth century, general recognition of the environmental consequences caused by pollution, including contaminated waterways and degraded habitat, spurred laws and regulations to promote clean water. Wastewater was a key sector of focus for such regulations.

1.1. Development of wastewater systems in the U.S.

Many wastewater systems in California were built decades ago. Collection systems in particular are often aging and operate based on old design parameters. As a consequence, historical precedent of wastewater system design still has an important influence on contemporary systems.

As U.S. cities grew in the nineteenth and early twentieth centuries, early sanitary engineering experts began recognizing important links between human health and drinking water quality. Industrializing cities started investing in infrastructure technologies to treat water for drinking. Newly available water supplies of higher quality increased daily consumption and created a new problem: large amounts of wastewater (Melosi 2000; Tarr et al. 1980).

With the advent of the toilet, wastewater soon overwhelmed existing household solutions. Cesspools leaked, causing soil and groundwater contamination. The rapid expansion of American cities, combined with space constraints, created a problem of surplus sewage and wastes (Tarr et al. 1980). Cities had to develop innovative wastewater conveyance and treatment technologies with limited scientific understanding of metabolic and bacteriological processes. Many urban sewer systems were adapted from a primary purpose of storm drainage to serve mixed uses of conveyance for both wastewater and storm runoff (Tarr 1984). Contentious debates ensued over municipal spending and infrastructure expansion (Blake 1956), but eventually, public health concerns motivated municipalities to adopt centralized, subsurface sewage conveyance.

While large industrial cities in the U.S. invested in drinking water treatment facilities in the early 20th Century, it took several decades for many to build sewage treatment facilities (Table TA-3.1). The push towards broader water and wastewater treatment accelerated after 1920. U.S. municipal and industry leaders advocated for expanded investments in municipal water and wastewater systems. Many smaller and mid-sized cities, however, could not afford expensive systems. Early sanitarians and founders of environmental engineering such as Abel Wolman and Linn Enslow expanded the reach of cost-effective technologies (White and Okun 1992), and federal agencies during the Great Depression took an increasing role in expansion of sewer systems.

After World War II, public investment in all types of domestic infrastructure continued, increasing from $8.6 billion to $13.6 billion between 1950 and 1960 (Aldrich 1980 pp. 59–71). Spending during the Post-WWII period was in part motivated by growing recognition of old, ineffective infrastructure in many cities (Melosi 2011). From 1945-1965, municipal water works in the U.S. increased from approximately 15,400 systems serving 94 million residents to over 20,000 systems providing for 160 million people (Babbitt and Doland 1955; Fair and Geyer 1958). With more spending came centralized bureaucratic control. Operations and management of water, wastewater, and stormwater systems was dispersed across departments and agencies. Bureaucratic fragmentation emerged, a legacy that recent efforts to emphasize "One Water" planning in cities tries to rectify to this day. Figure TA-3.2 shows historic trends in water sector investments across levels of government

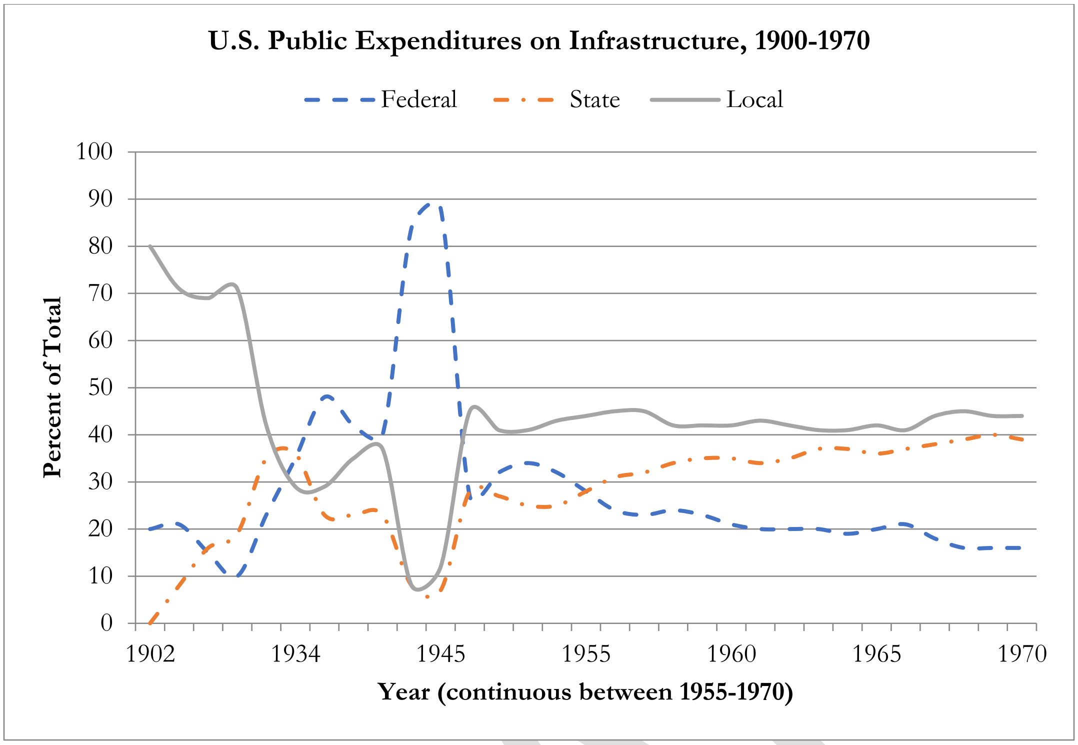
Table TA-3.1: Year of implementation for water and wastewater treatment technologies, by city.

City	Water Filtration	Water Chlorination	Sewage Treatment	Sewage Chlorination
Baltimore, MD	1914	1911	1911	after 1936
Chicago, IL	after 1940	1916	1949	after 1949
Cincinnati, OH	1907	1918	after 1945	after 1945
Cleveland, OH	1917	1911	1922	1922
Detroit, MI	1923	1913	1940	1940
Louisville, KY	1910	1915	1958	after 1958
Milwaukee, WI	1939	1915	1925	1971
New Orleans, LA	1909	1915	after 1945	after 1945
Philadelphia, PA	1908	1913	after 1945	after 1945
Pittsburgh, PA	1908	1911	after 1945	after 1945
St. Louis, MO	1915	1919	after 1945	after 1945

Notes: Adapted from Cutler and Miller (2005)

As federal infrastructure spending increased in the post-WW II period, changing societal attitudes regarding environmental pollution reinforced public health investments in water infrastructure. Federal legislation began to address urban water pollution. In 1948, the U.S. Congress passed the Water Pollution Control Act, which established baselines for water quality to protect human health. Subsequently, the Federal Water Pollution Control Act Amendments of 1961 and the Water Quality Act of 1965 followed, which provided funding for infrastructure improvements and required states to develop water quality standards. Still unsatisfied with state progress, Congress passed a "comprehensive recodification and revision of federal water pollution control law, known as the Federal Water Pollution Control Act (FWPCA) Amendments of 1972. The FWPCA regulated discharges from point-source pollution sources through the National Pollutant Discharge Elimination System (NPDES), focusing on industrial sources and municipal sewage. In totality, the legislation created a blanket of regulations that forced cities to develop advanced wastewater treatment facilities to control effluent. These investments and the regulatory framework serve as the basis for wastewater management today.

Figure TA-3.2: U.S. public sector expenditures between 1900-1970, broken down by level of government.



Note: Data is continuous between 1955-1970, but represents only a subset of years between 1900-1955. Data adapted from Tarr et al 1984, based on data from the 1975 U.S. Historical Census.

2. Literature Review

The contemporary management challenges for wastewater collection, treatment, and reuse systems in California from lower flows are not new. Past studies and theoretical modeling have evaluated how changes in the quantity and quality of wastewater can affect conveyance and treatment processes. The sections below survey existing research on identified effects in past eras and theoretical modeling of operations.

2.1. Impacts of drought and lower flows on wastewater systems

Like much infrastructure in the U.S., many wastewater treatment systems are old. Older systems were built to specifications and design capacities from earlier eras. Infrastructure systems are typically constructed and financed to be long-term investments. As such, they are "sticky" assets, meaning once built and operating, they are expensive to change.

In California, many existing wastewater treatment plants were built with the assumption of increasing populations and historically higher municipal water use. Increased water efficiency can lead to more concentrated influent and, for areas with stable or decreasing populations, lower influent flows. For instance, in analyzing impacts of the 1976-1977 drought, multiple studies from experts and the California Department of Water Resources described negative effects of water conservation on wastewater production and treatment. Notably, these studies also identified benefits that exceeded costs. In a 2017 survey of wastewater agencies in California, half encountered operational problems during periods of flow reduction from drought, but facilities were able to cope through adaptive actions. Changes in energy use and chemicals were the most significant items affected by influent flow reductions, with some facilities experiencing an increased need for one or both of these resources, and others experiencing a decreased need. Water use reductions that lead to reduced wastewater influent flows were assessed to save $210 million in capital expenditures.

The 2011–2016 drought was another iteration of the cascading effects that rapid changes in assumptions of infrastructure operations can have on existing systems; it also highlighted potential savings from unrealized costs. As municipal urban retail water supply agencies throughout the state promoted water use reductions to meet voluntary and later mandatory targets, wastewater systems were again stressed as downstream processors of sewage. In a contemporary context, current long-term risks that wastewater treatment facilities face are a function of many factors, including:

- Long-term declines in indoor per capita water use, which affects both conveyance and treatment systems. These declines can stem from reduced availability of new water sources that spur utilities to invest in conservation as well as more efficient indoor fixtures that are increasingly common in California's buildings;
- Acute declines related to drought or service interruptions, which spur more rapid drops in indoor water use;
- Climate change impacts that include loss of snowpack and more severe drought;
- Changing quality of influent from either more concentrated inflows or leaky collection and conveyance systems that can instigate acute changes in influent quality; and
- Increasingly stringent water quality regulations for effluent that is discharged to local waterways.

These dynamic conditions may instigate further stress on even well-maintained conveyance and treatment systems in the state. Many systems, however, are old and oversized for current conditions. Changing conditions will require adaptation and mitigation actions to maintain and improve the performance of wastewater treatment infrastructure.

This section of the document provides a review of literature on the effects of water use efficiency and conservation on wastewater treatment; it also describes methods that will be used to evaluate environmental effects of water use efficiency regulations on wastewater conveyance, treatment systems, and recycled water production.

2.1. Wastewater system design, operations, and management challenges

Wastewater infrastructure has a typical design life exceeding 50 years and therefore these systems must accommodate a great range of operating conditions. Most existing wastewater treatment systems for communities in California were designed and constructed at a time when both the population and wastewater composition were different.

The nature of indoor water use has a significant impact on the wastewater composition that reaches treatment facilities. Indoor water use is a function of many factors, including design of the water system, types of appliances that are used (local ordinances), and individual habits. Water shortages and periods of drought result in an increase in the value of water and motivates people to fix leaks, change their appliances, and become more water efficient through a mixture of voluntary and mandatory conservation measures. This improved efficiency in water use does not generally reduce the mass of materials being discharged with water, and, when a reduced volume of water is used to transport these materials through wastewater collection systems, higher constituent concentrations result. An example of how wastewater constituent concentrations have changed over time, as water use efficiency has improved, is presented in Table TA-3.2. Wastewater strength has increased significantly since the time when most wastewater management facilities were constructed.

Table TA-3.2. Comparison of how wastewater characteristics have changed over the life of typical California wastewater treatment facilities.

	Influent Concentration (mg/L)	
Indoor water usage (gal/cap-d)	*Biochemical Oxygen Demand (BOD)*	*Total Suspended Solids (TSS)*
125 (1970s)	161	156
50 (1990s)	402	391
37 (2010s)	543	528

Note: Assumed BOD and TSS loadings of 76 and 74 g/cap-d (Tchobanoglous et al. 2015).

2.1.1. Wastewater generation

Water is used indoors for various purposes, but nearly all of this water is eventually used to transport waterborne waste matter to wastewater collection systems. Factors that may have an impact on domestic wastewater generation and characteristics include changes in consumer product usage, new appliances, alternative water and drainage systems, and household activities. A summary of common factors and implications for water and wastewater systems is presented in Table TA-3.3. In some cases, these factors can impact the toxicity and salt content of wastewater, which can have a negative effect on subsequent wastewater treatment and water reuse. These factors can also influence the timing of wastewater discharge, which, as discussed subsequently, has a significant impact on the self-flushing design of wastewater collection systems.

Table TA-3.3: Summary of factors that can impact water and wastewater systems

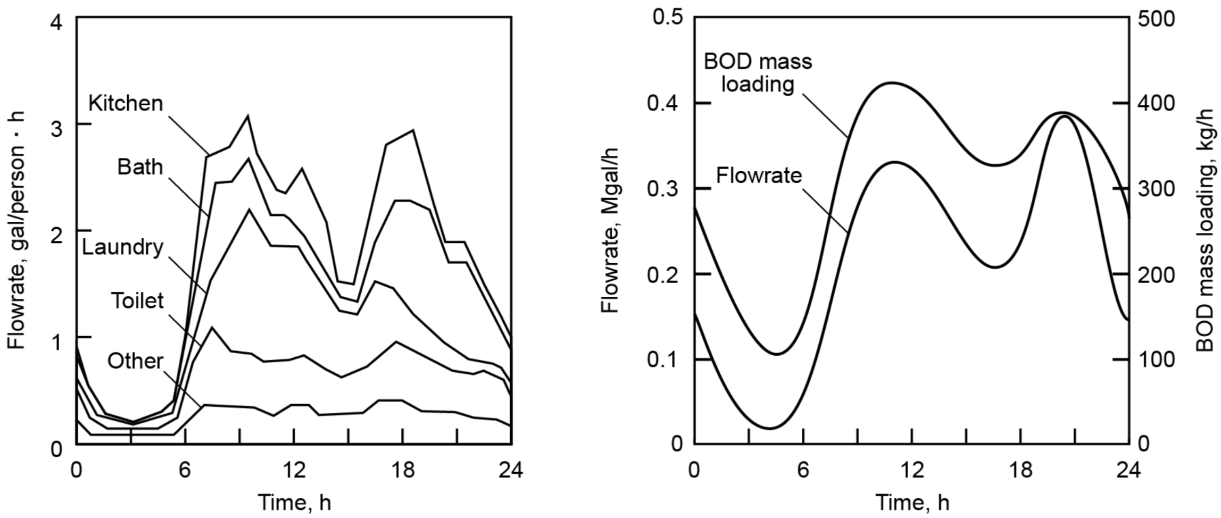
Strategy or activity	Examples	Expected impact on water and wastewater systems					
		Water demand outdoor	Water demand indoor	Wastewater concentration	Wastewater flowrate	Wastewater mass loading	Wastewater toxicity / salinity
Reduced flow appliances and fixtures	Waterless urinals Low-flow toilets & shower 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	No Change	No Change	No Change	No Change	No Change	Decrease
	Onsite pre-treatment	No Change	No Change	Decrease	No Change	Decrease	Decrease
	Food waste diversion	No Change	No Change	Decrease	No Change	Decrease	No Change
	Urine diversion	No Change	Decrease	Decrease	Decrease	Decrease	Decrease
	Water softeners (salt based)	No Change	No Change	Decrease	Increase	No Change	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 based on multiple sources

Patterns of water usage. Some of the factors noted in Table TA-3.3 impact the rate at which wastewater is discharged to wastewater collection systems. Many wastewater collection systems are dependent on diurnal (occurring each day) peak flow events to flush settled materials to downstream pump stations and treatment works. Thus, the operation of wastewater collection systems can be impacted by reductions in the diurnal peak flow.

The results of a study to determine how wastewater generation originates and varies with time are shown on Figure TA-3.3. Peak flow events historically occur in the morning and evening as a result of domestic activities such as bathing and laundry. With more efficient fixtures, it is possible that a conventional diurnal water use will become more uniform, leading to a tendency for increased accumulation of waste materials within wastewater collection systems due to reduced scouring flows for flushing.

Figure TA-3.3: Summary of wastewater generation characteristics: (a) typical wastewater generation pattern for an individual and (b) typical influent flow and loading pattern at a medium sized wastewater treatment facility



Note: Adapted from University of Wisconsin (1978); Tchobanoglous (2015).

Wastewater Composition. Wastewater is primarily composed of potable and non-potable water supply, which include various dissolved, colloidal, and particulate substances associated with domestic activities. In addition to the familiar components of wastewater, such as toilets, clothes washing, bathing, and cooking, there are a number of specific constituents that can have a significant impact on wastewater management operations. Constituents highlighted below include oil and grease (O/G), grit, trace organics, and fibrous products. The impact of these constituents can increase as their concentrations become elevated with high levels of conservation.

In the early 1900s, lard was the primary fat used in cooking. Lard would pass through wastewater collection systems with the high water use of the day, and accumulate as grease balls in wastewater treatment reactors. Modern cooking fats have much different properties and the increased use of various cooking oils has caused a significant increase in the accumulation of O/G in wastewater collection systems, contributing to blockages and spills. In some cases, O/G accumulations can increase the production of hydrogen sulfide, promote anaerobic reactions, and increase the rate of concrete corrosion. Minerals from hard water supply can enhance the formation of grease blockages in wastewater collection systems. Grease accumulations in wastewater collection systems require regular removal, therefore, the use of onsite grease traps at food service areas are required in many areas.

Grit is composed of inorganic settle solids, ranging in size from about 50 to 1000 micron. While similar in size to sand, within wastewater collection systems, grit particles can become coated with oils and other agents that cause these particles to become more buoyant. Under these conditions, grit can be transported far into wastewater treatment facilities. Grit then accumulates within settling tanks, aeration basins, and digesters, resulting in difficult and costly cleaning operations (Wilson et al., 2007)

The discharge of trace chemicals, which cannot be removed easily in conventional wastewater treatment processes, is a significant concern. These trace chemicals include residues from antibiotics, pharmaceuticals, and per- and polyfluoroalkyl substances (PFAS). Most of the chemicals present in consumer products end up in wastewater systems at relatively low concentrations, however, as many of these chemicals are not readily biodegradable, they are discharged with effluent to surface waters. The effect of these trace constituents in the environment is under investigation, but evidence of antibiotic resistant and disruption of aquatic ecosystems has been observed.

The increased use of various products containing natural and synthetic fibers, including diapers and towels, combined with lower flows from water conservation, has resulted in significant maintenance issues across California. Most solids and paper products disintegrate during wastewater collection and pumping due to the turbulence and mixing present. However, a recent surge in the use and flushing of various products consisting of fabrics, which remain intact during wastewater collection, is causing significant issues. These fabrics include wipes, paper towels, clothing and underwear, and diapers. Recently, news sources reported widely that increased used of disinfectant wipes combined with shortages of toilet paper associated with the 2019–2020 novel coronavirus (COVID-19) resulted in increased use and flushing of cellulose fabric wipes, rags, and diapers. These products can cause or exacerbate clogging in wastewater collection systems as fibers can become entangled on corners, roots, and other irregularities, sometimes leading to enhanced clogging. Pump systems used historically are no longer adequate to manage the presence of these materials.

In summary, the composition of wastewater changes over time according to consumer behavior and consumer product formulation. Some of the recent shifts in products and behaviors have resulted in reduced reliability of wastewater collection systems and wastewater treatment operations. When combined with reduced water consumption, the impacts of wastewater constituents is greater.

2.1.2. Impacts of water conservation measures on wastewater discharge

As first documented in California over three decades ago, reductions in water use from conservation and long-term efficiency can directly affect the volume of influent that reaches wastewater treatment plants. Many California utilities have invested heavily in indoor water use efficiency, through measures such as low flow fixtures and efficient clothes washers and dishwashers (Diringer et al. 2018). Urban water agencies view such investments as cost-effective and preferable to expanding supply via increasingly expensive options subject to drought scarcity. Voluntary investments by agencies have been reinforced in recent decades through mandatory water use efficiency improvements to indoor fixtures, codified in federal and state building codes that require available products to use less water. Additionally, many utilities work with local businesses and industrial facilities to reduce consumption. Indoor and industrial water use efficiency investments started decades ago in some parts of the state, such as metropolitan Southern California where noticeable per capita demand reductions began prior to 2000.

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. For instance, a treatment plant that receives influent from a collection system located in a dry and flat area may be more susceptible to impacts from reduced flows than a facility that receives influent from a collection system located in an area with steeper slopes. The effects of per capita water demand reductions on wastewater systems could be mitigated, for instance, in cities where population growth occurs through conversion of single-family into multi-family properties, helping sustain the volume of base flow within the same pipe network area.

Beyond conservation actions, a broader series of potential changes in urban water use habits and infrastructure can affect existing wastewater operations. 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 non-potable 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).

Properly attributing the relative contribution of each of these factors to changes in wastewater treatment plant operations in a given region requires detailed data for facilities, households, water use habits, and climate trends, which could all be simultaneously correlated with wastewater treatment inflows to gauge relative contributions. As with many sectors of water management, changing environmental and regulatory conditions make it difficult to develop studies with equivalent statistical controls on potential confounding variables.

While detailed studies that control for all of these household-level and facility design factors do not exist, existing studies have evaluated methods to model wastewater generation in cities given a more limited set of contributing factors. For instance, the spatial distribution of wastewater influent contributions from various properties in a small New England community was modeled by combining detailed land use knowledge and surveys of domestic appliance usage to evaluate dry weather base flow in a wastewater system for a small community, with model results predicting mean daily and peak flows within 10% of observed values over a 25-day period (Butler and Graham 1995). As another example, modeling was used to estimate the operational impact on wastewater systems from water use reductions through low-flush toilets alongside reuse of greywater and roof runoff, identifying that rainwater reuse was an optimal strategy (in suitable climates) for reducing potable water demand while minimizing effects on existing collection systems (Parkinson et al. 2005).

2.1.3. Modeling changes in flow for wastewater generation

The first step in defining the wastewater system impacts resulting from reduced water use is to identify parameters of greatest importance (Koyasako 1980). A simplified model that can be used to approximate how factors affect the characteristics of wastewater could make use of the following parameters:

1) Population
2) Average discharge by households and businesses to the wastewater conveyance system
3) Peaking factor, defined as the ratio of peak wastewater flow to average wastewater flow
4) Inflow and infiltration, defined as the volume of environmental water that is introduced to the collection system from storm runoff, local water tables and groundwater, and anthropogenic sources such as irrigation water

There are various approaches to modeling wastewater discharges as a function of local agency characteristics and water demand. For instance, the relative influence of population, average building discharge, peaking factor, infiltration and inflow (I&I), and others can be estimated from known fundamental factors through a utility-specific model. In the City of San Francisco, the San Francisco Department of Water, Power, and Sewer developed spreadsheet models to estimate potable and non-potable water demands at the scale of both buildings and districts (SFPUC 2020). The models help developers and planners assess if local water reuse code applies to potential projects.

The influence of such factors on wastewater generation can also be scaled from analyzing historical data in a given area. Given sufficient known characteristics and past data for consumption and operations of both urban water supply and wastewater facilities in a region, statistical modeling can be used to control for influencing factors and developing metrics, such as wastewater generation per capita or building.

Finally, wastewater generation can be estimated by grouping communities of similar size, land use composition, and climate and searching for trends. This approach requires widely available and standardized data for wastewater treatment plant operations.

Wastewater production and treatment forecasting models often focus on near-term forecasting, with known daily discharge patterns and climate factors used to predict changes in the concentration of constituent flow. Many do not consider long-term changes in water demand that influence wastewater generation (Cook et al. 2018, 2010; El-Din and Smith 2002; Marleni et al. 2015; Penn et al. 2013). More detailed, theoretical modeling frameworks can outline the contributions of water consumption from each urban land use sector to wastewater flow, which helps predict long-term changes. Through simple models, the volume of base flow during dry weather to a treatment plant is equal to the sum of sanitary flows from residential, commercial, and institutional properties, base flows from industrial properties, and infiltration and inflow during precipitation or from surrounding groundwater, minus any wastewater that is removed prior to treatment such as flows that exceed the capacity of a plant (Cook et al. 2018). Scenario analysis using such theoretical models can identify types of wastewater collection and treatment systems that are most at risk to operational impacts from long-term water conservation. In general, scenario modeling identifies that systems most at risk are those with limited dry weather infiltration and inflow to support dry weather base flows, which allows solids and sludge to accumulate in the collection system and get washed through during wet weather events. Conversely, wastewater treatment facilities at low risk are those whose current base flow is near design capacity, but water use reductions can help postpone the need for new capital investments in expanded treatment capacity to meet population growth.

2.2. Conveyance systems

Wastewater collection systems are critical infrastructure and represent a large investment of municipal resources. Practically every building within a municipal sewershed is connected to the same wastewater conveyance system, which transports wastewater to a local or regional treatment facility.

Many central wastewater collection systems in California were planned out and designed in the mid-20th century, when population, materials, and water usage were much different than today. The typical design life for wastewater collection infrastructure is on the order of 50 years. Over time these collection systems have been repaired and upgraded as needed, including replacing corroded or collapsed sections of pipe with pipes manufactured from new materials, adding liners to susceptible pipe sections, and renovating lift stations. Yet, due to costs, wholesale replacement of pipe systems is rarely done, meaning that many pipes are likely operating beyond their nominal design lives.

2.2.1. Characterization of wastewater collection systems

Assessing the current status of wastewater collection systems requires an understanding of the design basis. Per capita water use of average households in the 1950s was much greater than it is today (Dieter et al. 2018; Donnelly and Cooley 2015). Many cities in California overestimated future growth. These assumptions of growth often translated into optimistic water demand projections. As a result, collection pipes located underneath communities in California are over-sized for typical contemporary conditions.

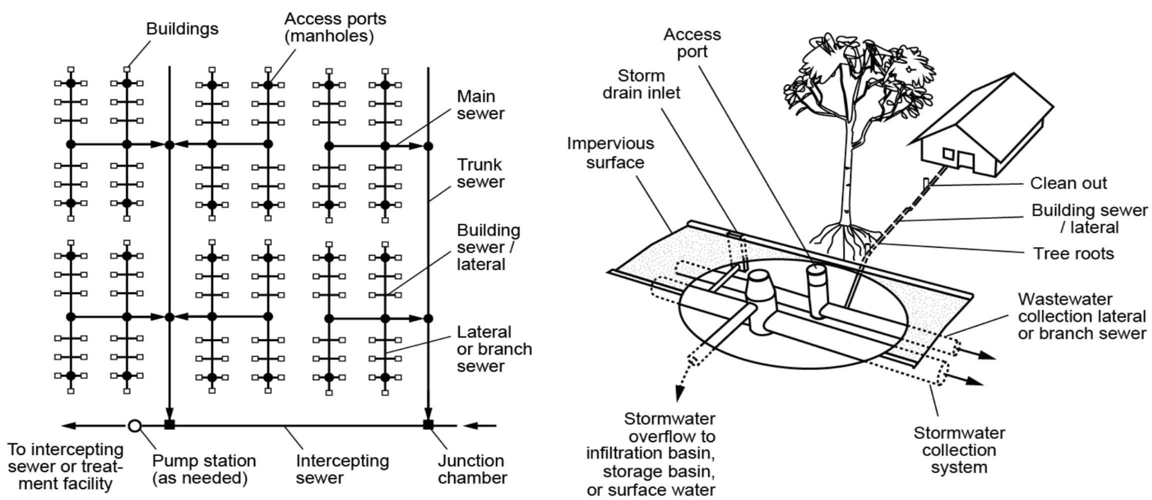
Elements of Wastewater Collection Systems. The general layout of a collection system is governed by the land uses in the service area and the desire to accommodate gravity flow of the wastewater. Conveyance systems are often arrayed in a grid pattern, with branches of the sewer extending out to remote 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. Key elements of wastewater collection systems are presented in Figure TA-3.4.

To achieve the pipe slopes needed for gravity flow, collection system layouts must be modified to account for variations in local topography. Few systems are as regular as that shown in the figure. Most, if not all, conveyance systems also include pump stations (also called lift stations). Pump stations push water over hills if needed, but most often they are used to bring wastewater up from a deep pipe to deposit into a line at a shallower depth so that it can continue its gravity-driven journey.

Materials. The primary materials used for the construction of wastewater collection pipes have evolved over time in response to the availability of new materials. The breakdown in materials currently in use for lateral sewers is shown in Figure TA-3.5.

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. VCP is corrosion-resistant and durable. It is also brittle. Over time, VCP can break. In addition, joint materials used to link pipe segments, particularly older ones, can decay, leading to leaks, blockages, and entry points for tree roots.

Figure TA-3.4: Definition sketch for components of wastewater collection systems: (a) grid or tree layout for wastewater collection pipes and (b) building sewer connection.



Note: Adapted from Tchobanoglous (2020).

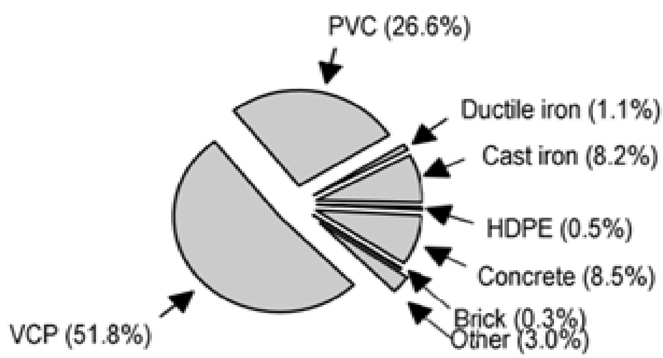
More recently, materials like PVC (polyvinyl chloride) and HDPE (high density polyethylene) have come into common use as well. These materials are not subject to corrosion, have watertight connections, and smooth interior surfaces. Because they are flexible, they are less likely to collapse while in service due to traffic loads or shifting soils.

Larger pipes (trunk sewers and interceptors) have usually been constructed of concrete, which may be reinforced, precast, or cast in place. Because concrete contains lime, it is susceptible to acids. Strong acids are not discharged regularly to wastewater systems, but biochemical reactions within collection pipes can produce acids with sufficient strength to corrode concrete. Replacing collapsed concrete pipe is a common service need in wastewater systems containing older concrete pipe sections. One way to prevent this problem is to install polyurethane or epoxy resin liners in old concrete pipes. This strategy is not a trivial expense, so it is employed selectively rather than wholesale across the conveyance system.

In a gravity collection system, all pipes larger than the service connections from small buildings are joined at manholes (see Figure TA-3.4). The most common construction material for manholes is concrete. Consequently, manhole corrosion is another recurring problem in conveyance systems.

Hydraulic Considerations. The design of wastewater collection systems has been based principally on hydraulic factors. 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 (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. Deeper pipe systems are expensive to construct and require more frequent installation of pump stations to bring the flow back near the ground surface. If the topography of a collection system is flat, pipes may be designed to provide scouring flow only periodically, such as during peak daily dry weather flow. The peak flow is calculated by multiplying the average daily flow by a jurisdiction-defined peaking factor. During the smaller, more frequent flows, the velocity is allowed to drop below 2 ft/s with the knowledge that any settled solids will be scoured out regularly.

Figure TA-3.5: Types of materials used for sewer lateral pipes.



Notes: Simicevic and Sterling (2005)

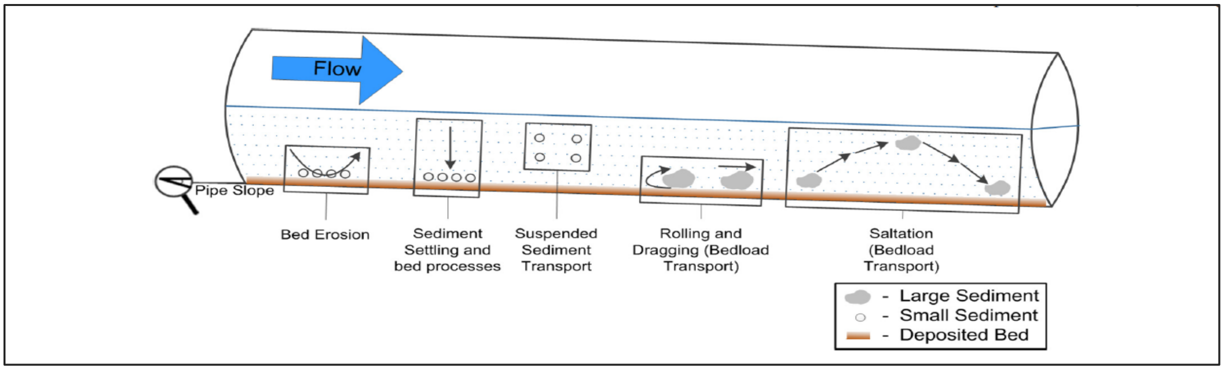
2.2.2. Impacts to wastewater collection systems from reduced flows

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. Septic wastewater leads to odor generation and accelerated corrosion/degradation of system elements. At the same time, it must be recognized that water conservation reduces the volume of water that must be pumped, which reduces the energy requirement of a conveyance system.

Accumulated solids and blockages. Sewer systems depend on the flow of wastewater to transport solids to a treatment plant. The different transport mechanisms in a typical pipe are illustrated in Figure TA-3.6 (Murali et al. 2019). For a given pipe size, lower flows lead to increased sediment settling and decreased bedload transport, resulting in an accumulation of wastewater solids. An 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). When flows are very low, particle accumulations can be exposed to air. This drying action can harden aggregated particles, making them more difficult to mobilize in subsequent flows. This problem is more significant in some small feeder pipes where flows may occasionally go to zero.

Accumulations of solids can restrict the interior space of pipes and cause pipe blockages. Short of that, accumulations reduce hydraulic capacity by restricting the interior space and increasing the friction of the pipe walls. When downstream pipes cannot carry enough flow, water starts to back up in upstream pipes. This can cause local flooding and endanger public health when flooded pipes lead to wastewater surfacing through manholes.

Figure TA-3.6: Settling, erosion, and transport or sediments in sewer systems.



Notes: Figure originally published by Murali et al (2019)

In a survey of over 100 wastewater agencies in California during the 2011-2016 drought, 27% of respondents reported increased frequency of blockages as flows declined (Chappelle et al. 2019). Similarly, work funded by the Water Research Foundation and multiple other water organization in California found similar results based on 2017 surveys from the California Urban Water Association and additional qualitative case study data. The Tuolumne Utilities District reported increased blockages and root intrusion in existing wastewater pipe networks during periods of reduced flow (WRF 2017).

These studies point to a physical correlation between reduced flows and a negative effect of accumulating solids, which can result in conveyance system failures. The studies do not, however, provide sufficient site-specific information to identify the relative influence of low wastewater flows on blockages alongside other factors, which may include ill-maintained conveyance pipes, slope, and climate. These all influence baseflow, infiltration, and inflow. The studies are indicative of risk, but inadequate for the task of quantifying effects of water use reductions associated with objectives to particular systems and agencies. Controlling for such factors via data collection, or using methods to incorporate the uncertainty of unobservable influences, can better identify relationships with statistically-significant relationships that relate the relative contribution of factors to sewer district utility maintenance needs.

Slug flows occur when significant infiltration and inflow scour out pipe systems. With a sufficiently large precipitation event, slug flows are pushed through the conveyance system and reach a treatment plant all at once. A slug of solids can significantly disrupt treatment plant operations by temporarily overloading the pretreatment and primary systems. While a phenomenon well-known to wastewater treatment plant managers, the topic has not been discussed in relation to the increasing likelihood of lower flows in conveyance systems. The total mass of solids to be treated by the plant does not change, only the timing in which it reaches the treatment plant. As such, depending on the treatment plant configuration, adaptation actions and costs for a treatment plant may not change.

Tree root damage to sewer lines is another potential outcome from lower flows. Reported correlations indicate that tree roots were identified in areas where wastewater pooled behind blockages from accumulated solids. The pooled water leaches into existing pipes and creates opportunities for root intrusion. The highlighted example from the Tuolumne Utilities District noted that remediation actions included retrofitting the pipes with a fiberglass lining, which preserved the existing pipe but inhibited further root growth. The study did not indicate prior refurbishment or replacement actions, nor the age of the pipes.

Many types of adaptation actions are available to deal with accumulated solids. Utilities can increase the frequency of system inspections, even using camera feeds within system lines to look for blockages, root intrusion, or other issues. Utilities also flush sewer lines, which moves accumulated solids through lines in smaller, more frequent, amounts. Utilities may also find themselves responding to more frequent emergency calls from residents reporting system overflows. In these cases, the utility would need to send out a vacuum truck that sucks solid matter in the identified blockage area out, allowing pipes to flow again. Utilities could also attempt to push through blockages using mechanical rodding. Finally, the pipe lining procedures highlighted in the Tuolumne Utilities District example is a remediation action to preserve existing pipes and prevent the need to replace buried pipes. Theoretically, pipe lining may increase the flow rate by reducing pipe diameter, though the increases are likely to be small or negligible when the lining thickness is small.

Data from Australia provide insights on methods to evaluate potential risk of conveyance system failures from reduced flows. From 2001 to 2009, Australia experienced significant drought. The so-called "Millennium Drought" spurred a host of adaptive actions by water agencies, including long-term studies of the effects of rapidly-changing expectations of water demand. The Victoria Essential Services

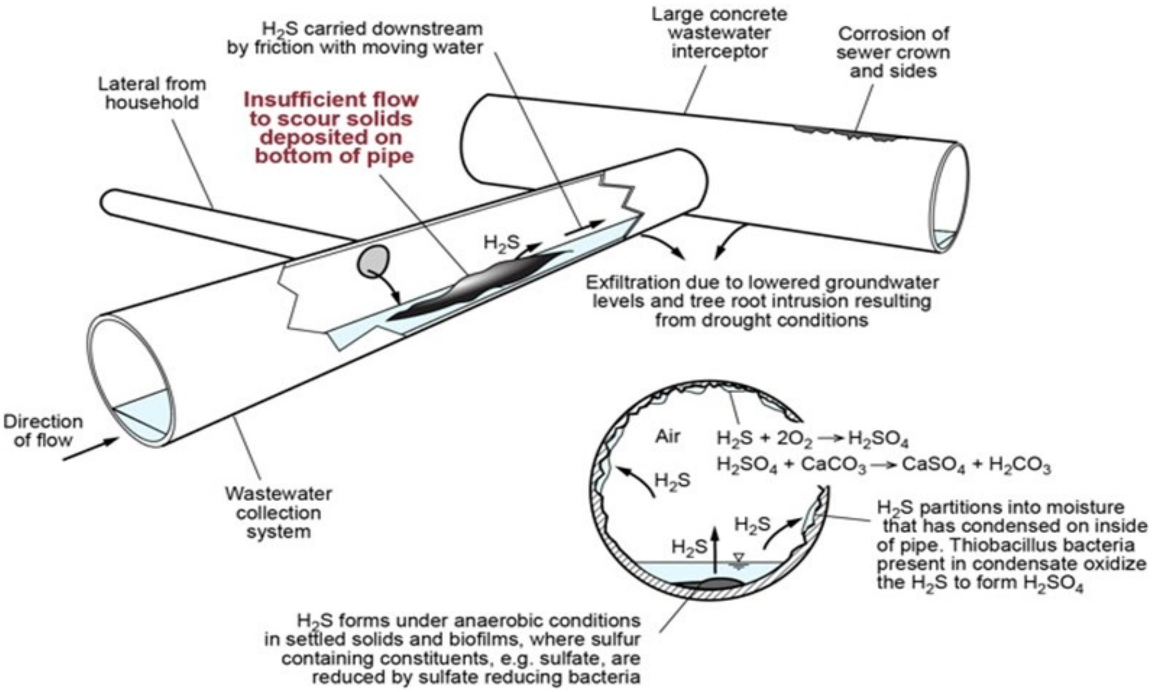
Septic Wastewater. Low flows lead to slower velocities and longer hydraulic residence times in pipe system. In addition, efficient plumbing fixtures dilute the same pollutant mass load into smaller volumes, leading to higher concentrations. Solids deposits also result in elevated pollutant concentrations. Higher concentrations promote faster biochemical reactions in the wastewater. In particular, aerobic degradation of organic compounds deplete the wastewater of oxygen, leading to septic (anaerobic) conditions. Under anaerobic conditions, microorganisms chemically reduce sulfate ion (SO^{-2}_4) to hydrogen sulfide (H_2S).

The metric of hydraulic retention time (HRT) describes how long wastewater lasts in a current part of a system, whether it be pipe systems or stages in a treatment plant. With higher HRTs, wastewater accumulates more material. Higher concentrations of organic carbon material and sulfur dioxide increase the material available for key reactions that produce methane (CH_4) and hydrogen sulfide (H_2S). Other characteristics of the wastewater, such as pH and alkalinity, may also drop and cause issues for a wastewater treatment plant that eventually receives the effluent (Figure TA-3.7).

The presence of hydrogen sulfide lead to an identifiable odor that is associated with "septic" wastewater. The odor can emit from conveyance systems and cause complaints of a "rotten egg" smell from residents. Only a small level of hydrogen sulfide is necessary to yield noticeable odors. Hydrogen sulfide can also be oxidized into hydrogen sulfate (H_2SO_4), which can corrode metals in various conveyance systems component, such as pump stations but especially concrete pipes and manholes. During recent drought in California, nearly one-fifth of surveyed utilities reported problems with increased odor and corrosion, with manholes- the outlets of accumulated gas- being particularly susceptible (Chappelle et al. 2019).

Research has attempted to quantify the magnitude of such effects. For instance, in a laboratory study, the effects of reduced flows on methane and hydrogen sulfide production was studied. Two laboratory simulations or rising sewer mains were devised and fed with wastewater of different strength and flow rates, which simulated sewers under normal conditions and reduced flow conditions that could be associated with lower water consumption. Sulfide concentrations in the simulation with reduced flows increased by 0.7–8.0 mg-S/L, depending on the time of a day and were mainly due to increased hydraulic retention time. Slightly reduced alkalinity could lead to more sulfide in molecular form available for emission. Similarly, dissolved methane concentrations under the low-flow condition was over two times higher than that under the normal flow condition and the total methane discharge was about 1.5 times higher. Modeling indicated that unit costs of managing odors would increase with lower flows, but overall costs would decrease due to the volumetric reductions in flow (Sun et al. 2015).

Figure TA-3.7: Summary of factors involved in hydrogen sulfide generation.



Notes: Figure originally published in Tchobanoglous (2020).

In another laboratory study, a potable hydrogen sulfide detector was used to validate predictive models of H_2S emissions under various scenarios and evaluate potential chemical remediations. Tests identified optimal doses of magnesium hydroxide, calcium nitrate, sodium hydroxide, and iron chloride for mitigating H_2S production, with sodium hydroxide and magnesium hydroxide being the best candidates. Further, the steeper the slope of the sewer, the faster H_2S disappeared in the gas phase (Abdikheibari et al. 2016).

Case studies with historical data provide important examples for understanding how theoretical principles or laboratory experiments play out in practice. Within the District of Columbia (Washington, D.C.), the local utility, the District of Columbia Water and Sewer Authority, manages a sewer system with over 1,800 miles of sanitary and combined sewers, many of which were installed over 100 years ago. In 2008, the utility implemented the first systemwide assessment in decades. Over five years, it evaluated 70 percent of the system's critical sewers, especially in areas under buildings with known issues. The study identified hundreds of millions of dollars in maintenance needs and laid out a plan to address the most urgent needs first, with subsequent improvements addressed through a Capital Improvement Plan (CIP). Since FY 2002, approximately $7 million in annual funding has been included in the CIP for sewer projects. Improved odor control and corrosion mitigation actions were identified priorities. The study represents a comprehensive approach to evaluating and upgrading sewer system needs, but also demonstrates the level of deferred maintenance requirements that can accrue within an old sewer system.

System managers have various responses they can undertake to deal with observable effects of odors and corrosion. To control odors, typical responses include:

- 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, management responses include:

- 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 expensive. As an alternative, pipes can remain intact 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.

Energy use. One important positive benefit that should not be overlooked is the energy savings 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. Almost all treatment plants will have a major pump station to bring the wastewater from the sewer up to ground-level. In addition, conveyance systems in hilly terrain will need to employ pump stations to move wastewater over obstacles. Even in flat systems, pumps must periodically raise water from deep sewers to shallow sewers so that gravity flow can be maintained.

Pumping requirements are highly specific to a given system. Reduced volumetric flows may also reduce the energy costs associated with pumping, but it could also increase pumping needs in other parts of a system.

Heat and drought. Heat, drought, and topography likely exacerbate risks associated with wastewater management for collection systems. Areas that are both flat and subject to extreme heat would likely be most at risk.

During peak temperatures, extreme heat may increase the temperature of wastewater effluent and pipes, facilitating some digestion to occur upstream of the treatment plant. Reduced precipitation during drought can reduce influent from infiltration that may support baseflows, while indoor water use often decreases during drought. In general, 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).

Indicator data such as temperature and precipitation are meteorological drivers of drought risk. Both temperature and precipitation are incorporated into climate zone delineations by the California Energy Commission through its climate zone determinations.

Topography. Topography can influence the efficiency of collection and conveyance systems. Pipes with steeper slopes have increased flow velocity. Higher velocities can prevent settling of solids in pipes. Collection systems with flat slopes are at a higher risk of sediment accumulation than those with gradually steeping slopes, especially in times of reduced flow. Additionally, the various effects of reduced flows in collection systems are exacerbated in flat areas because of even lower scour velocities.

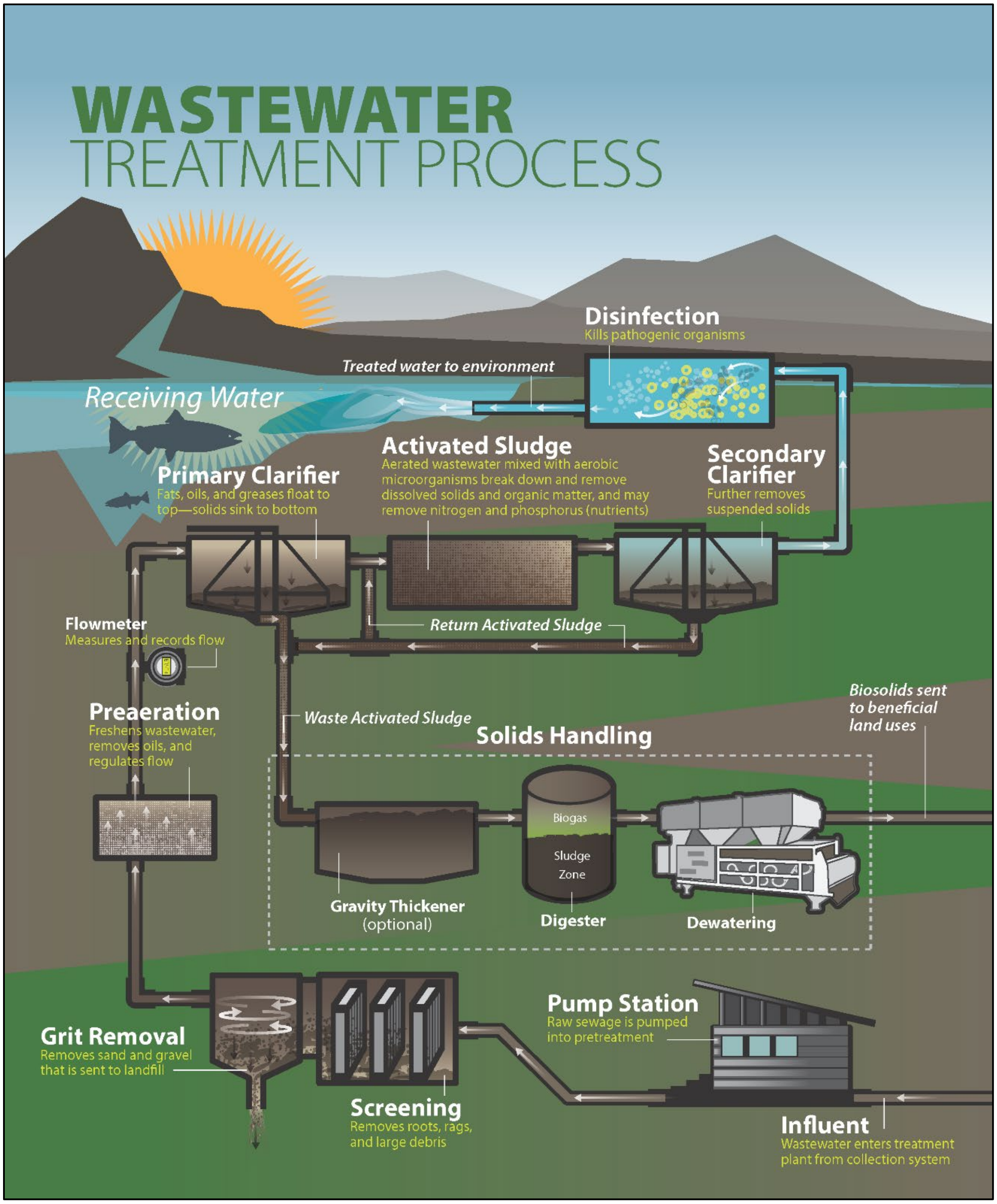
When water supply agencies make investments to reduce consumption in homes, businesses, and industrial facilities, it reduces the base flow of wastewater that is generated and sent to collection systems. The rate of change in water use reductions, however, interacts with other factors of population growth, climate, and system characteristics to yield a cumulative effect on flows, which may range from negligible to significant. For instance, a treatment plant that receives influent from a collection system located in a flat area that is also dry may be more susceptible to impacts from reduced flows than a facility that receives influent from a collection system located in an area with steeper slopes.

2.3. Wastewater Treatment

Wastewater treatment facilities are composed of systems that perform multiple processes, such as screening, equalization, settling, aeration, filtration, and disinfection, primarily used for the maintenance of one or more live bacterial cultures, followed by their separation from the liquid product. An example wastewater treatment facility (WWTF) is shown on Figure TA-3.8. Figure TA-3.9 shows a treatment train that also produces tertiary effluent.

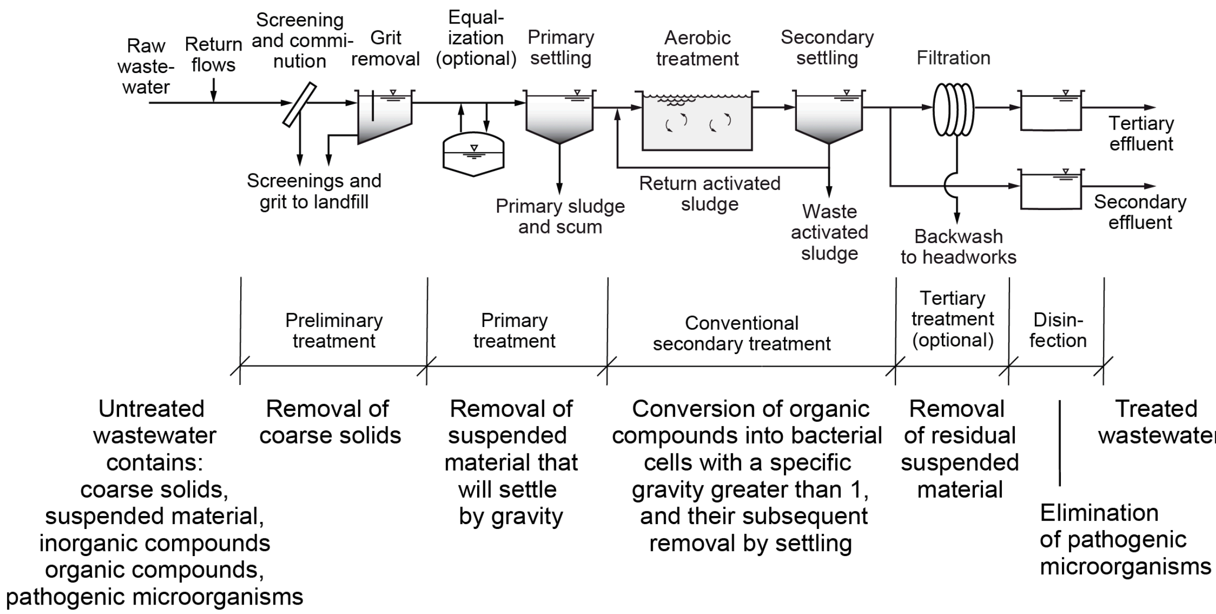
WWTFs typically have multiple stages. Primary treatment steps remove solids from wastewater, using settling or coagulation to clarify influent. The step removes suspended solids in the wastewater. The effluent from primary treatment moves on to secondary treatment, where additional finer-scale filtration combines with aeration (introduced oxygen) that spurs biological processes to break down contaminants. In some plants, effluent from secondary treatment moves on to tertiary treatment, where contaminants such as nitrates or phosphates are removed. A small but growing number of plants use advanced treatment technologies such as reverse osmosis or membrane filtration to reach high levels of effluent quality.

Figure TA-3.8: Typical primary, secondary, and disinfection steps in a wastewater treatment process (Source: Office of Water Programs at Sacramento State)



Notes: Figure courtesy of Office of Water Programs (OWP) at Sacramento State

Figure TA-3.9: Typical wastewater treatment process for production of secondary and optional tertiary effluent.



Notes: Figure originally published in Tchobanoglous et al., 2015.

As with wastewater collection systems, each WWTF represents unique piece of infrastructure because each facility was been designed for site specific-conditions, by different teams of people, located in different regions, at different periods of time, to meet different criteria, and modified periodically. Each facility receives wastewater influent of a unique signature, which is a function, in part, of the background chemistry of the water supply used indoors, behaviors of the water users, and characteristics and age of the wastewater collection system. Therefore, it is difficult to generalize the impacts across facilities. The following analysis only presents an overview.

WWTFs are built using relatively mature technologies available at the time of design. Given that most wastewater treatment facilities (WWTFs) and associated collection systems were designed and constructed many decades ago, it is understandable and even expected that facility upgrades are needed on a regular basis. These improvements and upgrades are typically driven by the need to: abandon processes and facilities that have exceeded their useful life; increase capacity with more efficient processes; and meet evolving regulatory and water quality objectives.

3. Methods: Evaluating Effects of Water Use Efficiency on Wastewater Management Systems

The sections below describe the steps that were used to assemble data and develop a preliminary estimate of effects on wastewater management systems and facilities. The steps included the following:

1) Identify wastewater management systems relevant to AB 1668-SB 606;
2) Merge data sources on key characteristics and historical operations;
3) Develop risk indicators of effects from lower wastewater generation and influent flow;

4) Validate data for analysis;
5) Evaluate systems and facilities at-risk of effects from lower flows (preliminary);
6) Refine estimated effects based on outreach.

3.1. Identify Wastewater Management Systems Relevant to AB 1668-SB 606

To link urban retail water suppliers with downstream wastewater collection and treatment systems, the team relied on several sources of data, including supplemental tables from summary tables of data from Urban Water Management Plans compiled by the Department of Water Resources (DWR), the California Integrated Water Quality System (CIWQS) managed by the State Water Board (SWB), and the SWB's Annual Volumetric Reporting (AVR) survey.

There are approximately 1,300 wastewater treatment facilities in California based on records within CIWQS databases (Table TA-3.4). CIWQS includes key attributes of influent capacity, location, and managing agency. It does not, however, contain data for service territory, population, or retail water supply agencies that the WWTF serves.

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 TA-3.10). Most WWTFs have flow rates less than 1 million gallons per day (Mgal/d, or MGD). Regional variations in population growth and regulatory requirements have led to a diversity of existing systems throughout the state, with some being upgraded with new technology to meet advanced water quality standards, while others still relying on existing systems that may be decades old. WWTFs are often designed to deal with the characteristics of local influent and incorporate assumptions of future growth. Retrofitting facilities with additional infrastructure to upgrade effluent quality can present design challenges.

Figure TA-3.10: Approximate distribution of centralized wastewater treatment level in CA (2019)

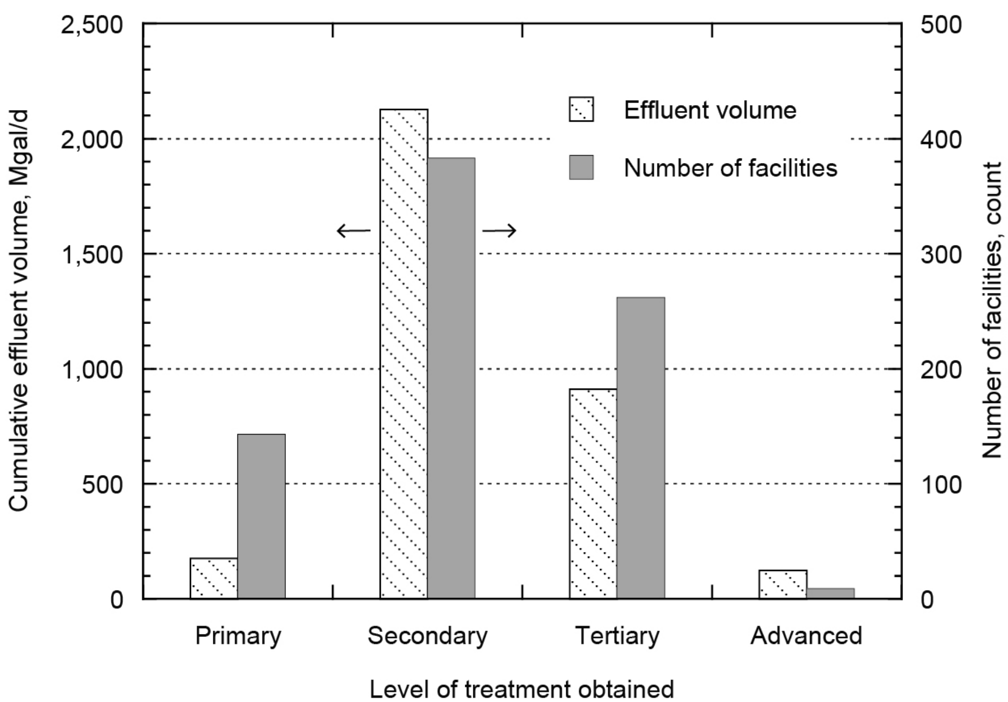


Table TA-3.4. Registered wastewater treatment facilities in California, by design capacity and Regional Water Quality Board jurisdiction.

	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 Capacity 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**

Notes: Author calculations based on data within the California Integrated Water Quality Information System (CIWQS)

To refine the list of all WWTFs in California to only those that serve Suppliers, Tables 6-2 and 6-3 of DWR's 2015 Urban Water Management Plans (UWMPs) was used. The table includes compiled, self-reported data from the UWMPs and provides the only available source of statewide information for links between urban water and wastewater systems. The tables describe connections between urban water supply retailers, wastewater collection systems, and wastewater treatment facilities. The self-reported data provides estimated volumes of influent from a Supplier to a collection system and WWTF. At the time of analysis, the 2015 tables were the most recent version available.

Analyzing data in the table reveals several types of network connectivity that exist between Suppliers and wastewater management systems across the state: 1) the service areas of a WWTF and a Supplier overlap, 2) the service area of a single WWTF overlaps with the service areas of multiple Suppliers, 3) the service areas of multiple WWTFs overlap with the service area of a single Supplier, and 4) the service areas of multiple WWTFs overlap with multiple Suppliers. In each case, one or more collection systems connect a Supplier to its downstream wastewater treatment facility (or facilities).

While the reported volumes in the latest available version of Table 6-2 are from 2015 and are not representative of current flows, the allocation of wastewater from a Supplier to one or more downstream collection systems and WWTFs is unlikely to change significantly between years. Thus, data from Table 6-2 was used to estimate the volume of wastewater that is sent from a Supplier to a WWTF by multiplying the percentage derived from Table 6-2 with a more recent reported or projected value of actual wastewater influent to the facility whenever possible.

The database in Table 6-2 from the 2015 UWMPs was converted into a network model representation to connect water supply agencies, collection systems, and wastewater treatment facilities. This allowed for projecting how potential reductions in urban water demand as a result of meeting water use objectives could affect downstream systems. Doing so required making some assumptions and considering baseline conditions.

Long-term investments to improve indoor water use efficiency may pre-date the AB 1668-SB 606 framework, yet still contribute to compliance. Differentiating past efficiency investments from new investments that might be undertaken as part of AB 1668-SB606 implementation is challenging. Baseline changes from on-going efficiency were evaluated based on both natural and enhanced fixture improvements. The network model was run for the baseline conditions to understand the estimated volume of future influent generation that would occur in the absence of AB 1668-SB 606 considering changes in population and indoor fixture efficiency.

After estimating baseline changes, to evaluate impacts of AB 1668-SB 606, the additional impacts of flow reductions related to compliance were estimated. For Suppliers where the objective value is equal to or greater than recent reported demand, no downstream effects on wastewater collection and treatment were estimated. For Suppliers where the objective value was less than reported recent demand and a reduction would be necessary, it was assumed that 15% of the total required reduction would come from indoor water use efficiency that would affect wastewater systems.

3.2. Merge Data Sources for Attributes and Historical Operations

Table TA-3.5 describes the origins, parameters, and timeframes associated with key data sources:

- **CIWQS** includes a table of attributes useful in analysis, including design flow for many facilities. Such attributes are available for a large portion of the 1,300 facilities.
- 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. Historic monitoring data is available for over 200 facilities, but not all of these serve Suppliers 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.
- **DWR Urban Water Management Plan Summary Data Tables 6-2 and 6-3** provide corroborative information on the managing agency for a WWTF, as well as connected collection systems and Suppliers. Table 6-2 identifies approximately 470 WWTFs of interest that serve Suppliers. Operations data from 2015 is provided at an annual time step.

Table TA-3.5: 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 your agency is responsible for	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 -Agency Address -Facility Name -Facility 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 Supplier 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

Notes: Compiled by authors

To merge data needed to estimate effects from AB 1668-SB 606, a multi-step procedure was developed.

First, name discrepancies between DWR's Table 6-2, CIWQS, and the AVR were rectified. Like many examples of data sources developed by state agencies California, the databases do not use common identifiers. A table with crosswalks between naming and ID conventions was created to connect facility and system attributes across data sources. Linking systems and facilities between the DWR and SWB tables required extensive work to match names and use other data such as addresses to create a crosswalk. For future data collection by state agencies, the Waste Discharger Identification (WDID) number within CIWQS and other SWB databases is a useful identifier to use across all databases.

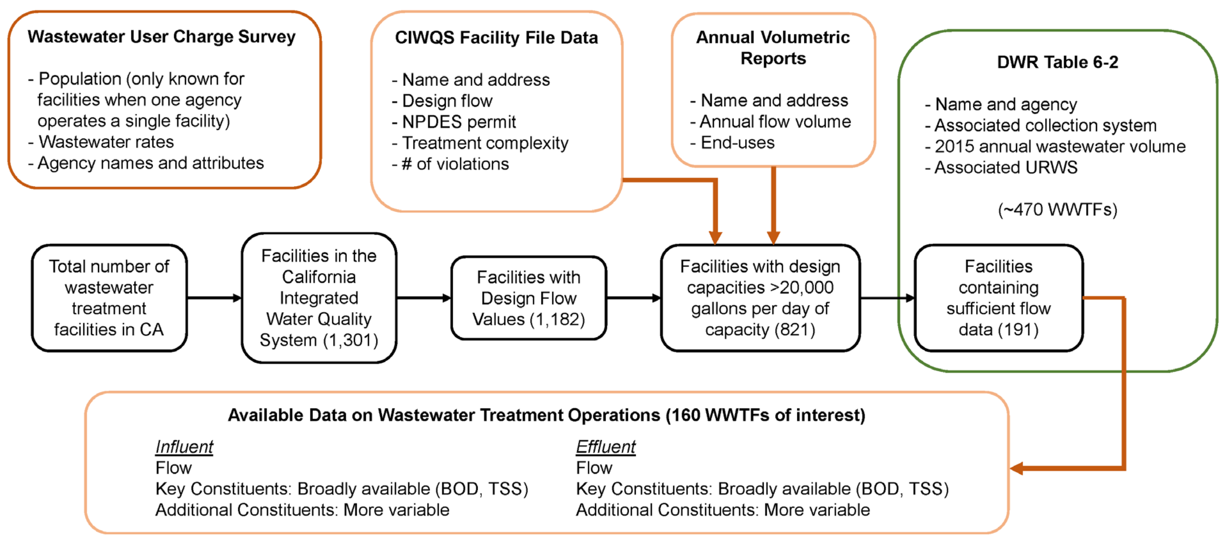
Second, after merging facility names of interest, facility characteristics (attributes) were collected and compiled from the three data sources (and other sources) to create a database of facility attributes. Based on the WWTF dataset, available WWTF attributes from data include: site type, lead agency, region, climate zone, recycled water production capacity, sole recycled water producer capacity, latitude, longitude, terrain, facility type, level of treatment, discharge location, discharge method, and capacity (CIWQS). For collection systems, a broader list of operational and managerial attributes was available through the Combined Sewer System Overflow (SSO) database (see Section 3.3 of this technical appendix).

Third, historical records for operations and monitoring were collected from CIWQS for the subset of WWTFs with available data. CIWQS does not have reported data for all WWTFs in the state or all WWTFs potentially affected by AB 1668-SB 606. Data was available for less than 50% of WWTFs serving Suppliers. Historic records in CIWQS were filtered for not only facilities that were known to serve Suppliers, but also those with reported capacity of at least 20,000 gallons per day and identified as municipal (not on-site) that could represent useful case studyies. Of the 1,300 facilities registered in CIWQS, approximately 180 facilities that met these criteria had available historic monitoring data. Thus, of the approximately 470 WWTFs of interest to AB 1668-SB 606 as described in DWR's Table 6-2, facility-specific historic operations data (daily and monthly) was available for no more than half of WWTFs to use for modeling.

In summary, no centralized source of data contains all the information needed to evaluate potential effects from AB 1668-SB 606 on wastewater treatment and reuse facilities. Additionally, no future source of data has all the information necessary to monitor effects over the long-term. For instance, AVR contains no information on design flow, while CIWQS has design flow but only has monitoring data for a portion of facilities and is difficult to access. An additional source of data, the Wastewater User Charge Survey, has agency-level information on service area population, but not for specific facilities, making it difficult to merge.

Of the various groupings of WWTFs based on data sources, DWR's Table 6-2 provides the best available sources of potentially-affected facilities under AB 1668-SB 606, while the WWTFs with historic operations data that are part of this group provide a useful record of past effects that can help evaluate potential future effects. The overall process of identifying relevant facilities is visualized in Figure TA-3.11, showing the WWTFs that fall within each increasingly specific group of facilities.

Figure TA-3.11: Summarizing the process to develop time series records of operations and monitoring for WWTFs with available data in the California Integrated Water Quality Information System (CIWQS)



Notes: Figure created by authors

3.3. Investigation of Risk Indicators of Effects from Lower Wastewater Influent Flow

A risk-based approach was adopted for projecting and extrapolating effects for wastewater systems and facilities. Indicators and metrics were explored for each of the major types of affected sub-sectors:

1) Wastewater collection systems
2) Wastewater treatment facilities
3) Wastewater reuse facilities

Many metrics were compiled and evaluated for their suitability to project effects of lower flows. Potential risk indicators captured system and facility characteristics related to: operational parameters; location; climate; topography; layout; and an estimated ratio of change for wastewater influent flowing to a WWTF based on potential water use reductions taken by a Supplier to comply with AB 1668-SB 606. In the end, a smaller set of risk indicators was adopted and combined with physical modeling to estimate environmental impacts on wastewater collection and treatment.

3.3.1. Water Use Efficiency Objective Impact Factor for Wastewater Systems

The Water Use Efficiency Objective (WEO) Impact Factor is metric developed to gauge potential influent reductions from regulations. The WEO impact factor for wastewater collection systems and treatment facilities is based on a network model representation of the connections between Suppliers, collection systems, and wastewater treatment and reuse facilities derived from DWR's Table 6-2 from the 2015 UWMPs. It calculates a ratio of recent vs. projected wastewater influent flowing to a collection system and WWTF from one or more Suppliers given potential reductions needed to comply with AB 1668-SB 606. To estimate downstream effects, the WEO Impact Factor was used (WEO_{wwtf}). It is defined as the ratio of the volume of estimated effluent produced given water use objectives and the volume of actual water demand:

$$WEO_{wwtf} = \frac{\sum_{r}^{R} V_{wwtf,future}}{\sum_{r}^{R} V_{wwtf,actual}} \quad (1)$$

In Equation 1, *r* represents a single Supplier and *R* represents the set of all Suppliers that contribute influent to a WWTF. For a given WWTF, the equation would capture all Suppliers that reportedly send influent to a WWTF. A WEO impact factor value of less than 1 indicates that the objective-based effluent generation would be less than recent levels. A value over 1 would indicate that the objective-based effluent generation would be greater than recent levels.

Estimating the volume of produced future wastewater for a retailer requires calculating the ratio of change for the Supplier (or Suppliers), referred to as the WEO Impact Factor, which compares recent historic demand with projected future demand given any necessary water use reduction compliance actions:

$$WEO_{Supplier} = \frac{V_{r,Objective}}{V_{r,Forecasted\ Demand\ in\ 2030}} \quad (2)$$

The WEO Impact Factor for the Supplier (or Suppliers) can be applied to recent reported actual wastewater flows to a treatment plant ($V_{wwtf,recent}$) to estimate the change in the volume of future influent for one link within the network:

$$V_{wwtf,future} = WEO_{Supplier(s)} * V_{wwtf,recent} \quad (3)$$

Summing values in Equation 3 over all of the connections between Suppliers, collection systems, and WWTFs yields the WEO Impact Factor value for WWTFs in Equation 1.

The value resulting from Equation 1 would represent the maximum possible change in wastewater influent flowing to a WWTF, as it would assume that any necessary reductions by Suppliers to comply with objectives would result from reductions that affect downstream flows to collection systems and WWTFs. The estimated impact was limited to 15% of the volume of reduction associated with the WEO Impact Factor based on the assumption that 15% of demand reductions for AB 1668-SB 606 would come from indoor water use efficiency.

WEO Impact Factor values for WWTFs were estimated for scenarios of objective input parameters that ranged from:

- An indoor standard of per capita daily consumption ranging from 35-55 gallons per capita per day (gpcd).
- An outdoor standard based on estimates of Irrigable Irrigated land area provided by DWR and an ETAF ranging from 0.55 to 0.8.

The various combinations of input parameters yielded 22 scenarios of objective values. However, for the analysis of wastewater impacts, results were only developed and are reported for the three identified scenarios of parameter values provided by the State Water Board.

3.3.2. Operational Risk Indicators

Three indicators were developed to capture trends in historic operations based on data available for WWTFs from CIWQS:

1) **Integrity Index (II)** - The ratio of the maximum month flow to the average dry weather flow over time for a WWTF. The integrity index is assumed to include a combination of runoff from stormwater events and base flow during the maximum month. It assesses the extent to which a collection system is compromised, which could lead to significant problems, especially during periods of high flow supplemented by infiltration and inflow. Higher values would indicate leaky and compromised collection systems.
2) **Dry Weather Capacity Index (DWCI)** – The ratio of the average dry weather flow to the facility's design flow over time. This index evaluates if dry weather base flow for a facility is significantly above, near, or significantly below the facility's design capacity, which could affect treatment efficiency. It can evaluate the number of facilities across California that may be over designed for current influent flow levels. Index values over time can evaluate if influent flow below design capacity is consistent or most noticeable during particular periods such as drought. Lower values indicate risk that a facility is typically operating under its design flow, which could exacerbate low flow effects during periods of drought or conservation.
3) **Wet Weather Capacity Index (WWCI)** – The ratio of the maximum month flow to the facility's design flow. The index evaluates remaining wet weather capacity for treating wastewater. A value significantly greater than one would indicate a facility that must take actions to divert or store wastewater influent during periods of high flows, especially from precipitation events that spur infiltration and inflow in upstream collection systems. Systems with significant infiltration and inflow could experience routine flushing that would limit some impacts from lower flows such as sedimentation and solids deposition.

For each index, changes over time were analyzed during the period of 2010-2019 for facilities with available data. Ultimately, the Dry Weather Capacity Index (DWCI) was used as part of the procedure to extrapolate effects for WWTFs through process modeling. For the Integrity Index and the Wet Weather Capacity Index, results could not be correlated with modeled results or findings from outreach, so they were not deemed to be reliable risk indicators without further evaluation and statistical controls.

3.3.3. Collection System Attributes: Sewer System Overflow Database

For wastewater collection systems, the Sewer System Overflow (SSO) database collected by the State Water Board provides a highly-detailed and well-maintained source of information for over 1,000 collection systems in California. The database is collected as part of regulations primarily related to regulating Sewer System Overflows.

There are 1,239 collection systems in the SSO database. The SSO database with violation records was downloaded ("SSO.txt") from the State Water Board's Sewer System Overflow Reduction Program website to analyze the number and severity of events. There were 896 collection systems with at least one reported violation. Violations may or may not include a spill. For violations with spills, the events can range in severity from "Category 1", "Category 2", and "Category 3". Category 1 events are events that posed an immediate threat to health and water quality and the most severe. Category 3 violations are events that posed only a minor threat to water quality and have little or no known potential for causing a detrimental impact on human health and the environment. The number of systems with Category 1 violations was 659. The number of systems with Category 2 and Category 3 violations was 534 and 845.

Based on analysis of the SSO database and insights from outreach, the team assessed that violations alone would not be a reliable indicator of increased effects from lower flows. However, the database of attributes included many factors of high value for considering impacts (Table TA-3.6). To investigate, data from the SSO questionnaire was extracted for use in predicting and extrapolating effects based on process modeling. Key attributes included sewer system age, frequency of maintenance, and the percentage of pipes by size.

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 in a collection system that was 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. The number of violations was normalized per 100 miles of sewer then plotted against the aforementioned factors.

Systems with reported violations tended to have older infrastructure (Table TA-3.7). Additionally, systems with violations reported lower percentages of sewer miles cleaned or inspected in the previous year. Although system flatness was identified as a possible indicator of sewer system overflows, systems with violations had the same percentage of lateral miles on average as all collection systems. Systems with violations were more likely to have a change ratio less than one indicating a reduction in flow.

Table TA-3.6. Comparison of infrastructure age, system maintenance, flow characteristics, and spending for all collection systems in the SSO database and those with reported violations.

Attribute	Sewer System Characteristics	All Collection Systems	Systems with Reported SSOs
Age	Miles Constructed Before 1959 (%)	20.3%	22.6%
	Miles Constructed Before 1979 (%)	52.1%	56.9%
	Miles Cleaned Prior Year (%)	43.0%	42.8%
Maintenance	Miles Inspected Prior Year (%)	12.0%	12%
	Average Miles as Pressure Sewer (%)	8.54%	3.89%
Layout	Average Miles as Gravity Sewer (%)	60.5%	66.3%
	Average Miles as Laterals (%)	31.0%	30.5%
	Median WEO Impact Factor	1.03	0.87
	Pump Stations Per Sewer Mile	0.42	0.40
Budget	Annual Capital Expenditure per Sewer Mile	$54,030	$58,090
	Annual Capital Expenditure per Capita	$204	$203
	Annual O&M Budget per Sewer Mile	$32,035	$31,248
	Annual O&M Expenditure per Capita	$ 239	$213

Notes: Calculations by authors based on data from SSO Survey database and calculated WEO Impact Factor values from network modeling. All values are averages for either all collection systems or those with available violation data. With the exception of the average change ratios, all values are reported as the percentage of total sewer miles.

Using data from the SSO survey database, systems were first grouped based on selected attributes in the following categories: reported operations budget, infrastructure age, sewer system maintenance, employee education and experience, and system topography. Within those categories, attributes thought to affect the risk of experiencing SSO events were chosen based on an analysis of data and expert judgement from the team. Selected attributes included the following:

- Annual capital budget per mile of sewer;
- Annual operation and maintenance budget per mile of sewer;
- Percent of sewer miles constructed prior to 1979;
- Percent of pump stations constructed prior to 1979;
- Percent of sewer miles cleaned in previous year;
- Percent of gravity sewers inspected in previous year;
- Percent of employees with CEWA grade I certification or higher;
- Percent of employees with more than 2 years' experience;
- Number of pump stations per mile.

Systems were then assigned a quartile value for each metric, calculated as relative ranking of that system for a metric as compared to other systems. They were grouped either as "< 25th Percentile", "25th – 50th Percentile", "50th – 75th Percentile", and "> 75th Percentile". For attributes where a significant number of systems did not report data, an additional category "Not Reported" was added. Table TA-3.7 provides a summary of the results, including the number of systems falling into each group, the number of those systems that reported SSO events, and the average SSO events per mile. For each attribute, these can be compared to the average SSO events per mile for all reporting systems, 17.1.

In general, systems categorized as "not reported" had much higher rates of SSO events per mile than average, indicating that lack of engagement could be an indicator for higher risk of violation. The only attributes that showed a clear correlation between percentile group and number of SSO violations were "Number of Employees per Mile of Sewer" and "Percentage of Employees with CEWA Grade I Certification or Higher". Systems ranking in higher percentiles of the number of employees per mile of sewer had higher averages of SSO events per 100 miles. Sewer systems that ranked higher for the percentage of employees being CEWA grade I certified or higher reported fewer SSOs per 100 miles. For all other characteristics no clear trend emerged. However, some characteristics with notably high rates of SSO events can be identified. Systems ranking above the 75th percentile for number of pump stations per mile had significantly higher rates of SSOs per 100 miles (39.1) than average (17.1).

Table TA-3.7. Average Number of SSO Events Per System, Grouped Based on Selected System Attributes

Attribute			Number of Systems	Number of Systems Reporting SSOs	Average SSOs per 100 Miles
All Sewer Systems			1238	376	17.1
Budget	Annual Capital Budget	Not reported	314	35	29.8
		<25th Percentile	226	62	12.2
		25th - 50th Percentile	226	79	11.6
		50th - 75th Percentile	226	95	17.4
		> 75th Percentile	227	99	20.5
	Annual O&M Budget	Not reported	94	5	31.3
		<25th Percentile	244	63	8.8
		25th - 50th Percentile	231	96	12
		50th - 75th Percentile	231	93	17.7
		> 75th Percentile	232	98	21.8
Age	Percentage of Miles Constructed Prior to 1979	<25 Percentile	271	82	20.5
		25th - 50th Percentile	264	113	9.08
		50th - 75th Percentile	276	93	17.0
		> 75th Percentile	272	78	24.8
	Percentage of Pump Stations Constructed Prior to 1979	<25 Percentile	189	71	23
		25th - 50th Percentile	184	93	11.7
		50th - 75th Percentile	36	25	4.94
		> 75th Percentile	347	111	15.3
Maintenance	Sewer Miles Cleaned in Prior Year	Not reported	158	41	44.0
		<25th Percentile	235	77	10.8
		25th - 50th Percentile	236	82	11.5
		50th - 75th Percentile	231	79	18.3

		> 75th Percentile	234	85	14
	Gravity Sewers Inspected in Prior Year	Not reported	158	41	44
		<25th Percentile	284	99	12.6
		25th - 50th Percentile	195	48	11.2
		50th - 75th Percentile	239	77	13
		> 75th Percentile	240	74	13.9
Employees	Number of Employees Per Sewer Mile	Not reported	161	17	29.1
		<25th Percentile	269	103	6.31
		25th - 50th Percentile	268	109	8.26
		50th - 75th Percentile	268	94	18.5
		> 75th Percentile	269	54	52.1
	Percentage Employees Grade I Certified or Higher	Not reported	383	86	29.2
		<25th Percentile	174	72	19.2
		25th - 50th Percentile	184	69	17.9
		50th - 75th Percentile	156	56	6.72
		> 75th Percentile	170	78	8.04
	Percentage of Employees with more than 2 Years' Experience	<25 Percentile	221	82	17.9
		25th - 50th Percentile	317	110	17.9
		50th - 75th Percentile	158	68	12.8
		> 75th Percentile	407	108	17.39
Topography	Number of Pump Stations Per Mile	Not reported	356	72	24.9
		<25 Percentile	187	64	7.11
		25th - 50th Percentile	263	124	8.49
		50th - 75th Percentile	184	77	10.6
		> 75th Percentile	187	65	39.1

Notes: Calculations by authors based on SSO Survey database.

Estimates were also evaluated by region (Table TA-3.8). There was a significant difference in both the percentage of systems reporting violations and the number of SSOs per 100 miles between different regions. Region 3 had the second highest percentage of systems reporting (61.5%) and the highest average of SSOs per mile (30.8). Region 7 had the lowest reporting percentage (5.41%) as well as the lowest SSOs per mile average (0.468). With the exception of region 9, regions where more systems reported SSOs also had the higher rates of violations per mile, whereas systems with low reporting percentages had low rates of violations per mile. This could indicate SSO violations are going unreported.

Table TA-3.8. Comparison of the Percentage of Systems Reporting SSOs and Average SSOs per Mile for each Region

Region	Number of Systems	Percent Systems Reporting SSO Violations	Average SSOs per 100 Miles
1	76	18.4	11.5
2	149	30.9	23.6
3	117	61.5	30.8
4	156	12.2	11.6
5	452	34.5	14.6
6	84	19.0	6.57
7	37	5.41	0.468
8	98	8.16	5.28
9	68	63.2	7.09

After analyzing violation data and correlating factors, the presence of violations alone in a collection system was not assessed to be a consistent indicator of potential effects of lower flows. Overall, there were not strong correlations between the number of SSO violations and the factors assessed to explain results from process modeling.

3.3.4. Climate and Topography

Climate and slope characteristics of WWTF and collection system service territories were estimated based on GIS analysis and assumptions of the service territory. GIS representations of sewersheds were not available on a statewide basis.

To attribute climate factors with systems and facilities, collection system locations were identified based on geocoding point locations from available addresses, while for wastewater treatment facilities, latitude and longitude coordinates were available within several databases. Climate zones from the California Energy Commission (CEC) were categorized into groups associated with high and low risk factors for effects from lower flows based on literature, expert judgement, and outreach. Low risk scores were associated with cool wet areas with higher potential rates of flushing from infiltration. Higher risk scores were associated with hot, dry areas were lack of precipitation would lead to limited self-flushing and higher root intrusion risk, while hotter temperature could lead to more septic systems and hydrogen sulfide production. An ordinal metric with values ranging from 1-5 was developed and applied to collection systems for use in extrapolating effects from a set of modeled systems.

To estimate topography, the change in elevation was calculated between the identified point location of a collection system (latitude and longitude based on geocoded addresses) and the edges of a geographic buffer around that system. The buffers were limited to only areas within local watersheds as identified within Hydrologic Units by the U.S. Geological Survey. This assumed that collection systems are primarily designed as gravity-flow sewers whenever possible. Ultimately, without actual maps of collection system survey areas, topography was not a reliable indicator of effects.

3.4. Thresholds of Changes in Wastewater Influent Flow Rates

Thresholds of influent flow may be correlated with historical development of wastewater collection systems and treatment facilities. Potential thresholds of influent flow rates over time were considered as an indicator of likely effects (Table TA-3.9).

Table TA-3.9: 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 alkalinity water supply, carbon addition, aeration process modifications (e.g., recirculation). Energy recovery issues. Salinity related issues for irrigation (high TDS water supply, high TDS blowdown flows)	Reconsidering designs and mass loading approach. Industry expects a design setpoint that will not change for 50 year.
< 50	Accelerated corrosion. Upgrade aeration system. Energy recovery limitations. Disinfection ultraviolet 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 costs.	Incorporating reduced flows and increased drought in designs. Adapting existing infrastructure is complicated by need to divert organics from landfills because food waste loading increases TDS/N and process/disinfection issues.

Source: Created by authors. BNR = Biological Nutrient Removal. TDS = Total Dissolved Solids

The threshold approach was applied to wastewater treatment facilities for purposes of evaluating needed capital improvements to manage the estimated change in influent flow associated with AB 1668-SB 606.

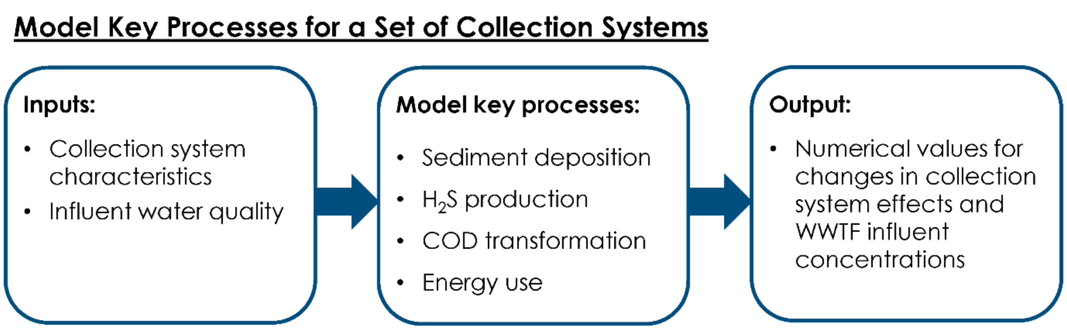
3.5. Physical Modeling of Wastewater Collection System Processes

An Excel-based model was developed to estimate changes in key processes within collection systems for volumes of wastewater influent generation that flow from varying rates of per capita wastewater generation in buildings.

The procedure to estimate impacts for all systems included (Figure TA-3.12):

1) Modeling key processes for a set of collection systems (50) based on input parameters from system attributes within the SSO database, estimated influent flow generation, and other data sources;
2) Examining explanatory factors of model outputs based on statistical analysis with clustering that correlated explanatory factors with four key model outputs;
3) Extrapolating effects to all collection systems based on clustering.

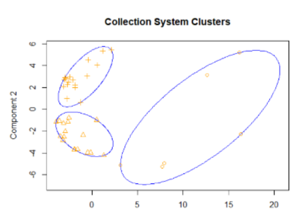
Figure TA-3.12: Procedure used to quantify operational effects on collection systems from AB 1668-SB 606, including first modeling key processes for a set of systems, then extrapolating effects across systems based on clustering with important attributes.



Extrapolate Effects for All Systems

Results from model

Collection System	% Increase per % Decrease in Per Capita Use			
	Corrosion Rate	H_2S Emissions	Sedimentation	Chemical Addition
1	1.98	0.34	0.31	0.38
2	2.00	2.52	0.24	0.61
3	3.20	0.46	0.19	0.76
4	1.98	1.67	0.30	0.35
5	2.11	2.36	0.27	0.62



Cluster systems based on risk indicators

Determine average incremental changes and apply to projected flow reductions for all systems based on clusters

Cluster	% Increase per % Decrease in Per Capita Use			
	H_2S Emissions	Corrosion Rate	Sedimentation	Chemical Addition
1	1.29	2.15	0.22	0.42
2	2.01	1.88	0.26	0.37
3	2.05	2.01	0.25	0.49

Notes: Developed by authors.

A detailed description of the equations and assumptions used in developing the model for collection systems is provided as a separate Technical Appendix to this report (TA-5). Results of the modeling for the subset of systems (50) and extrapolation to all collection systems of interest believed to serve Suppliers (446) are provided as part of the supplemental data files associated with this report.

3.6. Physical Modeling of Wastewater Treatment System Processes

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 it 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 TA-3.10).

Table TA-3.10: 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 chem addition	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.

Notes: Compiled by authors

Within *Biowin*, the sum of these effects across systems was normalized to a change in energy use relative to operating conditions in the absence of AB 1668-SB 606. The model input parameters and configurations are described in the sections below.

3.6.1. Wastewater Influent Loading Characteristics

The rate of per capita wastewater generation in the sewershed influences the concentrations of contaminants in the wastewater that reaches 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. Three thresholds of 100, 70, and 50 gpd were used to extrapolate linear changes in influent constituent concentrations. The influent concentrations (Table TA-3.11) used to simulate the influent characteristics under various per capita values (average values) were based on typical wastewater mass loading, which was then adjusted for conversions taking place within the collection system based on the process modeling (Section 3.5 of this Technical Appendix and Technical Appendix 5).

Table TA-3.11: 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

Notes: Estimated by authors based on literature and modeling

3.6.2. Wastewater Treatment Facility Configurations

Wastewater treatment facilities are designed to meet tailored discharge requirements based on unique characters of influent flow rates and concentrations. To consider such differences in potentially-affected facilities, three common configurations of wastewater treatment facilities were modeled to investigate differences in effects by facility type.

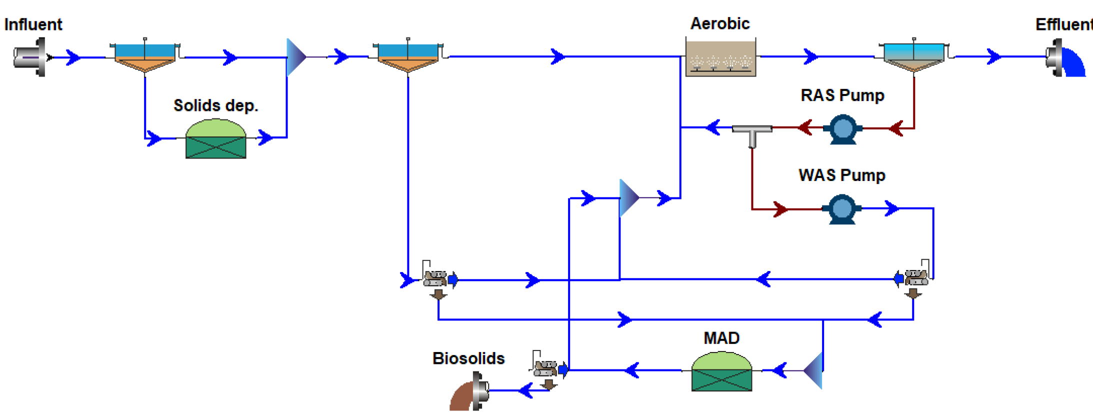
Biodegradable Organics Reduction

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.

BOD and Ammonium Removal

Some WWTFs treat influent to remove biodegradable organics and nitrification of ammonium in municipal wastewater prior to discharge, which typically discharge 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 TA-3.13.

Figure TA-3.13: Process diagram of the model used for simulating both BOD and ammonium reduction

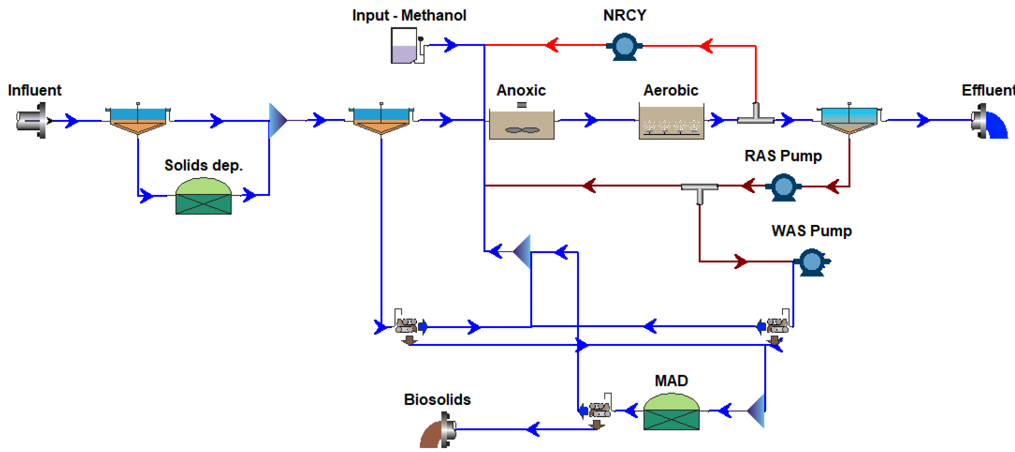


Notes: Developed by authors based on visualizations in software

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 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 TA-3.14.

Figure TA-3.14: Process diagram used for simulation of both BOD and total nitrogen reduction



Notes: Developed by authors based on visualizations in software

3.7. Normalizing Model Runs and Outputs

The reference condition for *Biowin* simulations assumed 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 change in energy use across influent flow rates ranging from 100 gpcd through 40 gpcd was estimated.

For a wastewater treatment facility operating with a constant volume of influent flow, as per capita influent flow rates decrease, the energy required to meet discharge requirements increases. This occurs when the growth in population is large enough to make up for the declines in wastewater influent generation in the service territory.

Alternatively, a wastewater treatment facility may operate with a decreasing volume of influent flow. For these cases, as per capita influent flow rates decrease, the energy required to meet discharge requirements may be equal or decrease. This occurs when the growth in population is not large enough to make up for the declines in wastewater influent generation in the service territory.

These two cases lead to different scenarios of mass loading, which are defined as:

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[1] value of 1.0 at all gpcd values.
2) Total volume of influent decreases as per capita influent flow rate also decreases. Under this scenario, a facility operating at design capacity would have a DWCI value of less than 1.0.[2] The value changes (decreases) as influent flow rates drop.

Each of these cases was modeled in *Biowin* for the three configurations of wastewater treatment processes across the range of wastewater influent flow rates from 100 to 40 gpcd (Figure TA-3.15).

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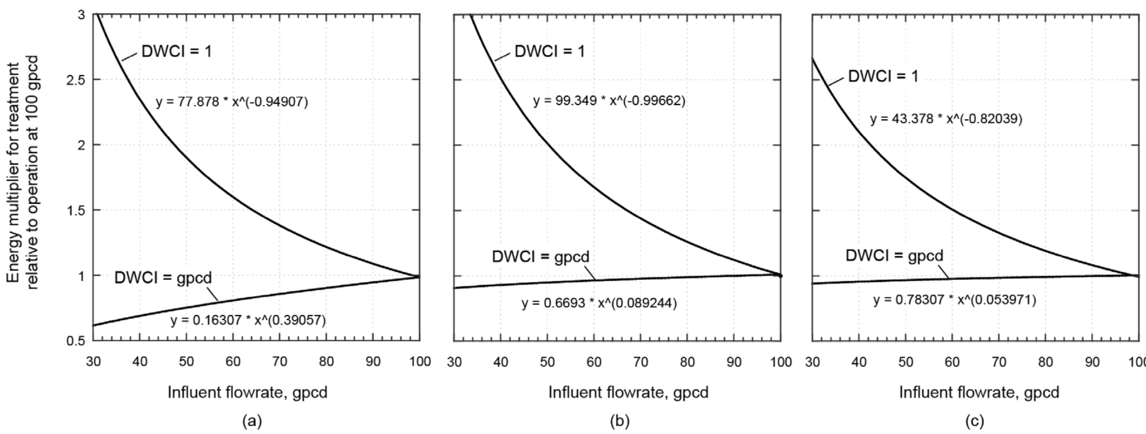
[1] The Drinking Water Capacity Index is the ratio of dry weather influent flow and design capacity. WWTFs with a DWCI at or near 1.0 would be operating near the design capacity in dry weather events.

[2] A DWCI value of less than 1.0 assumes that the WWTF has already experienced a decrease in influent flow since its year of initial operations.

The result was a series of curves that quantify the estimated change in energy use from the reference condition to a projected future state. Energy use was used as a way to normalize all impacts at the facility. Figure TA-3.15 shows the curves for each case and configuration. For facilities serving increasing populations, indoor water conservation drives a change in influent flow rate, which yields increased energy use. For facilities serving constant or decreasing populations, indoor water use conservation can lead to equivalent or lower energy use. Generally, results for each process have similar characteristics. For purposes of estimating process energy changes, Fig. TA-3.15(b) was used and provides a conservative estimate for any type of WWTF.

Figure TA-3.15: 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.



Notes: Author calculations based on modeling

Initial conditions of the volumetric flow rate for each wastewater treatment facility are needed to locate a facility within the upper and lower curves. These values, however, were not readily available from available data. Instead, to benchmark outputs against the reference condition, the *Dry Weather Capacity Index* (DWCI) was used. As described in Section 3.3.2 of this Technical Appendix, the DWCI is defined as the ratio of the average dry weather flow ($Q_{dry\ weather}$) to the facility's design flow Q_{design}over time:

$$DWCI = \frac{Q_{dry\ weather}}{Q_{design}} \tag{4}$$

The DWCI served as a reference point to understand how far a facility may be operating below the assumed initial condition of design and construction.

The modeled scenarios of per capita influent flow rate and population change 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. The upper and lower curves in Figure TA-3.15 can be represented by exponential models that estimate energy as a function of influent flow rate (Table TA-3.12).

Table TA-3.12: Exponential models of changes in energy use with unit reductions in per capita inflow flow

Modeled/estimated parameter	Change in energy use per unit reduction in per capita influent flow
Change in energy compared to reference condition (DWCI = 1)	$99.4 * x^{-0.997}$
Change in energy compared to reference condition (DWCI = current gpcd)	$0.67 * x^{0.089}$

Notes: Author calculations based on modeling. Reference conditions for this modeling are benchmarked using the estimated Dry Weather Capacity Index value for a WWTF.

3.8. Applying Exponential Models to Potentially-Affected Facilities

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 procedure that included the following steps:

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 (Tables 6-2 and 6-3) or the SWB's 2019 Annual Volumetric Report survey (AVR). Current populations were estimated based on linking collection systems and treatment facilities 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 TA-3.15, 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 TA-3.15, 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.

Results were quantified for Scenario 2 (indoor standard = 42 gpcd, outdoor standard = 0.62 in 2030). The effects were quantified and summarized for only the facilities within current per capita influent flow in the modeled range (40 to 100 gpcd).

Out of 334 wastewater treatment facilities with potential outputs from the network modeling, 204 had potential values of the WEO Impact Factor less than 1.0 and were deemed at-risk of potential effects. Of these, facilities with unrealistic values of WEO Impact Factors (values close to 0.0) were eliminated, as they likely represent facilities with incomplete or inconsistent data.

After eliminating WWTFs with influent flow rates out of the modeled range (100 to 40 gpcd) and WEO Impact Factors out of the at-risk range (<1.0), results from a total of 92 WWTFs were summarized based on the weighted average of the change in energy use (percent) and population (percent of modeled statewide value) to yield a statewide average value of operational effects.

3.9. Example: Applying *Biowin* Outputs to a Facility

For a facility that removes Nitrogen during the treatment process, the model can be applied to estimate the change in energy use. Several input parameters are required based on available data. For this example, the follow input parameters are used:

- The facility will experience a decrease in per capita influent flow rate from 56 to 50 gpcd from 2020 to 2030.
- The facility currently serves 215,000 people and will experience a 20% increase in population from 2020 to 2030.
- The facility has a design flow of 19.5 million gallons per day (MGD).
- The facility has a baseline influent flow of 12 MGD.

The procedure included nine steps.

1. Estimate the baseline (*B*) per capita influent flow rate:

    B-per capita influent flow rate, or B-gpcd = 12 Mgal/d / 215,000 = 56 gpcd

2. Estimate the baseline DWCI:

    B-DWCI = 12 MGD / 19.5 MGD = 0.62

3. Estimate the future (*F*) total influent flow rate:

    F-per capita influent flow rate, F-gpcd = 1.2 (215,000) * 50 gpcd = 12.9 Mgal/d

4. Estimate the future DWCI:

    F-DWCI = 12.9 MGD / 19.5 MGD = 0.66

5. Estimate the lower and upper bound baseline energy use changes:

    a. Baseline operations energy use change (lower bound):

    B-Energy Use Change (lower), or B-EUC-lower = 0.67 (*B-gpcd*)^0.089

    = 0.67 (56)^0.089 = 0.96

    b. Baseline operations energy use change (upper bound):

    B-Energy Use Change (upper), or B-EUC-upper = 99.4 (56)^-0.997 = 1.79

6. Estimate the baseline energy use change by scaling between the upper and lower curves:

    a. Baseline scaling factor

Baseline Scaling Factor, or B-sf = [(*B-DWCI* * 100) – *B-gpcd*] / *B-gpcd*

= [(0.62 * 100) – 56] / 56 = 0.11

b. Baseline energy use change scaled to DWCI:

Baseline Energy Use Change, or B-EUC = 0.96 + (*B-sf*) * (1.79 – 0.96)

= 0.96 + 0.11 * (0.83) = 1.05

7. Estimate the lower and upper bound future energy use changes:

a. Future operations energy factor (lower bound)

Future Energy Use Change (lower), or F-EUC-lower = 0.67 (*F-gpcd*)^0.089

= 0.67 (50)^0.089 = 0.95

b. Future operations cost factor (upper bound)

Future Energy Use Change (upper), or F-EUC-upper = 99.4 (50)^-0.997 = 2.01

8. Estimate the future energy use change by scaling between the upper and lower curves:

a. Future scaling factor (*F-sf*)

Future Scaling Factor, or F-sf = [(*F-DWCI* * 100) – *F-gpcd*] / *F-gpcd*

= [(0.66 * 100) – 50] / 50 = 0.32

b. Future energy use scaled to DWCI:

Future Energy Use Change, or F-EUC = 0.95 + (*F-sf*) (2.01 – 0.95)

= 0.95 + 0.32 *(1.06) = 1.28

9. Estimate the change in operations cost from baseline to future

(*F-EUC* – *B-EUC*) / *B-EUC* = (1.28 – 1.05) / (1.05) = 22% increase

The future percent change in operational energy use as an indicator of all effects is expected to be 22% larger in 2030 based on the changes in population growth and influent flow rate.

4. Supplemental Results

Supplemental results are provided below for effects on collection, treatment, and reuse systems.

4.1. Wastewater Collection Systems

The clustering procedure extrapolated effects from the set of 50 modeled collection systems to all collection systems in the state. Statistical analysis was used to identify key explanatory factors of model outputs.

4.1.1. Correlating Model Outputs with System Attributes

With the goal of extrapolating effects from a set of modeled systems to all systems at-risk, collection system attributes were analyzed as explanatory factors of model outputs, which can predict modeled impacts.

Based on analysis of literature, outreach and interviews, and preliminary modeling, the team identified a set of likely potential explanatory factors for use in clustering systems. The factors included:

- Total per capita wastewater influent flow
- Change in per capita wastewater influent flow
- System age indicators
- Length of pipe (normalized by population)
- Indicators of the distribution of pipe sizes within systems
- Operational indices, including the Dry Weather Capacity Index (DWCI)
- Maintenance indicators and professional training

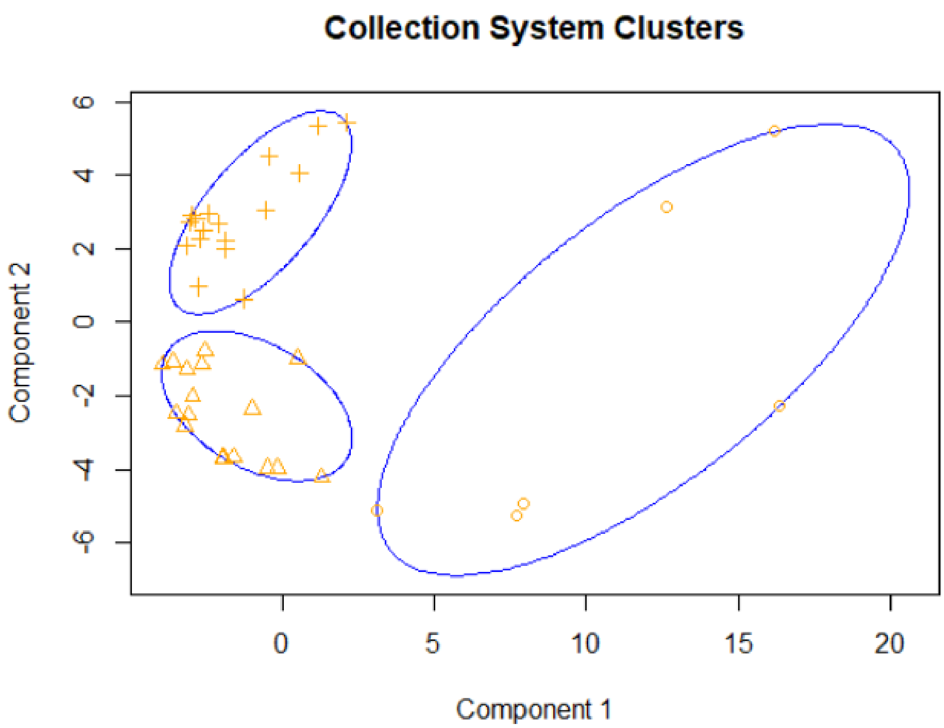
Numerous statistical models with multivariate linear regression were developed to explore potential factors that explained model outputs. Key model outputs that capture potential changes in mitigation actions included corrosion rate, hydrogen sulfide emissions, sediment depth, and chemical addition needs. Results from each of the four statistical models identified explanatory factors with key process model outputs. The results are summarized as follows:

- Response variable: Corrosion rate
  - Model fit: moderate
  - Significant explanatory variables: Total influent flow per capita, Percent of 6” & 8” pipes
- Response variable: H_2S Emissions
  - Model fit: moderate
  - Significant explanatory variables: Climate zone risk score, Percent of 6” & 8” pipes
- Response variable: Sediment depth
  - Model fit: moderate
  - Significant explanatory variables: Total influent flow per capita, Percent of 6” & 8” pipes
- Response variable: Chemical addition
  - Model fit: moderate
  - Significant explanatory variables: Average summer temperature, Climate zone risk score, Percent of 6” & 8” pipes

Results indicated that explanatory factors to predict impacts should include the estimated per capita influent flow, the percent of 6”-8” pipes in a system, the climate zone risk score (ordinal variable from 1-5), and average summer temperature. Based on the models and additional analysis, the key overlapping indicators across models were folded into a single set of explanatory factors for purposes of clustering. This set of factors for clustering included the percent of 6”-8” pipes in a system, climate zone risk score, current per capita influent flow, and percent of the sewer system constructed before 1979.

The explanatory factors for the set of modeled systems (50) were compiled in a database. Using the *cluster* package in R *Studio*, an unsupervised clustering analysis was performed based on k-means with shortest distance weighting between values. 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. For 41 systems with results from the process modeling, results indicated that two principal components based on the four explanatory inputs were good factors for clustering. Three distinct clusters were identified as part of two components that explained 85% of the variability (Figure TA-3.16). 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 TA-3.16: Results from clustering of collection systems to extrapolate effects



Notes: Created by authors based using a clustering algorithm with data from the State Water Board’s Sewer System Overflow (SSO) Survey database and network modeling of influent flow.

Table TA-3.13: Ranges of attributes for sewer systems in each of three clusters used to extrapolate statewide effects

Response Variable: Estimated Effect from Process Model	**Significant Explanatory Variables: Risk Factors**	**Relationship**	**Model Stats (for a model with just significant variables)**
Corrosion rate: % change with % change in per capita flow	Estimated total flow per cap Percent of 6"-8" pipes	inverse, p-value < 0.001 positive, p-value < 0.001	R^2 = 0.50, Adj R^2 = 0.47 F-stat = 18.8 on 2 & 38 D.F.
Corrosion rate: Baseline flow value (in/yr)	Estimated total flow per cap Percent of 6'-8" pipes	inverse, p-value < 0.001 positive, p-value < 0.001	R^2 = 0.50, Adj R^2 = 0.45 F-stat = 12.2 on 3 & 37 D.F.
H2S Emissions: % change with % change in per capita flow	Climate zone risk score (1-5, 5=worst) Percent 6" gravity pipes	inverse, p-value < 0.1 Inverse, p-value < 0.001	R^2 = 0.45, Adj R^2 = 0.42 F-stat = 16.24 on 2 & 40 D.F.
H2S Emissions: Baseline flow value (lb-d/mile)	Climate zone risk score (1-5, 5=worst) Percent 6"-8" pipes	positive, p-value < 0.05 Inverse, p-value < 0.001	R^2 = 0.42, Adj R^2 = 0.39 F-stat = 14.71 on 2 & 40 D.F.
Sediment Depth: % change with % change in per capita flow	Estimated total flow per cap Percent of 6'-8" pipes	inverse, p-value < 0.001 positive, p-value < 0.001	R^2 = 0.58, Adj R^2 = 0.56 F-stat = 26.8 on 2 & 38 D.F.
Sediment Depth: Baseline flow value (in)	Percent of 6'-8" pipes	inverse, p-value < 0.001	R^2 = 0.68, Adj R^2 = 0.66 F-stat = 42.97 on 2 & 40 D.F.
Chemical Addition: % change with % change in per capita flow	Average summer temperature Climate zone risk score Estimated total flow per cap	positive, p-value < 0.1 inverse, p-value < 0.05 positive, p-value < 0.1	R^2 = 0.21, Adj R^2 = 0.12 F-stat = 2.4 on 4 & 36 D.F.

Notes: Created by authors based on multiple statistical models with multivariate linear regression.

4.1.2. Extrapolating Model Outputs to All Systems Through Clustering

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 TA-3.14).

Table TA-3.14: 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

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

Summary statistics of model outputs for each cluster were calculated (Table TA-3.15). 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 since a change in flow was assumed to directly correlate with a change in pumping energy. System topography was not identified as a key explanatory risk indicator based on analysis and outreach.

Table TA-3.15: 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%

4.1.3. Estimated Impacts for All Systems by Cluster

Estimated impacts by system are detailed in worksheets as part of the supplemental material provided for this report.

Based on the clustering and extrapolations, wastewater influent to collection systems is expected to decrease by an average of 2% (+/-5%) to 5% (+/-5%) across the Scenarios (Table TA-3.16). 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%). 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 TA-3.16: 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%)

Notes: Author calculations

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 TA-3.17). 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 outputs could be greater in territories where Suppliers invest more aggressively in indoor water use conservation for compliance or less in territories where outdoor water use conservation is emphasized.

Table TA-3.17: Average modeled outputs by cluster for objectives values based on parameters for Scenario 2 (indoor standard = 42 gpd, outdoor standard = 0.62).

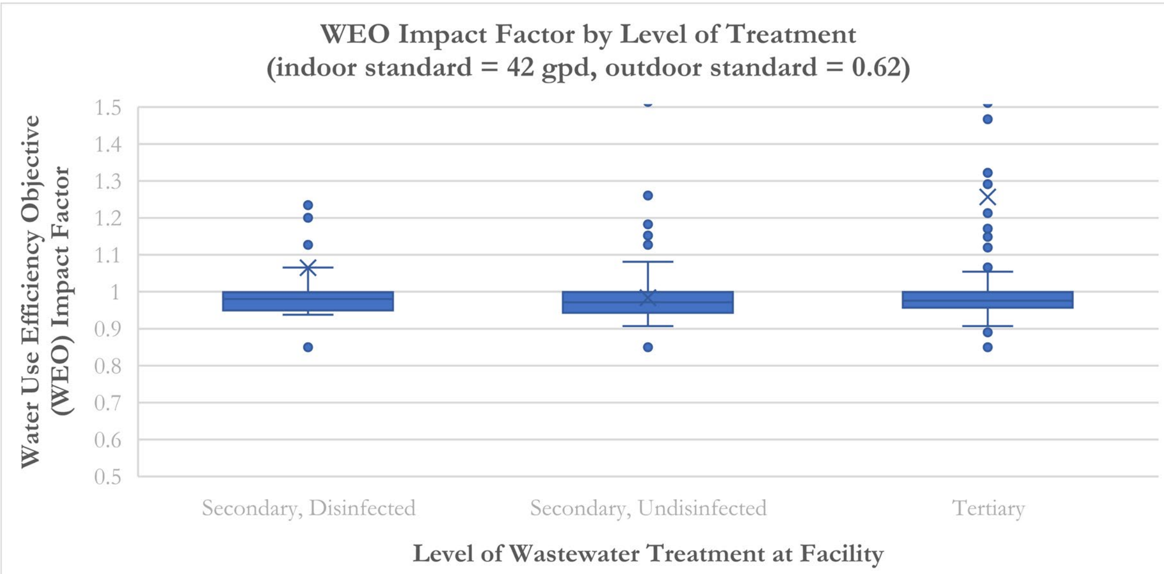
	Cluster			
Model Output (% Increase: Average)	*1*	*2*	*3*	***All***
Pipe Replacement Costs	7.5%	8.9%	9.5%	9.0%
H_2S Emissions	7.3%	8.6%	9.2%	8.7%
Corrosion Rate	7.1%	8.5%	9.0%	8.5%
Sedimentation	0.9%	1.0%	1.1%	1.0%
Chemical Addition	1.7%	2.0%	2.2%	2.1%
Pumping Costs	-3.5%	-4.2%	-4.5%	-4.3%

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

4.2. Wastewater Treatment Facilities

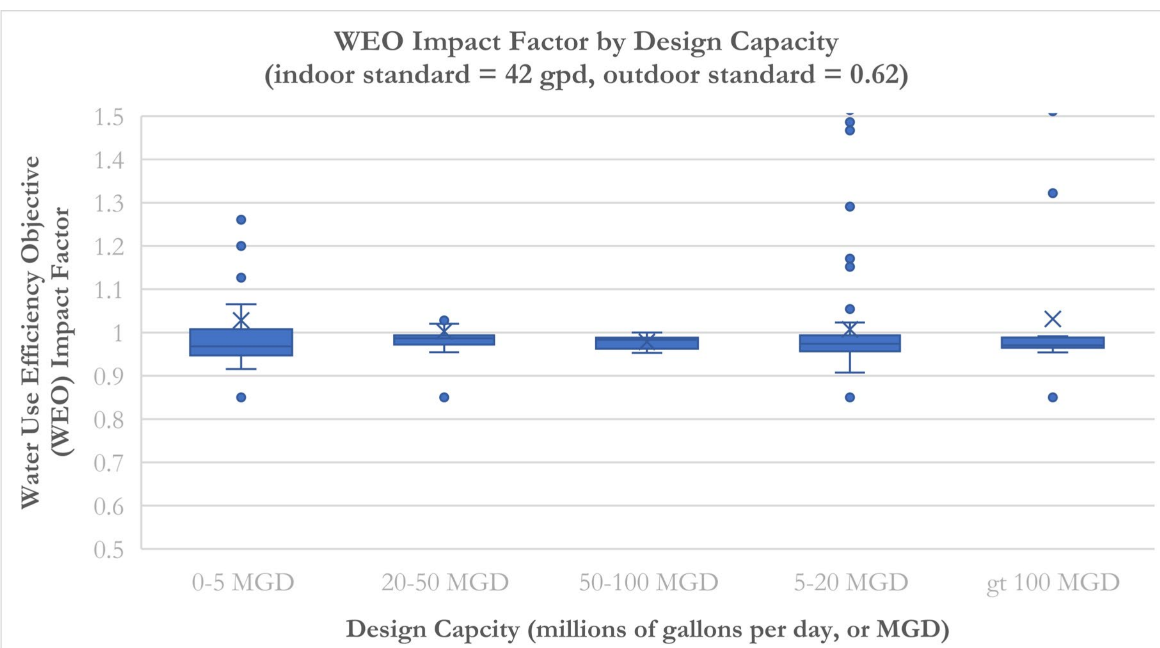
The WEO Impact Factor values varied across levels of treatment (Figure TA-3.17) and design capacities (Figure TA-3.18) at a facility.

Figure TA-3.17: WEO Impact Factor ranges by level of treatment at a wastewater facility.



Notes: Author calculations for 265 based on available data.

Figure TA-3.18: WEO Impact Factor ranges by design capacity at a wastewater facility.



Notes: Author calculations for 250 facilities based on available data.

4.2.1. Operational Effects

For operational effects, of the 204 potentially-affected WWTFs identified through network modeling for Scenario 2, 92 WWTFs had sufficient data for modeling operational impacts using *Biowin*. Applying the *Biowin* model outputs to these WWTFs within the range of 40 to 100 gpcd yielded a statewide weighted average increase in annual energy use of 1.4%. The median value across facilities, however, was negative (-1.8%), indicating that more facilities would see a decrease in future energy use and operational costs as a result of AB 1668-SB 606.

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 TA-3.18.

Table TA-3.18: 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%

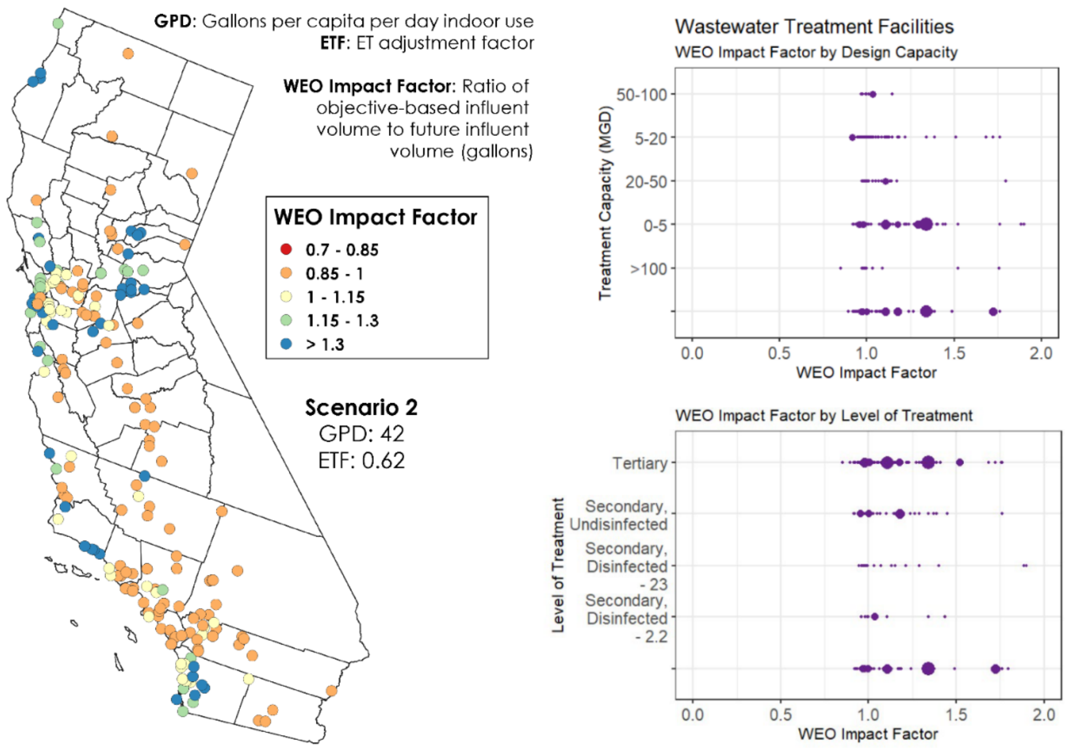
Notes: Author calculations based on modeling.

4.2.2. Mapping Operational Indices

The WEO Impact Factor values were mapped across WWTFs as described in the text of the main report (Figure 6-13 in main report, also included in this Technical Appendix as Figure TA-3.19). The mapping procedure illustrated the geographic distribution of effects across the state.

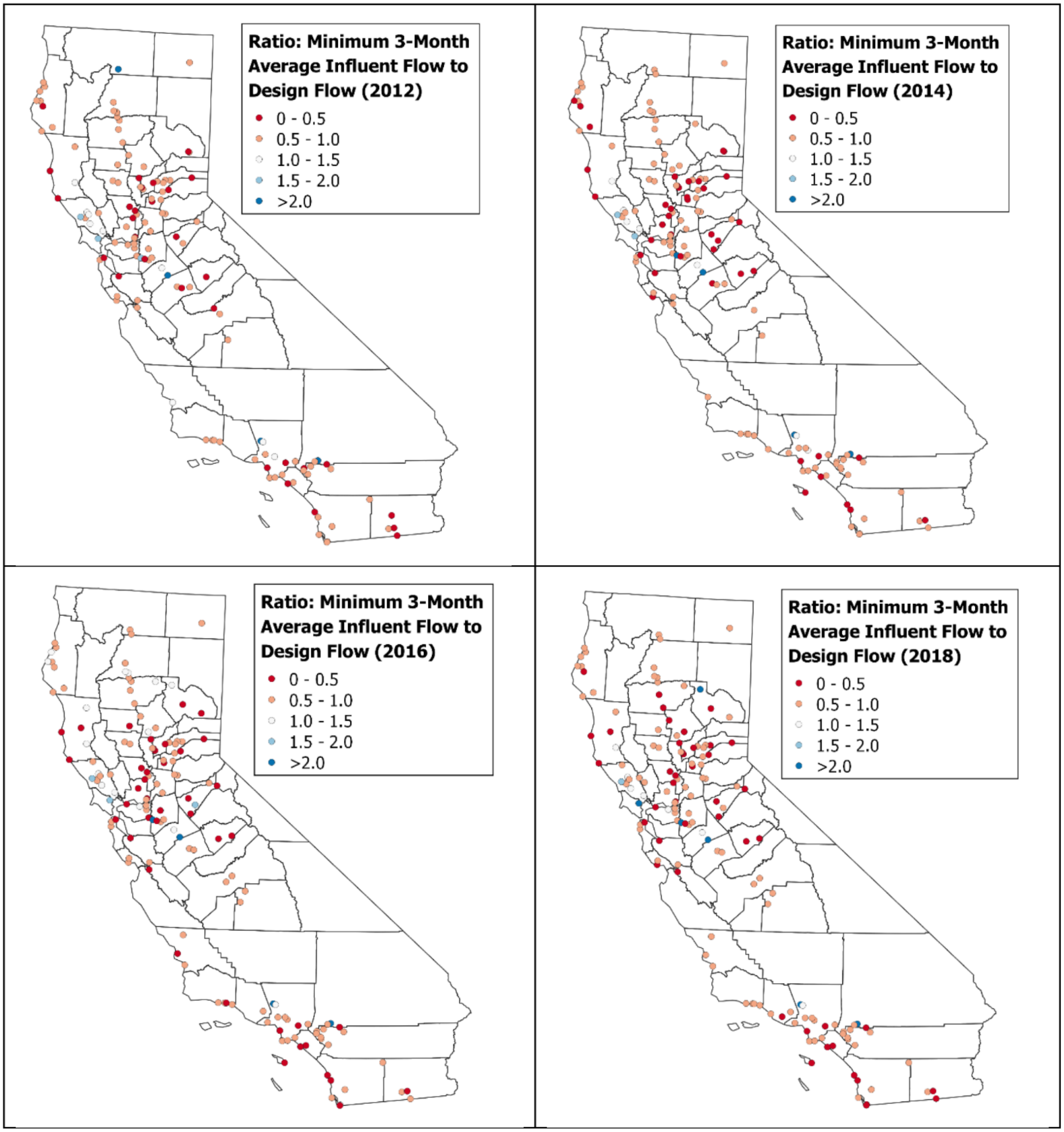
However, to get to this summary map and first-order indicator, numerous statistics and maps were examined to understand the value of potential indicators for extrapolating effects. For example, Figure TA-3.20 shows a plate of maps for the Dry Weather Capacity Index over years for WWTFs with available data in CIWQs. The maps illustrate how dry weather flows in most recent years are well-below design capacity in many parts of California. Wastewater treatment facilities in California are often designed to manage across a range of flows given the state's potential for extreme climate, but as drought and water scarcity increase in future years, the maps also indicate the progression of risk in systems that may be operating based on design principles from past decades.

Figure TA-3.19: 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).



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

Figure TA-3.20: Visualizing historical trends in operations and influent flows for wastewater treatment facilities in California by comparing dry weather influent flows with facility design capacity.



Notes: Created by authors, based on analysis of data from the California Integrated Water Quality Information System (CIWQS) for wastewater treatment facilities with available data since 2012.

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