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The feasibility of industrial wastewater reuse onsite in the Tri-City area

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Abstract

Industries typically discharge wastewater to a centralized wastewater treatment plant, but given ongoing water scarcity from repeated droughts, onsite wastewater reuse within the industrial facility's plant is an attractive alternative. However, information on economic and technical feasibility on wastewater reuse onsite is limited. A literature review showed that membrane bioreactors are a promising wastewater reuse treatment technology due to their reduced footprint and high quality produced effluent. A watershed assessment of the Tri-City area was conducted to evaluate future water supply. A case study was then performed on industrial dischargers in the Tri-City area applying this technology. Finally, the costs of membrane bioreactors was evaluated compared to the benefits. It was found that water supply shortages of up to 18% are predicted during drought years in the Tri-City area and up to a 50% shortage is predicted during a catastrophic event, such as an earthquake. Membrane bioreactors were proven to be a viable option producing high quality produced effluent capable of meeting California water reuse standards. The economic feasibility increased as wastewater strength (i.e., chemical oxygen demand and suspended solids) and wastewater volumes increased, making it most economically feasible for companies like Tesla, who discharges an average of 115,077,012 gallons of wastewater per year. It is recommended that policy is implemented to require industrial wastewater users to evaluate their processes for potential areas to reuse water and identify areas to reduce water usage. In addition, incentives and education should be provided to encourage wastewater reuse within an industrial facility's plant.

Introduction

Across the world, manufacturing growth of 400% is projected to drive water consumption 55% by 2050 (Walsh et al., 2016). Water is used as a raw material in many industries, for example the beverage industry, and also used in many industrial processes, like cleaning in manufacturing or cooling water (Walsh et al., 2016). Water is a valuable resource to industry, which is also problematic considering its diminishing conditions throughout the world right now. Drought is an ongoing issue throughout the world, especially in California. In the past 20 years, California is experiencing droughts more severe and longer in duration than it has seen historically (U.S. Drought Monitor, 2021). For Alameda County Water District, water shortages of up to 18% are expected in years of drought (ACWD, 2020).

Alameda County Water District is the sole municipal water supplier for Union City, Fremont, and Newark, also known as the Tri-City area. This area is made up of mostly residential water consumers; however, 33% of these water consumers consists of commercial, industrial, and institutional customers (ACWD, 2020). The service area includes various types of industries, which includes the 5.3 million square foot Tesla Factory, in addition to other high-tech, biotech, and manufacturing industries (ACWD, 2020; Tesla, 2021). Tesla is one of the top industrial wastewater discharger in the service area among various other industries.

The top industrial dischargers in the service area include automotive manufacturers, hospitals, commercial laundry services, and high tech manufacturers (USD_c, 2021). The wastewater volumes produced by these companies have generally increased over the past three years with wastewater volumes from individual dischargers ranging from 16,084,992-136,393,723 gallons per year (USD_c, 2021). Within the top industrial dischargers in the region, the types of industries and wastewater volumes can be seen in the below table:

Table 1: Top industrial dischargers in the Tri-City area and their industry type. The types of industries for each industrial discharger was found on their company websites. Average annual wastewater discharge volumes were provided by Union Sanitary District. For wastewater volumes marked with an asterisk , only two years of wastewater discharge volumes were available (USD$_c$, 2021).

Industrial Discharger	Industry	Average Annual Wastewater Discharge Volume from 2018-2021 (gallons)
Tesla	Automotive Manufacturing	115,077,012
Western Digital	Hard Disc Drive Manufacturing	63,449,237
Lam Research	Water Fabrication/Semiconductor Manufacturing	42,487,507
United States Pipe & Foundry	Pipe & Fittings Manufacturing	41,460,411
Kaiser Permanente	Hospital	20,329,125*
Mission Linen Supply	Commercial Laundry Services	19,131,168*
Washington Hospital Health-Care System	Hospital	29,004,720

The industrial dischargers found in the above table currently discharge their wastewater to Union Sanitary District, the municipal wastewater treatment plant for the Tri-City area. Union Sanitary District serves approximately 356,000 people and the type of customers in the district are residential, commercial, and industrial (USD$_a$, 2021). The Union Sanitary District service area, which consists of Newark, Fremont, and Union City, can be seen in the figure below:

Figure 1: Union Sanitary District Service Area Location map. The green-shaded area shows the geographical area that discharges their wastewater to Union Sanitary District, otherwise known as the Tri-City area (USD$_b$, 2020)

As water consumption continues to increase while supply is questionable in drought conditions, alternate sources of water will need to be evaluated. Wastewater reuse is a concept of increasing popularity in these times of drought.

In California, wastewater reuse has increased over 200% since 1970 (WateReuse Action Plan Committee, 2019). In 2019, there was a reported 265 wastewater treatment plants that produced recycled water (WateReuse Action Plan Committee, 2019). However, there is little information available on the feasibility of implementing industrial wastewater reuse within the industrial plant. Increasing purchased water and wastewater discharge costs are driving the need for decentralized industrial wastewater reuse within the industrial plant's own footprint.

Membrane bioreactors have been increasing in popularity due to their reduced footprint needs and high quality produced effluent, making it a viable option for industrial wastewater reuse (Chan et al., 2009; Wu and Kim, 2020). However, little information exists on the capital and operating costs for businesses to make an economic business decision. This study focuses on the feasibility for industrial dischargers in the Tri-City area to install membrane bioreactors within their own plants to treat and reuse their wastewater.

Research Objectives

The goal of this study is to evaluate the costs and benefits of installing a membrane bioreactor in the Tri-City area. First, I will launch into a watershed assessment was to evaluate the sustainability of the water supply in the catchment. Then I will provide some regulatory background surrounding wastewater and analyze the wastewaters that are being discharged in the Tri-City area. Next, I will review the technical details of membrane bioreactor technology, and assess case studies using membrane bioreactors to compare their removal efficiencies to the local industrial wastewaters. Finally, a cost evaluation will be conducted to determine the economic feasibility.

Methodology

Data Collection and Analysis

Through a Public Information Request, I requested the following information from Union Sanitary District: 1) the top 10 industrial dischargers by wastewater discharge volume in the district and their wastewater discharge volumes for the past three years, 2) sampling reports for the top 10 industrial dischargers for the past 12 months, and 3) the top 10 industrial dischargers annual sewering fees for the past three years. Industrial dischargers for which I was given wastewater discharge volumes and sampling reports were only used. One industrial discharger was omitted to avoid any conflicts of interest. Using the sampling report data, minimum, median, first quartile, third quartile, and maximum values were calculated to create box and whisker plots for chemical oxygen demand and suspended solids. The process I used to analyze the costs provided by Union Sanitary District are discussed in more detail in the Cost Evaluation section below.

Literature Synthesis of Existing Treatment Technologies and Government Management Plans

SCOPUS was used to conduct a literature review of existing wastewater treatment and reuse technologies using only Q1 and Q2 sources. After reviewing the literature, I decided to focus this feasibility study on membrane bioreactors since these appeared to be promising technology solutions specifically for industrial companies due to their reduced footprint and high quality produced effluent. A literature review on government agency management plans was also conducted to conduct a watershed assessment for the Tri-City area.

Case Study

Existing cases of wastewater treatment and reuse in the literature were evaluated. These case studies were then compared to the industrial users in the Tri-City area using only Q1 and Q2 sources in SCOPUS. The removal efficiencies of the membrane bioreactors in these studies were applied to the industrial users in the Tri-City area and then evaluated to see if they would meet California water reuse requirements. Q3 sources were used for literature on the costs of membrane bioreactors due to there being limited available information on the operating and maintenance costs.

Cost Evaluation

The annual cost of purchasing water from Alameda County Water District was calculated for each top discharger by multiplying the unit cost of purchasing water (provided by Alameda County Water District) by the annual wastewater discharged (provided by Union Sanitary District) and added to the annual service charges (provided by Alameda County Water District). It was assumed that the amount of water purchased was the same as the amount of wastewater discharged. This is a limiting factor as water consumption is most likely greater than wastewater discharged due to evaporation and water lost in other processes. Alameda County Water District provides two charges for purchasing water; a consumption charge and bimonthly service charges. The consumption charge was multiplied by the amount of wastewater discharged. The bimonthly service charges are determined by the meter size at the industrial site. A 6" meter size was used to determine the bimonthly service charges for each industrial discharger. These costs were added to the consumption costs to get the total cost of purchasing water.

The total cost of purchasing water was then added to the total cost of discharging wastewater for each industrial discharger. A unit cost was then calculated by dividing the total cost of purchasing and discharging water by the volume of wastewater discharged for each industrial discharger to find the cost per cubic meter of wastewater discharged to compare it to unit costs found in the literature. The unit costs for the industrial dischargers in the Tri-City area were then compared to similar membrane bioreactor sizes found in the literature to understand whether membrane bioreactor treatment costs are economically feasible compared to industrial dischargers current wastewater discharge costs.

Analysis of Industrial Discharger's Wastewater Usage and Water Supply in the Catchment

Alameda County Service Area

Alameda County Water District is the sole water retailer that has jurisdiction over the Tri-City area delivering water to Newark, Union City, and Fremont (ACWD, 2020). Alameda County Water District serves approximately 357,000 people with the population expected to increase to 450,000 by 2045. In fiscal year 2019/2020, Alameda County Water District's customers comprised mostly of singe family users (46%) while the next largest customer classification was multi-family homes (20%). The remaining customers fall under dedicated landscape (13%), commercial (12%), industrial (6%), and institutional (3%) (ACWD, 2020). Historically, water demand from these customers has fluctuated year over year.

Water Demand

There have been many factors that have influenced water demand in the past and continue to affect water demand in the future. In the 1990s, population growth was a factor in increasing water usage as shown in the below figure:

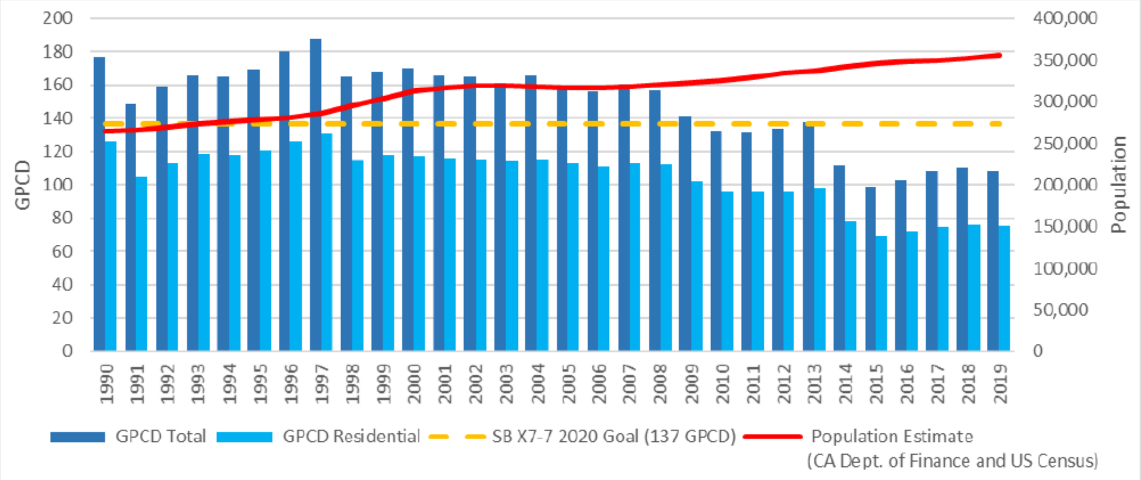


Figure 2: Projected population estimates compared to historic and current water demand. The bars in blue show the gallons per capita per day (GPCD) of water that was used in the Alameda County Water District's service area. The darker shade of blue shows total for all water consumers while the lighter shade shows only residential. The red line shows the population estimate during that time. The yellow dashed line shows the value of gallons per capita per day that was mandated through Senate Bill X7-7 (SB X7-7) (ACWD$_b$, 2021).

However, from around 2004 and on, population continues to increase while water usage decreases. In 1995, the state set water efficiency goals to reduce water demand. Additionally, Senate Bill X7-7 was implemented in 2009 requiring that water suppliers (e.g., Alameda County Water District) increase water efficiency (also known as the Water Conservation Act of 2009) (ACWD$_b$, 2021). Alameda County Water District set their efficiency goal to 137 gallons per capita per day. It can be seen that after 2009 when the 137 gallon goal was set, the state met its goal from then on with exception of 2013 (ACWD$_b$, 2021). This demonstrates that policy is an influence on water use and can be used to combat increasing water use driven by population demand. However, these are not the only factors in influencing water use.

Drought and the economy have also played a role and how much water is consumed. In the figure above, it can be seen that from 2013 to 2014, water usage decreased from about 137 gallons per capita per day to approximately 115 gallons per capita per day (ACWD$_b$, 2021). This can be attributed to the drought California was facing at the time and can be seen in Figure 3 below:

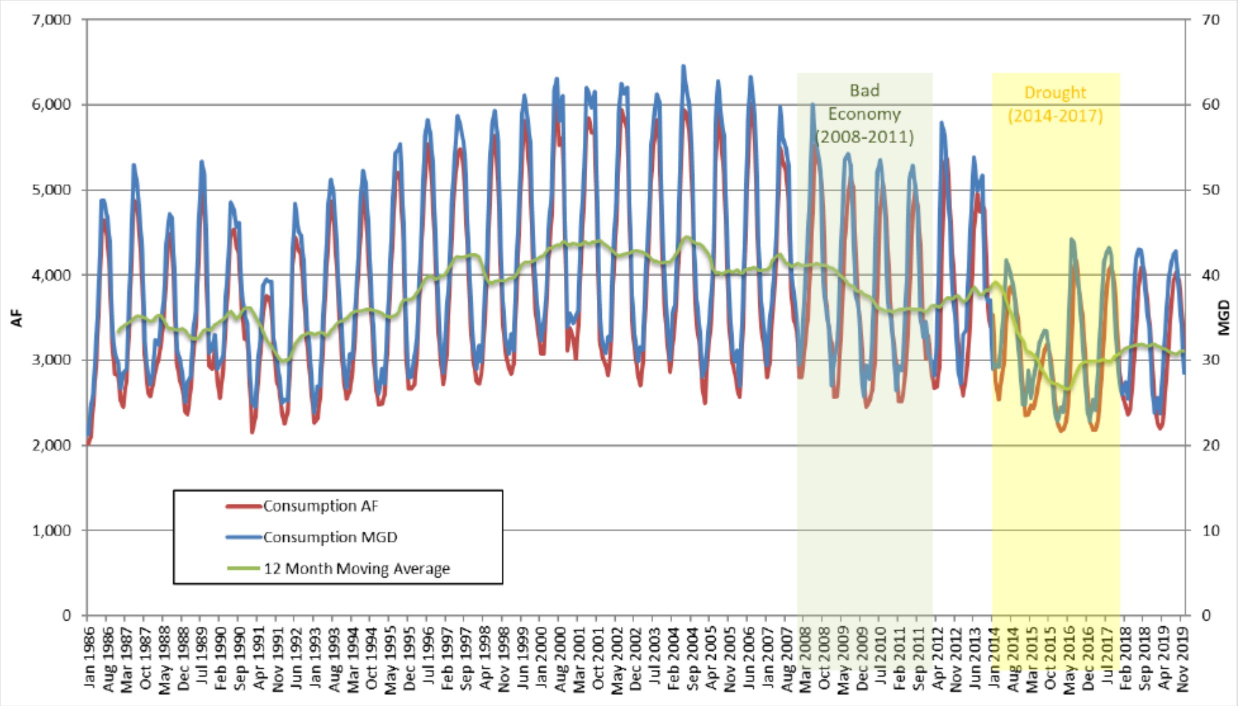


Figure 3: Historical water consumption amounts in the Alameda County Water District service area. The red line shows water consumption in acre-feet while the blue line shows water consumption in million gallons per day. The green line shows the 12 month moving average in acre-feet. The green shaded area highlights the time from 2008-2011 when poor economic conditions existed. The yellow shaded area highlights the time from 2014-2017 when the area was experiencing a multi-year drought (ACWD$_b$, 2021).

Water consumption dropped from 2014 to 2017 during a drought period. This is due to the state declaring a drought state of emergency and imposing voluntary restrictions at first, and then eventually mandatory restrictions when one of its water supply sources (the State Water Project, which Alameda County Water District receives 40% of its water from) was reduced to 0% (ACWD$_b$, 2021). These restrictions imposed in 2014 included a 20% reduction in water use and focused mainly on outdoor water use restrictions, even though the state only required Alameda County Water District to achieve a reduction of 16% in 2015 (ACWD$_b$, 2021). Alameda County Water District owes its success to its early implementation of water use restrictions and rebate programs to customers who modified their landscape to drought tolerant landscapes (ACWD$_b$, 2021). Because of these measures, they ended up reducing their water consumption close to 30% (ACWD$_b$, 2021).

It can also be seen in the chart that the state of the economy drives water consumption. During 2008 to 2011, when the United States was well known to be experiencing a recession, water consumption decreased from an average just above 4,000 million gallons per day in 2008, to an average around 3,500 million gallons per day in 2010 ($ACWD_b$, 2021). This phenomenon can also be seen today during the COVID-19 Pandemic. In the industrial wastewater flow data from Union Sanitary District, most industries' wastewater flow decreased from 2019 to 2020. During the COVID-19 Pandemic, many companies were forced to cut back operations, and some even forced to shut down completely if not deemed essential, when the state enforced a shelter in place mandate in March 2020. Understanding the major factors of water demand can help us predict future demand.

Alameda County Water District predicted future demand using a Decision Support System (DSS) Model based off assumptions surrounding state plumbing codes and water efficiency measures taken. The Decision Support System Model is able to take into account varying conservation efforts to break down water production and its end uses (ACWD, 2020). California has implemented certain regulations surrounding plumbing fixture and building code requirements that Alameda County Water District considers to generate passive water savings, meaning that these savings happen naturally overtime and Alameda County Water District did not have to implement efficiency measures to obtain them ($ACWD_b$, 2021). These plumbing codes are taken into consideration when predicting future demand which can be seen in the figure below:

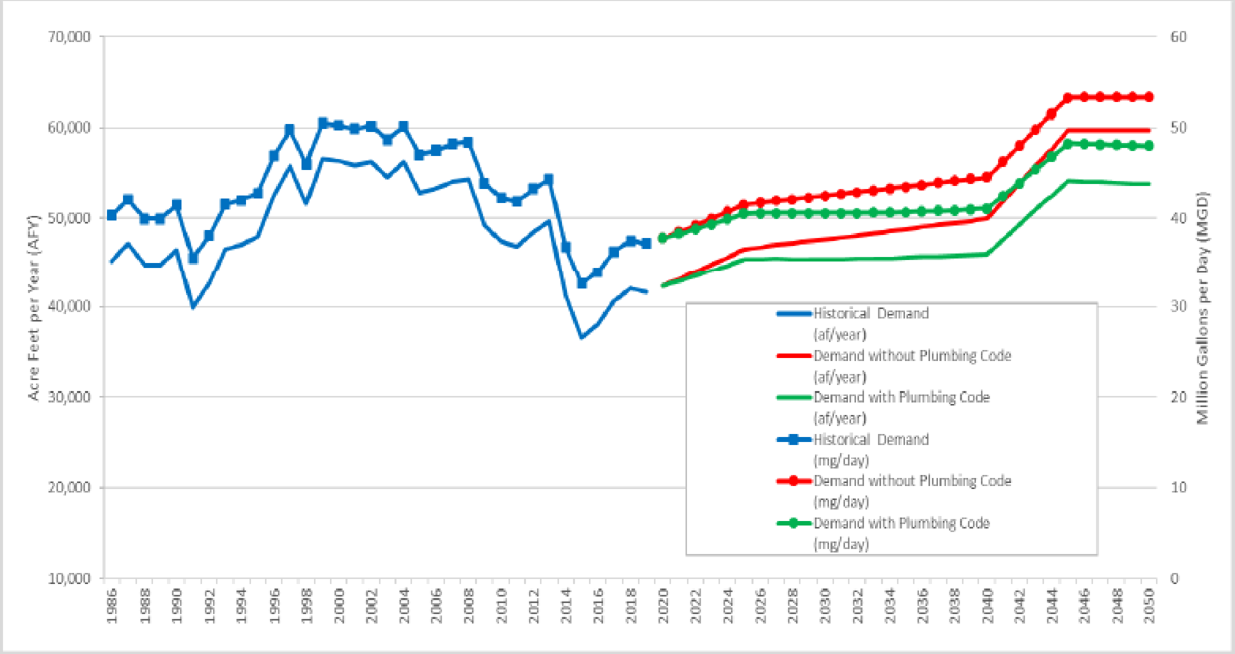


Figure 4: Alameda County Water District's projected water demand with plumbing code savings. The blue solid line shows historic water demand in acre-feet per year, while the dashed line shows the same but in million gallons per day. The red solid line shows the projected demand if plumbing code efficiencies were not mandated in acre-feet per year, while the dashed red line shows the same but in million gallons per day. The green solid line shows the projected demand if plumbing code efficiencies were mandated in acre-feet per year, while the dashed green line shows the same but in million gallons per day (ACWD$_b$, 2021).

It can be seen that water demand is expected to increase through 2050. However, water savings occur over time when considering plumbing codes, saving approximately 5 million gallons per day (ACWD$_b$, 2021). Additionally, Alameda County Water District estimated future water demand taking into account three different water efficiency strategies.

In 2018, California adopted Assembly Bill 1668 and Senate Bill 606 which requires the State Water Resources Control Board and the California Department of Water Resources to implement long-term standards surrounding water efficiency (ACWD$_b$, 2021). For industrial users, the Department of Water Resources recommends implementing performance measures such as best management practices and creating a classification system (ACWD$_b$, 2021).

To meet state legislature and the district's water goals to increase water use efficiency, Alameda County Water District generated a list of water use efficiency measures and screened them by evaluating the feasibility, cost effectiveness, interest of their customers, and if they meet their water efficiency goals ($ACWD_b$, 2021). The screening criteria can be seen in more detail in the figure below:

Measure Screening Criteria

Cost (Total & Per Unit) – Is the total cost to implement the measure reasonable? Is the cost per unit of savings less than the cost per unit for additional water supplies?

Feasibility – Ease of Implementation: If not easy to implement, can it be or is it already administered on a regional level or through a third party that will make it feasible to implement?

Customer Equitability – Does the measure provide water use efficiency services to all customers and demographics (low income accessible)?

Saturation – Is there a need for the measure based on how many customers have already adopted this measure (e.g., clothes washers are fairly saturated so this measure may not be selected)?

Staff Resources – Can existing staff run the measure? If not, would it take a lot of additional staff to run it? Or can existing staff plus other support run the measure?

Legislation – Does the measure provide a greater opportunity to achieve state requirements?

Service Area Match – Is the measure or related technology appropriate for the area's climate, building stock, or lifestyle?

Savings Quantifiable – Are the water savings quantifiable? For example, it is more difficult to determine the amount of water saved as a result of a water wise demonstration garden compared to replacing a grass playing field.

Customer Acceptance – Would customers within the service area be interested in and accepting of the conservation measure as well as willing to implement it? Can be gauged through public input from surveys/workshops.

Water Savings Potential – Does the measure have the potential to save a significant amount of water per account and the ability to confidently quantify savings?

Technology – Is the technology needed to implement the conservation measure, such as an irrigation control device, commercially available and supported by the local service Industry?

Market Influencer – Is the measure a new technology that can turn the whole market toward more efficient products?

Figure 5: Alameda County Water District efficiency measure screening criteria. This is the criteria that Alameda County Water District utilized to create their water efficiency goals ($ACWD_b$, 2021).

Using the above criteria, Alameda County Water District came up with three different strategies including the different selected waste efficiency measures to use to predict future demand. The three different strategies, Strategy A, B, and C, can be seen below in the figure:

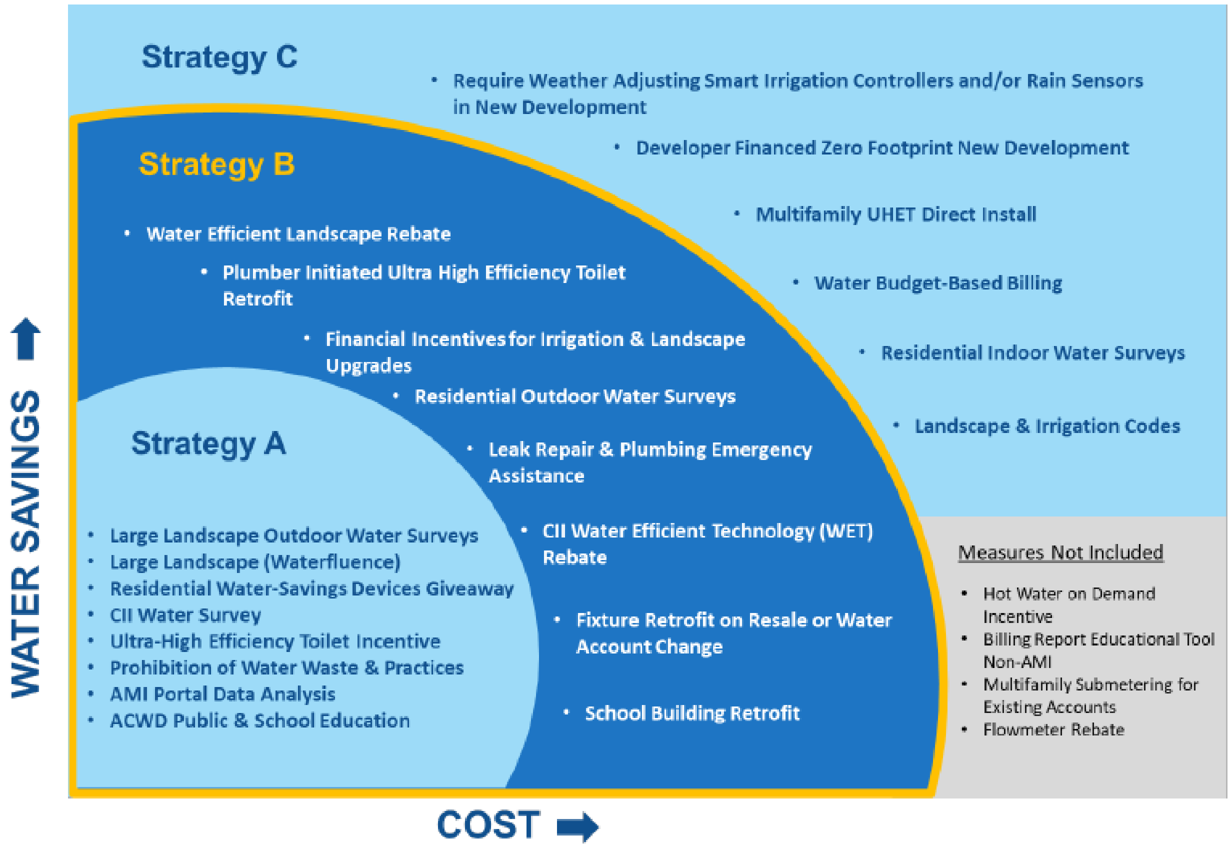


Figure 6: Alameda County Water District's water savings strategies. Strategy A, B, and C are three separate strategies that were created to predict water demand in the future. Strategy C is the most aggressive strategy in reducing water demand while Strategy A was the least aggressive. Ultimately, Alameda County Water District chose Strategy B (ACWD$_b$, 2021).

Using these three different strategies, Alameda County Water District then predicted future water demand which can be seen in the figure below:

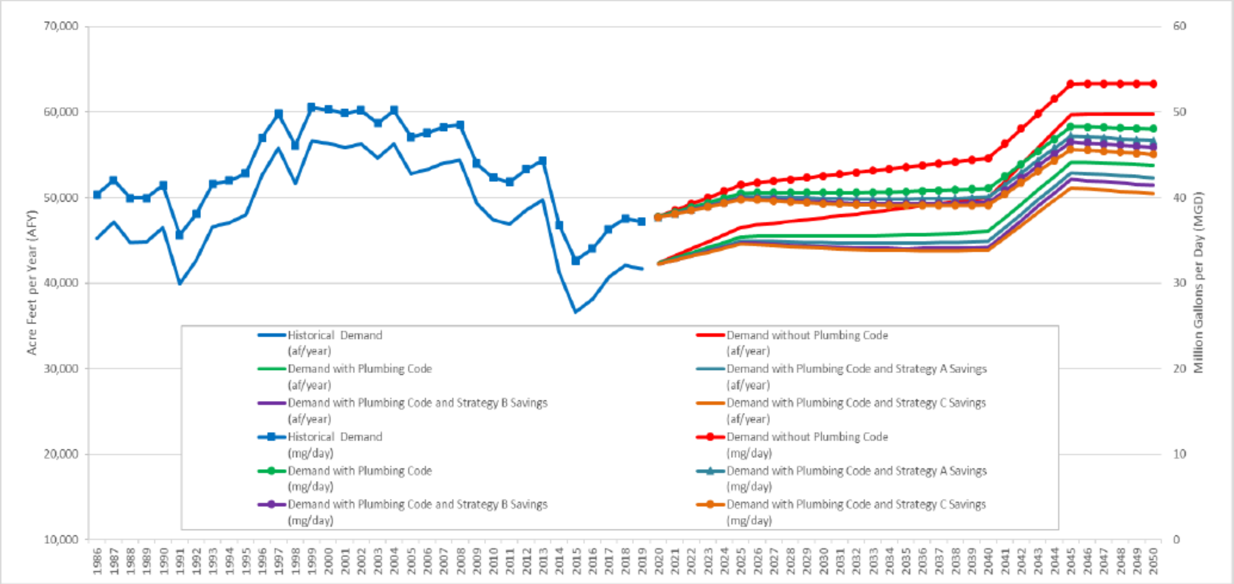


Figure 7: Alameda County Water District's projected water demand with plumbing code and water strategy savings. The blue solid line shows historic water demand in acre-feet per year, while the dashed line shows the same but in million gallons per day. The red solid line shows the projected demand if plumbing code efficiencies were not mandated in acre-feet per year, while the dashed red line shows the same but in million gallons per day. The green solid line shows the projected demand if plumbing code efficiencies were mandated in acre-feet per year, while the dashed green line shows the same but in million gallons per day. The solid purple line shows demand with Strategy B savings in acre-feet per year, while the dashed purple line shows demand in million gallons per day. Similarly, the orange line shows Strategy C savings and the teal line shows Strategy A savings (ACWD$_b$, 2021).

Alameda County Water District selected Strategy B to predict their short term (through 2025) and long term (through 2050) demands because it is the most cost efficient option while still achieving the county's water saving goals (ACWD$_b$, 2021). It can be seen in the figure that Strategy B forecasts demand around 45 million gallons per day (~51,000 acre feet per year). Understanding the water demand is important to understand if there will be enough water supply in the future.

Water Supply

Alameda County Water District currently supplies its water from three main sources: 1) the State Water Project, which receives its supply from northern Sierra runoff, 2) San Francisco Public Utilities Commission, which receives its supply from central Sierra runoff, and 3) local supplies, which receive its water from local watershed runoff and groundwater storage (ACWD, 2014). Water supply sources, storage, and conveyances can be seen more clearly in the below figure:

Figure 8: Alameda County Water District's water supplies. Alameda County Water District sources its water mainly from three sources; 1) the State Water Project (SWP), 2) San Francisco Public Utilities Commission (SFPUC), and 3) local supplies including local rainfall and groundwater. The SWP's water source is northern sierra runoff and the SFPUC's water source is central sierra runoff. Each box above provides the source, where the water is stored before delivery to Alameda County Water District, the conveyance method to Alameda County Water District and the how the water is used by Alameda County Water District.(ACWD, 2014)

There are many factors which determine the reliability of the water supplies discussed above. Regulatory and contractual agreements play a role in supplying water to Alameda County

Water District from both the State Water Project and San Francisco Public Utilities Commission which provide 40% and 20%, respectively, of the county's water supply (ACWD, 2020). The State Water Project supply availability depends on the hydrologic conditions which can reduce Alameda County Water District's supply up to 50% in multiple dry-year periods (ACWD, 2020). The supply from San Francisco Public Utilities Commission also can depend on the hydrologic conditions and can be reduced to the wholesale customers (i.e., Alameda County Water District) in a declaration of a water shortage emergency (ACWD, 2020). Hydrologic conditions are also a factor in determining local water supply availability, as well as climate change (specifically drought and saltwater intrusion) (ACWD, 2020). In California, drought severity and intensity has increased in the past 20 years as seen in the figure below:

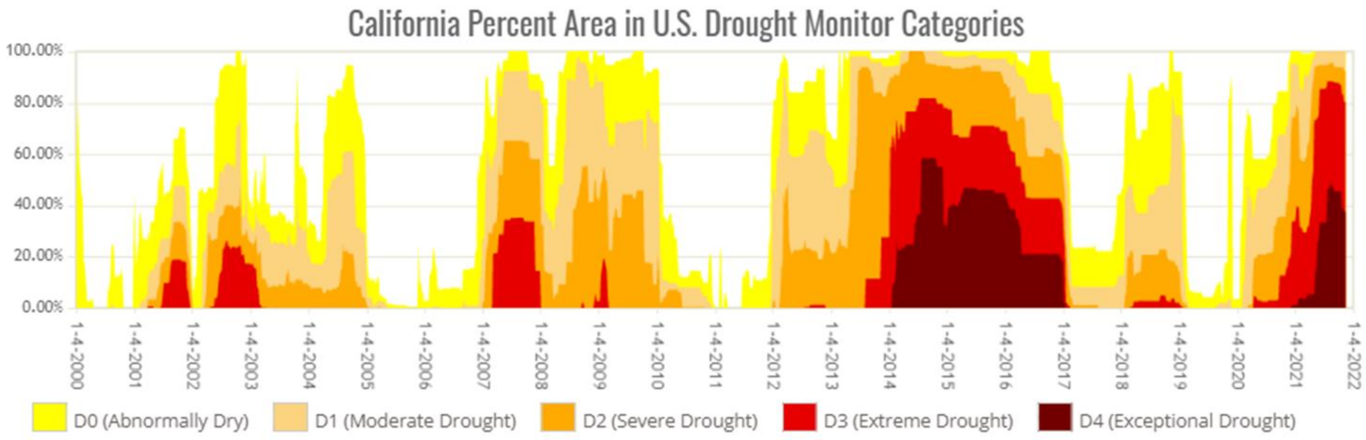


Figure 9: Historic and predicted drought conditions in California by percentage of area. Deeper red areas show more severe drought while yellow areas show lesser sever drought. (U.S. Drought Monitor, 2021)

Groundwater availability is dependent upon local runoff from the Alameda Creek Watershed (ACWD, 2020). The availability can also be affected by sea level rise, causing the saltwater from the ocean to intrude into groundwater. Alameda County Water District has the capability to treat saltwater at the Newark Desalination Facility, which has the capability to treat 10 million gallons per day, but low groundwater levels and saltwater intrusion can have a deleterious effect to the desalination process (ACWD, 2020).

Comparing Water Supply and Demand

With the existing supplies under the current operating and hydrologic conditions, Alameda County Water District is able to meet the current water demand. Using the demand projections as earlier discussed, Alameda County Water District can compare demand to projected future supply. Even though demand is predicted to increase while supply remains the same, water supply is sufficient to meet water demand through 2045 and also have some excess water supply (ACWD, 2020). In 2020, it was predicted for the district to have 9,500 acre-feet excess water supply which allows Alameda County Water District to bank this excess in local groundwater storage for use later on in more dry years (ACWD, 2020). The excess supply reduces to 600 acre-feet by 2045. However, Alameda County Water District also predicts water supply versus demand in a single dry year as well as multiple dry years.

To predict water supply in drought conditions, the district assumed the same hydrologic conditions as the most severe single year drought that California has experienced, which occurred in 1977 (ACWD, 2020). Using this scenario, Alameda County Water District estimates that there would be a water supply shortage of up to 18% in 2045 (ACWD, 2020). Alameda County Water District furthers this analysis to predict water supply under multiple dry year conditions, modeling the same conditions that occurred during the 1988-1992 multiple year drought. It was determined that the District would see interim year shortages of up to 16% due to demand rebound effects and future demand growth (ACWD, 2020). In these conditions, supply is able to meet demand through 2040-2045, (ACWD, 2020). However, from 2041-2045, a shortage of up to 16% can be predicted (ACWD, 2020). These projected water supplies and demand comparisons can be seen in the below tables:

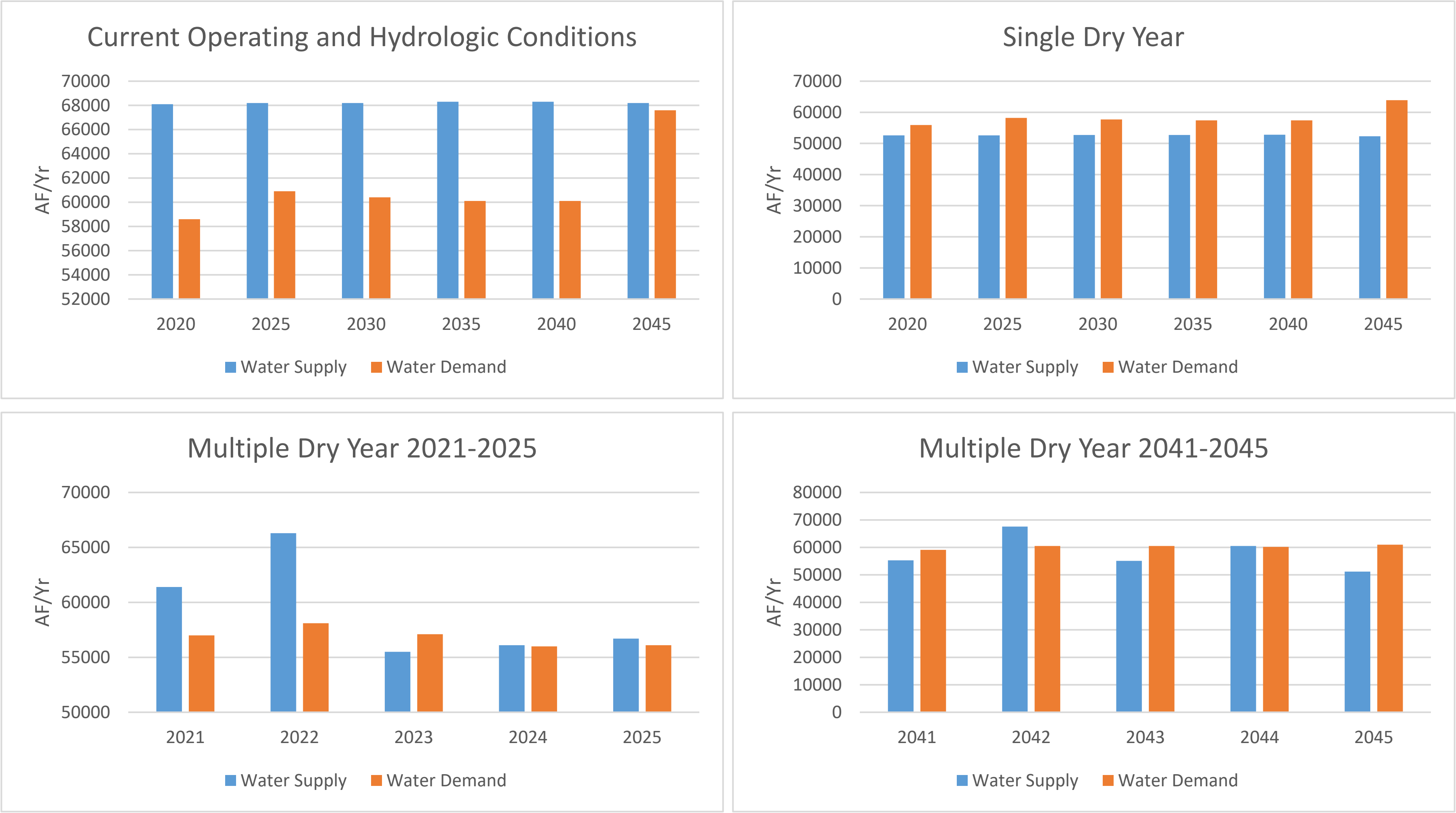


Figure 10: Alameda County Water District predicted water supply vs. demand in various hydrological conditions. Water supply is represented by the blue bars while demand is represented by the orange bars. These values were provided by Alameda County Water District, but graphed to more easily see the difference in supply and demand. For the single dry year panel, supply values were predicted by using the worst drought on record in 1977. For the multiple dry year panels, supply values were predicted by using the worst multi-year drought conditions from 1988-1992. Using these scenarios, Alameda County Water District predicted water supply to compare to predicted water demand.

Due to these expected shortages, Alameda County Water District has plans in place to mitigate water shortages in the future.

Alameda County Water District's Water Shortage Contingency Plan

To mitigate water shortages, Alameda County Water District has developed a Water Shortage Contingency Plan. In addition to preparing for hydrologic conditions like drought, the Water Shortage Contingency Plan also prepares for catastrophic interruptions like a large magnitude earthquake or water quality impacts that have the capability to impact water supply (ACWD, 2020). Alameda County Water District will take actions to protect its local groundwater supplies and attempt to maximize imported water to rely less on local groundwater, but this would not be enough to mitigate the shortages (ACWD, 2020). Alameda County Water District's Water Shortage Contingency Plan includes demand restrictions at different shortage levels based on water supply and groundwater levels, as required by the California Water Code (ACWD, 2020). The stage levels (1-6; 1 being moderate restrictions while 6 is more severe restrictions) are defined by the groundwater elevation above mean sea level and is illustrated in the figure below:

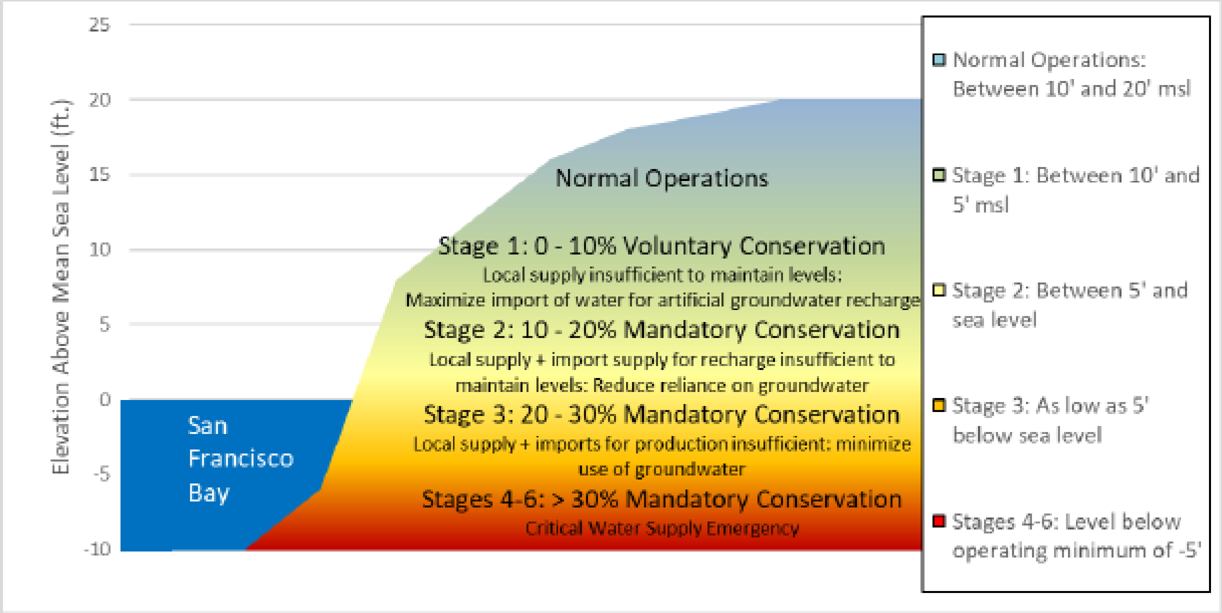


Figure 11 Alameda County Water District's water conservation stages by elevation above mean sea level (msl). Each stage (1-6) is defined by the elevation above mean sea level and determines what percentage of conservation is going to be mandated (ACWD, 2020).

Each stage level defines what actions Alameda County Water District will take, mandates their customers (including residential, business, industrial, city and school customer groups) will be required to take, in addition to the enforcement actions that Alameda County Water District would implement.

Water supply priority is first given to public health and safety needs in Alameda County Water District, so reductions would come from outdoor use, residential indoor use, and commercial indoor use in that order (ACWD, 2020). As earlier mentioned, drought years can cause a water supply shortage of up to 18%. A water supply shortage of 18% would put Alameda County Water District in the Stage 2 water shortage contingency plan of a moderate shortage. For industrial users, this would require them to take measures to identify water efficiency opportunities including potential water reuse in addition to improving industrial processes (ACWD, 2020). The Stage 2 plan would also require industrial users to comply with any water reduction ordinances, including a budget for landscape watering (ACWD, 2020). Therefore, it is possible that some aspects of water reuse is mandatory for industrial users in the future. Although Alameda County Water District anticipates water shortages of up to 18% due to drought, greater water shortages can be anticipated due to catastrophic conditions, e.g. an earthquake (ACWD, 2020).

The service area for Alameda County Water District and Union Sanitary District is located in the middle of the Hayward Fault and is nearby to the Calaveras and San Andreas faults (ACWD, 2020). Alameda County Water District reports that there is a 31% chance of a 6.7 magnitude earthquake along the Hayward Fault in the next 30 years. However, the United States Geological Survey (USGS) reports that in the San Francisco Bay Area there is a 72% chance of a 6.7 magnitude earthquake, a 51% chance of a 7 magnitude earthquake, and a 20% chance of a 7.5 magnitude earthquake within the next 30 years. These fault lines in relation to the service area can be seen more clearly in the figure below:

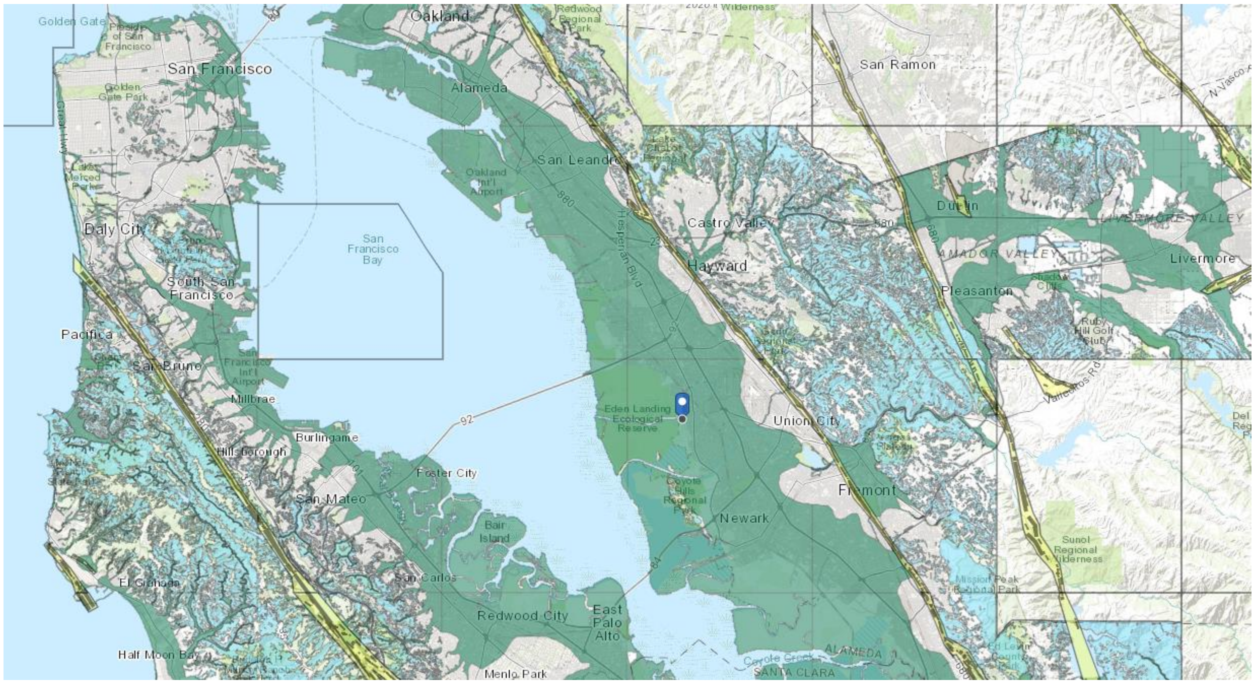


Figure 12: Map of the Bay Area showing fault and liquefaction zones. The green shaded areas are liquefaction zones and the yellow shaded areas are fault zones. The blue blip is where Union Sanitary District's wastewater treatment plant is located. The teal shaded areas are landslide zones (USGS, 2021).

In addition to being located in the middle of the Hayward Fault and near other fault lines, the service area is predominantly located in a liquefaction zone. Liquefaction is the term used to describe how the ground behaves during an earthquake. The ground would act like liquid during an earthquake which has the potential to cause building collapse (USGS, 2021).

Both Alameda County Water District and Union Sanitary District are taking measures to lower the risk of service interruption (ACWD, 2020; USD_a 2019). Alameda County Water District takes preventative actions including maintaining: partnerships to supply water in the event of an emergency, water supplies on both sides of the Hayward Fault, seismic retrofits of valves, equipment, and piping; emergency generators sufficient to meet 75% of the average water production in case of a power outage, amongst others (ACWD, 2020). Union Sanitary District is currently implementing their Enhanced Treatment and Site Upgrade (ETSU) Program which includes retrofitting existing infrastructure and strengthening bracing (USD_a, 2019). Although Alameda County Water District and Union District are preparing for the possibility of service interruption due to an earthquake, there is no way of fully predicting the damage that can result; therefore the possibility of major water shortages still exist.

Water shortages of up to 50% or greater due to catastrophic events would have additional implications for industrial water users. These additional required measures would include conducting an internal water audit to assess inefficiencies and opportunities for water reuse, no landscape watering, monitoring water usage for spikes to avoid fines, amongst others (ACWD, 2020). The worst-case scenario for water shortages of greater than 50% would mean that the use of water would be restricted to essential health and safety reasons only (ACWD, 2020). This could mean that if an industry is considered non-essential to health and safety, they could be without any water (ACWD, 2020). Because the San Francisco Bay Area is in an earthquake-prone area, it is not unlikely that these kind of shortages could occur and it would benefit industrial water users to prepare for this.

Treatment of Industrial Wastewaters

Federal & Local Regulatory Background

In 1972, the Federal Water Pollution Control Act, also known as the Clean Water Act, was passed to protect the nation's navigable waters from pollutants (EPA, 2011). The term "pollutant" is a vague term that is used to cover most discarded material including industrial waste. Specifically, the Clean Water Act defines pollutant as a "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water," (EPA, 2011). The Clean Water Act established the National Pollutant Discharge Elimination System (NPDES) to regulate dischargers who discharge directly into water sources, called point source discharges, and also to regulate dischargers who discharge to a publicly owned treatment works (POTWs), called an indirect discharge (EPA, 2011). For the purposes of this paper, the regulations surrounding indirect discharges will be discussed further in depth.

Most publicly owned treatment works are not designed to be able to effectively treat the pollutants that are found in industrial wastewaters, but are designed to treat domestic sewage (EPA, 2011). Therefore, if discharged to a publicly owned treatment works, wastewaters generated from industrial users have the potential to bypass the publicly owned treatment works and end up in receiving rivers, streams, or lakes. To prevent this, the National Pretreatment Program was created as part of the National Pollutant Discharge Elimination System (EPA, 2011).

Through the National Pretreatment Program, publicly owned treatment works take on the responsibility of regulating industrial and commercial users by enforcing the national pretreatment standards, as well as any local standards that are necessary to prevent site-specific pollution (EPA, 2011). The publicly owned treatment works that this paper will focus on is Union Sanitary District. To enforce compliance, the publicly owned treatment works establishes permit limits for industrial and commercial users based off general prohibitions, categorical standards (i.e., industry specific standards) or more general local limits (EPA, 2011).

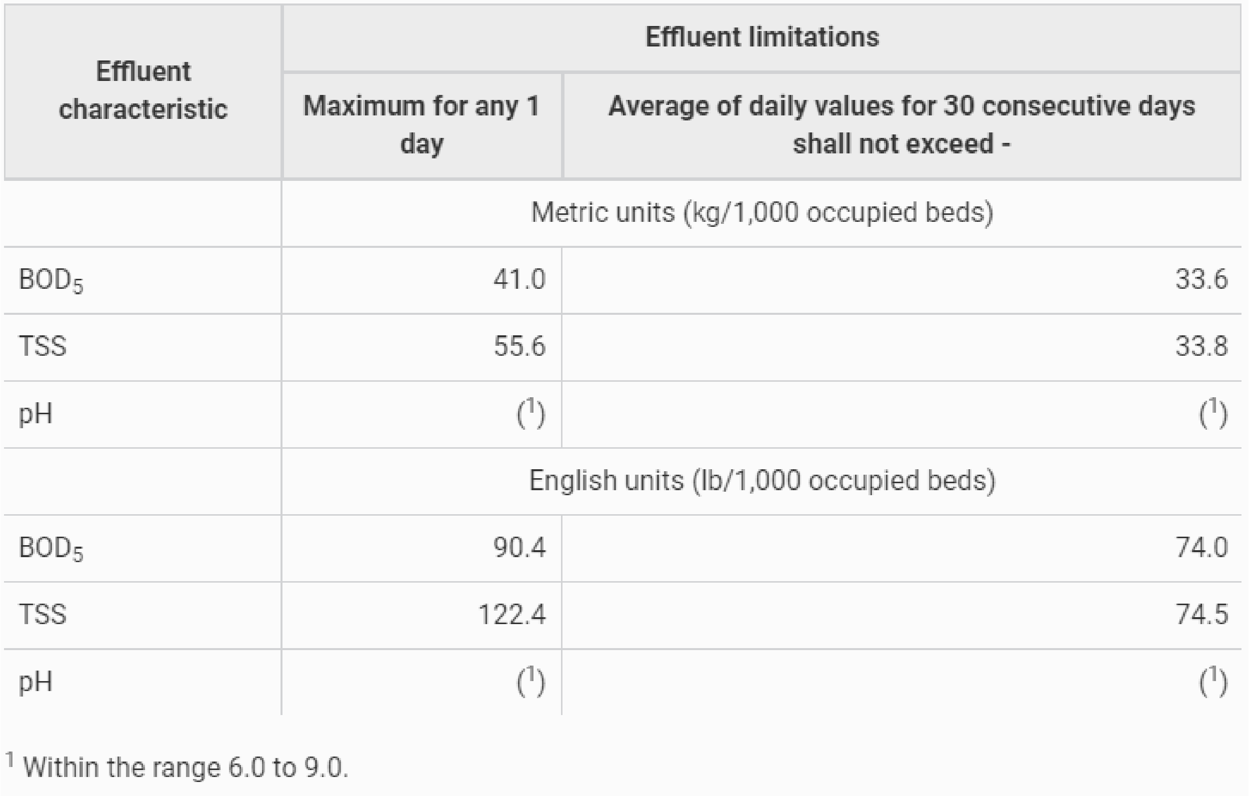
The categorical standards are federal standards that set forth different effluent limits dependent on the type of industry (EPA, 2011). A few common examples of industrial categories that are federally regulated have been retyped and are found in table 2 below:

Table 2: Common examples of 40 Code of Federal Regulations industry categories that have categorical standards. Industries that fall under categorical standards have specific wastewater effluent guidelines that they need to comply with (USD, 2016).

Industry Category	40 CFR Part	First Promulgated
Battery Manufacturing	461	1984
Cement Manufacturing	411	1974
Dairy Products Processing	405	1974
Electrical and Electronic Components	469	1983
Electroplating	413	1981
Fertilizer Manufacturing	418	1974
Glass Manufacturing	426	1974
Hospitals	460	1976
Iron and Steel Manufacturing	420	1982
Petroleum Refining	419	1982
Pharmaceutical Manufacturing	439	1983

To provide an example, hospitals are an industry that have categorical standards (Federal Water Pollution Control Act, 1976). The specific effluent limits that they have to comply with are biochemical oxygen demand, total suspended solids, and pH based, dependent on the number of occupied beds (Federal Water Pollution Control Act, 1976). This is shown in the table below:

Table 3: Categorical pretreatment standards for hospitals. These are the effluent limitations that hospitals need to comply with in addition to the local limits and general prohibitions (Federal Water Pollution Control Act, 1976).



Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed -
	Metric units (kg/1,000 occupied beds)	
BOD$_5$	41.0	33.6
TSS	55.6	33.8
pH	(1)	(1)
	English units (lb/1,000 occupied beds)	
BOD$_5$	90.4	74.0
TSS	122.4	74.5
pH	(1)	(1)

[1] Within the range 6.0 to 9.0.

In addition to these specific industry categorical standards, industrial users would generally need to comply with the local limits and general prohibitions as well.

General prohibitions are general limitations to prevent pollutants from bypassing the publicly owned treatment works and entering into waterways. Another goal is to physically protect the treatment plant as well, e.g. from a fire or explosion (EPA, 2011). These clauses prohibit generalized pollutants from entering the wastewater treatment plant. The general prohibitions are summarized by Union Sanitary District and have been copied below:

- Pollutants that create a fire or explosion hazard;
- Pollutants that cause corrosive structural damage to the sewer system;
- Solid or viscous pollutants in amounts that obstruct flow;
- Any pollutant, including biological oxygen demanding pollutants (BOD), in quantities or concentrations that interfere with treatment plant processes;

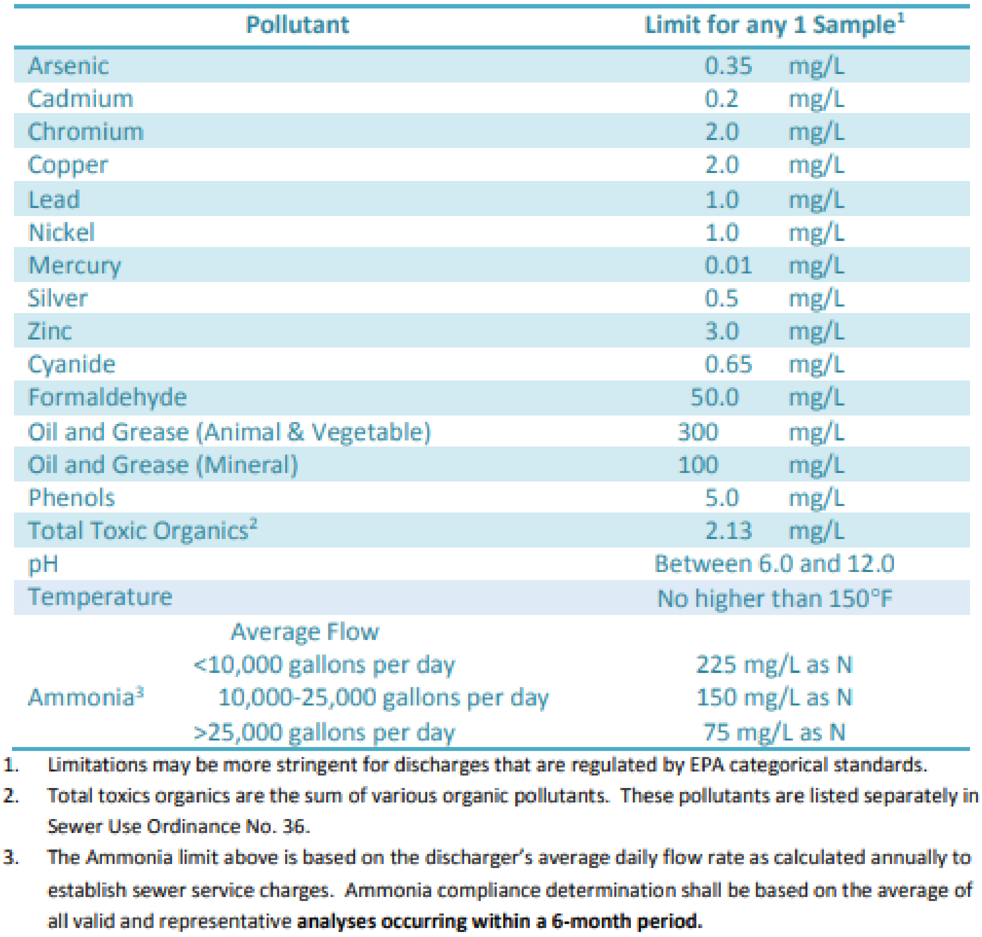
- Wastes that cause the temperature at the treatment plant headworks to exceed 104°F;
- Petroleum oil, non-biodegradable cutting oil, or products or mineral origin in amounts that pass through or interfere with the treatment plant processes;
- Wastes which contain or result in the production of toxic, corrosive, explosive or malodorous gases (which may create worker health and safety problems);
- Trucked or hauled wastes, except at discharge points designated by the District.

(USD, 2016)

All industrial users must comply with the general prohibitions as well as the local limits set by the publicly owned treatment works, Union Sanitary District in this case.

Union Sanitary District has set local limits to protect the treatment plant and the specific receiving waters that it discharges treated wastewater to, namely Hayward Marsh and the San Francisco Bay (USD_b, 2020). The EPA recommends that local limits are based off of the maximum allowable headworks loading (MAHL) which should be calculated for each pollutant that the publicly owned treatment works is concerned of (EPA, 2004). It is up to Union Sanitary District to determine what pollutants are of concern, i.e., which pollutants have a potential to pass through or interfere with their treatment system. The local limits that Union Sanitary District has set can be seen in the table below:

Table 4: Union Sanitary District’s Local Discharge Limits. These limits are set by Union Sanitary District and are the effluent limits that each industrial discharger must meet when discharging their wastewater to Union Sanitary District (USD, 2016).



Pollutant		Limit for any 1 Sample[1]
Arsenic		0.35 mg/L
Cadmium		0.2 mg/L
Chromium		2.0 mg/L
Copper		2.0 mg/L
Lead		1.0 mg/L
Nickel		1.0 mg/L
Mercury		0.01 mg/L
Silver		0.5 mg/L
Zinc		3.0 mg/L
Cyanide		0.65 mg/L
Formaldehyde		50.0 mg/L
Oil and Grease (Animal & Vegetable)		300 mg/L
Oil and Grease (Mineral)		100 mg/L
Phenols		5.0 mg/L
Total Toxic Organics[2]		2.13 mg/L
pH		Between 6.0 and 12.0
Temperature		No higher than 150°F
	Average Flow	
Ammonia[3]	<10,000 gallons per day	225 mg/L as N
	10,000-25,000 gallons per day	150 mg/L as N
	>25,000 gallons per day	75 mg/L as N

1. Limitations may be more stringent for discharges that are regulated by EPA categorical standards.
2. Total toxics organics are the sum of various organic pollutants. These pollutants are listed separately in Sewer Use Ordinance No. 36.
3. The Ammonia limit above is based on the discharger’s average daily flow rate as calculated annually to establish sewer service charges. Ammonia compliance determination shall be based on the average of all valid and representative **analyses occurring within a 6-month period.**

Setting the local limits is an ongoing process that is periodically reevaluated by Union Sanitary District (USD, 2016). Understanding what each industrial discharger is allowed to discharge helps us to better understand what will be in their wastewater.

Union Sanitary District

As mentioned, industrial wastewater dischargers located in the Tri-City area are discharging their wastewater to Union Sanitary District located in Union City. The Tri-City area consists of Fremont, Newark, and Union City as mentioned earlier.

After industrial users discharge their wastewater to Union Sanitary District, the wastewater is transported to and treated at Union Sanitary District’s Alvarado Treatment Plant which provides secondary activated sludge treatment. Secondary treatment is the minimum requirement for municipal wastewater treatment (EPA, 2010). Secondary treatment involves the use of microorganisms to remove organics in the wastewater while primary treatment is intended to remove solids, like wipes and debris, and smaller sand-like material (EPA, 2011).

At Union Sanitary District, screens are used to filter out solids while the remainder of the wastewaters head to primary clarifiers, or settling tanks, where further solids removal can occur. From there, the wastewater is sent into an aeration basin where bacteria-filled sludge and air are used to break down organic matter into by-products (EPA, 1998). The activated sludge is used over again and returned to the aeration tank to treat new, incoming wastewater. The wastewater then heads to another secondary clarifier and then sent to be disinfected with sodium hypochlorite (USD_b, 2020). This process can be seen in more detail in Figure 13 below:

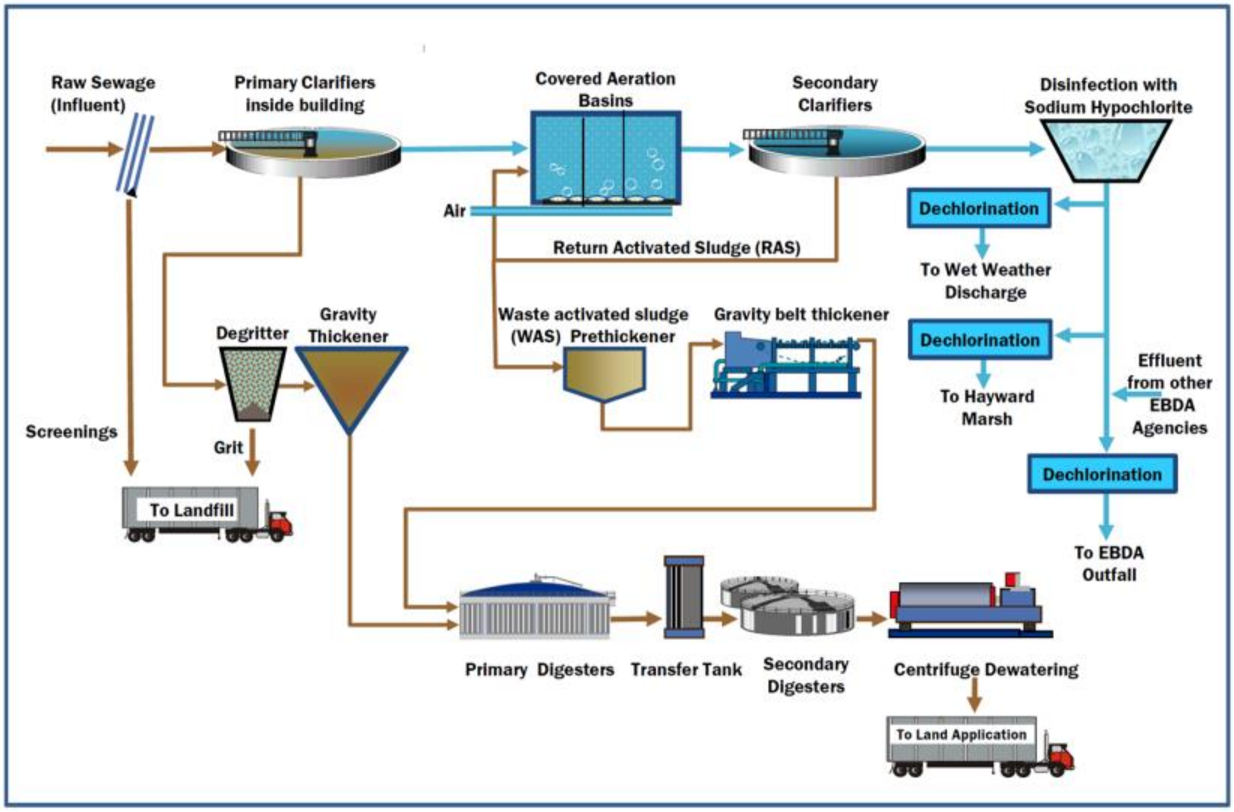


Figure 13: Alvarado Wastewater Treatment Plant Process at Union Sanitary District. Union Sanitary district provides secondary treatment. The flow diagram above shows step-by-step what happens to the raw wastewater that comes into their plant (influent) (USD_b, 2020).

Treated wastewater from Union Sanitary District is not reused. The treated wastewater is discharged through a series of pipelines and pump stations and eventually is discharged in either the Hayward Marsh, or the EBDA Common Outfall, 37,000 feet from shore in the San Francisco Bay (USD$_b$, 2020). The EBDA Common Outfall and Hayward Marsh can be seen in the figure below:

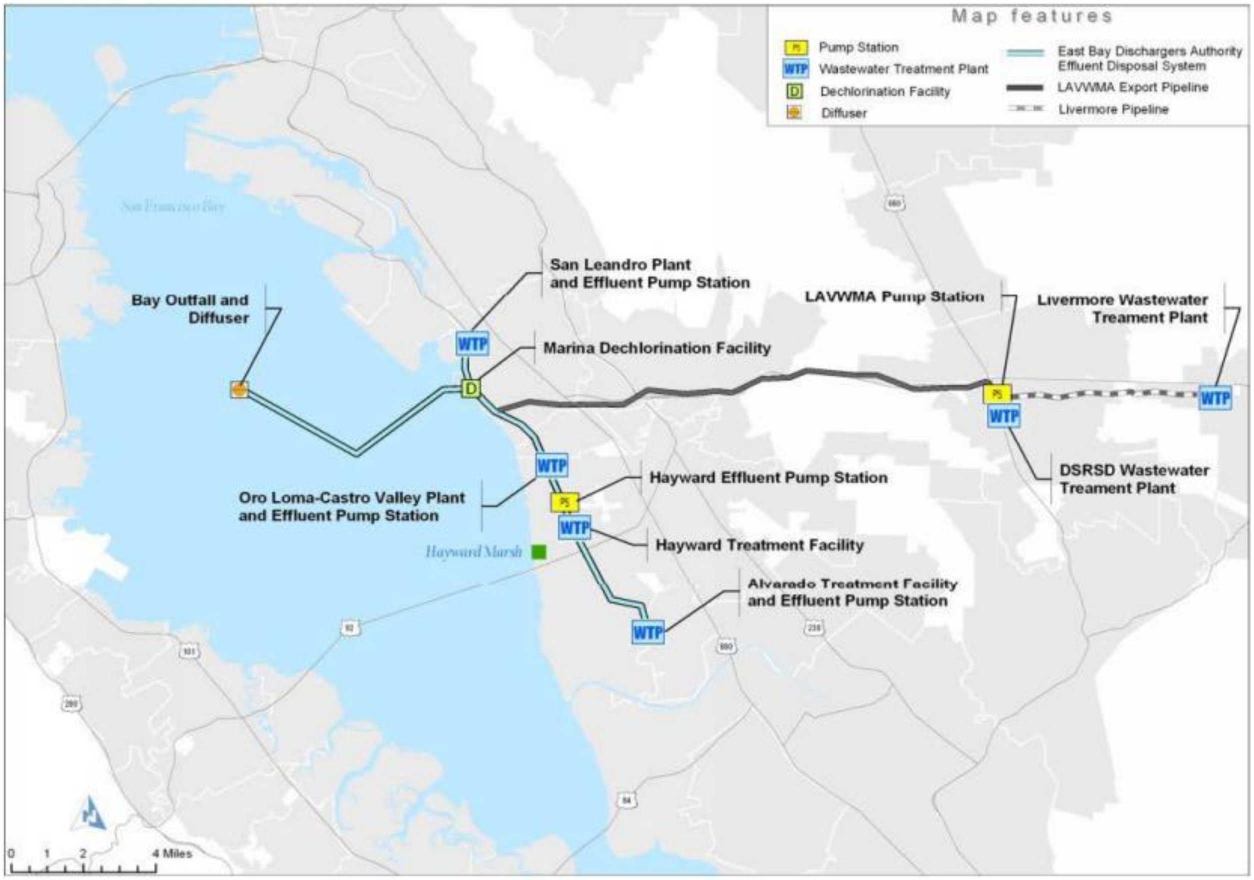


Figure 14: Map of the San Francisco Bay Area showing the EBDA Common Outfall (the Bay Outfall and Diffuser) and the Hayward Marsh. After wastewater has been treated at the Alvarado Treatment Facility by Union Sanitary District, wastewater travels through a series of piping and pump stations to the Hayward Marsh and/or the San Francisco Bay via the Bay Outfall and Diffuser (EBDA, 2015).

In 2020, Union Sanitary District treated 23.16 million gallons of wastewater per day on average (USD, 2021). In comparison, this discharge quantity is the greatest discharge quantities compared to the other member agencies that discharge their wastewater through the EBDA Common Outfall. San Leandro discharges 4 MGD, Livermore discharges 17.5 MGD, Oro Loma discharges 12.6 MGD, and Hayward discharges 12.2 MGD (EBDA, 2015). The top ten industrial dischargers accounted for approximately 1.3 million gallons of the average daily flow in 2020, accounting for approximately 5.6% of the daily average (USD, 2021). Out of the 118,973 sewer connections, only 1,344 are industrial connections (approximately 1.1% of the connections) with the majority of the remaining connections being domestic/residential (115,857) and commercial (1,772) (USD,2021). This data shows that individually, the top 10 industrial dischargers produce large amounts of wastewater on a daily basis compared to residential and commercial users.

Industrial Wastewaters Discharged to Union Sanitary District

The type of industrial wastewater that Union Sanitary District receives can vary between the industrial users in the region. Although Industrial dischargers are subject to local and national pretreatment standards, the industrial wastewater discharged can still contain pollutants at trace quantities, below the local limits as earlier mentioned in the background section (i.e., metals, oil and grease, phenols, cyanide, etc.). In addition to these pollutants, industrial wastewaters also contain high organic matter, as measured in chemical oxygen demand (COD), and suspended solids (SS). Industrial dischargers may be required to collect samples at their effluents periodically to demonstrate compliance with local limits and limits set in their wastewater permits (USD_c).

Sampling results were provided by Union Sanitary District for the top ten industrial dischargers by wastewater quantity, for Q3 2020 through Q2 2021 (July 2020 through May 2021). The industrial dischargers for which sampling data was received for are; 1) Tesla, 2) Western Digital B1, 3) Western digital B2, 4) United States Pipe & Foundry, 5) Lam Research, 6) Washington Hospital, 7) Kaiser Permanente Hospital Fremont, 8) Mission Linen Supply and 9) Thermo Fisher Scientific.

The samples taken for each industrial discharger were analyzed for the local limits pollutants listed in Table 1 above. Additionally, chemical oxygen demand (COD), suspended solids (SS), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and fluoride were analyzed (fluoride was only analyzed for Lam Research). Overall, all the industrial dischargers wastewater samples were under the local limits with a few exceptions. Kaiser Permanente Hospital Fremont exceeded the Oil and Grease (animal/vegetable source) limit with a sample of 610 mg/L (local limit is 300 mg/L). Mission Linen Supply also exceeded the Oil and Grease (petroleum source) limit twice with a sample of 180 mg/L and 250 mg/L (local limit is 100 mg/L). Fluoride samples were also taken for Lam Research. The highest result was 35 mg/L, the lowest was 1.5 mg/L and the average was 12.54 mg/L. Lam Research could possibly be regulated under the categorical standard for electric components, which includes a semiconductor subcategory. In these standards, the semiconductor industry has an effluent limitation of 32.0 mg/L for any one day. Therefore, Lam Research did exceed this.

Chemical oxygen demand and suspended solids are especially important parameters. Chemical oxygen demand is a measurement used to understand the amount of oxygen that has been consumed by organic material, expressed in mass of oxygen consumed over volume of solution (Hu and Grasso, 2005). Suspended solids are any particles that are suspended in the solution including sand, silt, organic debris, or other particulate matter (APHA, 1991). Union Sanitary District bases their sewer service and capacity charges based on the total annual flow of chemical oxygen demand and suspended solids loadings (USD, 2016). Chemical oxygen demand and suspended solids determine the pollutant strength of the wastewater and wastewater with high strength is more costly for Union Sanitary District to treat (USD_{a}, 2020). From the sampling results data, I calculated median and upper/lower extreme values using excel for chemical oxygen demand and suspended solids for each industrial discharger and are represented in figure 15 and 16 below.

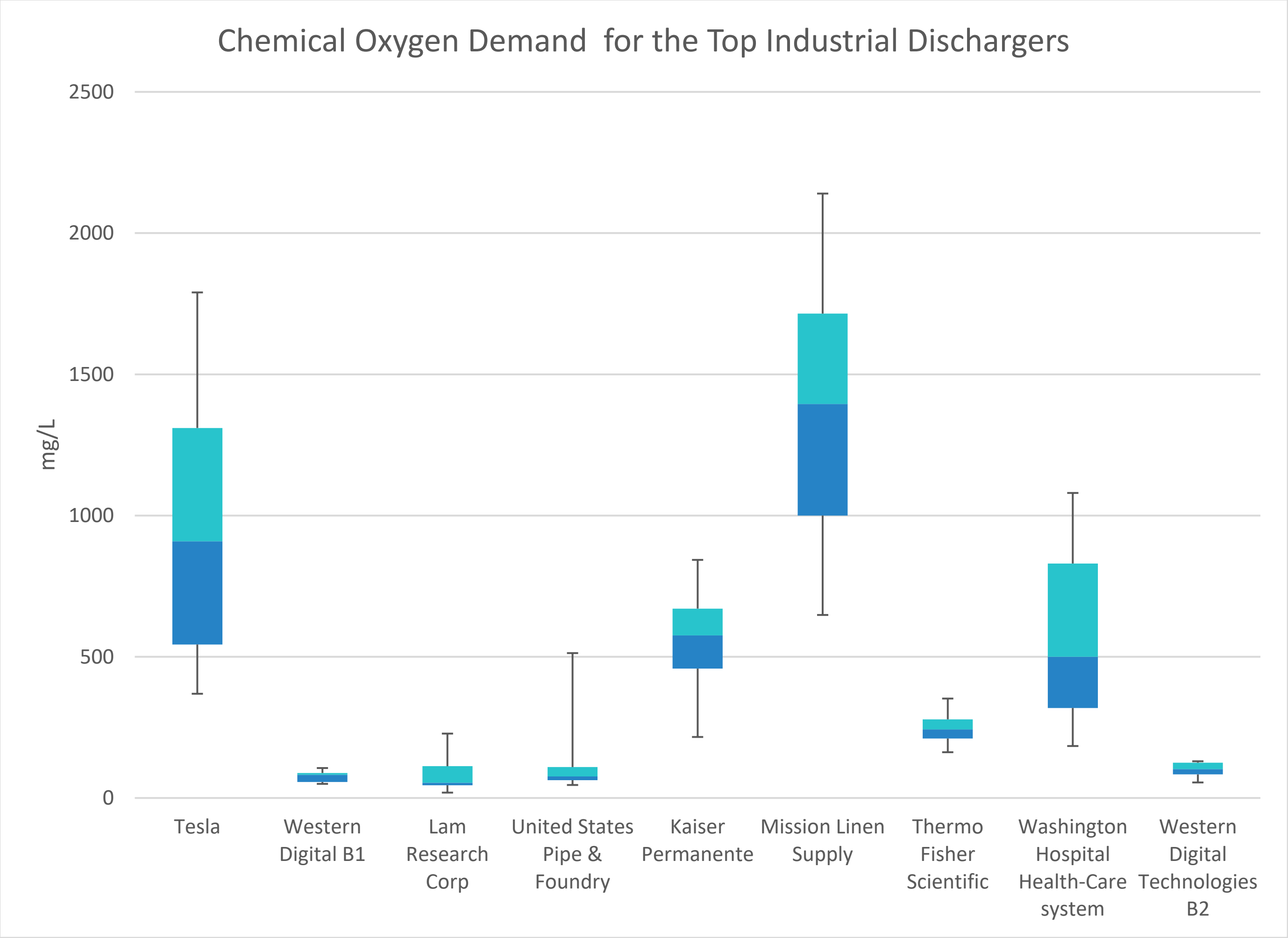


Figure 15: Median and upper/lower extremes for chemical oxygen demand (COD) for each top ten industrial discharger in Union Sanitary District. Blue boxes represent lower quartiles and teal represent upper quartiles. Whiskers represent upper and lower extremes. Data was provided by Union Sanitary District.

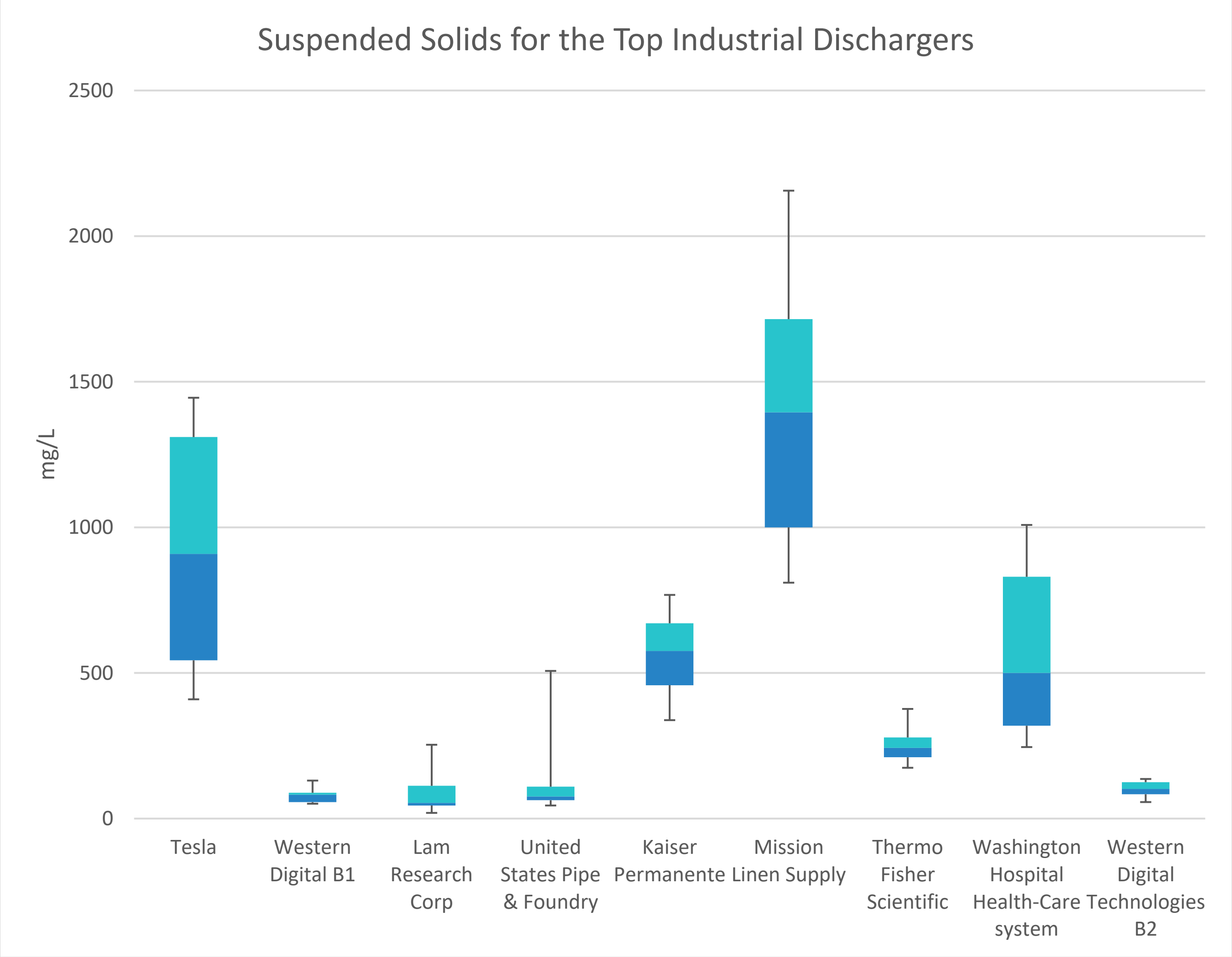


Figure 16: Median and upper/lower extremes for suspended solids (SS) for each top ten industrial discharger in Union Sanitary District. Blue boxes represent lower quartiles and teal represent upper quartiles. Whiskers represent upper and lower extremes. Data was provided by Union Sanitary District.

For chemical oxygen demand, Mission Linen Supply had the largest median sample concentration with 1,395 mg/L and Lam Research had the lowest at 54 mg/L. From Figure 2 you can see that there is a wide range of chemical oxygen demand concentrations between industrial users. For suspended solids, Mission Linen Supply also had the largest median sample concentration with 534 mg/L and Western Digital B1 had the lowest at 21 mg/L. Suspended solids sample concentrations also have a wide range between industrial users as seen in Figure 3.

Using chemical oxygen demand and suspended solids, we can estimate which category of wastewater these industrial dischargers fall into, weak, moderate, or strong. Union Sanitary

District typically assigns these classifications based on the type of industry, wastewater volums, and the average chemical oxygen demand and suspended solids values (USD_a, 2020). Examples of the types of industries in each classification and the average chemical oxygen demand and suspended solids values have been compiled in a table below:

Table 5: Union Sanitary District wastewater strength classifications. Union Sanitary District uses wastewater volume and the average chemical oxygen demand and suspended solids values to determine wastewater strength for industrial dischargers who have an industrial discharge permit (USD_a,2020).

Classification	Average Chemical Oxygen Demand Value	Average Suspended Solids Value
Strong	1,999 mg/L	495 mg/L
Moderate	519 mg/L	220 mg/L
Weak	343 mg/L	186 mg/L

Using these classification parameters, we can see that the top ten industrial discharger’s wastewater strength in Union Sanitary District can vary from weak-strong, which can be seen more clearly in the figures below. This is an important factor to understand what kind of treatment technologies for reuse might be most efficient.

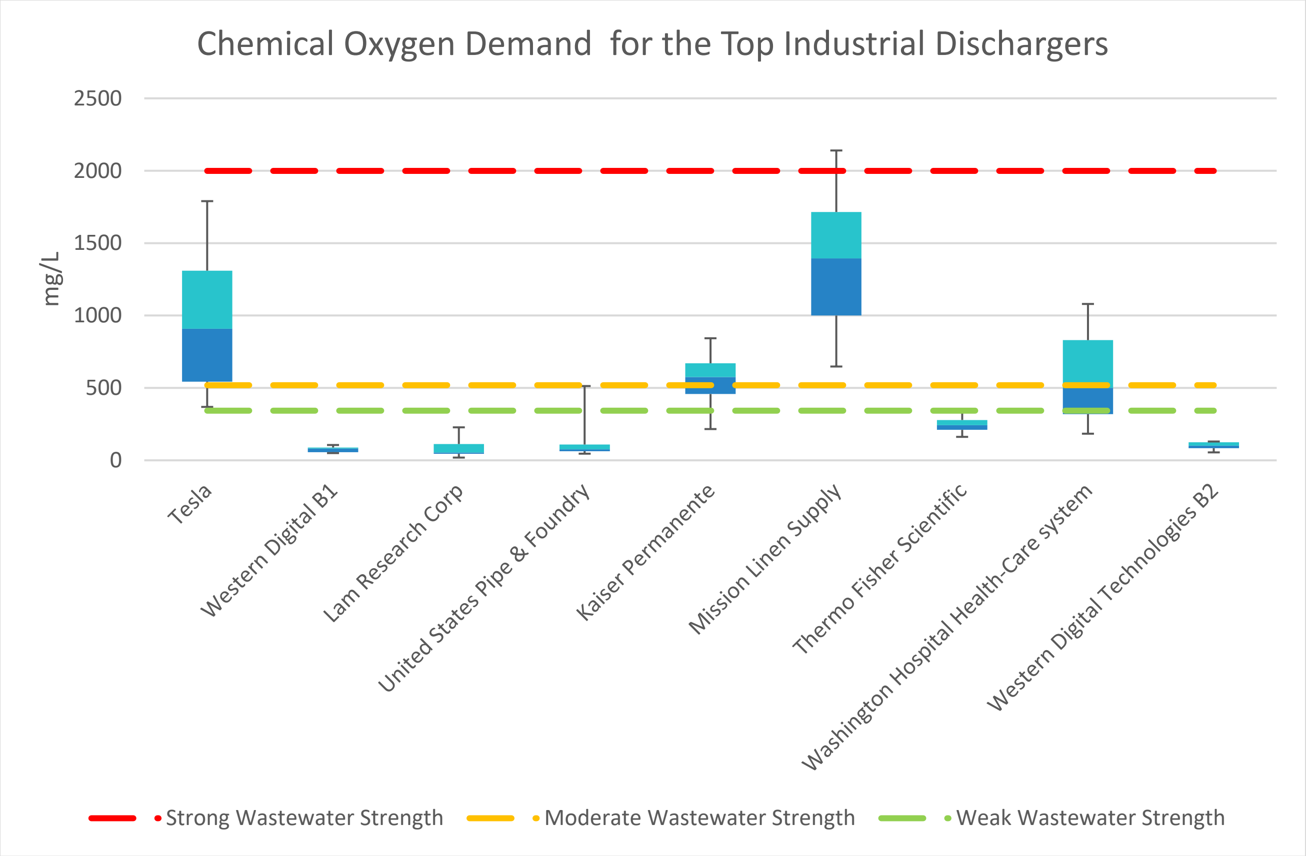


Figure 17: Chemical oxygen demand strength for the top industrial dischargers in the Tri-City area. Blue boxes represent lower quartiles and teal represent upper quartiles. Whiskers represent upper and lower extremes. The red dashed line shows the value that Union Sanitary District considers strong-strength wastewater, the yellow dashed line shows moderate-strength, and the green dashed line shows weak-strength. Data was provided by Union Sanitary District.

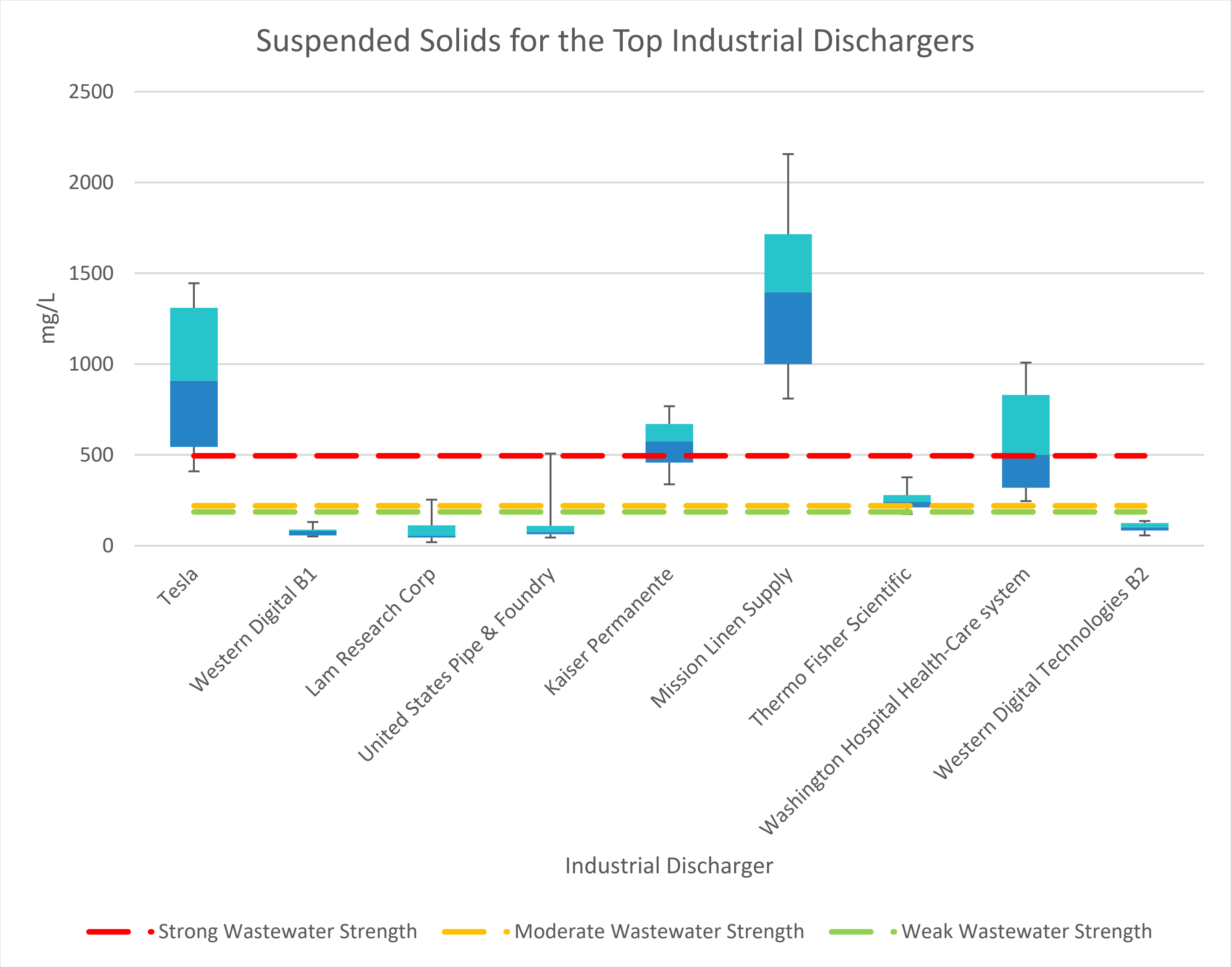


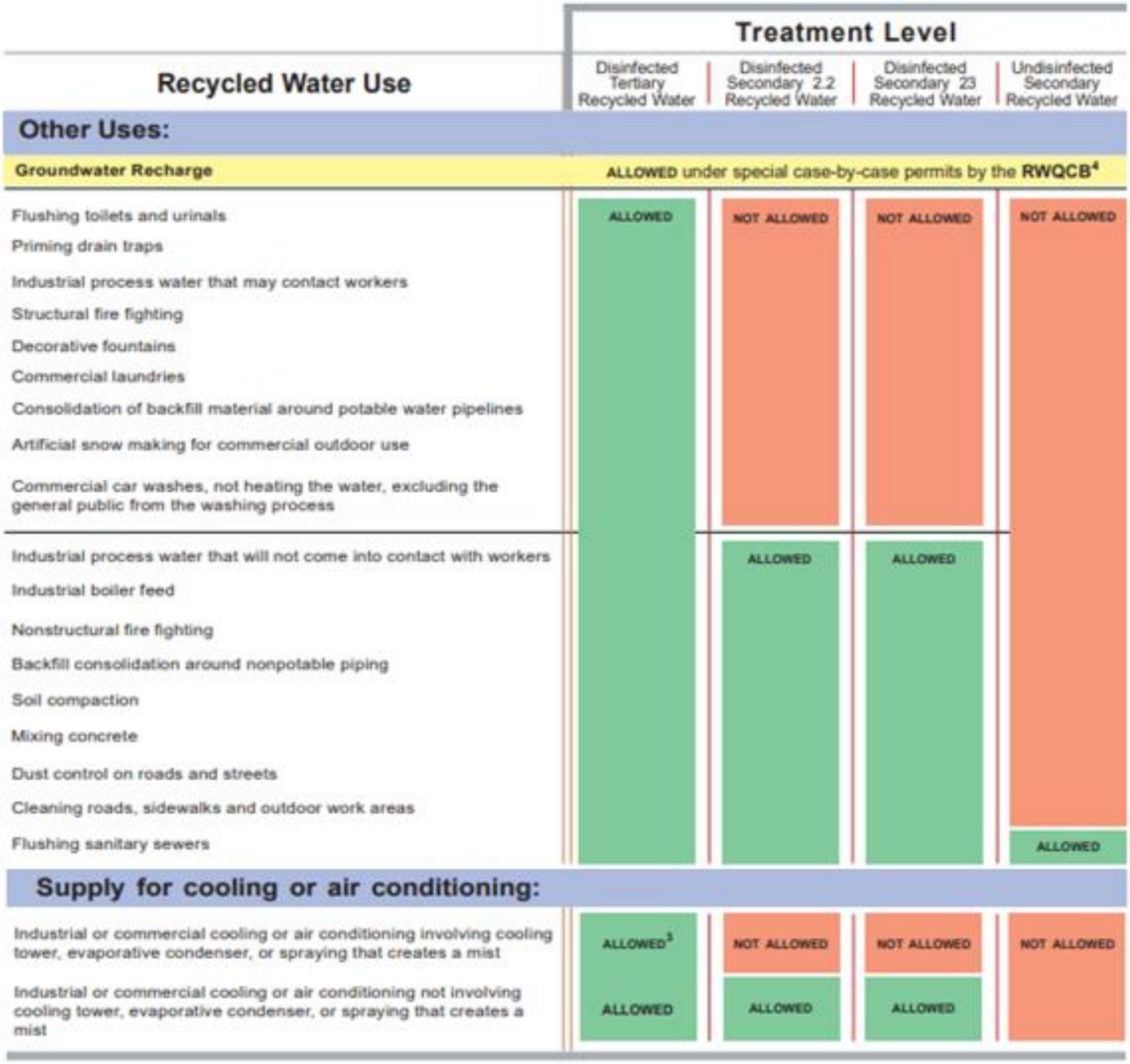
Figure 18: Suspended solids strength for the top industrial dischargers in the Tri-City area. Blue boxes represent lower quartiles and teal represent upper quartiles. Whiskers represent upper and lower extremes. The red dashed line shows the value that Union Sanitary District considers strong-strength wastewater, the yellow dashed line shows moderate-strength, and the green dashed line shows weak-strength. Data was provided by Union Sanitary District.

Although we have samples that show what kind of pollutants are in each industrial discharger's wastewater, it might not be inclusive of all the wastewaters produced at each site. To meet each industrial discharger's effluent limits, it is possible that they can be withholding wastewaters from being discharged to Union Sanitary District if the wastewater exceeded one of their permit parameters. For example, a wastewater from a certain process in an industrial discharger's manufacturing process might be high in metals and considered a hazardous waste. In this case, they would need to truck the wastewater off-site to a disposal facility who can accept hazardous wastes. Therefore, industrial discharger's wastewaters could have other pollutants in them and they also could have higher quantities of wastewater. However, as long as they meet California water reuse requirements, it might be still be possible to reuse these wastewaters.

Water Reuse Regulations in California

In California, water recycling and reuse for potable and non-potable use is governed by Title 22 of California Code of Regulations and is regulated by the State Water Resources Control Board. The State Water Resources Control Board recognizes that water recycling will be an important factor in conserving the state’s water supply in the future (SWRCB, 2021). Therefore, to protect environmental and public health, Title 22 of California Code of Regulations was established in 1978 (SWRCB, 2018). For purposes of this paper, water reuse for non-potable purposes will be discussed further in depth.

California regulates non-potable water reuse not by water quality standards, but by treatment level, although some water quality parameters are required which will be discussed, (e.g., disinfection standards) (SWRCB, 2018). In Article 3 of Title 22 of California Code of Regulations, specific treatment requirements are set for varying uses of recycled water. That is, the level of treatment required depends on what the recycled water is intended to be used for. There are four general categories in which Article 3 establishes required treatment levels for: 1) irrigation, 2) impoundments, 3) cooling, and 4) other purposes (SWRCB, 2018). These treatment requirements, specifically ones that industrial water users might need to adhere to, are summarized in figure 19 below:



Recycled Water Use	Treatment Level			
	Disinfected Tertiary Recycled Water	Disinfected Secondary 2.2 Recycled Water	Disinfected Secondary 23 Recycled Water	Undisinfected Secondary Recycled Water
Other Uses:				
Groundwater Recharge	**ALLOWED** under special case-by-case permits by the **RWQCB**[4]			
Flushing toilets and urinals	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Priming drain traps				
Industrial process water that may contact workers				
Structural fire fighting				
Decorative fountains				
Commercial laundries				
Consolidation of backfill material around potable water pipelines				
Artificial snow making for commercial outdoor use				
Commercial car washes, not heating the water, excluding the general public from the washing process				
Industrial process water that will not come into contact with workers		ALLOWED	ALLOWED	
Industrial boiler feed				
Nonstructural fire fighting				
Backfill consolidation around nonpotable piping				
Soil compaction				
Mixing concrete				
Dust control on roads and streets				
Cleaning roads, sidewalks and outdoor work areas				
Flushing sanitary sewers				ALLOWED
Supply for cooling or air conditioning:				
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED[3]	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Industrial or commercial cooling or air conditioning not involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED	ALLOWED	ALLOWED	

Figure 19: Required treatment level for various recycled water uses. This figure shows the required level of treatment (i.e., secondary vs. tertiary and disinfected vs. undisinfected) depending on what the water is planned to be reused for. This table is not inclusive of all recycled water uses and requirements, but rather is inclusive of uses that industrial water users might reuse water for, e.g., industrial processes or industrial cooling processes (WateReuse Association, 2000).

From the tables, it can be seen that disinfected tertiary is the highest level of treatment required for various uses while undisinfected secondary treatment is the lowest level of treatment required. In general, the level of treatment increases as the risk of coming into contact with people increases. For example, disinfected tertiary treatment is required for recycled water used for industrial processes where the water may come into contact with workers whereas only disinfected secondary treatment is required if the recycled water does not come into contact with workers. We do not know exactly what industrial water users might reuse the water for, but reusing water for industrial processes, industrial boiler feeds, industrial cooling towers and flushing toilets and urinals are possible uses. All of these uses require disinfected tertiary treatment. Therefore, for the purposes of this paper, disinfected tertiary will be the aimed level of treatment to broaden what the industrial recycled wastewater can be used for.

Title 22 of the California Code of Regulations goes further in defining what constitutes disinfected tertiary recycled water. As earlier mentioned, there are some water quality parameters that are required to be met. Section 60301.230 of Title 22 of the California Code of Regulations defines disinfected tertiary recycled water as a filtered and subsequently disinfected wastewater that meets certain disinfection criteria. This section goes on to require that disinfection is conducted by one of two different ways: 1) a chlorine disinfection process that provides a contact time value of not less than 450 milligram-minutes/L with a model contact time of at least 90 minutes, and 2) a type of disinfection method is not directly specified, but it requires that the disinfection process demonstrates that 99.999% of plaque-forming units (PFU) of F-specific bacteriophage MS2, or the polio virus, have been inactivated or removed (SWRCB, 2018). In addition to the method in which wastewater is disinfected, there are also some water quality parameters that must be met surrounding turbidity (i.e., water clarity) and total coliform (i.e., bacteria) (SWRCB, 2018). Table 6 below provides a summary of these water quality standards for water recycling.

Table 6: Water quality standards for recycling water in California. This table includes any water quality parameters that are required for each treatment level (Brown and Caldwell, 2011).

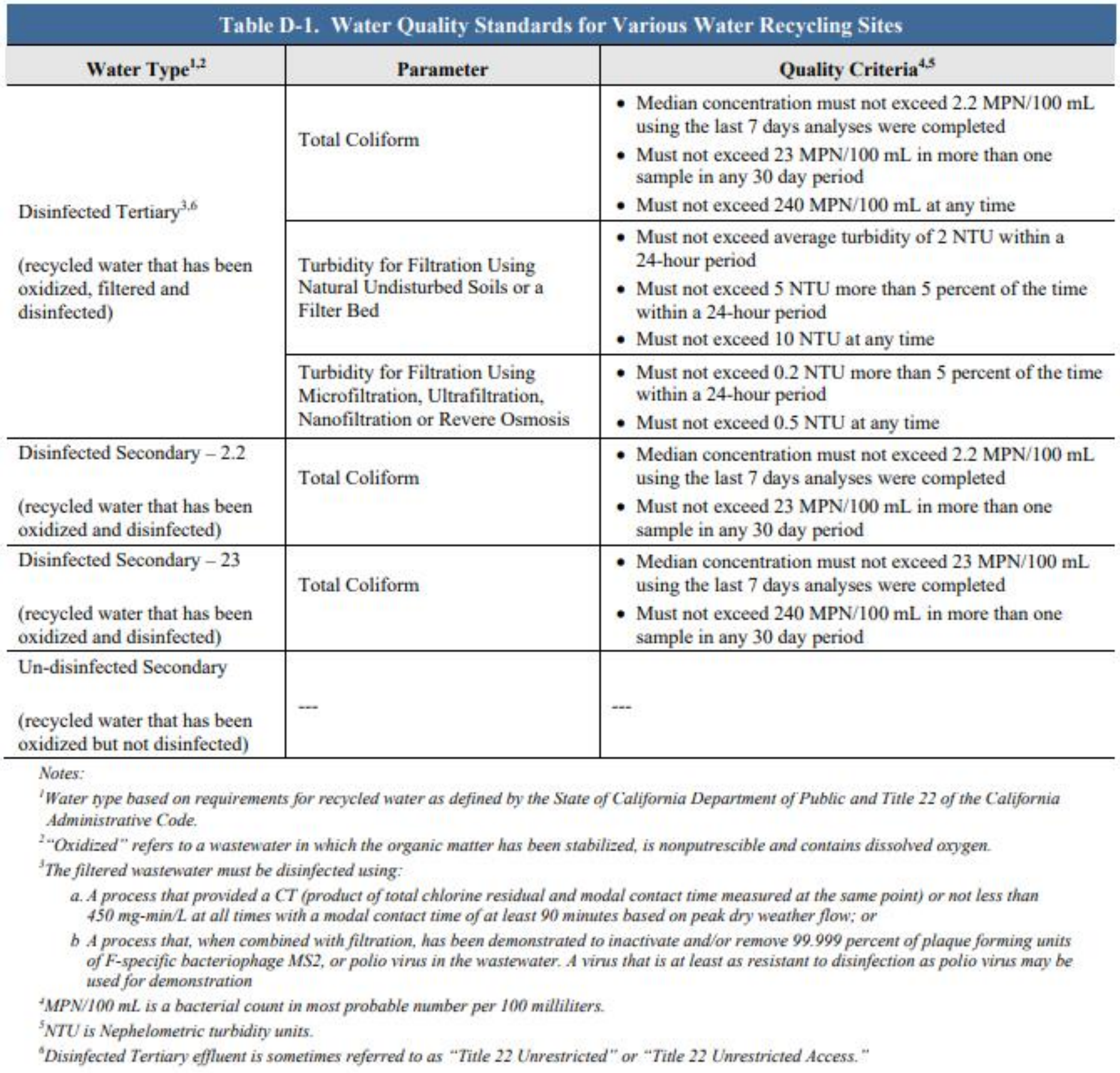


Table D-1. Water Quality Standards for Various Water Recycling Sites

Water Type[1,2]	Parameter	Quality Criteria[4,5]
Disinfected Tertiary[3,6] (recycled water that has been oxidized, filtered and disinfected)	Total Coliform	• Median concentration must not exceed 2.2 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 23 MPN/100 mL in more than one sample in any 30 day period • Must not exceed 240 MPN/100 mL at any time
	Turbidity for Filtration Using Natural Undisturbed Soils or a Filter Bed	• Must not exceed average turbidity of 2 NTU within a 24-hour period • Must not exceed 5 NTU more than 5 percent of the time within a 24-hour period • Must not exceed 10 NTU at any time
	Turbidity for Filtration Using Microfiltration, Ultrafiltration, Nanofiltration or Revere Osmosis	• Must not exceed 0.2 NTU more than 5 percent of the time within a 24-hour period • Must not exceed 0.5 NTU at any time
Disinfected Secondary – 2.2 (recycled water that has been oxidized and disinfected)	Total Coliform	• Median concentration must not exceed 2.2 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 23 MPN/100 mL in more than one sample in any 30 day period
Disinfected Secondary – 23 (recycled water that has been oxidized and disinfected)	Total Coliform	• Median concentration must not exceed 23 MPN/100 mL using the last 7 days analyses were completed • Must not exceed 240 MPN/100 mL in more than one sample in any 30 day period
Un-disinfected Secondary (recycled water that has been oxidized but not disinfected)	---	---

Notes:

[1] *Water type based on requirements for recycled water as defined by the State of California Department of Public and Title 22 of the California Administrative Code.*

[2] *"Oxidized" refers to a wastewater in which the organic matter has been stabilized, is nonputrescible and contains dissolved oxygen.*

[3] *The filtered wastewater must be disinfected using:*

- *a. A process that provided a CT (product of total chlorine residual and modal contact time measured at the same point) or not less than 450 mg-min/L at all times with a modal contact time of at least 90 minutes based on peak dry weather flow; or*
- *b A process that, when combined with filtration, has been demonstrated to inactivate and/or remove 99.999 percent of plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for demonstration*

[4] *MPN/100 mL is a bacterial count in most probable number per 100 milliliters.*

[5] *NTU is Nephelometric turbidity units.*

[6] *Disinfected Tertiary effluent is sometimes referred to as "Title 22 Unrestricted" or "Title 22 Unrestricted Access."*

Although these are the most current water reuse standards, regulations are subject to change as research becomes more available in the future.

In July 2019, California established the California WateReuse Action Plan developed by the California WateReuse Action Plan Committee. This action plan outlines the goals and initiatives California plans on taking to increase the use of recycled water in the state. Using recycled water in California is increasing and currently offsets 9% of the state's urban water demands (WateReuse Action Plan Committee, 2019). Future planning goals provide the purpose of increasing recycled water establish more reliable future water supplies. One of the goals outlined in the action plan addresses non-potable recycled water regulations. California plans to update the existing non-potable recycled water regulations and begin the public comment process by 2023 as these regulations are outdated and provide more burden than necessary to protect public health and the environment (WateReuse Action Plan Committee, 2019). The trend of wastewater reuse in California is that it is increasing due to the state's goals and initiatives. The increasing trend of water reuse and future projections can be seen in figure 20 below.

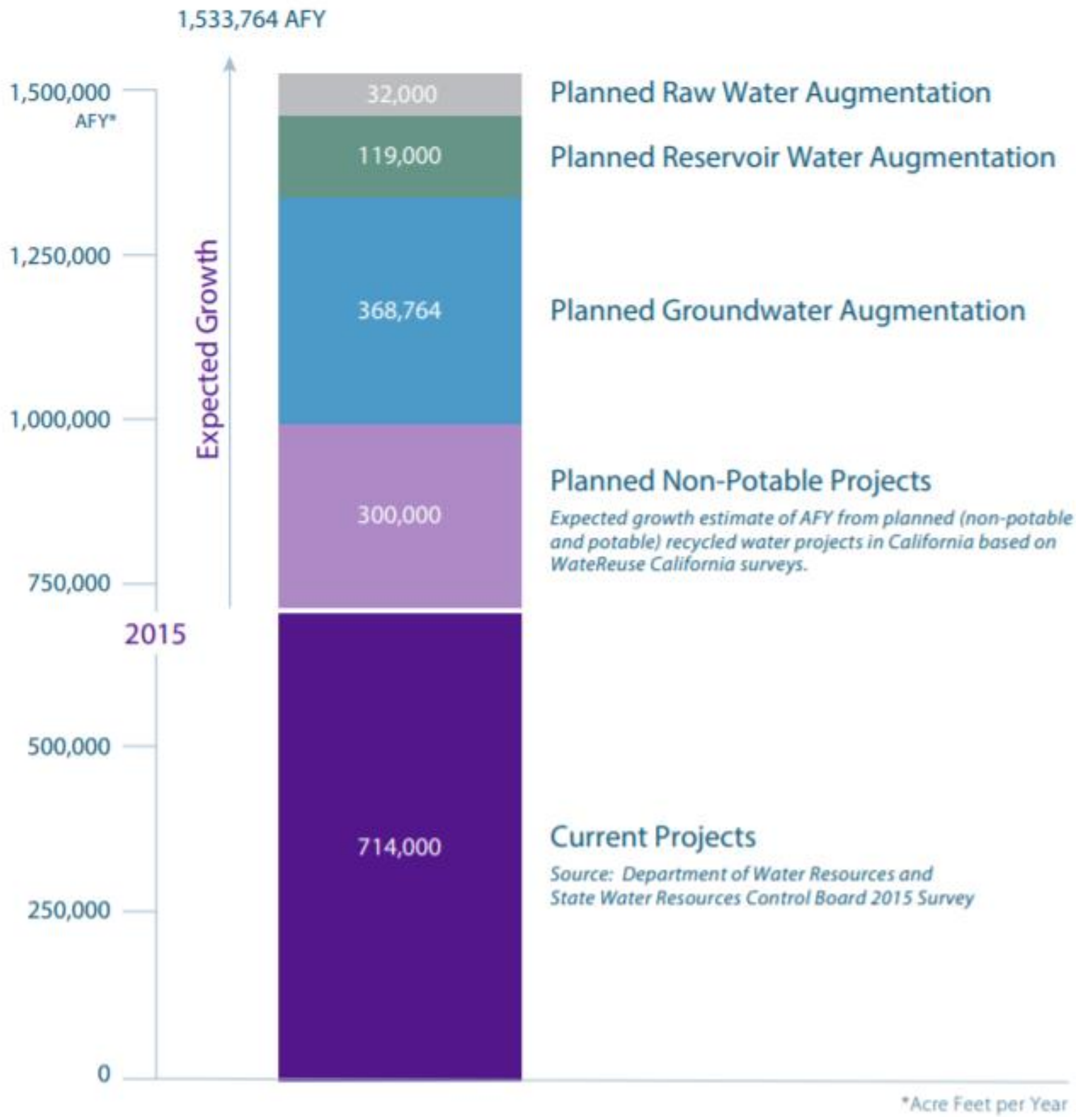


Figure 20: Current and future planned water recycling projects in California including the current and expected acre-feet per year (AFY) of recycled water production.

The topic of water reuse in California is a trending topic due to the current droughts that California endures year-after-year.

Evaluation of Membrane Bioreactors for Reuse

Conventional wastewater treatment plants, like Union Sanitary District, were typically designed to handle only domestic water (i.e., indoor and outdoor water use in homes for drinking, bathing, flushing toilets, and watering lawns, etc.) (EPA, 2011). Therefore, these current treatment technologies are not suited to handle the wastewater composition of industrial wastewater reuse. Recently, there has been increased research and attention to advanced technologies and the capability to treat and reuse industrial wastewaters due to the rapid growth of industry and population (Yaqub and Lee, 2019). Because California requires disinfected tertiary wastewater treatment to recycle water in industrial processes (including cooling) and in flushing toilets and urinals, disinfected tertiary treatment options will be considered (SWRCB, 2018).

The use of membrane-based technologies, specifically membrane bioreactors, have become increasingly popular for industrial wastewater treatment and reuse (Yaqub and Lee, 2019; Zheng et al., 2015; Agana et al., 2013) and therefore are the focus throughout this paper. Membrane filtration systems have proven to remove industrial contaminants at a high efficiency rate and unlike conventional wastewater treatment systems with large clarifiers and sand filters, have a relatively small footprint (EPA, 2007; Agana et al., 2013). A membrane-based treatment process includes the use of a membrane, and the flow of wastewater through the membrane to separate out pollutants (EPA, 2007). The membranes can be made of organic or inorganic materials such as synthetic organic polymers or ceramics (Ezugbe and Rathilal, 2020). Membrane filters are usually configured with a bioreactor system that can be aerobic or anaerobic. The main difference between aerobic and anaerobic is that aerobic uses oxygen for organic digestion while anaerobic uses bacteria (EPA, 2021).

Some of the industrial contaminants that membrane filtration filters out at high removal efficiencies are bio-chemical oxygen demand (BOD), total suspended solids (TSS), phosphorous, nitrogen, and bacteria (EPA, 2007). There are four major types of membrane filtration; 1) ultrafiltration (UF), 2) reverse osmosis (RO), 3) microfiltration (MF) and 4) nanofiltration (NF) (Agana et al., 2013; Yusuf et al., 2020). These next sections will discuss membrane bioreactors and the four types of membranes most commonly seen.

Membrane Bioreactors

A membrane bioreactor uses a physical process, i.e., the membrane, to filter out solids combined with a biological reactor for digestion (EPA, 2007). Membrane bioreactors have become an increasingly used technology in recent times due to their relatively small footprint and removal capabilities (Chan et al., 2009; Wu and Kim, 2020). An example of a membrane bioreactor is shown in the figure below:

Figure 21: Image of a membrane bioreactor. It can be seen in this image that membrane bioreactors are similar in size to a shipping container (Evoqua, 2021).

They have proven to have high removal efficiencies for chemical oxygen demand (COD), total suspended solids (TSS) and biochemical oxygen demand (Chan et al., 2009). There are many types of membrane bioreactors, but basic aerobic and anaerobic configurations will be discussed in this paper. Aerobic membrane bioreactors (AeMBR), as earlier mentioned, use oxygen to break down organic wastes to biomass in sludge and CO2 (Chan et al., 2009). This digestion is performed through an aeration basin using air bubbles in the bottom of the tank (AZ Water Association, 2020) as seen in Figure 22 below.

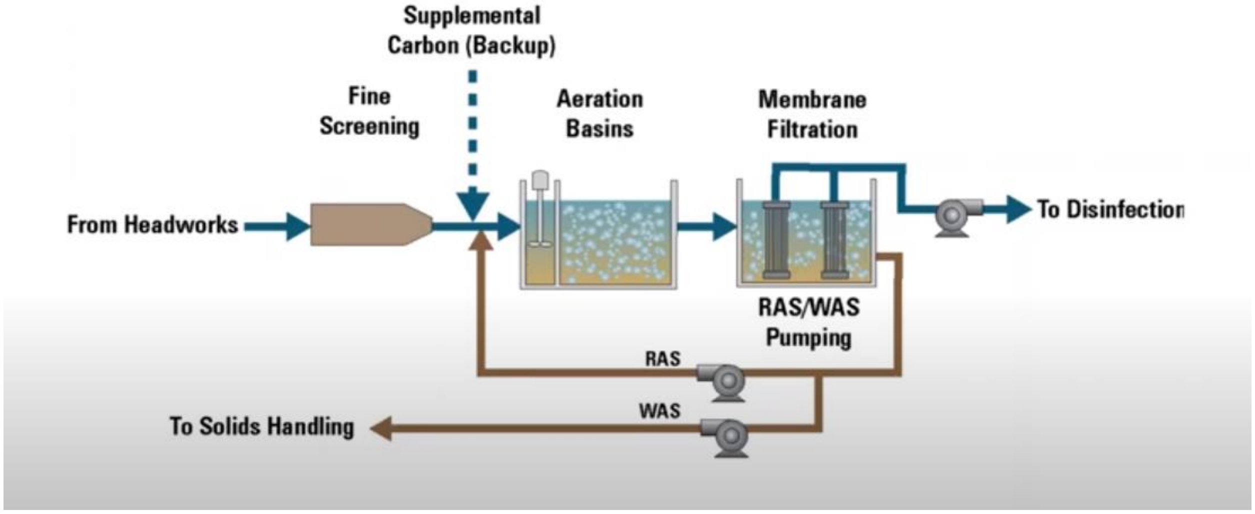


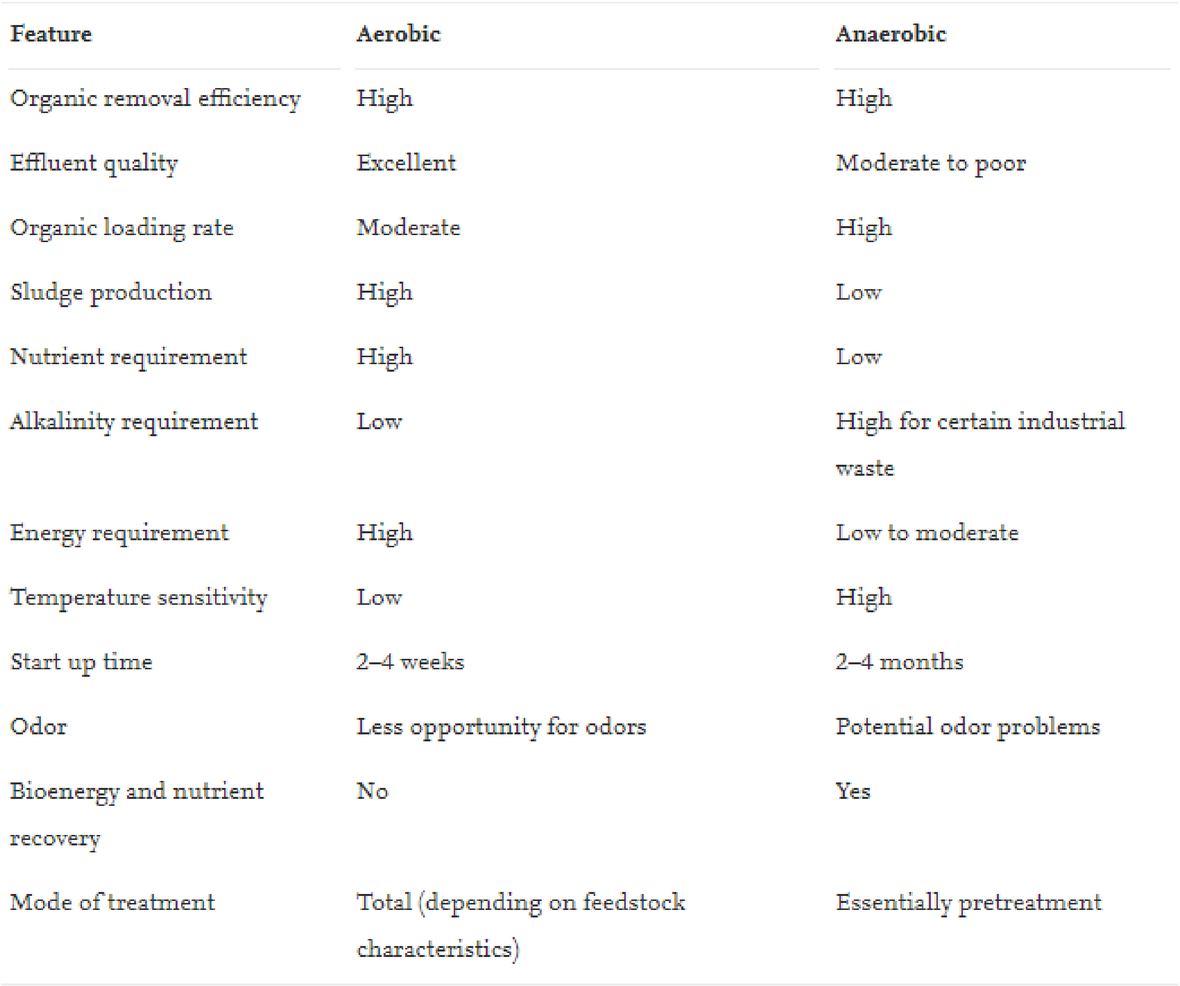
Figure 22: Aerobic Membrane Bioreactor Treatment System (AZ Water Association, 2020)

Anaerobic membrane bioreactors (AnMBR), on the other hand, do not use oxygen to break down organic matter. Anaerobic membrane bioreactors use bacteria to convert the organic matter into methane, carbon dioxide, and water by hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Chan et al., 2009; Aziz et al., 2019). Anaerobic membrane bioreactors also achieve a high removal efficiency of chemical oxygen demand, biochemical oxygen demand, and suspended solids.

There are many advantages and disadvantages to both systems, one of the major ones being energy use. Aerobic systems use significantly more energy than anaerobic systems as anaerobic have the potential to generate energy in the form of methane gas and aerobic systems also produce less sludge (Chan et al., 2009). However, aerobic systems produce higher effluent quality and are less operationally sensitive, e.g. they are less sensitive to temperature. Low strength wastewaters (COD < 1,000 mg/L) tend to be treated more efficiently in aerobic systems and high strength wastewaters (COD > 4,000 mg/L) tend to be treated more efficiently in anaerobic systems (Chan et al., 2009). The industrial wastewaters discharged to Union

Sanitary District fall closer to the low strength end of the spectrum. A table highlighting the advantages of aerobic versus anaerobic can be seen below in table 7.

Table 7: Advantages and disadvantages of aerobic vs. anaerobic bioreactors compiled in a review (Chan et al., 2009)



Feature	Aerobic	Anaerobic
Organic removal efficiency	High	High
Effluent quality	Excellent	Moderate to poor
Organic loading rate	Moderate	High
Sludge production	High	Low
Nutrient requirement	High	Low
Alkalinity requirement	Low	High for certain industrial waste
Energy requirement	High	Low to moderate
Temperature sensitivity	Low	High
Start up time	2–4 weeks	2–4 months
Odor	Less opportunity for odors	Potential odor problems
Bioenergy and nutrient recovery	No	Yes
Mode of treatment	Total (depending on feedstock characteristics)	Essentially pretreatment

One of the larger issues with membrane bioreactors is membrane fouling. Membrane fouling is when unwanted materials become lodged into the membrane and thus decreases process performance of the membrane (AlSawaftah et al., 2021). Membrane fouling can be classified into four types of categories; 1) particulate, 2) organic, 3) inorganic, and 4) biofouling (AlSawaftah et al., 2021). Membrane fouling can have significant effects on maintenance costs and performance of the system and has been a major obstacle in industrial wastewater treatment. The type of membrane can determine how successful the bioreactor system is in removing contaminants and different membrane types are used depending on the type of pollutants expected.

Reverse Osmosis and Nanofiltration

Reverse osmosis and nanofiltration are similar in that both are a physical treatment process which is designed to remove and reduce contaminants such as total dissolved solids (TDS, i.e., the amount of dissolved materials in water as opposed to suspended particulate) and total suspended solids (TSS) (EPA, 2013). High pressure pumps are used to push water through a membrane while retaining organic and inorganic pollutants, such as pesticides, pharmaceuticals, endocrine-disrupting compounds, bacteria and viruses, or other contaminants of emerging concern (EPA, 2013; Rizzo et al., 2020).

Reverse osmosis membranes have the smallest pore size in comparison to other membrane filters ranging from 0.0001-0.001 micrometers while nanofiltration has slightly larger pore sizes with a range of 0.001-0.01 micrometers (EPA, 2013). Reverse osmosis and nanofiltration can also remove nutrients, like nitrogen and phosphorous. Reverse osmosis has proven to be a leading option for wastewater reuse for its versatility in removing a range of contaminants, which may make it a strong option for the range of contaminants seen in industrial wastewaters. One drawback to reverse osmosis and nanofiltration is that they often require a pretreatment method, such as microfiltration or ultrafiltration, to remove solids or to prevent membrane fouling (Zheng et al., 2015; Rizzo et al., 2020). Nanofiltration is the less costly of these two treatment options as it uses a reduced amount of energy (Verma et al., 2021). Reverse osmosis and nanofiltration are both tertiary forms of treatment technology.

Reverse osmosis and nanofiltration have also shown to be successful in the removal of heavy metals, such as those found in industrial wastewaters at low levels. For example, reverse osmosis has shown to have a removal efficiency of >95% for copper, 99% for cadmium, and 99.5% for nickel. Nanofiltration has also been proven to have removal efficiencies of 98.1% for copper, 97.25 for cadmium, and 99% for Lead (Verma et al., 2021). These are just a few of the metals that nanofiltration and reverse osmosis have shown high removal efficiencies for, but others metals that were removed >90% include arsenic, cobalt, manganese, mercury, and zinc

(Verma et al., 2021). The rate at which the metals are removed are mostly dependent upon electrostatic forces and the molecular weight of uncharged solutes (Verma et al., 2021). Molecular weight cut off (MWCO) is a term used to describe the retention capability of a membrane and is defined by Singh as the molecular weight at which 90% of the solute is rejected by the membrane (Singh, 2005). The molecular weight cut off (MWCO) for reverse osmosis is 0.2-2 kilo Dalton while nanofiltration is 2-20 kilo Dalton (Ezugbe and Rathilal, 2020).

Ultrafiltration and Microfiltration

Ultrafiltration and microfiltration are often pretreatment filtration steps to reverse osmosis and nanofiltration to prevent membrane fouling and to pre-filter out solids (Rizzo et al., 2020). These membranes have the next largest pore sizes with ultrafiltration ranging from 0.01-0.2 micrometers and microfiltration ranging from 0.1-3.0 micrometers (Ashraf et al., 2021). The molecular weight cut off (MWCO) for ultrafiltration is 20-150 kilo Dalton and the molecular weight cut off (MWCO) for microfiltration is 100-500 kilo Dalton. The types of solutes that microfiltration retains are bacteria, fat, oil and grease, colloids, organics and micro particles while ultrafiltration retains proteins, pigments, oils, sugar, organics, and microplastics. Ultrafiltration has also shown to have a removal efficiency in poultry slaughterhouse wastewater of > 94% for chemical oxygen demand and biochemical oxygen demand and 98% for suspended substances (Ezugbe and Rathilal, 2020). While membrane bioreactors are proven to meet high-quality water reuse standards, an additional disinfection step is often needed.

Disinfection

Disinfection is a form of advanced tertiary treatment that is required to recycle wastewater in California for various uses (SWRCB, 2018). The purpose of disinfection is to kill any pathogens or viruses that might be contained in wastewater to prevent contaminating surface water, or in the case of reuse, from coming into contact with people (Chen et al., 2021). Disinfection is especially important in more recent times when global pandemics are a real threat, as seen with the COVID-19 outbreaks going on today. As earlier mentioned, the membrane treatment technologies listed earlier (microfiltration, ultrafiltration, nanofiltration, reverse osmosis, and membrane bioreactors) have all been shown to successfully remove pathogens and viruses. In addition, there are other existing technologies that can be utilized to successfully disinfect wastewater; 1) chlorination, 2) ultraviolet radiation, 3) ozonation and 4) photocatalysis/electrocatalysis (Chen et al., 2021).

The differences in these disinfection technologies is physical versus chemical. The membrane treatment technologies rely on physical separation of the organism to filter out viruses and pathogens and thus filter size becomes important. Pathogens and viruses will also absorb into sludge particles within bioreactors. Although membrane processes are a viable option for disinfection, membrane fouling can affect the efficiency of disinfection (Chen et al., 2021).

Chlorination is a commonly practiced form of disinfection due to its low cost and high removal efficiency. However, chlorination can result in toxic by-products that can have adverse effects on human and environmental health (Collivignarelli et al., 2021). Therefore, more sustainable options have been explored, including ultraviolet radiation. Ultraviolet radiation is a more environmentally sustainable option as no toxic by-products are produced while maintaining a high removal efficiency (Collivignarelli et al., 2021).

Overall, each of these treatment technologies provide adequate disinfection, although some more than others. Figure 5 below compares the removal efficiencies of each technology. Removal efficiency is expressed in log reduction values, 1 representing a low removal efficiency and 10 representing a high removal efficiency. Log removal value is defined by the following equation:

Log Removal= -log(concentration$_{out}$/concentration$_{in}$) (Hai et al., 2014)

When the log removal value (LRV) is 1, this equals a 90% reduction rate. When the log removal value is 2, this equals a 99% reduction rate. Then 3 equals 99.9%, 4 equals, 99.99% and 5 equals 99.999% (99.999% is the California standard for removal of bacteriophage MS2 and polio virus standard) (Hai et al., 2014).

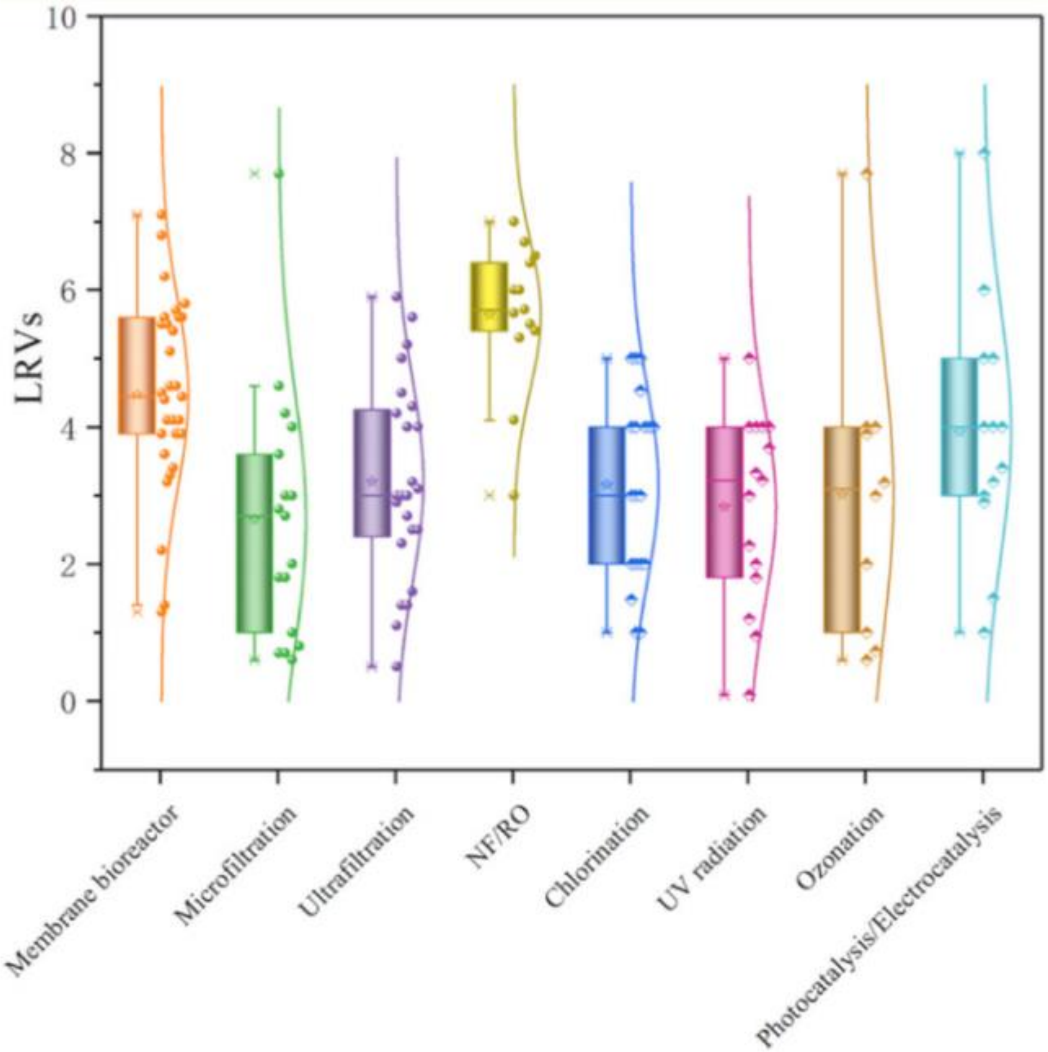


Figure 23: Virus removal efficiency ranges expressed in Log Reduction Values (LRV) for various viruses. Removal efficiency is expressed in log reduction values, 1 representing a low removal efficiency and 10 representing a high removal efficiency (Chen et al., 2021).

Nanofiltration/Reverse Osmosis and membrane bioreactors are of the higher ranked technologies in regards to removal efficiencies (Chen et al., 2021).

Case Studies of Membrane Bioreactors in the Literature

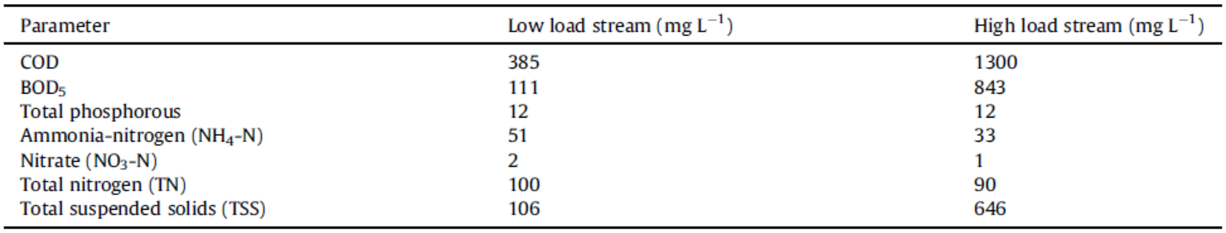
For this paper, two case studies will be used; a case study using a membrane bioreactor at a dairy product manufacturing plant in Uruguay and a case study using a membrane bioreactor at a hotel/casino in California. The dairy producer case study was used because it provided removal efficiencies on high-strength and low-strength wastewaters as well as providing information on important pollutant removal efficiencies, like chemical oxygen demand and suspended solids. It was important to be able to see the removal efficiencies of varying wastewaters strengths because the industrial users in the Tri-City area have varying wastewater strengths. The hotel/casino case study was chosen because it was located in California and aimed towards California water reuse standards. It also filled some gaps that the dairy producer case study did not have data on, such as turbidity.

Introduction to the Case Studies

A pilot-scale membrane bioreactor was installed at a company producing dairy products in Uruguay to assess the feasibility of designing a full-scale treatment system. This company discharged their wastewater directly into the Santa Lucia river basin in Uruguay, which provides drinking water for approximately 60% of the population in Uruguay (Fraga et al., 2017). Due do water quality conditions in the watershed decreasing, local authorities have set more stringent guidelines for industries discharging directly into the watershed. The

The dairy plant produced powdered milk and various types of butters. The site already had some wastewater treatment in place consisting of an anaerobic pond and a grease removal pond. To test different efficiencies of the membrane bioreactor, the plant treated wastewater effluent from two different locations, effluent from the anaerobic pond which resulted in low strength wastewater and effluent from the grease removal pond which resulted in high strength wastewater (Fraga et al., 2017). Therefore, the characteristics of the wastewater varied and can be seen more clearly in the below table:

Table 8: Average wastewater characteristics of each effluent to be treated in the membrane bioreactor. The low load stream represents the wastewater effluent from the anaerobic pond wastewater and the high load stream represents the wastewater effluent from the grease removal pond (Fraga et al., 2017). The average is based off 17 grab samples.

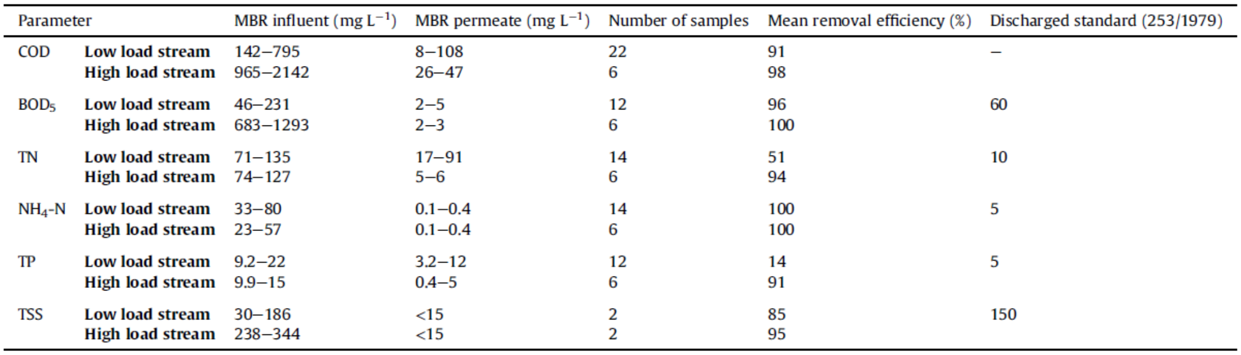


Parameter	Low load stream (mg L^{-1})	High load stream (mg L^{-1})
COD	385	1300
BOD_5	111	843
Total phosphorous	12	12
Ammonia-nitrogen (NH_4-N)	51	33
Nitrate (NO_3-N)	2	1
Total nitrogen (TN)	100	90
Total suspended solids (TSS)	106	646

The pilot-scale membrane bioreactor that was selected consisted of a four tank system including an anoxic tank, a biological aerobic tank, a permeate storage tank, and a sludge stabilization tank (Fraga et al., 2017). The system was also designed with two ultrafiltration membranes having a pore size of 0.04 µm (Fraga et al., 2017). This membrane bioreactor design provided multiple diffusers to promote digestion of organic material and also for membrane scouring, which is the cleaning of the membrane to reduce fouling.

The membrane bioreactor configuration proved to achieve high removal efficiency for all contaminants and is demonstrated in the table below:

Table 9: Contaminant removed efficiencies for low load wastewater and high load wastewater influents compared against Uruguay discharge standards. COD= Chemical Oxygen Demand, BOD= Biological Oxygen Demand, TN= Total Nitrogen, NH_4-N= Ammonium, TP= Total Phosphorous, TSS= Total Suspended Solids.



Parameter		MBR influent (mg L^{-1})	MBR permeate (mg L^{-1})	Number of samples	Mean removal efficiency (%)	Discharged standard (253/1979)
COD	**Low load stream**	142–795	8–108	22	91	–
	High load stream	965–2142	26–47	6	98	
BOD_5	**Low load stream**	46–231	2–5	12	96	60
	High load stream	683–1293	2–3	6	100	
TN	**Low load stream**	71–135	17–91	14	51	10
	High load stream	74–127	5–6	6	94	
NH_4-N	**Low load stream**	33–80	0.1–0.4	14	100	5
	High load stream	23–57	0.1–0.4	6	100	
TP	**Low load stream**	9.2–22	3.2–12	12	14	5
	High load stream	9.9–15	0.4–5	6	91	
TSS	**Low load stream**	30–186	<15	2	85	150
	High load stream	238–344	<15	2	95	

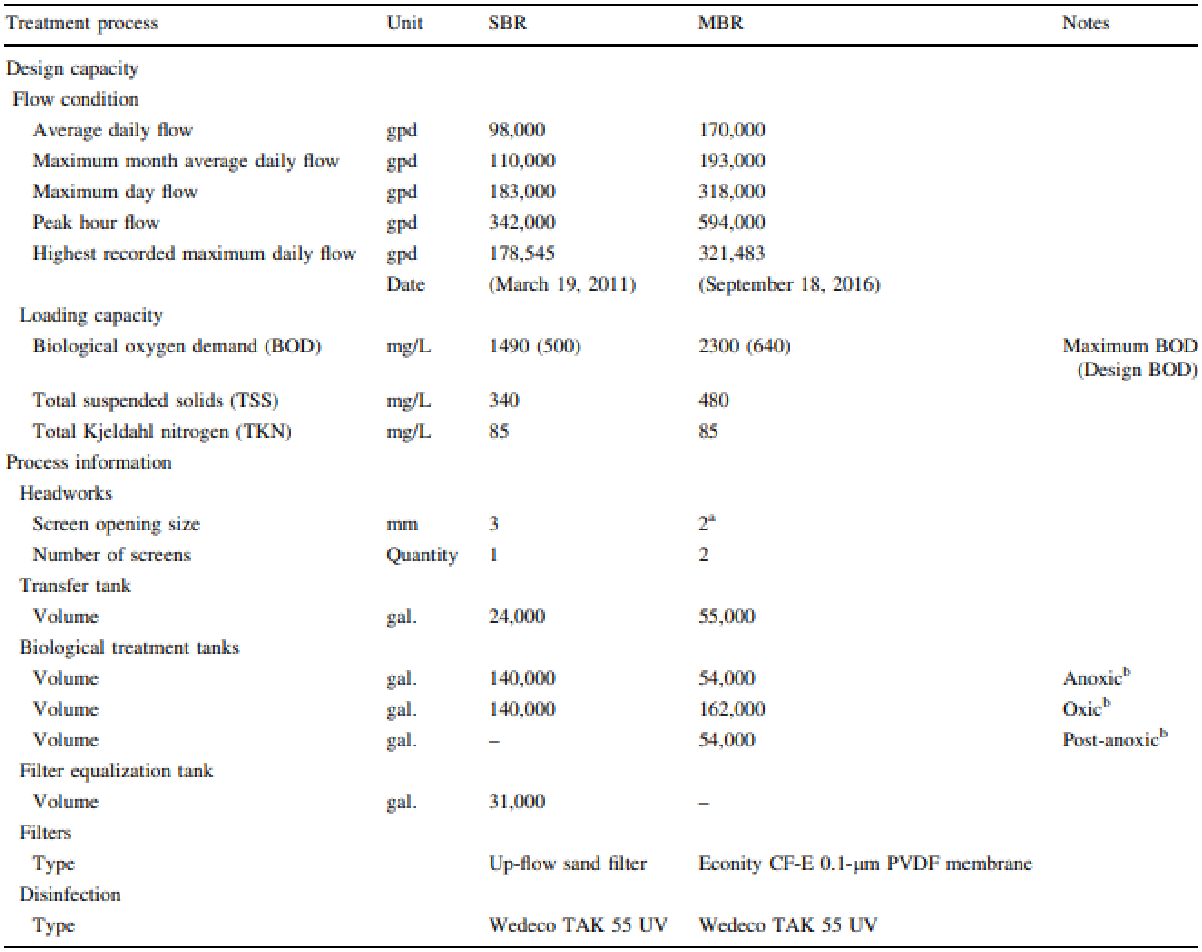
Removal efficiencies of greater than 90% were demonstrated for most contaminants, especially ones of the high load stream. This case study provides helpful information on varying level of wastewater strength but does not provide information on turbidity, which is another California water reuse requirement. The Chumash Casino case study provides more information on turbidity removal efficiencies.

The Chumash Casino in Santa Ynez California was expanding and their current wastewater treatment system, a sequencing batch reactor, was not able to keep up with the increased flow. Therefore, a membrane bioreactor was installed to help meet the increased flow and comply with California’s Code of Regulations, Title 22 requirements (Kim et al., 2017). The wastewater at the casino consisted of toilets from the hotel and restaurant wastewater in wastewater volumes ranging from an average of 111,000 gallons per day to the maximum of

183,000 gallons per day (Kim et al., 2017). The sequencing batch reactor could not handle the wastewater load and was not producing an effluent that met California reuse standards (Kim et al., 2017). Therefore, the membrane bioreactor was installed to allow for expansion and meet California reuse standards.

The membrane bioreactor that was installed consisted of a polyvinylidene fluoride hollow fiber membrane with a 0.1µm pore size (Kim et al., 2017). The below table provides more information on the design and wastewater treatment capacity of the sequencing batch reactor compared to the membrane bioreactor. This shows the magnitude of difference of what membrane bioreactors can handle from previous wastewater treatment technologies.

Table 10: The design capacity of membrane bioreactors compared to a sequencing batch reactor. Flow units are shown in gallons per day (gpd), pollutant concentrations in milligrams per liter (mg/L), screen opening size in millimeters (mm) and transfer tank sizing in gallons (gal) (Kim et al., 2017).



Treatment process	Unit	SBR	MBR	Notes
Design capacity				
Flow condition				
Average daily flow	gpd	98,000	170,000	
Maximum month average daily flow	gpd	110,000	193,000	
Maximum day flow	gpd	183,000	318,000	
Peak hour flow	gpd	342,000	594,000	
Highest recorded maximum daily flow	gpd	178,545	321,483	
	Date	(March 19, 2011)	(September 18, 2016)	
Loading capacity				
Biological oxygen demand (BOD)	mg/L	1490 (500)	2300 (640)	Maximum BOD (Design BOD)
Total suspended solids (TSS)	mg/L	340	480	
Total Kjeldahl nitrogen (TKN)	mg/L	85	85	
Process information				
Headworks				
Screen opening size	mm	3	2[a]	
Number of screens	Quantity	1	2	
Transfer tank				
Volume	gal.	24,000	55,000	
Biological treatment tanks				
Volume	gal.	140,000	54,000	Anoxic[b]
Volume	gal.	140,000	162,000	Oxic[b]
Volume	gal.	–	54,000	Post-anoxic[b]
Filter equalization tank				
Volume	gal.	31,000	–	
Filters				
Type		Up-flow sand filter	Econity CF-E 0.1-µm PVDF membrane	
Disinfection				
Type		Wedeco TAK 55 UV	Wedeco TAK 55 UV	

The membrane bioreactor was better suited for the increase in wastewater flow and the quality of the effluent it achieved was higher than that of the sequencing bioreactor.

The membrane bioreactor was able to effectively treat the increased biochemical oxygen demand and turbidity concentrations, which the sequencing bioreactor could not handle (Kim et al., 2017). The turbidity levels were kept below the California reuse standards of 0.2 NTU while the sequencing bioreactor constantly produced turbidity concentrations around 2 NTU (Kim et al., 2017). The membrane bioreactor was paired with an ultraviolet disinfection system, which is consistent with the literature of membrane bioreactors requiring an additional disinfection step. After reviewing the data provided in each case study, we can now apply these cases to the Tri-City area industrial dischargers to see whether these membrane bioreactors would allow them to achieve California's reuse standards.

Chemical Oxygen Demand

Although none of the top ten dischargers in Union Sanitary District manufactures dairy products, the dischargers do have similarities in regards to their wastewater discharges. Tesla and Mission Linen Supply's average chemical oxygen demand fall into the same chemical oxygen demand range as the high load stream of the dairy wastewater. According to the data provided by Fraga et al. in 2017, this would correlate with an average removal efficiency of 98% for these industrial users for chemical oxygen demand concentration. United States Pipe & Foundry, Kaiser Permanente, Thermo Fisher Scientific, and Washington Hospital's chemical oxygen demand averages fall within the low load chemical oxygen demand stream of the dairy wastewater while Western Digital and Lam Research fall below the low load stream. According to the data provided by Fraga et al., this would correlate with an average removal efficiency of 91% for these industrial users for suspended solids.

Total Suspended Solids

Tesla, Mission Linen Supply, and Washington Hospital's average suspended solids range higher than the high load stream of the dairy wastewater. Therefore, it cannot be determined whether this pilot-scale membrane bioreactor would have had the same removal efficiencies against a higher suspended solids load, especially for Tesla. Tesla's average suspended solids concentration was 609.26 mg/L, almost double the higher end of the range for the dairy wastewater. However, Washington Hospital was pretty close to the end of the high stream range with an average of 388.33 mg/L. Therefore, it is possible that the average 95% removal efficiency shown in the dairy wastewater pilot would also apply here.

Kaiser Permanente's average suspended solids fall into the same suspended solids range as the high load stream of the dairy wastewater. Compared against the dairy wastewater, this would correlate with an average removal efficiency of 95%.

Lam Research Corporation, United States Pipe & Foundry, Thermo Fisher Scientific, and Western Digital's average suspended solids fall into the same suspended solids range as the low load stream of the dairy water. This would correlate with an average removal efficiency of 85% for these industrial users for suspended solids concentration.

Ammonia-nitrogen

Ammonia-nitrogen concentration values were lower in the top industrial dischargers than in the dairy wastewater. The lowest average concentration of Ammonia-nitrogen was seen in Tesla's wastewater at 0.5975 mg/L while the highest seen was in Washington Hospital's wastewater at 26 mg/L. The pilot-scale membrane bioreactor achieved 100% average removal efficiency for Ammonia-nitrogen for both low and high streams.

Water Reuse Potential Comparing to California's Reuse Standards

As mentioned earlier in the California Water Reuse Regulations section, California requires disinfected tertiary treatment (filtered and subsequently disinfected) to reuse wastewater for many uses, including industrial processes and flushing toilets. The pilot-scale membrane-bioreactor in Uruguay with ultrafiltration membranes as well as the membrane bioreactor in California would meet the filtered part of the requirement, but the question is whether it would meet the disinfection requirement and whether the total coliform bacteria levels would meet the standards. Unfortunately, in this dairy wastewater and casino case study, coliform samples were not taken and therefore concentrations after being treated are unknown.

Fraga et al. indicated that membrane bioreactors do not always meet disinfection standards and that further disinfection processes may be needed to meet the standards. Hai et al. argues that when membrane bioreactors are operating at optimal conditions, and depending on the material the membrane is made out of, membrane bioreactors have achieved log removal values of >6 (>99.999%) for varying viruses. However, additional disinfection processes (e.g. chlorination) may still be recommended to ensure the wastewater meets the reuse standards (Hai et al., 2014). This is consistent with the Chumash Casino case where the membrane bioreactor was paired with an ultraviolet disinfection step to meet disinfection levels.

The advantage of using a membrane bioreactor is that it can significantly reduce the need for post-chlorination and therefore reduce operating costs (Hai et al., 2014). As mentioned in earlier sections, if disinfection via a chlorine disinfection process is utilized, then a contact time value of not less than 450 milligram-minutes/L is required in California. It has been demonstrated that after using a membrane bioreactor, a 99.999% removal efficiency was achieved using only one-tenth of the 450 milligram-minutes/L (Hai et al., 2014). Overall, it seems that a membrane bioreactor may be sufficient to meet California reuse standards, but some additional disinfection steps would ensure reuse quality, as in the Chumash Casino case study.

California also requires certain water quality parameters surrounding turbidity for filtration using ultrafiltration, i.e., the wastewater must not exceed 0.2 NTU (Nephelometric Turbidity Unit) more than 5% of the time within a 24-hour period and must not exceed 0.5 NTU at any time (SWRCB, 2018). The Chumash Casino case study was able to prove that the membrane bioreactor was able to meet California turbidity standards. However, since we do not have turbidity samples for the top industrial discharges in the Tri-City area, we are not able to directly compare if this would be sufficient for them. However, membrane bioreactors have been proven to be sufficient in removing turbidity 99-100% (Ezugbe and Rathilal, 2020; Shi et al., 2021).

In a pilot study, a 0.2µm membrane bioreactor was used to filter bath wastewater at a college campus. The membrane bioreactor achieved a 99% removal rate and the treated effluent had a turbidity concentration of 0.05 NTU (Shi et al., 2021). This turbidity concentration would be sufficient for California's reuse standard of <0.2 NTU. Since the pore size of the membrane in the bath wastewater pilot study was larger than the pore size of the dairy wastewater pilot study, we can assume that the membrane in the dairy wastewater study would produce turbidity removal rates of at least the same efficiency, if not greater.

Conclusions and Concerns

Overall, the membrane bioreactor produced the most efficient removal rates when the strength of the wastewater (i.e., high chemical oxygen demand and high suspended solids) was on the higher end comparative to the low strength wastewater. The pilot-scale membrane bioreactor in the case of the dairy wastewater would likely achieve the highest removal efficiencies on Tesla, Mission Linen Supply and Washington Hospital's wastewater since their wastewater strength is on the higher end with high chemical oxygen demand and suspended solids concentrations.

In the case of the dairy wastewater pilot-scale membrane bioreactor, the treated wastewater produced would likely meet turbidity standards, but it is not definitive that it would meet California disinfection standards and an additional disinfection step may be required. Fraga et al. also concluded that the dairy wastewater would not be able to be reused in production processes due to bacteriological parameters, total dissolved solids, and sodium content. However, Fraga et al. compared these concentrations to the local drinking water standard, which is usually more stringent that industrial reuse standards. In addition to removal efficiencies, other factors should be taken into consideration, like operational maintenance and costs (cost analyses will be talked about later on).

During the pilot study, there were four occasions were the membrane bioreactor temporarily went out of service due to low influent levels, a power outage, a high-pressure alarm, and membrane fouling due to excess ferric chloride (Fraga et al., 2017). Maintenance costs can become extensive if membrane bioreactors are not maintained and cleaned properly to prevent fouling (Fraga et al., 2017; AlSawaftah et al., 2021). These operating costs will be discussed further in the cost analysis section.

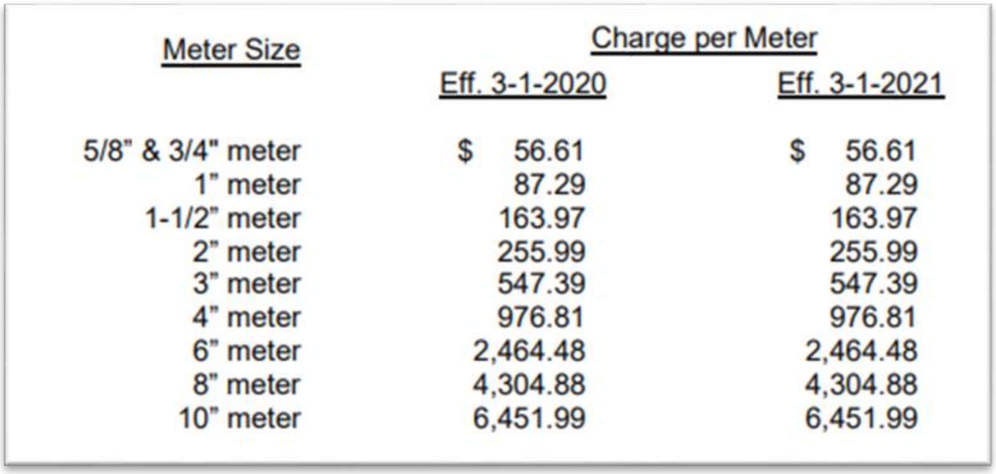
Cost Analysis

Annual Cost of Using Water in the Tri-City Area

The costs of installing and operating wastewater treatment systems for reuse is one of the more important and prohibitive factors in deciding whether to install them or not (Fraga et al., 2017;). Understanding the true cost of using water at the industrial site is important to understand. For the purposes of this cost analysis, the cost of purchasing water and discharging wastewater will be compared to costs found in literature of installing and operating wastewater treatment systems since this will be the majority of where the costs come from. Although it is important to note that there are additional water costs, e.g. energy costs, costs of current chemical treatment, etc. However, these additional costs for these industrial users is unknown.

For the cost of purchasing water, it is assumed that these industrial users buy 100% of their water from Alameda County Water District, the water supplier for the Fremont, Newark, and Union City service area (ACWD, 2020). Alameda County Water District currently has two charges for their purchased water: a bimonthly (every two months) service charge depending on the size of the site's meter and a consumption charge (ACWD, 2021). The bimonthly service charges can be seen below in Table 11:

Table 11: Bimonthly (every two months) service charges by Alameda County Water District. Customers are charged per meter depending on the size of the meter (ACWD, 2021).



Meter Size	Charge per Meter	
	Eff. 3-1-2020	Eff. 3-1-2021
5/8" & 3/4" meter	$ 56.61	$ 56.61
1" meter	87.29	87.29
1-1/2" meter	163.97	163.97
2" meter	255.99	255.99
3" meter	547.39	547.39
4" meter	976.81	976.81
6" meter	2,464.48	2,464.48
8" meter	4,304.88	4,304.88
10" meter	6,451.99	6,451.99

For the purposes of this paper, we will assume a 6’’ meter as a conservative estimate. To put this in perspective, residential meters are usually between 5/8’’ and 2” (Kaser et al., 2013). The current consumption charge effective 3/1/2021 is $4.596/unit. A unit equates to 100 cubic feet or 748 gallons of water (ACWD, 2021). Prices have increased each year from 2018-2020. In 2019, the consumption charge rate was $4.419/unit and the bimonthly service charge for a 6” meter was $2,369.69. In 2018, the consumption charge rate was $4.249/unit and the bimonthly service charge for a 6” meter was $2,278.54 (ACWD, 2021)

Using these two charges, and the quantity of wastewater discharged per year, the amount of money spent on purchasing water can be estimated. It is important to note that the amount of purchased water is likely greater than the amount of wastewater discharged, assuming that these industrial sites do not already use some kind of water reuse onsite. Water can be lost through evaporation throughout its use and it can also be lost in a site’s product if the product they are producing contains water. Using wastewater to calculate how much is spent on purchasing water is likely a conservative approach. Figure 24 below shows the annual cost of purchasing water from 2018-2021 for the top ten industrial dischargers that I also had sampling data for:

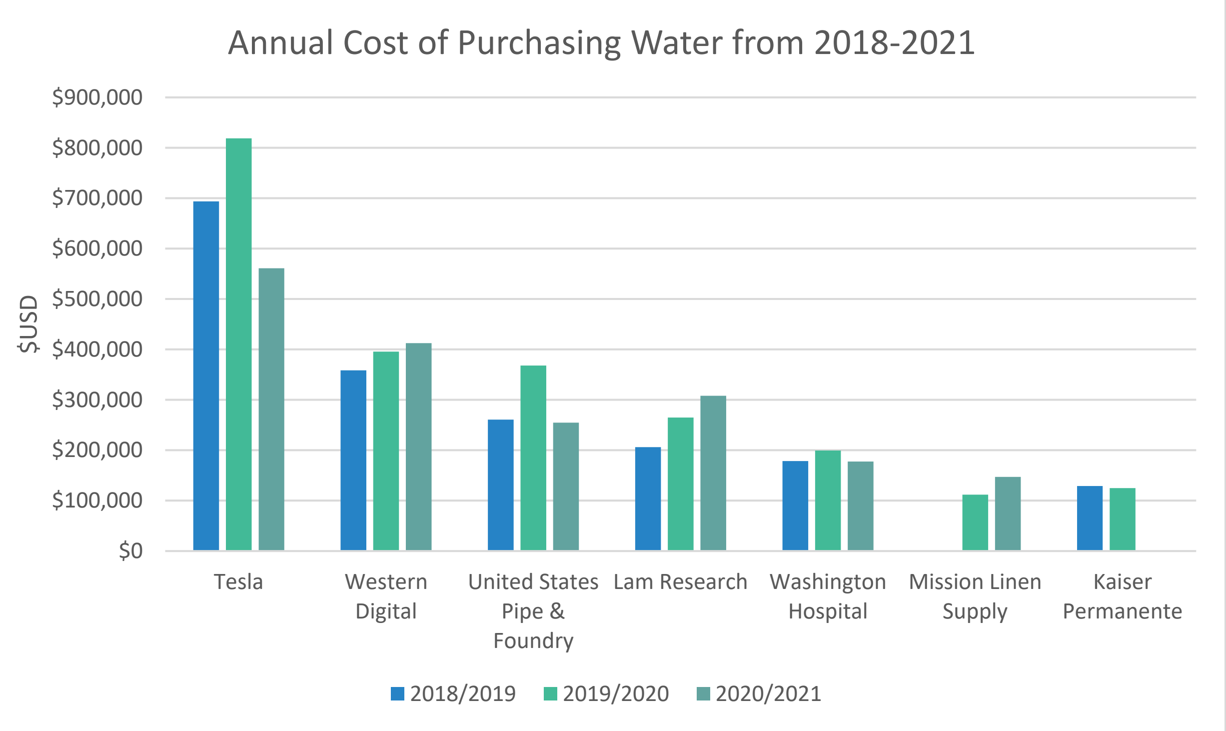
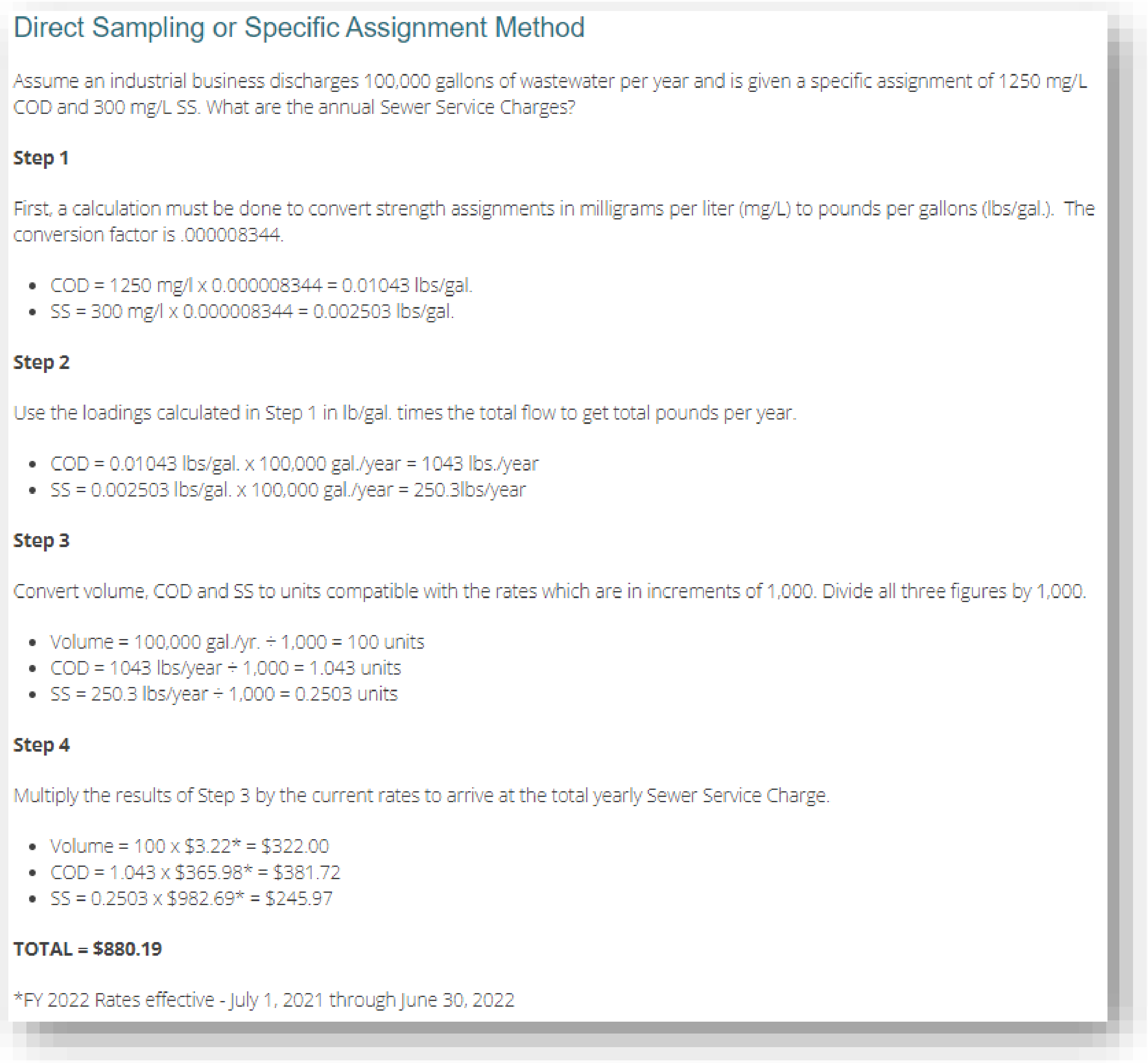


Figure 24: The annual cost of purchasing water from Alameda County Water District for each of the top ten industrial dischargers. To calculate the annual cost, the price per unit was multiplied by the annual wastewater discharged and added the annual service charges. This is assuming that the amount of wastewater discharged is the same as the amount of water purchased, which is a limiting factor.

For the cost of discharging wastewater, Sewer Service Charges for the top ten industrial users were provided by Union Sanitary District. Union Sanitary District charges industrial users an annual sewer service charge in addition to initial capacity fees. However, initial capacity fees were not provided and only sewer service charges will be considered. Although Union Sanitary District provided the annual sewer service charges, it is still important to understand how these fees are calculated.

Sewer service charges are based on the annual flow, chemical oxygen demand, and suspended solids of the industrial user. For industrial discharges who have a discharge permit and wastewater sampling is conducted (as in the case with the top ten dischargers), the sewer service charges are calculated by taking the annual average chemical oxygen demand and suspended solids and using the annual flow to convert these concentrations to pounds/year. Union Sanitary District currently charges $365.98 per 1,000 pounds per year of chemical oxygen demand and $982.69 per 1,000 pounds per year of suspended solids. On top of these two charges for chemical oxygen demand and suspended solids, $3.22 per 1,000 gallons per year of wastewater flow is also charged. Union Sanitary District provides a sewer service charge calculation sample in the figure below:



Direct Sampling or Specific Assignment Method

Assume an industrial business discharges 100,000 gallons of wastewater per year and is given a specific assignment of 1250 mg/L COD and 300 mg/L SS. What are the annual Sewer Service Charges?

Step 1

First, a calculation must be done to convert strength assignments in milligrams per liter (mg/L) to pounds per gallons (lbs/gal.). The conversion factor is .000008344.

- COD = 1250 mg/l x 0.000008344 = 0.01043 lbs/gal.
- SS = 300 mg/l x 0.000008344 = 0.002503 lbs/gal.

Step 2

Use the loadings calculated in Step 1 in lb/gal. times the total flow to get total pounds per year.

- COD = 0.01043 lbs/gal. x 100,000 gal./year = 1043 lbs./year
- SS = 0.002503 lbs/gal. x 100,000 gal./year = 250.3lbs/year

Step 3

Convert volume, COD and SS to units compatible with the rates which are in increments of 1,000. Divide all three figures by 1,000.

- Volume = 100,000 gal./yr. ÷ 1,000 = 100 units
- COD = 1043 lbs/year ÷ 1,000 = 1.043 units
- SS = 250.3 lbs/year ÷ 1,000 = 0.2503 units

Step 4

Multiply the results of Step 3 by the current rates to arrive at the total yearly Sewer Service Charge.

- Volume = 100 x $3.22* = $322.00
- COD = 1.043 x $365.98* = $381.72
- SS = 0.2503 x $982.69* = $245.97

TOTAL = $880.19

*FY 2022 Rates effective - July 1, 2021 through June 30, 2022

Figure 25: A sample sewer service charge calculation (USD$_b$, 2021)

The annual sewer service charges from 2018-2021 for the top ten industrial dischargers are represented in the figure below:

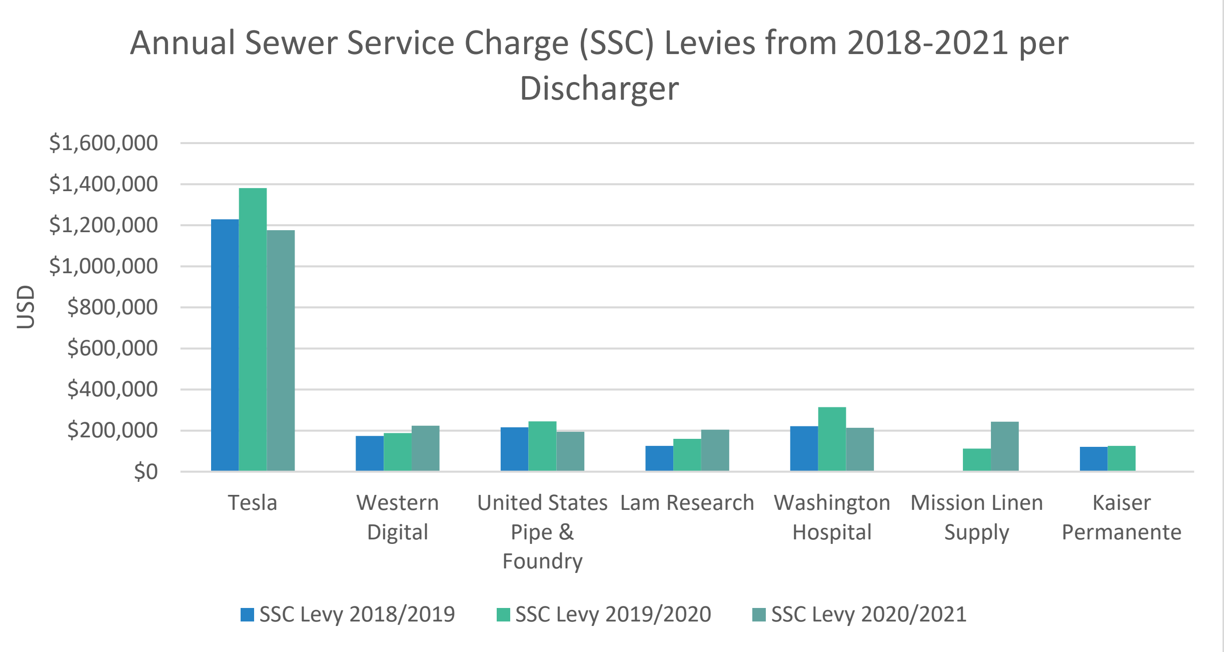


Figure 26: Annual sewer service charge levies (SSC Levy) for each top ten industrial discharger from 2018-2021 (USD$_C$, 2021).

Finally, the cost of purchasing water and discharging wastewater are added together to see an estimate of the cost of using water. These two charges combined can be seen in the graph below:

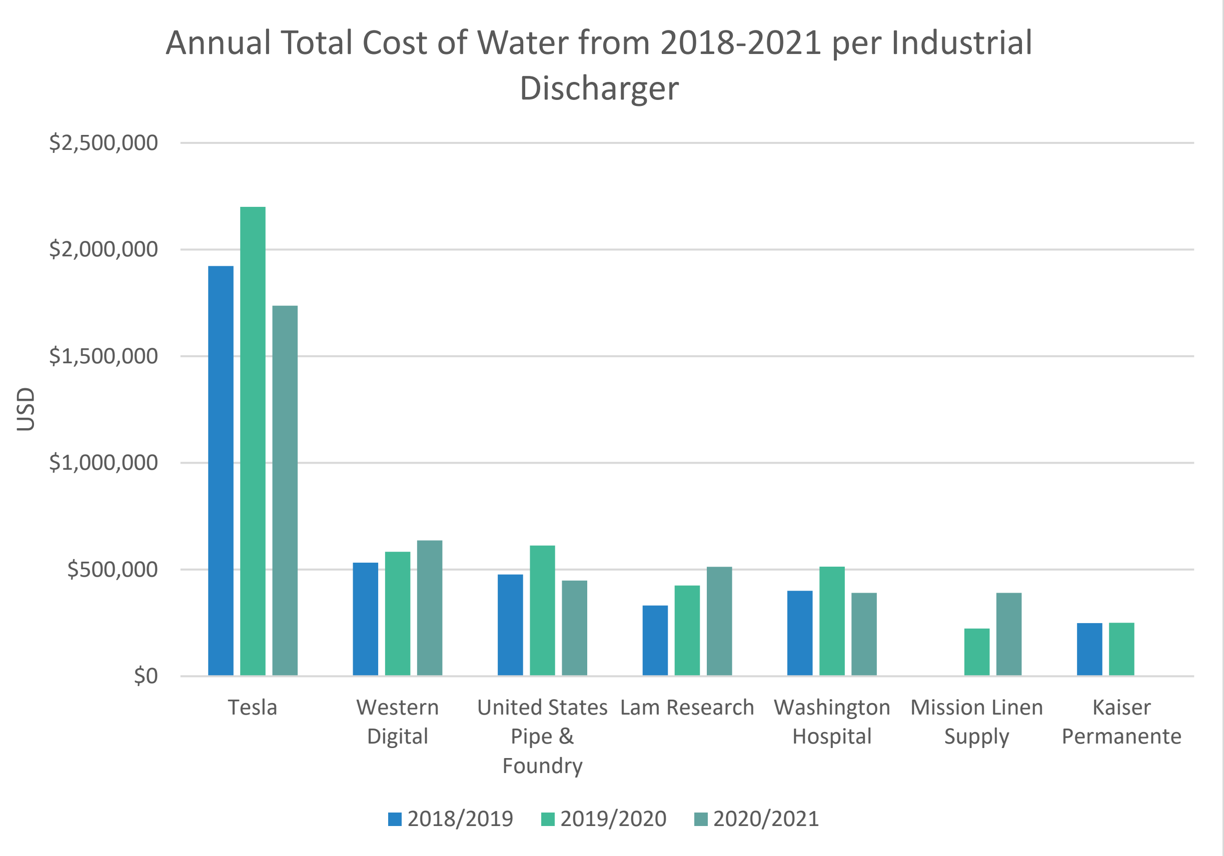


Figure 27: The annual cost of purchasing water combined with the annual cost of discharging water for each top ten industrial discharger from 2018-2021. To calculate the annual cost of purchasing water, the price per unit was multiplied by the annual wastewater discharged and added the annual service charges. This is assuming that the amount of wastewater discharged is the same as the amount of water purchased, which is a limiting factor (USD$_c$, 2021).

These costs can be further broken down to understand the cost per gallon of wastewater discharged by dividing the annual total costs of purchasing water and discharging water, as seen in figure 27, by the flow of annual wastewater discharged ($ per year/gallons per year= $ per gallon). The cost was then converted to dollars per cubic meter and is shown in figure 28 below:

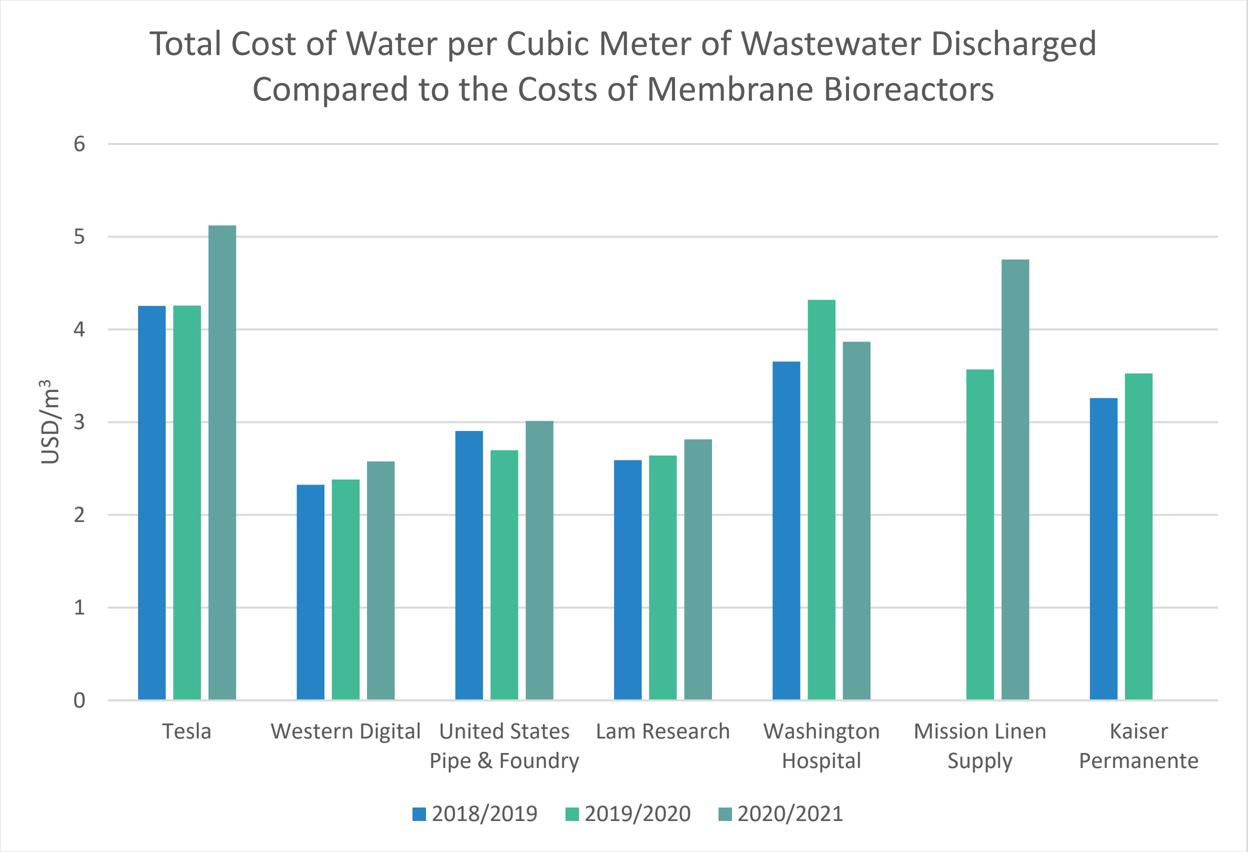


Figure 28: Total cost of water per cubic meter of wastewater discharged from 2018-2021. These unit costs were calculated by dividing the annual total cost of purchasing and discharging water by the annual wastewater discharged.

To understand whether the cost of using water makes it economically feasible to install wastewater treatment and reuse systems onsite, installation and operational costs will be reviewed from the literature.

Costs of Installing and Operating Wastewater Treatment and Reuse Systems

Two costs are typically looked at when analyzing the cost of membrane bioreactors: operating costs, or OPEX, and capital costs, or CAPEX. Operating costs encompass all the day-to-day costs that it takes to operate and maintain the membrane bioreactor. These can include energy consumption, the cost of chemicals, parts replacement, labor costs, sludge waste disposal costs, cleaning costs, amongst others (Judd and Carra, 2021). Capital costs include the upfront costs of installing the treatment system, including redesigning any piping and infrastructure configurations. Since we do not have data on the current operational costs of the top ten industrial dischargers current configuration, it is not possible to compare the full cost to membrane bioreactors, but we can look at the literature and assess the trends.

Capital costs can be variable depending on the type of configuration for the membrane bioreactor, i.e., type of membrane, size, etc. and also the region of the world they are purchased in (Judd, 2017). For this reason, capital costs found in the literature have been inconsistent. Judd and Carra reported total CAPEX costs to range from approximately $800,000-$12M (converted from Pounds in the literature to USD) while Yang et al. used an estimate of $425,000 (Converted from Euros in the literature to USD) for their CAPEX costs. Rashidi et al. used certain cost factors to determine the construction costs of membrane bioreactors; approximately $58 per square meter of membrane area plus $255 per cubic meter of membrane tank volume.

Operational costs (OPEX) found in the literature were also significantly variable depending on the type of configuration, treatment capacity, and what was deemed to be an operational cost. Energy costs were always included as a major factor in the operational costs, but other costs that were included varies. For example, the main factors Yang et al. used in their operational costs calculations were: energy consumption, environmental tax, membrane replacement, and maintenance and repair while the main factors Atanasova et al. used were: electricity consumption, maintenance, desludging, and membrane cleaning. Other case studies included costs around employee labor to maintain the membrane bioreactor, chemical costs, membrane life expectancy, amongst others (Zhang et al., 2021; Judd, 2017; Dalri-Cecato et al., 2020).

Feasibility Determination

There have been various methods to determine the economic feasibility in these case studies in the literature. A frequent method that was found was calculating the Net Present Value (NPV) (Lo et al., 2015; Fraga et al., 2017). The Net Present Value calculates the expected income over a certain period of time by factoring in all costs, i.e., operational and capital costs, similar to a return on investment. In the case of the dairy wastewater in Uruguay, Fraga et al. calculated the Net Present Value using the equation in Figure 29.

$$NPV = \sum_{i=1}^{n} \frac{F_i}{(1+k)^i} - I_i$$

where

F_i = cash flow at each period i
I_i = Initial investment = CAPEX
n = number of periods
k = reference rate

Figure 29: Net Present Value equation (Fraga et al., 2017)

In their calculation, included in the OPEX were penalties that the dairy plant would be subject to if they did not comply with the stricter discharge guidelines (Fraga et al., 2017). The Net Present Value would be accepted when the result was a positive value. It was concluded that when penalty fines were above \$380,000/year, the membrane bioreactor would be economically feasible (Fraga et al., 2017).

Another study indicated that Net Present Value has a power law relationship with flow rate and plant life, i.e., the net present value (in \$) increases as flow rate (m^3/day) and plant life (in years) increases (Lo et al., 2015). This study looked at costs for three membrane bioreactor systems with different flow capacities: 100 m^3/day, 500 m^3/day, and 2,500 m^3/day. This trend was similar to the findings found in other case studies. After CAPEX and OPEX costs were determined for these three systems, the cost (\$) per m^3 permeate was calculated for OPEX and the cost (\$) per liter/day was calculated for CAPEX for each system capacity and the results can be seen in figure 30 below:

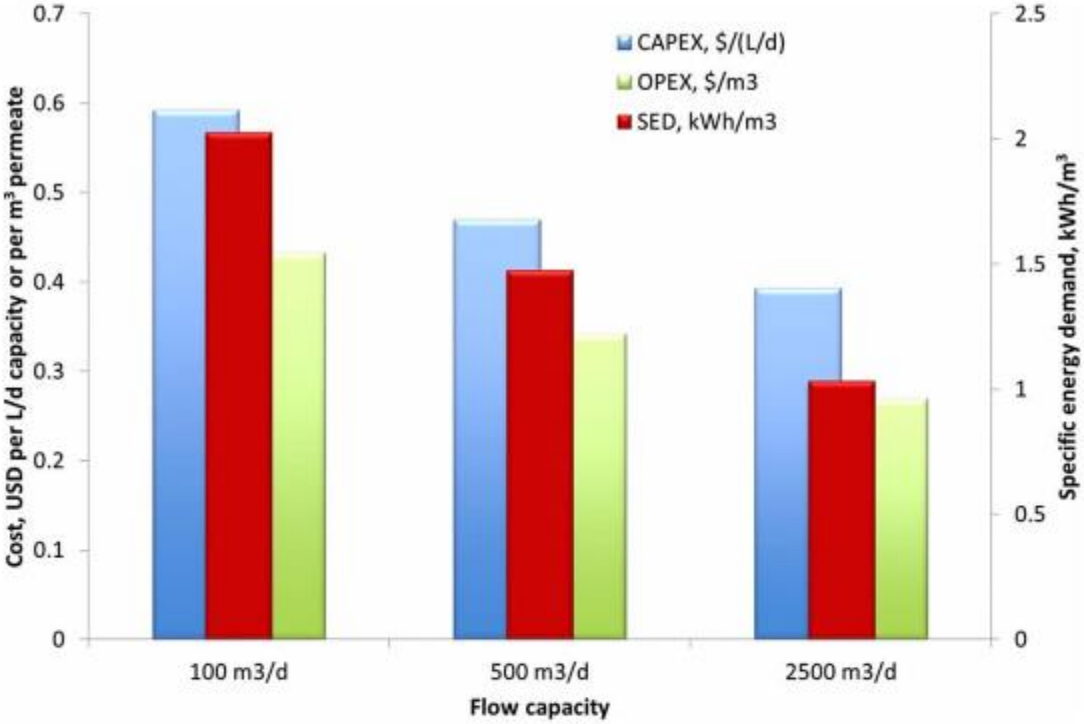
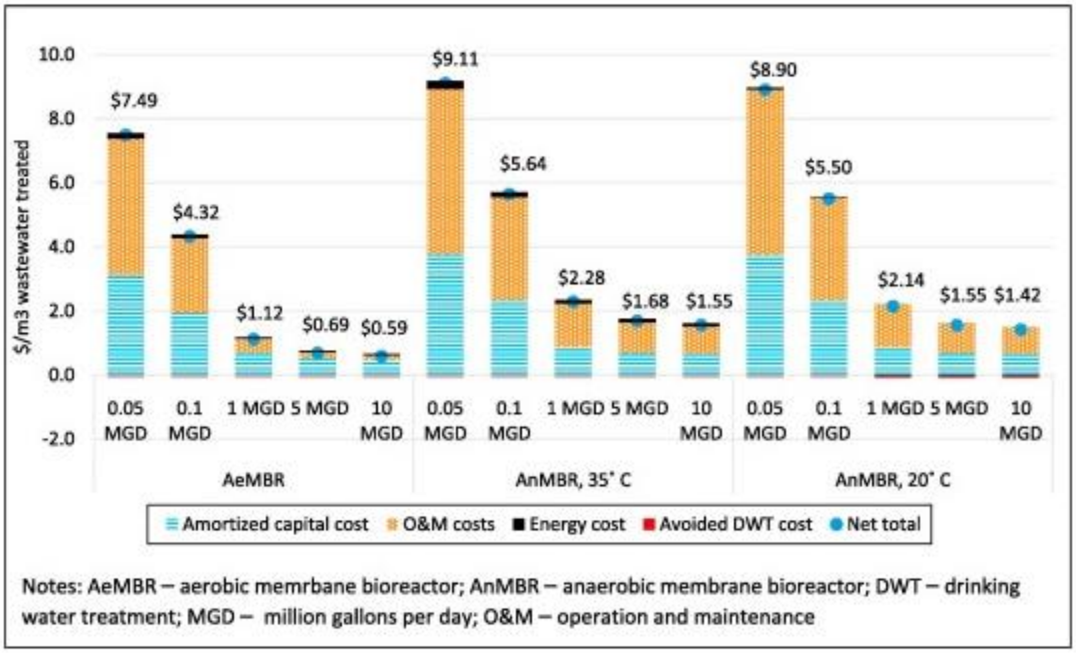


Figure 30: Results from a case study comparing the unit operating (OPEX) and capital (CAPEX) costs of membrane bioreactors with varying flow capacities. The blue bars are capital costs (CAPEX) in dollars per liter per day, the green bars show operating costs (OPEX) in dollars per cubic meter of permeate and the red shows specific energy demand (SED) in kilowatt-hour/cubic meter (Lo et al., 2015).

This data shows that as flow capacity increases, the cost per unit decreases. A study by Cashman et al. portrayed results consistent to these. Cashman et al. performed a life cycle cost analysis of three types of membrane bioreactors and found that the cost per cubic meter ($/m^3) of wastewater treated decreased as the capacity and scale increased as seen in the figure below:



Notes: AeMBR – aerobic memrbane bioreactor; AnMBR – anaerobic membrane bioreactor; DWT – drinking water treatment; MGD – million gallons per day; O&M – operation and maintenance

Figure 31: Results from a case study comparing unit costs of membrane bioreactors with varying flow capacities (Cashman et al., 2018)

Increase in flow does not appear to be the only factor to affect the unit cost of membrane bioreactors. Fetouh et al. conducted a study comparing the cost of 500 m3/day to 5,000 m3/day capacity membrane bioreactors at varying wastewater strengths, weak, medium and strong. In addition to finding that the unit cost decreased as the membrane bioreactor capacity increased, Fetouh et al. also found that as the strength of the wastewater increased, the unit cost also decreased. This relationship can be seen in the figure below:

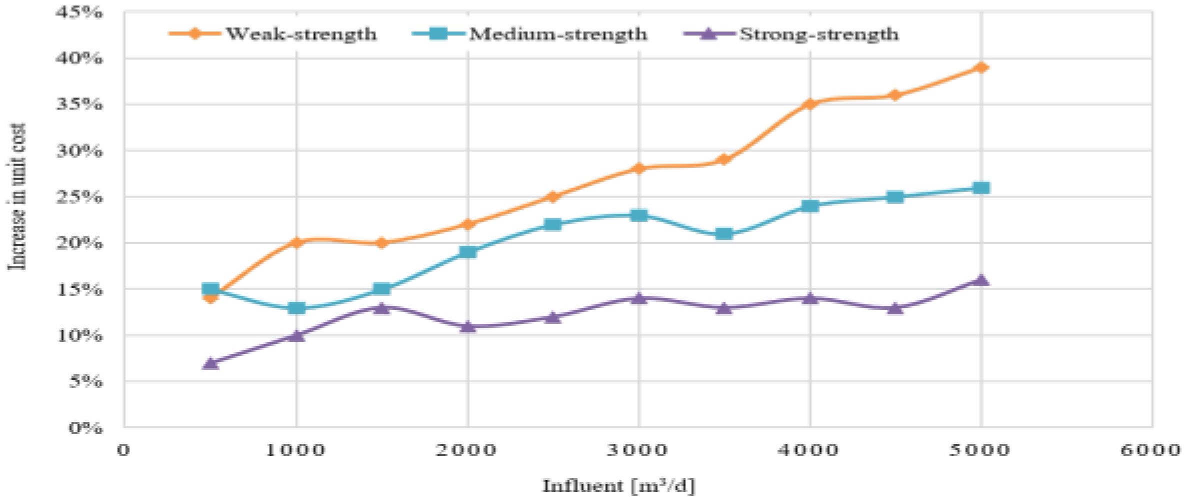


Figure 32: Increase in unit cost percentage between varying wastewater strengths from the Fetouh et al. case study. The orange line portrays the weak strength wastewater, the blue line portrays the medium strength wastewater, and the purple line shows the strong strength wastewater. Strength of wastewater is determine by chemical oxygen demand and suspended solids values, i.e., the greater the chemical oxygen demand and suspended solids values, the greater the wastewater strength (Fetouh et al., 2021)

This is consistent with the literature in that membrane bioreactors are more efficient in removing high-strength wastewaters compared to low strength wastewaters (CITE A FEW SOURCES). Using these trends in the data, we can predict scenarios where the economic feasibility might be greater in some areas rather than in other areas.

From the annual wastewater quantity and sampling data gathered from Union Sanitary District, we can see that some industrial dischargers discharge significantly higher volumes of wastewater and at higher strength than other industrial dischargers. For example, Tesla has the highest amounts of wastewater discharged with an average of 115,077,012 gallons of wastewater discharged per year, and also has comparatively high wastewater strength with chemical oxygen demand and suspended solid values second highest to Mission Linen Supply. In reviewing the trends found in the literature that the unit cost of operating a membrane bioreactor decreases as flow capacity and wastewater strength increase, it can be reasonably concluded that it would be more economically feasible for Tesla than for other industrial dischargers. Although we cannot calculate an exact net present value or return on investment for each discharger without knowing what the true operating costs would be at each facility, we can compare the data we have to existing data in the literature on the unit costs of operating membrane bioreactors.

To make an estimate on which industrial dischargers wastewater reuse might be feasible for, we can compare the calculated total costs of water per cubic meter wastewater discharged calculated in Figure 28 to the membrane bioreactor cost per cubic meter of wastewater discharged in Figure 31. I graphed these costs together to produce the below graph:

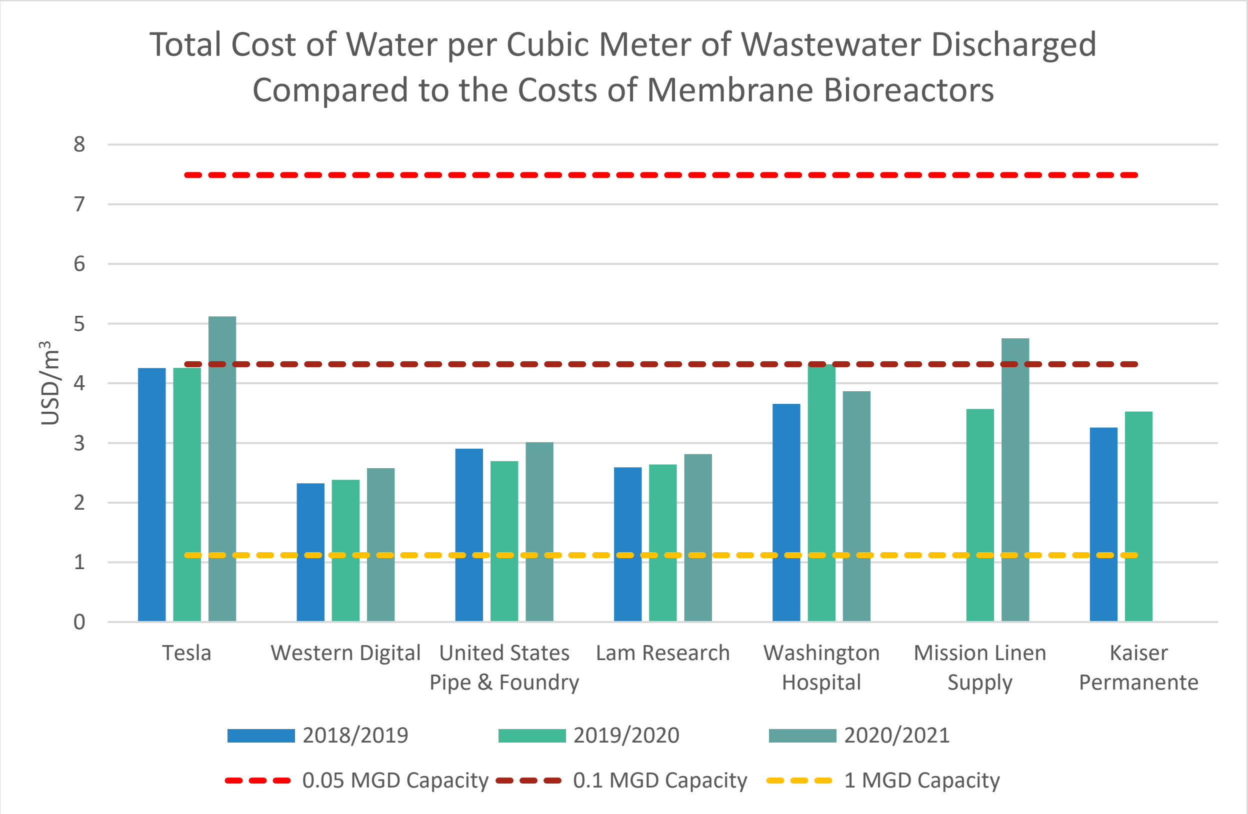


Figure 33: Industrial dischargers in the Tri-City area unit costs of current wastewater operations vs. the unit costs of operating a membrane bioreactor. The industrial dischargers current wastewater operation unit costs were calculated by dividing the annual total cost of purchasing and discharging water by the annual wastewater discharged. The membrane operating costs (the dashed lines) were provided by Cashman et al. in 2018.

For an aerobic membrane bioreactor, Tesla would fall within the 0.1-1 Million Gallons per Day range, which equates to $1.12-$4.32 per cubic meter of wastewater treated (Cashman et al., 2018). It can be seen in the figure above that Tesla's current cost of water is greater than the higher end of this range at $4.52/cubic meter of wastewater discharged. This shows that the current costs of water are greater than the costs of membrane bioreactor treated wastewater. However, there are a few limiting factors in this comparison.

Cashman et al.’s studied membrane bioreactors that were used for a central waste water treatment plant. Therefore, its costs factored into the equation included capital costs, operation and maintenance costs, energy costs, and avoided drinking water treatment costs (which Tesla would not have). The calculated cost of $4.52/cubic meter of wastewater discharged is making many assumptions (e.g. water consumption is the same amount as wastewater discharged) and not inclusive of all operating costs. Because the avoided drinking water costs are minimal compared to the other costs and Tesla’s true costs of water with their current setup would in actuality be higher than what was calculated, it is still likely that the costs of operating an aerobic membrane bioreactor would be less for Tesla. However, this would not be true for other industrial dischargers.

The average calculated of water for the past three years for Western Digital was $2.39/cubic meter of wastewater discharged. In Cashman et al.’s study, Western Digital would fall within the 0.1-1 million gallons per day range, which also falls within the $1.12-$4.32 per cubic meter of wastewater treated range. Western Digital’s wastewater discharge volumes fall closer to the 0.1 million gallons per day, therefore the cost of operating an aerobic membrane bioreactor would likely cost more than their current configuration.

Co-Benefits of Decentralized Wastewater Treatment and Reuse

There are several co-benefits to using a more decentralized wastewater treatment system compared to the traditional central wastewater treatment plant. As population and industry begin to increase, the wastewater treatment plants may reach their capacity on the amount of wastewater that can be treated resulting in the need for infrastructure updates (Wu et al., 2020). The need for infrastructure updates will drive costs for the wastewater plant, which will subsequently drive costs for the industrial dischargers. Relying less on the wastewater treatment plant will keep costs in the control of the industrial discharger. Relying less on the central wastewater treatment plant also benefits the industrial discharger and the plant in the case of extreme events.

Decentralized wastewater treatment and reuse systems allow industrial dischargers to procure less water from Alameda County Water District, resulting in less stress on the water supply in the catchment. Water use reductions allow the area to expand without causing water stress to the region, especially in cases of drought and also assist the district to meet demand.

In the case of an earthquake, there could be water supply shortages of up to 50% as discussed earlier (ACWD, 2020). Using a decentralized wastewater treatment reuse system increases the chance of having an unaffected water supply in case an earthquake affects Alameda County Water District's water supply. This may not be sustainable long-term, but it would at least provide temporarily relief. Relying less on Alameda County Water District's water supply also benefits the entire watershed area.

Management Recommendations

Implement Policy

As it currently stands in California, there are not any regulations surrounding the efficient use of water until there is a water shortage in the district and the water contingency plan is activated (ACWD, 2020). Policy should be implemented to take a more proactive approach rather than reactive. There are many actions in the water shortage contingency plan that will be required in a water shortage that could be implemented now that would have the capability to conserve water at little cost to industry. One that could especially make a difference in conserving water is requiring industry to conduct an internal audit of all water use to identify opportunities to improve efficiencies or opportunities for water reuse. This action currently exists in stage 3 (water shortage up to 30%) of Alameda County Water District's water shortage contingency plan. Understanding a facility's water use is an important aspect to water conservation. It is possible that there are major inefficiencies that the industrial user is unaware of and many areas where the industrial user could reuse their wastewater. By requiring industrial users to conduct an internal water use audit, this gives them the opportunity to identify any "low hanging fruit" in reducing water use and reusing their water to make a meaningful impact on water reduction. Industrial water users could potentially be more inclined to reuse their water when they are able to identify where their inefficiencies are.

California should implement the requirement of an initial internal water use audit to industrial users in addition to requiring the industrial user to set goals to reduce water use as an outcome of the audit and evaluate the feasibility of reusing water. Because water reuse is more feasible to industrial dischargers who generate high amounts of wastewater, California should implement a threshold at which industrial users need to evaluate the feasibility of wastewater reuse. The industrial user should also be required to report on the progress of those goals every couple of years to ensure progress is being made. California has a similar requirement surrounding hazardous waste generation, Senate Bill 14 (SB14). SB14 requires generators of hazardous waste, who generate over a certain threshold, to identify their processes generating the greatest amount of waste and goals to reduce waste generation at the source. Generators are required to report on their progress every four years.

Incentivize

For businesses, Alameda County Water District currently provides two rebate options: 1) high efficiency toilet and urinal rebates and 2) weather-based "smart" irrigation controller rebates (ACWD_c, 2021). Alameda County Water District should provide further rebate options for installing water reuse and water efficiency equipment at industrial plants. The initial capital costs and maintenance cost of wastewater treatment and reuse systems, particularly membrane bioreactors, can be cost prohibitive. Providing financial incentives to industrial users to install and maintain these systems may further motivate industrial users to implement wastewater reuse.

East Bay Municipal Utility District (EBMUD, the water supplier in the East Bay of the San Francisco Bay Area) currently offers their business customers this option (EBMUD, 2021). Businesses must go through EBMUD's application process which includes participating in a water conservation survey that identifies water conservation measures and opportunities to improve water efficiency and reduce water usage by installing technology (EBMUD, 2021). The rebate provided is $0.75 cents per 748 gallons of water saved (EBMUD, 2021). This provides the business an opportunity to offset the costs of installing and maintaining the treatment systems (EBMUD, 2021). The percentage of industrial customers for Alameda County Water District (5%)

is similar to the percentage of industrial customers for East Bay Municipal Utility District (6%) (ACWD, 2020; EBMUD, 2021). Alameda County Water District should implement similar rebate programs to East Bay Municipality Utility District for industrial and business water users to promote wastewater reuse with the ultimate goal of conserving water in the district.

Provide Education

Alameda County Water District's current educational material provided through their website is largely focused on residential customers. The education material consists of brochures, fact sheets, Alameda County Water District's plans, and information on special projects and programs (ACWD_c, 2021). They also provide newsletters to their customers three times per year (ACWD_c, 2021). However, the newsletters appear to be more aimed towards residential customers and what residential customers can do to conserve water. Alameda County Water District should provide education materials directly for industrial customers to educate them on the consequences of drought to industrial customers and current technologies to improve water efficiency and implement wastewater reuse.

East Bay Municipality Utility District has a commercial, industrial, and institutional website page that provides education materials specifically for these types of customers (EBMUD, 2021). These education materials include their commercial, industrial, and institutional rebates, a WaterSmart Guidebook, which provides information on water-saving technologies available for industrial users, and a newsletter specific to commercial/industrial customers (EBMUD, 2021). Alameda County Water District should provide more water efficiency education for industrials water users to promote wastewater reuse and educate industrial users of the potential of water shortages in the case of drought. This may motivate industrial users to find alternate sources of water supply, e.g. wastewater reuse, since it is in the best interest of the business to be able to maintain and expand operations.

Conclusions

Federal and local pretreatment regulations determine what will be found in the industrial wastewaters in the Tri-City area when they are discharged to Union Sanitary District.

The local limits specify which pollutants are restricted at certain concentrations and general prohibitions prohibit certain types of pollutants. This can help us to better understand what the industrial wastewaters in the Tri-City area consist of to determine the appropriate treatment and reuse technology.

The industrial dischargers in the area encompass a variety of industries from automotive manufacturers, like Tesla, to hospitals, like Kaiser Permanente. This also means that the composition of the industrial wastewaters in the area can vary as well. Some industrial wastewaters contained high-strength wastewater, i.e., high chemical oxygen demand and suspended solids, while others contained low-strength wastewaters. Volumes can vary from 16,084, 992 to 136,393,723 gallons discharged per year, per industrial discharger. Overall, almost every industrial discharger in the region increased their wastewater discharge volumes year after year.

The increase in demand of water consumption is problematic for the future Alameda County Water District water supply. As demand continues to increase through 2050, water shortages is predicted to be seen during times of drought. Water shortages of up to 18% are predicted during single and multiple dry years, which are expected to continue and worsen in California. Extreme events, such as earthquakes, can result in more extreme water shortages of up to 50% and greater. Due to these expected water shortages, industrial companies should evaluate wastewater reuse as an alternative water supply source.

Water reuse regulations in California drive what kind of technology needs to be used to meet reuse requirements. For most industrial wastewater reuse purposes, disinfected tertiary treatment is required while turbidity and disinfection levels must be met. Membrane bioreactors are a viable option to meet California wastewater reuse standards in addition to meeting the needs of some of the industrial dischargers in the Tri-City area.

Membrane bioreactors have been proven to be an attractive wastewater treatment and reuse technology option due to their reduced footprint and high-quality produced effluent. There are several case studies in the literature that prove that membrane bioreactors, paired with ultraviolet disinfection, would be sufficient to meet California water reuse standards. Membrane bioreactors are most compatible with high-strength wastewaters at high volumes (i.e., hundreds of thousands gallons wastewater treated per day). It is obvious that membrane bioreactors are a good candidate to treat wastewaters at the acceptable reuse standards, but it is not as obvious as to whether this is economically feasible for industrial dischargers in the Tri-City area.

The costs of purchasing and discharging water is expected to continue to increase in the Tri-City area. The top industrial dischargers in the area pay from a range of just over $2.25/cubic meter of wastewater discharger to around $5.00/cubic meter of wastewater discharged. This is a conservative estimate that assumes water consumption is the same as wastewater discharged and other costs, like wastewater trucked off-site and treatment chemicals, are not included in the calculations. Capital and operational costs of membrane bioreactors can be high. However, only taking purchasing and discharging water costs into consideration, wastewater treatment and reuse at some of these industrial sites appears to be economically feasible.

Membrane bioreactor technology is most feasible for companies that discharged high volumes of wastewater and at high-strengths, like Tesla. These higher volumes and higher strength wastewaters increases their cost of discharging wastewater, making a membrane bioreactor more feasible. Alternatively, industrial companies with lower wastewater volumes at lower strengths might not find it economically feasible to install a membrane bioreactor, like Western Digital. Industrial wastewater reuse onsite is not only beneficial to the industrial company, but to the wastewater treatment plant and the entire catchment as well. Reduced wastewaters being discharged to the wastewater treatment plant, i.e., Union Sanitary District, can prevent the treatment plant from being overloaded resulting in additional infrastructure needed. Decentralized wastewater treatment and reuse systems will also lessen the stress on water supply allowing for population increase. Industrial wastewater reuse at the industrial plant's own site is a beneficial treatment alternative which should be evaluated more often.

Municipalities should implement policy to require industrial dischargers to evaluate inefficiencies in their wastewater process and set goals to increase efficiency. Understanding a site's wastewater processes will help these companies understand where water is being wasted and can motivate them to implement more efficient measures including wastewater reuse.

Incentives should be provided to offset the costs of installation and maintenance costs to promote the implementation of current technologies. Lastly, education should be provided specifically to industrial users to make them aware of the potential water shortages and to inform them of current technology alternatives.

Industrial wastewater reuse is an attractive solution, especially to large companies like Tesla. In this drought stricken in environment, industry is going to have to play a role in conserving water for their own benefit. Predicted water shortages in the future are going to force industrial users in the Tri-City area to reduce their water usage. It would be beneficial for industry to reduce their water usage by reusing their wastewater proactively over time, rather than reactively when government mandates force them to.

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