5-15-2021

Cost Saving Proposal for Dubai Main Wastewater Pumping Stations

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By

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A Graduate Paper/Capstone Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Master of Engineering in Engineering Management

Department of Mechanical & Industrial Engineering

Rochester Institute of Technology

RIT Dubai

May 15, 2021

RIT

Master of Master of Engineering in

Engineering Management

Graduate Paper/Capstone Approval

Student Name: Mohammad Mansoor & Khaled Alhosani

Paper/Capstone Title: Cost Saving Proposal for Dubai Main Wastewater Pumping Stations

Graduate Paper/Capstone Committee:

_Dr. Slim Saidi________________ ___Associate Professor___ ______ _____May 18, 2021_

Name **Designation** **Date**

Name **Designation** **Date**

Abstract

A city that is free of hazardous chemical and pollution is a city with safe and healthy population. Keeping a city such as Dubai safe and healthy is a never ending task with too many stakeholders and too many variables. Examples are reducing carbon footprint, timely trash disposal, wastewater management, and the list goes on. Wastewater management is one of the most important and essential requirement for keeping the city and its people safe and healthy. There is an existing sewerage system that the emirate of Dubai continues to heavily rely on. The network includes the pipelines, the wastewater pump stations, and major wastewater treatment plants in order to manage and remove wastewater from the city. In addition to the administrative resources required to operate and maintain the network, it also consumes tremendous amount of energy each year as part of the operational requirements. The level of energy has been on the rise for the last few years and continues to do so. This paper investigates the possibility of reducing the energy required to run the wastewater pumping stations that are part of the network. Based on the information gathered and the data collected, we have established that most of the energy consumption is due to the power consumption of the pumping stations. Therefore, Dubai Municipality can reduce the energy consumption of these major wastewater pumping stations and save from 15% to 25% of the total cost in the next five years. Although there are some constraints and limitations, an integrated planning approach including qualitative and quantitative measures can help realize such saving.

Keywords: Wastewater, Pump, KPI, Flow Rate, Head Loss, Forecast, Energy Consumption, Statistical Analysis, ANOVA, SWOT, RCA

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Section 1: Problem Statement

Regardless of its form, energy has always been and will continue to be the most precious of all resources. For energy, difficulty arises at various stages. For example, energy is difficult and expensive to transform, to transport, to control, to increase its efficiency, etc. Thus, being as precious as it is, energy saving should be on the top of the list of any organization's agenda.

Dubai Municipality is one of the leading governmental entities in Dubai responsible for providing various services and managing several ongoing projects. One of them is the wastewater management service in the emirate of Dubai. The sole purpose of this service is keeping the city clean and free of hazardous elements that could endanger the lives of its people. Wastewater management consists basically of collecting all wastewater, transporting it to designated areas through the network and pumping stations, and finally treating it before safely disposing it or recycling it (e.g. irrigation).

A large portion of the process involves moving wastewater through the sewerage network using gravity and/or lifting pumps. In case of electrical pumps, energy consumption is substantial and the cost can reach millions in UAE Dirhams. Energy consumption has been on the rise for the last few years and if left alone, it will continue to do so unless we do something about it.

As we know, Dubai does not have too many natural resources such as oil and gas and thus, energy can be expensive to come by. The problem is how to reduce energy consumed by these electrical pumps at the wastewater pumping stations to an acceptable level.

In this paper, we will define what an acceptable level is and how we can go about reducing energy consumption of the major pumping stations in the coming five years.

Section 2: Literature Review

2.1 Optimization of Wastewater Lift Stations for Reduction of Energy Usage and Greenhouse Gas Emissions. (David Wilcoxson and Travis Crane).

This is an assessment report for the Intergovernmental panel on climate change (IPCC) concentrating on the relationship between the increase in the greenhouse gas (GHG) concentration and the higher global temperature. Lifting pumping stations uses a lot of energy causing major GHG emissions. The study focuses SCADA configuration to minimize various types of waste. The author suggests utilizing the hydraulic modelling results to reduce operating pressure and energy consumption of the pumps. This study can also be used as a guidebook to optimize using advanced hydraulic modelling and new generation SCADA systems.

The article starts with factors that contribute to unstable flow rates and higher energy consumption by the pumps such as inflow and infiltration of the network, the old and aging equipment, etc. Despite the advances made in technology, the author claims that many of the wastewater stations still rely on old and sometimes obsolete or manually-operated control systems which lead to energy wastage. Additionally, oversized pumping designed for peak loads is also one of the factors that lead to higher energy consumption.

The project team proposes a revised operation control for the wastewater lifting stations system using "new control system configuration that will allow data communication directly from the PLC's at the lift station to the wastewater centre control room." The author claims that this SCADA system will ultimately reduce operation cost by reducing the energy consumption around 20%. Thus is done through automated "commands to sequence the pumping units to maximize capacity and reduce the energy demands of the pumping units."

2.2 The US EPA's Collection Systems Technology Fact Sheet, Sewer Lift Stations

This is an article that emphasizes the importance of having a centralized monitoring system that uses real time data to analyze the network performance taking into account various factors such as infiltration, inflow, maintenance schedules, etc. and use it to help operate more efficiently. With efficient operation, maintenance and service costs can be reduced at all time.

As stated by the US EPA's Fact Sheet, "Sewer Lift Stations states that "power costs account for 85% to 95% of total operational and maintenance cost". (Beaudoin, Benoit and Pierre Michaud 2018).

With the above in mind, the author focuses on the importance of reducing cost by reducing the electrical energy used by the pumping stations. Having the right tools (software and hardware) that can help to monitor the system and provide the necessary information/data that can help in isolating the problem and reduce the energy waste. For example, the information on the current can tell us when the pumps start and stop and therefore we can till the amount of energy consumed by the pumps during its operation.

One system the author suggests is the SCADA system. It is a centralized monitoring system that is used in various fields such as the fire prevention. SCADA control system can provide information on each and every pump at predefined intervals or during times when the alarms sound off. Thus, it alerts to any abnormal behavior. When it is linked with other software, the system can even trigger alarms that indicate low efficiency. For example, when the pump is operating at lesser capacity but still the electrical energy consumption is a bit high. Such system can also help prevent catastrophic events. In addition, there are supporting systems that can be jointly installed with SCADA and can help making the necessary changes dynamically which leads to more efficient operation.

2.3 Statistical modelling of wastewater pumping stations costs. (Marth Carbal, Dalla Louertro, Daida L.C. Covas).

An interesting research on the key-parameters that influence the construction cost of wastewater pumping stations in addition to a method to estimate/forecast the cost using statistical methods. A set of 360 wastewater pumping stations in Portugal were analysed using both principal component analysis and cluster analysis in addition to linear regression analysis. This article highlights some of the essential requirements for estimating the cost of new pumping station. Thus, giving us the necessary information what it takes to build, maintain and operate one. As stated in the article, this is an important step in the strategic planning. Although our paper talks about cost saving in the operational arena, the operating cost is a direct function of the station capacity. For example, cost of building a pumping station is depends on the required total hydraulic power which in turn depends on the estimated flow rates. What matter to us here is the fact that if we were to reduce the operational cost, we have to be careful to balance the current needs and the future needs with the equipment required such as the type of pumping stations, number of pumps groups, total flow-rate, the pumping head of each pump group and the total hydraulic power required. .

2.4 Operational energy-efficiency improvement of municipal water pumping in California (A. DeBenedictis, B. Haley, C.K. Woo b, E. Cutter).

The purpose of this article is to discuss regression based approach to estimating the energy (kWh) and the kW saving using Operational Energy-efficiency program for a municipal water pumping station in California. An interesting approach in which VSD (Variable-speed drive) technology aided by a PLC (Programmable-logic-controller) might improves operational energy efficiency. The authors agree with our point which states that electricity savings can occur via water supply management, leak prevention and better equipment life cycle plan. Using the same methodology that we used which is collecting past history data (May 2010 to Aug 2011) to perform their study. The authors also suggest that the best statistical method to use here is a linear regression one which is what we used in analysing our data as well. They also emphasize on the importance of operating the pumps at its designed efficiency level (near its optimal kW-output level). Variable pump speeds using PLC might do more harm than good to the pumping system efficiency. This is an important point in which this article contributes to the pumping stations energy saving studies. Without getting into the technical details, the authors conclude by stating that regression model is the best method to describe the operational efficiency and second, we have to be careful of using VSD-PLC on pump efficiency as it is not always the solution. VSD-PLC is more suitable for pump stations that are not operating within their optimal kW-output values.

2.5 BSI Standards Publication European standard for the Pump system energy assessment ISO/ASME 14414:2019).

This is the European standard approved on 27th December 2018 as the bibliographical reference. Written in three languages (English, French and German), for the CEN members of 34 countries most them in Europe. After brief introduction, the document provides some valuable information about pumping systems and consumption of energy. The document emphasizes the points discussed in this paper. For example, excess energy added to the pumping system, factors that increase the cost of maintenance, energy waste caused by using oversized pumps and sub-systems, etc. It also provides some suggestions on how to reduce energy consumption and improve efficiency while at the same time leading to reducing the carbon footprint. The information and the examples provided in this document on running efficient system and energy reduction opportunity are based on knowledge and wealth of experience. For example, it helps on deciding the required software, how to perform the pre-screening worksheet, description of the specific energy consumption, information on the parasitic power, and examples on the pumping system efficiency indicator. It starts with the basic knowledge on how to perform energy assessment for a pumping system, types of power to be assessed, what is required for an assessment team (skills). What support is needed, how the communication should be, what the objectives are and to decide on the boundary of the assessment, how to form an action plan, what and how to collect necessary data, what the different levels of assessment/analysis are, etc. It provides guidelines on how to report the findings before it concludes with the information on how to find opportunities for improvement. I find this document to be one of the best and it should be, in my opinion the catalyst in which the Dubai Municipality should use to formulate their frame work for energy saving on the major pumping stations.

2.6 Object KPIs for the digital transformation.
(Jordan, Frank, PhD. Comenius University, Bratislava)

In this article, the author defines what KPI (Key Performance Indicator) are as the way he understands it based on knowledge and experienced gained by the individual. Organizations use KPI as control mechanism to manage their companies or operations. The author also spoke about the importance of data and how nowadays large amount of data can be easily analyzed using available advances in technology such as cloud computing, AI and deep learning. He emphasizes on the importance of KPI to help organization improve their processes and grasp the opportunities out there. We believe that without KPI or some kind of standard in which we need to refer to, we would not be able to evaluate our process whether it is good or bad and therefore if improved is needed. KPI although helpful, they do not provide direction to employees and management for improvement.

The author illustrates the importance of having KPI as performance measures especially in an industry similar to the one we are discussing here, the wastewater management. for example, KPI can be used to measure the upper and lower limits of operation hours of the pumps in the pumping stations and then use the pump design specification (working hours) to set the upper and lower boundaries and decide whether we are in the critical or not. Based on the results, we then can take one step further to bring the number of the pump working close to the design one and thus maximize the overall efficiency of the pumps. The author goes one step further and suggests a feedback back loop based on the KPIs as input for the business model and OPEX and CAPEX as output.

Building a suitable adaptive business model supported by suitable KPIs and fully automated process can bring efficiency up saving on energy and at the same time reduce the risks of failure and emergencies.

2.7 Australia Wide Pump Energy Efficiency Benchmarking Demonstrates Opportunities for Improvement. (Daniel Livingston et al.)

This is an interesting article about the importance of pump energy efficiency benchmarking and possible improvement. Australia is one of the countries that are very much concerned about the availability of water and the greenhouse effect. To reduce the greenhouse effect, energy at the pumping station should be reduced but by how much? The author answers this question in his study going through there steps: develop a common energy benchmark for the wastewater pumping station, identify measures that are implemented and led to best practice on energy efficiency performance, use this information to further learn from this best practice.

Pump energy efficiency indicator is basically the amount of consumed against the work done. This of course depends on the liquid volume, flow rate, gravity, pressure differential, and several other variables. The goal is to reach 100% which is the energy consumed is equal to energy imparted. Of course, I reality this is does not happen. The author then goes about how the data was collected from 128 pumping stations, validated and then analyzed. In his article, he emphasized on the data validation since there possible errors due to instruments, method of taking the data, etc. and how to improve the data quality.

In his results, he discussed the importance of having reliable instruments, constraints when designing larger pumping stations, and more attention is paid to larger pumping stations.

Last but not least, he provided some very useful recommendation on what constitutes a good practice to increase wastewater pumping station efficiency such as efficient piping work to reduce friction head, better pumping control system that matches the flow rate, using multiple pumps' size based on the need, better maintenance plan and importance of having the right data.

Section 3: Introduction

Basic human needs are defined by the five levels of Maslow's Hierarchy of needs. The first and the basic needs are grouped under the Physiological needs such as food, sleep, shelter, etc. Shelter as we know contributes also to the second level in Maslow's pyramid which is safety and security. The availability of safe and secure shelter might have been in the past the responsibility of one person who is the head of the family. However, now more than ever, we humans are social beings and thus live as groups in social communities. As the groups get larger and larger, communication and interaction among the groups become more and more. For example, houses become neighbors; neighbors become villages, and nearby villages grow to become cities and so on. The interaction among humans in such social environment becomes so mingled like a network of many nodes that is tightly held together and cannot be easily separated once they are entangled. In real life, these nodes can be presented by the different entities or authorities which reflects the type of interactions that come together to serve the population.

The nodes or the entities work together to bring different communities under one unified umbrella. Under this umbrella, communities share many services (economies of scale). For example, food, clothing and other products are provided through various entities that work directly or indirectly together such as suppliers, retailers, airports, seaports, transportation centers, etc. An average size city such as Dubai is a good example of how the different types of pre-determined needs are achieved through the availability of resources. For example, Dubai electricity and Water Authority (DEWA) with its facilities works with various governmental and non-governmental entities to ensure the need of electricity is provided in the right quantities on time and at all times. Other entities such as Dubai Municipality with its partners provide the some services including but not limited to urbanization planning, sewerage service and wastewater management/treatment.

One of the most important and highly needed services is the management and treatment of wastewater. Wastewater cannot be left alone to become a health hazard. Thus recycling and/or disposing of it, is a task that is by no means an easy one. It involves careful understanding of the existing situation, its source, driving forces and the requirements that must carefully be considered to ensure safe wastewater management solutions. The bad news is that it is not an easy task for many reasons. For example, wastewater service is a dynamic one in which it is defined by the input nodes, that is the wastewater and the output nodes and that is the treated or recycled water that can be used or disposed of in the best manner possible. Thus, wastewater management is basically a series of events or steps that are first identified, measured and analyzed for better control and improvement. Despite the various challenges, the good news is that Dubai Municipality has the resources necessary to manage wastewater in the best way possible. In doing so, a lot of resources are used to support wastewater management. As the population increases, so is the type and level of services increase as well. For example, maintenance service and energy provisioning are on the rise as more people demand/expect more services.

This document focuses only on the energy consumed by the wastewater major pumping stations located in the emirate of Dubai. Using available data and statistical means, we will first investigate the reasons behind the increase in the energy consumption. Second, we will present solutions that can lead to reducing energy consumption over a period of time. Last but not least, we are going to briefly mention the list challenges and constraints that limit or influence the solutions.

Section 4: Current Situation

If we were to describe the Municipal part of a government, it is basically a territorial body that is responsible for a defined area. Dubai municipality provides many services within the emirate of Dubai in which these services are driven by the demands of the public such as clean neighborhoods and wastewater management. Such needs are actually essential to maintain good and healthy environment in which the population can have a better life.

In recent years, the demand for wastewater management service by the various governments and non-governments has increased tremendously which has enticed many changes to ensure continuous and smooth operation. To help achieve its goals, the emirate of Dubai has given extensive power to the municipality to decide and setup its own local projects. Some are short-term projects while others are long-term projects that span over many years. Moving forward with its planning, Dubai municipality defines success by its ability to achieve its goals within the given time frame and available resources. Projects' planning and resources allocation constitute major activities of the department. For example, wastewater management in the emirate of Dubai must ensure all wastewater, as they are generated, are continuously pumped out to the allocated sewerage catchments before taken to the treatment plants. Failure to do so will result on endangering the health and safety of the city and its population. As we will find out later, it requires tremendous amount of effort and resources. However, the wastewater network does not cover the entire area of the emirate. The reasons vary from limited available budget to the fact that not all areas need to be included in the network since it is has very low population.

The emirate of Dubai has two major sewerage catchments. The first one called Al Warsan (WSTP) which is located in Deira district. The second treatment Plant is Jabel Ali (JSTP) is located in Bur Dubai district. Please see appendix 1**.**

Both plants include major and subsidiary pump stations. While the major pump stations transfer wastewater mainly by using the gravity force directly to the STPs, pumps of lesser forces are used to help pump the waste water as well.

There are a total of twelve major pump stations in the entire network. Again, each and every pump in these stations is being fed by subsidiary pump stations using various means and including the gravity flows.

Al Warsan catchment: it has four pump stations; PS-C, PS-E, PS-G and PS-V that pump into the pump station PS-X which in turn it pumps into the Al Warsan Treatment Plant. In addition, pump stations PS-Q, PS-K and PS-I pump directly into the Al Warsan Treatment Plant.

Jabel Ali Catchment: on the other hand, this catchment consists of three pump stations PS-H, PS-S and PS-Sn that pump into the pump station PS-X1 which in turns goes to the Jabel Ali Treatment Plant. Please see appendix 2 & 3 for both catchments.

Although regular operation is maintained throughout the year, planned pump station shutdowns do take place to service and maintain the pumps and their associated systems. It is important to mention that each and every pump station has additional backup pumps in case of one of the pumps stops. In rare cases, unplanned station shutdowns take place due to pumps being inoperable and corrective maintenance is required. In such cases, wastewater flow is diverted to nearby pump stations. However, this requires careful monitoring in order not to exceed the specified design flow for the pumps which if it happens too often might damage the pump or at least reduce its life span.

Although majority of the water is wastewater, water could also inter the network from other sources such as Storm water and infiltration. Thus, these types of water should be minimized to reduce pressure on the network in general and on the pumps and treatment plants in particular. The last two types of water is difficult to estimate and thus difficult to control. However, it is easy to measure the level on infiltration and storm water by taking the measurement at the input and the output and then compare the difference. Minus delta means there is leak in the network while positive delta means there is infiltration probably due to storm water or underground water. Please see appendix 4.

Without getting off the main topic, it is still important to mention that it is important to monitor the underground water level to see whether the water has changed path for example which might flood or damage other underground areas. Also it is important to monitor the flow rates at the exit point prevent wastewater from polluting the underground water. Additionally, rising ground water endangers the high rise buildings and other underground facilities. In fact, there are a substantial number of buildings along the coastlines and thus rising underground water levels pose the greatest risk due to various reasons such as increasing salinity. It is very important that we study or know the geology of the underground soil if we were to monitor and control the movement of the underground water. For example, the amount of rain water that seeps into the underground depends on the type of soil (porous) and whether there is a bed rock underneath. Some areas in which water is collected underground (like a pool) can be of great concern.

Wastewater from different facilities such as residential, commercial, and industrial is collected throughout the network using gravity and into the manholes before it is gathered at one of the pumping stations. As it reaches the pump stations, readings are taken every two hours by the operators for a total of twelve readings per day. These reading are taken manually from the flow meters connected to the pumps at the stations.

In addition to the flow rate readings, electricity consumption is recorded and the DEWA send monthly statement every month for the energy consumption of the pump stations. Although the energy consumption of a pump station includes other areas in the station (such as lights) the major consumption is due to the running of the pumps.

As we have previously stated above, higher flow rate is noticed in areas with higher population level/density. Mainly due to residential areas at 40% flow rate while industrial and commercial contributes 26% each to the total incoming wastewater flow rate. The remaining other facilities contribute only to about 7% wastewater flow rate. Please see appendix 5.

Additional challenge is caused by the water seeping into ground especially rain water as it falls on buildings, factories, plants, scrap yards, landfills, septic tanks, roads that are contaminated by tires, etc. it brings with it substantial amount of chemicals. This rain water can bring with it chemical from underground oil tanks (from petrol stations) and other chemical factories that might have leaking tanks. All this can increase the level of chemicals in the underground water causing it to be very dangers hazardous solvent if it reaches high level or if it flows under structures. In addition, the more contaminated the water is and it infiltrates the sewerage network, the more costly it is to treat it. Not to mention the additional cost needed to maintain and repair waste water pumps as its life being shorten by the heavily contaminated rain/waste water.

Returning back to the available data, the following figure shows the available data from 2017 to 2020 on the served population, flow rates of each pump stations, energy consumption in kWh and the cost of electrical energy in UAE dirham respectively. This is actual data that was obtained from Dubai Municipality:

POPULATION

Pump Station	2017	2018	2019	2020
PS-E	197,371	199,103	200,695	201,754
PS-S	314,630	318,637	323,128	331,585
PS-Sn	274,211	288,388	304,261	339,906
PS-H	216,236	229,070	244,500	268,300
PS-Q	279,131	282,802	287,197	292,516
PS-K	183,014	192,916	204,257	216,636
PS-X	598,182	623,438	655,436	715,258
PS-I	39,784	42,933	46,332	50,000
PS-C	225,449	226,439	227,697	229,297
PS-G	211,802	212,864	214,127	227,842
PS-V	156,739	179,942	209,419	253,926
PS-X1	805,077	836,095	1,072,584	1,141,545
Population	**2,696,549**	**2,796,532**	**2,917,049**	**3,127,020**

FLOW RATE

Pump Station	2017	2018	2019	2020
PS-E	649.85	636.42	999.89	777.87
PS-S	884.90	958.63	1,140.71	994.53
PS-Sn	1,033.43	1,086.68	951.54	1,057.77
PS-H	877.55	906.74	966.85	1,028.74
PS-Q	994.56	1,012.86	629.70	977.67
PS-K	598.13	618.98	1,912.35	686.11
PS-X	1,950	2,077.52	373.34	1,740.41
PS-I	355.91	364.45	690.61	383.10
PS-C	690.08	674.53	842.21	603.55
PS-G	852.14	836.02	394.94	856.63
PS-V	362.82	577.98	394.94	611.47
PS-X1	2,996.50	3,222.84	4,025.21	4,480.21
Flow Rate (L/s)	**10,295.86**	**12,973.63**	**13,693.60**	**14,198.07**

Pump Station	2017	2018	2019	2020
PS-E	1,627,920	1,641,440	1,647,120	1,643,680
PS-S	1,675,200	1,834,300	2,010,170	2,097,460
PS-Sn	1,586,160	1,668,978	1,632,170	1,624,430
PS-H	1,778,080	1,816,588	1,822,800	2,058,010
PS-Q	3,487,403	3,531,054	3,536,430	3,445,270
PS-K	1,818,277	1,892,727	1,943,106	1,964,076
PS-X	6,709,578	6,814,240	5,735,542	5,522,950
PS-I	540,422	565,701	595,786	657,739
PS-C	1,553,940	1,508,360	1,476,540	1,251,650
PS-G	1,814,400	2,001,880	2,114,960	2,372,615
PS-V	541,906	631,314	633,767	922,203
PS-X1	9,067,680	10,064,200	12,947,570	14,597,480
Cost (AED)	**32,200,966**	**33,970,782**	**36,095,962**	**38,157,563**

COST (AED)

Pump Station	2017	2018	2019	2020
PS-E	3,654,000	3,548,000	3,474,000	2,951,000
PS-S	8,150,984	8,252,497	8,265,000	8,053,000
PS-Sn	1,272,562	1,331,350	1,401,317	1,545,394
PS-H	4,310,040	4,483,180	4,600,340	4,642,200
PS-Q	3,876,000	3,900,000	3,912,000	3,904,000
PS-K	4,320,000	4,564,000	4,784,000	5,363,000
PS-X	1,318,473	1,545,387	1,554,160	2,225,030
PS-I	3,936,000	4,306,000	4,715,000	4,918,000
PS-C	3,720,000	3,912,600	3,827,000	3,809,000
PS-G	4,216,000	4,302,100	4,320,000	4,867,000
PS-V	15,684,600	15,928,000	13,419,400	12,925,000
PS-X1	21,192,000	23,506,000	30,215,000	34,052,000
Energy (kWh)	**75,650,659**	**79,579,114**	**84,487,217**	**89,254,624**

ENERGY

Table 1: Population, Flow rates, Energy and Cost year 2017-2020

However, there is a limitation to the data obtained, please see the section on limitations and constraints.

Section 5: Analysis

Our main objective is to reduce cost by reducing the energy consumption at each pump stations. To do that, we need to understand where this energy is used first. For example, which part of the pump station uses the most of the energy and why?

Most of the electrical energy is used by the water pumps at the pumping station while small amount is used for minor requirements such as lights and so on. So after careful study of the pump design parameters, we came to the conclusion that there are two main factors that contribute to the pumps' level of energy usage:

5.1 Total Head Loss Correction for the pumping system (H):

Please Note: Most of the information in this section is taken from European Committee for Standardization Annex B: Recommendations on efficient system operation and energy reduction, examples.

Head loss of a pump is defined as the sum of the static and dynamic losses.

- **Dynamic Major Head Loss**: this type of loses depends on several factors such as the flow velocity, the pipe diameter and length, and the friction factor. The friction factor depends mainly on how rough the pipe is and the Reynolds number of the flow.
- **Dynamic Minor Loss**: this is basically the loss caused by the friction within the internal walls of the pump. For example, the fittings, the gate value and check value.
- **Static Head Loss**: this is basically the difference between the elevations of the upstream of the pumping system at the suction side and the downstream of the pumping system at the discharge.

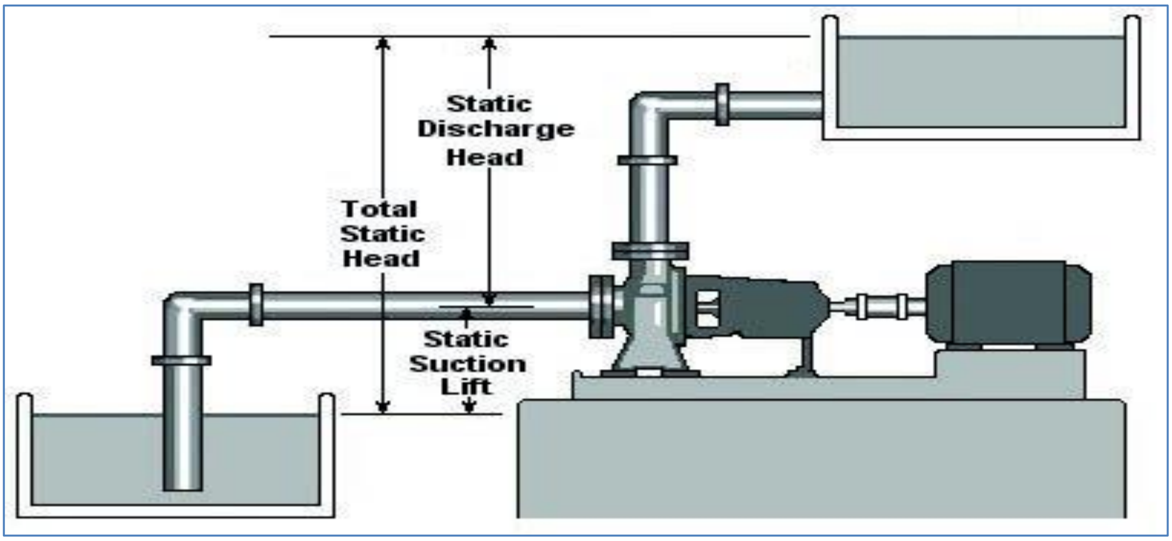


Figure 1 static head locations

5.2 Resistance coefficients:

Using the Darcy-Weisbach equation, we can estimate the head loss in any valve and fitting:

$$H_f = K_r \frac{V^2}{2g}$$

Where:

- Kr = resistance coefficient, dimensionless,
- Hf = head losing fitting (ft. (m)),
- V = average velocity (ft./s (m/s)),
- g = acceleration of gravity (32.2 ft./s2 (9.81 m/s2)).

$$K_r = \frac{fL}{D}$$

Where:

- Kr = fitting resistance coefficient, dimensionless,

- fm = Moody friction factor, dimensionless,
- L = length (ft.),
- D = pipe inside diameter (ft.).
- Darcy-Weisbach equation:

Darcy Weisbach Formula for calculating the dynamic major loss in the pipe:

hf = f (L/D) x (v^2/2g)

Where:

- hf = head loss (m)
- f = friction factor
- L = length of pipe work (m)
- d = inner diameter of pipe work (m)
- v = velocity of fluid (m/s)
- g = acceleration due to gravity (m/s²)

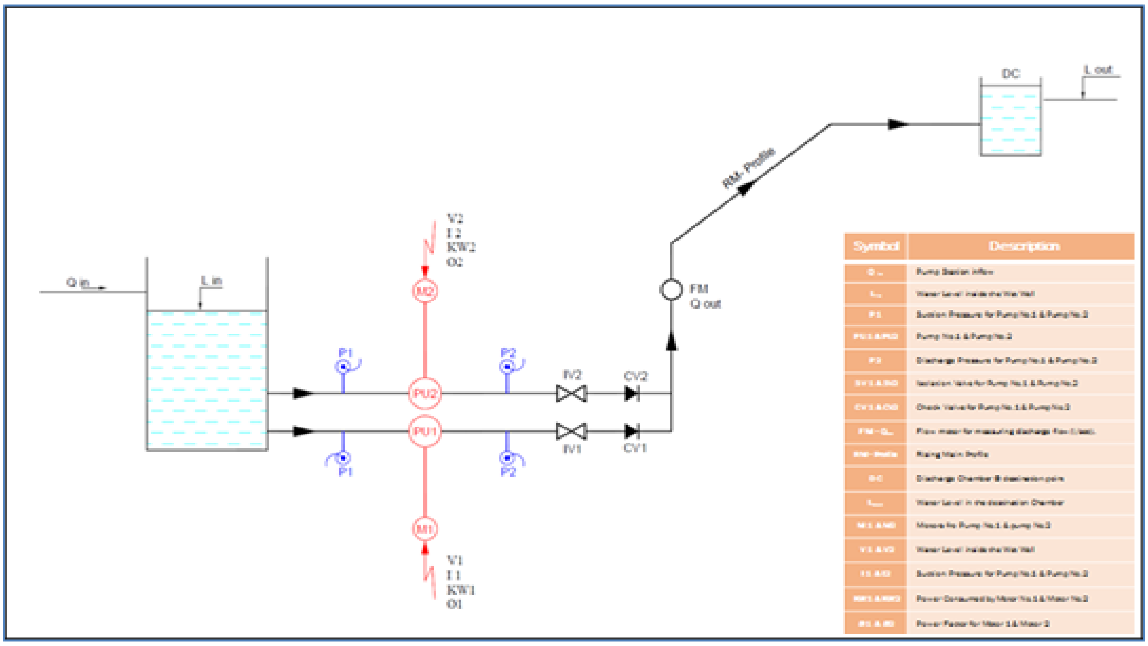


Figure 2 Schematic Display of Sewerage Layout

The figure above shows a typical example of what constitutes a pumping system boundary. Within this boundary, the total head loss can be identified and measured. Using the pump system curve, we can easily define the characteristics of the curve of the selected pump. It is a major key factor in the formula shown below that is used to find the energy consumption based on the flow rates and the head loss:

$$Energy = [p * g * H * Q * 24 * 365] / [1000 * N_{motor} * N_{pump}]$$

Where:

- N_{motor} = Motor efficiency (%)
- N_{pump} = Pump efficiency (%)
- H = Total head loss (m)
- Q = Flow-rate (m3/s)
- *P* = Density of the water (997 kg/m^3)
- g = acceleration due to gravity (m/s^2)
- Energy = Total energy used in the pumping system (KWh/annually)

The next step is to figure out which one of the pump curve applies. Necessary information can be obtained from the manufacturer(s). We then proceed to merge both curves (the system curve and pump curve) in order to come up with the correct pump characteristic/curve.

The total head loss correction should fall underneath the pump operation philosophy to operate the pumping system at the best efficiency point. Manufacturers typically specify a preferred operating range around BEP and sometimes an allowable operating range as well. The way these regions are defined differs slightly among manufacturers. Care must be taken to work as close as possible to the BEP. A deviation of –20% or + 10% of the flow in BEP could mean that the mean time between failures (MTBF) is halved. For variable flow pumps, careful consideration must be given to selecting the best efficiency point in the relation with the operating range as shown in the figure below:

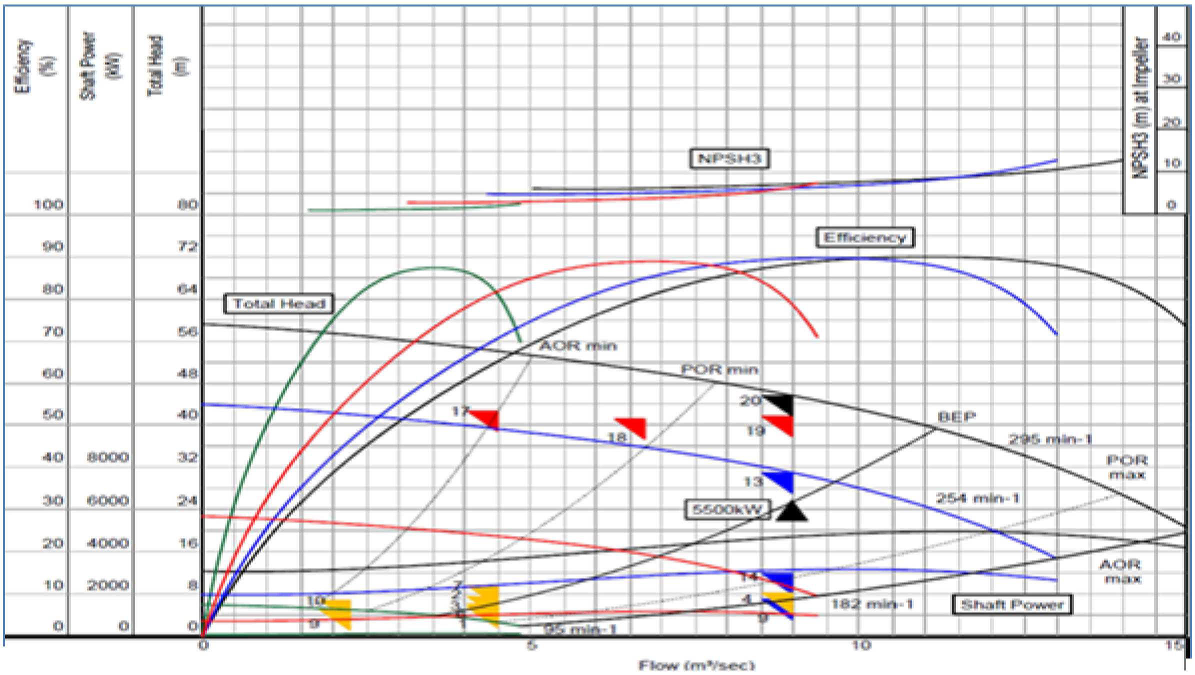


Figure 3 Typical presentation of pump's curve

5.3 System management to ensure economic operation:

A three-phase asynchronous motors that are used to drive pumps should be dimensioned so that they work at or near maximum efficiency under all operating conditions (typically 50% to 100% load and 35% to 100% load for high-performance motors according to IEC 60034-Series). For other types of actuators, the operating range must be as recommended by the manufacturer. Of course rules for managing operations, maintenance and repairs need to be well established. Operational performance records and technical files must be retained and maintained at all time for future use. All administrator as well as all technicians must be fully trained to ensure smooth operation. (Source: BSI EN ISO 14414-2019).

5.4 System management recommendations:

Efficient system components must be used and operated in such a way that a high level of system efficiency is maintained. For systems that operate under partial load for long periods of time or that have large changes in demand, appropriate measures must be taken to maintain high operating efficiency under all conditions, if feasible from a technological and financial point of view. The process requirements must be assessed to determine whether the system is operating efficiently within the applicable quality, health and safety requirements. If the system does not operate within the established limits, a corrective plan should be drawn up and implemented." (Source: BSI EN ISO 14414-2019).

5.5 System updating and improvement:

For any system that does not meet the efficiency requirements determined after an assessment, the operation of the system should be audited and a report should be drawn up to document current operations, including the test methodology and data analysis needed, measures should be taken to improve both efficiency and accountability. In all cases, whenever a pumping system is installed or upgraded, a formal assessment should be the next step to ensure peak efficient performance under typical operating conditions. (Source: BSI EN ISO 14414-2019).

5.6 Common Causes & Corrective Actions for Excessive Power Consumption in Rotodynamic Pumps:

It is important to have a thorough understanding of system requirements, including differentiating between system design specifications and actual process requirements, prior to evaluating energy savings opportunities prior to using any analytical technique. It should be understood that once physical or operational changes are made, the system curve is likely to change, resulting in different system requirements and the need for another iteration of systems analysis. Whenever the system is changed, the optimal operation for that system can be redefined. (Source: BSI EN ISO 14414-2019).

5.7 Reduce system head losses:

Below are some suggested steps to reduce system load:

- Elimination/reduction of unnecessary circulating and / or throttling currents; cleaning or servicing dirty components such as heat exchangers;
- Isolate flow paths to non-essential or non-operational equipment;
- Maintaining adequate filling and ventilation of elevated pipe sections;
- Reduction/elimination of deposits and limescale deposits in pipes, heat exchangers and process components;
- Do not employ an air gap between the pipe outlet and the receiving tank if insulation is not required.
- Adjust the flow rate to the requirements of the process without exceeding them;
- Maintaining the design pump temperature when pumping viscous products;
- Separate secondary systems that require very low flow rates with a head much higher than that required by the main system.

  (Source: BSI EN ISO 14414-2019).

5.8 Reduction of system flow rate:

- Below are some steps that can be taken to reduce system flow. However, this list is not comprehensive:
- Maintaining optimal differential temperatures in heat exchanger applications, preferably taking into account the efficiency of the heat exchanger design;
- Isolate unnecessary flow paths, unnecessary pump circulation and leaky valves, check valves, minimum flow valves;

- Reducing the flow rate in batch processes that are essentially filled and emptied as long as this does not result in an unacceptable change in the production schedule;
- Switching off the pumps when no flow is required.

(Source: BSI EN ISO 14414-2019).

5.9 Ensuring that components operate close to best efficiently:

Operational efficiencies of the various components that make up the pumping system can vary significantly depending on where they operate on their respective curves. As a rule of thumb, motors should work where their efficiency curve is flat. Rotodynamic pumps should preferably be operated in the vicinity of BEP as shown in the figure below. Operating outside the BEP quickly degrades the efficiency and reliability of the pump. Also note that different types of electric motors and other controls can differ significantly in efficiency.

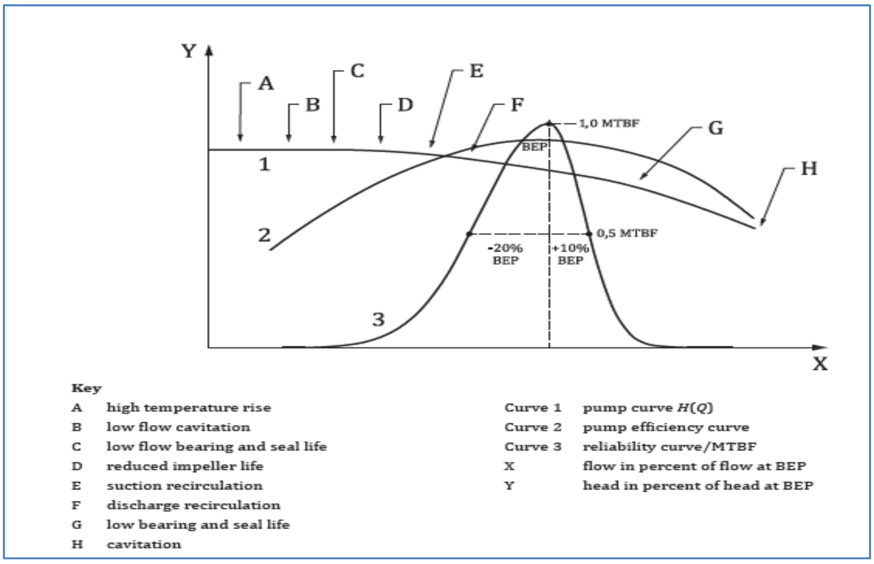


Figure 4 BEP curve

(Source: BSI EN ISO 14414-2019)

5.10 Change pumping system run time:

Opportunities based on a change in system availability are often seized when the system requirement is dominated by the reaming head. Such uses include, but are not limited to:

- Pumps/pumping stations;
- Systems with electricity tariffs that change depending on the duration of use or the demand component;
- Systems that work when the process is not running A recirculation circuit is often used instead of turning off a pump when flow is not needed;
- Systems with multiple pumps in parallel that run more pumps than necessary to meet process requirements

In most cases the pumping capacity will be greater than required, especially in storage applications, e.g. B. Filling tanks in industrial applications, pumping wet wells or filling tanks in municipal applications. In the wet well or in the tank/reservoir Lower flow rates mean a longer running time; on the other hand, lower flow rates lead to savings due to lower friction losses. In installations with high demand, changes that reduce the flow rates can result in lower energy requirements and thus cost savings can be achieved. This does not always mean energy savings. In many applications the pumps can run longer than required. Examples of such applications are multiple pumps operating in parallel producing more flow than required. Applications that concern them do not unusual cooling towers and chillers, operators do not turn off the pumps when they can, but they run when they are not needed. This situation can be detected by measuring the temperature difference in the cooling tower/heat exchanger. If the temperature difference is not optimal, the flow rate is too high. In such a situation one or more pumps could be switched off or the capacity could be reduced by changing the speed of the pump (s). (Source: BSI EN ISO 14414-2019)

5.11 Flow rate (Q) and the population:

Flow rate (Q) is basically the rate at which the wastewater flows into the pump station. Looking at the numbers from 2017 to 2020, we noticed overall increase in the level of flow rates as the years pass by. This is not to say that each and every pump station has experienced flow rate increase, however, when the total flow rates for all major pumping stations are taken for each year and then compared with the flow rates of the subsequent year; we notice steady increase from year 2017 to 2020. Kindly refer to **Table 1 above: Population, Flow rates, Energy and Cost year 2017-2020.**

With the support of the experts at the Dubai Municipality and further checking of the numbers of the communities' populations, we noticed interesting fact that the numbers for the population (that is being served) have also increased over the same number of years.

Based on this observation, we setup our Null Hypothesis to find out the whether there is any relation between the population and the flow rates. Thus, factors are flow-rates & population:

For the flow rate (Q):

- Ho: the means among the flow rates for each year are equal
- H1: at least one mean is not equal to zero

For the population (P) increase rate (we classified population as low, medium and high):

- Low Population <= 650
- Medium Population <=1033
- High population > 1033

And the Null Hypothesis:

- Ho: the means among the population increase rate for each year are equal

- H1: at least one mean is not equal to zero

For the interaction between the flow rate and the population:

- Ho: the means among the interaction are equal
- H1: at least one mean is not equal to zero

To check our hypothesis, we used the method available in Minitab; "Analysis of the Variance" (ANOVA). We are in particular concerned if there is any interaction between the wastewater flow rates and the population change from year from 2017 to 2020.

Fortunately, the results were as per our expectations. The change in population has direct impact on the wastewater flow rate. Here are the results of the analysis:

	Source of Variance	Sum of Squares	Degreee of Freedom	Mean Square	F_o	F Critical	P-Value
	Model	16,394,181	11.00	1,490,380	2.571		< 0.0001
A (Flow Rate)	SS_A	175,885	3	58,628	0.10	2.880	0.95
B (Population)	SS_B	15,986,964	2	7,993,482	13.79	3.275	-
AB (Interaction)	$SS_{Interaction}$	231,333	6	38,555	0.07	2.380	0.999
Error	SS_E	20,870,815	36	579,745			
Total	SS_T	37,264,996	47				

Figure 5 ANOVA for Q and P (year 2017-2020)

5.12 Interpretation of the results:

As shown above, there is a strong interaction between the flow rates recorded and the population level demonstrated by the high P value at 0.999. Thus, the wastewater flow rate is directly impacted by the number of people living in the same area.

However, we have to be careful of our numbers. For example, the population is only those who are being served by the wastewater network and not the entire populations of Dubai as there are many areas not currently being served by the network. These people are still depending on the wastewater being collected using tankers and other means.

It says that the devil is in the details. Note that they are some areas where we do not see the flow rates increase a lot such as the old downtown of the city. The population density in this area has already reached its limit and therefore any increase in the population is low and thus, changes to the flow rates in such areas are very unlikely as well.

To go one step further, Dubai has a unique feature when it comes to the industrial and commercial sectors. Many who work in Dubai are from the nearby emirates such as from Ajman, Sharjah, Al Fujairah and so on. Thus, the rate of consumption increases during the day in these two sectors and then drops down during the evening. It also means that the increase of the flow rates is also because of the people working in Dubai but do not live in Dubai. It will be interesting to look at the wastewater flow rates of the nearby other cities during the morning and compare it with their flow rates in the evening.

There is also the matter on which the Dubai real-estate is operated. Many houses/apartments in Dubai are owned by tourists or other investors not currently living in Dubai and thus these accommodations are empty for the better part of the year. Thus, we suspect that the residential area contributes more during certain months than others. Of course this also depends on the types and size of the properties which we have not accounted for.

Furthermore, there is the issue of the illegal wastewater being dumped each year into the network but we believe this is a negligible amount when compared to other sources of wastewater. However, the issue with illegal dumping is not so much the amount but what it contains. Such wastewater is most likely to have chemicals and sediments (from construction projects for example) that may solidify once it is inside the network. This may damage the network pipelines and/or ends up leaking into the underground and pollute the underground water and causes unnatural changes that we may not be even able to foresee until it is too late.

Additionally, storm water and infiltration from ground water add to the total inflow of water entering into the network but this amount is very much less as rain levels in UAE is generally very low. As an example, see appendix 6 Dubai Weather (year 2019) for the average precipitation in Dubai in Inches.

However, the problem is that is faced by the wastewater network team is the short and yet heavy rain that the emirate receive every few years. Such incident overflows the sewerage network leading to some difficulty in removing the wastewater few days. Building another network for storm water or expanding the existing network to accommodate storm water is not feasible since the amount of storm water is limited to few weeks over the year.

5.13 Forecasting:

The simplest way to forecasting is to use the data from past history or what we call the Historical Projection such as Moving average and Exponential Smoothing. However, we should be cautious here. Forecasting is always wrong. In other words, there is always an error. Depending on the methodology used, the forecasting can be checked for accuracy and adequacy and the error can be minimized to a certain degree. For example, the higher the accuracy of the data is and more it is related to the forecasting that we are trying to perform, the more accurate the forecasting will be. Another example, the closer we are to the event that we try to forecast, the more accurate the numbers are.

5.13.1 Forecasting methods used: available equations from Dubai Municipality were used to forecast the population, flow rates, energy consumption and cost. Below figure display the forecasted results:

$$Population = P_{n-1} *[(1+r)/100] * t_n - t_{n-1}$$

Pump Station	2021	2022	2023	2024	2025
PS-E	250,849	258,375	266,126	274,110	282,333
PS-S	327,328	337,148	347,262	357,680	368,410
PS-Sn	373,428	384,631	396,170	408,055	420,297
PS-H	311,498	320,843	330,468	340,382	350,594
PS-Q	316,510	326,005	335,785	345,859	356,235
PS-K	206,139	212,323	218,693	225,254	232,011
PS-X	626,033	644,814	664,158	684,083	704,605
PS-I	122,217	125,884	129,660	133,550	137,556
PS-C	226,079	232,861	239,847	247,043	254,454
PS-G	275,708	283,979	292,498	301,273	310,312
PS-V	129,289	133,167	137,163	141,277	145,516
PS-X1	1,317,707	1,357,238	1,397,955	1,439,894	1,483,091
Population	**4,482,784**	**4,617,268**	**4,755,786**	**4,898,460**	**5,045,413**

$$Flow\ Rate = Population * 0.28 / 86.4$$

Pump Station	2021	2022	2023	2024	2025
PS-E	812.94	837.33	862.45	888.32	914.97
PS-S	1,060.78	1,092.61	1,125.39	1,159.15	1,193.92
PS-Sn	1,210.18	1,246.49	1,283.88	1,322.40	1,362.07
PS-H	1,009.48	1,039.77	1,070.96	1,103.09	1,136.18
PS-Q	1,025.73	1,056.50	1,088.19	1,120.84	1,154.46
PS-K	668.04	688.08	708.73	729.99	751.89
PS-X	2,028.81	2,089.67	2,152.36	2,216.94	2,283.44
PS-I	396.07	407.96	420.19	432.80	445.78
PS-C	732.66	754.64	777.28	800.60	824.62
PS-G	893.50	920.30	947.91	976.35	1,005.64
PS-V	418.99	431.56	444.51	457.84	471.58
PS-X1	4,270.35	4,398.46	4,530.41	4,666.32	4,806.31
Flow Rate (L/s)	**14,527.54**	**14,963.37**	**15,412.27**	**15,874.64**	**16,350.88**

Pump Station	2021	2022	2023	2024	2025
PS-E	1,956,089	2,014,771	2,075,214	2,137,471	2,201,595
PS-S	2,552,457	2,629,030	2,707,901	2,789,138	2,872,812
PS-Sn	2,795,463	2,879,326	2,965,706	3,054,677	3,146,318
PS-H	2,429,016	2,501,887	2,576,943	2,654,252	2,733,879
PS-Q	3,504,702	3,609,843	3,718,138	3,829,682	3,944,572
PS-K	2,186,124	2,251,708	2,319,259	2,388,837	2,460,502
PS-X	4,393,545	4,525,351	4,661,112	4,800,945	4,944,973
PS-I	991,153	1,020,887	1,051,514	1,083,059	1,115,551
PS-C	1,586,639	1,634,238	1,683,265	1,733,763	1,785,776
PS-G	2,149,931	2,214,429	2,280,862	2,349,288	2,419,767
PS-V	1,108,994	1,142,264	1,176,531	1,211,827	1,248,182
PS-X1	16,029,458	16,510,342	17,005,652	17,515,821	18,041,296
Cost (AED)	**41,683,568**	**42,934,076**	**44,222,098**	**45,548,761**	**46,915,224**

$$Cost = Energy * Tariff$$

Pump Station	2021	2022	2023	2024	2025
PS-E	4,657,354	4,797,074	4,940,986	5,089,216	5,241,893
PS-S	6,077,278	6,259,596	6,447,384	6,640,805	6,840,030
PS-Sn	6,655,863	6,855,539	7,061,205	7,273,041	7,491,233
PS-H	5,783,372	5,956,873	6,135,579	6,319,647	6,509,236
PS-Q	8,344,528	8,594,863	8,852,709	9,118,291	9,391,839
PS-K	5,205,057	5,361,209	5,522,045	5,687,706	5,858,338
PS-X	10,460,821	10,774,645	11,097,885	11,430,821	11,773,746
PS-I	2,359,887	2,430,684	2,503,604	2,578,713	2,656,074
PS-C	3,777,711	3,891,043	4,007,774	4,128,007	4,251,847
PS-G	5,118,884	5,272,450	5,430,624	5,593,543	5,761,349
PS-V	2,640,461	2,719,675	2,801,265	2,885,303	2,971,862
PS-X1	38,165,376	39,310,337	40,489,647	41,704,337	42,955,467
Energy (Kwh)	**99,246,592**	**102,223,989**	**105,290,709**	**108,449,430**	**111,702,913**

$$Energy = [p * g * H * Q * 24 * 365] / [1000 * N_{motor} * N_{pump}]$$

Table 2 Results of Population, Flow Rates, energy and Cost (year 2021-2025)

5.13.2 Population equation: Looking at the actual numbers of year 2017 to 2020 for the population, we can see there is a steady (linear) increase in the population being served by the wastewater network. By the same token, we used the same formula that is being used by the Dubai authority to calculate the expected for the years to come:

$$Population = P_{n-1} *[(1+r)/100] * t_n - t_{n-1}$$

Where P(n-1) is the last year population and (r) is the growth rate. Notice that this equation is basically an exponential smoothing question that uses past history [t(n-1) last year] number to predict the following year (t) numbers.

And we got the following estimated numbers for the population from 2021 to 2025:

Pump Station	2021	2022	2023	2024	2025
Population	4,482,784	4,617,268	4,755,786	4,898,460	5,045,413

We can see that the population is increasing steadily over the years.

5.13.3 Flow rate equation: As defined by the Dubai Municipality, the water consumption per person is 280 Liter per day. Converting the flow rates from cubic meter per day to cubic liter per seconds as per the below formula:

$$\text{Flow Rate} = \text{Population} * 0.28 / 86.4$$

This has resulted in the following numbers:

Pump Station	2021	2022	2023	2024	2025
Flow Rate (L/s)	14,527.54	14,963.37	15,412.27	15,874.64	16,350.88

We can see the number increase steadily as well for the flow rate over the five years since this is actually a taking the population figures and multiplying them by a constant.

5.13.4 Energy equation: As for the energy consumption, all independent variables were held constant with the exception of the flow rate:

$$\text{Energy} = [p * g * H * Q * 24 * 365] / [1000 * N_{motor} * N_{pump}]$$

The only variable here is the flow rates while the rest are fixed at the design level. Thus calculating for the energy, we get the following results:

Pump Station	2021	2022	2023	2024	2025
Energy (Kwh)	99,246,592	102,223,989	105,290,709	108,449,430	111,702,913

Again, we see steady increase in the expected energy consumption.

5.13.5 Cost equation: The cost is simply the energy in Kilowatt multiplied by a constant which is the DEWA tariff rate (AED 0.42) for electricity:

$$\text{Cost} = \text{Energy} * \text{Tariff}$$

Form which we get the following AED costs:

Pump Station	2021	2022	2023	2024	2025
Cost (AED)	41,683,568	42,934,076	44,222,098	45,548,761	46,915,224

Note: that in all the above calculations, we used the same formulas that were used by Dubai Municipality to estimate/forecast the population increase, flow rates (based on the population), the energy consumption with the flow rate (Q) is the only variable and the Cost of the energy (constant AED 0.42). The above are linear equations that are best fit for this type of estimation: "the multiple regression models are more robust and accurate comparing with the simple models since it specifies the type of pumping station and the location of the utility." (Marth Carbal et al. 2018)

5.14 SWOT Analysis:

What drives any business is first the goal to make profit and second the need to grow. Without these two, a business is doomed to fail. Companies' success depends on its ability to build a solid business/operation foundation and the ability to sustain it. Thus, it must evaluate its capabilities and weaknesses. There are several ways to do this and one of them is the famous SWOT analysis:

5.14.1 Strengths: these are basically internal competency or things that the company is good at. For example and in our case, the Dubai Municipality has given strong authority to plan and schedule its own project with enough resources to sustain its operation for many years to come. Below is some major strength:

- **Availability of resources**: backed up by the Emirate of Dubai, Dubai Municipality has ample resources in terms of man power, machines, etc. to conduct its day to day operations and to plan for long term projects.
- **Budget**: being an essential part of the government that provides essential service to the public, Dubai Municipality financial needs are within it reach. However, as we know, there is no such thing without limited budget and thus, management at the Dubai Municipality must sort out and prioritize first enough budgets to serve the immediate public needs.
- **Knowledge (Experts):** as a government entity, access to knowledge and experience are within the reach of Dubai Municipality be it internal or international. In fact, the entity always seeks out the support of those who are expert in the business that can help ensure the best cost-benefit scenarios.
- **Data:** data availability and access to data is of no major concern here as the municipality builds and manages it own pumping and treatment stations. With that in

mind, data gathering for new projects or data collecting of existing ones are available for immediate and future use.

- **Strong higher management support**: each and every governmental sector in Dubai seeks to be the second to none in what they provide. Dubai Municipality is of no exception. In fact, the management always strive to be leaders in their achievement to serve the public. Like any other entities, they are being evaluated based on their set targets and how much they have achieved of it. This is a big responsibility as the higher leaders of the Emirate of Dubai keep an eye on Dubai Municipality as one of the leading service providers in Dubai.
- **Strong infrastructure**: one of the strength of Dubai Municipality is its strong infrastructure that it has been building for since 1960 under the late His highness Sheikh Rashid Al Maktoum. In fact, one of the reasons that Dubai started early on building its infrastructure was due to lack of natural resources such as oil and gas. The early leader of Dubai understand that if he were to achieve his dream and make Dubai one of the leading business hubs in the region, having a strong infrastructure in which to build other services is a must. Dubai Municipality wastewater network is one of the best in the region and even rivals some major cities of similar size. Network pipelines are adequately and well distributed through the city and in major crowded areas. New areas planned for urbanization are receiving the same attention as well. Dubai Municipality is even planning to have a strong wastewater infrastructure by building its own underground tunnel that is supposedly will help manage all sewerage needs for many years to come.

5.14.2 Weaknesses: these are internal to the organization. Things in which, for example Dubai Municipality cannot do it on its own and yet still required. In this case, it is better to turn to the professionals.

- **Lack of automation**: one of the serious and important issues that need to be tackled immediately is the less-than-required technology. Organization should always be on the lookout for new technology in their field of business. This is not to say that they should use every new technology that comes out but they should look into its applications. Unfortunately, the SCADA system the link the major pumping stations does not have the capability to use life data to build scenarios that could help with network flow rates. Failure to be on the edge of technology forces organizations and companies in general to fall behind and then innovation become revolution which means major upgrade that can be costly when done at once.
- **Lack of timely communication**: mostly data collecting and sharing is weak. For example, data of flow rates and power consumptions are read of the gauges at the pumping stations and recorded manually. Then it is written using Excel sheets and sent on weekly basis. In many instances we noticed that data were not recorded for many days simply because there was no one to record it. Additionally information received either late or in a format that usually is required to be changed. Such old fashion of operation should be improved if we are to be proactive than reactive to changes especially during emergencies.
- **Maintenance, servicing & calibration**: unfortunately, most organizations and companies when they plan their projects, they fail to plan for long term maintenance and calibration requirements. Major pumping stations have faced unplanned shutdown a couple of times for maintenance and repairs. Although things might go wrong from time to time, we can still reduce the impact and the likelihood of something that might go wrong if proper risk mitigation planning was in place. For example, one of the pump stations was shutdown in 2017 because the equipped procured by the contractor was not up to specifications. This incident could have been avoided if there were

proper risk mitigation plan that includes using authorized vendors only and proper verification procedure was performed.

- **Better documentation and record keeping**: one of the things we faced while performing this study is the incompleteness of the data available. In many instances for example flow rates data was not available. Sometime for few days while other times for months. Keeping good records is important for such type of service since going back to the Root Cause Analysis is quite important as Dubai Municipality cannot afford to have the same mistakes happening twice. The level of investment including monetary and human resources are huge while at the same time disruption to the daily operation will have ripple effects that will be felt all over the emirate for many days. In addition, the nature of the business requires frequent forecasting of demands and it is usually built on both past history and existing data. That is why the Municipality cannot afford to have incomplete or inaccurate data

5.14.3 Threats: entities or situations that pose danger to Dubai Municipality operation. For example actions by individuals or entities that leads to disruption of the wastewater service or worse damages to the wastewater network including the pumping stations and the treatment plants.

- **Illegal activates (industry):** unfortunately people continue to dump chemicals into the drainage such as paint, cement product, fertilizers and so. In addition, industrial leftover sometimes end up in the drainage causing damages and blockage to the pipelines. Although there are heavy fines imposed on such illegal act, it is still difficult to monitor and control each and every location. The best course of action is to continue educating the public on the seriousness of such act and monitoring the situation.

- **Tariff hike**: at any moment, even now, the DEWA might decide to increase the electricity tariff rates. With the current level of power consumption and predicted future requirement, the increase in the tariff rates will have a substantial impact on the overall cost of energy consumptions. That is why planning for saving should start from today.
- **Inflow & infiltration**: we have talked already the threat if water seeping into the network and the importance of protecting the network and associated systems from the inflow and infiltration of storm water and ground water. Failure to do so will results on overloading the network, increasing the maintenance cost and higher energy bill.
- **Increasing Service demand**: as we saw in our analysis, flow rates are positively correlated with the population. Except for few areas with saturated population, the number is always on the rise whether it is local or from tourism and industry. Regardless of the reasons, proper urban planning is a key factor in minimizing future expenses. For example, direct growth in constructions towards areas with lower utilization of pumping stations.

  "Electricity savings can occur via water demand management, reducing water consumption cuts water pumping and hence, its electricity use. Alternatively, electricity savings can occur via water supply management that encompasses leak detection and remedy, and replacing energy inefficient equipment." (DeBenedictis et al. 2013).

  Of course we understand that this is easier said than done since urbanization depends on a lot of factors such as the economic and industrial needs of the Emirate. See appendix 7.
- **New rules & regulations (e.g. climate policy):** as life gets complicated, so is the law and regulations. Today's set of laws might not be suitable for tomorrow and new rules might be placed to minimize harm resulting from unfortunate changes that disrupt

having peaceful life. Thus, Dubai Municipality understands the needs for change for the benefit of all and thus needs always to be prepared (to some degree) by having its business continuity plan ready for implementation when necessary.

5.14.4 Opportunities: the kanji writing for the Chinese word Crises is written using two Kanji characters. The first one means damage while the second one means opportunity. It is the right way to thinking when faced with a problem or a challenge. Opportunities are all around us in all situations if we look carefully. Dubai Municipality with its current challenges has the opportunity to:

- **Improved pumping system**: as described above, data and records keeping is the first step that requires improvement since the data will be used to make future informed decisions. Considering the importance and level of service required from Dubai Municipality, using up-to-date system such as comprehensive and automated SCADA system is a step toward the right direction.
- **Increase population awareness**: as stated before, this is one thing that Dubai in general and the municipality is strong at and should continue to do so. It requires some additional improvement to its existing communication to educate the public about the importance of water and electricity savings which ultimately leads to less waste including wastewater and energy consumptions.
- **Reduce inflow & infiltration:** protection the network is a critical matter not only to reduce the level of unnecessary pumped and treated water but also to prevent damages to the network pipelines and other associated systems/equipment. This is within the grasp of Dubai Municipality and should be of high priority in order to extend the life span of the system.

- **Technology usage**: we would be surprised to find out how much advances have been made in this wastewater management field all around the world. It is only logical to think in this manner since wastewater management is a common challenge for each and every modern city in the world. Through sharing of knowledge and technology, Dubai municipality has an excellent opportunity to find new ways in which to improve its wastewater management system and at the same time save greatly on the energy used.
- **International cooperation**: back to the point above, knowledge sharing, technology sharing and many other areas where Dubai Municipality can join hands with many organizations in the same business to enhance its operation, planning and forecasting of wastewater management. We mentioned previously a couple of organizations, the US EPA and the International Society of Automation (ISA) - Optimization of Wastewater. However, there are hundreds of similar organizations and companies and probably hundreds of seminars, research and articles presented on energy saving and environment protection that can be of great use to the teams in Dubai Municipality to work on its attempt to save on energy consumption.

5.15 Root Cause Analysis:

Another method in which we can reduce energy consumption is if we take the process and try to look at the contributors of higher energy consumption. In other words, by identifying exactly what and how energy is used, we might have the chance to prevent or at least minimize the energy consumption by making the necessary changes over the coming five years. In our study, we were able to identify the following factors or contributors to higher or unnecessary flow rates which leads to waste of energy:

5.15.1 End-user releases water into the sewage network:

These are action committed by the end-users at the residential, industrial, commercial and other type of owners of properties:

- **Illegal dumping**: chemicals, construction materials, fertilizers, plastic, etc.
- **Over consumption**: takes place usually during the prayer times and at the hotels.
- **Storm water**: not as frequent but it can overflow the system and leads to temporary shutdown in some areas to protect the network.
- **Ground water**: requires close monitoring of ground water movement in order to protect the network from the inflow and infiltration.
- **Plantation near main lines (tree root issue)**: less frequent but can cause inconvenient to the community if it happens.
- **Blockages**: many reasons such as tree’s roots, illegal dumping, piling of sludge due to improper service and cleaning, etc.
- **Water loss (leaks):** small cracks in the pipelines can leads to leaks of wastewater from the network and into the ground polluting the ground water.

- **Incomplete connections**: not all stations are connected to central SCADA system and thus up-to-date data is not always available to control the flow rates.
- **No instrument / old instrument and equipment**: some pumping stations still have old gauges or gauges that require calibration. This causes error in the data taken not to mention the inability to determine the flow rates when the instrument is broken/down.
- **Human error (readings):** this is an on-going issue that needs to be resolved by using automated systems to record the flow rates and the electricity consumption.
- **Overflows (Chamber) / Flooding of network/station**: in one of the pumping stations, one time chamber was flooded and the pumping station was shut down. This has resulted in diverting the flow of wastewater to other pumping station causing additional pressure on the other pump station.
- **Blockages**: this happens mostly due to sludge build up caused by the reasons mentioned above. Additionally, sand also enters into the network.
- **Unavailability of information**: life data from the SCADA is either is not available as needed or is not linked to a system in which scenarios can be built on the spot.
- **Unexpected diversion**: from time to time, directing flow from one sector to another take place when maintenance is required or in case of emergency shutdowns.
- **Breakage (high pressure):** Network pipelines breaks due to high pressure resulting from the flow of wastewater or weakness over the year in the pipes themselves.
- **Water loss (leaks):** as stated above, leaks of wastewater can take place also within the network in between the pumping stations as well. One option would be is to replace pipelines that show cracks with new and better quality ones.

- **Unplanned Shutdowns**: at the time of almost reaching the pumps' design capacities or sometimes exceeding them, this action is taken to protect the pumps and the stations associated systems such as the valves and the regulators.

- **Overdue or improper calibration**: although not as frequent, calibration can be overdue or improperly done. This is extremely important since the pumps' head loss can be substantial and impact the energy consumption.

- **Power surge/tripping:** Not as frequent, it is a problem that must be corrected once it occurs or it might disrupt the node and its neighbouring ones causing ripple effect.

- **Inadequate Pump maintenance**: no task is performed at 100% all the time and every time. Maintenance and servicing of the pumps in particular and the station in general is an up and down activity that is effected by availability of spare parts, consumables, tools and instruments, market circumstances (COVID-19) , etc.

5.15.2 Water travels from main station to treatment plant:

- **Water loss (leaks):** again, similar to the statement mentioned above. However, the flow coming to the treatment plants is much higher than the ones going into the pumping stations and thus carries with it higher risk.
- **Blockages**: unlikely but might take place if proper inspection and cleaning is not done on time or not properly done.
- **Overflows (Chamber):** this could be avoided if proper control of flows in between the nodes (major pump stations) is adequately performed. Again, this takes up back to our early points about data availability and SCADA system requirements.

Section 6: Proposed Solutions

Various steps can be taken to help understand the existing situation and therefore minimize the energy consumption:

6.1 Improve data availability and data accuracy:

Many wastewater pumping stations are in need of better and up to date instrumentations for better monitoring of the flow rate and energy consumption. With such instruments, errors caused by human can be eliminated. In addition, readings are sent once every week. If such data were to be available (online for example), immediate and informed decision (for example to divert water flow to other stations and eases pressure on a certain pump) can be taken on the spot. Thus, better monitoring of the pumps status and extending the life span of such important equipment.

6.2 Better Data analysis:

Currently simple data analysis is what is being done. However, with support from the experts, information can tell a lot about a system. For example, changes in the flow rate can help forecast flow rates due to seasonality and thus certain steps can be taken before hand to minimize pressure on the pumps. In addition, at this moment there are no international standards or performance indicators (KPIs) for Main Sewage pump Stations that is being followed. Having such standard that is based on reliable resources is important for better management of the pumping station. For example, at what level should we consider the flow rate to be critical and what action and measures should be taken to mitigate this risk? Here is an example:

"A plant can have hundreds of performance indicators…. this example uses one year which is equal to 8760 hours per year. The KPI IAS1 will measure the time during which no alarm or fault has been activated against the total time in operation, which is an indicator for the healthiness of the system:

- Upper limit 99% of hours per year equals 8672h
- Lower limit 98% of hours per year equals 8584h
- Slope = 0.011363636
- Intercept= -97.5455

This KPI is considering the running hours, which can be counted by a SCADA system and feed into the linear formula." (Frank Jordan 2020).

Unfortunately, there is no comprehensive system in use that creates scenarios on the spot using real time data. Using hydraulic modeling to build scenarios helps mitigate risk and prevent overflow and over utilization of pumps.

6.3 Educate the public to reduce water consumption:

The emirate of Dubai continuous to educate the public about water and energy savings using various available means (emails, social media, information provided on the monthly bills, etc.). Public awareness changes both social and cultural norms to reduce harmful practices. For example, awareness on the danger of wastewater and how to reduce it from the source helps reduce not only the amount of wastewater but also reduces demand on electricity and fresh water and therefore reduces the carbon footprint since electricity and fresh water are generated using fossil fuel. Additionally, programs to protect the environment are being conducted in schools and other facilities which help minimize various types of waste include wastewater.

Educating and campaign awareness strategies are better conducted at the source of the problem. For example, DEWA continues to educate the public about the importance of better electricity and water usage by printing this information on the monthly utility bills including but not limited to monthly/yearly consumptions, tariff rates based on the consumption range, carbon footprints, etc. In addition, information on reducing utilities usage is being sent on regular basis to end-users.

6.4 Apply/Increase tariff:

So far, the charges for using sewerage service have not been well established and/or uniformly applied across the emirate of Dubai. We strongly believe that this tariff will add great benefit for the following reasons:

- Reduce water consumption at the source if people were to pay based on the amount of water used. For example, people will stop spilling a lot of water while washing their lawns and their cars.
- Reduce water consumption at the source from industrial and commercial entities.
- Better monitoring and control of wastewater usage by sector (residential, commercial, etc.)
- Periodic checking/testing of the quality of underground water near factories.
- Provide financial support to the Dubai Municipality which can amount to substantial amounts each month.
- Motivate people to know and learn more how to reduce their wastewater bills.
- Help protects the environment (ground fresh water).

6.5 Plan lifting pumps and network maintenance and servicing:

Pumps used at the wastewater stations are heavy industrial types ones. Their purchase price is very high in addition to the cost of periodic service and regular preventive and corrective maintenance. Additionally, the cost of the spare parts, consumables and upgrades can be extremely high. Additional cost for calibrations, special instrumentation and tools are skyrocketing as well. Here we are only talking only about operational requirements not to mention the administrative ones such inventory cost, ordering cost and other logistics costs such as transportation and packaging. Furthermore, to save on time and effort, digitalized (video) maintenance display is the way to go nowadays. This will also ease and speed up the communication and sharing of information while performing the maintenance.

In addition to the above cost, there is the cost opportunity which is basically the amount of money that is put into maintaining the operation instead of investing the money somewhere else.

Last but not least, there is the cost of shutting down one of the pumps or an entire pumping station. Regardless of the reason, it is sometimes necessary to proceed with the shutdowns due to planned maintenance or emergencies and divert the wastewater through other pumping stations causing overloading the network and/or other pump stations and getting very close to the system design specification or worse exceeding it. The energy consumption in this case exceeds planned as motors are running at lower efficiency.

When the above are added up, the overall yearly cost can be a real burden on the Dubai Municipality. Thus, controlling the wastewater at the source through tariff should be the first strategy to reduce waste and energy consumption in the network.

6.6 Reduce district cooling discharge:

Although it might not be as much as other contributors of wastewater, still the amount of wastewater discharged by the district cooling does amount to a good level since district cooling systems are now being implemented more and more as part of the constructions' requirements. Each and every facility for the last twenty years or so is having some type of cooling system that discharges wastewater into the sewage network.

In addition, the environmental impact is really alarming. First, the discharged wastewater adds unnecessary load to the network, the pumping stations and the treatment plants. Second, the discharged wastewater seeps into the ground and changes the ground structure and the ground water quality and quantity leading to changes in the ground water behavior/path. Third, the discharged wastewater is generated from electrical cooling systems which require energy that is generated from fossil fuel. Thus, adding to the carbon footprint.

Again, controlling the amount of wastewater discharged by the district cooling system will have a ripple effect on the overall wastewater levels.

6.7 Increase Green landscape:

One strategy that is easy to implement and also cost effective is to increase the green landscape areas in the emirate of Dubai especially in areas with less than required wastewater connections. It can be very costly to build rain water network. In fact, it is not very much effect to do so when the rain falls only few days per year. The problem in UAE in general and Dubai in particular is not the amount of rain water that falls throughout the year but the amount of water that falls within very short time (two to three days) that leads to overloading the wastewater network.

Increasing the green landscape will first help reduce the amount of storm water that is going into the network through the gutters (inflow) and the amount of ground water seeping into the network (infiltration) and thus removing unnecessary clean/fresh water from the network.

Second, with the increase in the green landscape is, the better the environment is. For example, higher oxygen level and at the same time, lower carbon levels.

Third, heavy rain water must be properly disposed of using proper guiding channels for example leading to the sea, river, lakes or manmade storage tank. Heavy rain in the city can increase the amount of ground water to dangerous levels endangering the foundations of the high-rise buildings and other underground structures such as sewerage network, electrical cables, fresh water network, etc.

6.8 Network protection/isolation:

We talked above the inflow caused mainly by the storm/rain water and the infiltration caused by the ground water but we did not talk about the danger such inflow and infiltration causes. Rainwater for example collects various types of chemical (from streets, factories, scrap yards, chemical plants, etc.) before it seeps into the ground. The chemicals in this water pollute the ground water and together damage the pipelines of the sewage network both from outside and inside.

Furthermore, sometimes illegal dumping of chemicals (bleach, fertilizers, paint, solvents, etc.) or wastewater mixed with such chemicals into the sewage network damages the piping system in the near future. Inspections and testing of the ground water and pipelines have to be performed regularly adding to the overall cost of the network maintenance. In many cases, chemicals that are illegally dumped into the network blocks the pipelines/joints leading to expensive repairs and costly temporary operation stoppage. Isolating the network if a difficult task and that is why heavy fines should be imposed on those who violate the laws that protect the city’s infrastructure include the wastewater network.

Additional measures can be taken to protect the wastewater network by adding filtrations or screening measures at the various stages of the network. As much as possible, foreign objects such as plastics, metal, woods, solidified chemicals, sand and gravel, etc. should be screened out to keep the wastewater flow as smooth as possible.

Protecting the network includes also preventing leaks from the network itself. Wastewater that is yet to be treated imposes great danger on the ground water. Leaks of wastewater can poison the ground and harm the natural ecosystem underground (plants root, insects, bacteria, etc.). Generally we can identify possible leaks in the network by simply measuring the inflow and comparing it with the outflow at different nodes. If they differ by much, it means we have a leak in the network and the network maintenance teams need to inspect and repair the leaks. Additional devices can be used to monitor that status of the network pipelines such as odor and leak sensing devices as well. Pegging devices that are supplied with cameras similar to those used for oil pipelines can also be used to perform inspection when needed. Once a leak is detected, it must be repaired immediately. At the same time, regular cleaning of network pipelines and joints is of great importance to prevent foreign deposit and sludge as early as possible to prevent bigger problems in the future.

Last but not least, network protection can be improved with the support from the weather forecasting authority. With advanced warning on storm and rain, wastewater management teams better prepare for heavy storms/rain condition. For example in areas where rain might cause damages, closing these gutters and similar openings can prevent damages to the network. Additionally, areas in which the soil cannot absorb the storm water, a separate and smaller network can be built to divert rainwater to a safe place instead of letting it goes into the sewerage network and overloading the network in such areas.

6.9 On-line monitoring and control system:

You cannot control what you cannot measure. This is statement is a true regardless what you try to control. The first and most important step in being able to control the amount of wastewater and hopefully reduce it is to identify the sources and the causes of the wastewater levels. We have established that the source of wastewater is the end-users and some of the causes are the inflow, infiltration, lack of awareness, illegal dumping and so on. However, the sewerage network of Dubai city is quite complicate considering that it is a small city when compared with much bigger international cities. See appendix 7 for an illustration of the wastewater network for the emirate of Dubai. Managing such network is not easy without using proper monitoring SCADA system that is well integrated into the network. A SCADA system that is equipped with enough and up-to-date equipment and sensing devices can aids with the monitoring and operating the wastewater network.

The SCADA system should take the flow rates at the desired nodes in real time and use them to create scenarios to better control the flow between and within the network using suitable sensors and actuators to control the valves and other similar devices:

“The integration of the software applications plus the advanced communication capability of modern SCADA systems have significantly optimized the operations of multiple lift stations, discharging into a common force main. The result has been to tie real-time flow and climate data to the hydraulic model and SCADA system application software. The SCADA system has been modified to generate commands to sequence the pumping units to maximize capacity and reduce simultaneous running cycles. This will reduce operating pressures in the common force main and reduce the energy demands of the pumping units for years to come.” (Wilcoxson, David and Travis Crane 2012)

With the available technology and the rate at which it is advances, such system is affordable and easy to upgrade on regular basis with reasonable cost. In fact, much of the system can be operated using available sources with low cost available online such as iCloud and IOT.

More suppliers of SCADA system are now available in the market than before with good number of different software and hardware that are suitable for the purpose at hand and can be implementing within short amount of time without much changes to the existing infrastructure. In fact, there is an existing SCADA system that is currently being used to monitor the wastewater system but unfortunately does not provide real life data or utilize the existing data to provide scenarios to better control the flow rates at the nodes.

By integrating the substations with SCADA programming, that the lift station pumping can be scheduled and controlled from a central location for energy efficient operation. By reducing force main operating pressures and total dynamic head leads to reduction in electrical power consumption.

In addition, better scheduling of motor and pump on/off operating cycles to increase drive component service life and reduced service calls. Also by reducing the facility operating cost by designing system capacity based on optimized system Operations (i.e. reduced pumping capacity, force main capacity, peaking flow treatment works Capacity.

- Propose new system improvement such as SCADA system, better control systems, better sensors, changing the pumps capacity closer to actual requirements, etc. For example, there is software that can simulate lifting pump station network to high degree of accuracy. SCADA system comes on line; it is often tested by simulating events, such as tank levels and valves status, using extended period simulation (EPS) model runs. Results from these tests were used to determine control set points, levels, and VFD settings where applicable
- Using proper software to build models that can be as close as possible to the real requirements can be a challenging task even for the most experts since there are many variables to deal with (to forecast).
- Wastewater management system is one of the systems that redundancy are built in at the design stage and implemented during the construction stage. Redundancy in such systems is important due to the vital role that such system plays to support the emirates infrastructure. Re-evaluating and reducing the redundancy system using available new technology will most likely reduce the energy future consumption of at least the rate of its increase.

Here are some points that we would like to highlight on the benefit of using a comprehensive SCADA to control and simulate flow scenarios:

- Reduction in the energy consumption by properly controlling the on/off pumping activities.

- Integrated network that is easy to manage and control from one location using life information from all pump lifting stations.
- Better data recording for future improvement.
- Reduction on the GHG (contributing to Dubai and the country goals to reduce GHG emissions).
- Increase in the life expectancy of the lifting pump stations as maintenance and servicing are done on time and with fewer delays if any.
- Increased pumping availability and thus less dependency on the redundancy system.
- Reduced man-hour requirement/wastage due to better communication system (SCADA).
- Less pumping capacity since flow requirements are fed into the system using SCADA software and thus less energy consumption.
- Less plant operating cost of associated systems due to better monitoring and control of the whole station.
- Changing electrical components to newer and more efficient ones leads to overall lower energy consumption of the station. For example, reduction in pump size or a change of the electrical components to a Variable Frequency Drive (VFD) may be better utilized than a solid state starter with or without a throttling valve.
- This study and implementation can serve as guideline to other emirate that might be needed to upgrade and/or want to reduce the energy consumption.
- It is important that the implementation of the solution is done in a controlled way. Many organizations have embraced their own method of project management. It is generally speaking a good idea to stay in line with this method, as long as it contains the following aspects: project definition, organization, planning, necessary means and budget, a risk management plan, communication plan and training demands.

- After the implementation the project can be handed over to the line organization. The first point of contact for the Black- or Green belt is the sponsor as owner of the problem and eventually the owner of the solution. Proper project documentation forms the reference work for the current process owner and any future process owners as well. It is therefore important to document the reasons behind changes in the process and the implemented solutions, including their yield. This prevents people from needlessly reinventing the wheel in the

6.10 Adopt Specific energy as an indicator:

The sole function of a pump is to move liquid from point A to point B though the network. Energy consumption can be reduced using the Specific Energy (Es), which is basically the energy consumed to move a given volume through the system.

If adopted, Specific energy consumption can help as a direct measure of the pumping cost once the energy costs are known. Here is the equation for the Specific energy (Es):

$$E_S = \frac{P_e \cdot t}{V} = \frac{P_e}{Q}$$

Where

- t = time
- *P*e = input power to driver
- V = volume
- Q = flow rate
- *E*s: Specific energy consumption

Source: BSI EN ISO 14414-2019

Based on a study that was conducted in Australia, it was found that the “energy consumption increases in pump stations where having simultaneously increasing in the differential head and flow rate due to high friction in the head loss Cal auction, therefore better to operate pump at the lower flow rate to minimize friction head loss."

Adopting the results of the calculated specific energy of the pump as one of the indicator to evaluate the pump performance and decide whether further action is needed such as changing the flow rate is one methodology that can be used in order to reduce the energy consumption.

Section 7: Conclusion and Recommendations

The study conducted by the EPA and other organizations on the major pump stations have shown the most of the 85% cost or even more are due to the power requirement. Thus, by reducing the energy consumption we can reduce the cost. Furthermore, we have shown that energy consumption at the pump stations is mainly due to the running pumps. Therefore, it is logical to try to reduce the energy consumed by the pump. This can achieved either by reducing the head losses of the pumps or the flow rates or both. Flow rates or the amount of wastewater discharged depends on the amount of water used by each person. Thus, the first options here would be to reduce the water usage per person.

We have talked about the various ways in which the amount of wastewater can be reduced such as reducing the daily consumption per person, imposing tariffs, urbanization strategy, reducing the inflow and the infiltration, etc. Each and every one of the above mentioned solutions contribute to reducing the flow rates and therefore the overall energy consumption at the pump stations. However, it is in this authors' opinion that educating the public, better urbanization strategy and imposing tariffs are the best three solutions that can be adopted.

With the above in mind, saving in UAE Dirham is estimated between AED 33.19 and AED 55.30 million or 15% to 25% respectively over the next five years from 2021 to 2025.

The above estimated figures are possible saving only from the operations. In other words, additional saving is most likely to be obtained. For example, better urbanization strategy (redistributing of population) from over utilized pumping stations to less utilized ones will eliminate the need to build new pumping stations that could cost millions of Dirhams and thus reducing the amount of CAPEX investment.

Finally, we hope this study will trigger some questions at the higher level at the Dubai Municipality and other governmental entities in the Emirate of Dubai to work together toward better energy utilization and less waste. After all, **"He who does not think about energy does not think of the future. " Sheikh Mohammed Bin Rashid Al Maktoum.**

Section 8: Limitations and Constraints

8.1 Data: Although the data obtained was from reliable sources (Dubai Municipality and DEWA), unfortunately there was missing data such as the flow rate for pump station PS-V in 2017. Additional data was missing for PS-H and PS-Sn for few days on in Aug 2017. More data was unavailable for PS-K and PS-Q probably due to shut-down and maintenance. In such cases where few days are missing, we assumed the pump stations were not in operation. However, when the data is not available for the entire year while the pump station was available, we estimated the flow rate based on following years and the design capacity and the population level. We believe our estimate is reasonable when compared with the following years flow rates.

8.2 KPIs: None of the existing water and sewage pump stations do have any kind of measurement or standard to refer to. In other words, the problem consists mainly with the lack of proper performance measurements and controls. Or, lack of Key Performance Indicators (KPIs) in which we can monitor, control, correct and even improve the system. The problem definition can be summarized as follows:

- No opportunities in precise controlling pumping system energy
- Lack of accurate data for future project planning
- Carbon foot print in Dubai emirate at elevated level.
- Late identification/action of polluted underground stream of water due to damaged sewage pipelines.
- Difficulty in determining organization’s success criteria
- Incomplete available data: missing or in accurate data

8.3 Centralized Control System: Unavailability of comprehensive SCADA system (scenarios) that can help properly manages water movement through the network and thus alleviates some of the pressure on certain pump stations when required. (Mismatch of water overflow and treatment plants).

8.4 Walkthrough: Field sites visit and walk through are required to validate the data and build a hydraulic model which then can be assessed later on based on the BS EN ISO Standard 14414:2019 for the Pump system energy assessment.

8.5 Sampling: There is no sampling done to measure the level of wastewater and therefore decide on the action required to reduce the contamination that in turn impacts the pumps performance and therefore the energy consumptions.

8.6 Ground water movement study: Additional study is required to understand the ground water movement and storm water to decide on methods to reduce inflow and infiltration into the network.

8.7 Hydraulic modeling: is in use but should be linked to SCADA system. Thus, linking the SCADA (using life data) to the hydraulic model can help improve the system performance.

8.8 Cooperation: Alignment between the Dubai Municipality and Dubai strategic planning objective for urbanization should part of the future planning and improvement of the network. For example, such as coordination between Dubai Municipality and other entities such as DEWA, RTA, private sectors, etc.

8.9 Pump stations utilization: Problems associated with utilization of oversized pumps often develop because the system is designed for peak loads, while normal operating loads are much smaller.

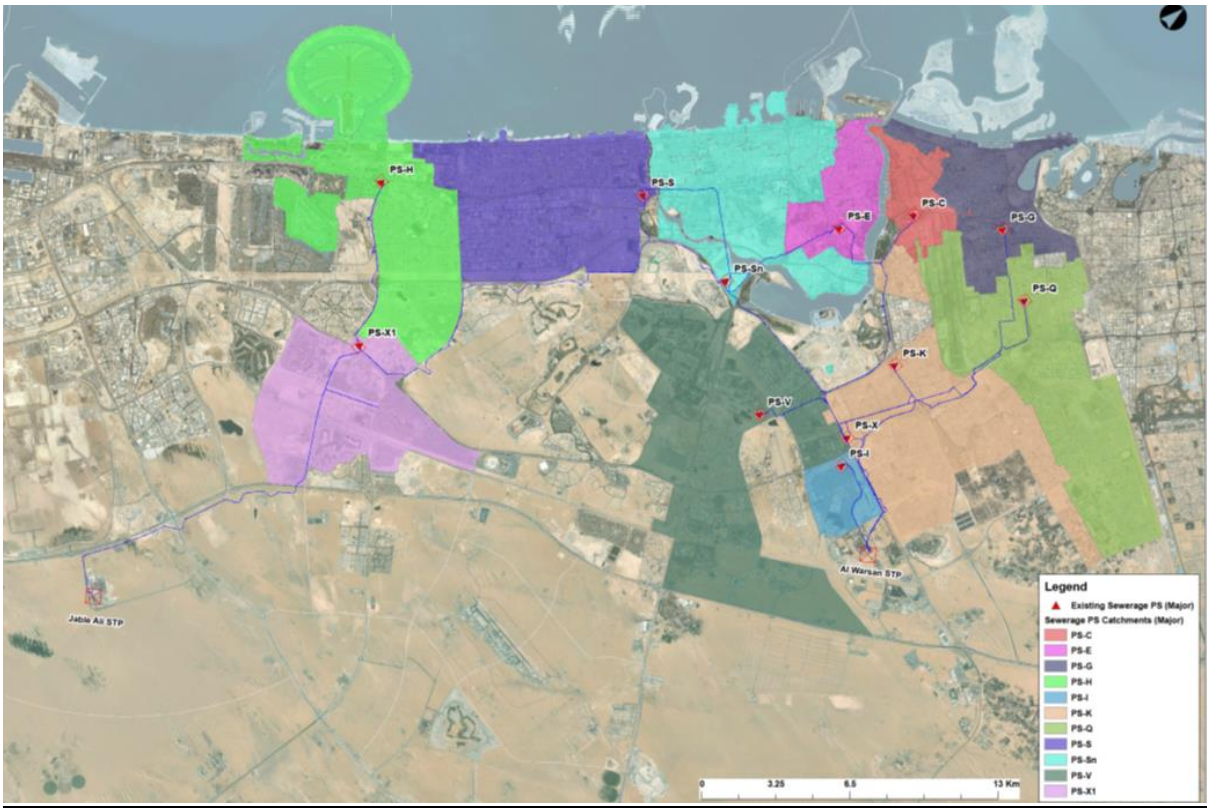
8.10 Pipelines: Pipeline fouling and scaling, and future production rates also result in design conservatism leading to pump oversizing.

8.11 Suggested further studies: despite the limitation we have, there is still wide area for impairment. Here are some suggested:

- **Pump station characterization**: Physical characteristics of the pump stations to represent head discharge, wet well storage and pump cycle time were documented. The information collected included: wet well size, pump on/off cycles, pump head discharge curve, number of pumps at each station, and type of pumps (booster v's local pumps).
- **Collection system characterization**: Pipes and fitting materials, pipe dimensions (diameter, length, and connectivity), slope, and air pocket accumulation were assessed
- **Hydraulic modeling, validation, and calibrations**: The modeling is to conduct on the scenarios that are similar to actual conditions. Hydraulic model calibration to conduct for flow distribution and diurnal flow patterns.
- **Energy measurement**: Energy consumption measurement of the existing system was conducted through review of electricity bills and using onsite measurement devices (as available).

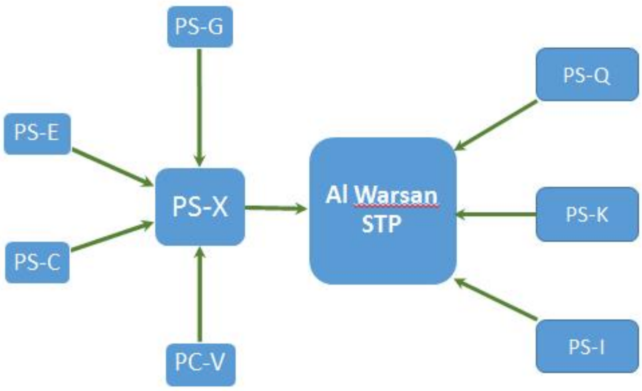
Section 9: Appendixes

Appendix 1: Dubai Pumping Stations



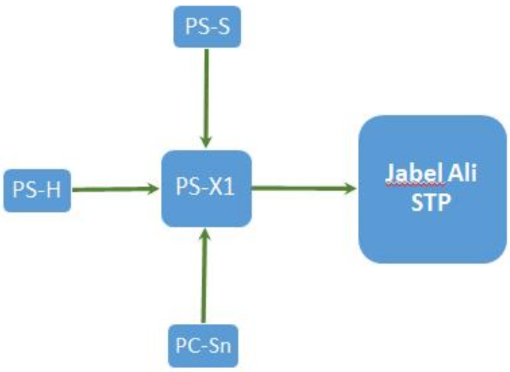
Appendix 2 & 3: Al Warsan and Jabel Ali Catchments

AL WARSAN CATCHMENT CONFIGURATION & FLOW



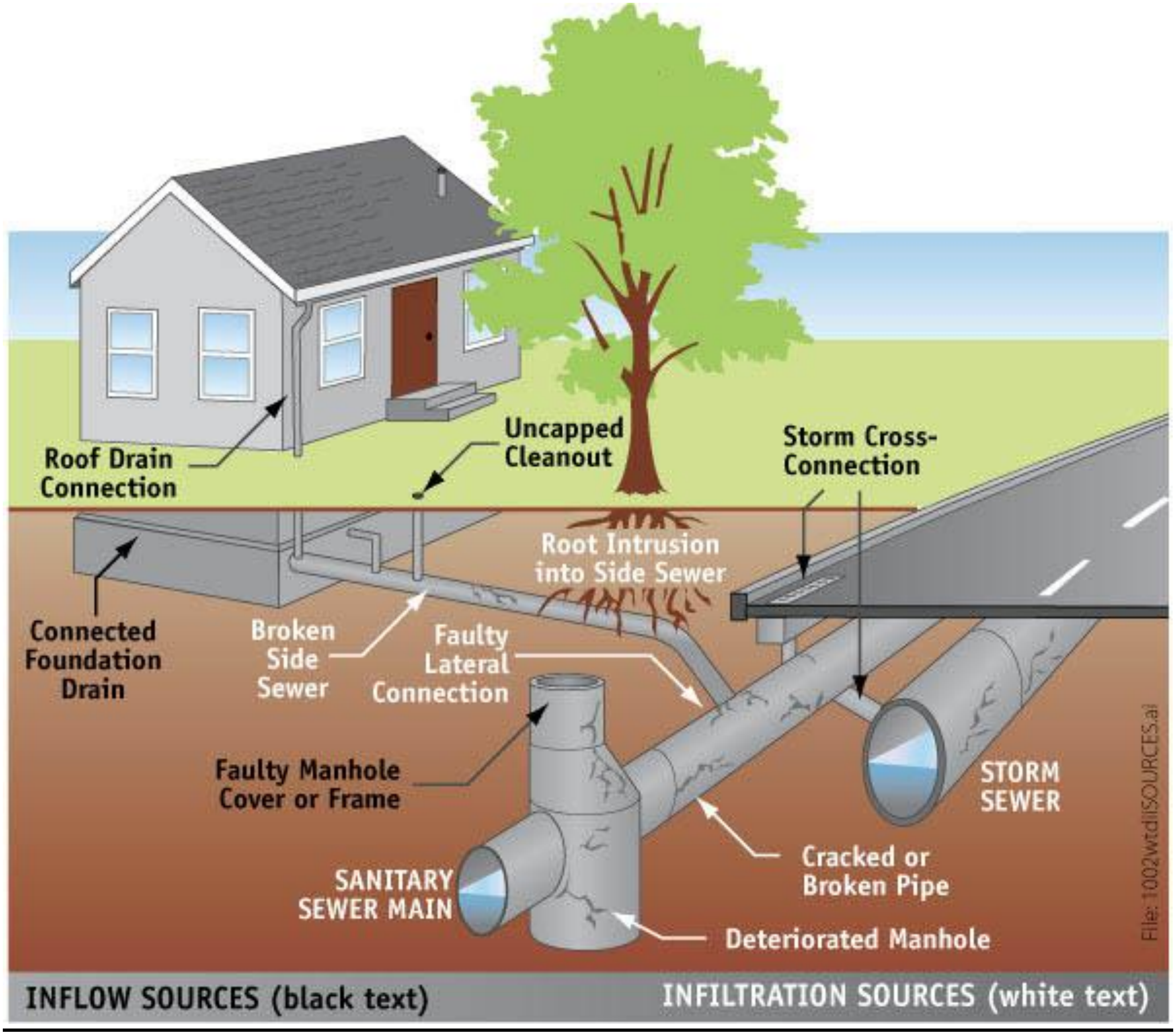
Al Warsan Catchment	
PS Name	**Capacity (l/s)**
C	1,500
E	1,600
G	1,550
V	1,860
K	1,998
I	600
Q	2,000
X	3,700

JABEL ALI CATCHMENT CONFIGURATION & FLOW

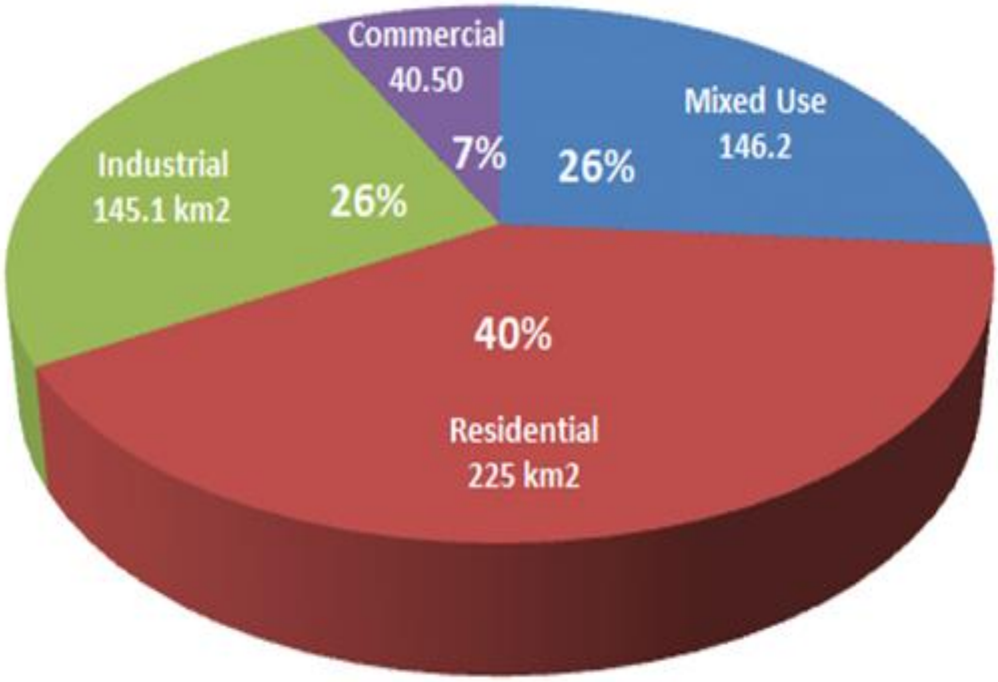


Jabel Ali Catchment	
PS Name	**Capacity (l/s)**
H	2,250
Sn	1,900
X1	6,750
S	1,650

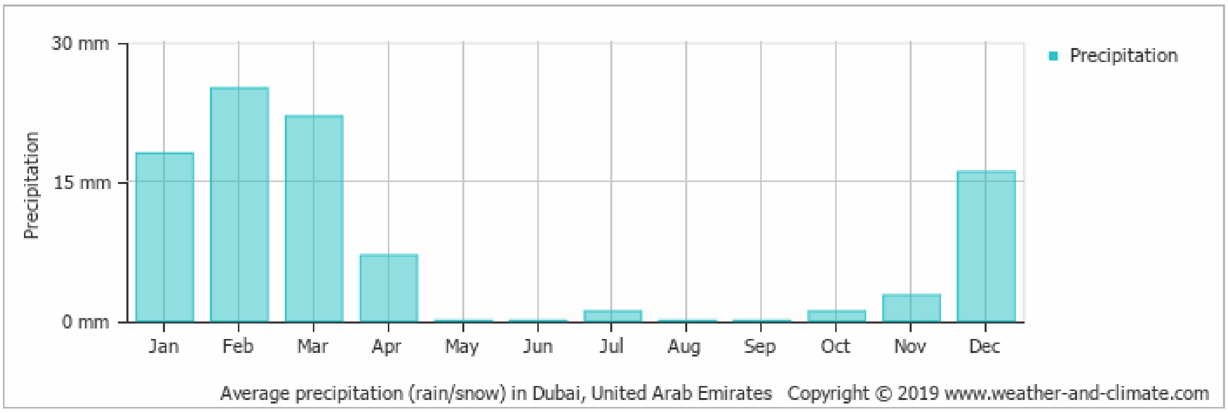
Appendix 4: Inflow and Infiltration



Appendix 5: Wastewater Flow Percentages by Sector



Appendix 6: Weather in Dubai (year 2019)

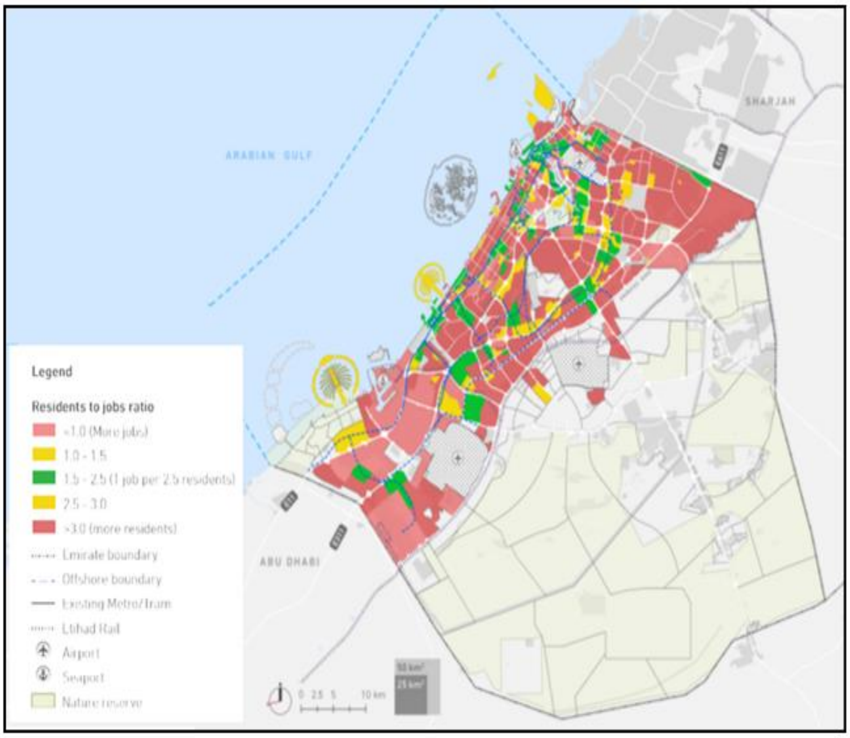


Show average precipitation in Dubai in Inches

<u>**Appendix 7: Utilization Percentage of Pumping Stations**</u>

PS	Designed	2017	2018	2019	2020
PS-E	1600	60.92%	59.66%	71.84%	72.93%
PS-S	1650	80.45%	87.15%	90.90%	90.41%
PS-Sn	1900	81.59%	85.79%	90.06%	83.51%
PS-H	2250	58.50%	60.45%	63.44%	68.58%
PS-Q	2000	74.59%	75.96%	72.51%	73.33%
PS-K	1998	44.90%	46.47%	47.27%	51.51%
PS-X	3700	52.70%	84.22%	77.53%	70.56%
PS-I	600	88.98%	91.11%	93.33%	95.78%
PS-C	1500	69.01%	67.45%	69.06%	60.36%
PS-G	1550	82.47%	80.91%	81.50%	82.90%
PS-V	1860	29.26%	46.61%	31.85%	49.31%
PS-X1	6750	66.59%	71.62%	89.45%	99.56%

$$\text{Utilization} = \frac{\text{Flow Rate}_{\text{Actual}}}{\text{Flow Rate}_{\text{Design}}} \times 100\%$$



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