Guide for The Optimization of Potable Water Distribution in Puerto Rico

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Abstract — *The system of distribution of drinking water is one of the most important infrastructures of any population in the world. Water is necessary to cover the basic needs of human beings, and also to maintain a healthy flora and fauna. Therefore, all the populations must have an optimal drinking water distribution system that can meet the needs of all. These systems of distribution of drinking water are very affected by the deterioration caused by the use and wear through time, lack of maintenance, personnel poorly trained in their field operations among other factors. In this project a guide was established to optimize the drinking water system of Puerto Rico in an orderly and efficient manner, with the use of advanced technology in terms of geography and instrumentation. The optimization guide is focused on ensuring that the distribution of water provides a high-quality service to the entire population, locating all the components of the distribution system and monitoring them.*

Key Terms — *Geographical Information System, Optimization, Supervisory Control and Data Acquisition system, Quality.*

INTRODUCTION

In Puerto Rico, 97% of the potable water distribution system is administered and operated by the Aqueduct and Sewer Authority of Puerto Rico. This distribution system consists of a system of pipes, pumps, tanks, accessories, and structures that supply the water from the different reservoirs to the homes, shops, and industries of the population (see Figure 1). The drinking water distribution system has deteriorated with time, becoming inefficient. This deterioration affects the quality and quantity of water that reaches the population that uses it. The elements by which this system is formed have been damaged by wear and tear, by inadequate design in the distribution lines, lack of maintenance and adequate monitoring. The current distribution system does not have an inventory in which the replacement of equipment that is damaged and that has been replaced in the field is updated. This makes it difficult in the future to replace the necessary equipment in the field such as pumps, valves, among others. The lack of monitoring in the system further aggravates the deficiencies of the distribution system due to the loss of drinking water in leaks through the distribution pipes and overflows in storage tanks. This project proposes to develop a guide to optimize the distribution system of drinking water in Puerto Rico, with which they can improve and avoid all the deficiencies mentioned above.

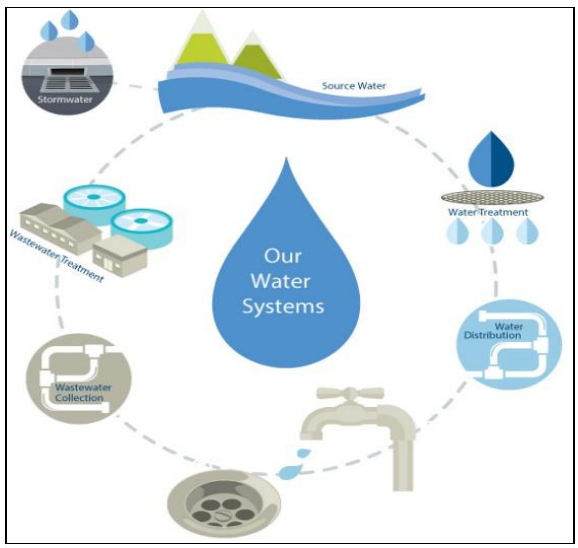

Figure 1
Water Supply System

JUSTIFICATION

This project seeks to improve a water distribution system that is providing an inefficient service to the population. This guide would help facilitate the field operations of the water distribution system. They will have access to more advanced and accurate technology tools, with which all the design standards of the Aqueduct and Sewer Authority of Puerto Rico can be met. The design standards are intended to establish the necessary requirements and the proper process for the distribution of drinking water in Puerto Rico, in which it is established as a priority that the quantity and quality of water are always optimal [1].

LITERATURE REVIEW

The optimization of drinking water distribution systems has been carried out in many parts of the world, implementing technologies with which operational expenses can be reduced and a more efficient service provided. In 2018, the United States Environmental Protection Agency (USEPA) identified more than $160 billion dollars in funds to make improvements in water distribution systems and their components [2]. The United States Environmental Protection Agency (USEPA) estimates that in the next 50 years the need to replace equipment and instruments for the distribution of drinking water will continue to increase (see Figure 2) [3].

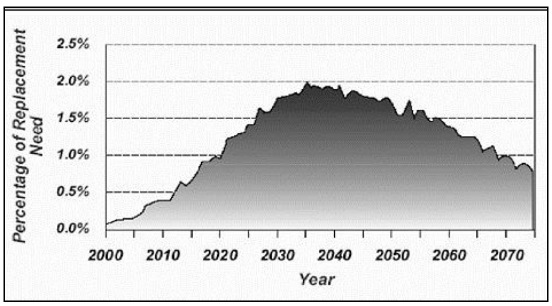

Figure 2
Percentage of Replacement in the Next 50 years

As part of these improvements, it has been proposed to implement analytical systems to improve the design and planning of operation and maintenance of drinking water distribution. The implementation of these systems helps determine the status of distribution components such as tanks, pipes, pumps, and valves. Population growth should be taken into account when the distribution system is optimized, as the population grows, in turn, the demand for potable water will increase. The increase in this demand is one of the most important factors to be taken into consideration in order to define the possible extensions needed in the distribution, such as tanks, pipes, and pumps of greater capacity to bring drinking water to new areas of residential or commercial construction [2]. The operation of the water distribution system is a very expensive one and the component that has the most attention when optimizing water distribution is pumps. Pumps are the highest operational expense of most distribution systems (see Figure 3). This is due to their high energy consumption and the costs of monitoring and maintenance. Therefore, in the optimization of the system it is identified how the pumps are working in order to minimize the energy and maintenance costs.

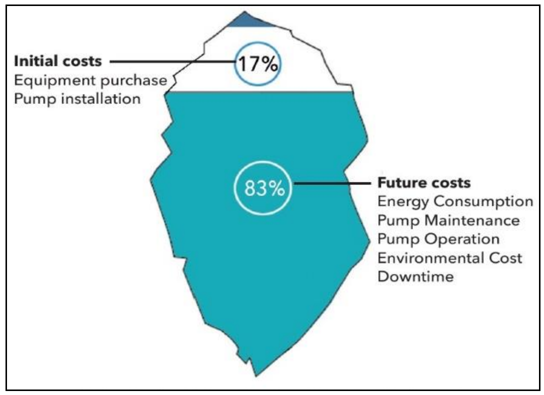

Figure 3
Pumps Percentage Costs

This optimization has been done by installing monitoring systems and controls with which the pumps can be operated remotely and can be identified promptly when one of them is not operating correctly. While an updated field inventory is available if the pump needs to be replaced by any mechanical damage, it would be replaced with equipment of equal or better quality than the one that had been avoided, thus creating deficiencies in the water distributions.

The tanks, valves, pumps, and other equipment that makes the water distribution system possible are separated into different categories, such as components, subcomponents, sub-sub components, which help to have a better organization of how it works and how the system is organized. In this same order you can define the optimization priorities of each part of the system. (see Figure 4)

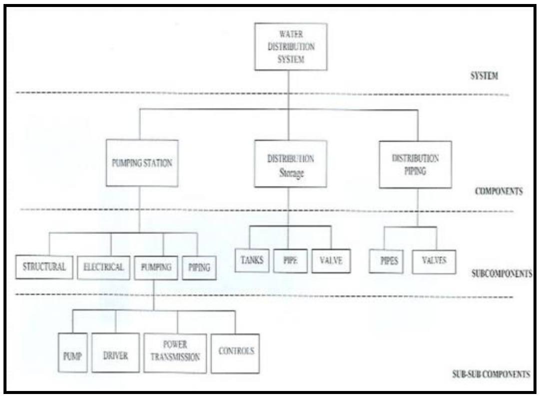

Figure 4
Distribution System Components

GUIDE FOR THE OPTIMIZATION

As part of the optimization process, the Aqueduct and Sewer Authority will have to carry out an analysis of the demand for potable water. This analysis must evaluate if the demand for potable water in the distribution system is correct, this demand will be determined through the elaboration of a population census where the real population of consumption in the system can be estimated. Studies conducted in the population of Puerto Rico indicate a decrease in the population and an annual rate of accelerated decrease for the next 30 years (see Figure 5) [4].

This factor will be crucial to implement the optimization guide in a correct way, since in this way it will be possible to determine if it is necessary to make extensions to the system, replace equipment, or eliminate part of the components of the distribution system (see Figure 6).

This guide also includes improving the quality of drinking water and that it meets all the requirements of state and federal laws, especially with the Safe Drinking Water Act of the United States Environmental Protection Agency (USEPA) (see Figure 7) [5].

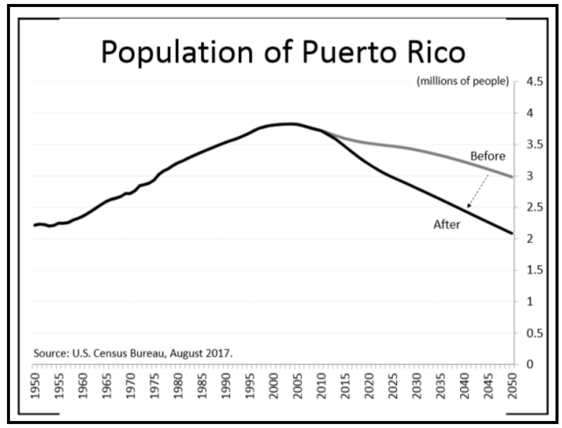

Figure 5

Population of Puerto Rico

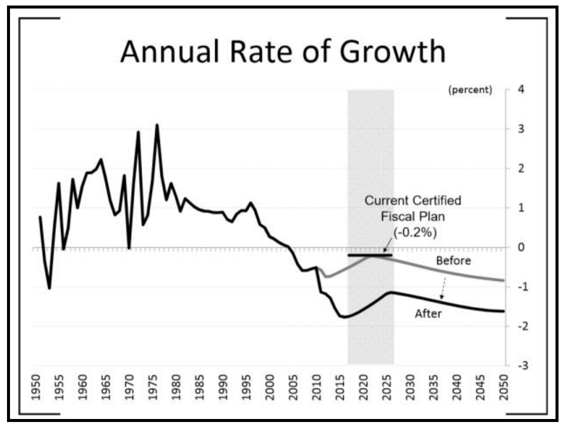

Figure 6

Annual Rate of Growth

The Safe Drinking Water Act (SDWA)
• Drafted in 1974
• Amended in 1986 & 1996
• Sets national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water.
• The US EPA is responsible for regulation and enforcement by setting national standards for drinking water based on sound science to protect against health risks, considering available technology and costs.

Figure 7
Safe Drinking Water Act (SDWA)

METHODOLOGY

In the methodology we will see all the elements that will be part of the optimization guide and how they will be developed in the implementation of the guide in the drinking water distribution system. The elements that will form the methodology will include implementation of the Geographical Information System (GIS) program, create a complete inventory of all components of the distribution system and that it can be monitored and controlled with the Supervisory Control and Data Acquisition system (SCADA), inventory sheet in the field. The following information explains the function of each element of the methodology that will be implemented in the drinking water distribution system to be developed in this investigation.

Geographical Information System (GIS)

The Geographic Information System (GIS) is an advanced system in which different types of geographic information are raised, such as elevations, rivers, soil types, as well as infrastructures. Among the infrastructures that can be erected in this system are roads, pipes, dams, among others. This system can analyze all this data simultaneously in its interface. The Geographic Information System (GIS) must be used to lift the entire existing structure of the potable water distribution system to determine what are the lengths and diameters of existing pipelines, also where all tanks, valves, and stations are located, pumps within the distribution system, where the distribution of the flow begins and where it ends in order to create a complete and updated network of the distribution system in which all its components are named (See Figure 8) [6].

After raising all the infrastructure, the existing elevations of these components must be collaborated to help determine if these components of the distribution system are in the indicated geographical area. The complete network of distribution of drinking water already established in the Geographic Information System (GIS) also helps determine possible alternatives about where to redirect the flow or activate other nearby equipment in case one of the pipes in the distribution network breaks or a pump is out of operation. This way you could maintain the distribution of drinking water without affecting the population.

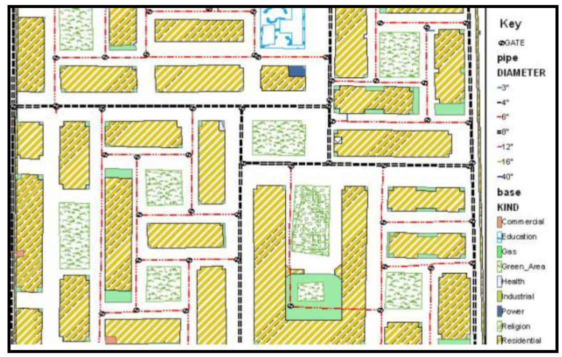

Figure 8
Network Distribution Diagram (GIS)

Supervisory Control and Data Acquisition (SCADA)

Operating and monitoring a drinking water distribution system can be very complicated, these systems handle a lot of data at the same time and in different areas, a system as important as this one must be operated in a safe and accurate way to provide a quality service to the population [7]. Many of the operations tasks of this system require human intervention to be carried out and sometimes this intervention is done late or inadequately due to not having the correct information. In order to have an optimal distribution system, constant monitoring of it and a system of controls is needed to help prevent any failure in the distribution network.

Data Supervision and Acquisition Control (SCADA) is a system focused on managing and monitoring data at industrial levels. In this system, most of the components of the distribution system can be monitored in real time; in this way we can monitor the state of the tanks and know how fast they are filling and emptying (see Figure 9). We can monitor pressures of flows in the system, with which it could be determined if there is a water leak in it, also see the operation of the water pumps and see at what capacity they are working, or if at some point they stop working interrupting the water flow through the network. The program also allows to interact with the system's components; remotely either manually or automatically can turn on and off equipment, regulate pressures, improve their performance, and prevent ruptures and damages in the distribution system of drinking water that would interrupt the flow of water.

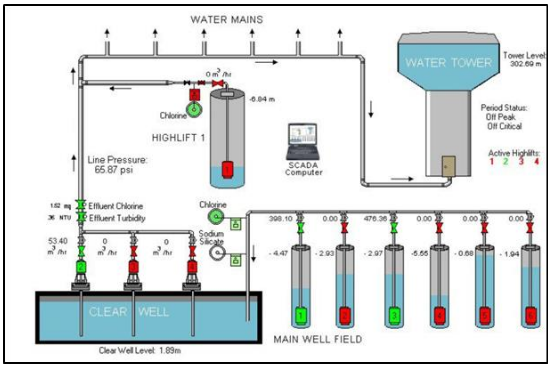

Figure 9
Water Distribution System (SCADA)

This system is composed of elements of field instrumentation, communication, hardware, and software that allow communication between all the equipment (see Figure 10).

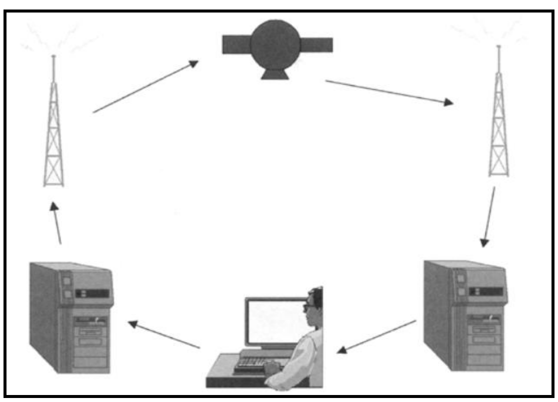

Figure 10
Elements of SCADA System

Field Inventory Sheet

The equipment in the distribution systems are often damaged, broken, or simply stop working due to a failure in the equipment or in the system. A system as important for the population as it is the system of distribution of drinking water is necessary to repair or replace these equipments as soon as possible. But the repair or replacement of these equipment must be done in an appropriate manner and maintain an orderly record of the repair or replacement that was performed. For this, a field inventory sheet is recommended, in which the type of repair that was made can be reported, or if the equipment was completely replaced. This sheet must be signed by the engineer or field supervisor and sent to the offices of the relevant region to create an electronic record with which you can maintain an updated and real inventory of equipment and components that are in the field and that they are part of the distribution system. All repairs and replacements made in the field, even if small, should be considered so that the field inventory is not affected and performance and equipment effectiveness analyses are not made due to a wrong or delayed inventory.

CASE STUDIES

In the western region of Puerto Rico, specifically in the municipality of Rincón, many sectors with a deficiency in the drinking water service have been reported (see Figure 11). This system is operated by the Aqueduct and Sewer Authority of Puerto Rico (PRASA). Many of these deficiencies are low water pressure, places where water does not reach, or constant service interruption.

They also have problems with the equipment and components of the drinking water distribution system. The system has a current demand of 1.4 GPD. This demand is to supply a population of approximately 5,300 people, which means a high volume of drinking water flow and a broad distribution system (see Figure 12).

The objective of analyzing this drinking water distribution system is to optimize the distribution of drinking water in the area using the optimization guide that was developed in this project. Information was obtained from the Aqueduct and Sewer Authority of Puerto Rico (PRASA), in order to acquire knowledge of this system such as equipment, capacity of tanks and pumps, among other components of this system.

Figure 11
Areas of Service

Sectors of Services	Customers	Demand(GPD)
CAGUABO 115	2,593	684,552
CAGUABO II	16	4,224
CALVACHE BARRERO	22	5,808
CALVACHE-ATALAYA 1	93	24,552
CUADRADO	991	261,624
JAGUEY CRUCES	269	71,016
PIRAMIDE	98	25,872
RINCÓN NUEVA	1,079	284,856
SNOW BAKERY	101	26,664
TOTAL	5,262	1,389,168

Figure 12
Water Demand by Sector

CASE STUDIES ANALYSES & APPLICATION

The water distribution system of this region is a typical one, which is composed of tanks, pumps, valves, and pipes of different diameters. Something a little different from this system is its geography since this area has different types of land, it has flat places, coasts, and high places. The water reaches this system from the Miradero filtration plant in the municipality of Añasco, also the system has wells that use for supply water too (see Figure 13). Many of the components of this system have mechanical, capacity, or design flaws. It is a rather old system, which was designed with a demand lower than the demand that is now required in this region. This is one of the biggest problems that this system has, and it causes many damages. To update and optimize this system we will follow the steps established in the distribution guide.

Population

A census of the population must be carried out in order to know how much the population of this municipality has increased. By carrying out this study you can confirm if the amount of people they have registered in the system is the current and actual amount of the municipality of Rincón. This study must be carried out considering all the houses that are in the town, but we must also consider all industries, beaches, and all recreational areas. Rincon is a town that receives many tourists during all times of the year, this factor must be considered because it substantially increases the use of drinking water. Once the study is done, it is possible to determine with certainty what the current population is and based on this, make improvements and expansions in the distribution system. Preliminarily we know that there are places that are almost not getting water and tanks that the authority informs that they are never filled. These are clear indications of the need to increase the supply of water since the current amount is not enough to satisfy the need of water for all.

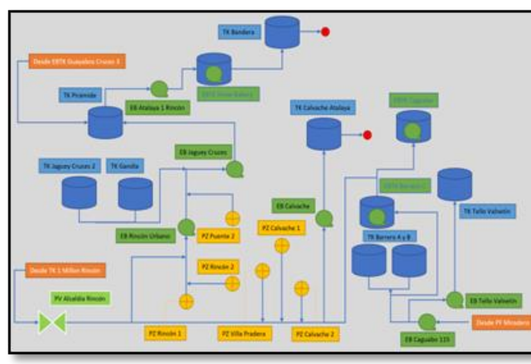

Figure 13
Water Distribution Network

Geographical Information System (GIS)

The geography of this area was raised in the Geographic Information System (GIS), in which you can see all the changes of elevation and the wells that exist in this distribution system. This system also identified the entire infrastructure of the system, such as tanks, pumps, pipes, valves, among others. In this way, a more complete analysis of all the factors that must be taken into consideration when optimizing the system can be performed (see Figure 14) since you can see the diameters of the pipe, where the tanks and pumps are located, and can determine which is the correct pump for each pumping station depending on where it will be located geographically. Knowing the diameter of the pipes that distribute the water in the system can be more easily identified where there may be an increase or decrease in water pressure due to the diameter of the pipe that was installed and at what point exactly it occurs and who will be the part of the population that will be affected. In base of all the geographic information help to see if in any place maybe is missing a storage tank closer for bring more water or bring the water more quickly to other place (see Figure 15).

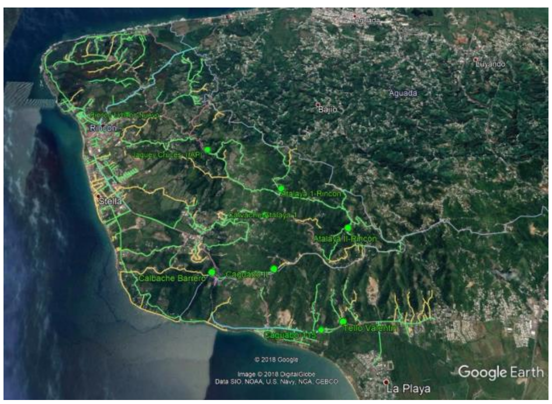

Figure 14
Pump Stations

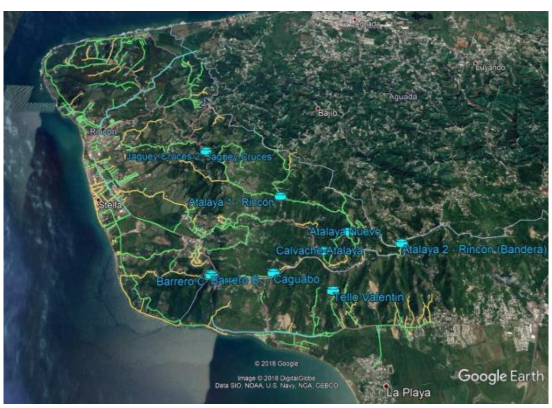

Figure 15
Storage Tanks

Monitoring

The distribution system of the municipality of Rincón does not have an automated monitoring and control system. Therefore, there is no knowledge of when the equipment fails, the water pressure drops, or if there is no water flow. The system has no control to reduce and increase pressures or turn on and off the equipment that is part of the distribution system. In the field visit made to this distribution system, some of the people in charge of it did not realize that one of the pumps was out of service, since they have no way of being notified when something like this happens. Other regions of the Puerto Rico Aqueduct and Sewerage Authority system (PRASA), have an automated monitoring and control system. Lack of monitoring aggravates the situation of the deficiencies that the potable water distribution system suffers since they have no way of knowing anything about what goes on in the system. This causes thousands of gallons of water to be lost daily; also the population runs out of drinking water service or receives very little water due to the lack of control of the system.

CONCLUSIONS & RECOMMENDATIONS

These systems of distribution of drinking water in Puerto Rico have been abandoned and neglected, they are not given proper care or maintenance. We see that the equipment is not updated with modern and quality technology and field studies are not carried out to determine the state of the equipment. There are no studies to update the demand for drinking water. These systems must be fully optimized. The system of Geographic Information System (GIS) must continue to be developed in all distribution systems in order to continue to know more about the entire geography and infrastructure of water distribution. It is recommended to expand the Data Supervision and Acquisition Control (SCADA) system that is already installed in some regions of the Puerto Rico Aqueduct and Sewer Authority (PRASA).

This is needed to have more control of the drinking water distribution system and knowledge of any breakdown or failure that occur in it. It is recommended to develop a field study to assess the status of all components of the system and see what status they are in and if they need to be repaired or replaced. The field inventory sheet that was previously discussed in the project must be used when this field study is done in order to maintain a real and updated record of all the equipment. The optimization guide that was developed during the project serves as a guide to the Aqueduct and Sewer Authority of Puerto Rico (PRASA) to perform a complete optimization of the water distribution system in an efficient and orderly manner.

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