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Report Submitted to:

Professor Laura Menides

Professor Douglas Woods

WPI Puerto Rico Project Center

By

Todd L. Clark

Steven W. Cove

Christian J. Derderian

In Cooperation With

Mr. Omar García-Bengochea, Hydrology & Hydraulic Group

Ms. Agnes Ayuso, Hydrology & Hydraulic Group

CSA Architects & Engineers

OPERATIONAL BENEFITS OF A WORKING HYDRAULIC MODEL

May 9, 2000

CSA Group

WPI

Abstract

This project was commissioned by CSA Architects & Engineers in San Juan, Puerto Rico. The project team did research on the problems with Puerto Rico's water distribution system as well as on the computerized hydraulic model that the joint venture of CSA and CH2M Hill developed as part of an aqueduct plan for northern Puerto Rico. The team then did a cost/benefit analysis of updating and maintaining the model as a tool for the water utility to use in the future to improve their operations and customer service. We concluded that if the water utility adopts the model, its impact would result in a five-year savings of $144 million due to the reduction of unaccounted for water and labor costs.

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- Mr. Mark Zacharias, Director Adjunto Region Metropolitana

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- Dr. Susan Vernon-Gerstenfeld
- Prof. Laura Menides
- Prof. Douglas Woods

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Executive Summary

Introduction

This project, conducted for the CSA Architects & Engineers in San Juan, Puerto Rico, evaluates how the computerized hydraulic model developed by CSA Architects & Engineers could serve the Autoridad de Acueductos y Alcantarillados (AAA) to improve the efficiency of the island's water service. Over the past twenty years the efficiency of service of the water system has slowly diminished. As a result of the inefficient water service a branch of the Puerto Rican government, known as the Infrastructure Financing Authority (AFI), began funding capital improvements to the water system. Two or three years ago AFI hired the joint venture of CSA and CH2M Hill, herein called the JV, to develop an island wide computerized hydraulic model of the water system that would serve as a tool to assist in new improvements planning. The citizens of Puerto Rico depend on the water produced and distributed by AAA, and thus the need for a reliable water system is crucial. The use of a detailed hydraulic model would offer AAA the opportunity to fine tune their operations, reduce losses of water and improve customer service.

Objective

The Infrastructure Financing Authority (AFI) is currently benefiting from the computerized hydraulic model developed by the JV to design capital improvements and to study the effects of new water supplies on the water system. Additional benefits of the model can be reached if the model is further developed and updated. The objective of this project is to evaluate the costs and benefits of updating and maintaining the hydraulic model, so that AAA can use it in its daily operations and long term planning.

Background

Puerto Rico is an island 100 miles long and 30 miles wide with a population of nearly four million people. The Autoridad de Acueductos y Alcantarillados (AAA), a government owned water utility, is in charge of maintaining the water system. However, a French firm named Companía de Aguas de Puerto Rico (CAPR) was hired by the government to manage the operations of AAA because the water system has not been able to fully satisfy the needs of its customers. Other outside firms were also contracted by AFI to complete large-scale projects. A firm from England entitled Thames Dick was hired to construct the North Coast Super Aqueduct, which will supply 75 million gallons of water per day (MGD) to the San Juan Metropolitan Region. CSA Architects & Engineers was also contracted by AFI to develop a computerized model of the island's water system.

Two of our project goals are to look at the history of the Puerto Rican water system and to analyze how a computerized hydraulic model can improve the operations of AAA and the service of the water system. This report analyzes the costs and benefits that would be incurred if AAA implemented the hydraulic model. We also analyze the future impact that the model would have on water conservation and capital improvement costs.

Present Situation

The current hydraulic model, which has been developed by the JV for the past two or three years, is a skeletal model of the actual water system of Puerto Rico. The Infrastructure Financing Authority (AFI), an organization created by the Puerto Rican government to assist in the development of the island's infrastructure, has hired the JV to improve the efficiency of Puerto Rico's water system, which is owned by Autoridad de Acueductos y Alcantarillados (AAA). The computerized hydraulic model is being used to identify areas with insufficient water service, analyze the validity of improvements to these areas, and prioritize improvements by their cost/benefit ratio. Once projects are identified and prioritized they are presented to AFI to coordinate between the projects that can be funded and the ones that have to be deferred.

Future of the Hydraulic Model

The computerized hydraulic model has proven itself to be a very beneficial water system analysis tool. Our five-year analysis indicates that if a detailed model is implemented at AAA in cooperation with a leak detection program, then approximately 52 MGD of unaccounted for water (UFW) could be saved in the fifth year of model operation. This UFW savings would generate over $47 million of revenue in the fifth year[1]. Through the collection of precise field measurements, the model would have the capability to isolate water leaks, monitor system status, predict future problems, improve logistics, and reduce the time required for field operations. These benefits could be accomplished through an aggressive water conservation program that would be working in conjunction with the model's expanding database.

Conclusions and Recommendations

The computerized hydraulic model developed by the JV, though in a developing stage, would be beneficial to AAA because of its ability to assist in improvement planning. Through our analysis we estimate that the minimal Year 1 benefits would nearly pay for the model after the first year of operation. The Year 1 hydraulic model cost of approximately $4.8 million is greatly out weighed after the second year by the increasing net savings provided by the use of a model in a leak detection/prevention program[2]. We also analyzed the impact that the model would have on capital improvements. If AAA implemented the model, we estimate that it would currently defer the annual payment of $18 million required to fund the development and construction of a new 85 MGD water production plant until the year 2020 when the adjusted maximum day demand (MDD) meets the supply[3].

Once the model is in full operation, it would save AAA an estimated $53 million dollars annually in unaccounted for water (UFW) reduction and labor fees after the fifth year of model operation[4]. We estimate that after 20 years of operation along with a leak prevention program, the water deficit/surplus would be in a better condition than it is today. This benefit would be felt after the initial cost of approximately $4.8 million to transfer the model to AAA and train them in its use and an annual operating cost of approximately $2.2

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[1] Numbers shown in the "Data Analysis" Table at the end of this section
[2] Numbers displayed in the bar graph titled "Five Year Water Conservation Study"
[3] Refer to the line graph titled " Water Supply Analysis – Current and Future Conditions"
[4] Number shown in Year 5 Net Savings of the "Data Analysis" table

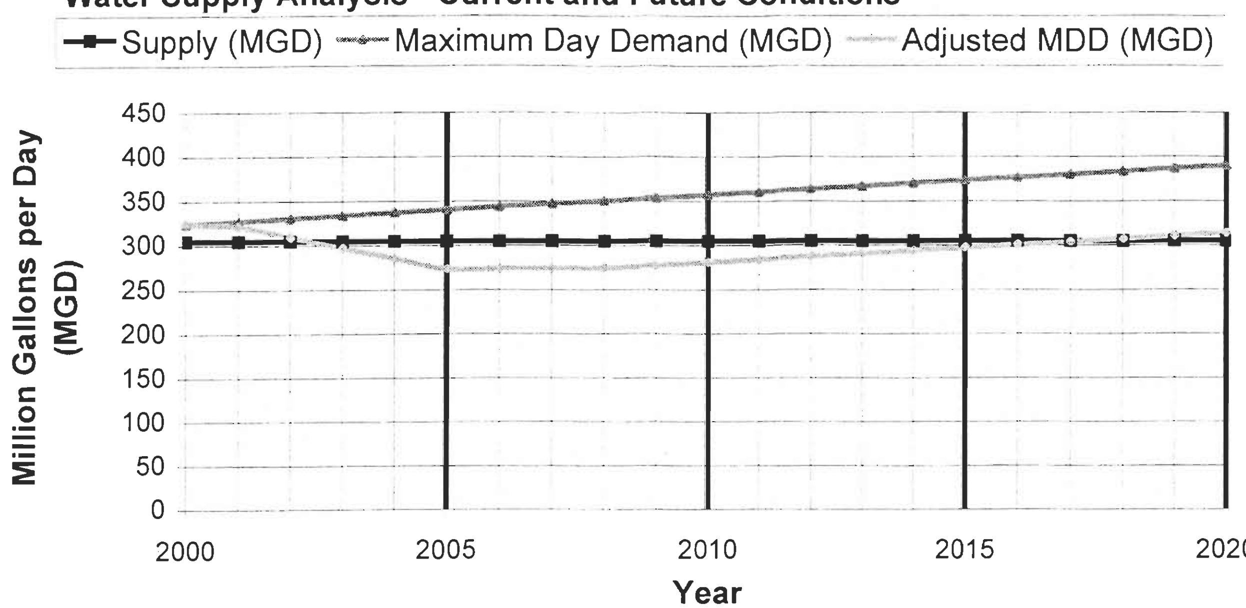
million. This is a small price to pay for a more efficient service, a better understanding of the system, and water for the next 20 years without the construction of a new production facility.

Hydraulic Model Cost Benefit Analysis for the Executive Summary

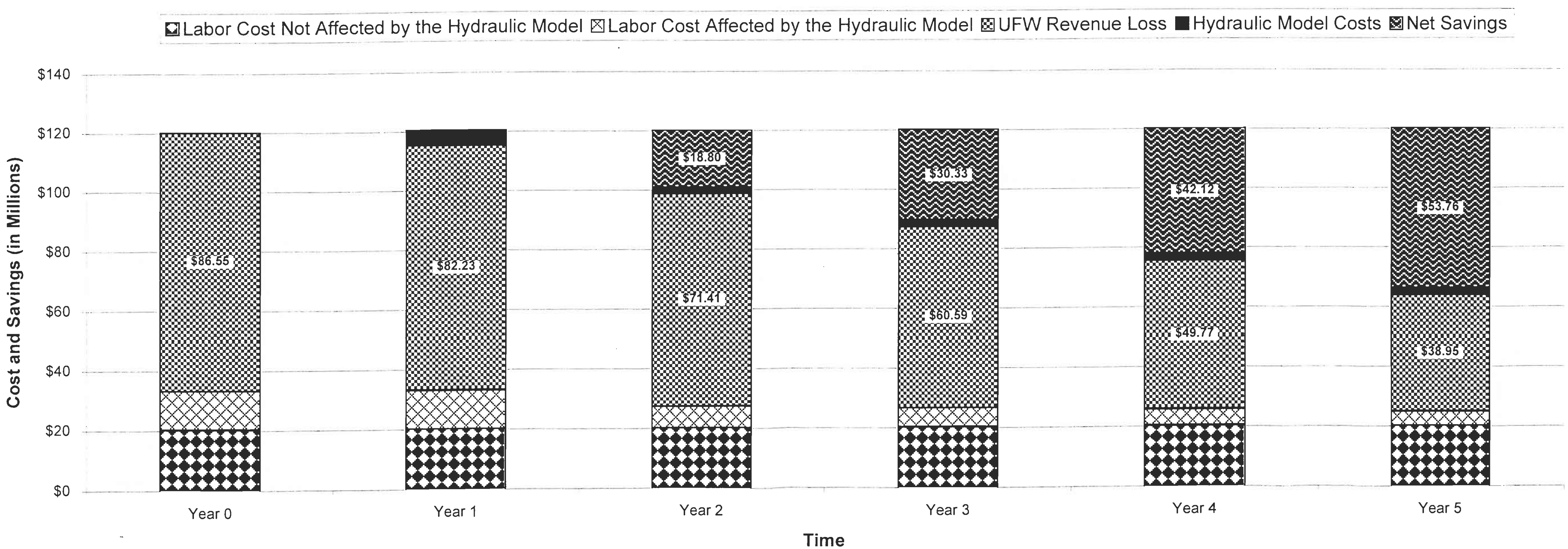
Data Analysis

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Avg. Day Production (MGD)	235	235	235	235	235	235
Estimated UFW % of Production	40%	38%	33%	28%	23%	18%
Estimated UFW (MGD)	94	89	78	66	54	42
Estimated UFW Savings (MGD)	0.0	4.7	16	28	40	52
Estimated UFW Savings	$0	$4,327,738	$15,147,082	$25,966,426	$36,785,770	$47,605,114
Estimated Labor Cost Savings	$0	$261,294	$5,893,261	$6,610,404	$7,578,546	$8,401,468
Estimated Hydraulic Model Cost	$0	$4,868,170	$2,244,336	$2,244,336	$2,244,336	$2,244,336
Estimated Net Savings	$0	-$279,139	$18,796,007	$30,332,494	$42,119,981	$53,762,246
Estimated Cumulative Net Savings	$0	-$279,139	$18,516,868	$48,849,362	$90,969,343	$144,731,589

Water Supply Analysis - Current and Future Conditions



Hydraulic Model Five Year Water Convservation Study



1.0 Introduction

This Interactive Qualifying Project (IQP) was conducted for CSA Architects & Engineers. Located in San Juan, Puerto Rico, the joint venture (JV) of CSA and their business partner CH2M Hill provide a variety of services including: integrated management consulting, architecture, engineering, planning, environmental sciences, construction, and program management[5]. They are involved the largest public works project ever undertaken in Puerto Rico. This project, known as the AFI AAA Initiative, includes the updating and restructuring of the water distribution system in Puerto Rico. As a tool for improvement planning, CSA and CH2M Hill have been developing a computerized hydraulic model of Puerto Rico's water system. After some additional detail is added to the computerized hydraulic model, CSA hopes that the Autoridad de Acueductos y Alcantarillados (AAA) will implement it into their daily operations. CSA Architects & Engineers has asked the IQP team to evaluate the uses of the computerized hydraulic model. Included in this evaluation is a cost/benefit analysis of the model.

The inefficiency of the water system in 1994 led the government of Puerto Rico to intervene in the management of the system. Since then the Infrastructure Financing Authority (AFI), a government organization, has been involved in the AFI AAA Initiative. This project involves improving the current water system to provide better customer service. The JV was hired by AFI to define and prioritize improvement suggestions that will aid in the redevelopment of the water system. To aid them in their improvement planning, CSA and CH2M Hill developed a computerized hydraulic model. When their work is finished, CSA hopes that AAA will implement the model, and use it as a monitoring and maintenance tool. The implementation of a computerized hydraulic model would give AAA the advantage of anticipating and preventing problems.

[5] This report was prepared by students of Worcester Polytechnic Institute at the Project Center in Puerto Rico. CSA and their business partner CH2M Hill design and oversee large-scale public projects in both the public and private sectors. The mission and organization of CSA Architects & Engineers is further presented in Appendix A.

The computerized hydraulic model is computer software that allows the user to create a working map of the existing pipelines in a water system. The model's database houses detailed specifications of the water system's elements. These specifications include length, diameter, elevation, pressures, flow rates, and construction material of pipes, valves, pumps, and storage tanks. Based on the geographic information for each element in the system, the model connects the elements to make a map of the water system. Once the model is constructed, the computer can simulate water flow, locate pressure problems, isolate leaks, and test new system design ideas.

The goal if this Interactive Qualifying Project is to evaluate how the computerized hydraulic model could continue to serve AAA in the future to streamline operations and improve customer service. Puerto Rico has had some problems with the water system that resulted in water shortages. Such problems include burst pipes, leaks, or incorrect valve positions. AFI has hired the joint venture of CSA/CH2M Hill to model the water system's elements to identify areas that need improvements. Once the model accurately reflects each element's specifications, as discussed above, it can be used as a powerful tool to aid in the daily operations and maintenance of the water system. The development of a computerized hydraulic model requires a continuous effort to ensure that the model mimics the behavior of the water system.

Our primary objective was to study the operation of the water system in Puerto Rico and present a report that conveyed all the costs and benefits of AAA using the hydraulic model as an operational tool. This report includes the estimated cost of developing and maintaining the model, the possible uses of the model, and a cost/benefit analysis of these uses. This report is important to CSA/CH2M Hill because they have been developing the computerized hydraulic model for two years and once AFI is done with supporting improvements to the water system they would like to see the model continue to offer benefits to Puerto Rico. Therefore CSA/CH2M Hill will present our report to AAA as a basis for demonstrating the importance of maintaining and upgrading the hydraulic model so that AAA may operate the model and continue to derive benefit from it.

The computerized hydraulic model was created using several software packages. A database was used to store the specifications of the water pipes, tanks, pump stations, and reservoirs found during field studies. The second software package needed was a CAD program, called MicroStation, used to make a computerized map of the water system in Puerto Rico. These two programs when linked together have the capabilities of running real time tests to discover any problems within the water system.

As Puerto Rico attracts more and more people, these new households present an additional demand on the water system. Supplying water to this added demand can be difficult, however a computerized hydraulic model can help in the decision of where to move water from to avoid any future problems. Another benefit of the model is the ability to determine pressure and flow problems and evaluate solution alternatives. During the completion of this Interactive Qualifying Project, the project team performed a cost/benefit analysis of the model and assessed how the Autoridad de Acueductos y Alcantarillados (AAA) and its customers can benefit from its use.

Completion of an Interactive Qualifying Project (IQP) is required for graduation from Worcester Polytechnic Institute. This project specifically qualifies as and IQP because it demonstrates the impact that a computerized hydraulic model of the water system can have on society. This project challenged students to identify, investigate, and report on the relationship between society's need for water and the technology of a computerized hydraulic model. Using the computerized hydraulic model operators can detect problems that were previously unknown. This highly technological equipment would benefit the water system in improving operations and maintenance resulting in a more reliable and efficient water system.

Society depends on water and the need for a reliable water system is crucial. The continuity of daily life should not be interrupted by an unreliable water system; therefore water system monitoring and maintenance must be effective and efficient. A hydraulic model can provide detailed maps and an inventory of a water system's facilities, as well as water system analysis. Therefore a hydraulic model can increase the amount of information known about the system and thus streamline the ways maintenance and planning are done. Our project can be considered an IQP because we will be carefully looking at the hydraulic model and the possibility of its future use at AAA and hopefully improving daily life in Puerto Rico.

2.0 Background and Literature Review

The following chapter contains our understanding of the literature that pertains to our project. To educate ourselves, we reviewed books and journals on water distribution systems, read modeling software manuals and government websites, and performed interviews. Some of the information contained in this chapter is from research and interviews performed in Worcester, Massachusetts, while most of it is a review of the literature that we studied as well as information gathered during the interviews conducted in Puerto Rico. To demonstrate the need and usefulness of a working hydraulic model, we had to understand the information contained in the following chapter.

2.1 Social Impacts from Past Problems

Puerto Rico is an island 100 miles long by 30 miles wide with a population of nearly 4 million people. In 1945, the Government of Puerto Rico created the Autoridad de Acueductos y Alcantarillados (AAA) to own and operate all of the water system. Due to the large responsibility and area, AAA has experienced many problems. One of the major problems in Puerto Rico's water system is leakage, which is the main cause of a lack of water in the system. Improvements and restructuring are another reason for water service to be interrupted.

2.1.1 Leaks

The major problem with the Puerto Rican water system is the significant water loss. In some areas, water loss tops 40% (Gregory, 3). A person in San Juan can walk down the street and spot two or three leaks, one spurting up through the pavement, or another spilling out of a fire hydrant. Through simple observation one can see that leaks are a primary reason the water system is in disarray.

These leaks have a great effect on the people the system services. The leaks reduce the pressure in the pipes, which means housing in higher elevation is inadequately supplied with water and increase the cost of water production and distribution. This problem must be dealt with to improve water service to all the customers. If the problem persists, as it has in the past, the price of water will continue to rise and the island will continue to experience droughts during the dry season.

During the summer months in Puerto Rico, a dry season usually results in a drought felt in the southern regions of the island. However, in 1994 the drought had an island-wide impact that resulted in massive forced water conservation. The plan that was used for conservation involved water rationing throughout the entire island. Due to the lack of water storage and the deteriorating water system, the people of Puerto Rico were not protected from this drought and suffered an uncomfortable if not unsafe living style (McKim, 7: ASA Begins).

In several interviews with employees at CSA Architects & Engineers that lived in Puerto Rico during the drought, we came to understand the feeling of emotional pain that they had endured. Jorge Camacho was one of the individuals we spoke to, and his first reply was "I don't want to remember those days. It was a very difficult summer that year. My mother did not want to cook dinner for us because we had no water to clean the dishes" (Camacho, 2000).

This drought forced the government to take action and look for money for development to prevent unmanageable droughts from happening in the future. The government sold the publicly owned phone company and used the proceeds to pay for the projects necessary to improve the water system and services to its customers (Garcia, O. 2000).

2.1.2 Restructuring and Maintenance

The improvements planning of Autoridad de Acueductos y Alcantarillados also resulted in short lived problems. A reporter of the San Juan Star writes "150,000 in Ponce to lose water" (STAR staff, 14). This problem was a result to the relocation of a 36-inch pipe for the construction of a highway in the area. This major maintenance is one of the inconveniences that restructuring has on the island and the customers of water service.

Marc Zacharias, the director of the Metro San Juan region of the Companía de Aguas, (Companía de Aguas is the operator hired by AAA to operate the water company) informed us that other water system problems that have occurred are the incorrect closing of valves. This problem is due to the lack of knowledge about the water system in Puerto Rico. The operators have little knowledge of what each valve controls, so it is not unlikely for an incorrect valve to be turned off and thus water in an unaffected area will now be affected as well (Zacharias, 2000). A reporter from the San Juan Star writes that these minor errors have impacted the lives of the Puerto Ricans so much that it is not unusual for a household to wake up and have no water (Fajardo, 3).

2.2 Government Intervention

The local government in Puerto Rico is currently in charge of the water system updating. They own the Autoridad de Acueductos y Alcantarillados (AAA) and Infrastructure Financing Authority (AFI). Discussion of privatization and/or private management organization began in 1994 when the previous year's financial reports were released. According to that report, AAA had lost nearly $50 million during fiscal year 1993 (Albanese 15). Because the service and performance of AAA did not meet the standards set by the Government, they hired the French firm, Companía de Aguas (CAPR). CAPR is now operating and managing the water system.

The government-owned Infrastructure Financing Authority (AFI) is currently working to improve the infrastructure of the water system. Chosen by AFI as their design consultant, the joint venture of CSA Architects & Engineers and CH2M Hill are privately owned consultants working for AFI on the water projects. See Figure 2-1 below for more information.

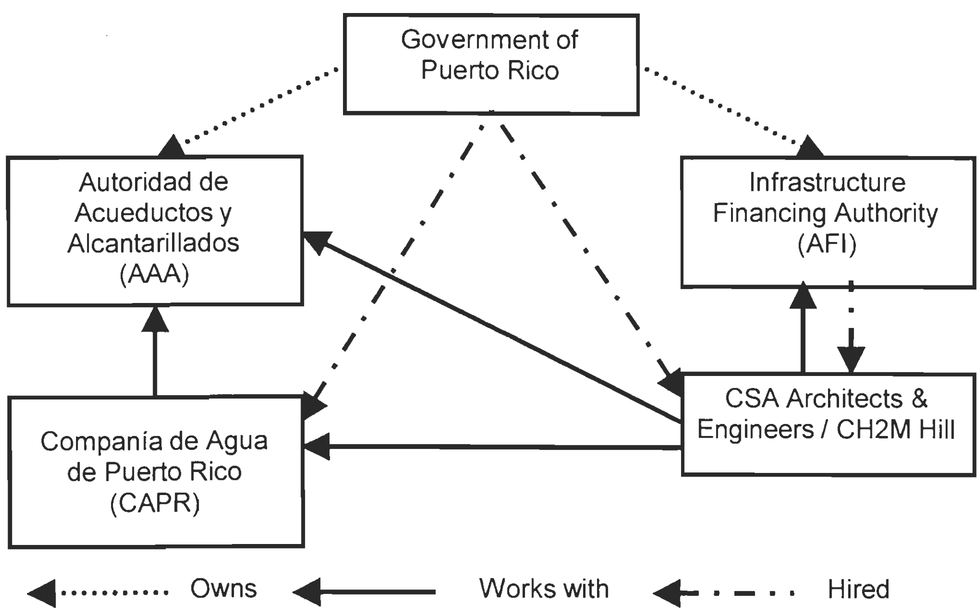


Figure 2-1: Government Intervention Organizational Chart

2.2.1 Operation

The Autoridad de Acueductos y Alcantarillados (AAA) is the government branch that currently owns the water distribution system in Puerto Rico. The quality of their operations began to deteriorate sharply in the past decade, which triggered the local government to hire an outside contractor to operate AAA. The company that was contracted was the Companía de Aguas and will be operating the water system until the government believes it is no longer necessary.

2.2.1.1 Autoridad de Acueductos y Alcantarillados (AAA)

In 1945, the Puerto Rican government established the organization of the Autoridad de Acueductos y Alcantarillados (AAA). The mission statement of this organization reads: AAA intends to "develop, own, and operate all necessary installations and facilities necessary to provide potable water and sewage collection and treatment services to the people of Puerto Rico" (AFI, 1/24/00: What Is?). The path set by this mission has led AAA to consolidate the operation and management all of the municipal aqueducts and sewer collection and treatment plants in Puerto Rico.

Puerto Rico is required to comply with all US Environmental Protection Agency regulations concerning water quality as a minimum, but the local health department may impose further regulations on the Autoridad de Acueductos y Alcantarillados. Located in Caguas, AAA's main laboratory facility opened in 1996. While capable of testing over 1000 potable water and 700 sewage samples daily, the facility also houses laboratories configured to test for the presence of protozoa, parasites, and viruses (AFI, 1/24/00: What Is?).

2.2.1.2 Companía de Aguas de Puerto Rico (CAPR)

Mark Zacharias informed us that the Companía de Aguas is a firm owned by the French corporation VIVENDI. A small task force is working here with AAA to operate the water system on a day-to-day basis excluding future planning or capital improvements. They are currently working on a contract that is scheduled to end in 2001 (Zacharias, 2000).

VIVENDI's goal is to be close to its customers and to anticipate their needs through imagination and innovation whether the customers are local authorities, companies or individuals. VIVENDI employs 275,000 people worldwide and in 1999, topped 41 billion Euros in net sales (VIVENDI, 2000). As a company, they aim to improve the quality of life of their customers through excellence in environmental services and communication infrastructure. Since CAPR is a VIVENDI company, they hold the same values to be their own.

2.2.2 Intervention

The drought of 1994, mentioned earlier, impacted not only the people of Puerto Rico, but caused a domino effect within its government. The officials of Puerto Rico knew something had to be done. They decided to take immediate action toward this water problem. After weighing their options, they chose to sell the government owned phone company of Puerto Rico to a private investor. With the funds generated from this sale, they set the organization, now known as Infrastructure Financing Authority (AFI), in charge of updating the water system.

2.2.2.1 Infrastructure Financing Authority (AFI)

Established in 1988, the organization was designed to aid in the operations of those companies involved in developing and operating the infrastructure facilities of Puerto Rico. Infrastructure Financing Authority provides the companies with temporary financial and administrative assistance that enables them to operate in a more efficient manner.

Infrastructure Financing Authority is a government owned and controlled corporation, through which the Commonwealth of Puerto Rico can operate its public works projects. The board of directors of AFI is comprised of two government offices, the Board of the Government Development Bank and the Secretary of the Treasury of Puerto Rico. The government passed an act, called the Enabling Act, to define the infrastructure as the following:

> Infrastructure [includes] public works and facilities of substantial public interest, such as water supply systems; wastewater treatment and disposal systems; resource recovery systems; electric power systems; highways; roads; airports; bridges; maritime ports; tunnels; transportation systems, including mass transportation; communications systems including telephones; industrial facilities; land and natural resources; and tourist infrastructure facilities (AFI, 1/24/00: What Is?).

Currently AFI is using its capital created by the sale of the telephone system to jump-start the water system. The branch of AFI dealing with the water system is known as the AFI AAA Initiative. The structure of the Initiative has four parts. The Strategic Projects group deals with capital improvements on the water system. The Immediate Actions Projects (IAP) deals with smaller problems that require fast, short-term solutions. The Environmental Compliance group ensures the Initiative's compliance with rules and regulations that apply to their projects. And finally the Technical Support team offers in house engineering services to the projects of the Initiative. Further detail regarding the structure of the AFI AAA Initiative can be viewed in Section 7.6, Appendix F. Once AFI completes its work on the water system, they will be reassigned to work on other areas of infrastructure.

2.2.2.2 CSA Architects & Engineers (CSA)

CSA Architects & Engineers, an engineering firm in San Juan, is currently working as a joint venture partner for AFI. Along with their business partner CH2M Hill, CSA has been developing the hydraulic model to provide project design, planning, and management for the AFI AAA Initiative. Their hope is that the model will eventually be used as an everyday tool for operations, monitoring, and also future design work. The current model is not island-wide because their work has only been in certain areas of the island. The figure below can demonstrate the coverage of the model. The areas outlined in black, in Figure 2-2, are where the modeling has been completed thus far. As you can see there are several different modeling groups involved with the island water system. However, CSA/CH2M Hill has been working with AFI and is in charge of the majority of the modeling.

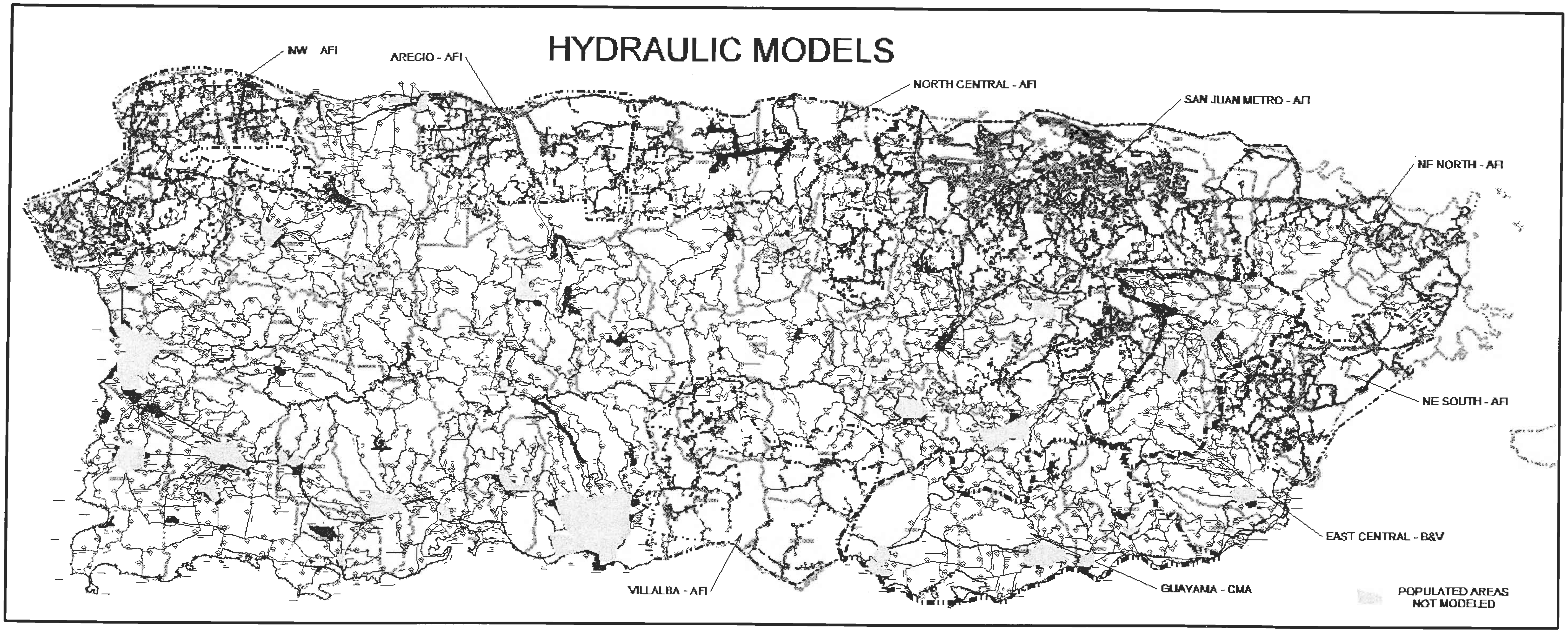


Figure 2 - 2: Island Coverage of the Hydraulic Model

2.3 Hydraulic Modeling

A hydraulic model is a computer simulation of the flow of water within a network of water pipes. Water companies worldwide use this tool to locate flow problems, adjust their systems for changing usage patterns, and test alternate flow directions. Since the model is a computerized program it is very easy to operate when used for design or analysis purposes. The model is being continuously modified and updated until the desired detail is met for analysis required by the water system. A various range of analysis can be done depending on the model's level of detail, which can vary from a skeletal to a high-detail model.

The model being developed by CSA/CH2M Hill is skeletal, which involves pipes that are greater than a certain diameter depending on the size of the transmission lines in that specific region. In the model of the San Juan Metropolitan Service Area (SJMSA), the pipes that are included are those that are eight inches in diameter or greater. The computerized hydraulic model provides assistance in producing the best solutions to improve the service of the water system. The SJMSA model is currently being used for capital improvements, which involve identifying new projects in the water system for better water service.

Another type of model is one with a high level of detail, which can be used for daily operation by a water utility. This highly detailed model allows for analysis of the entire water system continuously, giving feedback of where water is being lost, areas of low pressure, and other operational problems. This analysis can only be completed if the model is calibrated, which means precise details about every characteristic of the water system, such as elevation, length, pipe diameter, pressure, flow rate, and demand must be collected. To get this type of detail, the water company must have records from the beginning of the construction of the water system, or take the time to locate and analyze all the pipes, valves, tanks, reservoirs, and pump-stations.

At the heart of the hydraulic model is the Geographic Information System. The following sections deal with the software involved with the model.

2.3.1 Geographic Information System (GIS)

A geographic information system (GIS) is a computer-based tool for analyzing digital maps of man-made systems and natural events. GIS technology has the ability of integrating common database operations with the benefit of map based geographic analysis. This ability distinguishes GIS from other information systems and makes it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies.

The data can be viewed as having two elements, geographical and statistical. The geographical information provides the geographic position and a reference for the statistical or attribute data (Goodchild, 1991: 11). Any variable that has a position in a given space can be stored into GIS. GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use (United States Geological Survey, 2000).

2.3.1.1 History of GIS

GIS is a computerized system for the storage, retrieval, manipulation, analysis, and display of geographically referenced data. Geographic Information Systems (GIS) were developed in the 1950s, primarily in the public sector. In the 1970s and 1980s, a vigorous GIS industry developed, with clear US leadership. Mapmaking and geographic analysis are not new, but a GIS performs these with more efficiency than manual mapmaking methods. Before GIS technology only a few people had the skills necessary to use geographic information to help with decision-making and problem solving. Today, GIS is a multibillion-dollar industry employing hundreds of thousands of people worldwide. GIS is taught in schools, colleges, and universities throughout the world. Professionals in every field are increasingly aware of the advantages of thinking and working geographically. (Chrisman, 4/4/00: The GIS History Project)

2.3.1.2 GIS within CSA Architects & Engineers

The modeling team within CSA Architects & Engineers uses GIS maps developed by United States Geological Survey. These maps allow the components of the water system drawn in MicroStation to have a relative geographic location. The MicroStation software is discussed in section 2.3.2.5, Bentley's MicroStation. The GIS is also used as a back-up plan, to confirm the details of the Computer Aided Design (CAD) drawings in MicroStation. Once the GIS maps are imported into the background of MicroStation, the modelers can check their drawings for accuracy.

2.3.2 Modeling Software

CSA Architects & Engineers has been using a hydraulic model for design purposes affiliated with the AFI AAA Initiative. The computer systems for the hydraulic model contain several software packages. The following sections discuss those software packages and their uses.

2.3.2.1 LYNX

The LYNX program is an engineering analysis tool developed by CH2M Hill, for creating, editing, and reading infrastructure maps and the technical data that corresponds to those maps. LYNX is used along with MicroStation's CAD and Graphical User Interface (GUI) capabilities. LYNX provides the means for storing infrastructure element data in a database such as Microsoft Access. The main feature of LYNX is its capability to manage a database of the infrastructure and efficiently incorporate that information into a mapping program (CH2M Hill, 2000: LYNX User's Guide).

2.3.2.2 EPANET

The EPANET software package was created by the Environmental Protection Agency for free use to the public. EPANET's goal is to better the services of water companies and to provide accurate data on system activity. Among its many abilities, EPANET can perform extended period simulation of hydraulic behavior within pressurized water distribution systems. By representing pipes, tanks, reservoirs and pumps as lines and nodes, EPANET can determine water flow-rates, nodal pressures, and tank/reservoir water levels. Along with these features, EPANET also allows the user to perform substance concentration tests and detect the water source at a node in the system. These features are useful for water quality testing, as well as for water system age analysis. Some of the more advanced features of EPANET include analysis of the reactions within the bulk flow, reactions at the pipe wall, and mass transport between the bulk flow and the pipe wall. The output of this analysis is in the form of a color-coded map with additional information in tabular and graphical form (EPA, 4/3/00: EPANET).

2.3.2.3 Microsoft Excel

Produced by Microsoft, the Excel 97 V. 7 spreadsheet software provides powerful data computational support to the LYNX software package. With the ability to compute large fields of output data at once, Microsoft Excel is capable of handling the enormous data fields created by EPANET and Bentley's MicroStation (Microsoft, 4/3/00: Microsoft Office).

2.3.2.4 Microsoft Access

Access 95 V. 7 is a relational database management system for storing and organizing data. Since there are more than ten thousand specific points in the hydraulic model, Access is used to label each location and hold the data that is specific to that point. This is how MicroStation, which will be discussed in the following section, is able to display all of the data relating to a point on the model when a query is requested. Without Access the LYNX package would not have a means for storing and linking its information (Microsoft, 2000: Microsoft Office).

2.3.2.5 Bentley's MicroStation

Bentley's MicroStation 95 v. 5 is the CAD assistant in the LYNX package. This program allows hydraulic engineers to interface graphically with the model they are using. By clicking on simple button icons and tool menus, a modeler can change, build, adjust, move or delete items in the model (Camacho, 2000).

2.4 Case Studies

Hydraulic modeling software has been used all over the world by water utilities and consulting agencies specializing in hydraulics. The joint venture of CSA and CH2M Hill has worked closely with a few water systems throughout the world in developing beneficial computerized hydraulic models. Cairo, Egypt and San Juan, Puerto Rico are the two case studies that the IQP team studied. Another modeling case study was conducted in Worcester, Massachusetts during our preliminary research. These case studies provide information about the use of the hydraulic model and the benefits of implementation.

2.4.1 East Bank Water System Master Plan

The General Organization of Greater Cairo Water Supply (GOGCWS) hired CH2M Hill, partner to CSA, for help with its water system. The general problem was that the GOGCWS had a lack of knowledge about the water pipe network. Before the help of CH2M Hill, GOGCWS was trying to improve the water system by spending large amounts of money on new pumps, pipelines, and reservoirs, but the system did not improve as expected. Some of the unsolvable problems faced by the GOGCWS were: non-increasing pressures, pipes breaking due to high pressures, large amounts of un-accounted for water, and pipe failures on major pipelines with too much time spent finding the valves needed to isolate the broken pipe (CH2M Hill, East Bank, 4.56). CH2M Hill consultants came into Cairo and set up a water loss prevention program to solve their problems.

CH2M Hill suggested five interrelated tasks that should become an essential part of GOGCWS's daily operations. The tasks are: to develop GIS computerization, install 100 permanent pressure gauges (PPG), maintain PPG's, update hydraulic model, and run hydraulic model. CH2M Hill engineers noted the benefits that GOGCWS would encounter once completely finalizing these tasks. With the correct information entered into the GIS maps and hydraulic models, future planning for the GOGCWS will be hundreds of thousands of dollars cheaper than having a consultant develop this information. By developing their own information, GOGCWS will acquire the proper knowledge of its water system and the hydraulic model to save millions of dollars by improving operations, and eliminating unnecessary consultant fees usually spent to run a hydraulic model (CH2M Hill, East Bank, 4.57).

Once the computerized hydraulic model was completely updated, the operation of the GOGCWS was to locate leaks and fix them according to the priority of the problem towards the entire water system. With the implementation of the hydraulic model, CH2M Hill had previously determined that GOGCWS would save $43 million by isolating and fixing pressure zones. For GOGCWS, the addition of the hydraulic model proved to benefit their water system by saving them money, and also giving the operators a daily tool to locate equipment and isolate problems to make their water system more efficient (CH2M Hill, East Bank, 4.57).

2.4.2 San Juan Metro Service Area Phase II

CSA Architects & Engineers are working for a branch of the government known as Infrastructure Financing Authority (AFI) in the long-term improvement planning of the operation of the water system in Puerto Rico. Involved in this planning is the development of the computerized hydraulic model of the San Juan Metropolitan Service Area (SJMSA). Several years ago CSA began to develop a hydraulic model of the Puerto Rican water system. CYBERNET, an early AutoCAD based version, was the original software used to develop the model. Two or three years ago, the model needed to be updated and LYNX was used as the software to build the updated model (CSA, 2000: ES-2).

The joint venture of CSA and CH2M Hill was able to use this model to analyze the water system of the San Juan Metropolitan area, and to suggest recommendations to the Autoridad de Acueductos y Alcantarillados (AAA) to improve its operations in that area. The land in the Metropolitan area has varying topography and therefore the pressures need to be relatively high for the water to reach the customers at high elevation. The model that CSA developed flagged areas of low pressure, and then modelers were able to reduce the occurrence of these flagged areas by adding in improvements to the model and suggesting those improvements to AAA (CSA, 5-4). Some of these improvements were to build pumping stations, build storage tanks, install larger pipes, or reroute pipelines. These recommendations for improvement were handed into AAA and they have been added to the list of things to do in Phase II of the long-term improvements planning of the water system (CSA, 6-1).

2.4.3 Worcester Water System

Two interviews were conducted at the Department of Public Works (DPW) in Worcester, Massachusetts as part of our background research. Both of these interviews were with the Supervisor of Distribution Engineering, Mike Ferguson. He discussed the steps that are taken and the tools that are used to maintain the Worcester water system. Our goal in this interview was to identify the operations and maintenance of the Worcester DPW and how to understand a hydraulic model is used in their maintenance procedures.

2.4.3.1 Hydraulic Model

According to Ferguson, a computerized model is a very useful tool for locating areas that need to be fixed. This system model was developed in a software package entitled Water Max. Water Max is an analytical tool that simulates the water flow through the piping network. To develop a schedule that will maintain the system effectively, problematic areas must be located. With this instrument, problems can be detected before they occur. The information in the program must be continually updated to ensure reliable data for planning maintenance. The information in the model is kept current through testing, where hydraulic testing is done to measure water flow and pressure in certain pipes.

Another method to providing a reliable water system is locating and repairing pipe leaks. In Worcester, a crew is hired to follow certain sections of the system and listen for leaks with sonic leak detection equipment. Using the proper equipment a high pitch sound indicates a leak in a certain area. This process of leak detection is done at nighttime to avoid excess noise from traffic. Also, licensed field inspectors follow hired contractors to note what is being installed and ensure they are in accordance with the regulations of the American Water Works Association. The freezing temperatures of New England winters prevent underground construction. As a result, the inspectors spend their winters updating the DPW database using their notes taken from the previous season. All of the measurements are then entered into Water Max so the program can do a correct simulation of water flow (Ferguson, 2000).

2.4.3.2 Maintenance Scheduling

According to Ferguson, the Worcester DPW developed a five-year plan for maintaining the water system. A schedule for repairs or new installation of pipes is based on certain factors, including the pressure in fire hydrants, the street paving schedule, and system needs displayed by a computerized model.

As a distribution engineer, Ferguson stated that his highest priority is providing enough water pressure in fire hydrants. If there is not a significant amount of water pressure in a hydrant then a fire cannot be extinguished. The Insurance Services Office (ISO) provides guidelines for flows available at a hydrant. ISO recommends that 750 gallons per minute (gpm) in a residential area and 1250 gpm be available from a given hydrant with a residual pressure of 20 psi. A minimum flow rate is required to ensure that there will be a sufficient volume of water available to extinguish a fire without drying up the main pipes. Hydrant flow testing verifies that a suitable level of pressure is present. This involves connecting two hydrants on the same pipeline. Water pressure is measured from the beginning hydrant of the test segment of pipe and then the same measurement is taken at the second hydrant. If these measurements do not comply with the specifications for hydrant water pressure, the area will have to be studied further to isolate and solve the problem. When a maintenance schedule is created, the areas with poor hydrant pressure are the first to be repaired (Ferguson, 2000).

Ferguson further stated that the city's schedule for street paving is another important aspect to be considered when planning a five-year maintenance program. A meeting is held every month by the DPW street resurfacing engineers to notify all the utility companies which streets will be repaired so the utilities can plan their maintenance appropriately. The water utility company does not want to ruin the newly paved road to fix the underground pipes. Therefore, cooperating with the street paving crew is the central factor to be considered when designing a maintenance schedule for the water system of Worcester (Ferguson, 2000).

Ferguson continued to say that residents' complaints are also a means for finding problems in the system. Customers may call the Worcester Department of Public Works and report problems such as insufficient pressure, rusty water, or visible leaks and flooding. These complaints alert the distribution engineer as to where undetected problems are occurring. The degree of these problems is assessed and included in the maintenance schedule (Ferguson, 2000).

In conclusion, Ferguson says there are many factors to be considered when designing a maintenance schedule. The top priority for the water utility is to provide adequate water pressure for the fire hydrants. Street paving plans must also be considered when scheduling maintenance. In addition, useful information on problematic regions is provided by computer software and through customer complaints. To optimize maintenance scheduling all of these factors must be taken into account (Ferguson, 2000).

The background research done in Worcester relates to our current study in Puerto Rico because it further establishes the benefits of a computerized hydraulic model. Our goal in Puerto Rico is to identify the costs and benefits of implementing a computerized hydraulic model into the operations of AAA. Through researching Worcester's water system we identified that their hydraulic model was used for locating problematic areas with poor water supply as well as recognizing if there would be enough water to supply surrounding towns. Even though Worcester had very detailed hand drawn maps of their water system they recognized the benefits in hiring an outside firm to digitize all of its maps into a GIS software package.

3.0 Methodology

The objective of this project is to present a report outlining the costs and benefits of the use of the hydraulic model developed by the joint venture (JV) of CSA and CH2M Hill for the Autoridad de Acueductos y Alcantarillados (AAA) if they were to implement the hydraulic model. The goal of this methodology is to explain the steps taken and methods used to collect our data for a cost/benefit analysis of the hydraulic model and to portray the social impacts of a technologically deficient water system. We collected data by researching in Worcester and by means of newspaper research and interviews in Puerto Rico. We then analyzed the data using cost/benefit analysis techniques.

3.1 Newspaper Research

Addressing the social impacts of an inefficient water system is one of the requirements of the Interactive Qualifying Project, and although this project dealt with the costs and benefits of the hydraulic model, we had to address the issues affecting society in order to satisfy the IQP requirements. Local newspapers, such as The San Juan Star, are a good source of the public's opinion on government issues such as the water. Upon arrival in Puerto Rico we began collecting newspaper articles that contained information regarding the water system. Understanding these social impacts of the unreliable water system in Puerto Rico were useful in presenting the benefits of the hydraulic model for possible adoption by AAA. By reading and analyzing these newspaper articles we got a broader picture of the problems with the water system.

Investigating the history of Puerto Rico's water system was vital to address its problems and correlate the benefits of the computerized hydraulic model to solve those problems. By relating the issues that society deals with due to an inefficient water service to the many benefits of a hydraulic model, we identified a useful application of the model for the daily use of maintaining the water system.

Locating newspaper articles in English we looked for The San Juan Star, the only English newspaper in Puerto Rico. We went to the University of Puerto Rico to find past issues of this newspaper to collect information pertaining to the history of the water system. We also read current articles daily to find any problems with the water system. In organizing the articles, we looked for information pertaining to the social impacts of an erratic water system and evidence of the necessity for improvement.

3.2 Understanding the Hydraulic Model

Producing a cost/benefit analysis of the hydraulic model for possible adoption by AAA, the IQP team was required to become familiarized with the computerized hydraulic model that the joint venture developed. In the first two days we were at CSA, we interviewed the current modelers and discussed the importance and benefits of the computerized hydraulic model to AAA. After meeting with two modelers, we had a basic understanding of the hydraulic model that is in operation at CSA. The information we gathered about the model was used in our analysis in the cost/benefit section. As one of the last steps in our project, we created spreadsheets that illustrate the costs and benefits of using the hydraulic model during a five-year period.

3.3 Interviews

Interviews were an important source for information. After getting a basic understanding of the hydraulic model and its benefits, we then conducted interviews with personnel whose work we assumed would benefit from the model's use. The people we interviewed were employees of Infrastructure Financing Authority (AFI), CSA Architects & Engineers, the Autoridad de Aqueducts y Alcantarillados (AAA), and the Companía de Aguas de Puerto Rico (CAPR).

3.3.1 AFI Employees

The employees of Infrastructure Financing Authority (AFI), including CSA modelers working with AFI, are currently using the model as a design tool for their project work. These employees have the best understanding of the model and showed us its immediate benefits. We gained a solid understanding of the model and its benefits and were then able to proceed with the interviews at AAA, described in section 3.3.2.

3.3.1.1 CSA Project Managers

The project managers design projects and coordinate the construction of these projects with contractors. By understanding their job we were able to investigate how the computerized hydraulic model impacts their work. Gaining information on how professional engineers need the aid of the model helped us explain its benefits. Since the interviews were mainly exploratory, two members conducted them, one person asking pertinent questions and the other recording responses. The third team member continued to work on the final written report. This method was chosen for most of the interviews throughout this project.

3.3.1.2 Immediate Actions Projects (IAP)

As discussed earlier, the Immediate Actions Projects group is currently responsible for performing quick fixes in the water system. Their scope of operations does not include capital improvements or future planning. Through the projects that IAP completes using the computerized hydraulic model developed by the JV, we understood its immediate benefits if AAA were to implement the model.

3.3.1.3 Water Resource Expert

After a good background of the water system in Puerto Rico was established, we interviewed a water resource expert, Dr, Santiago Vasquez, who shared with us his experiences with the water system. His involvement with the system is so extensive that he noticed trends in the quality of service of the water system. He was a part of the design teams involved with the original design of the water system. He also has clear ideas on what the status of the system is expected to be in the future, and how AAA plans to get there.

The social impacts on this project are so important that we found it necessary to incorporate the entire group in this interview. We used the format of one interviewer and two recorders. We also allowed the recorders to ask any question they may have had during the interview.

3.3.2 AAA Employees

The objective of our project is to find the benefits of the hydraulic model for future use by AAA. The goal of these interviews is to understand what AAA sees in its future as the owners and possibly future managers of the computerized hydraulic model. For each member of the group to have a clear view of where the project was heading. These interviews informed us about what AAA needs to know about the model and how water operations can benefit from its implementation.

3.3.2.1 Technical Services and Planning Managers

AAA engineers have developed their own maps of the water system. Interviewing these employees defined the necessity of the model at AAA. Finding out the costs and benefits these engineers have experienced with the use of a computerized model aided the project for generating benefits of a more powerful modeling tool.

3.3.2.2 AAA Operators

The operators of the water system have hands-on experience with the system and know what areas of the water system need to be improved. Conducting interviews with these operators allowed the group to discover what tools the operators use, and the amount of time it takes to complete an operation. We also asked which task the computerized hydraulic model would affect.

3.3.2.3 Companía de Aguas de Puerto Rico

Companía de Aguas de Puerto Rico (CAPR) was hired to be the operators of AAA. The interviews held with these employees allowed us to evaluate the importance of a hydraulic model in the efficiency of a water system. The team analyzed the information received from Companía de Aguas, and used that to adjust our recommendations to CSA for improving the hydraulic model to better serve CAPR and AAA.

3.3.3 Recording and Analyzing the Data

During each interview a member of the group took notes to record what the interviewees' responses were to our questions. After each interview, the one who took the notes went back to his computer and summarized all of what was said and the information we gathered from the interview. Once finished summarizing, the team members reviewed the notes and discussed what was learned from each interview. This information is analyzed in section 4.2, Interviews Results and Analysis and the notes are located in Appendix B.

When we interviewed the CSA project managers, we gathered and analyzed the information given to us about the benefits of the hydraulic model, and some of the costs to make the model and keep the model updated. When we interviewed the IAP employees, we collected and analyzed the benefits of the model for producing quick fix solutions to problems in the water system. In analyzing the information received from the water resource expert, we looked for information about the history of the water system such as recurring problems and problems that still exist.

Interviewing AAA employees was the most important part of our project. As the managers of AAA, Companía de Aguas plays a major role in its operations. We analyzed the information that these interviews provided, and assessed the possibility of the computerized hydraulic model's adoption at AAA. This information is contained in section 4.2, Interviews results and analysis.

3.4 Cost/Benefit Analysis

The main part of our project was to conduct a cost/benefit analysis to evaluate the hydraulic model for a possible adoption by the AAA. In the following sections we describe our method for arriving at an estimated cost for establishing and operating the hydraulic model. Some of those methods include mathematical equations, while others are explained through their benefits to society.

3.4.1 Identifying Costs and Benefits

The interviews the IQP team has completed established clear costs and benefits of implementing a hydraulic model for daily operation at the AAA. The interviews, held with the hydraulic modelers, generated a better background of the hydraulic model. From the project managers we learned how the model assists the design and realization processes. After interviewing employees of AAA we saw how a model would impact their work and improve their operations. Finally we came up with a list of costs and benefits for the implementation of the model. We then expanded these items to include their specific benefits and a best estimate at a dollar amount cost. Some of the benefits were far less cooperative when it came to assigning a dollar amount, so those items were analyzed in a manner that discussed their social implications.

The items classified as costs are expenses that would be accrued if the computerized hydraulic model were implemented in the daily operations of AAA. We considered hardware, software, and training expenses and also any other future costs that we learned about in our research and interviews.

The items classified as benefits are savings that AAA would encounter if the computerized hydraulic model were implemented into daily operations. Some of these benefits include leak detection, pipe and valve locating, and troubleshooting.

3.4.2 Means for Comparison

The IQP team used several different processes for analyzing the importance and cost effectiveness of the hydraulic model. Some include actual costs and others are simply a discussion of the societal impacts of improved water service.

3.4.2.1 Physical Costs vs. Time Saving Benefits

To quantify and compare the costs and benefits of a computerized hydraulic model, the IQP team used a Microsoft Excel worksheet. Within the worksheet we divided the costs into two categories: One-Time Start-Up Costs and Annual Operating Costs. The initial expenses are costs that should only be paid for when first starting a modeling team at AAA, for example, costs for computer hardware, software, office furniture, and training. Each of these costs is calculated in separate tables using the unit cost for each item and then multiplying that cost by the number of items required. The subtotal for each table is calculated and a grand total of the one-time start-up cost is found by adding all of the subtotals. The basic sub-table format is shown below.

Table 3-1: Blank Initial Start-Up Cost Spreadsheet

1 Hardware	**Item Quantity**	**Item Cost**	**Total Cost**
			$ -
			$ -
			$ -
			$ -
			$ -
		Hardware Sub-Total:	**$ -**

The annual operating cost table was used to calculate the perpetual costs that would be incurred by AAA if they were to update and maintain a computerized hydraulic model. This cost table is split into two sections, one for the annual labor costs and another for the annual expenses. The cost of labor table lists the job descriptions and number of employees that would be required at AAA should they adopt the computerized hydraulic model. In the table, the amount of office space for these employees is tabulated along with their hourly rate and the individual hours worked in a year. We multiplied the hourly rate and the individual hours worked in a year for each employee in order to calculate the total annual cost for labor.

Table 3-2: Blank Annual Labor Cost Spreadsheet

7 Labor	# of Positions	Space Required	Hourly Rate	Hours per Day	Annual Cost
		sq. m			$ -
		sq. m			$ -
		sq. m			$ -
		sq. m			$ -
		sq. m			$ -
		sq. m			$ -
				Annual Trained Labor Sub-Total:	$ -

The second section of the annual operating costs is the annual expenses. The annual expenses table is divided into five columns respectively labeled: Annual Expenses, Units, Monthly Cost per Unit, and Annual Cost. In the annual expenses column a brief explanation of the cost is provided. Next the Units column lists the amount of each item that will be needed. These annual costs are split up into their monthly cost per unit. The amount of time these expenses are paid for is provided in the Months column. Finally the total cost is calculated by multiplying the number of units by the monthly cost per unit by the number of months. For both the Annual Labor Costs and the Annual Expenses a subtotal is found for each table by adding all its costs.

Table 3-3: Blank Annual Expenses Cost Spreadsheet

8 Expenses	Units	Monthly Cost per Unit	Annual Cost
			$ -
			$ -
			$ -
			$ -
		Annual Expenses Sub-Total:	$ -

As a result we have the Initial Investment Cost, the Consulting Fee Total, and the Annual Operating Cost. Adding these three costs together gave us the total cost for the first year of the models operation by AAA. Next we calculated the benefits of a hydraulic model by the amount of money it will save in operations on the water system for a year. Using the total cost amount and the total benefit savings we can compute how much time it would take before the model could make a profit for AAA.

The IQP team used another worksheet in Microsoft Excel to analyze the amount of money a hydraulic model could save the AAA. The basic form of the benefit analysis spread sheet is contained in Table 3-4 at the end of this section. The first column of the benefit savings worksheet provides a description of the operations of AAA that could benefit from the use of a computerized model. The second column in the table accounts for the amount of time needed for data collection and conversion, such as valve location, before AAA could use the model as an operational tool. Next, from our interviews, we discovered how much time it currently takes AAA operators to complete a task and then compared that amount of time to how long the same task would take using the hydraulic model. The difference in these two times provides the time saved per operation. With the knowledge of the average number of operations done per week and the hourly wage paid to the working crews, we can figure the amount of money saved per week by multiplying these two values. Now we multiply this weekly dollar savings by 52 weeks in order to compute the funds saved in a year. Finally with the total cost and benefit savings we can calculate how long it would take for the computerized hydraulic model to make money.

Hydraulic Model Cost - Benefit Analysis

Sample - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total:

Percent Reduction in Water Loss from Previous Year Percentage:

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves						$ -	$ -	$ -
Pipelines						$ -	$ -	$ -
Enhanced Leak Detection						$ -	$ -	$ -
						Year 1 Locating:	**$ -**	**$ -**
2 Logistics								
Meter Reading Routes						$ -	$ -	$ -
Troubleshooting						$ -	$ -	$ -
						Year 1 Logistics:	**$ -**	**$ -**

Year 1 Labor Cost Affected by Model Sub-Total: $ - $ -

3 Labor Cost Not Affected by the Hydraulic Model

Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0	$ -
Labor Cost Not Affected by the Model:	$ -

Year 1 Labor Cost Not Affected by the Model: $ -

4 UFW Revenue Loss	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)		
Unaccounted for Water (UFW)					0	$ -	$ -
				Year 1 Unaccounted for Water Costs:		$ -	$ -

5 Hydraulic Model Costs

Initial Costs - Carried Over from Sheet 1	$ -
Annual Costs - Carried Over from Sheet 1	$ -
Year 1 Hydraulic Model Costs:	$ -

Year 1 Net: $ - $ -

Table 3 - 4: Blank Benefits Analysis Spreadsheet

3.4.2.2 Water Conservation vs. Capital Improvements

The model could also be used to help detect leaks. As of right now, eyewitnesses are the only means of leak detection. With the model in place, leaks could be detected more efficiently with the continuous monitoring system, which would record pressures and flow rates of the water system. The model would then be able to detect where water is being lost when the metered water does not meet the demands. This would hasten the repairing process that in turn would improve customer service and reduce the overall unaccounted for water (UFW) on the island.

The IQP team has come up with a mathematical way to suggest a dollar amount for two methods of improvement in the water system. The first method of improvement is by simply relying on customer complaints to quick fix leaks. The second method is to make use of the model's ability to detect leaks.

This equation relates the average day demand (ADD) and the value of the unaccounted for water.

$$ADD_{Gallons} \times \%UFW_{System} \times (Price / Gal)_{AVG} = ValueofUFW\ (\$)$$

The first term is the average day demand based on estimates made by AFI in their study of the San Juan Metropolitan Service Area (SJMSA). The second term is the estimated UFW in the SJMSA. Finally, that total is multiplied by the price AAA charges for a unit of water. The final result would be the total value unaccounted for water in the system. This total is the amount of money that would be generated if a water conservation plan were implemented. This analysis would defer the cost of the improvement due to lower water loss in the system. Supplying extra water would not be needed if the leaks were effectively fixed.

That same figure can be used to demonstrate the importance of the hydraulic model. By comparing the cost of the hydraulic model to the cost of the capital improvements, the savings with using the model are apparent. By finding the difference in the costs of the two projects, we can show that there would be a savings if the hydraulic model were used. There would eventually be a savings from the value of the water that would be conserved after the leak repairing. In addition, there will be an environmental benefit in not having to remove more water from the island's rivers and estuaries. These discoveries will be discussed in section 4.5, Water Supply Analysis.

4.0 Results and Analysis

Following the procedures discussed in the Methodology section, we have composed, organized, and analyzed our findings in this Results and Analysis section. This information demonstrates the potential costs and benefits of the hydraulic model that could be used to streamline operations and improve the water service provided by the Autoridad de Acueductos y Alcantarillados (AAA). The cost/benefit analysis conducted in this project, detailed in this section of the report, demonstrates that, should the AAA adopt the model, and also maintain and update it for five years, they will realize substantial cost and societal benefits.

4.1 Newspaper Research Results and Analysis

As discussed in the Methodology, the IQP team reviewed many newspaper articles dealing with the water problems in Puerto Rico. We looked at materials written during the time of the drought in 1994 and also current articles to define the problems occurring now. The importance of this topic was apparent by the abundance of information reported in The San Juan Star. We found the greatest frequency of articles in the May 1994 issues, since this was the height of the 1994 drought. In these article we noted the difference in public and government opinion, yet in the current articles the IQP group notes all the current problems occurring that the computerized hydraulic model can prevent in the future.

4.1.1 Public Opinion

When public opinion was documented in the collected 1994 newspapers, it continuously cried out for the easing of water rationing. Since the drought of 1994 put a tremendous strain on the reservoirs in Puerto Rico, AAA was forced to implement water rationing. Most people would agree that being without water is difficult. Juan A. Faría, a cattle rancher, told Maritza Stanchich of The San Juan Star that seven of his cows had died so far due to the drought. Juan Alvarado López, a retired cattle rancher, told the reporter that the cost of a dairy cows and bulls was $1500 and $400 respectively. The deaths created an unnecessary strain on the ranchers' funds. This lack of water put the ranchers in the south in the poorest position of all of those affected by the drought (Stanchich 12). Because the drought was so severe in the south, the governor declared this region a disaster area and made ranchers eligible for feed subsidies (Stanchich 12).

Of the 34 articles taken from The San Juan Star during February, March and May of 1994, eight comment on the lack of response to water problems. A San Juan resident confirmed that it took three weeks for a leak in his neighborhood to be fixed. He and other neighbors were putting rocks over the leak to stifle the loss but to no avail. He claimed, "It's enough water to wash car after car" (Blasor 13). Another reported that a leak in Levittown was not addressed for over a day, and at the same time, AAA was preparing to extend its rationing plan. This type of disregard for water loss was bothersome to AAA's customers. They would rather see AAA "fix the house before they ask us [customers] to sacrifice" (McKim 6). Another comment by Ocasio Méndez reflects upon the public opinion of water rationing: "Asking people to conserve water is like the priest preaching in his underwear" (McKim 6). Plainly, he felt that the AAA's conservation request was a joke. Another article further describes citizens' frustration. Ms. Canales had long been complaining about a leak in front of her home, but she still continued to water her gardens. Her belief was that if AAA was not going to conserve the water that they have, the public was not going to react well to the continuation of water rationing (McKim, 6).

Solving a lack of water by water rationing seems illogical to the people of Puerto Rico if, at the same time, water is wasted and leaks not repaired by the water company. The people feel that there is a better way to fix the problem involving the lack of water, and that is to repair the pipes where the water is being lost. If AAA were to implement the computerized hydraulic model, it would enable the water utility to locate leaks and know which pipes need repair.

4.1.2 Government Opinion

The government officials at the water company responded to citizens' complaints during the 1994 droughts by citing AAA budget and funding. Of the 34 articles we collected in the three months in 1994, February, March, and May, eleven with money and how AAA gets it. One article from March 1994 responds to the impact of water loss on the "hefty losses" of AAA. These losses are due to broken water mains that remain in disrepair for long periods of time. AAA Executive Director Emilio Colon responded to citizens' complaints by stating that AAA has cut down the time it takes to fix these problems by 20% (Garcia, I. 10). This improvement in response is due to the Acuatel phone system. This service, according to its director, Christina Miaja, enables residents to not only get up-to-date account balances, but also to report leaks and pressure drops. The service, Miaja said, is online 24 hours a day and can be accessed in English or Spanish. The goal of this system, explains Miaja, is to enable AAA to respond to complaints within 24 hours of their reception (Albanese 14).

Other newspaper articles reported that the government continually threatened to cut back funds to the water company, AAA (Walzer 5). House Speaker Zaida Hernández suggested to AAA that the legislation cut back on its funds until AAA can freeze workers' salaries and benefits. This threatened cutback would also hinder AAA's plans for capital improvements. Finally, Hernández wrote to Director Colon, "The legislature cannot continue aiding AAA at the expense of other programs and other entities" (Walzer, 5). These types of discussion continue throughout the newspaper.

According to these articles, the main topic that the government is concerned about is the money drain that AAA puts on the legislature. They seem to be most concerned with money wasted over items regarding salaries and over-spending. Despite all the citizen complaints, the government continued pumping in more water to distribute into the system, leaving a smaller number of people without water, however not solving the problem.

4.1.3 Current Problems

The IQP team continued our research by reading current issues of The San Juan Star involving the operation of AAA and also the current problems ailing the Puerto Rican water system. In the April 23, 2000 edition of The San Juan Star, Anahid Berberian, commented on the poor response of AAA in fixing leaks in pipelines. This article identified a significant amount of water loss and it questioned the water authorities as to who is going to pay for all the unaccounted for water (Berberian 34). Articles such as this one demonstrated that the water problems are still occurring in the year 2000 and are not being solved in an efficient manner.

The people of Puerto Rico depend on the water that is provided by AAA, but it is not unusual for some people to wake up in the morning and not have any water in their faucets (Fajardo, 1). Rosario Fajardo, reporter for The San Juan Star, stated in her article that "Puerto Ricans have lived with an erratic water system for years now; if it is not a drought forcing water rationing, it is a burst pipe or a broken pump which decreases water pressure or cuts off water service altogether" (Fajardo, 1). One example of the lack of water service can be seen in an article from The San Juan Star, which is titled, "150,000 in Ponce to Lose Water" (STAR staff, 14). The lack of knowledge of the water system can be seen in this article, which describes having to completely turn off the water service to an entire city in order to fix a single pipe (STAR staff, 14). The benefits offered from the computerized hydraulic model developed by the JV include possible quick-fix solutions, such as rerouting a water supply to feed an area that may need to be turned off, like the case in Ponce.

The Puerto Rican water system, as stated above, often experiences problems, be it a leak, a burst pipe, or even a pump-station being broken down. The most frequent problem reported by the public is a leak. The San Juan Star published a column every Monday called "The Mess of the Week." The number of times that a water-related problem has occurred as the mess of the week is five out of the eight weeks we collected the current newspapers. One issue reported a leak coming directly out of a fire hydrant (STAR staff, 4/24/00 1). The operation of a fire hydrant is necessary for the proper function of the fire department. If a fire were to occur near that hydrant with water leaking from it, there is no way that the hydrant will be operational enough to put out the fire. For AAA to have operational fire hydrants, successful water service, and improved operations, the organization must implement a monitoring system that will keep track of all pressures and pressure variations of the entire water system. The computerized hydraulic model that the JV has developed has these capabilities, and through our cost/benefit analysis, found in section 4.3, we found that the model, were it implemented and kept up to date, would be cost beneficial.

4.2 Interview Results and Analysis

The second part of our methodology was the use of interviews to gather further information and insight about the computerized hydraulic model, its present and future uses, and the costs and benefits. We interviewed a wide range of individuals from multiple companies that are involved with the model and the water system. These interviews provided us with valuable information and helped us to evaluate the costs and benefits of the model.

4.2.1 Past and Present Uses of the Model

CSA Architects & Engineers and CH2M Hill, the Joint Venture (JV), have been developing a computerized hydraulic model for the past two years. The model has been used to provide an overall picture of the water system. While the JV has been working in association with AFI, the model has been used to produce improvements to the water system. The model is a skeletal structure of the entire water system, containing pipelines larger than 8 inches in diameter for most of the island. It also displays water sources, such as reservoirs and tanks. For the past two years of its development, AFI employees have used the hydraulic model to help restructure and improve the water system in Puerto Rico.

Interviewing the current Immediate Actions Project employees, a branch of AFI, has led us to further insight into the benefits of the computerized hydraulic model. In an interview with Romie Lat, a mechanical process support specialist and member of the IAP, he shared experiences using the current computerized hydraulic model for improving the water system in Puerto Rico. In one instance he used the model to reroute a pipeline in order to better the supply water in Canóvanas, Puerto Rico. The city was not receiving enough water to meet their demand, so the designers used the computerized model to predict a solution to the problem. Lat said that without the use of the model the IAP would have just suggested increasing the capacity of a local pumping station. Instead, the model helped create the solution of building a new 2.5 mg water tank with a pump station. Also the installation of a new pipeline would reroute the water from this tank and create a more reliable water supply to Canóvanas than simply increasing the capacity of the existing pump station (Lat, 2000). Creating more beneficial solutions to existing problems is a current benefit offered by the computerized hydraulic model developed by the JV.

The benefits of the model that many of our interviewees discussed with us involve its ability to help design improvements to the water system. Mark Rincon, CSA Senior Project Manager, stated that the current model is used to predict system improvements and also provide system requirements such as equipment size and location (Rincon, 2000). In an interview with Paul da Silva, Technical Services Manager and member of the IAP, he shared with us that AFI has already experienced a savings of over 6 million dollars with the current benefits offered by the computerized hydraulic model. This savings allowed AFI to reallocate that money into other projects to further improve the water system of Puerto Rico (da Silva, 2000). Zacharias agreed and went on to explain that the model will generate savings for as long as it is being maintained (Zacharias, 2000). If AAA implements this computerized hydraulic model, they will also have the opportunity to save some money and use that money to improve upon the system.

4.2.2 Future Uses of the Model

One can acknowledge the current benefits of the model but at the same time fear that the model is under-developed for it to be fully operational in a daily use by AAA. Paul da Silva, the technical services manager of IAP, can note all the current benefits, but as for future benefits, he realizes that the model will need to be updated with more accurate information about the water system (da Silva, 2000). According to Mark Rincon, CSA Senior Project Manager, for the model to be used for daily operation by AAA it must have up-to-date information, such as pressure, flows, and demands, to keep accurate data for real-time calculations. This would involve installing gauges or monitors at many strategic locations throughout the water system that would measure pressure and flow rates. Also AAA would need to put forth a large effort to locate all the components of the water system, such as pipes, valves, tanks, pump stations, and reservoirs (Rincon, 2000). Zacharias feels that to update the model to a fully operational level it would involve the help of 20-30 field workers working for one to one and a half years to locate all the pipes, valves, tanks, and other equipment of the water system completing an entire mapping of the water system (Zacharias, 2000). Once this update is finalized, all the benefits offered by the model would be apparent.

A future benefit that can be seen from using an updated CSA model is trouble-shooting problems. Zacharias explains that problems with the water system could be fixed more efficiently through the use of the model. A hydraulic modeler can trouble-shoot the problems and use the model to help figure out the best solution to those problems (Zacharias, 2000).

More benefits offered by the future updated computerized hydraulic model are the ability of the model to isolate leaks, to locate pressure problems, and also to inventory the equipment of the water system. The model can also be used as a mapping tool, which enables quicker location of valves, pipelines, and customers. Zacharias notes that there have been many occasions when a leak has been located and a valve was shut off to stop the water flow through the pipes. Often an improper valve was shut off and cut off the water supply to a different region (Zacharias, 2000). With the use of the model, the operator would know which valve controls each area, thus eliminating the chance of improperly shutting off water supply to customers.

A further benefit of using the model as a mapping tool is for easier location of pipes and customers. If there are complaints by a person about a leak in the middle of the street, the operators can locate the problem on the model and find the exact pipe and valve to shut off the water until the leak is fixed. If a customer calls up and says he or she does not have any water, the operators can locate the customer on the model and find out the problem. Zacharias also told us that knowing the location of all the meters would allow for easier meter reading routes for the field staff who monitor the amount of water each meter is served (Zacharias, 2000). As a result of implementing the computerized hydraulic model into its daily operations, AAA would reduce the amount of unaccounted for water and improve their water service.

The final portion of our interviews was dedicated to the cost/benefit analysis necessary for our project, which is included in the next section.

4.2.3 Costs/Benefits

The major issue with a computerized hydraulic model is the cost that a water company would encounter as a result of implementing this advanced software. Interviews with Omar Garcia, Manager of AFI's Modeling Team, suggest that the major cost would be the software and consulting fees if AAA were to adopt the model. All this information is contained in sections 4.3 and 4.4.

Further investigating AAA, we conducted an interview with Marc Zacharias, the Operations Director of the San Juan Metropolitan Area for the Companía de Aguas. He provided us with information quantifying the benefits and savings in labor that could be realized by using the model. This helped us perform a cost/benefit analysis. This information included unaccounted for water statistics, annual total labor cost for 1352 employees, and information regarding employees that would interact with the hydraulic model. All this information is contained in section 4.3 and 4.4.

4.3 Cost Results and Analysis

Several interviews with Omar Garcia provided cost estimates for implementing a computerized hydraulic model of the San Juan Metropolitan Service Area (SJMSA) at the Autoridad de Acueductos y Alcantarillados (AAA). His cost estimates are based on previous modeling experience in Alexandria, Egypt. The JV was hired by the Infrastructure Financing Authority (AFI) to identify and prioritize areas of the water system that require improvements. Garcia identified most of the costs that would be associated with implementing a computerized model at AAA. The costs can be categorized into two sections, initial costs and annual costs. The breakdown of these expenses is shown along with the discussion of each cost in the following sections. The complete cost analysis is shown in Tables 4-9 and 4-10 at the end of section 4.3, Cost Results and Analysis.

4.3.1 Initial Investment Costs

The first six sections of Table 4-9 identify all of the initial start-up costs that would be associated with the use of a hydraulic model in the operations of AAA. In several interviews with Omar Garcia he identified that the initial costs consist of hardware, software, office furniture, field equipment, and consulting fees.

4.3.1.1 Computer Hardware

Included under the cost for computer hardware, in Table 4-1 are several computer workstations that support GIS and CAD programs. A 21-inch monitor for each workstation would be required to view the computerized hydraulic model with significant detail. Also a printer and plotter would be needed to produce large-scale maps of the water system and letter-size documents. To communicate between personnel and computers a computer network and telephone connections would need to be installed (Garcia, O. 2000). Table 4-1 describes computer hardware required to fully develop and maintain a detailed hydraulic model.

Table 4-1: Computer Hardware Cost

1	Hardware	Item Quantity	Item Cost		Total Cost	
	GIS/CAD Workstations w/ 21" Monitor	14	$	5,500	$	77,000
	36" E-Size color plotter	1	$	16,000	$	16,000
	Letter/Tabloid laser printer	1	$	3,000	$	3,000
	Data/Com Connections	21	$	700	$	14,700
	Network	1	$	20,000	$	20,000
			Hardware Sub-Total:		**$**	**130,700**

4.3.1.2 Computer Software

The second part of the initial costs table, shown below in Table 4-2, displays the software programs that would be required to develop and analyze a computerized hydraulic model of the SJMSA. Garcia identified the first software program required as LYNX. This program manages and links together other computer programs to produce a GIS-based model of the water system. The version of the LYNX software necessary is the one that allows an unlimited number of users and pipe nodes.

The second piece of software, entitled Bentley's MicroStation 95 v. 5, similar to a CAD program, is essential for drawing the components of the water system in relation to one another. Several licensed copies of MicroStation would be required for the model operators, managers, and their trainers.

Microsoft Office, which includes Access, Excel, and Word, is another valuable software tool. Microsoft Access is a database that is essential for storing and managing all of the information about the water system. Data preparing and reporting can be done using Excel and Word. Multiple licensed versions of Microsoft Office would also need to be provided for each model operator, manager, and their trainer.

Table 4-2: Computer Software Cost

2	**Software**				
	LYNX	1	$ 17,000	$	17,000
	Microstation	14	$ 4,500	$	63,000
	Access, Excel and Word	14	$ 800	$	11,200
	EPANET	14	$ -	$	-
	DGN Files	250	$ -	$	-
			Software Sub-Total:	**$**	**91,200**

The other software program required to run an analysis on the pipe network system with computations of flow rates in pipes and pressures at pipe junctions is called EPANET. This program is a public-domain program developed by the U.S. Environmental Protection Agency. A unique version of EPANET would be required for each operator of the model.

Finally the reference DGN files provide a background of aerial topography photographs, contour data, digital USGS quadrangle maps, highway maps, census and political boundary maps, that can be displayed behind the CAD drawings of the water system in MicroStation. These DGN files could be provided as part of the model set up effort (Garcia, O. 2000).

4.3.1.3 Office Furniture

Creating a modeling team at AAA requires additional office furniture that could be accounted for as a one-time cost. As further discussed by Garcia, several desks and chairs would be needed for each AAA employee working on the modeling team and the CSA training staff. Also filing cabinets would be needed to store documents, maps and office supplies (Garcia, O. 2000). The chart for totaling the office furniture cost is shown below in Table 4-3.

Table 4-3: Office Furniture Cost

3	**Office Furniture**				
	Desk	44	$ 150	$	6,600
	Chair	44	$ 90	$	3,960
	Filing Cabinet	4	$ 100	$	400
			Office Furniture Sub-Total:	**$**	**10,960**

4.3.1.4 Field Equipment

The hydraulic model could be used as an operational tool if an estimated 9 to 15 months were dedicated to locating all of the water system's components in the SJMSA. Several pieces of equipment, listed in Table 4-4, would be required in order to detect components of the water system, mainly valves and pipelines.

Table 4-4: Field Equipment Cost

4	**Field Equipment**				
	Global Positioning System	2	$ 15,000	$	30,000
	Sonic Leak Detection Equipment	1	$ 100,000	$	100,000
	Ground X-Ray Equipment	1	$ 80,000	$	80,000
	Pitometer Pressure Sensor	8	$ 4,250	$	34,000
	Pitometer Flow Meter	6	$ 11,250	$	67,500
	Calibration/Maintenance/Training	1	$ 10,000	$	10,000
	Metal Detectors	15	$ 200	$	3,000
		Field Equipment Sub-Total:		**$**	**324,500**

During an interview with Garcia, he explained that the hydraulic modeling team at CSA uses a Global Positioning System (GPS) to identify the geographic location of any piece of equipment in the field. This system would need to be purchased as well as sonic leak detection equipment that would be useful to AAA for listening to the pipelines to identify the exact location of a leak (Garcia, O. 2000).

Next Marc Zacharias suggested that ground X-ray equipment be purchased to locate underground equipment without having to dig up any streets or private property. He also identified the need for pressure sensors and flow meters to calibrate the hydraulic data in the model with actual field measurements. The calibration/maintenance/shipping cost listed on Table 4-4 is for maintaining the measurement equipment and for shipping of the equipment from one work site to another. Finally a metal detector would be needed by each field crew of two workers to locate any equipment, specifically valves that have been covered over during the paving of a street (Zacharias, 2000).

4.3.2 Consulting Fee

Operating and developing the computerized hydraulic model would require AAA to train several employees to work with the model. The estimated cost of labor and expenses for the consulting firm is discussed in the sections below.

4.3.2.1 Consulting Labor Cost

Training of AAA's modeling team could best be done by a group of employees from CSA Architects & Engineers. CSA employees already have experience in collecting field data and conveying this information to the model operators to create a computerized model of the water system. The complete analysis of the employee training cost is shown in Table 4-5.

Table 4-5: Consulting Labor Cost

5	Labor	# of Positions	Office Space (sq. m)	Hours per Day	Hourly Wage	Months Training	Total Wages
	UFW Expert	1	6	8	$ 145	12	$ 301,368
	Senior Review / QC	1	-	8	$ 145	6	$ 150,684
	Project Manager	1	6	8	$ 145	12	$ 301,368
	Model Operator	2	6	8	$ 90	12	$ 374,112
	Information Technician	1	6	8	$ 90	12	$ 187,056
	Programmer	1	4	8	$ 90	6	$ 93,528
	Adminstrative Assistant	1	6	8	$ 50	12	$ 103,920
	Model Trainer	2	4	8	$ 90	3	$ 93,528
	Field Staff	2	2.5	8	$ 75	12	$ 311,760
					Training Sub-Total:		**$ 1,917,324**

An Unaccounted for Water (UFW) Expert would be needed, according to Garcia, to analyze the water production records along with the billing records in order to make comparisons. The UFW Expert would also lay out and monitor a leak detection program with the assistance of the hydraulic model. An analysis of the leak detection results and recommendations for water loss reduction would be a major part of the UFW Expert's job. Also a Senior Reviewer would make sure all work is being done correctly and would act like a quality controller (Garcia, O. 2000).

Garcia further explained that one project manager from CSA would be needed for the first year to oversee all of the employee training process and primarily to train the future manager of the modeling team at AAA. Two experienced model operators from CSA would also work for the first year, training the model operators at AAA on how to use the modeling software, communicating with the field staff, and converting existing maps of the system into GIS format. There would be two more model trainers for the first month to provide extra assistance in software training and development of a detailed computerized model (Garcia, O. 2000).

An Information Technician (IT) from CSA would be needed to train the IT at AAA for six months on computer networking and management. The IT would also assist in the initial setup of the computer network and troubleshoot any computer problems. The IT would address computer hardware problems that impede the work of the hydraulic model operators, and ensure that time and months of work are not lost (Garcia, O. 2000).

Another important role in a modeling team, according to Garcia, is a computer programmer who would write program code to add leak information and analysis to the model. As more information is available necessary changes can be made to the model to simulate real conditions (Garcia, O. 2000).

Organizing all the documents and appointments one administrative assistant from CSA would be needed to train the AAA assistant to organize all of the documents and appointments. The administrative assistant would handle all secretarial tasks such as organizing meetings, answering phones, and communicating between field staff and model operators (Garcia, O. 2000).

Finally two field staff from CSA would train the field crews of the modeling team on the proper use of field equipment and the correct method to record data collected so that it can be clearly communicated to the model operators (Garcia, O. 2000).

4.3.2.2 Consulting Expenses

Along with the cost of hiring consultants there is a fee included for their expenses. This fee includes vehicles, office space, travel and lodging, and miscellaneous expenses. We estimate that twelve consultants would require six vehicles for the full year. These consultants would also need to have adequate office space for their work. Travel and lodging expenses would be required because a few of the consultants may be required to come from firms outside of CSA and Puerto Rico. The added miscellaneous expense would cover the need for tools, supplies, and anything else that may arise during the program.

Table 4-6: Consulting Expenses

6	Expenses	Item Quantity	Item Cost	Total Cost
	Vehicles	6	$ 750	$ 4,500
	Office Space (sq. m)	53	$ 50	$ 2,650
	Travel & Lodging	1	$ 100,000	$ 100,000
	Miscellaneous Expenses (per month for 12 months)	12	$ 3,500	$ 42,000
			Expenses Sub-Total:	**$ 149,150**

4.3.3 Annual Costs

Sections 7 and 8 of Table 4-10 identify the annual costs involved with AAA using a computerized model of the water system in the San Juan Metropolitan Service Area (SJMSA). The costs of using and maintaining a model year after year consist of annual labor costs and annual expenses.

4.3.3.1 Annual Labor Costs

Many work hours would need to be dedicated to updating the computerized model so that Autoridad de Acueductos y Alcantarillados (AAA) could use it as a tool to aid in its operations to provide quality water service to the SJMSA. The model would start to benefit AAA's operations once an initial study of the system is completed and enough field data are collected and entered into the model. Even then the water system would be continually growing and would always require maintenance, as would the hydraulic model that represents the water system. Therefore, an extensive modeling team would be necessary to provide and maintain an accurate model. After the majority of the information about the water system is collected and added to the model, this group of employees may be reduced in size. Table 4-7 below shows the number of positions needed for each job title, the office space required, the hourly wage for each job, the hours per day each employee needs to work, and the individual hours worked in a year. The table then calculates a total labor cost.

First shown in Table 4-7 below is the Field Staff that would use high technology field equipment to locate the exact location of pipelines, valves, meters, and leaks. As suggested in an interview with Marc Zacharias about 15 crews of 2 field workers would be needed to collect the information in a sufficient amount of time. Field crews of 2 workers can divide up the task of locating the water system's facilities in the SJMSA and as enough information is collected this staff could be reduced in size (Zacharias, 2000).

Table 4-7: Annual Labor Cost

7	Labor	# of Positions	Space Required	Hourly Rate	Hours per Day	Annual Cost
	Field Staff	30	2.5 sq. m	$ 20	8	$ 1,247,040
	Model Operator	8	6 sq. m	$ 25	8	$ 415,680
	Information Technician	1	6 sq. m	$ 25	8	$ 51,960
	GPS Technician	2	6 sq. m	$ 20	8	$ 83,136
	Manager	1	6 sq. m	$ 35	8	$ 72,744
	Administrative Assistant	1	4 sq. m	$ 15	8	$ 31,176
			Annual Trained Labor Sub-Total:			**$ 1,901,736**

The second job title listed in Table 4-7 is a Model Operator. Garcia explained that one computer model operator for every 4 members of the field staff would be sufficient. Therefore a model operator can work closely with 2 field crews in collecting and converting maps of the SJMSA into a GIS-based model (Garcia, O. 2000).

Garcia also recommended that an Information Technician (IT) be a part of the modeling team at AAA. The role of the IT is vital because they would maintain the computer network and fix anything that may go wrong with the model. Garcia further suggested that two Global Positioning System (GPS) Technicians would be needed to use the GPS equipment to locate the exact geographic location of the water system's facilities such as pipes, tanks, pumps and valves. The geographic elevation of these facilities is important in understanding any water system because gravity affects the flow of water from different elevations (Garcia, O. 2000).

Finally a manager and an administrative assistant would be part of the hydraulic modeling team, according to Garcia. The manager would coordinate the tasks needed to be completed by the team of employees and make sure members of the team are doing their job correctly and efficiently. Secondly, the administrative assistant would handle all secretarial tasks such as organizing meetings, answering phones, and communicating between field staff and model operators (Garcia, O. 2000).

4.3.3.2 Annual Expenses

Annual Expenses would be the costs for services and equipment that need to be paid for continually. The first annual expense shown in Table 4-8 below is office space. Using the number of job positions and the amount of office space required by each employee in square meters, the total amount of office space can be calculated. In an interview with Omar Garcia, he identified the amount of space required by each employee, shown in Table 4-7 above, and the cost of $50 per square meter of space per month (Garcia, O. 2000). With these figures a total cost for one year of office space rental is calculated below in Table 4-8.

Table 4-8: Annual Expenses

8	Expenses	Units	Cost per Unit	Annual Cost
	Office Space (sq. m)	151	$ 50	$ 90,600
	Vehicles	17	$ 1,000	$ 204,000
	Tele Communications	1	$ 1,000	$ 12,000
	Miscellaneous Equipment & Supplies	1	$ 3,000	$ 36,000
		Annual Expenses Sub-Total:		$ 342,600

Another annual cost would be the renting of vehicles for 12 months every year. Each crew of 2 field staff and the GPS Technicians will require a heavy-duty vehicle for transportation and to carry their equipment. Garcia provided a vehicle rental cost of $1,000 per month (Garcia, O. 2000). Therefore the annual cost for vehicles is calculated in Table 4-

8 by multiplying the number of vehicles with the monthly rental fee and with the number of months rented in a year.

The cost for Tele Communications, according to Garcia, includes cellular phones, telephones, pagers, and computer network connections. Finally a cost for miscellaneous equipment was added into the annual expenses to account for any unexpected future costs that may occur. Garcia suggested a miscellaneous cost of $36,000 for office supplies, equipment that may break and need to be replaced, and any unexpected act of nature that may occur (Garcia, O. 2000).

Adding the subtotals from Table 4-7 and 4-8 provides an annual cost, of $2.2 million, for AAA to maintain a hydraulic model of the SJMSA. The total cost for the first year of maintaining a hydraulic model was estimated to be $4.8 million by adding the annual operating cost and the one-time start-up expense of $2.6 million. This is also shown in Table 4-10.

Hydraulic Model Cost - Benefit Analysis

Initial Investment

	Item Quantity	Item Cost	Total Cost
1 Hardware			
GIS/CAD Workstations w/ 21" Monitor	14	$ 5,500	$ 77,000
36" E-Size color plotter	1	$ 16,000	$ 16,000
Letter/Tabloid laser printer	1	$ 3,000	$ 3,000
Data/Com Connections	21	$ 700	$ 14,700
Network	1	$ 20,000	$ 20,000
		Hardware Sub-Total:	**$ 130,700**
2 Software			
LYNX	1	$ 17,000	$ 17,000
Microstation	14	$ 4,500	$ 63,000
Access, Excel and Word	14	$ 800	$ 11,200
EPANET	14	$ -	$ -
DGN Files	250	$ -	$ -
		Software Sub-Total:	**$ 91,200**
3 Office Furniture			
Desk	44	$ 150	$ 6,600
Chair	44	$ 90	$ 3,960
Filing Cabinet	4	$ 100	$ 400
		Office Furniture Sub-Total:	**$ 10,960**
4 Field Equipment			
Global Positioning System	2	$ 15,000	$ 30,000
Sonic Leak Detection Equipment	1	$ 100,000	$ 100,000
Ground X-Ray Equipment	1	$ 80,000	$ 80,000
Pitometer Pressure Sensor	8	$ 4,250	$ 34,000
Pitometer Flow Meter	6	$ 11,250	$ 67,500
Calibration/Maintenance/Training	1	$ 10,000	$ 10,000
Metal Detectors	15	$ 200	$ 3,000
		Field Equipment Sub-Total:	**$ 324,500**

Initial Investment Cost Sub-Total: $ 557,360

Consulting & Training Support

5 Labor	# of Positions	Office Space (sq. m)	Hours per Day	Hourly Wage	Months Training	Total Wages
UFW Expert	1	6	8	$ 145	12	$ 301,368
Senior Review / QC	1	-	8	$ 145	6	$ 150,684
Project Manager	1	6	8	$ 145	12	$ 301,368
Model Operator	2	6	8	$ 90	12	$ 374,112
Information Technician	1	6	8	$ 90	12	$ 187,056
Programmer	1	4	8	$ 90	6	$ 93,528
Adminstrative Assistant	1	6	8	$ 50	12	$ 103,920
Model Trainer	2	4	8	$ 90	3	$ 93,528
Field Staff	2	2.5	8	$ 75	12	$ 311,760
					Training Sub-Total:	**$ 1,917,324**

6 Expenses	Item Quantity	Item Cost	Total Cost
Vehicles	6	$ 750	$ 4,500
Office Space (sq. m)	53	$ 50	$ 2,650
Travel & Lodging	1	$ 100,000	$ 100,000
Miscellaneous Expenses (per month for 12 months)	12	$ 3,500	$ 42,000
		Expenses Sub-Total:	**$ 149,150**

Consulting & Training Support Sub-Total: $ 2,066,474

Initial Investment Summary

1	Hardware	$	130,700
2	Software	$	91,200
3	Office Furniture	$	10,960
4	Field Equipment	$	324,500
	Initial Investment Cost Sub-Total:	$	557,360

Consulting Fee Summary

5	Labor	$	1,917,324
6	Expenses	$	149,150
	Consulting & Training Support Sub-Total:	$	2,066,474

Initial Investment & Consulting Fee Total $ 2,623,834

Hydraulic Model Cost - Benefit Analysis

Annual Operating Costs

7 Labor	# of Positions	Space Required	Hourly Rate	Hours per Day	Annual Cost
Field Staff	30	2.5 sq. m	$ 20	8	$ 1,247,040
Model Operator	8	6 sq. m	$ 25	8	$ 415,680
Information Technician	1	6 sq. m	$ 25	8	$ 51,960
GPS Technician	2	6 sq. m	$ 20	8	$ 83,136
Manager	1	6 sq. m	$ 35	8	$ 72,744
Administrative Assistant	1	4 sq. m	$ 15	8	$ 31,176
				Annual Trained Labor Sub-Total:	**$ 1,901,736**

8 Expenses	Units	Monthly Cost per Unit	Annual Cost
Office Space (sq. m)	151	$ 50	$ 90,600
Vehicles	17	$ 1,000	$ 204,000
Tele Communications	1	$ 1,000	$ 12,000
Miscellaneous Equipment & Supplies	1	$ 3,000	$ 36,000
		Annual Expenses Sub-Total:	**$ 342,600**

Annual Operating Costs Sub-Total: $ 2,244,336

Annual Labor	**$**	**1,901,736**
Annual Expenses	**$**	**342,600**
Annual Operating Cost	**$**	**2,244,336**

Initial Investment Summary

1	Hardware	$	130,700
2	Software	$	91,200
3	Office Furniture	$	10,960
4	Field Equipment	$	324,500
	Initial Investment Cost Sub-Total:	$	557,360

Consulting Fee Summary

5	Labor	$	1,917,324
6	Expenses	$	149,150
	Consulting & Training Support Sub-Total:	$	2,066,474

Annual Operating Cost Summary

7	Labor	$	1,901,736
8	Expenses	$	342,600
	Annual Operating Cost	$	2,244,336

First Year Expenses Grand Total $ 4,868,170

4.4 Benefit Results and Analysis

We performed a five-year analysis of the affects of the hydraulic model on the San Juan Metropolitan Service Area (SJMSA). Our results include cost analysis and predictions of future water availability. Mark Zacharias, Sub-Director Metropolitan Region, described to us, the benefits of a working hydraulic model. The numbers he gave us were used in the analysis of the benefits. The expense of the model, discussed in section 4.3, shows its benefits after the first year of implementation. They following sections discuss the benefits of a working hydraulic model.

In the following section, we have not addressed interest rates and inflation when discussing savings in terms of dollars. We have decided that is not necessary since the numbers that we are presenting are rough estimates. If we were to include inflation and time dependent money values the results of our analysis would not reflect our thought process. We would rather present the raw numbers without inflation so we don't get distracted from the most important issues involved in this project.

4.4.1 Year 0 – Current Condition

Zacharias informed us that AAA spends $33.5 million annually in the SJMSA on labor. After analyzing the numbers he gave us, we determined that the cost of labor that will be affected by model implementation is approximately $13 million. This figure decreases as the years progress after the model is implemented due to its impacted on locating and problem solving. The numbers contained in sections 1 and 2 in Table 4-11 reflects the estimated current labor cost that will be affected by the hydraulic model. This is due to their association with location and the models ability to supply endless information regarding the location of elements in the system.

The second large expense that we estimate AAA has is it water loss. Through many meetings with Omar Garcia he has told us that, though no exact measurements have been made, current estimates are that Puerto Rico's water system looses 40% of its water. Garcia also informed us that the average day production of water in the SJMA is 235 million gallons a day (MGD). The estimated unaccounted for water (UFW) in the system currently is 94 MGD, 40% of 235 MGD. UFW is a term used to describe the combined amount of water that is lost due to leaks and theft. For our analysis we make the assumption that all of the 40% UFW is due to leaks. This assumption can be made based on a study done in February 2000 entitled Water Audit & Conservation Pilot Study Final Report. That study estimates that of the 40% UFW only 2% is due to theft. For our purposes that 2% is negligible. We also needed to convert the sale price for a unit of water taken from an actual water bill, as $0.66 per cubic meter, to the value of one million gallons of water. That figure ends up totaling $2521 per million gallons. We arrived at the number by doing the following:

$$\$0.66 \div 264.172 \times 1000000 = \$2521$$

The total is a result of dividing $0.66 by the conversion factor for gallons per cubic meters, and multiplying that by one million. The result is our estimated value for one million gallons of water. After addressing the issue of UFW and the estimated sale price of one million gallons of water, we applied a value to the estimated UFW by multiplying it by the estimated value of one million gallons of water. Since we estimated the annual UFW is 34,334 MG, the approximate loss of revenue accrued to AAA annually is $86 million. In our analysis we considered this amount to be an expense to AAA. Since the hydraulic model could assist in UFW detection, over time leaks will be located and repaired, and un-metered establishments will be metered and billed. Due to the enormous impact of UFW on AAA's budget we have considered this to be the largest benefit of the hydraulic model.

Our final cost for Year 0 is approximately $120 million. This is the sum of labor costs and the value of the UFW. Since we are only analyzing areas of AAA that would be directly impacted by the hydraulic model, this figure does not contain the cost of equipment, supplies, vehicles or working space.

Hydraulic Model Cost - Benefit Analysis

Year 0 - Current Condition

Percent Reduction in Operation Tasks from Previous Year Total: **0%**

Percent Reduction in UFW from Previous Year Percentage: **0%**

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost
1 Location							
Valves	3.00	13.0	2.5	$ 20	10	$ 19,305	$ 1,003,860
Pipelines	2.00	20.0	7	$ 20	1	$ 5,544	$ 288,288
Enhanced Leak Detection	80.00	0.5	2.5	$ 43	6	$ 25,920	$ 1,347,840
						Year 0 Locating:	**$ 2,639,988**
2 Logistics							
Meter Reading Routes	8.00	5.0	2	$ 16	150	$ 194,400	$ 10,108,800
Troubleshooting	0.50	75.0	2	$ 81	1	$ 6,075	$ 315,900
						Year 0 Logistics:	**$ 10,424,700**

Year 0 Labor Cost Affected by Model Sub-Total: $ 13,064,688

3 Labor Cost Not Affected by the Hydraulic Model

	Annual Labor Cost	Labor Cost Affected by the Model	
Annual Labor - San Juan Metropolitan Service Area	$ 33,500,000	$ 13,064,688.0	$ 20,435,312
		Labor Cost Not Affected by the Model:	**$ 20,435,312**

Year 0 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)	
Unaccounted for Water (UFW)	235	40%	94.0	$ 2,521	34,334	$ 86,554,754
					Year 0 Unaccounted for Water Costs:	**$ 86,554,754**

Year 0 Cost: $ 120,054,754

4.4.2 Year 1 – Implementation

The results of our analysis for Year 1 are quite similar to Year 0 with the exception of a slight reduction in UFW and labor operations. In addition to the Year 0 budget, the Year 1 budget includes the first year expense of the hydraulic model discussed in section 4.3.3.

We estimate that AAA will see a 2% reduction in UFW at the end of the Year 1, which results in an overall 38% UFW in the system. We also estimate a 2% reduction in the number of field operations after the first year of model implementation. These two reductions result in a savings of approximately $4.3 million and $261 thousand respectively. Since the first year cost of the hydraulic model is approximately $4.8 million, the Year 1 savings nearly pay for the first year start-up costs. The table at the end of this section, Table 4-12, provides evidence of the return on the original investment. The savings in the following years increase due to improved UFW values and fewer field operations.

Hydraulic Model Cost - Benefit Analysis

Year 1 - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total:	2%
Percent Reduction in Water Loss from Previous Year Percentage:	2%

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves	3.00	12.7	2.5	$ 20	10	$ 18,919	$ 983,783	$ 20,077
Pipelines	2.00	19.6	7	$ 20	1	$ 5,433	$ 282,522	$ 5,766
Enhanced Leak Detection	80.00	0.5	2.5	$ 43	6	$ 25,402	$ 1,320,883	$ 26,957
						Year 1 Locating:	**$ 2,587,188**	**$ 52,800**
2 Logistics								
Meter Reading Routes	8.00	4.9	2	$ 16	150	$ 190,512	$ 9,906,624	$ 202,176
Troubleshooting	0.50	73.5	2	$ 81	1	$ 5,954	$ 309,582	$ 6,318
						Year 1 Logistics:	**$ 10,216,206**	**$ 208,494**

Year 1 Labor Cost Affected by Model Sub-Total: $ 12,803,394 $ 261,294

3 Labor Cost Not Affected by the Hydraulic Model

Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0	$ 20,435,312
Labor Cost Not Affected by the Model:	**$ 20,435,312**

Year 1 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)	Annual Cost	Annual Savings
Unaccounted for Water (UFW)	235	38%	89.3	$ 2,521	32,617	$ 82,227,016	$ 4,327,738
					Year 1 Unaccounted for Water Costs:	**$ 82,227,016**	**$ 4,327,738**

5 Hydraulic Model Costs

Initial Costs - Carried Over from Sheet 1	$ 2,623,834
Annual Costs - Carried Over from Sheet 1	$ 2,244,336
Year 1 Hydraulic Model Costs:	**$ 4,868,170**

Year 1 Net: $ 120,333,892 $ (279,139)

4.4.3 Year 2 – Continued Use

Using the input we received from Omar Garcia, we choose to increase the expected reductions for Year 2. The change in UFW from an overall 38% to 33% results in an annual savings of $15 million as shown in Table 4-13. We also estimate that the number of field operations will continue to decrease; this we estimate is a 5% reduction from the previous year. That benefit results in a total savings of $5.8 million. We have also reduced the cost of the hydraulic model from an estimated first year cost of $4.8 million, shown as the final number in Table 4-10, to an estimated annual cost of $2.2 million shown on the same table as the "Annual Operating Cost". We estimate that the savings in Year 2 will total $18.8 million. The results of Year 2 analysis are contained in Table 4-13.

Hydraulic Model Cost - Benefit Analysis

Year 2 - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total: **5%**

Percent Reduction in Water Loss from Previous Year Percentage: **5%**

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves	0.25	12.1	2.5	$ 20	10	$ 1,498	$ 77,883	$ 925,977
Pipelines	2.00	18.6	7	$ 20	1	$ 5,161	$ 268,396	$ 19,892
Enhanced Leak Detection	32.00	0.5	2.5	$ 43	6	$ 9,653	$ 501,936	$ 845,904
						Year 2 Locating:	**$ 848,215**	**$ 1,791,773**
2 Logistics								
Meter Reading Routes	5.25	4.7	2	$ 16	150	$ 118,772	$ 6,176,161	$ 3,932,639
Troubleshooting	0.25	69.8	2	$ 81	1	$ 2,828	$ 147,051	$ 168,849
						Year 2 Logistics:	**$ 6,323,212**	**$ 4,101,488**

Year 2 Labor Cost Affected by Model Sub-Total: $ 7,171,427 $ 5,893,261

3 Labor Cost Not Affected by the Hydraulic Model

	Annual Cost
Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0	$ 20,435,312
Labor Cost Not Affected by the Model:	**$ 20,435,312**

Year 2 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)	Annual Cost	Annual Savings
Unaccounted for Water (UFW)	235	33%	77.6	$ 2,521	28,325	$ 71,407,672	$ 15,147,082
					Year 2 Unaccounted for Water Costs:	**$ 71,407,672**	**$ 15,147,082**

5 Hydraulic Model Costs

	Annual Cost
Annual Costs - Carried Over from Sheet 1	$ 2,244,336
Year 2 Hydraulic Model Costs:	**$ 2,244,336**

Year 2 Net: $ 101,258,747 $ 18,796,007

4.4.4 Years 3, 4, and 5 – Continued Use

The last three years of our plan are very similar. The only change during these years is an improvement in the number of field operations due to the improving system efficiency. In Year 3 we estimate a 10% reduction from the previous year and Years 4 and 5 are 15%. The resulting savings per year is $30, $42, and $53 million respectively. The data for these years is contained in Tables 4-14, 4-15, and 4-16.

As for UFW reduction, we estimate by the end of Year 5 the system will be operating with 18% UFW. This reduction from 40% the first year results in an estimated savings in UFW for Year 5 of $47.6 million. After five years of use, we estimate the hydraulic model saves, cumulatively, $144 million. Without any further analysis we can see that the model has been paid for after only 2 years of operation. The chart containing this information is contained in Figure 4-1 at the end of this section.

Hydraulic Model Cost - Benefit Analysis

Year 3 - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total: **10%**

Percent Reduction in Water Loss from Previous Year Percentage: **5%**

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves	0.25	10.9	2.5	$ 20	10	$ 1,348	$ 70,095	$ 933,765
Pipelines	2.00	16.8	7	$ 20	1	$ 4,645	$ 241,557	$ 46,731
Enhanced Leak Detection	32.00	0.4	2.5	$ 43	6	$ 8,687	$ 451,742	$ 896,098
						Year 3 Locating:	**$ 763,393**	**$ 1,876,595**
2 Logistics								
Meter Reading Routes	5.25	4.2	2	$ 16	150	$ 106,895	$ 5,558,545	$ 4,550,255
Troubleshooting	0.25	62.8	2	$ 81	1	$ 2,545	$ 132,346	$ 183,554
						Year 3 Logistics:	**$ 5,690,891**	**$ 4,733,809**

Year 3 Labor Cost Affected by Model Sub-Total: $ 6,454,284 $ 6,610,404

3 Labor Cost Not Affected by the Hydraulic Model

Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0 — $ 20,435,312

Labor Cost Not Affected by the Model: $ 20,435,312

Year 3 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)	Annual Cost	Annual Savings
Unaccounted for Water (UFW)	235	28%	65.8	$ 2,521	24,033	$ 60,588,327	$ 25,966,426
					Year 3 Unaccounted for Water Costs:	**$ 60,588,327**	**$ 25,966,426**

5 Hydraulic Model Costs

Annual Costs - Carried Over from Sheet 1 — $ 2,244,336

Year 3 Hydraulic Model Costs: $ 2,244,336

Year 3 Net: $ 89,722,260 $ 30,332,494

Hydraulic Model Cost - Benefit Analysis

Year 4 - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total: **15%**

Percent Reduction in Water Loss from Previous Year Percentage: **5%**

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Costs per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves	0.25	9.3	2.5	$ 20	10	$ 1,146	$ 59,580	$ 944,280
Pipelines	2.00	14.2	7	$ 20	1	$ 3,949	$ 205,323	$ 82,965
Enhanced Leak Detection	32.00	0.4	2.5	$ 43	6	$ 7,384	$ 383,981	$ 963,859
						Year 4 Locating:	**$ 648,884**	**$ 1,991,104**
2 Logistics								
Meter Reading Routes	5.25	3.6	2	$ 16	150	$ 90,861	$ 4,724,763	$ 5,384,037
Troubleshooting	0.25	53.4	2	$ 81	1	$ 2,163	$ 112,494	$ 203,406
						Year 4 Logistics:	**$ 4,837,257**	**$ 5,587,443**

Year 4 Labor Cost Affected by Model Sub-Total: $ 5,486,142 $ 7,578,546

3 Labor Cost Not Affected by the Hydraulic Model

Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0	$ 20,435,312
Labor Cost Not Affected by the Model:	**$ 20,435,312**

Year 4 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)		Annual Savings
Unaccounted for Water (UFW)	235	23%	54.1	$ 2,521	19,742	$ 49,768,983	$ 36,785,770
					Year 4 Unaccounted for Water Costs:	**$ 49,768,983**	**$ 36,785,770**

5 Hydraulic Model Costs

Annual Costs - Carried Over from Sheet 1	$ 2,244,336
Year 4 Hydraulic Model Costs:	**$ 2,244,336**

Year 4 Net: $ 77,934,773 $ 42,119,981

Hydraulic Model Cost - Benefit Analysis

Year 5 - Benefit Analysis

Percent Reduction in Operation Task from Previous Year Total: **15%**

Percent Reduction in Water Loss from Previous Year Percentage: **5%**

Labor Cost Affected by the Hydraulic Model

	Hours to Complete Task	Average # of Operations per Week	Personnel per Crew	Personnel Wage per Hour (x1.8)	# of Crews	Labor Costs per Week	Annual Cost	Annual Savings
1 Location								
Valves	0.25	7.9	2.5	$ 20	10	$ 974	$ 50,643	$ 953,217
Pipelines	2.00	12.1	7	$ 20	1	$ 3,356	$ 174,525	$ 113,763
Enhanced Leak Detection	32.00	0.3	2.5	$ 43	6	$ 6,277	$ 326,384	$ 1,021,456
						Year 5 Locating:	**$ 551,552**	**$ 2,088,436**
2 Logistics								
Meter Reading Routes	5.25	3.0	2	$ 16	150	$ 77,232	$ 4,016,049	$ 6,092,751
Troubleshooting	0.25	45.4	2	$ 81	1	$ 1,839	$ 95,620	$ 220,280
						Year 5 Logistics:	**$ 4,111,669**	**$ 6,313,031**

Year 5 Labor Cost Affected by Model Sub-Total: $ 4,663,220 $ 8,401,468

3 Labor Cost Not Affected by the Hydraulic Model

	Annual Cost
Annual Labor - San Juan Metropolitan Service Area - Carried over from Year 0	$ 20,435,312
Labor Cost Not Affected by the Model:	**$ 20,435,312**

Year 5 Labor Cost Not Affected by the Model: $ 20,435,312

4 UFW Revenue Loss

	Avg. Day Production (MGD)	Percentage Lost	Water Lost (MGD)	Cost per MG	Yearly Loss (MG)	Annual Cost	Annual Savings
Unaccounted for Water (UFW)	235	18%	42.3	$ 2,521	15,450	$ 38,949,639	$ 47,605,114
					Year 5 Unaccounted for Water Costs:	**$ 38,949,639**	**$ 47,605,114**

5 Hydraulic Model Costs

	Annual Cost
Annual Costs - Carried Over from Sheet 1	$ 2,244,336
Year 5 Hydraulic Model Costs:	**$ 2,244,336**

Year 5 Net: $ 66,292,507 $ 53,762,246

Table 4 - 16: Year 5 - Benefits Analysis

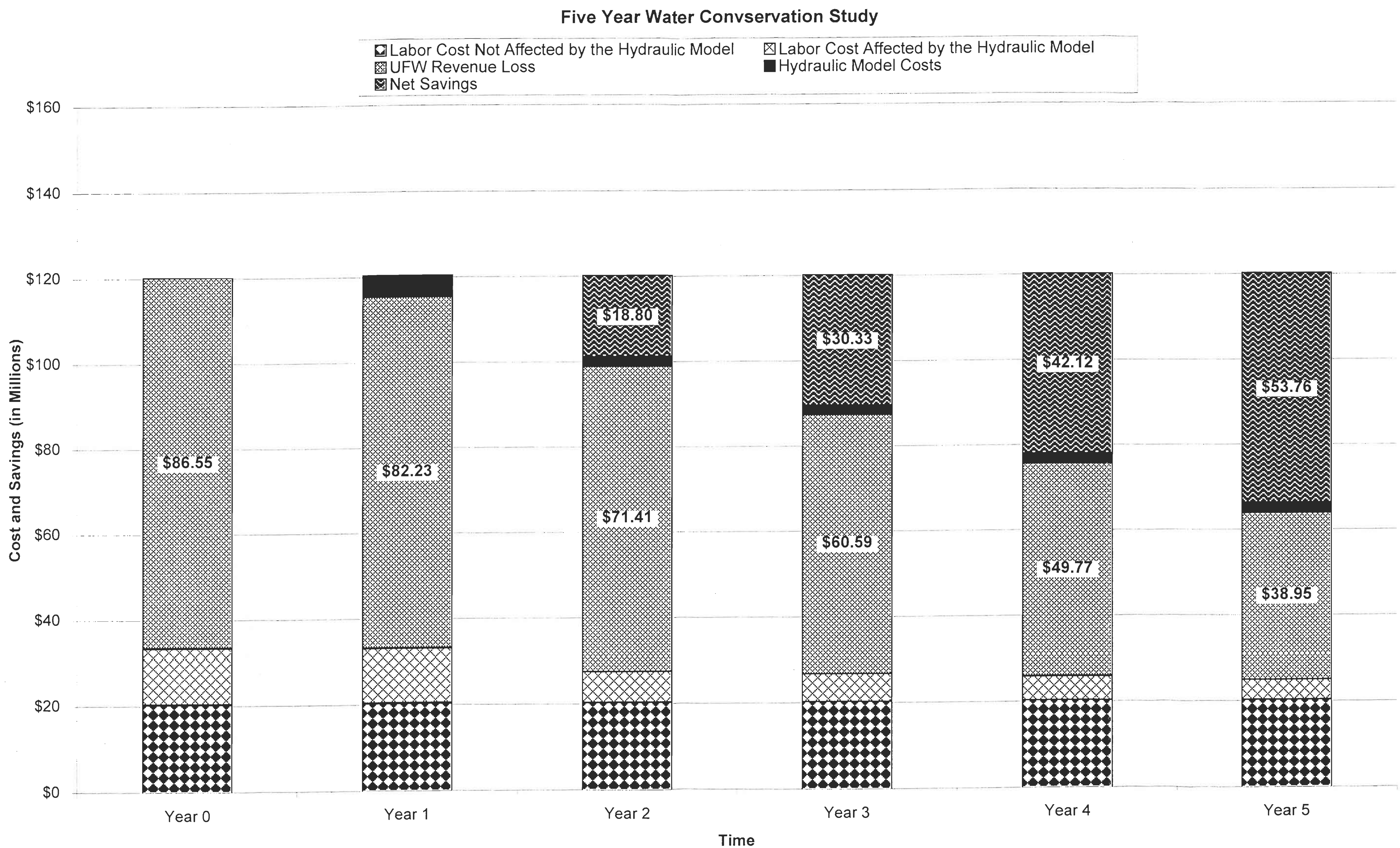


Figure 4 - 1: Five Year Conservation Study

4.5 Water Supply Analysis

We identified two other future benefits of the hydraulic model. The first is an addition to the available usable water in the system, which results in a surplus after 3 years of operation. The second future benefit that we have identified is the deferral of building a new water production plant. This deferral is due to the newly available water supply and its impact on accounted for water in the system.

4.5.1 Water Supply Analysis – Surplus/Deficit

Along with the analysis of the five-year plan using the hydraulic model, we performed a water supply analysis. Since we were dealing with water supply, we had to use maximum day demand (MDD) figures for the water system. Our water supply analysis extended for twenty years, until 2020, when the MDD is expected to be 390 MGD. This projection is a 20% increase from the current MDD of 324 MGD (CSA, 2000). Currently there is a supply of 305 MGD, which results in a 19 MGD deficit. Without any change to the system there will be an 85 MGD deficit in the year 2020. We tested the water demand situations with and without the models impact.

Using the estimate we made for the model's improvements on UFW in the water system, we have found some startling results. We first had to make the assumption that all of the UFW is due to water leakage. This assumption is being made because the amount of water stolen was estimated in the Water Audit & Conservation Pilot Study to be only 2% of the UFW. Using that assumption, after only 3 years of operations the model's impact will create an estimated additional 28 MGD available in the system, which results in a 9 MGD surplus in 2003. This surplus continues to mount until the model's effects level out after Year 5 at which point there will be an additional 52 MGD in the system, which figures to be a surplus of 33 MGD. As growth continues in the San Juan Metropolitan Service Area (SJMSA), as estimated by the SJMSA Phase II report, the surplus slowly diminishes. Through this analysis, we estimate the surplus would be gone in the year 2018 and by the year 2020 the surplus/deficit will still be in a better condition that it is now after only spending approximately $4.8 million on a working hydraulic model. The data from this analysis including graphical representations of the two conditions over a 20-year span can be found in Tables 4-17, and Figures 4-2 and 4-3 at the end of this section.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Future Analysis with Current Condition											
Supply (MGD)	305	305	305	305	305	305	305	305	305	305	305
Maximum Day Demand (MGD)	324	327.3	330.6	333.9	337.2	340.5	343.8	347.1	350.4	353.7	357
Deficit (MGD)	19	22.3	25.6	28.9	32.2	35.5	38.8	42.1	45.4	48.7	52
UFW %	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
UFW (MGD)	122	122	122	122	122	122	122	122	122	122	122
Accounted for Water (MGD)	183	183	183	183	183	183	183	183	183	183	183
Future Analysis with Model Implemented											
Supply (MGD)	305	305	305	305	305	305	305	305	305	305	305
Maximum Day Demand (MGD)	324	327.3	330.6	333.9	337.2	340.5	343.8	347.1	350.4	353.7	357
Saved Water	0	6.1	21.35	36.6	51.85	67.1	70.15	73.2	76.25	76.25	76.25
Adjusted MDD (MGD)	324	321.2	309.25	297.3	285.35	273.4	273.65	273.9	274.15	277.45	280.75
Deficit (MGD)	-19	-16.2	-4.25	7.7	19.65	31.6	31.35	31.1	30.85	27.55	24.25
UFW %	40%	38%	33%	28%	23%	18%	17%	16%	15%	15%	15%
UFW (MGD)	122	115.9	100.65	85.4	70.15	54.9	51.85	48.8	45.75	45.75	45.75
Accounted for Water (MGD)	183	189.1	204.35	219.6	234.85	250.1	253.15	256.2	259.25	259.25	259.25

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Future Analysis with Current Condition										
Supply (MGD)	305	305	305	305	305	305	305	305	305	305
Maximum Day Demand (MGD)	360.3	363.6	366.9	370.2	373.5	376.8	380.1	383.4	386.7	390
Deficit (MGD)	55.3	58.6	61.9	65.2	68.5	71.8	75.1	78.4	81.7	85
UFW %	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
UFW (MGD)	122	122	122	122	122	122	122	122	122	122
Accounted for Water (MGD)	183	183	183	183	183	183	183	183	183	183
Future Analysis with Model Implemented										
Supply (MGD)	305	305	305	305	305	305	305	305	305	305
Maximum Day Demand (MGD)	360.3	363.6	366.9	370.2	373.5	376.8	380.1	383.4	386.7	390
Saved Water	76.25	76.25	76.25	76.25	76.25	76.25	76.25	76.25	76.25	76.25
Adjusted MDD (MGD)	284.05	287.35	290.65	293.95	297.25	300.55	303.85	307.15	310.45	313.75
Deficit (MGD)	20.95	17.65	14.35	11.05	7.75	4.45	1.15	-2.15	-5.45	-8.75
UFW %	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
UFW (MGD)	45.75	45.75	45.75	45.75	45.75	45.75	45.75	45.75	45.75	45.75
Accounted for Water (MGD)	259.25	259.25	259.25	259.25	259.25	259.25	259.25	259.25	259.25	259.25

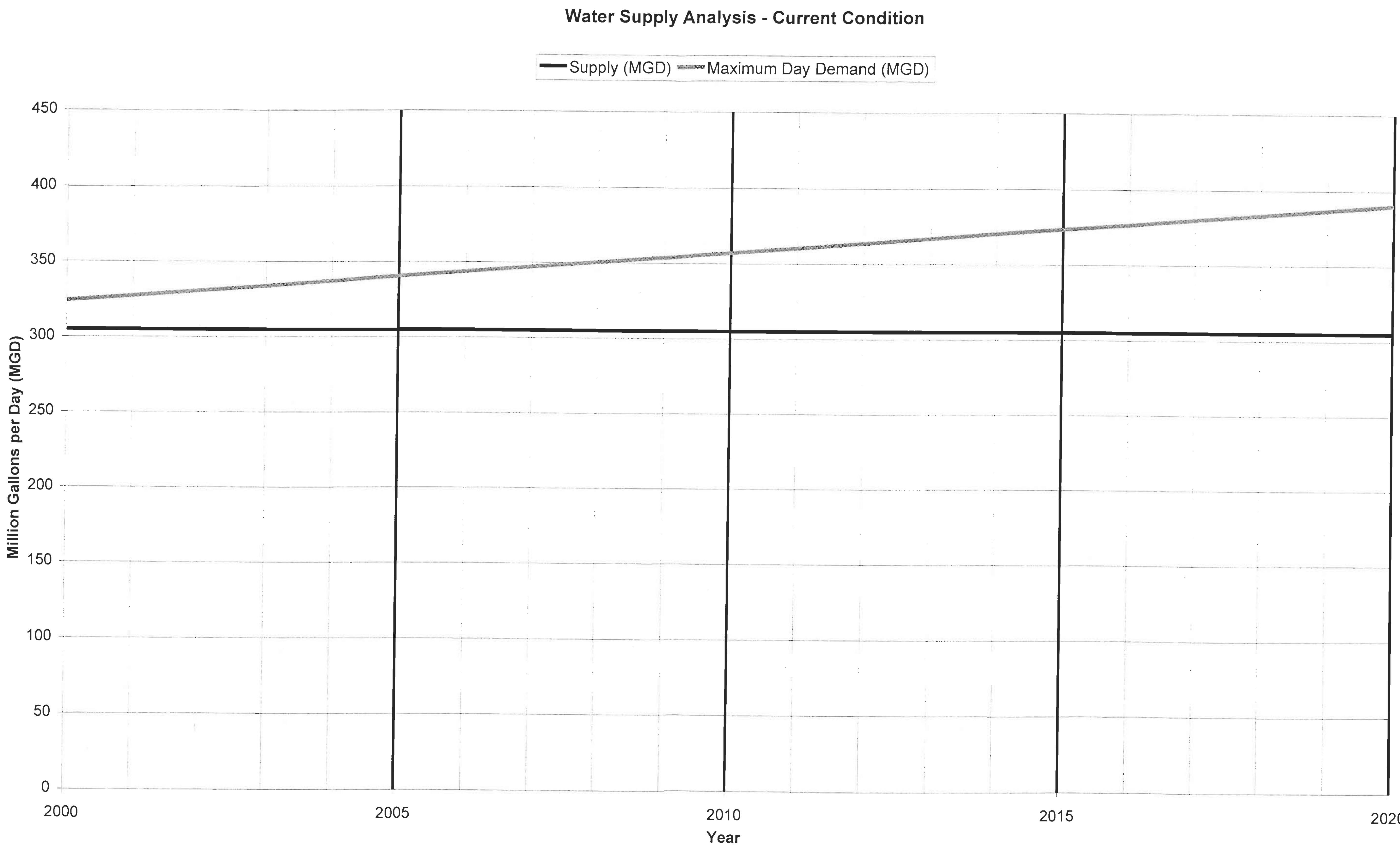


Figure 4 - 2: Current Condition - 20 yr. Projection

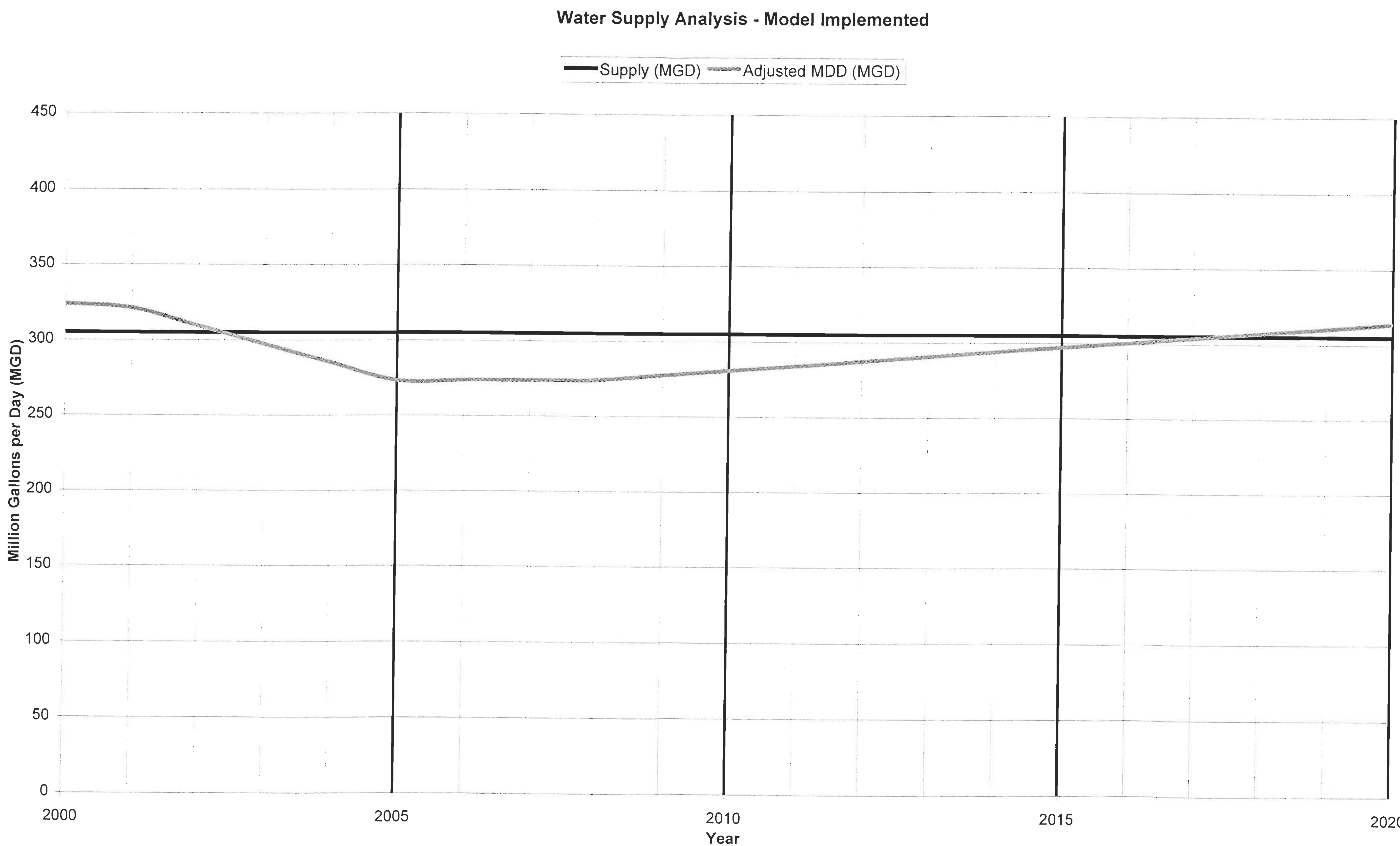


Figure 4 - 3: Model Condition - 20 yr. Projection

4.5.2 New Plant Construction Costs Deferred

The water savings, discussed in the previous section, could defer the cost of a water production plant for several years. We estimated that a new plant producing 85 MGD would cost $212 million. We projected that cost 20 years from now when the water deficit would be 85 MGD. After assessing the cost of a loan worth $212 million paid over 20 years, we estimated that AAA would have to spend approximately $18 million a year for the next 20 years to pay for that new plant. We considered the $18 million an annual savings to AAA, for they will not have to spend it until approximately 20 years after implementation of the model. The analysis of this benefit is contained in Table 4-18, and displayed in Figure 4-4.

Hydraulic Model Cost - Benefit Analysis

New Plant Construction Cost Deferral Analysis

Estimated Cost of a Water Production Facility

Cost per Gallon ($/gal)	Million Gallons Needed	Estimated Cost of Plant (Million $)
$2.50	85	$ 212.50

Loan Cost Analysis

Number of payments	Interest Rate	Present Value (Million $)	Annual Payment (Million $)
20	6.00%	$ 212.50	$ (18.53)

Deferral Cost Analysis

NOTE SEE BELOW	Labor Cost Not Affected by the Hydraulic Model	Labor Cost Affected by the Hydraulic Model	UFW Revenue Loss	Hydraulic Model Costs	Net Savings		Annual Payment on New Plant	Net Savings including New Plant Cost
Year 0	$ 20.44	$ 13.06	$ 86.55	$ -	$ -		$ -	$ -
Year 1	$ 20.44	$ 12.80	$ 82.23	$ 4.87	$ (0.28)		$ 18.53	$ 18.25
Year 2	$ 20.44	$ 7.17	$ 71.41	$ 2.24	$ 18.80		$ 18.53	$ 37.32
Year 3	$ 20.44	$ 6.45	$ 60.59	$ 2.24	$ 30.33		$ 18.53	$ 48.86
Year 4	$ 20.44	$ 5.49	$ 49.77	$ 2.24	$ 42.12		$ 18.53	$ 60.65
Year 5	$ 20.44	$ 4.66	$ 38.95	$ 2.24	$ 53.76		$ 18.53	$ 72.29
Year 6	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 7	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 8	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 9	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 10	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 11	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 12	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 13	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 14	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 15	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 16	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 17	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 18	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 19	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78
Year 20	$ 20.44	$ 4.66	$ 32.46	$ 2.24	$ 60.25		$ 18.53	$ 78.78

* Dollar amounts are in millions of dollars
** Values for years 7-20 are held steady from year 6's values

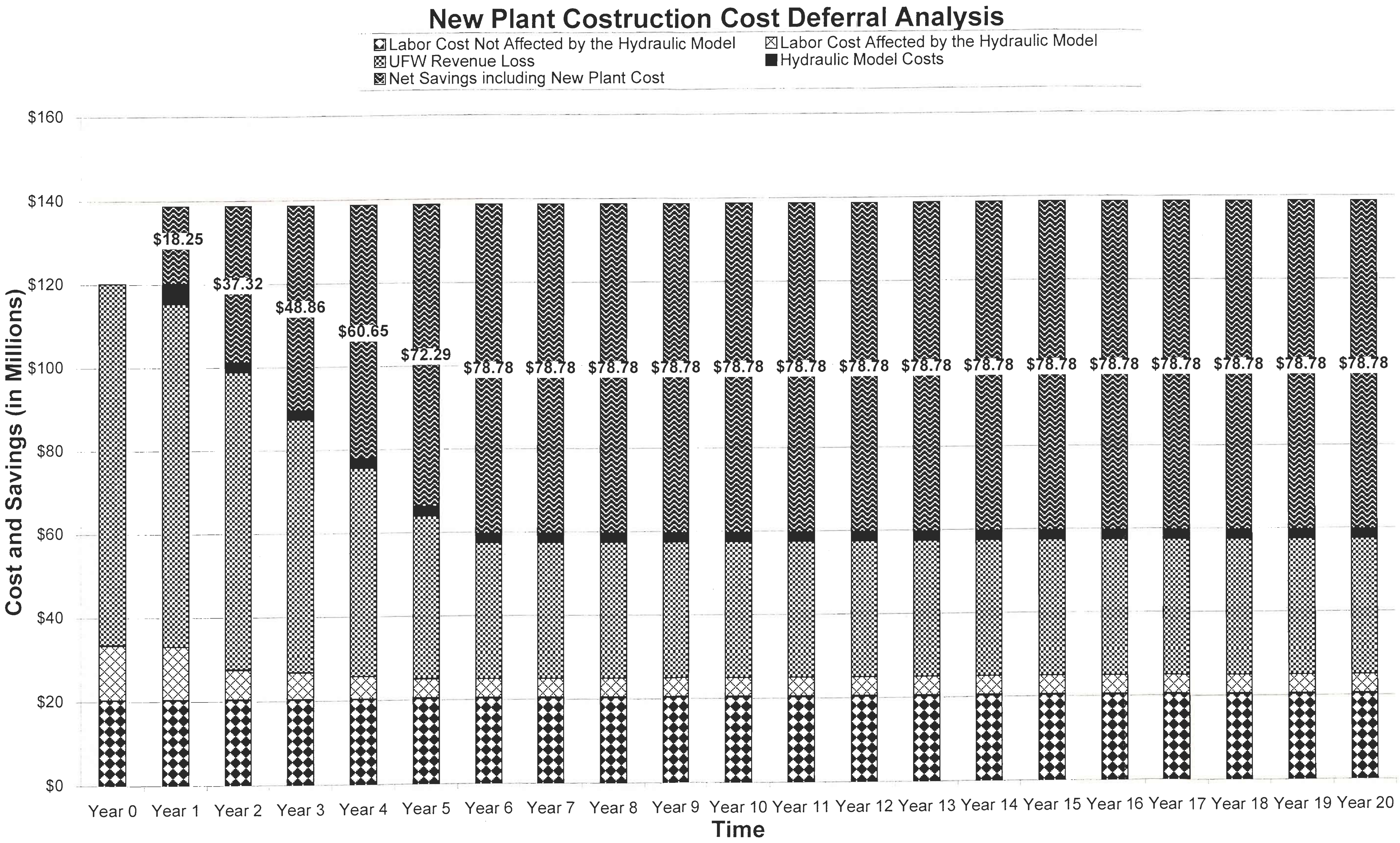


Figure 4 - 4: Plant Cost Deferral Chart

5.0 Conclusions and Recommendations

The JV of CSA Architects & Engineers and CH2M Hill developed the computerized hydraulic model for the Infrastructure Financing Authority (AFI) in their planning to improve the service of the water system. The hydraulic model simulates the water flow through the pipes with the capability of determining where there are pressure problems or leaks. The model that is in use at CSA's headquarters is used as a tool to identify areas for the improvements planning of AFI. This model helps in the design and location of new equipment to improve water service throughout the entire island.

Our analysis has exposed a long-term benefit for Autoridad de Acueductos y Alcantarillados (AAA) if they adopt and implement the hydraulic model into their daily operations. Some of these benefits include improved leak detection, faster valve and pipeline location, and quicker system troubleshooting. In chapter four we analyzed the costs and benefits of implementing a hydraulic model at AAA. We calculated that the costs of the initial year of model operation would be $4.8 million and the annual costs would be $2.2 million. The investment in a computerized hydraulic model would provide an estimated annual savings of $54 million in AAA's operations for the first 5 years from its implementation. Also a 22% increase in accounted for water was estimated for the first 5 years due to a loss prevention program working in conjunction with the model.

In addition, we compared the current water supply to the growing demand over the next 20 years. As shown in Figure 4-2 Current Condition – 20 yr. Projection, the current demand for water is slightly above the current supply. An even more threatening scenario is looming in the year 2020 when the demand will be approximately 85 MGD above the supply. This would suggest that a new water production facility would have to be built account for that growing water deficit. However, we conclude that with the use of a computerized hydraulic model in a leak detection/loss prevention program an 85 MGD production plant would not have to be built in order to meet the demand for water in 20 years.

With the help of Marc Zacharias and Omar Garcia, we have been able to identify the costs and benefits that AAA would encounter should they decide to implement the computerized hydraulic model that the joint venture has developed. This highly technological software tool could immediately provide AAA with the ability to prioritize areas that are not providing sufficient water service and also to visualize the effects of large-scale operations on the water system, such as the North Coast Super Aqueduct.

If AAA were to adopt the model, after approximately one year of a continuous effort to collect information concerning the water system's components, the model would be able to provide a multitude of benefits. AAA operators would know where problems exist, whether a valve is shut off when it should be on, whether water is being lost in a certain area, or whether pressures are too high or too low.

The use of the model would benefit AAA mostly by complementing a water loss reduction program. We estimate that with a leak prevention program, the amount of unaccounted for water (UFW) would be reduced by 2% the first year and 5% for the next four years. We estimate that 52 MGD will be saved in the fifth year. This reduction is the result of the percentage of UFW dropping from 40% to 18% in five years. This saving would result in an estimated revenue increase of $47 million. Detail information can be found in Tables 4-11 through 4-16 and in Figure 4-1 Five Year Water Conservation Study. We conclude that the majority of AAA's savings would be due to the reduction of UFW in the water system.

5.1 Use of the Model at AAA

As a result of the cost analysis presented in section 4.3, we recommend that the Autoridad de Acueductos y Alcantarillados (AAA) invest in a computerized model and loss prevention program. This investment would require an initial investment cost of $560 thousand, as shown in Table 4-9. The staff that we recommended in section 4.3.2 adds an estimated $2.2 million to the first year cost. The suggested staff would enable AAA to updated and improve the detail of the computerized hydraulic model. We recommend that AAA invest further in improving the detail of the current model. The final investment added onto the first year would be the consulting fees associated with training the new employees. This consulting fee, evaluated in section 4.3.2, will add approximately $2.0 million to the first year investment. We conclude that the final cost of the first year with our recommendations would be approximately $4.8 million. This cost would include purchasing computer hardware and software, office furniture and space, field equipment and supplies, as well as training and annual labor costs and expenses. From our detailed cost/benefit analysis, we estimate that improving the detail of the model would require several months of intense field study and data collection before any benefits will occur. From the start of the second year that the model is implemented, several benefits would be realized in the areas of labor-time savings and water loss reduction.

We recommend that a detailed computerized model of the water system be implemented at the offices of AAA along with an enhanced leak-prevention program in order to assist in their operations and improve the water supply to the San Juan Metropolitan Service Area (SJMSA). With a computerized model of the SJMSA, knowledge of the system can be improved, thereby reducing the time it takes to accomplish tasks, such as leak detection and valve locating. Using the model as a tool for locating pipelines and valves, leak detection of a specified area can be carried out more efficiently than would be the case if the model were not used. More leaks could be identified in the same amount of time, resulting in a decrease in the amount of water lost that we estimate would be 52 MGD by the end of the fifth year of operation.

Reducing the water loss is the main savings that the model would provide. Using the model to complete water audits and leak detection would result in money being saved because these functions are the first steps in a leak-repair program. Decreasing water losses reduces power costs to deliver water, defers construction of new facilities, safeguards public health, and reduces legal liability. Currently an average day demand of 235 million gallons per day (MGD) for the SJMSA is met by the facilities at AAA; however this production occurs with 40% of the water being unaccounted for through leaks, theft, and meter inaccuracies. Using the cost/benefit analysis of the hydraulic model one can see that the amount of unaccounted for water would be reduced from an estimated 94 MGD to 42 MGD in five years, which is enough to accommodate for the population growth of another 20 years. By saving this much water through enhanced leak detection AAA would not have to build a new 85 MGD water production facility costing $212 million until 2020. Therefore the benefits of using the hydraulic model clearly outweigh its costs and would increase the amount of water supply in the SJMSA.

5.2 Future Model Expansion in Puerto Rico

The cost/benefit analysis displays a five-year plan for the hydraulic model in the SJMSA. After these five years, enough information about the system would be entered into the model and the system would be supplying water with more efficiency. Therefore it would be time to implement the model in the other AAA districts in Puerto Rico. Autoridad de Acueductos y Alcantarillados (AAA) is divided into four districts strategically located about Puerto Rico. The trained staff that worked with the model in the SJMSA could be reduced to eight field staff from the original 30, and only two model operators would be required from the original eight. With the staff no longer needed in the SJMSA they could be employed in the other three AAA districts to develop and maintain other hydraulic models. These employees getting paid at their regular hourly wage could be used as full time employees and trainers for new staff in the other districts. Therefore the consulting fees that composed 80% of the one-time start-up costs and almost 40% of the total first year costs could be drastically reduced for the other districts because AAA would be using their own employees for training.

Our final recommendation, therefore, is that AAA invest the suggested staff and equipment to maintain and update a computerized model of the SJMSA as well as start a loss prevention program. This investment would result in several benefits such as reducing labor costs and reducing the amount of unaccounted for water. These benefits would provide enough savings to fund the initial model investment and materials needed to repair detected leaks. As the model is updated and detailed enough to provide a complete inventory of the water system's components, members of the modeling staff can be transferred to develop and maintain a model in the other districts of AAA. As a future recommendation, constant-monitoring sensors could be strategically placed on critical pipelines, storage tanks, and production facilities to allow for directly communication between the system and the model. As a result, implementing a computerized hydraulic model as an operational tool would benefit the water system of Puerto Rico by providing greater knowledge of the water system's behavior.

6.0 Appendices

Appendix A: Mission of CSA Architects & Engineers

Our information was obtained from Mr. Pepe Daubón and from http://www.csagroup.com.

CSA Architects & Engineers is located in San Juan, Puerto Rico. CSA provides a variety of services including: integrated management consulting, architecture, engineering, planning, environmental sciences, construction, and program management.

Mission of the Agency

> To continue developing business in Puerto Rico and demonstrating the company's solid capability base and successful track record in the United States, the Caribbean, and Latin America.

CSA's objectives are targeted at:

- Expanding CSA's management and technical teams in Puerto Rico and US office locations
- Developing strategic alliances with the large engineering and construction firms
- Developing long term relationships with the local and international financing and banking institutions
- Offering professional services as a strong and experienced Minority Business Enterprise (MBE) in the United States.

CSA designs and oversees the production of large-scale public projects in both the public and private sectors. Some ventures that CSA is involved in include architecture, civil engineering and planning, environmental sciences, construction and program management. CSA Architects & Engineers is a member of a professional partnership with CSA North America and CH2M Hill.

CSA is involved in the largest public works projects ever undertaken in Puerto Rico. They have been working with the Infrastructure Financing Authority (AFI) to develop hydraulic models and assist in project site management. They have foreseen one hole in this project: that the future use of their hydraulic model is unknown. Their team believes it is critical to implement a computer simulation of the current hydraulic system and provide for the future updating of the model. Our IQP is involved with representing the model as a useful tool for AAA to use for their future operations.

The CSA Group has been offering more than 40 years of reliable service, consistent quality and outstanding professional achievement. They are a 300-plus-business enterprise providing integrated management consulting, architectural, engineering, planning, environmental, and construction, project and programs management services to the public and private sectors throughout the Americas.

Appendix B: Interview Notes

Contained in Appendix B are the notes that we recorded during our interviews.

B.a: Michael Ferguson, Worcester DPW

We interviewed the Worcester Public Works Department to learn as much as we can so we are fully prepared to undertake projects in Puerto Rico. We want to learn how they manage their system.

1. How large is the Worcester Water system?

Worcester has a population of 165,000 people. There are 40,000 metered water accounts. These accounts are not relevant for finding the number of customers served because in some cases more than one customer is monitored by one meter. For example, a condominium only has one meter but water is served to all the residents of the condominium. The best way to determine the size of a system is the amount of people that demand water.

2. Do you have a scheduling system for maintenance?

Yes. Currently the Worcester DPW has a 5-year plan for maintaining the system. The maintenance schedule is centered on the street paving maintenance schedule. Every month a meeting is held to give all utility companies knowledge of what streets will be repaired so they can plan their maintenance when the street is dug up. Utilities do not want to go out a week later and have to dig up a newly paved street because they believed there equipment would last a little longer.

The pipes are also cleaned and cement lined when it is deemed necessary. To clean and line pipes a bypass water line is run along the road so customers do not lose water. A long rigid rod is put into one end of the pipe and exits on the other end. Machines pull this rod back and forth to scrape the rust and build up off the pipe. The scraper resembles a Christmas tree. After the scraping a rubber squeegee is used to wipe the pipe walls clean. Then a cement-spraying machine is put into the pipe. The walls of the pipe get covered with a layer of cement that is smoothed down and evened out by passing through the pipe a cone shaped object that is proportional to the diameter of the pipe. The method of cleaning and cement lining is more efficient than replacing pipes that have a low flow rate due to excess build up. It takes one hour to clean and line 800 feet of pipe. Using this process on pipes with larger diameter is more cost effective than replacing the pipes with brand new ones.

Another method to providing a reliable water system is locating leaks in the pipes. In Worcester a crew is hired to follow certain sections of the system and listen for leaks with high technology devices. Using the proper equipment a high pitch sound indicates a leak in a certain area. This process of leak detection is done at nighttime to avoid excess noise from traffic.

Fire hydrants are the main priority in maintaining a water system. If there is not enough pressure at a hydrant then a fire cannot be put out. Hydrant testing is also done to determine the flow rate of a section of pipe. Two hydrants are used for this testing. At one hydrant the water pressure and flow is measured. Then the same measurement is taken at the connecting hydrant and if these measurements do not match up to the specifications then work will need to be done.

Also resident complaints are a way for finding problems in the system. Customers may call the Worcester D.P.W. and report that they have little or no pressure, or that the water is rusty. These complaints notify the distribution engineer as to where problems are occurring.

A computerized model of the system was developed in WaterMax. This software simulates the flow of water through the piping network. Through the hydrant testing and leak detection the model can be updated.

3. What factors make your decision on which pipes are repaired first?

The first priority is providing the fire hydrants with enough water pressure. The computerized model flags pipes that have significant head loss. Hydraulic and flow testing are done in the field to measure the correct flow values that are used to calibrate the model. The model needs to have the correct measurements to correctly identify the areas that have problems. The model is a very useful tool because it can be used to predict future happenings. The second priority that the maintenance schedule depends on is the street maintenance schedule.

4. What is your yearly budget for system maintenance, salaries and building maintenance?

$2.5 million for new construction, maintenance, rehabilitation, broken hydrants, and flushing pipes.

5. What organizations oversee your operations (i.e. EPA)?

The Department of Environmental Protection has standards that the Worcester DPW needs to follow. The D.E.P. tells the water works company how often the water flow and quality must be checked and within a certain range. At least half of the system must be checked for leaks every year.

The EPA and DEP enforce the Safe Drinking Water Act. The water quality must be maintained by the treatment facility. The EPA and the DEP set standards for treatment such as how often the water needs to be tested and specifications for determining if water is clean enough to drink. There are also laws that were developed by these agencies to prevent contaminated water from flowing back into the water supply. There are devices that prevent contaminated water from reentering the system and this needs to be identified and tested at least once a year. The devices are owned by a building owner and not by the water utility.

The EPA and DEP also require the water utility to employee a certain amount of certified personnel based on the size of the system. For example the treatment facility is required to have three certified operators and the distribution department needs to have primary and secondary certified operators. In Worcester there are more certified operators employed than the minimum requirement set by these protection agencies.

6. What steps are taken in keeping records updated?

The records are kept updated through testing and inspecting. Hydraulic testing is done to measure flow and pressure of certain pipes. The measurements are then entered into WaterMax so the program can do a correct simulation of water flow. Also, licensed field inspectors follow contractors to see that they are working properly and note what is being installed. New England winters do not provide a good setting for underground construction, so the inspectors spend their winters updating the mapping records with the notes about the work done during the year.

7. Do you use private companies to do construction/maintenance work for you?

Yes. Bids for many jobs are put out to private contractors. The company puts out about 6 bids a year for specialized projects such as meter installation, construction, infrared paving and map conversion to GIS. Contractors do a lot of the construction and installation for the Worcester DPW. A recent job to remove old meters and install new ones all over the city was done by a contractor who put in the lowest bid. Contractors also install new pipes for the company.

8. What permits do those companies need to be able to work for you?

Contractors need to be licensed drain layers to work on the water system. Insurance is also a key issue when hiring private contractors to do work. They need to have a performance bond in the state, which says that a contractor has to complete a job once they have started. Contractors also have to be insured against any damage that could occur while they are working.

9. What is the sequence of events following a reported outage/emergency?

There is always a person that is on duty 24 hours a day to coordinate the steps that take place when a problem occurs. Upon notification of the problem, the person that is on duty will alert a supervisor of the situation. In turn the supervisor or foreman will gather a couple workers and head out to locate the problem. Using maps of the piping system the foreman will locate the pipe break and shut all the necessary valves to isolate the problem. The foreman assesses the situation and recommends a solution for repairs. Depending on the degree of the water outage it may take 20 minutes or half of a day to isolate the leak. This variation of time depends on where the valves that need to be turned off are located and the age of these valves. A newer valve can be turned off faster than some older ones.

Sometimes a machine is required to shut off a valve because over 300 turns may be required to close the valve. Also these valves need to be turned off slowly because water rebound can damage pipes.

Does this system work well?

The system works in solving the problem.

10. What would you suggest to make this system better?

A service agency could be utilized to answer the incoming calls that alert the person on duty of a problem. This phone answering service could be used to screen calls and determine the extent of the problem. Maybe the problem is not an emergency and it can wait until the next day to be resolved.

11. Do you know of any examples of private companies managing a city/town water system?

Privatization of utility companies is happening more than in the past years. Mostly small towns are becoming privatized instead of large cities. Large city utilities can maintain the system on its own because enough revenue is generated from the large customer base.

12. What steps would a poorly managed water system need to take to get updated maps and records, and isolate and fix current problems?

To isolate and fix current problems any manager of a water system will need current maps to locate a problem. Ideally, a Geographic Positioning System would be used to find the location of pipes and their intersections. An accurate GPS will provide the information needed to update maps and records.

13. Is water quality a problem concerning the pipes?

All the water entering the system from the reservoir goes through the treatment plant that is managed separately than the engineering or distribution department. Once the water is traveling through the pipes it may become contaminated. Rusty pipes, old pipes with build up on the walls, or pipes that leak provide water that is not of drinking quality.

14. What kinds of ways do you resolve the problem?

Cleaning and cement lining pipes is the most efficient and cost effective way to solve the water quality problem in most cases.

15. How do you locate the problem?

Customers report problems with the water quality. The problem can be located using a computer program that simulates the flow of water. The software can predict future problems and notify the user of them before it becomes a serious issue.

B.b: Jorge Camacho, CSA Modeling Engineer

Jorge Camacho is a graduate of University of Puerto Rico Mayaguez with a bachelor's degree in Civil Engineering and a Masters degree in Water Resources. Now Jorge is an essential part of the modeling team of CSA Architects & Engineers. As a modeler their job is to create digitized maps of the water system using the powerful software tools.

There are very few limitations that come along with Lynx and MicroStation. This is the software that was used to produce the hydraulic model. Yet like any other computer software, it is not perfect. The modeling software does not provide exact information, however the computations done by the program are more than accurate enough for its purpose. Jorge received his training through a couple of days of using the program

Jorge is currently in charge of developing and maintaining the model for the capital city of San Juan. In the past he has created the model for a smaller city named Vega Baja, Puerto Rico. He is also doing modeling work for the city of Atlanta, Georgia from his workstation in Puerto Rico.

Jorge was unsure of the price of the software so his co-worker was around, Bruce. He knew the answer to the question and the price depends on the number of nodes. CSA Architects & Engineers has an unlimited number of nodes so it cost them a little extra, around $17,000 for Lynx and $3,000 for MicroStation. He also mentioned that Lynx could also calculate Billing statements. Some of the other advantages of this software are that it can recognize a leak. When the supply is greater then the demand, a leak can be identified. However, the location of the leak is only isolated to a certain area, and the rest is manual labor.

According to Jorge, a Pipe-Valve Inter-Tie booklet, a book full of maps with pipe location and descriptions of the system at a scale of 1 in equals 1000 ft, was never created in

Puerto Rico. He also told us it would be a lot easier to make that than the model, but CSA Architects & Engineers does not need to generate that book. Jorge believes that the Water Company should create that book.

Leak Detection is one of the many benefits provided by the hydraulic model. Leaks in the pipes, tanks, and hydrants can be detected using the information provided by pressure and flow rate testing done out in the field. By knowing what the pressure and flow rate is supposed to be for a certain pipe and comparing it to the measured values in the field leaks in a certain area can be detected. However it cannot isolate the leak to the exact pipe causing the problem.

Jorge was living in San Juan when the big drought hit Puerto Rico in 1993. We noticed a displeased face when we brought the subject up. He told us he didn't even want to remember those memories of that time. It was a horrible time. His mother didn't want to cook food because they didn't have water to clean the dishes. They had to shower with a jug of water. Jorge was very uncomfortable talking about the drought so we changed the subject.

B.c: Mark Rincon & Robert Bredberg, CSA Project Managers

We interviewed these two Project Managers on Monday March 27, 2000. The interviewed lasted 45 minutes. The main focus of this interview was to explore the role of the hydraulic model in the design of a hydraulic system and how a design engineer does their job in accordance with construction contractors.

Both Mark Rincon and Robert Bredberg are Project Managers who design projects on the water system and coordinate the construction of these projects with contractors. A project is started with only 30% of the final design completed. The goal for this approach is to shorten the time of the total construction process. The construction and design are combined and carried out at the same time. However the design of a project is always ahead of its construction. Once the preliminary design is completed a project can be put out for bidding. The preliminary design identifies certain parameters like the flow rate, pipe size, pipe length, pipe location, pumps size and location, and tank size and location. With these preliminary specifications and a site location the construction crew can begin preliminary work like clearing the land for the project site.

Sometimes things do not work out when only designing 30% to start with. To reduce these risks more management is required between the designers and the builders. As a hydraulic system designer many parameters need to be identified and a 10% contingency cost is added to their design to account for unexpected changes or directives. The hydraulic model does not help reduce the risk of a project going astray from its initial design. Rather the model is currently a tool used for hydraulic analysis that can predict system improvements and provide design parameters such as equipment size and location. It is very important to accurately identify the size of the equipment because the equipment needs to be ordered and it usually takes 8 to 12 months for its arrival. Designers do not use the model to check their design to see if it will work. However they can use the model to try different tank locations at different elevations to see if they will work. It also identifies different pressure zones that need to be taken into consideration when designing a project because a pressure reducer maybe needed in a certain area.

Currently the hydraulic model is only a model but it can be updated to actually predict future problems and be an operational model. To be an operational model the field data used by the model would have to be extremely accurate. Currently field tests are done by monitoring the pressure and flow rate at a location for a 24 hour period. With the data from these tests the model can be calibrated and accurately perform trial runs of the water system. However a computer does not always produce correct data because a wrong number could have been entered. Therefore experienced model designers and analyzers can increase the accuracy of a computerized model.

Another method for updating the hydraulic model and increasing its accuracy are constant pressure and flow rate monitoring at many strategic locations in the water system. To use the model as an operations tool by Autoridad de Acueductos y Alcantarillados (AAA), constant monitoring of the system would have to be done. AAA already has some flow and pressure monitoring equipment but there are not enough monitors to provide enough data for the model. A company called Pitometer Associates is currently the sub consultant retained for field measurements by AFI. Currently the model is a skeleton of the water system but with the constant system monitoring the model can be updated to provide a much more powerful tool. AAA could use the model to compute mass balances of the water supply. Several water sources are required to supply the constant water demand in Puerto Rico and the model could predict where to route the water coming from the multiple sources.

Several months ago a large water shortage in the San Juan Metropolitan Service Area (SJMSA) occurred due to the eruption of the Super Aqueduct. The eruption of the aqueduct was caused by water hammering or reflection waves caused by improper opening and closing of the valves. The Super Aqueduct was not designed to withstand a significant amount of water hammering. 72-inch valves require approximately 24 hours to correctly and safely close. The eruption resulted in a delay of the aqueduct's construction. Therefore water had to be trucked into the area and be distributed from specific locations. With a lack of water supply sanitation issues become a huge concern because people did not have water to bathe.

B.d: Paul da Silva, IAP Technical Services Manager

Paul da Silva's background is with water and wastewater management planning and design. He is the Technical Services Manager of IAP. IAP is a quick fix organization that has 97% work with water and 3% work with sewage. The work that IAP does is based on undersized infrastructure of the water system, such as pipes, pumps, tanks, and reservoirs. The future planning of the population growth was not considered in the design of the system back in the 1940's, however the design was up to date with the most advanced piping equipment available, with a minimal number of errors.

The hydraulic model that has been developed by CSA Architects & Engineers has great predictive capabilities but is not quite ready for operation. The work on the field shows that the information that was used to develop the model has some incorrect elements such as elevation, pipe length or diameter.

AAA is a company that believes in its work and efforts and has not been subjected to the computer-integrated works of the new millennium. AAA may also believe that this is a pre-election phase that the government is going through. They don't believe that the services available now will be available in the future. Another reason AAA would not accept this model or the services of CSA is because they have no knowledge of what the model does or the possibilities of what it can do. Mr. da Silva suggested that CSA develop educational program that taught the models capabilities and how to use it, with field studies already done using the model.

The drought in 1993-1994 was a severe one unlike the ones in the past. The southern part of Puerto Rico usually felt the drought the worst, but in 1993, the Northern part struggled through the drought. This caused the government to look for money so they could end this drought season and have enough water supplies for those dry months of June, July, and August.

Suggestions:

- Model calibration
- 50% full capability
- $6-10 million dollars were reallocated due to the models suggestions
- Operation Strategies
- Reduce power cost by using the model

To get AAA to adopt the model CSA must show the benefits and teach the operators about the models use.

B.e: Marc Zacharias, CAPR Operations Director of Metro Area

On Monday April 3, 2000 we met with Marc Zacharias who is the sub-director for the San Juan Metropolitan Service Area (SJMSA). He works for the Companía de Aguas and has experience using a hydraulic model for water system operations. He has been involved in hydraulic modeling in Mexico City Mexico, Kali Colombia and Paris, France. The models have many benefits that can be categorized into two services, customer and technical.

With a properly functioning hydraulic model there are many benefits that can improve customer service. Most importantly the model can detect leaks by comparing the flow rate in an area with the amount of water consumed. The model can display low consumption areas with a different color that signifies a leak or even water being stolen from the system. With a constant monitoring flow rate system the consumption in an area can be monitored and studied. If the consumption goes up at night then comparing the consumption data to past trends can signify a leak. Fixing problematic areas provides better use of current sources. He said that the government's view is to build new sources rather than use the current sources better like 90% of private companies. There are also logistical benefits such as easily setting the routes for meter readers to travel. However detailed information about the customer location and account numbers is required for route setting. Finally the model can be used to monitor the flow of ground water but this benefit is not needed for a model that is used in the water utilities daily operations.

The technical benefits of the model are very valuable for future investment planning and system maintenance. To enhance a water system inefficient areas need to be located. With a hydraulic model areas that provide inadequate water service can be easily located for future enhancements. These future enhancements and new facilities construction need to be planned over the years and the model can provide enough information to prioritize the investments for upgrading the system. A hydraulic model can predict the impact of a new facility before it is even built. The model also provides a good estimate for project costs. For example if all new service connections were to be installed in a neighborhood, the distances of the pipes is displayed by the model and can be used to come up with a project cost.

Finally once all of the equipment location is known it will be much easier to carry out daily maintenance on the water system.

There are also some costs that come with the benefits of using a hydraulic model in the operations of a water utility. First the cost that would provide the most benefit is locating customers and entering each of their account numbers in the model's database. The next largest cost is getting the right amount of information about the location of pipes, valves and tanks. Marc Zacharias discussed his past involvements in other countries and the cost of obtaining the correct amount of information. In Mexico City there were no records on the efforts of 2000 people over 2 years was required to collect missing information. After these 2 years the amount of information was still inadequate because the water system was constantly changing and growing with the population. The amount of resources needed to collect the equipment information is based on the number of pipes, valves and customers. The model of Mexico City was not used for future investment planning because the model was misleading or did not completely represent the real world.

Marc Zacharias also worked on a hydraulic model in Kali, Colombia that was better organized than the model of Mexico City. There was initially more information about the water system in Kali to plan future investments. However the model of Kali did not contain enough information about customer location so the model was not used as a customer service tool. He also worked on a hydraulic model in Paris, France that had plenty of information about the water system. The Paris model was used for all technical, customer and resource benefits. Due to 150 years of detailed record keeping the model was so advanced in Paris that it was used for water quality monitoring.

He also discussed that the hydraulic model for these areas was maintained and operated by the water utility and not an outside firm. He said it is a flop if an outside firm uses the model because the people who deal with the system everyday need to have first hand contact with the model. As soon as a problem is detected the model is the first resource that needs to be used. The model needs to be constantly updated with the information found by the field crews. He said that the field crews should directly report to a person that operates the model and these crews would never do it if a different company ran the model.

B.f: Skip Martin, CSA Hydrologist

Skip Martin is a hydraulic modeler that has been working for CSA for 20 years. He worked in Cairo, Egypt for two years to improve the Cairo water system. The Hydraulic model consists of two parts, data and analysis. When considering using the model for operations, the most important part of the model is data. If AAA spends the time to input the data into a database, AAA will benefit by knowing more about the water system. The percentage of the model that is data is 80%, and analysis is 20%.

Utility companies need to maintain their system so the implementation of a model should be easy. The most difficult part is to reorganize the entire company for the use of the model. The company will have to make field measures, install several permanent pressure gauges that continuously update the model. AAA will never have enough data to run real time tests on the hydraulic model. The model is there to predict future improvements to the system.

B.g: Yamil Guanthier, CSA Quality Assurance of Super Aqueduct

Yamil Guanthier is a mechanical engineer, and has been working with CSA Architects & Engineers for 13 years. He is currently the director of Mechanical Engineers. He is currently the Quality Assurance leader of the Super Aqueduct project. He has been working on the Super Aqueduct project for 4 years, ever since AFI contracted CSA to manage the Super Aqueduct's design and construction. CSA released a bid out to the public and offered the design, construction and operation of the Super Aqueduct.

Thames Dick of England was the final choice of AFI as the firm to be in charge of the Super Aqueduct. Thames Dick used Kentucky Pipe to design the pipe network. The final proposal that Thames Dick had offered AFI cost them $2 million, while the actual completion of the Super Aqueduct cost $350 million. This proposal took Thames Dick 8 months to make, while CSA had 10 days to review the proposal and make comments on the design. One comment that CSA had made was to be careful with the butterfly valve, a valve that allows the operator to open/close a valve in any amount of time requested. Though the design engineers set the valve to be opened/closed in 30 minutes or more, the operator changed it to be closed in 5 minutes. This caused a surge in the water pipes and an implosion in the pipes. When empty, it takes 4 days to fill these pipes with water, yet when the operator closed the valve a shock wave passed back and forth through the system in 90 seconds.

The social problems of this Super Aqueduct involve the people that would live in the construction of this massive water pipe and the environment that may be effected. The problems involving the people are that the location of this system of pipes ran through private neighborhoods and construction would disbar this private setting. The people that would be at an inconvenience throughout the construction of the Super Aqueduct felt that the project was completely political and did not survey the people to which it would serve water.

The second social problem was the aquatic life that the Super Aqueduct might affect. The Department of Natural Environment Resources (DNER) has permitted the use of the River of Arecibo as long as CSA conducts a test that provides information confirming that the Super Aqueduct does not alter the habitat of the organisms that live in the river. This test must last for two years: one before the opening of the pipes and one after the opening. CSA has already completed the first year before the opening and is waiting for the final stages to be complete of the Super Aqueduct.

B.h: Romie Lat, IAP Mechanical Process Support Specialist

On Thursday March 30, 2000 we talked with Romie Lat about the use of the hydraulic model in one of his project designs. AAA identified many problematic areas that need improvements and notified the IAP of these areas. One of the problematic areas is in Canóvanas, which is a city in the San Juan Metropolitan Service Area (SJMSA). Canóvanas is a city two towns over from San Juan to the west.

A lack of supply was the problem in Canóvanas. The hydraulic model allowed the designers to come up with an ingenious plan to solve the problem. Without the model the designers would have simply increased the capacity of the pumping station that serves the area. El Comandante or Las Cuadras is the name for the pump station. However the designers cooperated with the modeling crew and decided to build a 2.5 MG water tank and install a 16-inch pipeline. This design will provide better service and a higher reliability of water service because the water tank does not depend on electrical power like the pumping station. The model assisted in finding a location for the water tank because the model displays the elevation of the land in the area.

B.i: Clara O'Neil and Roberto Maldonado, AAA

Autoridad de Acueductos y Alcantarillados (AAA) is a public corporation that deals with the water and wastewater management. The current operator of AAA is the Companía de Aguas, which is a private organization out of France; their contract ends in 2001. Clara O'Neil is the Director of Environmental Services Area and Roberto Maldonado is an engineer of AAA. The current operation of AAA is that Companía de Aguas is bringing in new technologies used in Europe to help the operation of the system. They are also installing monitoring systems at the treatment plants.

AAA is not involved in the technology speed track, and therefore has gotten left behind in the hydrology race. The one main reason for this is because the funds are not available to AAA to purchase the software or equipment required for this software. AAA engineers, such as Mr. Maldonado, do not know the benefits or capabilities of the software used at CSA.

When a major leak is detected, to locate and fix the leak may take 24 hours. Yet if there is a minor leak, this leak may take 3-6 months to locate and fix. This is due to problems communicating with the paving crew that goes around every year around election time. The paving is done over all valve holes so there is no valve identification to locate. This is where the model would benefit AAA with the ability to isolate a leak down to a certain area and also have the location of the valves on a digital map.

Appendix C: AFI AAA Initiative Program Elements

The AFI AAA Initiative is comprised of four main elements. At the top of this tree of elements is the Puerto Rican government. They have kept a close eye on the progress of the AFI AAA Initiative to maintain its direction towards its goals. The nature of the elements is discussed below and on the AFI website.

Immediate Actions Projects (IAP)

AFI classifies Immediate Actions Projects as those that result in an immediate impact on Puerto Rico's water and wastewater infrastructure. The teams involved in these operations work closely with both local and AAA officials to quickly identify problems, develop short-term solutions and implement those solutions in an effort to minimize the repercussions of the ailing water system.

In the past eight months these small task forces have identified 350 projects that could be addressed in a quick and cost-effective manor. All of these projects deal with the updating of older facilities and the building of new facilities where AFI decides it is necessary. Areas of work include pumping stations, treatment plants, distribution/collection systems, emergency generators, water storage reservoirs, electrical and control systems, and low head dams and intake structures. Twenty-five of these projects have already been completed. Projects such as these will invest a combined total of $150 million in small-scale, cost-effective projects that will span the entire island, servicing all of the municipalities and towns (AFI, 1/24/00: What Is?).

Environmental Compliance

The Environmental Compliance element of the AFI AAA Initiative is responsible for ensuring project compliance with environmental regulations imposed by government agencies dealing with the environment. The three main areas of this element focus on maintaining secondary treatment waivers for wastewater treatment plants, evaluating evolving regulatory program and recommending actions to avoid future compliance problems and mitigating problems that have resulted from regulatory compliance issues at AAA facilities (AFI, 1/24/00: What Is?).

Strategic Projects

There are eleven major projects that fall into the category of "strategic." Projects selected for this element of the AFI AAA Initiative must contribute to the goal of the AFI in the areas of customer service, economic development, compliance, health and safety, consistency with master plans, and environmental enhancement. This element of the Initiative deals with the most important and urgent improvements necessary to the water and wastewater systems and those facilities needed to sustain them. The estimated final capital costs of the eleven projects selected to be a part of the Strategic Projects element will be approximately $1 billion (AFI, 1/24/00: What Is?).

The benefits of these particular projects, not only fall upon the people using the systems, but on those people involved in developing, constructing and maintaining them, too. The projects were hired out in a way that gave all of the interested contractors and developers a fair chance to share in the funds generated by this project. This was done to facilitate the overall progress of the projects and diversify the distribution of income created by these projects.

Technical Support to AAA

This element of the Initiative is designed to address those problems requiring immediate response and resolution. The rehabilitation of the Carraízo Dam gates is one of many of the projects that the Technical Support to AAA group is providing. The people involved in this element are also assisting in the evaluation of the Capital Improvement Plan.

7.0 Weekly Progress/Task Chart

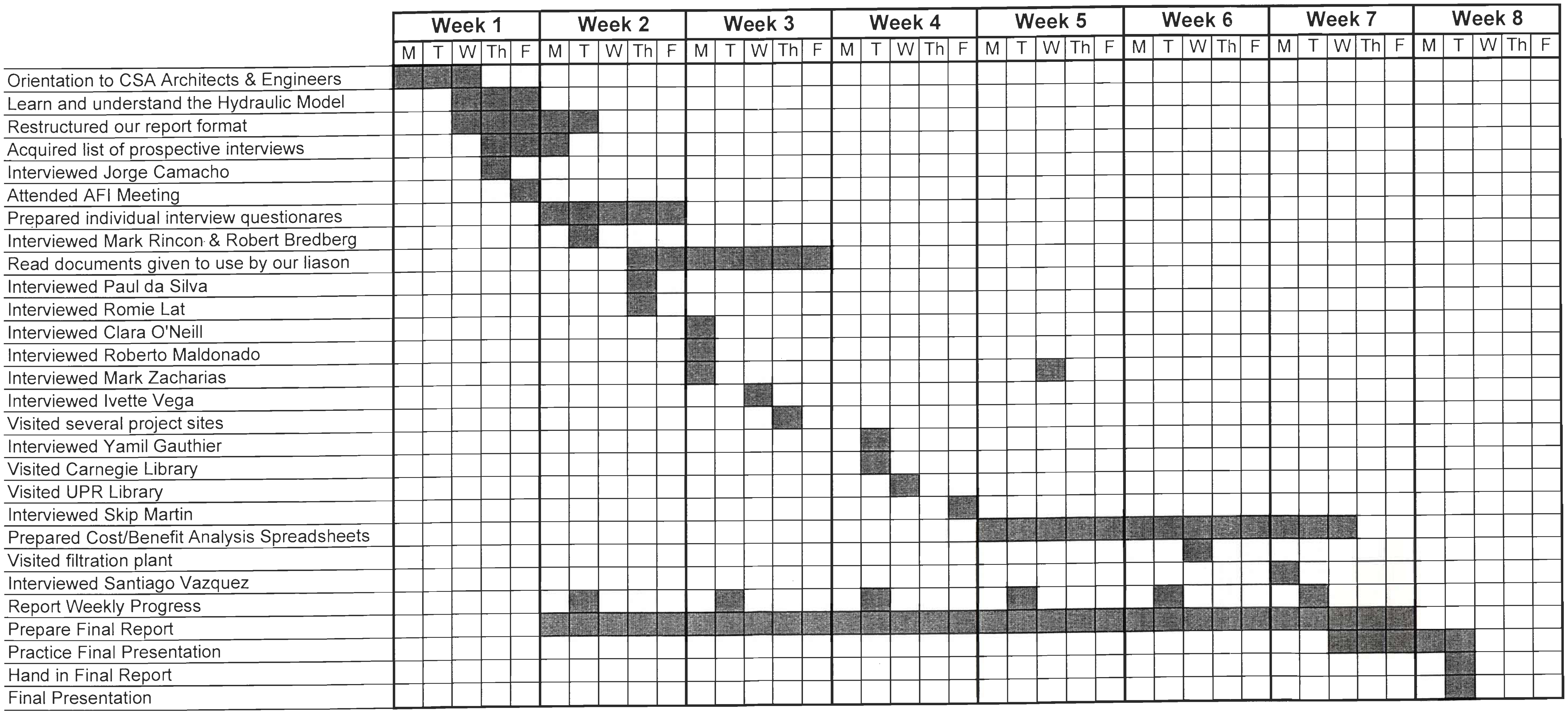


Figure 7 - 1: Weekly Progress/Task Chart

8.0 Glossary of terms

AAA – Autoridad de Acueductos y Alcantarillados – The government organization responsible for Puerto Rico's water system. The English translation is Aqueduct and Sewer Authority, sometimes referred to as the Puerto Rico Aqueduct and Sewer Authority.

ADD – average day demand – This value is the average of all water usage levels for the entire year.

AFI - Infrastructure Financing Authority – Government organization that supports the rehabilitation of infrastructure in Puerto Rico.

ASA – Aqueduct and Sewer Authority - see AAA and PRASA

CAD – Computer Aided Design

CAPR – Companía de Agua de Puerto Rico – Hired by the Puerto Rican Government to operate the water system.

CSA – Custodio, Suarez & Associates – The sponsors of this IQP. Further information regarding CSA can be found in Appendix A.

DPW – Department of Public Works

GIS – Geographic Information Systems

GUI – Graphical User Interface

IAP – Immediate Actions Projects, AFI affiliated

JV – Joint Venture – CSA Architects & Engineers and CH2M Hill are business partners.

MDD – maximum day demand – This value is 1.5 times the ADD. It is used to size new construction and facility capacities.

MG – millions gallons

MGD – millions gallons per day

PRASA – Puerto Rico Aqueduct and Sewer Authority - See AAA and ASA

PRAWDS – Procedure for Rehabilitation Analysis of Water Distribution Systems

Substance concentration – density of a given substance at a particular location example: chlorine concentration throughout a distribution system.

UFW - Unaccounted for Water – This is an estimated value based on the amount of water that is produced compared to the amount of water from which AAA receives revenue.

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