Water Distribution System Calibration Report

Project Title: Studying Distribution System Hydraulics and Flow Dynamics to Improve Water Utility Operational Decision Making

Water Distribution System: Paris, Kentucky

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1.0 Executive Summary

Introduction

The United States Department of Homeland Security has established the water sector as part of a network of critical assets. Because water utilities would benefit from a clearer understanding of distribution system flow dynamics, one of the main objectives of this large scale project is to develop a flow distribution model that allows utilities to evaluate behavior across the network in response to operational decisions. This project addresses the development of this model along with the model calibration. A successful calibration benefits the utility by greatly increasing understanding of the flow dynamics along with the overall behavior and performance of the system. When using the model to make decisions regarding the operation or improvement of the network, the utility will have confidence in the model to predict system behavior. Calibration also helps to uncover missing or incorrect data in the system, such as incorrect pipe diameters or closed valves.

In order to successfully calibrate the model, hydraulic tests were used to obtain information about the system. This project utilized C-factor tests along with Fire Flow tests to gather information. Field data, such as pressures, flow rates, and tank levels, were compared to model predictions. Parameters in the model were then altered until the model simulated field conditions. Calibration involves making changes to system demands, roughness of pipes, pump operating conditions, and other model attributes. Once the model accurately predicts field measurements under a wide range of conditions, the model will be an accurate tool to aid in planning, design, and daily operation of the water distribution system.

Project Scope

Successful calibration of the water distribution system in Paris, KY involves several major tasks that comprise the overall scope of the project.

- Data Collection
- Computer Model Development
- Field Testing
- Model Calibration
- Model Calibration Verification

Existing Distribution System

The Paris water distribution system consists of an intake pumping facility, a water treatment plant, a high service pumping facility, and a network of water mains. The Paris Water Treatment Plant (WTP) is supplied by surface water from Stoner Creek. The plant has a capacity of 3 million gallons per day, and the average daily demand is approximately 1.81 MGD. There are two high service pumps at the WTP and a booster pump located next to the 19th Street storage tank. The booster tank runs every morning for two hours along with three evenings per week for approximately 2 hours. The distribution system contains three elevated storage tanks, providing a total of 2,450,000 gallons of storage for the system. Both the 10th Street tank and Bypass tank have a capacity of 1.0 million gallons, while the 19th Street Standpipe has a capacity of 0.45 million gallons.

The distribution system consists of a network of mains with a total length over 112 miles (593,757 feet). The system contains pipe ranging from 1 to 18 inches in diameter, although the majority of the system consists of 6 and 8 inch diameter pipes. Pipes throughout the network mainly consist of PVC, cast iron, ductile iron, and galvanized steel.

Data Collection

In order to gather necessary data for model calibration, C-Factor tests and Fire Flow tests were conducted in Paris. The Hazen Williams equation relates physical and flow parameters to the resulting head loss or pressure drop in pipes, and the C-factor used in this equation varies for pipes based on pipe material and age. The frictional head loss experienced in the pipe will increase as the C-factor decreases. The C-factor test measures the flowrate in the field during hydraulic testing, along with parameters needed to find the corresponding head loss, and then it is possible to solve for the unknown C-factor. A portion of head loss through pipes is also caused by minor losses; these losses occur because of changes in the geometry of the pipes (bends, valves, fittings). The C-factor will encompass both friction losses and minor losses.

All pipes were categorized into calibration groups based upon age, material, and size. The results of the C-factor tests can be used to assign C-factors to other pipes in the system with similar characteristics. Table 1 shows the sites used for C-factor tests along with the calculated C-factor for each pipe segment.

Table 1 Summary of C-Factor Results

Site	Location	Pipe Material	Diameter (in)	Calibration Group	Head Loss (ft)	C-Factor
C-1	Glenview Drive	Ductile Iron	6	4	31	155
C-3	Redbud Lane	PVC	8	7	12	200
C-9	High Street	Cast Iron	6	0	53	43
C-10	Houston Oaks	Ductile Iron	8	3	1*	400*
C-11	Houston Oaks	Ductile Iron	10	3	7	100

*Very low head loss causes very high sensitivity to instrument accuracy

Fire flow tests were conducted to collect discharge and pressure data for use in calibrating the distribution system model. One hydrant was opened to full flow, while another hydrant in close proximity was used as a residual hydrant. System boundary condition data, such as tank levels and pump status, were also collected for calibration. Table 2 shows the summary of fire flow test results.

Table 2 Summary of Fire Flow Results

Site ID	Location	Pipe Diameter (in)	Pipe Material	Calibration Group
FF-2	Shannon Road	10	Ductile Iron	3,7
FF-3	Clinton Drive	6	PVC	8
FF-5	Duncan Ave	10	Cast Iron	0
FF-6	Higgins Avenue	6	Cast Iron	0
FF-7	Castle Blvd	6	Ductile Iron	4
FF-9	Wastewater Plant (South of Bypass)	8	Ductile Iron	3
FF-11	Houston Oaks Drive	8	Ductile Iron	3
FF-12	Mt. View Drive	4	Cast Iron	2,1
FF-13	Karla Drive	6	Ductile Iron	7,4
FF-14	High Street between 8th & 10th	6	Cast Iron	0

Boundary conditions are the specific system settings at times of concern in modeling, and these include the water levels in the storage tanks, system change patterns (valves opened/closed, pumps on/off, etc.), pump flow rates, pump pressures, and system demand. These conditions were collected by strategically placing pressure gages and flow meters around the distribution system. Three continuously recording pressure loggers were placed at all three storage tanks, and the flow meter was placed on the discharge end of the pump. Paris does not currently have a SCADA (Supervisory Control and Data Acquisition) system to record boundary conditions. However, the WTP was able to gather data for water levels in the Bypass tank and clearwell along with the flow and pressure of the high service pump.

Distribution System Model

A hydraulic model representative of the current water distribution system in Paris was created using the KYPIPE Program (Pipe 2010). Data input into the model is classified as geographical information, facilities data, operational data, and demand data.

- Geographical data: used to establish the physical location of the model.
- Facilities data: includes all the attributes of pipes, pumps, tanks, and reservoirs in the system. These data is the core component of the hydraulic model. For example, the pipe diameter, length, and initial roughness (estimated based off material and age) is needed for each pipeline in the system. A pump characteristic curve and geometry of storage tanks is needed as well.
- Operating data: includes attributes of the system that are subject to change, such as flowrates, valve/pump controls, and fixed pressures that create boundary conditions.
- Demand data: the amount of water consumption assigned to all demand nodes throughout the system, input in the model after the layout and facilities data has been accurately set up. Different types of customers and their water use patterns must be considered in this process. Customer types are classified as residential, commercial, and industrial.

The pressures at critical locations, such as a pump or storage tank, are important in model calibration, so it is critical that these elevations are accurate. Surveying methods and a global positioning device (GPS) were used to determine the elevations of these nodes. Digital elevation models were used to establish elevations for remaining nodes in the system.

Demand data is input in the model after the layout and facilities data has been accurately set up. Billing data showing the total water usage in gallons for each household during one month was provided. The total monthly demand was then divided evenly throughout the month to find a value for water usage in gallons per minute. In order to find the total demand in the system, the concept of mass balance was utilized. Outflow from the system subtracted from the inflow to the system equals the change in total storage. Inflow includes water pumped into the system from the supply source, outflow encompasses all water demand throughout the system, and the change in storage refers to the change in tank levels.

Different types of customers and their water use patterns were considered in the model development process, and customer types are classified as residential, commercial, and industrial. In order to model the temporal and spatial variability of demand throughout the day, a demand type was assigned for each junction node. Demand at each node can be scaled based on demand type, allowing the model to simulate the total system demand at a point in time and the spatial distribution of that demand throughout the system. Greater demands results in larger flows and more significant friction losses, which affect pressures in those areas.

A study conducted by Aquacraft, Inc. for the city of Westminster, CO in 1998 was used to approximate the daily demand distribution. The study identifies the daily demand for each consumer type and how much of that demand is consumed during each hour of the day. The hourly demand is expressed as a percentage of the average daily demand, and these percentages were used to allocate the total system demand at each time of the day to the residential, commercial, and industrial nodes, respectively.

Model Calibration

Calibration Overview

The process of calibration involves collection of known system conditions and hydraulic testing results using C-factor and fire flow tests. These results are compared to model predictions, and then parameters in the model are altered until behavior predicted by the model reasonably agrees with measured system performance over a range of operating conditions. The primary activities of the hydraulic calibration are pipe roughness adjustments, demand distribution and pump calibration. An investigation of system attributes and operating conditions prior to calibration is crucial in achieving timely and acceptable results.

Once the model accurately predicts field measurements under a wide range of conditions (meaning calculated static and residual pressures, pump discharge pressures, and pump outflows differ by no more than 10% of the measured value), the model is considered to be calibrated. To further verify the calibrated model an extended period simulation of a typical day is performed, using measured demands and change patterns with the actual tank levels. By using data from hydraulic testing in the calibration process, confidence in the model greatly increases. The model will be an accurate tool to aid in planning, design, and daily operation of the water distribution system (AWWA, 2005).

Calibration Process

The calibration process began by setting up ten cases in KYPIPE, one for each fire flow test, to apply the appropriate boundary condition and demand patterns. The boundary conditions were set up as change patterns, and the demand for the junction corresponding to the flowing hydrant in each test was set as the recorded flow rate measured in the field.

Because pumps experience wear and stress over time causing alterations to the original pump curve, the pump curve is commonly altered during the calibration process. A digital recording gage was placed on a tap immediately off the pump discharge and the recorded pressures were plotted against the flow from the pump as recorded by a venturi meter to produce a pump curve. These data points only include flows and pressures that occur over a typical day. To investigate the lower flow range of the pump curve, a gate valve was incrementally closed downstream of the pump, causing a reduction in flow.

The pipes were divided into calibration groups classified by diameter, age and material, and the calibration process involved incremental changes in pipe roughness. The initial model used published C-factor values for the calibration groups to develop a baseline from which to make adjustments. The static pressures are indicative of the ambient conditions in the system, and examining differences between initial model results and measured static pressures was used to check the data collection beginning the calibration process. Once the tank elevations and depths were confirmed, the major component affecting static pressures was the pump. If the pump in the model was operating at a different pressure and flow than the actual pump was during the test, adjustments were necessary.

Another factor in static pressure calibration is demand distribution. Some of the outer neighborhoods are fed by a single pipe stretching out from the the main system, where the entire demand from the neighborhoods travels through one pipe. This causes significant losses with relatively small demands. The residential demand factor for that time of day was adjusted to reduce the demand and losses. This was often a solution to negative deviations in model and measured static pressures.

In order to calibrate the C-factors, a table of the measured static and residual pressures at all fire flow tests was made comparing them to the calculated pressures at those same nodes in the model. If the calculated residual pressure was lower than the measured residual pressure, it was clear the model had more losses than the actual system. A feature in KYPIPE was used to display the pipe losses (in feet of head loss) for each simulation, making it obvious where the largest losses were occuring and which pipe group needed to be adjusted. The roughness for that group was increased and the simulation was repeated until the pressures converged.

Calibration Results

Table 3 below shows the initial published C-factor for each calibration group, along with the C-factor determined after the calibration process.

Table 3 C-Factor Calibration Summary

Group	Material	Diameter	Initial C-Factor	C-Factor
0	Cast Iron	Oldest (1926-1931)	70	40
1	Cast Iron	Older (1947-1959)	80	70
2	Cast Iron	All other	100	120
3	Ductile Iron	Large	140	180
4	Ductile Iron	Medium	130	180
5	Ductile Iron	Small	120	150
6	Other	All	120	130
7	PVC	Large	140	160
8	PVC	Medium	130	160
9	PVC	Small	120	150

Size Descriptor	Pipe Diameter
Large	Greater than 6”
Medium	6” Diameter
Small	Less than 6”

Table 4 below shows the summary of the fire flow calibration process, including the pressure drops in psi and percent difference in residual pressures.

Table 4 Fire Flow Calibration Summary

Test	Location	Residual Hydrant	Static Pressure (psi)	Percent Difference	Residual pressure (psi)	Percent Difference	Pressure Drop (psi)	Percent Difference
FF-2	Shannon Road	H-80	82.0 81.8	0%	72.0 67.4	-6%	10.0 14.4	44%
FF-3	Clinton Drive	H-90	54.0 55.1	2%	40.0 39.6	-1%	14.0 15.5	11%
FF-5	Duncan Avenue	H-278	76.0 71.6	-6%	48.0 67.2	40%	28.0 4.4	-84%
FF-6	Higgins Avenue	H-175	68.0 68.0	0%	52.0 54.9	6%	16.0 13.1	-18%
FF-7	Castle Blvd	H-71	65.0 67.1	3%	55.0 56.1	2%	10.0 11.0	10%
FF-9	Wastewater Treatment	H-308	98.5 97.6	-1%	88.5 86.5	-2%	10.0 11.1	11%
FF-11	Houston Oaks Drive	H-398	62.0 61.3	-1%	51.0 46.9	-8%	11.0 14.4	31%
FF-12	Mt View Drive	H-317	64.0 65.0	2%	28.0 25.1	-10%	36.0 39.9	11%
FF-13	Karla Drive	H-145	45.0 52.4	16%	16.5 14.1	-15%	28.5 38.3	34%
FF-14	Downtown High Street	H-189	86.0 83.1	-3%	54.0 55.4	3%	32.0 27.7	-13%

Model Validation

In order to validate the calibration process, an Extended Period Simulation (EPS) was performed on the calibrated model. Specifically, the pressures at the ByPass tank, 10th Street tank, and Pump-1 were examined. Data were also measured in the field over a several day period using continuous pressure recorders. The pressure data for the ByPass tank, 10th St tank, and Pump-1 taken on July 3, 2012 was compared to the EPS performed on the model. This comparison can be seen graphically; the model results are compared to the measured tanks levels for the 10th St and ByPass storage tanks in Figure 1. The results for pump head from both the model simulation and measured field results are shown in Figure 2. The goal of the EPS is to show that all values of percent difference comparing the model and measured results remain below 10%.

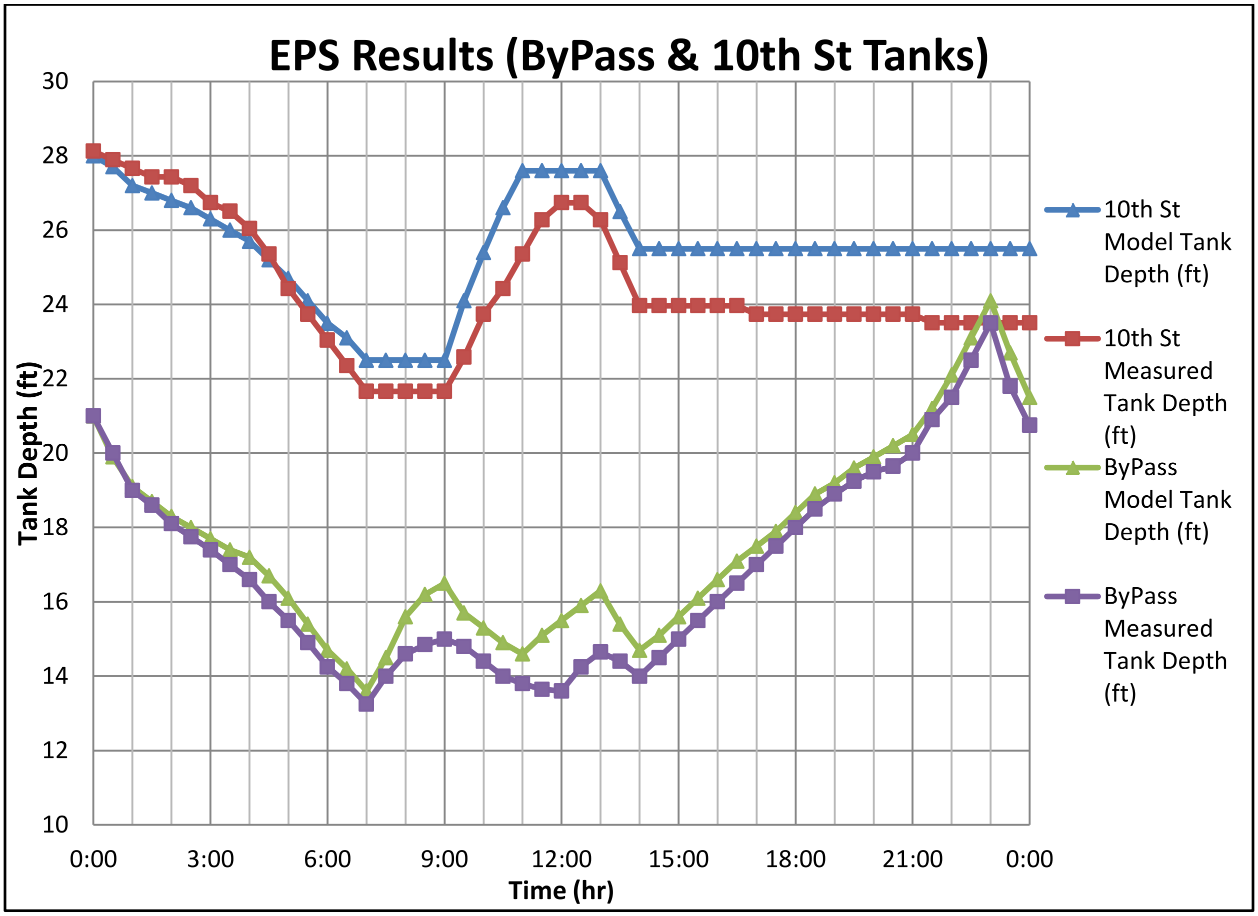

Figure 1 Summary of EPS Results for Storage Tanks for 7/3/2012

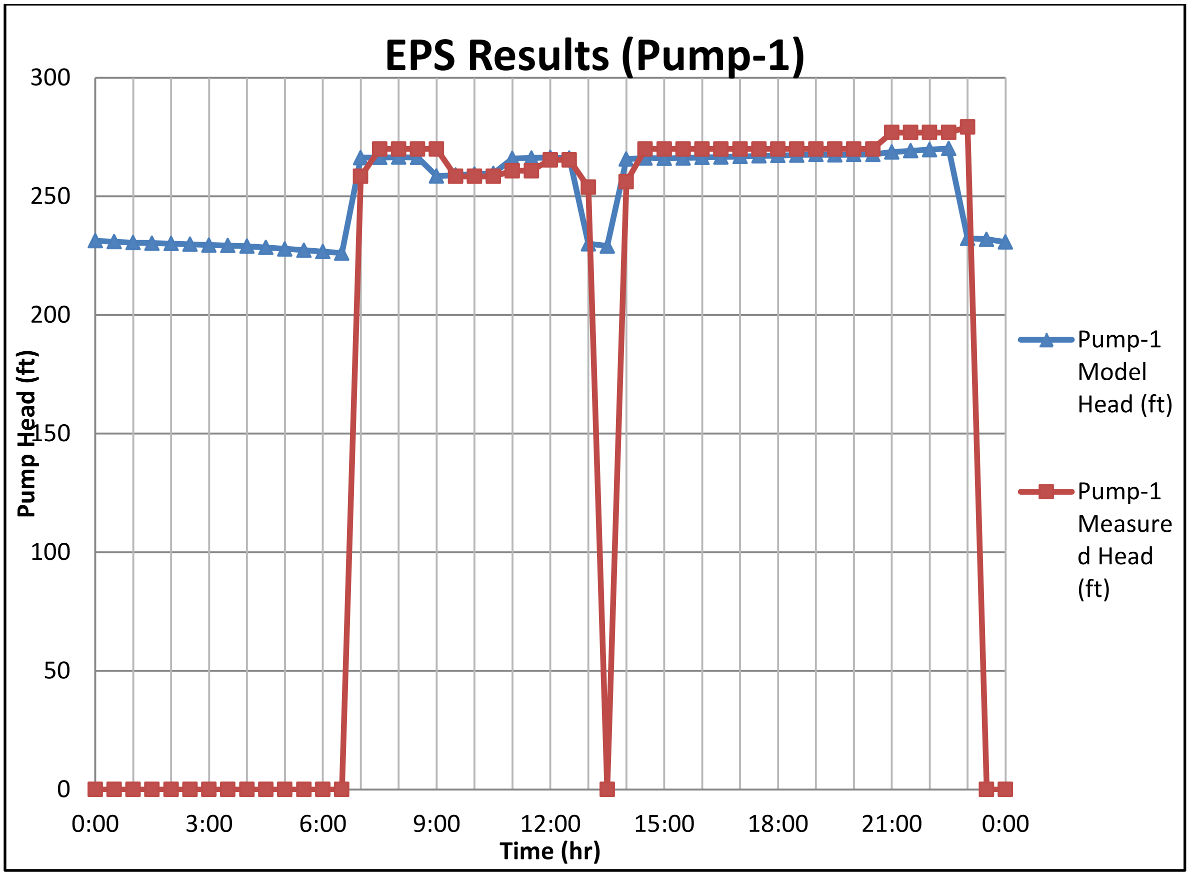

Figure 2 Summary of EPS Results for High Service Pump

Diurnal Demand Pattern

During calibration, real water usage data were used to assign demands to nodes throughout the system. When the model is used for future simulations, demand factors will be needed to estimate demand patterns during the desired time of simulation. These demand factors will adjust water usage throughout the system based on time and location. Figure 3 shows the demand factors found to be accurate over a period of time.

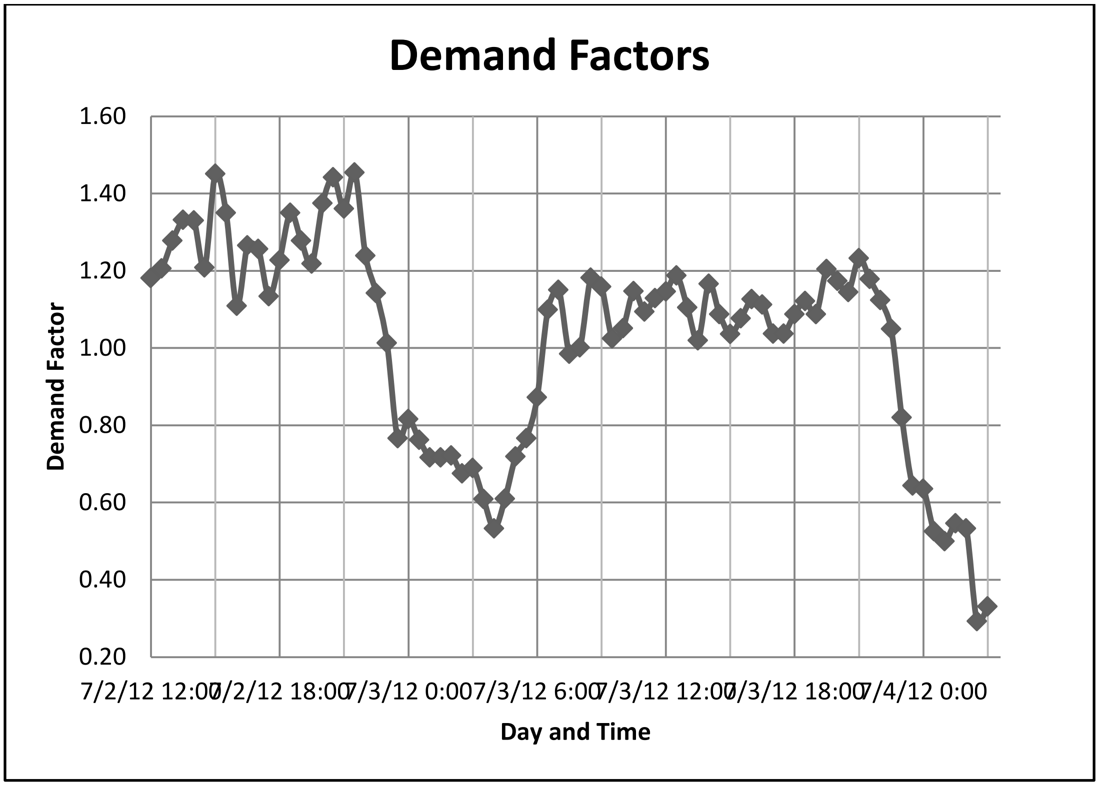

Figure 3 Summary of Demand Factors

2.0 Introduction

2.1 Project Background

The United States Department of Homeland Security (DHS) has established 18 sectors of infrastructure and resource areas that comprise a network of critical physical, cyber, and human assets. One of these sectors is the Water Sector. The Water Sector Research and Development Working Group has stated that water utilities would benefit from a clearer and more consistent understanding of their system flow dynamics. Understanding flow dynamics is important to interpreting water quality measurements and to inform basic operational decision making of the water utility. Such capabilities are critical for utilities to be able to identify when a possible attack has occurred as well as knowing how to respond in the event of such an attack. This research will seek to better understand the impact of water distribution system flow dynamics in addressing such issues.

In particular this project will: (1) test the efficiency and resiliency of the real-time hydraulic/water quality model using recorded data for system boundaries in order to understand the potential accuracy of such models, and understand the relationship between observed water quality changes and network flow dynamics, and (2) develop a toolkit for use by water utilities to select the appropriate level of operational tools in support of their operation needs. The toolkit is expected to have the following functionality: (a) a graphical flow dynamic model, (b) guidance with regard to hydraulic sensor placement, and (c) guidance with regard to the appropriate level of technology needed to support their operational needs.

Primary objectives of this project include:

1. Develop an improved understanding about the impact of flow dynamics changes on distribution system water quality, and the potential benefits of using real-time network models to improve operational decisions – including detection and response to potential contamination events.
2. Develop an operational guidance toolkit for use by utilities in selecting the appropriate level of operational tools needed to support of their operational needs.
3. Develop a flow distribution model that will allow small utilities to build a basic graphical schematic of their water distribution system from existing GIS datasets and to evaluate the distribution of flows across the network in response to basic operational decisions.

This project has been broken down into 12 different project tasks as shown in Table 5. This Water Distribution System Calibration Report addresses Task 6 of the project which is defined as “Develop and Calibrate Hydraulic Computer Models.”

Table 5 Summary of Project Tasks

Task #	Project Task
1	Establishment of an Advisory Group
2	Select Water Utility Partner
3	Survey and Evaluate SCADA Data
4	Build Laboratory Scale Hydraulic Model of Selected Water Distribution System
5	Develop Graphical Flow Distribution Model
6	Develop and Calibrate Hydraulic and Water Quality Computer Model
7	Quantify Flow and Water Quality Dynamics through Real-Time Modeling
8	Develop Sensor Placement Guidance
9	Develop Toolkit
10	Test and Evaluate Toolkit
11	Validate Toolkit
12	Write Report

2.2 Purpose of Project

One of the primary objectives of this project is to gain an understanding of the benefits of using distribution system models to improve operational decisions. Because these models will be used in decisions that involve significant investment and potential impact to the community, it is important that the model be an accurate representation of the actual conditions in the system. A successful calibration provides several benefits for the utility. When using the calibrated model, the utility will have confidence in the model to predict system behavior. The calibration process also greatly increases understanding of the flow dynamics in the system and the overall behavior and performance of the system. Calibration also helps to uncover missing or incorrect data in the system, such as incorrect pipe diameters or closed valves (Walski, et al.).

In order to successfully calibrate a model, hydraulic tests are used to obtain information about the system. The project utilized C-factor tests along with Fire Flow tests to gather information about the system. Values such as pressures, flowrates, storage tank levels, pump curves, etc. were gathered during hydraulic field testing. These field results were compared to model predictions, and then parameters in the model were altered until the model simulates field conditions. Data within the model wereadjusted until behavior predicted by the model reasonably agreed with measured system performance over a range of operating conditions (EPA, 2005).

Calibration involves making changes to system demands, roughness of pipes, pump operating conditions, and other model attributes (Walski, et al.). However, it is important that the data are adjusted only within reasonable limits. For example, changing C-factor values of pipes outside of reasonable values based on the pipe material and age would seem like apparent calibration for certain conditions, but would probably result in unlikely results for a new range of conditions.

The calibration process can also reveal closed valves, severely tuberculated pipes, missing pipes, and other issues that can be resolved to improve operation of the system (EPA, 2005).

Once the model accurately predicts field measurements under a wide range of conditions, the model is considered to be calibrated. A new set of hydraulic testing data should be collected in order to verify the calibration. If the new testing results closely match the calibrated model, the calibration is successful. The model is calibrated under the assumption of steady state conditions, simply utilizing known boundary conditions at the time the tests were performed. However, an extended period simulation (EPS) can also be utilized to verify calibration, simulating model behavior over a certain time period. By using data from hydraulic testing in the calibration process, confidence in the model greatly increases. The model will be an accurate tool to aid in planning, design, and daily operation of the water distribution system (AWWA, 2005).

2.3 Project Scope

Successful calibration of the water distribution system in Paris, KY involved several major tasks that comprised the overall scope of the project.

- *Data Collection:* Gather and review all available information on the Paris water distribution system in order to develop computer model. This includes Autocad/GIS files showing all pipes, demand nodes, hydrant, and valves in the system. Customer usage bills were also appropriated in order to gather accurate demand data. Specifications for the storage tanks, pumps, and Water Treatment Plant were also collected.
- *Computer Model Development:* Create a model of the system using KYPIPE, including all pipes, hydrants, nodes, junctions, demand nodes, elevated storage tanks, and pumps. Descriptive parameters that are known for each component wereentered appropriately.
- *Field Testing:* Develop and execute a field testing protocol. These tests included C-factor tests and Fire Flow tests (procedure to be discussed). All data were recorded appropriately, including all boundary conditions during test periods.
- *Model Calibration:* Results from field testing were compared to model behavior, and data in the model were adjusted until it reasonably agreed with measured system performance. System demands, roughness of pipes, pump operating conditions, and other attributes were altered in the model to match field conditions.
- *Model Calibration Verification:* To ensure the model calibration is an accurate representation of the system, a new set of field data were collected for verification purposes. An extended period simulation (EPS) was executed on the calibrated model and compared to results from field data over an extended time, such as water levels in elevated storage tanks. If the new test results closely match model behavior, the calibration is verified.

2.4 Project Management

2.4.1 Distribution List

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Agency for Toxic Substances & Disease Registry
National Center for Environmental Health
4770 Buford Highway
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2.4.2 Project Organization

The roles and responsibilities of project participants are listed below. Refer to Figure 1 on page 7 for the project organization chart.

Lindell Ormsbee, Director
Kentucky Water Resources Research Institute
University of Kentucky
Role: Project Manager
Responsibilities: Oversee data, Project Manager

Scott Yost, Associate Professor
Department of Civil Engineering
University of Kentucky
Role: Field Manager
Responsibilities: Manage data collection activities; ensure data collection conducted consistent with QAPP

James McCarty, Finance and Water Utilities Director
Paris Combined Utility
City of Paris
Role: Primary Contact for the Paris Water Department
Responsibilities: Provide assistance in obtaining data for the Paris Water Distribution System. Serve as liaison for Paris Utility personnel

Kevin Crump, Water Superintendent
Paris Combined Utility
City of Paris
Role: Primary Contact for the Paris Water Treatment Plant
Responsibilities: Provide assistance in obtaining data for the Paris Water Distribution System. Serve as liaison for Paris Utility personnel

Eddie Earlywine, Water Utility Staff
Paris Combined Utility
City of Paris
Role: WTP Staff
Responsibilities: Help coordinate and collect real time data from the WTP during field testing (i.e. pump discharges, tank water levels).

Morris Maslia
Research Environmental Engineers
Agency for Toxic Substances and Disease Registry
National Center for Environmental Health
Role: Tracer Analysis Consultant
Responsibilities: Provide general guidance on calibration techniques

Stacey Schal, Reese Walton, and Joe Goodin
Graduate Research Assistant(s)
Department of Civil Engineering
University of Kentucky
Role: Data acquisition oversight
Responsibilities: Collect field data from hydrant testing; troubleshoot field equipment; undertake corrective measures as needed to develop and calibrate hydraulic model of the water distribution system.

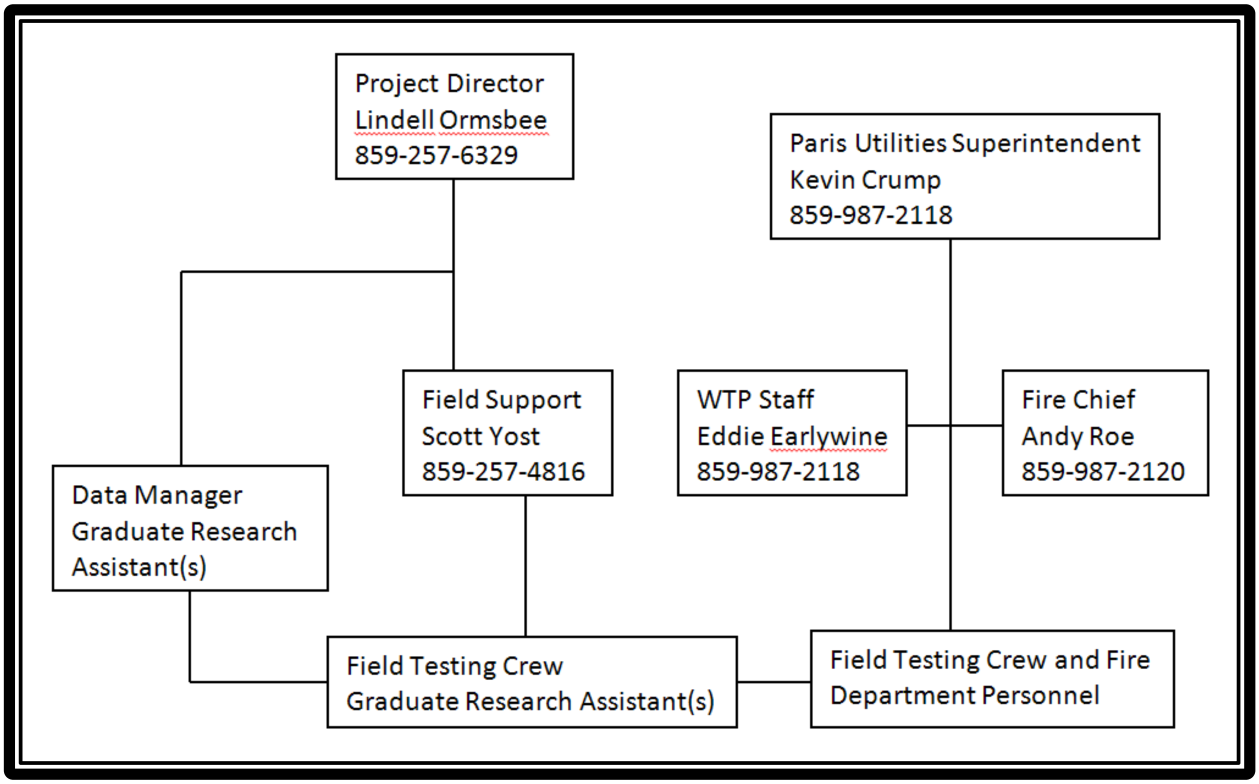

Figure 4 Project Organization Chart

3.0 Existing System

3.1 General

The City of Paris is located in Bourbon County, Kentucky northeast of the City of Lexington. The population is approximately 9,183. The city of Paris has a total land area of approximately 6.8 square miles, and the land area of Bourbon County is 291.43 square miles. The city of Paris is at an altitude of 843 feet above sea level using the courthouse benchmark, and the county elevation ranges from 715 feet to 1050 feet. The city is serviced by Paris Combined Utilities.

The Paris water distribution system consists of an intake pumping facility, a water treatment plant, a high service pumping facility, and transmission and distribution systems. After water is treated at the water treatment plant, a high service pump is used to pump water through a 16 inch line to the 10th Street elevated storage tank. Water then continues through a 12 inch main to the 19th street tank, and then to the Bypass tank. The majority of the system is looped through a combination of 10, 12, and 16 inch lines. However, there are also several neighborhoods located around the perimeters of the city that are not looped and contain dead ends in the system.

3.2 Supply Source and Storage

The Paris Water Treatment Plant (WTP) is supplied by surface water from Stoner Creek. Figure 5 shows the location of Stoner Creek (highlighted in blue) in Paris.

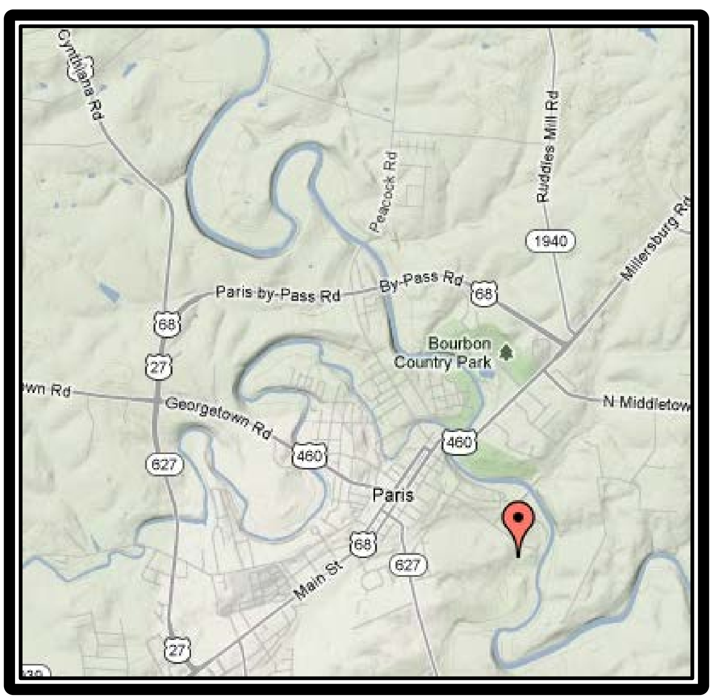

Figure 5 Stoner Creek

The three elevated storage tanks, provide a total of 2,450,000 gallons of storage for the system. One elevated tank is located off 10th Street near the pumping station, while another elevated tank is located off the Bypass near the intersection with Georgetown Road, in the northwest portion of the town. The last source of storage, the standpipe, is located off 19th Street between Hwy 68 and Clifton Avenue. Both the 10th Street tank and Bypass tank have a capacity of 1.0 million gallons, while the 19th Street Standpipe has a capacity of 0.45 million gallons. Specifications for each elevated storage tank are summarized below in Table 6.

Table 6 Elevated Storage Tank Specifications

Elevated Storage Tank Identification and Elevations*			
Name	**Bypass**	**19th Street**	**10th Street**
Type	Elevated	Standpipe	Elevated
Size (gallons)	1,000,000	450,000	1,000,000
Elevation of bottom of the tank (ft)	868	878	856
Minimum Level (ft)	1009.5	897.5	1001.5
Maximum Level (ft)	1039.5	977.5	1031.5
Depth of Tank (ft)	30	80	30

* Data from Paris Combined Utility

3.3 Water Treatment Plant

The Water Treatment Plant (WTP) is located at an elevation of approximately 846 feet. The plant has a capacity of 3 million gallons per day (MGD), and the average daily demand is approximately 1.81 MGD. The treatment plant (shown below in Figure 6) serves approximately 4,874 residential customers and 1 wholesale customer.

The Water Treatment Plant is only operational for 16 hours a day. At the beginning of each day (7 a.m.) the high service pumps are turned on until the elevated storage tanks are full. There are two high service pumps at the WTP and a booster pump located next to the 19th Street standpipe. The WTP currently has a telemetry system that records tank levels for the Bypass tank.

The Paris WTP provided real time data for pumping operations as well as tank levels, pump flows, and pump pressures. This data was obtained during field testing through communication with the Paris Water Department and was utilized to help calibrate the hydraulic model.

High service pump #1 typically operates in a range of flow between 3150 and 3400 gallons per minute (GPM). High service pump #2 usually operates within 2100 and 2400 GPM with a 9.00 inch impeller. The pump curves for both high service pumps are shown in Appendix A: Pump Curves on pages 64 and 65.

Figure 6 Water Treatment Plant

3.4 Booster Stations

The system also contains a booster pump located next to the 19th Street storage tank. The booster pump typically runs every day from 6 to 8 a.m. because this is a high demand time period. It also runs for approximately 2 hours between 11 p.m. and 1 a.m. on Monday night/Tuesday morning, Wednesday night/Thursday morning, and Friday night/Saturday morning.

The booster pump is also needed to aid in water quality. Because the 19th Street Standpipe is lower grade than the rest of the system, the booster pump is needed to turn the tank over. This turnover ensures that water in parts of the tank has not been stagnant for long periods of time, which would cause water quality problems. The pump curve for the booster pump is shown in Appendix A: Pump Curves on page 66.

3.5 Distribution System Piping

The treated water transmission and distribution system consists of a grid of mains with a total length in the system over 112 miles (593,757 feet). The system contains pipe ranging from 1 to 18 inches in diameter, but the majority of the system consists of 6" diameter pipes, followed by 8" diameter. 16.4% (18.4 miles) of the total water lines in the system are distribution mains with diameters between 10 and 18 inches.

Table 7 shows the distribution of varying pipe diameters in the system, and a schematic of the distribution system is shown in Figure 7. The aqua blue lines represent the water mains in the system with 10", 12", 16", and 18" diameters. The remaining blue lines show the pipes with diameters less than 10”. Figure 8 shows a zoomed in schematic of the system, highlighting the location of pumps and tanks.

Table 7 Distribution of Pipe Diameters in System

Pipe Diameter (in)	Length (ft)	Percentage of Total Length
1	665	0.11%
1.25	1108	0.19%
1.5	701	0.12%
2	16884	2.8%
2.5	206	0.04%
3	10133	1.7%
4	38661	6.5%
6	268429	45.2%
8	154640	26.0%
10	35561	6.0%
12	44015	7.4%
16	16960	2.9%
18	522	0.09%

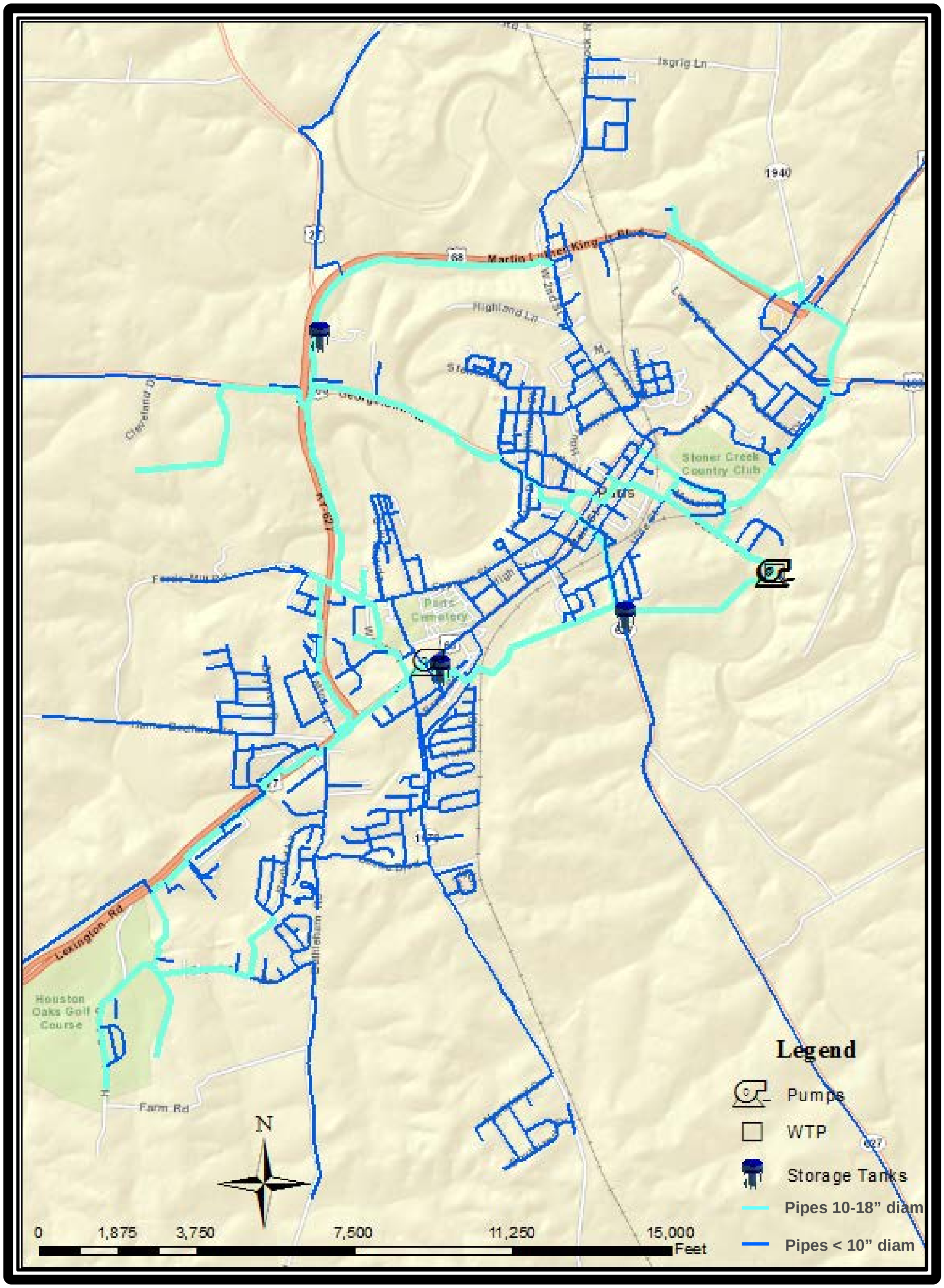

Figure 7 Schematic of Paris Water Distribution System

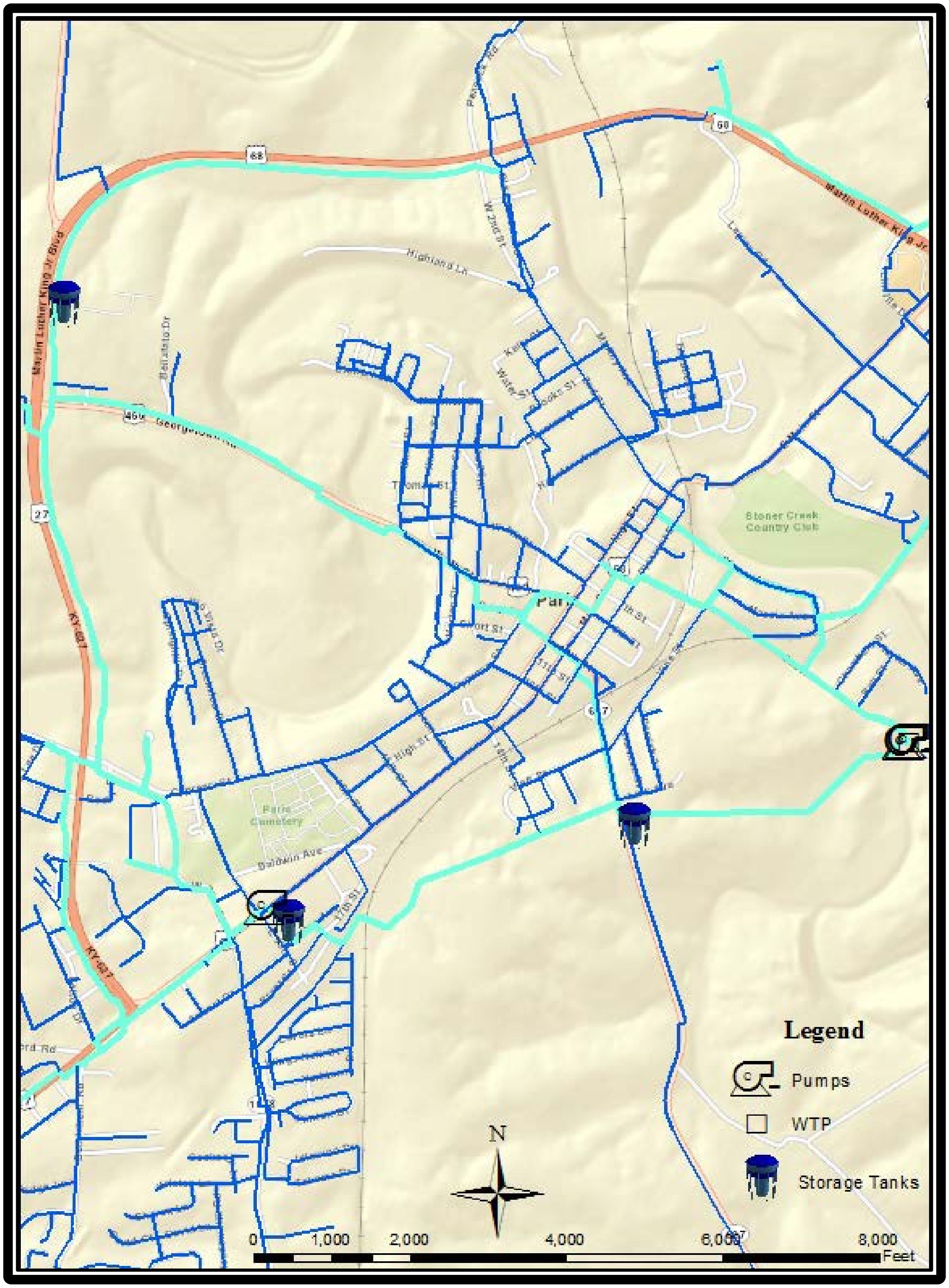

Figure 8 Components of Paris Water Distribution System

Pipes throughout the distribution network mainly consist of PVC, cast iron, ductile iron, and galvanized steel. The total percentage of each material is approximately 41%, 34% 22%, and 3%, respectively. The oldest pipes in the system were installed in 1926, and the majority of these pipes were made of cast iron. Approximately 17% of the pipes present in the existing system were installed in 1926, and about 91% of these pipes installed in 1926 were cast iron. The most widely used pipe material currently present in the system is PVC, but this material was not used extensively in the system until around 30 or 40 years ago. Table 8 shows the quantities of varying pipe materials in the system, and Figure 9 shows a schematic of the different pipe materials present in the system.

Table 8 Distribution of Pipe Materials in System

Pipe Material	Length (ft)	Percentage of Total
PVC	240809	40.6%
Cast Iron	198869	33.50%
Ductile Iron	129403	21.80%
Galvanized Steel	15516	2.61%
Polyethylene	2483	0.42%
Asbestos Cement	2343	0.39%
Copper	1988	0.33%
Steel	1217	0.20%
Wrought Iron	1129	0.19%

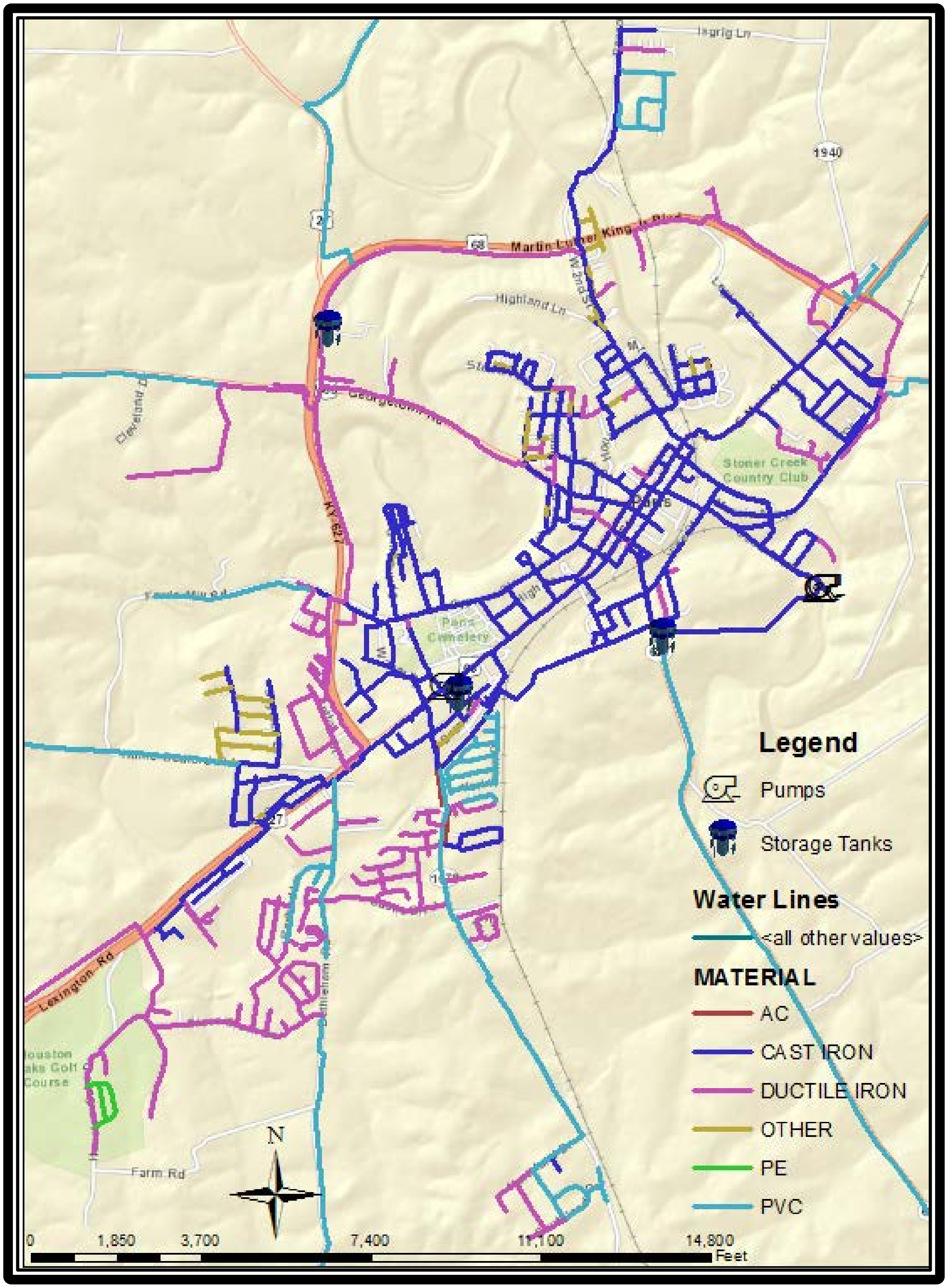

Figure 9 Pipe Materials in Water Distribution System

4.0 Data Collection

4.1 C-Factor Test

All pipes were categorized into different calibration groups based upon material, size, and age. The breakdown of calibration groups, along with the percentage of the distribution system that each calibration group encompasses, is shown below in Table 9. The diameter classification was divided into small, medium, and large. The small classification includes all pipes with diameters less than 6 inches, medium refers to pipes with exactly 6 inch diameters, while large encompasses all pipes with diameters greater than 6 inches. The calibration groups including cast iron pipes were also classified by age of the pipe. The majority of the first pipes installed in the system in 1926 were made of cast iron, and these original pipes encompass calibration group 0. Because the pipes in this group have experienced significant effects of age, the C-factors in this group vary greatly from younger pipes of the same material. Cast iron pipes installed in more recent years make up groups 1 and 2, and these groups were also divided by size. The remaining calibration groups are separated by size classification within each pipe material.

Table 9 Calibration Groups

Group	Material	Diameter	Length (ft)	Percentage of System
0	Cast Iron	Old	88484.7	14.8%
1	Cast Iron	Large – not old	28334.4	4.7%
2	Cast Iron	Small- not old	74921.5	12.5%
3	Ductile Iron	Large	65710.2	11.0%
4	Ductile Iron	Medium	51661.7	8.7%
5	Ductile Iron	Small	385.4	0.1%
6	Other	All	22369.0	3.7%
7	PVC	Large	64630.3	10.8%
8	PVC	Medium	77985.2	13.1%
9	PVC	Small	19721.5	3.3%

These pipes were then assigned an initial roughness value to be placed in the uncalibrated hydraulic model. The goal of the sampling locations was to try and perform a C-factor test for each of the calibration groups. The results of the C-factor tests can be used to assign C-factors to other pipes in the system with similar characteristics (EPA, 2005). This was not possible due to accessibility of hydrants and lack of available, suitable locations for a given pipe material. Ten sites were initially selected for C-Factor test. However, problems with the location and operation of valves made several sites impossible to carry out C-factor tests. The test was successfully executed at five sites in Paris. Additional background on the C-factor is described in section 5.4 Pipe Friction Losses on page 46.

4.1.1 C-Factor Sites

When selecting sites for C-factor tests, many factors had to be considered in order to gather data that would be useful in the calibration process. These factors include:

- Age of the Pipe: Pipes of different ages were selected to help obtain a representative sample of all pipes.
- Material of the Pipe: When possible, sampling sites contained different material to help obtain a better Hazen Williams coefficient.
- Accessibility of the hydrant: Some hydrant locations were not accessible due to location in a congested area, near hospitals/schools, etc.
- Diameter of the Pipe: Pipes of different sizes were selected to help obtain a representative sample of all pipes.
- Amount of Flow in the pipe: In order to obtain a good sample, enough flow should be produced to drop the residual pressure at least 15 psi (McEnroe, 1989).

It is also important that testing locations were not located near boundary conditions, such as pumps or elevated storage tanks. If data are collected near boundary nodes, the difference between model and field results may be minimal because of the short distance. However, the difference in slopes of the hydraulic grade lines will be significant (Walski, et al.). In order to calculate accurate C-factor vales, a homogeneous section of pipe between 400 and 1,200 feet should be selected. Selecting pipes in this length range will likely result in an adequate pressure drop (EPA, 2005). It is also necessary to close valves near the flow hydrant to force flow through the pipe section being measured (AWWA, 2005), so it is important that the required valve is accessible.

Each C-factor sampling location has been given a Test Site ID. Each test site corresponds to 3 hydrants and an associated valve(s) to be closed. Each individual hydrant and valve has been given an ID for this project (assigned in the KYPIPE Model). Figure 10 contains a map of the testing locations, and Table 10 shows descriptions of all sites used for C-factor tests.

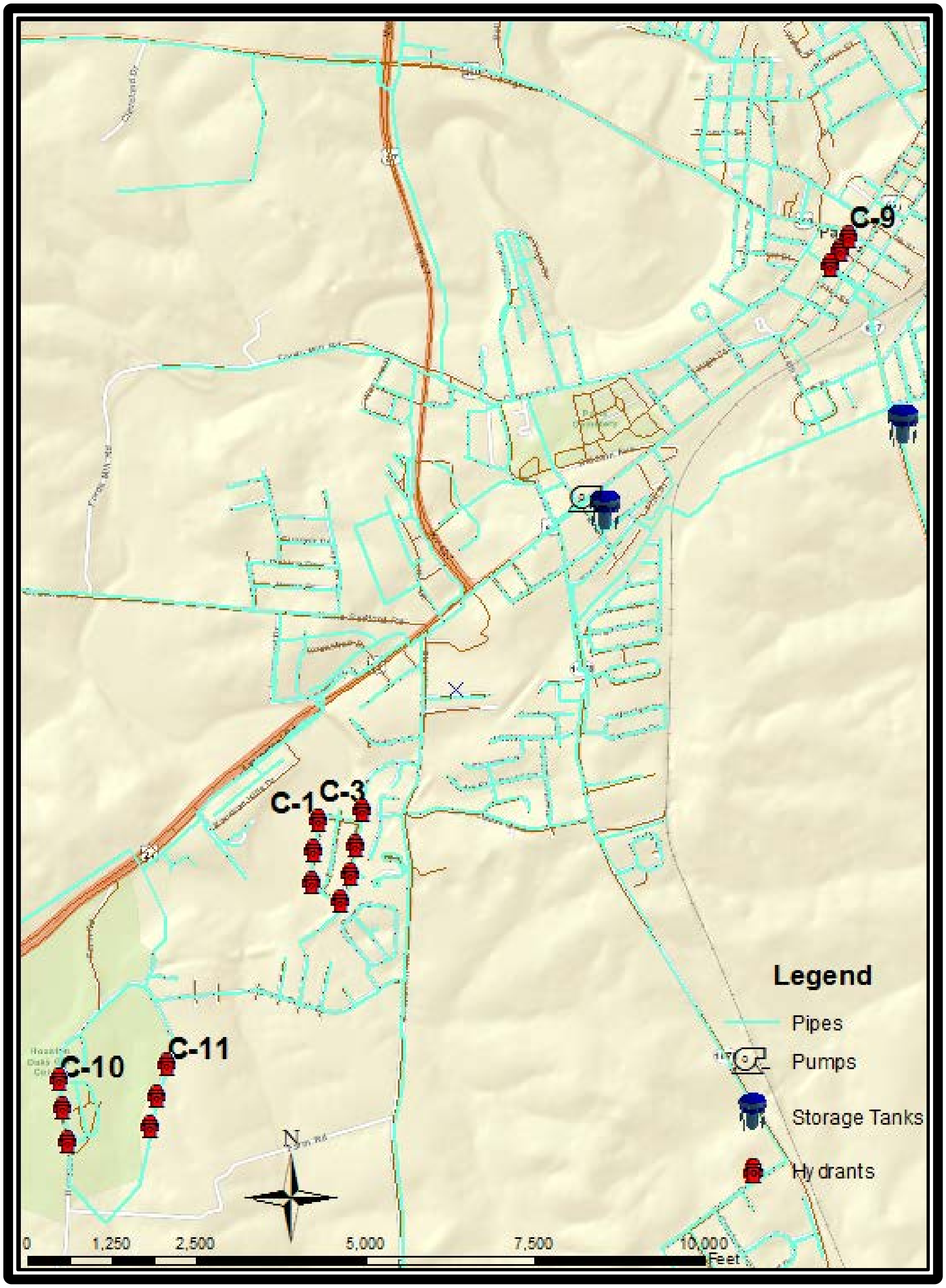

Figure 10 C-Factor Testing Sites

Table 10 C-Factor Testing Locations

Site ID	Flow Hydrant / Residual Hydrant #1 / Residual Hydrant #2	Location	Pipe Diameter (in)	Pipe Material	Calibration Group
C-1	H-78 H-77 H-76	Glenview Drive	6	Ductile Iron	4
C-3	H-84 H-82 H-81	Redbud Lane	8	PVC	7
C-9	H-191 H-189 H-190	High Street between 8th and 10th	6	Cast Iron (old)	0
C-10	H-317 H-398 H-65	Houston Oaks Drive	8	Ductile Iron	3
C-11	H-438 H-437 H-436	Houston Oaks Drive	10	Ductile Iron	3

4.1.2 C-Factor Test Procedure

C-factor tests calculate the friction coefficient used in the Hazen Williams equation (further explanation in section 5.4 Pipe Friction Losses on page 46) by measuring flow and head loss in the field. The two-gage method was used in Paris to execute the C-factor tests. During the test, pressure was read using a static pressure gage (equipment specifications to be discussed in section 4.4 Data Collection Equipment on page 30) at hydrants (residual) at the upstream and downstream ends of the section while a hydrant downstream of the section was opened to force flow and a sufficient pressure drop. The elevation difference between the residual hydrants was then used to calculate head loss in the section. It was important to select residual hydrants that are spaced far enough apart to induce a pressure drop of at least 15 psi. It was also necessary to close valves downstream of the flow hydrant to force flow through the pipe section being measured. A pitot gage was attached to the flow hydrant to measure the flow rate needed for calculations (EPA, 2005). All calculations used to determine C-factors are shown in Appendix D.1.2 C-Factor Calculations on page 74. A schematic illustrating the C-factor test setup is shown in Figure 11.

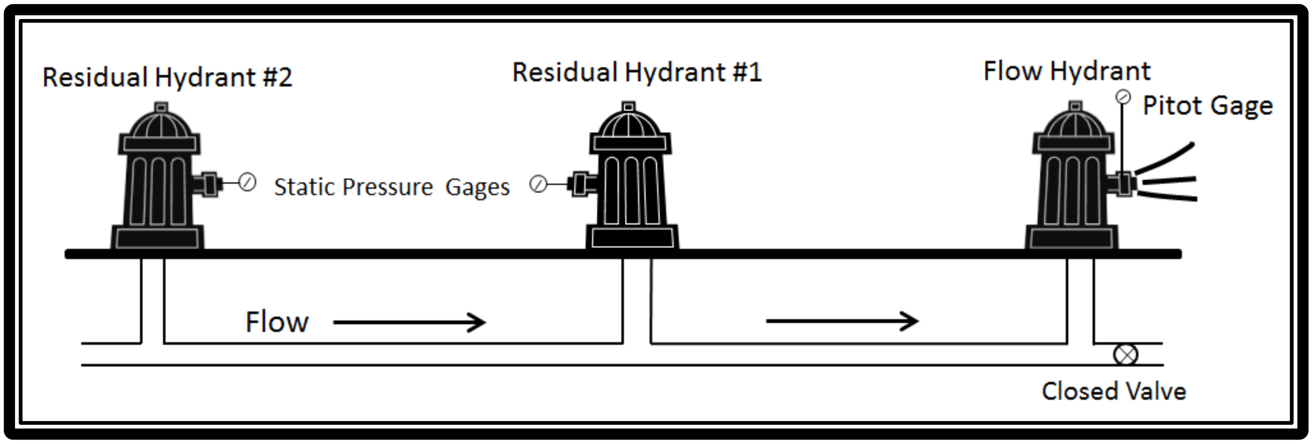

Figure 11 C-Factor Test Setup

C-factor testing procedures were performed according to the American Water Works Association M32-Computer Modeling of Water Distributions Systems. A step by step procedure for conducting the C-factor test is shown in Appendix D.1.1 C-Factor Test Procedure on page 73. All data collected during C-factor tests were recorded on specified data sheets, and these data sheets are shown in Appendix E: Data Collection Logs on page 80.

4.1.3 C-Factor Results

A summary of the results of the C-factor tests performed on the system is shown below in Table 11.

Table 11 C-Factor Results

Site	Pipe Material	Diameter (in)	Head Loss (ft)	C-Factor
C-1	Ductile Iron	6	31	155
C-3	PVC	8	12	200
C-9	Cast Iron	6	53	43
C-10	Ductile Iron	8	1*	400*
C-11	Ductile Iron	10	7	100

*Very low head loss causes very high sensitivity to instrument accuracy

4.1.4 C-Factor Sensitivity Analysis

The calculated C-Factors found for each C-Factor test performed are subject to error based on measurements used in the calculations. A sensitivity analysis was performed to investigate how the uncertainty in the C-Factor value can be attributed to the uncertainty of variables used in the calculations. This investigation provides information about which specific variables are more influential in the total uncertainty of the C-Factor. An uncertainty analysis was also performed to quantify the uncertainty in the calculated C-Factor. The level of precision in instruments used in the data collection process, along with the expected errors in reading the instruments, were taken into account to find a range of possible values associated with each C-Factor.

In order to perform an accurate sensitivity analysis, every variable used in the C-Factor calculation was taken into account. These variables include length of the pipe, coefficient of discharge of the hydrant, diameter of the hydrant opening, discharge pressure, diameter of the pipe, pressure at both residual hydrants, and elevation at both residual hydrants. The equation used to calculate the C-factor including every variable is shown in Equation 1.

Equation 1

$$\boldsymbol{C = 3.566\frac{L^{0.54} \times 29.84 \times C_d \times {D_o}^2 \times \sqrt{P_d}}{\left(\frac{\Delta P}{\gamma} + \Delta Z\right)^{0.54} \times D^{2.6277}}}$$

Where,
L = Length of pipe (ft)
C_d = Coefficient of discharge of hydrant
D_o = Diameter of hydrant opening (in)
P_D = Discharge pressure (psi)
D = Diameter of pipe (in)
ΔP = Change in pressure (psi)
ΔZ = Charge in Elevation (ft)

The partial derivatives with respect to each variable in the C-Factor equation were calculated and normalized. These equations were combined with the uncertainty due to the precision in measurement of each variable. The following equation illustrates a quantitative uncertainty in the C-Factor (labeled as ΔC) due to the uncertainty in each variable.

Equation 2

$$\boldsymbol{\frac{\Delta C}{C} = \left|0.54\frac{\Delta L}{L}\right| + \left|\frac{\Delta C_d}{C_d}\right| + \left|2\frac{\Delta D_o}{D_o}\right| + \left|0.5\frac{\Delta P_d}{P_d}\right| + \left|-2.627\frac{\Delta D}{D}\right| + \left|\left(\frac{-1}{1.854\gamma h_L}\right)\frac{\Delta(\Delta P)}{\Delta P}\right| + \left|\left(\frac{-1}{1.854 h_L}\right)\frac{\Delta(\Delta Z)}{\Delta Z}\right|}$$

The sensitivity analysis provides information about which variables have the greatest contribution to the total uncertainty in the calculated C-Factor. The uncertainty in the diameter of the pipe is the most influential in the uncertainty of the C-Factor, followed by the uncertainty in the coefficient of discharge of the hydrant and diameter of the hydrant opening. The uncertainty in the discharge pressure, length of pipe, and change in pressure and elevation between hydrants is not as influential in the uncertainty of the C-Factor as the variables already mentioned. An example uncertainty analysis is shown below for the data measured at Site C-9.

$$\frac{\Delta C}{43} = \left|(0.54)\left(\frac{3\ ft}{295\ ft}\right)\right| + \left|\frac{0.1}{0.9}\right| + \left|2\left(\frac{0.1\ in}{2.5\ in}\right)\right| + \left|0.5\left(\frac{1\ psi}{10\ psi}\right)\right| + \left|-2.627\left(\frac{0.03\ ft}{0.5\ ft}\right)\right| + \left|\left(\frac{-1}{1.854\gamma(53.2)}\right)\left(\frac{(2\times 1)\ psi}{22\ psi}\right)\right| + \left|\left(\frac{-1}{1.854(53.2)}\right)\left(\frac{(2\times 0.1) ft}{2.38\ ft}\right)\right| = 0.405$$

$$\Delta C = 17.4$$

$$C = 43 \pm 17.4$$

The uncertainty for each C-factor test was calculated, and the results for the uncertainty analysis are shown below in Table 12.

Table 12 C-Factor Uncertainty

	C-1	**C-3**	**C-9**	**C-10**	**C-11**
L (ft)	479.4	996.3	295.0	480.0	486.7
ΔL	3	3	3	3	3
Uncertainty in L	0.00338	0.00163	0.00549	0.00338	0.00333
Cd	0.9	0.9	0.9	0.9	0.9
ΔCd	0.1	0.1	0.1	0.1	0.1
Uncertainty in Cd	0.1111	0.1111	0.1111	0.1111	0.1111
Do (in)	2.5	4.0	2.5	2.5	4
ΔDo	0.1	0.1	0.1	0.1	0.1
Uncertainty in Do	0.08	0.05	0.08	0.08	0.05
Pd (psi)	40	23.9	10	32.5	27
ΔPd	1	1	1	1	1
Uncertainty in Pd	0.0125	0.0209	0.0500	0.0154	0.0185
D (ft)	0.5	0.667	0.5	0.667	0.833
ΔD	0.03	0.03	0.03	0.03	0.03
Uncertainty in D	0.1576	0.1182	0.1576	0.1182	0.0946
Head Loss (ft)	31	12	53	1	7
ΔP (psi)	14	12	22	4	11
Δ(ΔP)	2	2	2	2	2
Uncertainty in ΔP	2.77E-07	8.34E-07	1.03E-07	3.00E-05	1.56E-06
ΔZ (ft)	4.075	-14.597	2.38	7.62	13.85
Δ(ΔZ)	0.2	0.2	0.2	0.2	0.2
Uncertainty in ΔZ	0.00085	0.00062	0.00086	0.01416	0.00111
C-Factor	155	200	43	400	100
ΔC	0.3655	0.3025	0.4051	0.3423	0.2786
Total Uncertainty	56.65	60.50	17.42	136.91	27.86
C-Factor with Uncertainty	**155± 56.65**	**200± 60.5**	**43± 17.42**	**400± 136.91**	**100± 27.86**

4.2 Fire Flow Test

Fire flow tests are useful for collecting both discharge and pressure data for use in calibrating hydraulic network models. Opening a hydrant to full flow puts stress on the system, resulting in significant head loss in adjacent pipes. Such tests are normally conducted using a static pressure gauge (for measuring both static and dynamic heads) and a pitot gauge (for use in calculating discharge from the flow hydrant). In performing a fire flow test, at least two separate hydrants were selected. One hydrant was identified as the pressure or residual hydrant, and the remaining hydrant was identified as the flow hydrant.

In order to obtain sufficient data for an adequate model calibration, it is important that data from several fire flow tests be collected. Before conducting each test, it is also important that the associated system boundary condition data be collected, which includes information on tank levels, pump status, etc. It is a common practice for the local fire departments to conduct hydrant flow tests and record the time of day and corresponding flows and pressures. However, in most cases, such records do not include the boundary conditions associated with each hydrant flow test, as the main purpose for their tests is to rate the fire hydrant instead of hydraulic calibration. Therefore, care must be taken to avoid hydrant flow data that does not include the associated boundary conditions data.

The values for flow and pressure recorded during a fire flow test are used along with data about the state of the system including pump operation, tank water levels, and general system demand. The system model is run under the observed conditions and adjustments are made to the roughness coefficients or other parameters until the model represents the field data (EPA, 2005).

4.2.1 Fire Flow Sites

Fire flow testing should occur during peak flow conditions to ensure that adequate pressure drops are created. If sampling occurs during low flow conditions, the velocities may not be high enough to produce enough head loss for a good calibration.

In order to determine Fire Flow sampling locations several factors had to be taken into account. These factors include:

- Distance from Boundary Conditions: It is suggested that the testing site take place far away from boundary conditions such as tanks, WTP, PRV to increase the head loss in the system (Walski, et al.).
- Accessibility of the hydrant: Some hydrant locations were not accessible due to location in a congested area, near hospitals/schools, etc.
- Expected head loss: Walski suggests a head loss at least five times as large as the error in the head loss measuring device (Walski T. , 2000).
- Amount of Flow in the pipe: In order to obtain a good sample enough flow should be produced to drop the residual pressure at least 10 psi (AWWA, 1999).

Each fire flow sampling location was given a Test Site ID. Each test site contained 2 hydrants. One hydrant is the designated flow hydrant and the other hydrant is the residual hydrant. Each individual hydrant has been given an ID for this project (assigned in KYPIPE Model). Figure 12 shows the location for each fire flow site, and Table 13 shows descriptions of all sites used for fire flow tests.

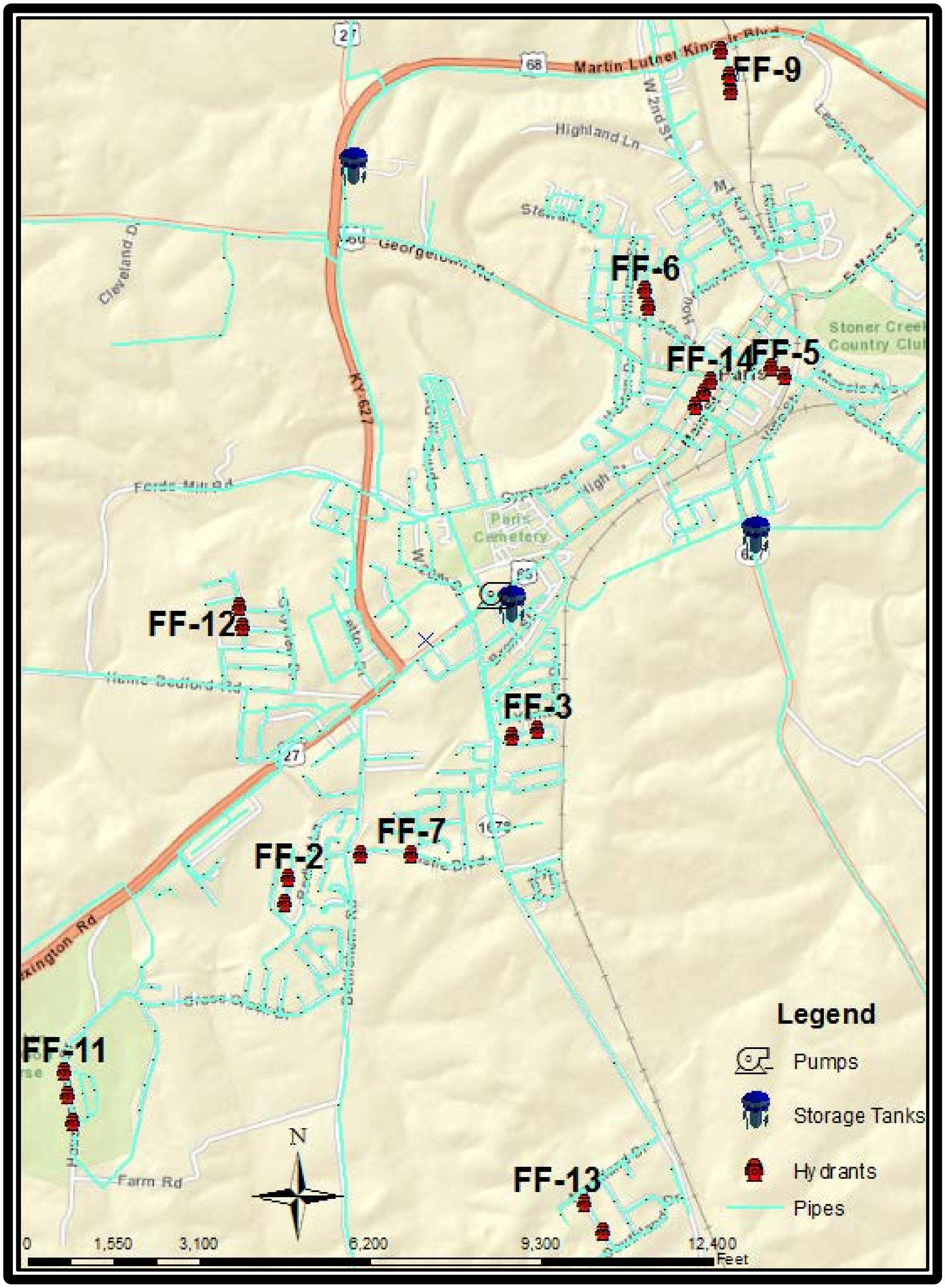

Figure 12 Fire Flow Testing Locations

Table 13 Fire Flow Testing Locations

Site ID	Flow Hydrant / Residual Hydrant / Residual Hydrant #2 (if any)	Location	Pipe Diameter (in)	Pipe Material	Calibration Group
FF-2	H-79 H-80	Shannon Road	10 8	Ductile Iron PVC	3,7
FF-3	H-97 H-90	Clinton Drive	6	PVC	8
FF-5	H-200 H-278	Duncan Ave	10	Cast Iron (old)	0
FF-6	H-174 H-175	Higgins Avenue	6	Cast Iron (old)	0
FF-7	H-70 H-71	Castle Blvd	6	Ductile Iron	4
FF-9	H-307 H-308 H-4	Wastewater Plant (South of Bypass)	8	Ductile Iron	3
FF-11	H-317 H-398 H-65	Houston Oaks Drive	8	Ductile Iron	3
FF-12	H-41 H-320	Mt. View Drive	4 6	Cast Iron Cast Iron	2,1
FF-13	H-149 H-145	Karla Drive	10 6	PVC Ductile Iron	7,4
FF-14	H-191 H-189 H-190	High Street between 8th and 10th	6	Cast Iron (old)	0

4.2.2 Fire Flow Test Procedure

The AWWA M17 guide- *Installation, Field Testing, and Maintenance of Fire Hydrants* was used to develop the standard operating procedures for the fire flow test. A schematic illustrating the setup of a Fire Flow test is shown in Figure 13. A step by step procedure for conducting the fire flow test is also outlined in Appendix D.2.1 Fire Flow Test Procedure on page 76.

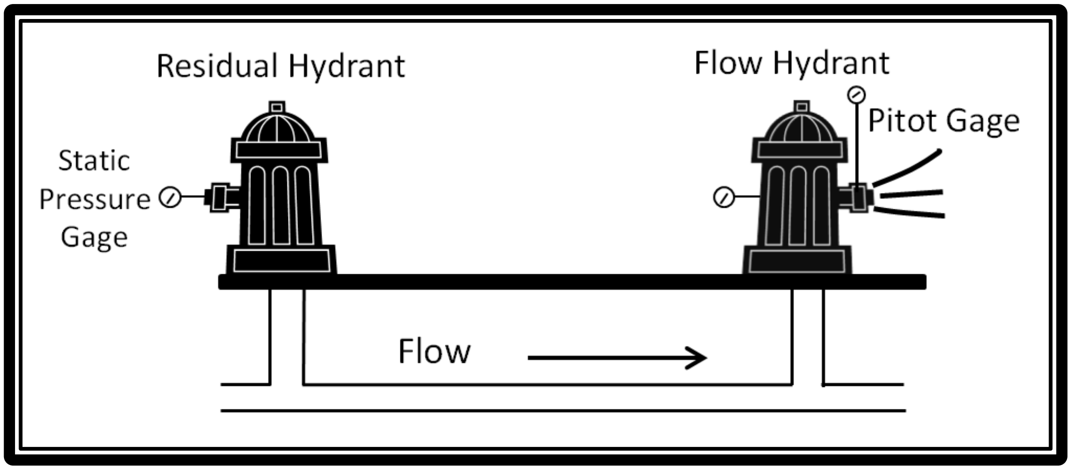

Figure 13 Fire Flow Test Setup

Fire flow tests are useful for collecting both discharge and pressure data for calibrating hydraulic network models. Calculations are performed to find the maximum capacity of a hydrant if it is pumped down to a 20 psi residual pressure. These calculations are shown in Appendix D.2.2 Fire Flow Calculations on page 78.

4.2.3 Fire Flow Results

The results from Fire flow tests executed in Paris are shown below in Table 14.

Table 14 Fire Flow Test Results

Test Number	Residual Hydrant	Static Pressure (psi)	Residual Pressure (psi)	Pressure Drop (psi)	Flow Hydrant	Static Pressure (psi)	Flow (gpm)
FF-2	H-80	82.0	72.0	10.0	H-79	78.0	1300
FF-3	H-90	54.0	40.0	14.0	H-97	61.0	1080
FF-5	H-278	76.0	48.0	28.0	H-200	74.0	489
FF-6	H-175	68.0	52.0	16.0	H-174	69.0	650
FF-7	H-71	65.0	55.0	10.0	H-70	69.5	1220
FF-9	H-308	98.5	88.5	10.0	H-307	97.0	1501
FF-11	H-398	62.0	51.0	11.0	H-317	61.0	1107
FF-12	H-317	64.0	28.0	36.0	H-41	64.0	780
FF-13	H-145	45.0	16.5	28.5	H-149	56.0	645
FF-14	H-189	86.0	54.0	32.0	H-191	83.0	531

4.3 Boundary Conditions Collection

Boundary conditions are the specific system settings at times of concern in modeling (such as during Fire Flow tests or extended period of data for simulations). These include the water levels in the storage tanks, system change patterns (valves opened/closed, pumps on/off, etc.), pump flow rates, pump pressures and system demand. All of these settings are needed as input data in the model. The outputs include pressures at junctions and pipe flows.

These boundary conditions were collected by strategically placing pressure gages and flow meters around the distribution system. Continuously recording pressure loggers (Dickson PR325) were placed at the three storage tanks (Bypass, 10th St and 19th St). The flow meter, used by Paris Combined Utilities, was placed on the discharge end of the pump with their pressure gauge at the same location. Both of Paris Utilities' gages are recorded continuously by an analog dial chart. Figure 14 shows the recording system used by Paris that measures the pump flowrate.

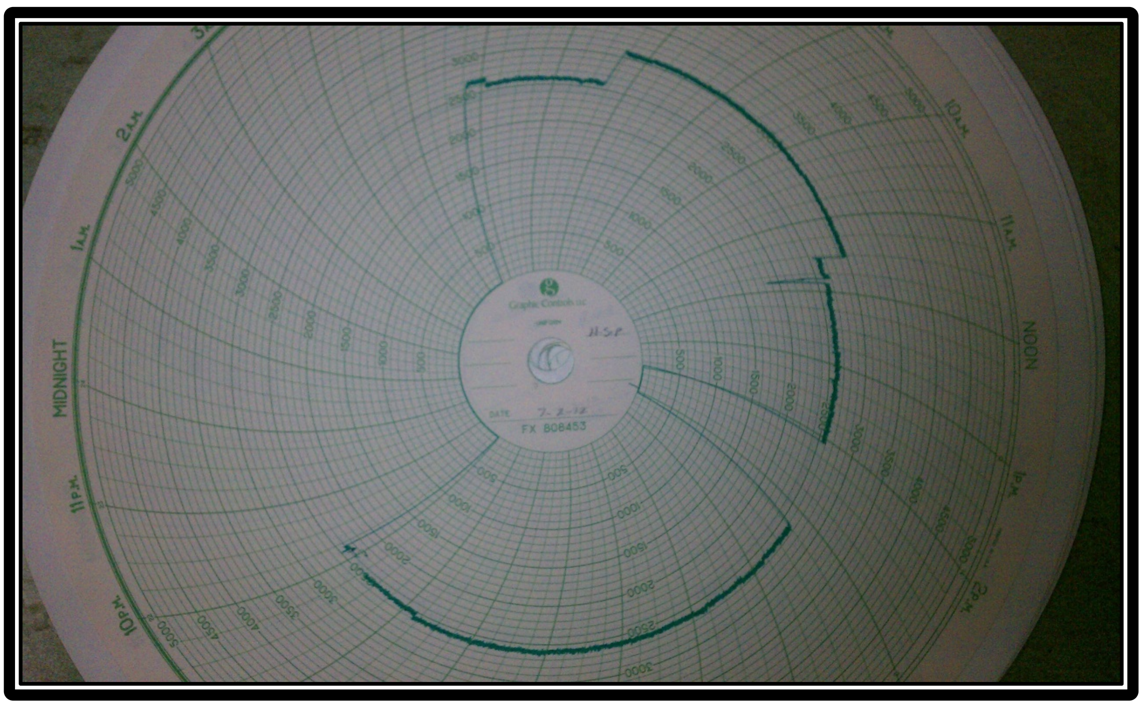

Figure 14 Example Dial Recorder - Pump Flow on 7/2/2012

In addition to the gages, change records were also used as dictated by the Paris Utilities supervisors. Table 15 below shows the conditions noted during testing times.

Table 15 System Conditions during Testing (6/6/2012)

Item	Change Pattern
Winchester (10th St) Tank Inlet Pipe	Open: 9:00 am – 11:04 am (closed rest of day)
Booster Pump @ 19th St Tank	On: 6:00 am – 8:00 am (off rest of day)
High Service Pump #1	On: All Day

Paris does not currently have a SCADA (Supervisory Control and Data Acquisition) system to record and store all boundary conditions. However, the WTP was able to gather data for water levels in the Bypass tank and clearwell along with the flow and pressure of the high service pump. A venturi meter system was utilized to measure the flowrate from the high service pump. A differential pressure gage was used to measure the pressure difference, and the flowrate was found using the known areas within the venturi meter. Figure 15 illustrates the concept of a venturi meter.

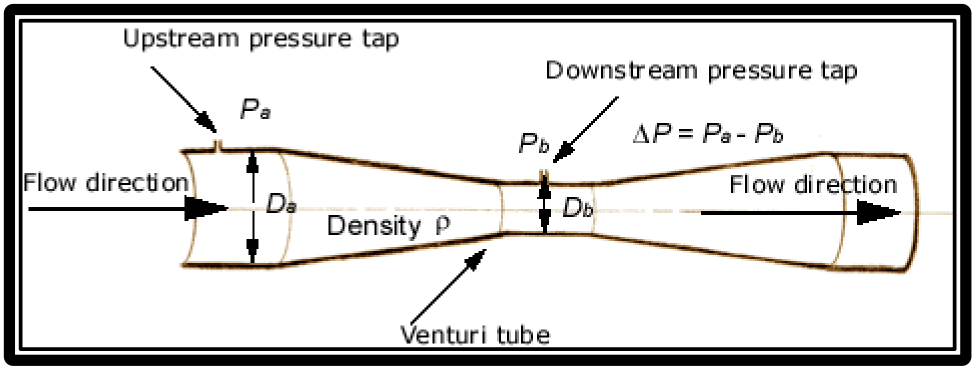

Figure 15 Venturi Meter

The WTP was able to record water levels in one of the storage tanks (located on the Paris Bypass) as well as the pump discharge and pressure. The water level in the Bypass tank is a differential pressure gauge that relates the water pressure to the water level in the tank. Continuous pressure recorders were used to collect the other necessary boundary conditions. A digital pressure gage was placed at each of the two remaining storage tanks, and pressure readings were recorded at 30 second intervals. Figure 16 illustrates the critical boundary conditions present in the system during testing.

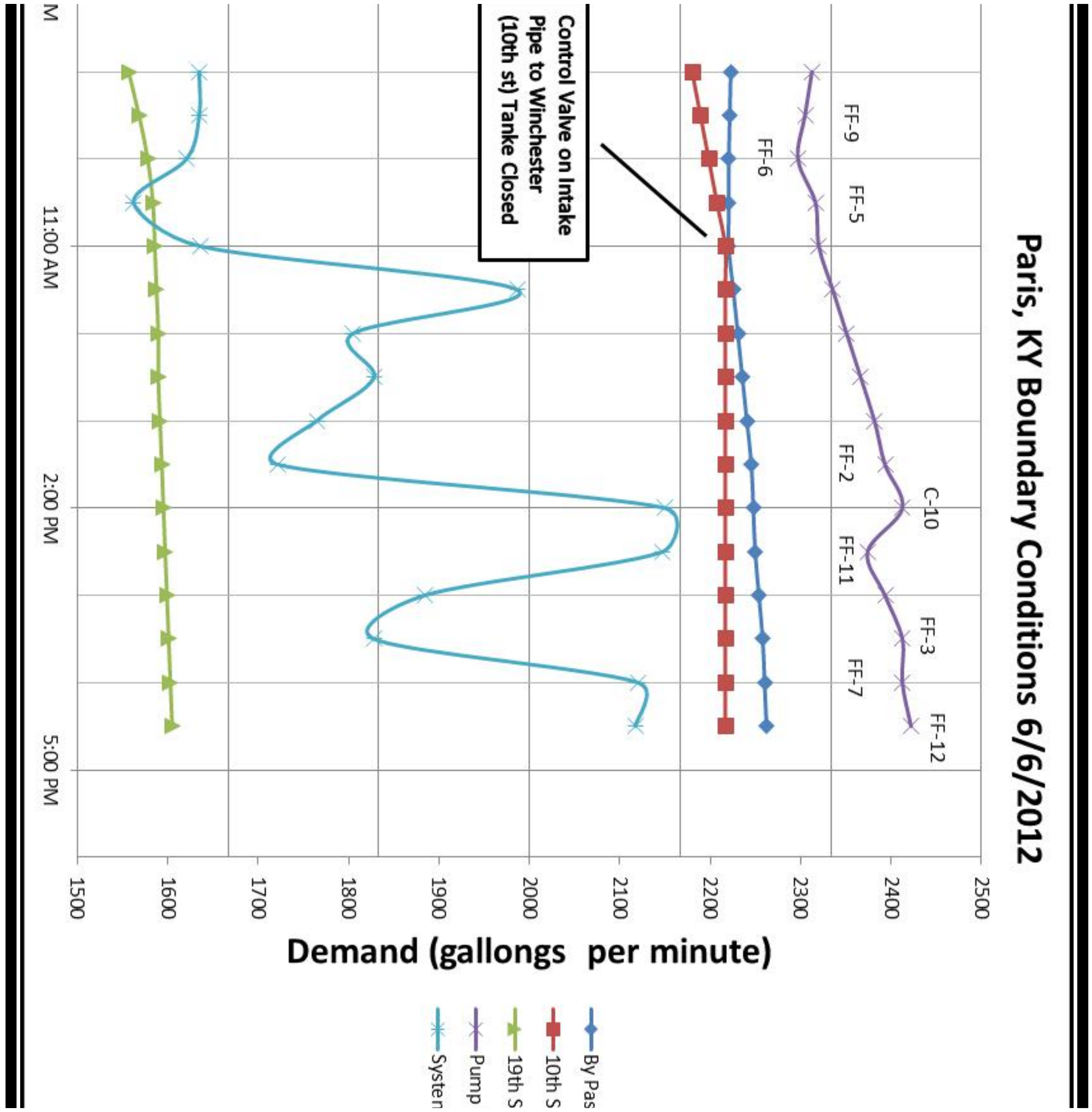

Figure 16 Boundary Conditions – Testing Day 6/6/2012

4.4 Data Collection Equipment

Table 16 below shows all equipment used during field testing. Descriptions of various equipment items are also described below.

Table 16 Data Collection Equipment List

Field Testing Supplies	Supplier	Item #
Hydrant Flow Meter	Pollard	P669LF
Hydrant Static Pressure Gage	Pollard	P67022LF
Pressure Snubbers	Pollard	P605
Hydrant Wrenches	Pollard	P66602
LPD Pitot Kit	Pollard	LPDPITOTKIT
FHG Digital Pressure Loggers 0-300 psi	Pollard	FHGPR325
Software and Download Cable	Pollard	A016
Removable Flash Storage Card	Pollard	A210

- *Hydrant Flow Gage*: Hydrant flow data were gathered using the Pollard hydrant flow gage for both the Fire Flow Test and C-Factor test. During the test, hydrant flow data was recorded by viewing the flow gage and recording the results. These observations were confirmed by a second field person before recording.
- *Hydrant Static Pressure Gage*: Static and residual pressures were be recorded using a Pollard hydrant static pressure gage. The fire hydrant gage comes with a bleeder valve allowing the user to vent air and water from the hydrant before taking readings. Once installed on the hydrant, the Hydrant Static Pressure Gage was used to record the residual pressures by visually recording the gage data.
- *Continuous Pressure Recorder*: Tank levels were measured using a Pollard continuous pressure recorder. The continuous pressure recorder was placed on a hydrant near or below the water tank level and pressures were recorded in 30 second intervals. The data were then extracted via cables or a flash drive onto a computer and stored for further use. The continuous pressure recorder can also be used in other applications similar to the hydrant static pressure gauge. In some instances the continuous pressure recorder may be placed in other areas throughout the system to help monitor pressures.

4.5 Data Collection Safety Procedures

The approved QAPP was distributed to all project personnel via email prior to data collection. All personnel became familiar with all the SOPs and associated Quality Assurance/ Quality Control (QA/QC) protocols. Prior to any field data collection, all graduate research students viewed a short video produced by American Water Works Association entitled

Field Guide: Hydrant Flow Tests. The video covers the basic protocol and necessary steps for proper fire flow testing.

4.5.1 Communication and Contingencies

Each member of the field testing crew had in their possession at all times during testing a cellular telephone or two-way radio communication device. Each member also had a complete list of all cellular telephone numbers and radio frequencies. This would allow immediate communication during the testing and for a quick response in the event of an emergency. Possible problems associated with hydrant testing such as downstream flooding, mechanical problems with the distribution system, poor instrumentation and inaccurate record keeping were documented along with actions to remedy and prevent such problems.

The health and safety of the public is extremely important in conducting the field testing procedures. A Paris WTP staff operator was present while the hydrants were flowed. The WTP staff operator was responsible for frequently monitoring the flow in the system and if anything unusual was observed, the operator would take the proper action to remedy the situation.

4.5.2 Health and Safety Issues

Prior to testing, Paris city government, Paris police department, and Paris fire department were notified of the location, time and extent of field sampling. Emergency contact numbers for the field team were provided to all relevant authorities. The team also had in their possession emergency contact numbers for all relevant agencies. All traffic regulations, procedures, and laws were strictly observed by teams when driving vehicles from site to site. Because of the duration of time that field teams were possibly exposed to the sun, sun block was provided. All field personnel were required to wear reflective vests during the tests as well as proper clothing and shoes to protect against injury. Field testing teams were also required to carry proper identification on them at all times in the field in case a situation arose where a field member needed to be identified by local residents.

Before any tests that involved the opening and flushing of hydrants were executed, the location of the tests were approved by local water utility and fire department officials to ensure that system pressures were not lowered below a level that could induce cross contamination of the system by sucking contaminants into the distribution system. The field team also had the option to survey the area to determine the direction of flow and ultimate disposition of any discharges so as to prevent any safety issues or loss or damage of private property. Where warranted, a hydrant diffuser or a 4 x 8 piece of plywood was available to avoid damage to green space as a result of the discharging jet of water from the fire hydrant.

Prior to opening any hydrant nozzle, the field crew confirmed that the hydrant valve was closed. As an added precaution, the nozzle cap was removed with a hydrant wrench with the field personnel standing to the side so as to prevent injury from a hydrant cap shooting off in the event the hydrant valve was actually open. In opening any hydrant, care was observed to open the hydrant slowly and in incremental steps so as to minimize any transient pressure issues in the distribution system. Prior to installing any instruments (i.e. flow/pressure gage) on the discharge nozzle of the hydrant, the hydrant was first opened and flowed until the water flowed clear to remove any particles or rust that may have accumulated in the hydrant service line and barrel. Once this was performed, the hydrant valve was closed and the instruments installed prior to opening the hydrant a second time for use in data collection.

4.6 Documentation and Records

Raw data collected in the field were recorded on paper forms (in ink) that were developed for this purpose (shown in Appendix E: Data Collection Logs on page 80). Once completed, the forms were scanned into an adobe pdf for subsequent electronic archival. The data were also transcribed into an Excel spreadsheet. The Data Manager reviewed all data for consistency and compliance with all sampling QA/QC protocols prior to recording. Any apparently anomalous values were verified with the field personnel prior. This information was conveyed to the Field Supervisor for possible review and revision of the current data collection protocols. Electronic data backup was performed after each entry session on DVD or peripheral hard drive. A hardcopy of all project logs, forms, records, and reports were archived by the Data Manager. Hardcopies of all logs, forms, records, and reports can be made available upon request and pending approval of the Data Manager.

4.7 Quality Control for C-Factor Testing

The quality of the data collected as part of the C-factor testing was controlled through the procedures described in the following sections.

4.7.1 Review of Construction Records

Prior to conducting any C-factor tests, recent construction records were reviewed to identify those parts of the system where valves could have been left closed or partially closed. These valves were checked in the field to verify that they were in the open position.

4.7.2 Pressure Gage Calibration and Validation

Prior to the use of pressure gages in the field, the gages were calibrated against a known pressure source in the University of Kentucky hydraulics laboratory. Following the field tests, the gages were again checked against the known pressure source to confirm the gages were still within the calibration limits (i.e. + - 2 psi). In the event that any of the gages were found to be out of calibration, then the associated error in each gage was determined and the error information recorded on the data logging sheets for any tests in which the gage was used.

Following calibration in the laboratory, each gage was further tested against a field pressure source to confirm the gages were within the specified calibration limit. The field source could either be a tap on the downstream side of the pump discharge at the Paris Water Treatment Plant or at the base of one of the water tanks with known water surface elevation.

4.7.3 Duplicate Pressure Observations

All pressure gage readings were performed independently by two separate observers. These readings were confirmed prior to recording a single value. In the event the observed values remain consistently apart, the mean of the readings was recorded.

In performing any C-factor tests, two pressure gages were used. Prior to flowing the discharge hydrant, the static pressure at the residual hydrant was measured and recorded. In order to minimize any potential gage error, the static pressures at each hydrant were measured twice during certain tests, with the gages switched between measurements. The observed pressures should have remained consistent within the specified pressure tolerance (i.e. + - 2 psi). In the event the gage readings were not consistent then the difference was noted on the data collection form prior to use. This test was performed during the first test and the last test of the day to confirm that the gages did not lose their calibration over the course of the tests.

After the static difference was confirmed, the C-factor test was performed twice, with the gages switched between tests. The observed pressures should have remained consistent within the specified pressure tolerance (i.e. + -2 psi). In the event the gage readings were not consistent then the difference was noted on the data collection form prior to their use. This check was performed during the first test and the last test of the day to confirm that the gages did not lose their calibration over the course of the tests.

4.7.4 Adequate Hydrant Discharge

In order to insure that sufficient head loss was generated during the C-factor test to allow the accurate calculation of the C-factor, the pressure drop between the two residual hydrants should have been at least 15 psi. If such a pressure drop was not obtained, it was necessary to open additional hydrants, creating more flow, so as to generate a sufficient pressure drop. If a low pressure drop was associated with an unexpected low discharge from the hydrant it was possible that there was a closed or partially closed valve upstream of the test area.

4.8 Quality Control for Fire Flow Tests

In conducting a fire flow test for the purpose of hydraulic model calibration, a minimum of two hydrants were employed. One hydrant (flow hydrant) was used to discharge flows to the environment while another upstream hydrant (residual hydrant) was used to measure the pressure drop.

4.8.1 Adequate Hydrant Discharge

The magnitude of the discharge from the hydrant should be sufficient to ensure a pressure drop in the residual hydrant of at least 15 psi. In the event that such a drop was not achieved, then a second downstream hydrant may need to be flowed simultaneously with the first. In this case, both discharge hydrants needed to be instrumented with flow/ pressure meters. If a low pressure drop was associated with an unexpected low discharge from the hydrant it is possible that there is a closed or partially closed valve upstream of the test area. If this occured, the upstream valves should have been re-checked to make sure that they are opened prior to repeating the test.

4.8.2 Discharge Measurement

Most hydrant flow/pressure gages come with two scales, one for discharge and one for pressure. The discharge scale is only applicable for certain types of hydrant nozzles. As a result, the discharge scale should not be used. Instead, the discharge pressure was measured and then converted into discharge using the discharge equation (shown in Appendix D.2.2 Fire Flow Calculations on page 78).

In some cases, the accuracy of the results cannot be determined on site due to the time needed to input the collected data into KYPIPE. Once the data is entered into KYPIPE, there may be additional errors with the data that were not readily identified in the field. An example would be if the computer model produced a low Hazen Williams Coefficient such as 40 or below. This would indicate that there may have been a valve closed in the system or that there was error in the C-factor test data. These errors were reviewed by the Principal Investigator and a course of action was determined based upon the complexity of the situation.

4.8.3 Fire Flow Test Validation

The city of Paris has previously run fire flow tests on many of their existing hydrants. In the event that one of the hydrants used in this study corresponded to one of these previously tested hydrants, the previous fire flow results were obtained and compared with the results from the new fire flow test. Prior testing information usually contains the available fire flow at a 20 psi residual. In the event that these results were significantly different (e.g. significantly lower), the field crew checked to ensure that there were no closed or partially closed valves upstream of the test area. In the event that such errors were identified, then the fire-flow tests were re-run. In the event that no such valves could be located, the field team noted the discrepancy and attempted to develop a hypothesis for the difference. The data comparing fire flow tests executed by the Water Utility and tests performed for the model calibrations are shown in Appendix D.3 Fire Flow Validation on page 79.

While every attempt was made to ensure that the system geometry of the computer model was correct and that there were no closed or partially closed valves upstream of the test area, such errors may not be readily apparent until after the collected data are entered into the computer and the model used to predict the observed pressures and flows. When such an analysis required a roughness coefficient excessively lower than those observed during the C-Factor test, the most likely reason is due to errors in the system geometry or the existence of closed or partially closed valves. In the event that such errors were determined, then the fire flow tests were repeated.

5.0 Distribution System Model

5.1 General

A hydraulic model representative of the current water distribution system in Paris was created using the KYPIPE Program (Pipe 2010). KYPIPE was developed by civil engineering professors at the University of Kentucky. The program allows users to create a model of a system comprised of pipe links, internal nodes, and end nodes. The point where pipes intersect is represented as a junction, and locations where a demand occurs are shown as nodes. Background maps and drawings can be input in vector and raster formats.

The model can be created to precisely match the conditions present in the system. The program can be used to simulate numerous different scenarios in the system, analyzing the network through an iterative process utilizing the mass balance concept. The process provides results for pressures, velocities, hydraulic grade lines, etc. in pipes and nodes throughout the system. The program can be utilized to analyze both steady state and extended period simulations.

5.2 Development of System Schematic

5.2.1 General Procedure

A system schematic illustrates the system of pipes and other components in a water distribution network. Various categories of data regarding the system are required in order to create an accurate model. These categories are classified as geographical information, facilities data, operational data, and demand data (AWWA, 2005).

Geographical data are used to establish the physical location of the model, including aspects like jurisdictional boundaries and street centerlines. Facilities data include all the attributes of the pipes, pumps, tanks, and reservoirs in the system. Parameters describing the pipes that are required for an analysis include diameter, length, and pipe roughness. These data are the core component of a hydraulic model. Operating data included attributes of the system that are subject to change, such as flowrates, valve/pump controls, valve/pump status, and fixed pressures that create boundary conditions in the system. Demand data are the amount of water consumption assigned to all demand nodes throughout the system (AWWA, 2005).

5.2.2 Elevation Data

Modeling software has the ability to graphically present results of a system analysis, so it is important that input data contains the geographical (x-y) coordinates and elevation (cartesian z-coordinates) for each node. A GIS (Geographic Information System) file of the system used by the utility can be used in the modeling software, and the coordinate system from GIS will ensure spatial compatibility. It is also important for elevations to be accurate to ensure that various calculations for pressures, C-factors, and other attributes are accurate.

Two types of elevations are used in a hydraulic analysis, control elevations and ground elevations. Control elevations are located at critical components of the system, such as a pump. The pressures at these locations are critical in model calibration, so it is important that these elevations are accurate. The elevation should be measured exactly where the pressure gage is located, and surveying is commonly used to gather accurate elevation data for these points. Control elevations in this system were considered to be pumps, storage tanks, the Water Treatment Plant, and all hydrants used in both C-factor and fire flow tests.

Two methods were utilized in Paris for determining elevations of control points. Surveying the elevations of points, utilizing benchmarks in Paris as a starting location, was one method used. The surveying procedures for C-factor tests are shown in Appendix B.1.1 on page 67, and the resulting elevations of hydrants used in these tests are shown in Appendix B.1.2 on page 67. The surveying procedure for fire flow tests are outlined in Appendix B.2.1 on page 69, and the fire flow surveying results are shown in Appendix B.2.2 on page 70. A global positioning system (GPS), calibrated using a benchmark, was also utilized to measure accurate elevation points. The GPS unit used for this project was the Topcon high accuracy kit, containing the antenna (PG-A5) and GRS-1 unit. A two meter carbon fiber rod was used to mount the antenna and GRS-1 unit. The surveying results for the storage tanks, WTP, and benchmark are shown below in Table 17. The WGS84 Ellipsoid height is the elevation of the location before taking into account the density of the earth at that specific location. The geoid separation is the correction to include density of the earth, resulting in the true elevation of the points.

Table 17 Control Points Surveying Data

Name	WGS84 Ellipsoid Height (US ft)	Geoid Separation (US ft)	Elevation (ft)	Standard Dev. of Elevation (US ft)
10th St Tank 1	770.694	-114.455	885.149	0.1
10th St Tank 2	771.278	-114.455	885.733	0.1
19th St Tank	781.576	-114.442	896.018	0.099
Bypass Tank 1	776.646	-114.663	891.309	0.1
Bypass Tank 2	774.265	-114.658	888.923	0.247
WTP	685.117	-114.468	799.585	0.241
Bench Mark 7/2	745.434	-114.529	859.963	0.164
Bench Mark 7/27	745.292	-114.529	859.821	0.419
Bench Mark 7/6	746.156	-114.529	860.685	0.149

*Actual Benchmark Elevation: 859.143

Ground elevations include the elevations of the remaining nodes throughout the system, such as typical demand nodes. These elevations are not as critical, but still need to be accurate within 1.5 feet (AWWA, 2005). They are used for calculating available delivery pressures in the system.

Elevations were also established for these remaining nodes in the system, those not considered control elevations. Data were extracted from digital elevation models (DEMS), obtained from kymartian.ky.gov, and input to GIS. These digital elevations models were extrapolated to obtain elevations for all remaining nodes in the system.

5.2.3 Facilities Data

Facilities data usually remains fairly constant in an analysis. When entering data for each pipeline in the model, the pipe diameter, length, and initial roughness coefficient (estimated based on material and age) are needed. Manufacturers of pipes provided typical roughness coefficients for new pipes of a certain material. These coefficients will generally remain accurate for several years, until the effects of corrosion, encrustation, and biofilm buildup cause the roughness inside of the pipe to change (AWWA, 2005). This buildup with time that occurs inside of pipes will also cause the diameter of the inside of the pipe to decrease, causing a slight difference between the nominal diameter and the actual diameter. However, the actual diameter of the pipe is difficult to measure, so the nominal diameter should be used in the model and the roughness coefficient will often account for these changes (AWWA, 2005).

Pumps in the distribution system are important for filling storage tanks and also providing adequate pressure in the system. A pump characteristic curve shows the relationship between discharge pressure and flow for a particular pump. A pump manufacturer provides the utilities with this curve upon installation, though they are of questionable accuracy to actual pump performance. Wear and stress on the impeller over time will negatively affect pump performance. The pump curve is commonly altered during the calibration process (AWWA, 2005).

Storage facilities within the system are needed for water supply and they also supply pressure to the system. The overall capacity of the tanks includes fire and emergency storage, so the total storage will not be available for peak flow periods. The tank geometry, total capacity, freeboard constraints, and minimum/maximum water levels are important parameters to enter into the model (AWWA, 2005).

5.2.4 Connectivity Errors

A set of plans of the distribution system was acquired from the utility in order to check the validity of the KYPIPE model. The model setup was checked with the plans to ensure every pipe shown in the plans was present in the model and each pipe was connected properly. This check for accuracy of the model was ongoing throughout the calibration process.

After attempting C-factor tests at several sites throughout Paris, it became clear that there were many valves that were broken or the utility was unable to locate. The valves were left in the model in the open position, and the C-factor calculations were able to account for the uncertainties in valve position.

5.3 Development of Demand

5.3.1 Demand Allocation

Demand data is input in the model after the layout and facilities data have been accurately set up. In order to input accurate demand data into the system model, billing data (from September 2011) showing the total water usage in gallons for each household during that month was provided. The total monthly demand was then divided evenly throughout the month to get a value for water usage in gallons per minute.

Equation 3

$$\boldsymbol{Instantaneous\ Demand} = \frac{\boldsymbol{Demand}}{\boldsymbol{Month}} \times \frac{\mathbf{1}\ \boldsymbol{month}}{\mathbf{31}\ \boldsymbol{days}} \times \frac{\mathbf{1}\ \boldsymbol{day}}{\mathbf{24}\ \boldsymbol{hrs}} \times \frac{\mathbf{1}\ \boldsymbol{hr}}{\mathbf{60}\ \boldsymbol{min}}$$

Geocoding is a process used by GIS that matches addresses to their spatial location based on a street network. This is a similar process to how GoogleMaps or Bing locates an address, except GIS does it with a large list of addresses. By geocoding the addresses from billing records, a demand can be assigned in gallons per minute to a particular spatial location in the system.

Because KYPIPE only allows demand at pipe junction nodes, each demand node was assigned to the closest junction. To determine the closest junction Thiessen polygons were created from the junction nodes using GIS, and a demand node was assigned to a junction if it resided inside that Thiessen polygon. A Thiessen polygon (shown in Figure 17) is a shape determined by the proximity of nodes and is a process used in hydrology to develop regional weather data based on gauges at specific points.

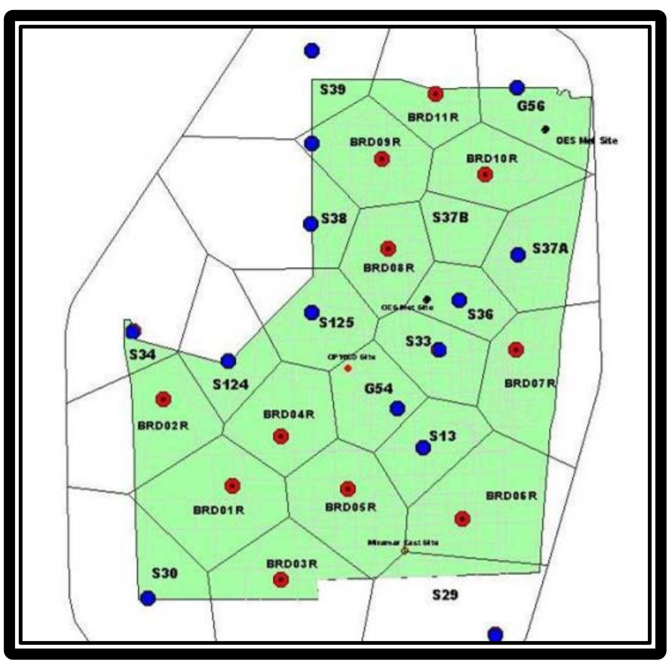

Figure 17 Thiessen Polygons

All the demand nodes that were assigned to a junction were summed to yield the total demand at that junction. This grouping process resulted in each junction node in the model accounting for the demand of several households in the nearby vicinity and was accomplished with the Spatial Join tool in the ESRI Spatial Analyst extension of ArcGIS.

5.3.2 System Demand

In order to find the total demand in the system, the concept of mass balance was utilized by looking at the inflow, outflow, and changes in storage in the system. Specifically, the outflow from the system subtracted from the inflow to the system equals the change in total storage. Inflow includes water pumped into the system from the supply source, outflow encompasses all water demand throughout the system, and the change in storage refers to the change in tank levels.

The change in storage (water levels of storage tanks) is found using the methods of continuous pressure gages and recording data at the WTP previously discussed. These data are used with the known pump flow inflow to the system recorded at the WTP to calculate the total outflow of water out of the system (system demand).

The Law of Conservation of matter states that the rate of change in storage (S) is equal to the difference in inflow (I) and outflow (O).

Equation 4

$$\boldsymbol{\frac{dS}{dt} = I - O}$$

$$dS = (I - O)dt$$

$$\int_{t_o}^{t_1} dS = \int_{t_o}^{t_1} (I - O)dt$$

$$\Delta S = \int_0^t I\,dt - \int_0^t O\,dt$$

Since the pump flows were measured (inflow into the system) at specified times those measurements can be used to estimate the total inflow into the system of the time period between the two measurements by numerical integration; the trapezoidal rule was used for this calculation.

Trapezoidal Rule of Integration:

$$\int_{t_i}^{t_{i+1}} I(t)dt \approx \Delta t\ \frac{(I_{t_i} + I_{t_{i+1}})}{2}$$

The mean value theorem of integration states that there is an average value of a function (in this case demand as a function of time) that represents the function over that period. This was used to approximate the average demand over each time period.

Mean Value Theorem:

$$\int_{t_i}^{t_{i+1}} O(t)dt = \bar{O}\,(t_{i+1} - t_i)$$

$$\bar{O} = average\ outflow\ over\ period\ t_i\ to\ t_{i+1}$$

This was used in the equation for conservation of mass to yield an expression for average demand over a given time interval.

$$\bar{O} = \frac{\Delta t\ \frac{\left(I_{t_i} + I_{t_{i+1}}\right)}{2} - \Delta S}{(t_{i+1} - t_i)}$$

Equation 5

$$\boldsymbol{\bar{O} = \frac{I_{t_i} + I_{t_{i+1}}}{2} - \frac{\Delta S}{\Delta t}}$$

Example:

	Tank Depth (ft)			**Pump Flows (gpm)**
Time	Bypass	10th Street	19th Street	
9:00	17.25	20.1	54.2	3015
9:30	17.125	21.2	55.6	3007

Tank	**Diameter (ft)**
Bypass	81
10th Street	77
19th Street	32

$$\Delta t = 30min$$

$$\Delta S = \sum_j \Delta h_j \frac{\pi}{4} D_j^2; \quad j = tank\ 1, tank\ 2, tank3$$

$$\Delta S = (17.125 - 17.25)\frac{\pi}{4}81^2 + (21.2 - 20.1)\frac{\pi}{4}77^2 + (55.6 - 54.2)\frac{\pi}{4}32^2 = 41{,}278\ gal$$

$$\bar{O} = \frac{3015\ gpm + 3007\ gpm}{2} - \frac{41{,}278\ gal}{30\ min} = 1635\ gpm$$

5.3.3 Demand Classification

Different types of customers and their water use patterns must be considered in this process, and customer types are classified as residential, commercial, and industrial. Residential demand consists of domestic consumption (drinking, cooking, showering, etc.) that typically peaks in the morning and early evening along with irrigation use (watering of lawns and gardens). Industrial customers include manufacturing plants and other high use customers that have unique use patterns based on hours of production. This type of demand typically does not vary seasonally as residential demand does. Commercial customers include restaurants, stores, office complexes, etc. The demand at these locations is dependent on the hours of operation, and water use typically remains fairly constant throughout these hours (AWWA, 2005).

In order to model the temporal and spatial variability of demand throughout the day, a demand type was assigned for each junction node. KYPIPE uses demand multipliers for each type which scale the demand at each node with that type. Assigning a demand "type" allows the modeler to change not only the total system demand at a point in time but the spatial distribution of that demand throughout the system. For instance, during the lunch hour most of the total system demand is being drawn to the commercial districts and restaurants instead of residential neighborhoods. Larger demands results in larger flows and more significant friction losses, which affect pressures in those areas. Three demand type designations were used; 0 for residential, 1 for commercial and 2 for agricultural/industrial.

Junction demand types were assigned using a land use zoning map of Paris, KY, which was digitized as a GIS shapefile by the Bourbon County government. Using GIS, a demand type was assigned to each node based on the surrounding land use (a junction node in a residential zone would be assigned type 0). These codes are used by KYPIPE to sort out which demand multiplier to use for that time period. Table 18 shows the land use classification, and Figure 18 illustrates the different zoning classifications throughout Paris.

Table 18 Land Use Classification

Zone	Type	Description
A	2	Agricultural
B-1	1	Commercial
B-2	1	Commercial
B-3	1	Commercial
C	1	Commercial Convenience
H	1	Public
H-M	1	Public
I-1	2	Industrial
I-2	2	Industrial
NOZONE	2	Nozone
PUD	0	Planned Unit Development
R-1	0	Residential
R-2	0	Residential
R-3	0	Residential
R-4	0	Residential
R-5	0	Residential
R-6	0	Residential
R-7	0	Residential
R-8	0	Residential

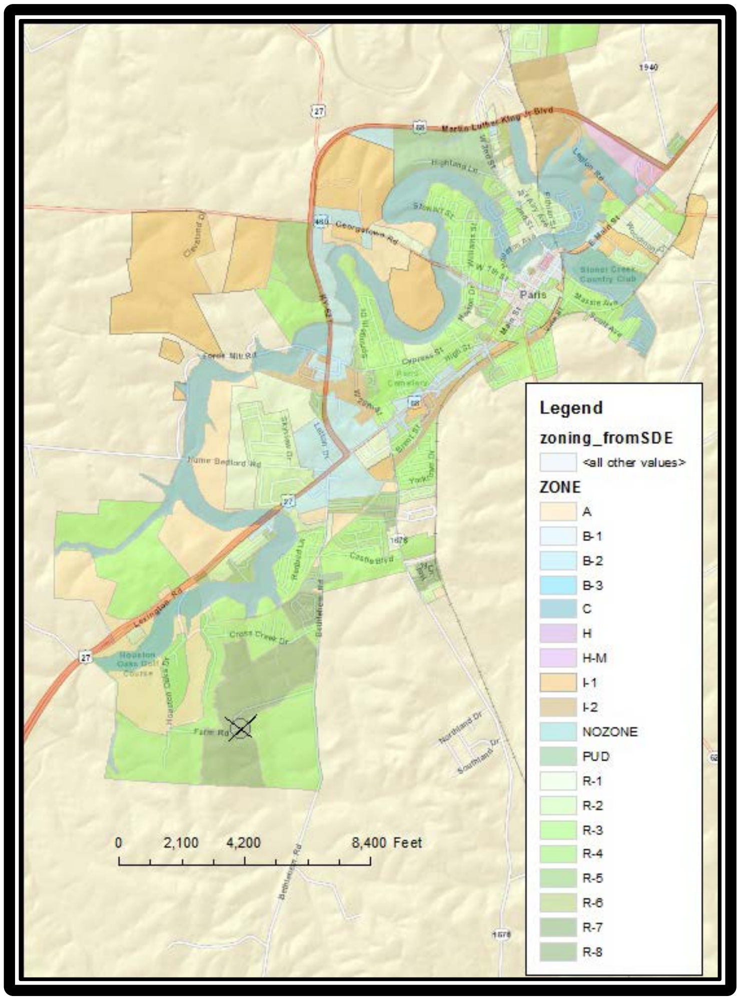

Figure 18 Zoning Map of Paris, KY

5.3.4 Demand Pattern

Because water usage in different customer classifications has varying water use patterns throughout the day, it was necessary to investigate demand patterns over a 24 hour period. For example, the majority of testing occurred in residential areas and all testing occurred between 9:30 a.m. and 4:30 p.m. Residential areas during this time period will typically have lower demand than during the early morning and evening.

Developing an average daily demand pattern for each usage type is a very in depth study that uses flow meters at individual points of demand and logs the flow over a long period of time. To approximate this daily demand distribution a study conducted by Aquacraft, Inc. for the city of Westminster, CO in 1998 was used. The study identified the daily demand for each consumer type and how much of that demand was consumed during each hour of the day. The hourly demand was expressed as a percentage of the average daily demand. The data used for these calculations are shown in Appendix C: Demand Data on page 72. We used these percentages to allocate the total system demand at each time of the day to the residential, commercial, and industrial nodes, respectively.

KYPIPE calculates node demand by multiplying the stated demand by a "demand factor" that is defined for every demand type and for every time/case of hydraulic analysis. The total system demand is the sum of the cumulative demand for each type multiplied by their respective factors. In section 5.3.2 System Demand on page 41, the total system demands were calculated for the time intervals of testing and for an extended period simulation. In order to align the daily demand patterns for different users and the calculated total system demand, a global demand factor was used for each period to match both the demand distribution and total demand.

Example:

Residential demand from meter data = 200 gpm

Commercial demand from meter data = 300 gpm

Industrial demand from meter data = 200 gpm

Total System Demand at 4 p.m. = 2,000 gpm

Average Day Demand Multipliers at 4 p.m. =

Residential (0)	Commercial (1)	Industrial (2)
0.4	0.85	0.21

(Westminster, CO study (Aquacraft, Inc. , 1998))

$$Modeled\ Demand = 0.4 * 200 + 0.85 * 300 + 0.21 * 200 = 377 gpm$$

$$Global\ Demand\ Factor = \frac{Calculated\ Demand}{Modeled\ Demand} = \frac{2{,}000\ gpm}{377\ gpm} = 5.31$$

Demand Factors Input into KYPIPE for time 4:00 p.m. =

Residential	Commercial	Industrial
2.12	4.51	1.11

5.3.5 System Losses

The process of gathering demand data also had to take into account water loss in the system. Real loss is the physical loss of water from the system, usually in the form of leaks. Apparent losses encompass meter inaccuracy, fire hydrant flushing, water plant use, and unauthorized use. At the time of data collection, the Paris distribution system was experiencing a leak that accounted for approximately 40% of their total water usage. This amount most likely encompassed both real loss and apparent loss. These leaks had to be accounted for in the model since they were not included on the meter billing data. The total loss was simply distributed evenly throughout the system (to each node), and this process was simplified by increasing the global demand factor in KYPIPE.

5.4 Pipe Friction Losses

5.4.1 Hazen-Williams Equation

Various equations have been developed to determine the head losses in a pipe due to friction forces. The Hazen Williams equation is widely used to relate the physical properties and flow parameters of a pipe to the resulting head loss or pressure drop that will occur. A widely used version of the equation in English units is shown below (Mays, 2011).

Equation 6

$$h_L = \frac{4.73 * L * Q^{1.85}}{C^{1.85} * D^{4.87}}$$

Where,
h_L = head loss (ft)
L = length of pipe (ft)
Q = flow rate (cfs)
C = Hazen Williams C-Factor
D = diameter of pipe (ft)

The C-factor used in the Hazen Williams equation varies for pipes based on pipe material and age of the pipe. Different pipe materials will result in varying C-factors because pipe roughness is dependent on pipe material. Steel and PVC pipes tend to be smoother and result in less friction loss than cast iron pipes (AWWA, 2005).

The C-factor is also dependent on the age of the pipe. New pipes are typically very smooth and have not yet undergone a great deal of corrosion and deposition, resulting in minimal head loss. After time, the pipes will accumulate deposits and experience tuberculation on the interior of the pipe. This reduces the actual inside diameter of the pipe, causing the actual inside diameter to be less than the expected nominal diameter, which allows less water than expected to flow through the pipe. The accumulation of deposits also causes greater frictional head loss from the increased roughness in the pipe. When the C-factor is determined through field measurements, the C-factor can compensate for the change in diameter based on build up in the pipes (Walski, et al.).

In terms of the C-factor coefficient used in the Hazen Williams equation, the frictional head loss experienced in the pipe will increase as the C-factor decreases. Therefore, pipes made out of smoother material, such as PVC, will have higher C-factors than materials with greater roughness vales like cast iron. Similarly, older pipes of the same material that have experienced significant corrosion and deposition will have lower C-factors than new pipes of the same material (AWWA, 2005). If the flow rate remains constant, a smaller C-factor will result in a larger pressure drop in a segment of pipe. Table 19 shows typical C-factors for pipes based on material and age.

Table 19 Typical Hazen Williams C-Factor Coefficients

Pipe Material	Age (years)	Diameter	C Factor
Cast Iron	New	All Sizes	130
	5	>380mm (15in)	120
		>100mm (4in)	118
	10	>600mm (24in)	113
		>300mm (12in)	111
		>100mm (4in)	107
	20	>600mm (24in)	100
		>300mm (12in)	96
		>100mm (4in)	89
	30	>760mm (30in)	90
		>400mm (16in)	87
		>100mm (4in)	75
	40	>760mm (30in)	83
		>400mm (16in)	80
		>100mm (4in)	64
Ductile Iron	New		140
Plastic PVC	Average		140
Asbestos Cement	Average		140
Wood Stave	Average		120

The purpose of the C-factor test is to measure all factors in the Hazen Williams equation during hydraulic testing and then solve for the unknown C-factor. The flowrate is measured in the field, along with parameters to find the corresponding head loss, in order to calculate the unknown C-factor (EPA, 2005).

5.4.2 Minor Losses

The majority of the total head loss through a specific segment of pipe can be attributed to the frictional head loss. However, a portion of head loss through pipes is caused by minor losses. These losses occur because of changes in the geometry of the pipes such as bends, valves, and other fittings. Losses at these fittings are typically minimal for normal velocities in the system (AWWA, 2005). The C-factor calculated through field testing will account for minor losses (EPA, 2005). Even though the effects are minimal, the minor losses will increase the overall head loss measured in the field. Because the C-factor is calculated using field data, the coefficient will encompass both friction losses and minor losses. The added effects of minor losses will cause the C-factor values to decrease.

6.0 Model Calibration

6.1 General

The hydraulic model can be very beneficial to the utility in planning and everyday operation of the water distribution system. Like every type of model, the objective is to predict future conditions based on known system data; and the quality of a model is its ability to accurately predict those conditions. Calibration of a model involves the *post* diction of known system conditions based on simultaneously collected system data; all of which are gathered during the fire flow and C-factor tests. The system data (which are used as inputs) are tank levels, pump settings (on or off), valve closures and water demand. The model outputs are system pressures, pipe flows and pump operating conditions; namely discharge pressure and flow.

Calibration involves adjusting system demand distribution, pipe roughness, pump curve and other model attributes (Walski, et al.). However, it is still important that the data are adjusted only within reasonable limits. For example, changing a C-factor value of a pipe outside of reasonable values based on the pipe material and age might seem like appropriate calibration in a particular circumstance, but would probably result in unlikely results for a new range of conditions. The process of calibration can also reveal undocumented changes to the pipe system such as additional pipe connections, closed valves, severely tuberculated pipes, missing pipes and other issues that can be resolved to improve operation of the system (EPA, 2005).

Once the model accurately predicts field measurements under a wide range of conditions, the model is considered to be calibrated. Accurate is defined as within 10% of the target value; calculated static and residual pressures, pump discharge pressures and pump outflows differ by no more than 10% of the measured value. To further verify the calibrated model, an extended period simulation of a typical day, using measured demands and change patterns (valve closures and turning the pumps on and off), is compared with the actual tank levels.

The primary activities of the hydraulic calibration are pipe roughness adjustments, demand distribution and pump calibration. These activities are only effective as “fine tuning” measures for a much more general procedure. If the broader system details such as tank elevations and total system demand are not accurate, the pipe roughness will have little impact on converging model results and measured values. A thorough investigation of system attributes and operating conditions prior to calibration is paramount in achieving timely and acceptable results.

However, working with an un-calibrated model can lead the modeler to questionable data sources, inconsistent testing procedures, or omitted operations procedures (such as active valve and pump schedules). Upon finding input data errors, such as previously undocumented pipe changes or erroneous instrument measurements, the modeler should re-measure all possible values with redundancy (repeating tests if necessary) to verify the error and any new measurements.

6.2 Calibration Methods

Hydraulic calibration is a long process that involves a lot of changes and, so far, is not well automated by programming (AWWA, 2005). Therefore, it is beneficial to keep a log of changes and their impacts on model results. An example of this log (shown in Table 20) was used on the calibration of the Paris system.

Table 20 Calibration Log

Date/ Time	Change	Modeler	Result Set	Explanation	Model Version	Status

Date / Time	Time of change
Change	Short description of change (i.e. Changed C-Factors)
Modeler	Name of engineer making change (if multiple persons are calibrating)
Result Set	A reference to a separate page of indexed result sets for each change. Each result set should include all information that can change such as boundary conditions (i.e. pump curve and demand factors) and results (i.e. static and residual pressures for all fire flow sites)
Explanation	A thorough description of changes and reasoning for why change was made (i.e. roughness for cast iron was decreased to reduce losses and increase residual pressure result for FF-9)
Model Version	Drafts of the model should be saved both as backups and to revert to previous changes
Status	In Use / Rejected

6.2.1 Calibration Setup

The calibration started by setting up ten cases in KYPIPE, one for each fire flow test, so as to apply the appropriate boundary condition and demand patterns. The boundary conditions were set up as change patterns, which override the setting at specified nodes or pipes with a new value that is applied to that case. For example FF-9 was modeled as case 6, and the HGL for all of the tanks are “changed” to the HGL’s recorded for that test for KYPIPE to use those in the hydraulic analysis. If not performing extended period simulations, KYPIPE uses these demand patterns and change patterns as a series of steady state simulations.

To model the fire flows, junction nodes were added at the locations in the model of the hydrants used in testing. In the change pattern, the junction corresponding to the flowing hydrant was set as the recorded flow from the test. In order to analyze both static and residual pressures, two sets of change data were used that were exactly the same except one changed the demand at these junctions to zero.

Using this procedure, KYPIPE will report the results of all the simulation runs (all the fire flow tests) simultaneously. This setup allows the modeler to easily see the effect of changes on all tests; which is advantageous since changing pump or pipe attributes will affect all other simulation runs, if only slightly.

6.2.2 Pump Curve Calibration

The manufacturer's pump curve for both high service pumps and booster pump are shown in Appendix A: Pump Curves on page 64. A pump manufacturer provides the utilities with this curve upon installation, though they are of questionable accuracy to actual pump performance. This concept along with wear and stress on the impeller over time will negatively affect pump performance. If pumps are not tested periodically to update the pump curve, the actual pump curve could vary dramatically from the curve provided by the manufacturer. This attribute is commonly altered during the calibration process (AWWA, 2005).

Paris Combined Utilities have two recording sensors on the two pumps from the water treatment plant. The pumps have a combined outflow, which is where both sensors are located. Paris Utilities measures flow with an electronic venturi meter and pressure with a differential pressure cell. For redundancy a digital recording gauge of known accuracy was placed on a tap immediately off of the pump discharge and pressures were recorded over a full day. Because the equipment is not available to provide redundant measurement of the pump discharge flow, this remains a potential source of error.

The pressures recorded by the digital gauge were plotted against the flow from the pump as recorded by the venturi meter to produce a pump curve. These data points only include flows and pressures that occur over a typical day. To investigate the lower flow range of the pump curve, a gate valve was incrementally closed downstream of the pump and pressure recorder, causing a reduction in flow. The results of this test are shown below in Table 21, including the pressure and flowrate for the high service pump.

Table 21 High Service Pump Data

Pressure (psi)	Flow (GPM)
135.0	1850
129.0	2020
125.0	2250
121.1	2450
119.4	2500
118.4	2550
118.2	2600
117.6	2650
114.3	3000
113.6	3050
113.2	3100

6.2.3 C-Factor Adjustment

The calibration of the Paris model involved incremental changes in pipe roughness. The pipes were changed as groups, and these groups are classified by diameter, age and material as previously shown. This aids calibration, as pipes of similar size and material should have similar roughness. However, pipes with similar attributes will wear differently over the years depending on their location in the system, causing their roughness values to diverge. The initial model used published C-factor values (labeled as initial C-factor) for the calibration groups so as to develop a baseline from which to make adjustments.

Table 22 Initial C-Factors

Group	Material	Diameter	Initial C-Factor
0	Cast Iron	Oldest (1926-1931)	70
1	Cast Iron	Older (1947-1959)	80
2	Cast Iron	All other	100
3	Ductile Iron	Large	140
4	Ductile Iron	Medium	130
5	Ductile Iron	Small	120
6	Other	All	120
7	PVC	Large	140
8	PVC	Medium	130
9	PVC	Small	120

Size Descriptor	Pipe Diameter
Large	Greater than 6”
Medium	6” Diameter
Small	Less than 6”

The calibration began by focusing on the static pressures. The static pressures are indicative of the ambient conditions in the system, so the tank levels and pump head are the main factors affecting these. Because of this, examining differences between initial model results and measured static pressures is a good way of checking the data collection before getting into the calibration process. For the Paris model, once the tank elevations and depths were confirmed, the major component affecting static pressures was the pump. If, for a test case, the pump in the model was operating at a different pressure and flow (i.e. a different point on the pump curve) than the actual pump was during the test, then adjustments were required.

The operating point (pressure and flow) for a pump is a result of what is called the “system curve”. This curve is a relationship between energy head and flow in the system and is a quantitative description of how hard a pump has to push water into the system in order to produce a certain flow. A pump will push water until it reaches the point on its pump curve where it can no longer overcome the head loss and elevation change in the system; this point is called the operating point. Figure 19 below illustrates the concept of a pump curve and operating point.

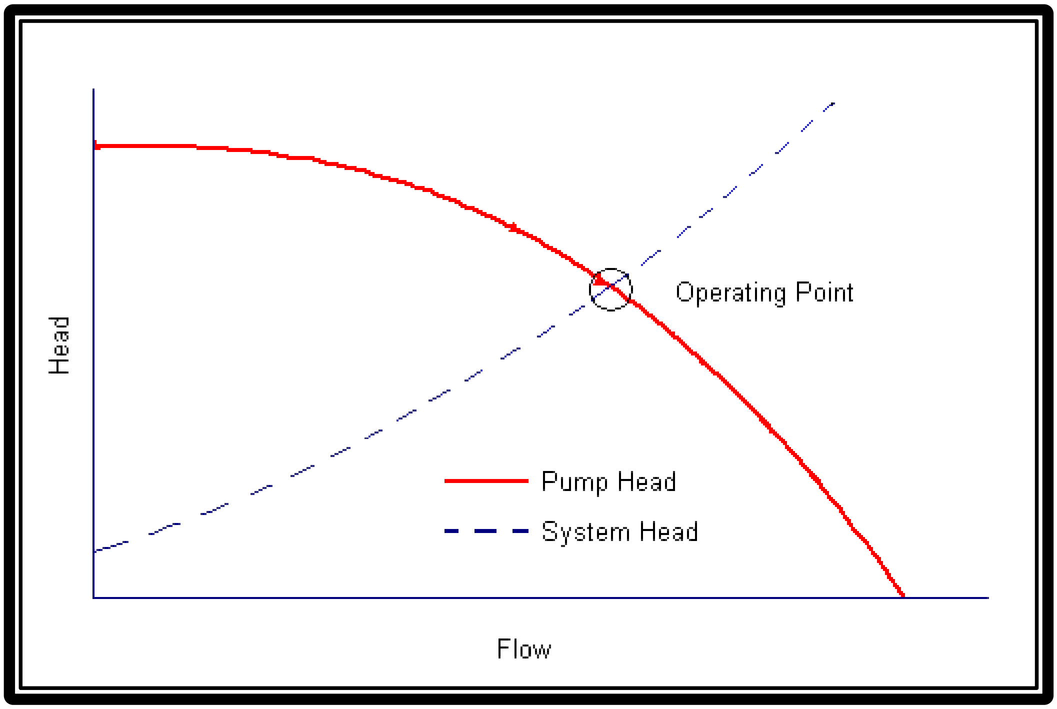

Figure 19 System Curve and Pump Curve

The initial model run for Paris yielded pump flows that were consistently higher than the measured discharges with correspondingly lower pressures. Since the pump curve had been calibrated, it was clear that the adjustment had to be made in the system to change the operating point to be higher pressures and lower flows. To accomplish this the losses around the pump were increased by lowering the C-factors of the immediately adjacent pipe groups 0 and 1 (old cast iron pipe). This causes a reduction in pressures in some areas of the system but an increase in others as the pump is now operating at a higher pressure.

Another factor in static pressure calibration is demand distribution. In the outer neighborhoods, consisting entirely of single family houses, some of the calculated pressures were lower than measured. Some of these neighborhoods are fed by a single pipe stretching out from the the main system, where the entire demand from the neighborhoods travels through that one pipe. Therefore, there can be significant losses with relatively small demands in those neighborhoods. By adjusting the residential demand factor for that time of day the demand is reduced along with the losses in the main feeding pipe. This was often a solution to negative deviations in model and measured static pressures.

To calibrate the C-factors, a table of the measured static and residual pressures at all fire flow tests was created and compared to the calculated pressures at those same nodes in the model. If the calculated residual pressure was lower than the measured residual pressure, the model had more losses than the actual system. KYPIPE can display simulation results visually, such as junction pressures or pipe flow, by applying a color to a range of results. For C-factor calibration this feature was used to display the pipe losses (in feet of head loss) for each simulation. This allowed the user to easily pick out where the largest losses were occuring and which pipe group needed to be adjusted. The roughness for that group was then increased and the simulation was rerun, repeating the process until the pressures converged.

6.2.4 Model Sensitivity to C-Factor Analysis

A sensitivity analysis was also conducted on the model to investigate how changes to the determined C-factors would affect behavior of the system. Fire Flow testing sites were used to observe the changes in pressure at the residual hydrant used in the test. It was necessary to investigate changes to the system if the C-factor in every calibration group of pipes was altered. It was also necessary to make varying degrees of change to the C-factors of each calibration group. For example, the calibration group #4 (consisting of ductile iron pipes with medium diameters) was assigned a C-factor of 180 after calibration. In the sensitivity analysis, the C-factor for this group was changed to 150, 100, and 50. A model simulation was run and the pressure was observed at the residual hydrant for each new C-factor. Similar changes were made to the C-factors of all remaining calibration groups and pressure changes were examined.

The results in Table 23 show the changes in pressure of the residual hydrant in fire flow tests after changes were made to the C-factor of the calibration group listed.

Table 23 Model C-Factor Sensitivity Results

16	FF-2	J-307	FF-3	J-251	FF-5	J-717	FF-6	J-760	FF-7	J-724	FF-9	J-516	FF-11	J-464	FF-12	J-6
hannon Rd		Clinton Dr		Duncan Ave		Higgins Ave		Castle Blvd		WWTP		Houston Oaks		Mt View Dr		
SE	1	CASE	2	CASE	3	CASE	4	CASE	5	CASE	6	CASE	7	CASE	8	CA
tic	Residual	Static	Residual	Static	Residual	Static	Residual	Static	Residual	Static	Residual	Static	Residual	Static	Residual	Sta
.7	67.3	54.1	39.5	71.7	71.0	68.2	66.5	66.9	56.3	97.8	87.2	61.2	46.3	65.1	25.1	51
.7	67.2	54.1	39.4	71.7	70.7	68.2	65.2	67.0	56.1	97.9	87.0	61.2	46.2	65.1	25.0	51
.6	67.4	55.1	39.6	71.6	67.2	68.0	54.9	67.1	56.1	97.6	85.5	61.3	46.9	65.0	25.1	52
.7	67.8	55.5	40.5	71.5	67.6	68.1	55.0	67.4	56.8	97.5	85.2	61.5	46.8	65.4	25.6	52
.7	67.7	55.2	40.1	71.7	67.7	68.1	55.0	67.3	56.6	97.6	85.4	61.4	46.6	65.3	25.4	52
.6	67.4	55.1	39.6	71.6	67.2	68.0	54.9	67.1	56.1	97.6	85.5	61.3	46.9	65.0	25.1	52
.7	69.2	55.1	41.2	71.7	67.8	68.1	55.1	67.3	57.9	97.6	85.9	61.4	48.7	65.6	36.5	52
.6	67.4	54.8	39.6	71.7	67.2	68.1	54.9	67.1	56.1	97.7	85.5	61.3	46.9	65.2	25.1	52
.6	58.6	54.2	31.5	71.8	67.6	68.0	53.3	66.3	47.0	98.0	79.2	60.9	35.5	62.7	-82.7	51
.6	67.4	54.8	39.6	71.7	67.2	68.1	54.9	67.1	56.1	97.7	85.5	61.3	46.9	65.2	25.1	52
.6	62.5	55.4	38.5	71.8	67.6	68.1	54.6	67.3	53.0	97.6	68.9	61.6	32.9	65.2	22.2	52
.6	52.8	57.6	36.4	72.0	67.4	68.0	53.9	68.1	47.1	97.5	9.5	62.7	-12.5	65.6	17.1	53
.6	67.4	54.8	39.6	71.7	67.2	68.1	54.9	67.1	56.1	97.7	85.5	61.3	46.9	65.2	25.1	52
.6	62.5	55.2	26.8	71.7	67.7	68.1	54.7	67.1	54.0	97.7	85.4	61.2	45.2	65.1	24.7	52
.6	48.1	55.6	-21.4	71.7	67.7	68.1	54.0	67.0	44.6	97.7	85.3	61.2	44.3	65.0	24.2	53
Very Few Pipes																
.6	67.4	54.8	39.7	71.7	67.7	68.1	54.9	67.1	56.1	97.6	85.6	61.3	46.1	65.2	26.8	52
.6	67.4	55.1	39.6	71.6	67.2	68.0	54.9	67.1	56.1	97.6	85.5	61.3	46.9	65.0	25.1	52
.6	67.4	54.8	39.7	71.8	67.7	68.1	54.9	67.1	56.1	97.8	83.7	61.3	45.6	65.1	7.6	52
.8	67.4	55.1	39.6	71.6	67.2	68.0	54.9	67.1	56.1	97.6	85.5	61.3	46.9	65.0	25.1	52
.5	64.1	54.7	36.8	71.7	67.7	68.1	54.9	66.9	52.7	97.7	85.4	61.2	44.5	65.1	24.6	51
.4	61.1	54.7	32.6	71.8	67.7	68.1	54.9	66.7	48.5	97.7	85.4	61.2	43.0	64.9	24.0	51
.8	67.4	55.1	39.6	71.6	67.2	68.0	54.9	67.1	56.1	97.6	85.5	61.3	46.9	65.0	25.1	52
.5	67.0	54.7	38.9	71.7	67.7	68.1	54.9	67.2	54.0	97.7	85.4	61.3	45.6	65.2	25.0	52
.4	66.2	54.8	37.0	71.8	67.7	68.1	54.9	67.3	47.9	97.7	85.3	61.2	44.9	65.1	24.7	52
Very Few Pipes																

6.3 Calibration Results

6.3.1 Final Calibrated C-Factors

The calibration process resulted in alterations to the C-factors for pipes in the system model. These new C-factors, developed for each calibration group, were assigned to pipes in the model and varied slightly from the published C-factors initially used in the model. These results are shown below in Table 24.

Table 24 C-Factor Calibration Results

Group	Material	Diameter	Initial C-Factor	C-Factor
0	Cast Iron	Oldest (1926-1931)	70	40
1	Cast Iron	Older (1947-1959)	80	70
2	Cast Iron	All other	100	120
3	Ductile Iron	Large	140	180
4	Ductile Iron	Medium	130	180
5	Ductile Iron	Small	120	150
6	Other	All	120	130
7	PVC	Large	140	160
8	PVC	Medium	130	160
9	PVC	Small	120	150

Size Descriptor	Pipe Diameter
Large	Greater than 6”
Medium	6” Diameter
Small	Less than 6”

6.3.2 Comparison of Pressures between Model and Field Tests

Results from each fire flow test performed were also found using the model and compared to real field results. The pressure drops (between static and residual pressure) were observed for both model and field results, and the percent difference was calculated. The results are shown below in Table 25.

Table 25 Fire Flow Calibration Results

Test	Location	Static Pressure (psi)	Hydrant Flow (gpm)	Residual Pressure (psi)	Pressure Drop (psi)	Percent Diff
FF-2	Shannon Road Model	82.0 81.8	1300	72.0 67.4	10.0 14.4	44%
FF-3	Clinton Drive Model	54.0 55.1	1080	40.0 39.6	14.0 15.5	11%
FF-5	Duncan Avenue Model	76.0 71.6	489	48.0 67.2	28.0 4.4	-84%
FF-6	Higgins Avenue Model	68.0 68.0	650	52.0 54.9	16.0 13.1	-18%
FF-7	Castle Boulevard Model	65.0 67.1	1220	55.0 56.1	10.0 11.0	10%
FF-9	Wastewater Treatment Model	98.5 97.6	1501	88.5 86.5	10.0 11.1	11%
FF-11	Houston Oaks Drive Model	62.0 61.3	1107	51.0 46.9	11.0 14.4	31%
FF-12	Mt View Drive Model	64.0 65.0	780	28.0 25.1	36.0 39.9	11%
FF-13	Karla Drive Model	45.0 52.4	645	16.5 14.1	28.5 38.3	34%
FF-14	Downtown High St Model	86.0 83.1	531	54.0 55.4	32.0 27.7	-13%

6.4 Model Validation

6.4.1 24 hour-EPS Simulation

In order to validate the model calibration process, an Extended Period Simulation (EPS) was performed on the calibrated model. A 24 hour period was examined in 30 minute intervals. Specifically, the pressures at the ByPass tank, 10th Street tank, and the Pump-1 were examined. The change in pressure of the storage tanks reflects the change in water level in the tanks. Data were also measured in the field over a several day period using continuous pressure recorders, storing data at 15 minute intervals. The pressure data for the ByPass tank, 10th St tank, and Pump-1 taken on July 3, 2012 were compared to the EPS performed on the model. This comparison can be seen graphically; the model results are compared to the measured tanks levels for the 10th St and ByPass storage tanks in Figure 20. The results for pump head from both the model simulation and measured field results are shown in Figure 21.

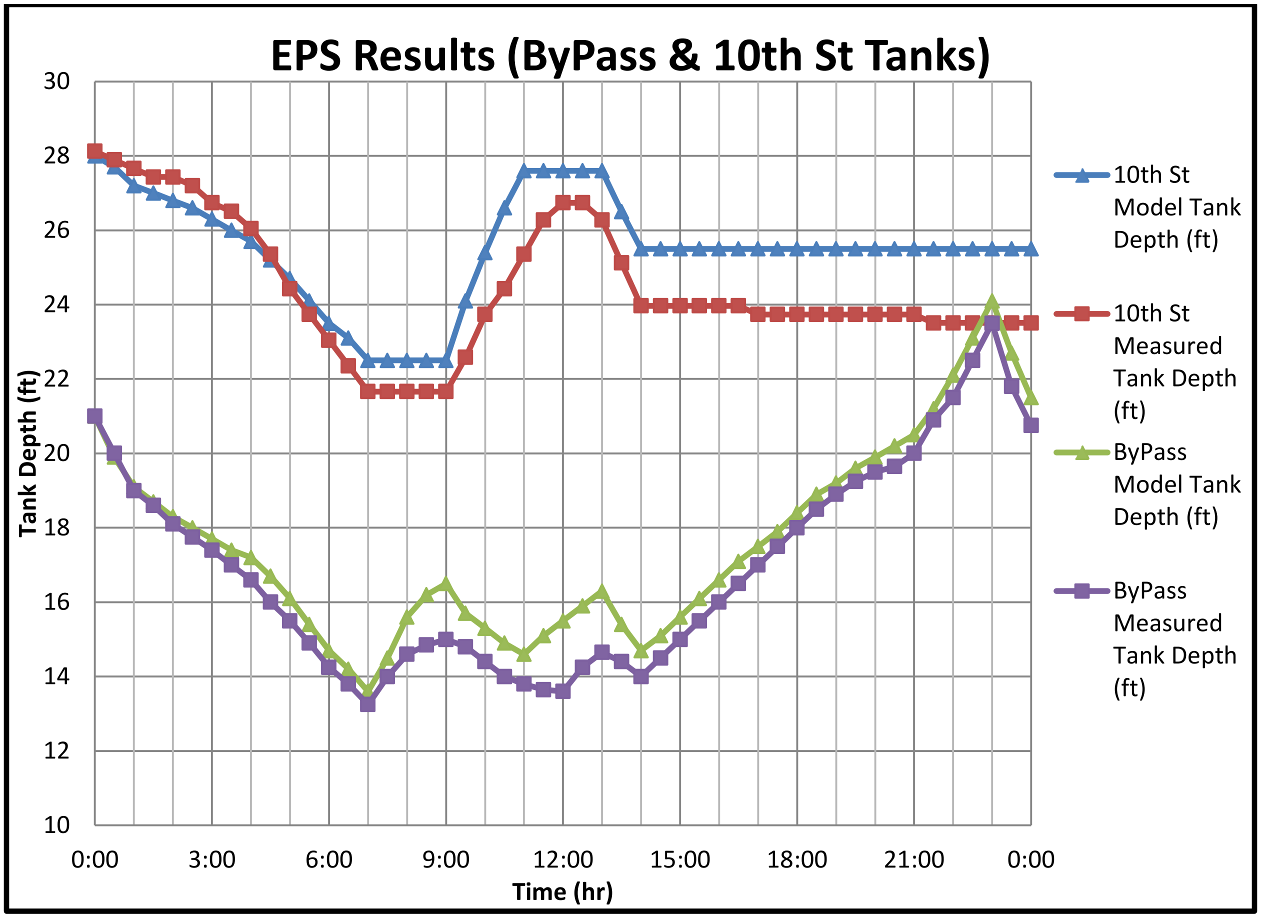

Figure 20 EPS Results for Storage Tanks for 7/3/2012

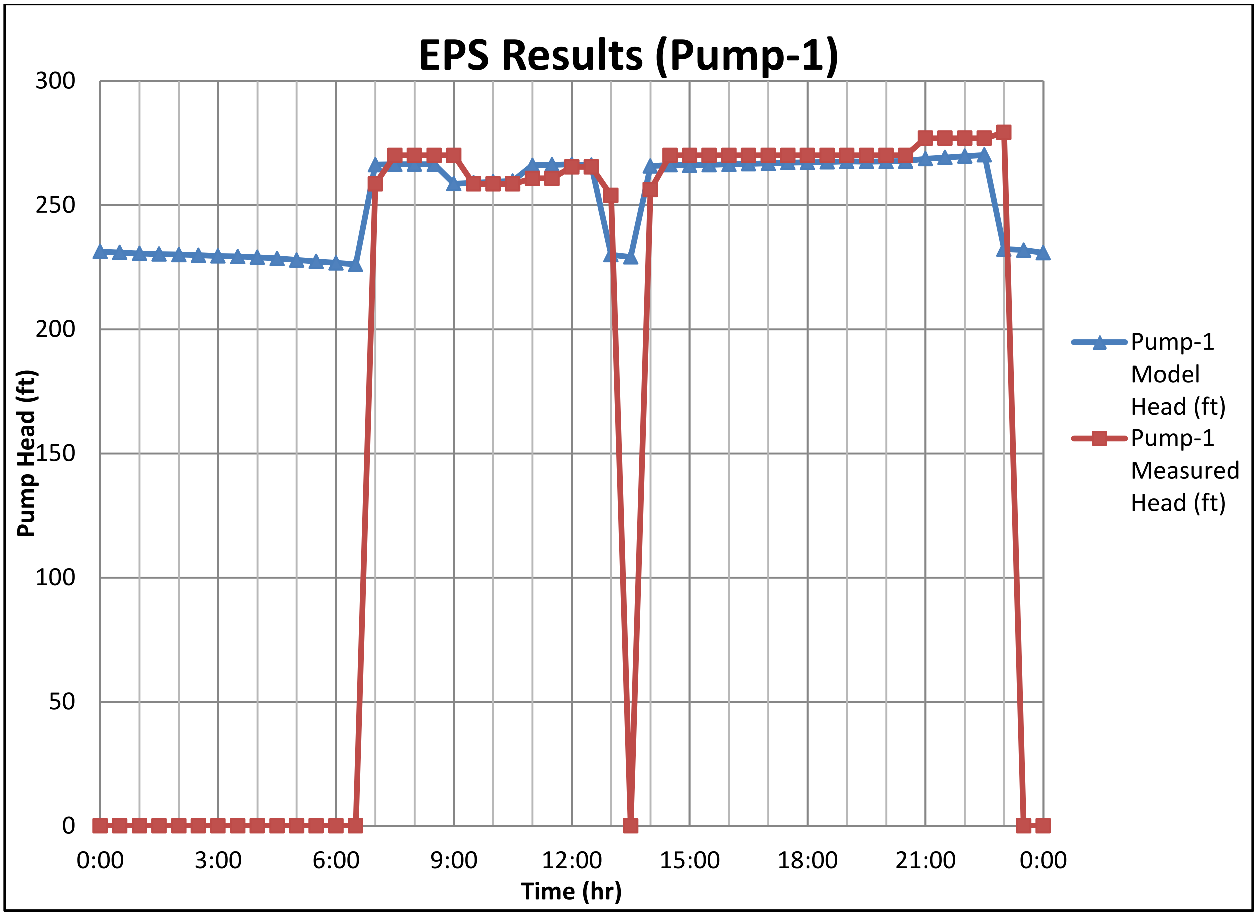

Figure 21 EPS Results for High Service Pump

The results from the model and field data can be easily compared by examining the values for tank depth (10^{th} St and ByPass tanks) and pump head shown in Table 26. The elevation of the bottom of both storage tanks was subtracted from the hydraulic grade line to find the depth of water in the tank. This was executed for both the model EPS results and collected field data, and the percent difference between the values was calculated. The pump head was also calculated using the known elevation of the pump. A portion of the measured results for Pump-1 show a pump head of 0 feet, and this occurs when the pump is not operating. The goal of the EPS is to show that all values of percent difference for results comparing the model and measured results remain below 10%.

Table 26 EPS Simulation Results

	10th Street Tank			ByPass Tank			Pump -1		
Time	Model Tank Depth (ft)	Measured Tank Depth (ft)	% Diff	Model Tank Depth (ft)	Measured Tank Depth (ft)	% Diff	Model Pump Head (ft)	Measured Pump Head (ft)	% Diff
0:00	28	28.1	0.4%	21	21	0.0%	231.3	0	0
0:30	27.7	27.9	0.7%	19.9	20	0.5%	230.9	0	0
1:00	27.2	27.7	1.7%	19.1	19	0.5%	230.5	0	0
1:30	27	27.4	1.6%	18.7	18.6	0.5%	230.3	0	0
2:00	26.8	27.4	2.3%	18.3	18.1	1.1%	230.1	0	0
2:30	26.6	27.2	2.2%	18	17.75	1.4%	229.8	0	0
3:00	26.3	26.7	1.6%	17.7	17.4	1.7%	229.5	0	0
3:30	26	26.5	1.9%	17.4	17	2.4%	229.3	0	0
4:00	25.7	26.0	1.3%	17.2	16.6	3.6%	229	0	0
4:30	25.2	25.4	0.6%	16.7	16	4.4%	228.5	0	0
5:00	24.7	24.4	1.1%	16.1	15.5	3.9%	227.9	0	0
5:30	24.1	23.7	1.5%	15.4	14.9	3.4%	227.3	0	0
6:00	23.5	23.0	2.0%	14.7	14.25	3.2%	226.7	0	0
6:30	23.1	22.4	3.3%	14.2	13.8	2.9%	226.1	0	0
7:00	22.5	21.7	3.9%	13.6	13.25	2.6%	266.3	258.5	3.0%
7:30	22.5	21.7	3.9%	14.5	14	3.6%	266.4	270	1.3%
8:00	22.5	21.7	3.9%	15.6	14.6	6.8%	266.5	270	1.3%
8:30	22.5	21.7	3.9%	16.2	14.85	9.1%	266.4	270	1.3%
9:00	22.5	21.7	3.9%	16.5	15	10.0%	258.6	270	4.2%
9:30	24.1	22.6	6.7%	15.7	14.8	6.1%	259	258.5	0.2%
10:00	25.4	23.7	7.0%	15.3	14.4	6.2%	259.4	258.5	0.4%
10:30	26.6	24.4	8.9%	14.9	14	6.4%	259.7	258.5	0.5%
11:00	27.6	25.4	8.9%	14.6	13.8	5.8%	266	260.8	2.0%
11:30	27.6	26.3	5.0%	15.1	13.65	10.6%	266.2	260.8	2.1%
12:00	27.6	26.7	3.2%	15.5	13.6	14.0%	266.4	265.4	0.4%
12:30	27.6	26.7	3.2%	15.9	14.25	11.6%	266.1	265.4	0.3%
13:00	27.6	26.3	5.0%	16.3	14.65	11.3%	230	253.8	9.4%
13:30	26.5	25.1	5.5%	15.4	14.4	6.9%	229.1	0	0
14:00	25.5	24.0	6.4%	14.7	14	5.0%	265.7	256.2	3.7%
14:30	25.5	24.0	6.4%	15.1	14.5	4.1%	266.2	270	1.4%
15:00	25.5	24.0	6.4%	15.6	15	4.0%	266	270	1.5%

15:30	25.5	24.0	6.4%	16.1	15.5	3.9%	266.2	270	1.4%
16:00	25.5	24.0	6.4%	16.6	16	3.7%	266.4	270	1.3%
16:30	25.5	24.0	6.4%	17.1	16.5	3.6%	266.6	270	1.3%
17:00	25.5	23.7	7.4%	17.5	17	2.9%	266.8	270	1.2%
17:30	25.5	23.7	7.4%	17.9	17.5	2.3%	267.1	270	1.1%
18:00	25.5	23.7	7.4%	18.4	18	2.2%	267.2	270	1.0%
18:30	25.5	23.7	7.4%	18.9	18.5	2.2%	267.4	270	1.0%
19:00	25.5	23.7	7.4%	19.2	18.9	1.6%	267.6	270	0.9%
19:30	25.5	23.7	7.4%	19.6	19.25	1.8%	267.5	270	0.9%
20:00	25.5	23.7	7.4%	19.9	19.5	2.1%	267.6	270	0.9%
20:30	25.5	23.7	7.4%	20.2	19.65	2.8%	267.7	270	0.9%
21:00	25.5	23.7	7.4%	20.5	20	2.5%	268.7	276.9	3.0%
21:30	25.5	23.5	8.5%	21.2	20.9	1.4%	269.2	276.9	2.8%
22:00	25.5	23.5	8.5%	22.1	21.5	2.8%	269.7	276.9	2.6%
22:30	25.5	23.5	8.5%	23.1	22.5	2.7%	270.2	276.9	2.4%
23:00	25.5	23.5	8.5%	24.1	23.5	2.6%	232.3	279.2	16.8%
23:30	25.5	23.5	8.5%	22.7	21.8	4.1%	231.9	0	0
0:00	25.5	23.5	8.5%	21.5	20.75	3.6%	230.8	0	0

6.4.2 Diurnal Demand Pattern

During the calibration process, real water usage data was used to assign demands to nodes throughout the system. When the model is used for future simulations, demand factors will be needed to estimate demand patterns during the desired time of simulation. These demand factors will adjust water usage throughout the system based on time and location. The graph shown in Figure 22 shows the demand factors found to be accurate during the time of testing.

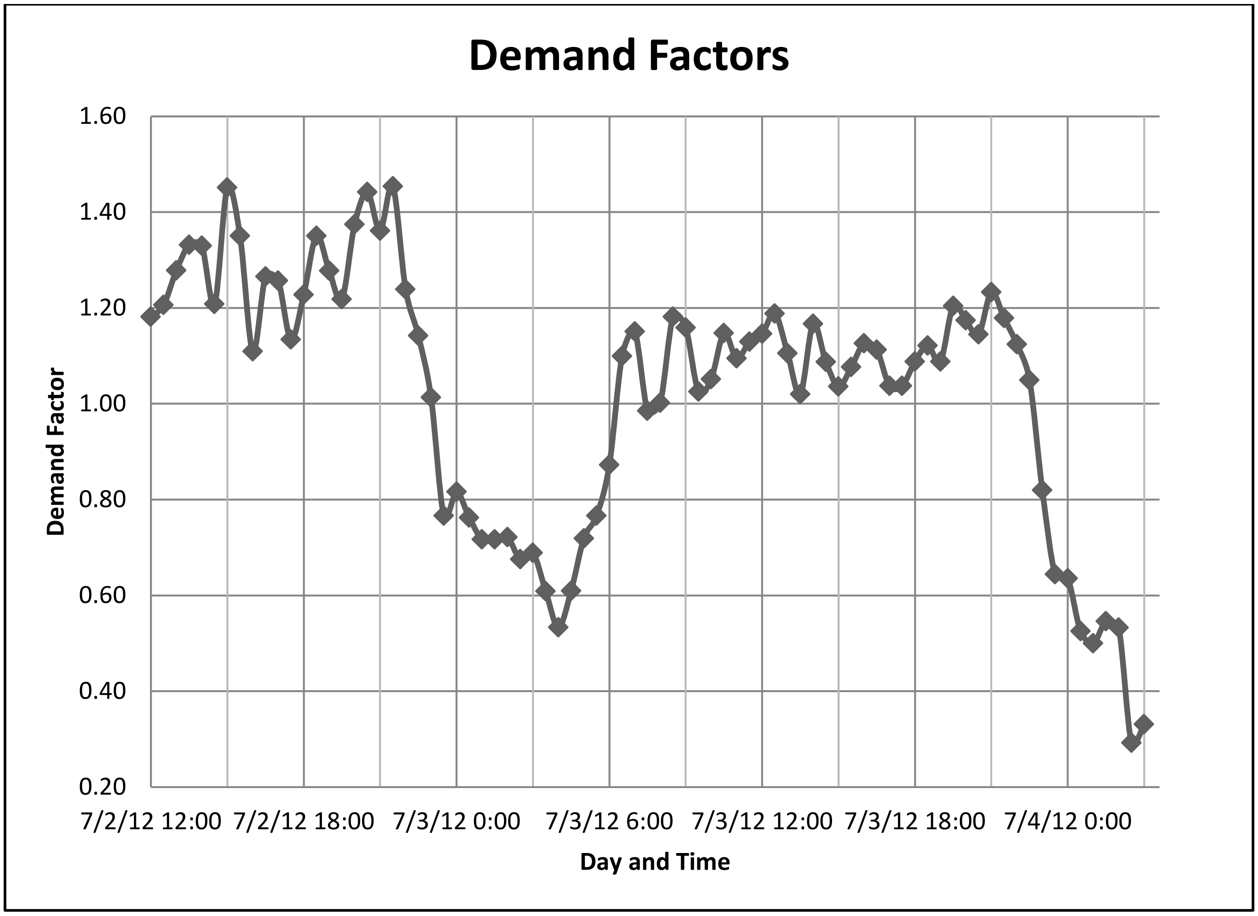

Figure 22 Demand Factors for Week of 7/2/2012-7/5/2012

7.0 Summary

Water utilities would greatly improve their ability to make operational decisions regarding their distribution system with a solid understanding of their system flow dynamics. Decisions regarding everyday operation along with system improvements can have significant impact on the community and require substantial investment as well. A distribution system model is a helpful tool for simulating the behavior of a system under various conditions, but it is important that the model be an accurate representation of the actual conditions in the system.

The calibration process will ensure that the model is able to accurately predict system behavior. Once hydraulic tests are executed to gather information about the system, these field results are compared to behavior predicted by the developed hydraulic model. The model developed prior to calibration encompasses all known information about the system, which would provide a fairly reasonable representation of system behavior. During the calibration process, data within the model is adjusted until behavior predicted by the model reasonably agrees with measured system performance over a range of operating conditions. This causes the model to include parameters of the system that are unknown or altered over time, such as closed valves, weakened pump performance, increased roughness in pipes over time, etc. These adjustments made to the model allow the utility to observe flow dynamics and behavior of the system accurately through model simulations. Because the model will closely match true conditions of the system, the model will be a critical tool for the utility.

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Appendix A: Pump Curves

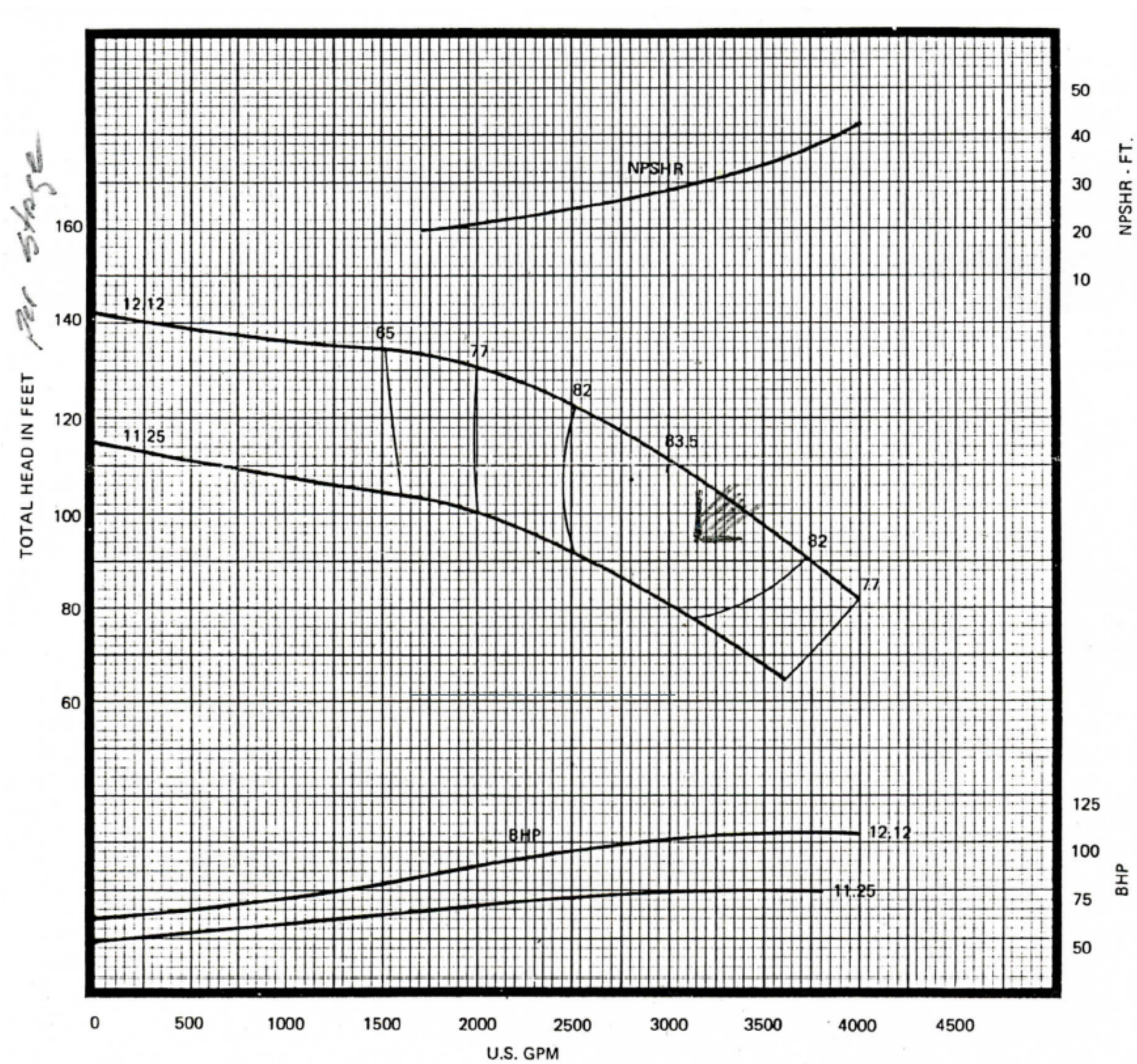

Figure 23 Manufacturer's High Service Pump #1 Curve

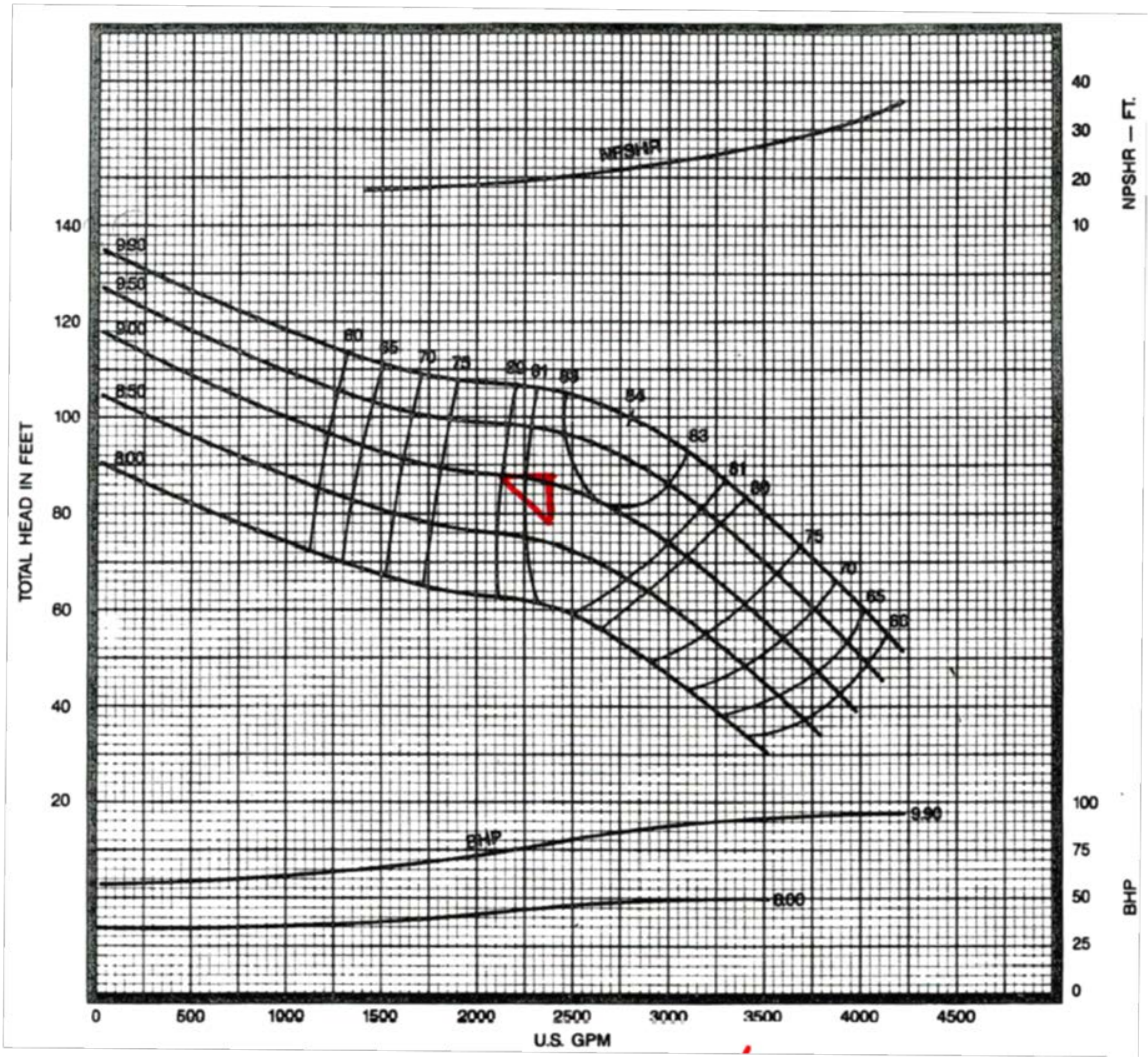

Figure 24 Manufacturer's High Service Pump #2 Curve

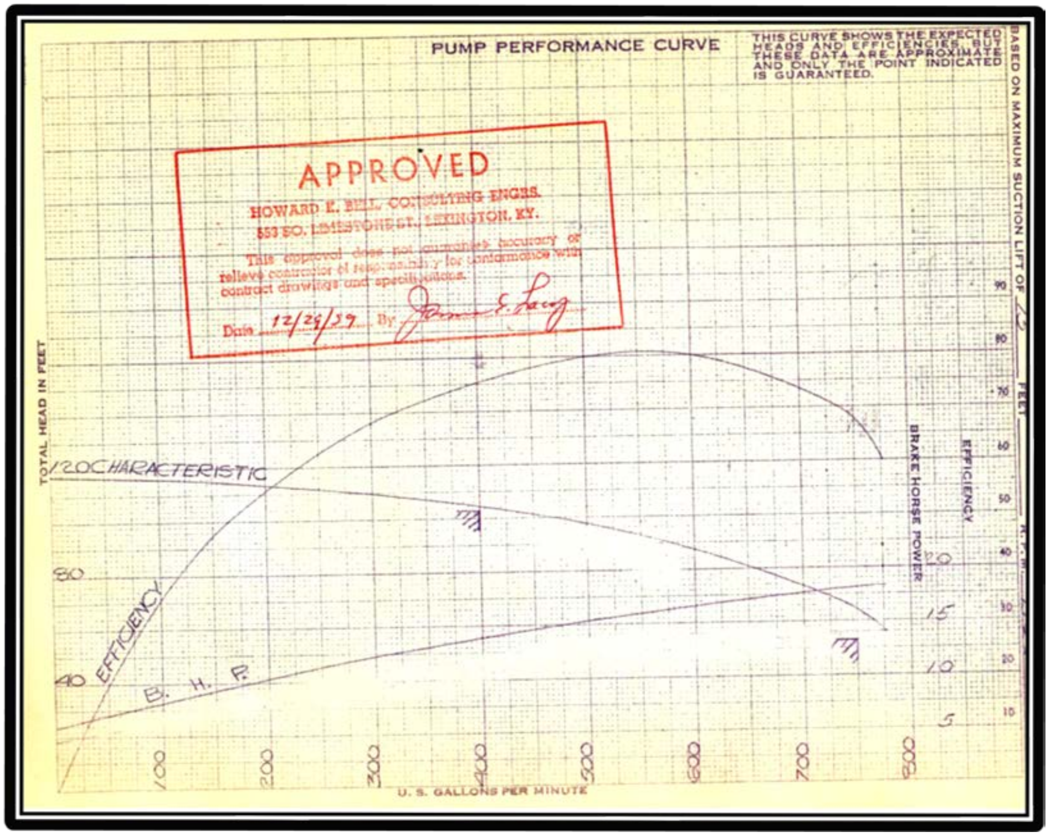

Figure 25 Manufacturer's Booster Pump Curve

Appendix B: Surveying Procedures and Data

B.1 C-Factor Surveying

B.1.1 C-Factor Survey Procedure

During the C-Factor Testing prescribed for this project, it was necessary to determine the difference in elevation between hydrants. The following provides an outline of the appropriate procedure for performing a C-Factor Hydrant Elevation Survey. NOTE: Prior to any surveying activities, the proper care and operation of the total station and its accompanying equipment should be studied and reviewed.

1) Identify the hydrants that are designated as the flow and the residual and position a Leica TC400NL Total Station and its tripod so that the machine can have a clear line of sight to both hydrants.
2) Level the total station and measure the instrument's height using a tape measure, yard stick or similar device. Duplicate this height on the prism rods. In situations where it is impractical or undesirable for the instruments and rods to have the same height, record each individual height for use in future calculation.
3) At this point, the total station is turned on and the rods are placed at their respective hydrants. Place the rods on top of the nut located in the center of the desired flow nozzle. This will approximate the elevation at the center of the hydrant's flow.
4) Once the rods are placed and steady, the total station operator can take a measurement by sighting the center of the prism and pressing the "DISP" button on the instrument. After a few moments, the total station will display the slope distance, horizontal distance, vertical angle and the vertical distance between the prism and the instrument's sight. The vertical distance should be recorded for this hydrant on the C-Factor Surveying Data Log.
5) Step 4 should be repeated, leaving the total station in place and simply turning it towards the second hydrant.
6) Once the vertical distances for both hydrants have been measured and recorded, elevations will be assigned to each residual hydrant to differentiate which hydrant is located at a higher elevation (with the lower elevation being assigned a 0 ft elevation). The difference between elevations of the residual hydrants will be calculated and recorded on the same C-Factor Surveying Data Log.

B.1.2 C-Factor Surveying Results

Table 27 shows the relevant calculated results needed for C-factor calculations, and Figure 26 illustrates the log used to record surveying data in the field.

Table 27 C-Factor Surveying Results

C-Factor Surveying Data Log										
Site ID	**Flow Hydrant ID**	**Res 1 Hydrant ID**	**Res 2 Hydrant ID**	**Elev Diff. 1 & 2 (ft)**	**Dist. between 1 & 2 (ft)**	**Res #3 Hydrant ID (if any)**	**Elev diff 2 & 3 (ft)**	**Elev diff 1 &3 (ft)**	**Dist. between 1 & 3 (ft)**	**Dist. between 2 & 3 (ft)**
C-1	H-78	H-77	H-76	4.075	479.420					
C-3	H-84	H-82	H-81	-11.67	436.037	H-74	-2.929	-14.597	996.251	560.214
C-9	H-191	H-189	H-190	2.382	294.953					
C-10	H-317	H-398	H-65	7.615	480.0					
C-11	H-438	H-437	H-436	13.85	486.663					

C-Factor Surveying Data Log

Site ID	Location	Flow Hydrant				Residual Hydrant #1				Residual Hydrant #2						Residual #3 (if any)						
		Hydrant ID	Vertical Distance Reading	Horizontal Reading	Angle	Hydrant ID	Vertical Distance Reading	Horizontal Reading	Angle	Hydrant ID	Vertical Distance Reading	Horizontal Reading	Angle	Elevation Difference 1 & 2 (ft)	Distance between 1 and 2 (ft)	Hydrant ID	Vertical Distance Reading	Horizontal Reading	Elevation difference 2 & 3 (ft)	Elevation difference 1 &3 (ft)	Distance between 1 & 3 (ft)	Distance between 2 & 3 (ft)
C-1	Glenview Road	H-78				H-77	0.348	226.767		H-76	4.423	257.948	196.989	4.075	479.420							
C-3	Redbud Lane near intersection of Glenview	H-84				H-82	17.857	985.028	100.083	H-81	6.189	549.707	102.028	-11.668	436.037	H-74	3.260	48.444	-2.929	-14.597	996.251	560.214
C-9	High Street between 8th and 10th Street	H-191				H-189	0.998	58.788		H-190	3.380	259.582	121.967	2.382	294.953							
C-10	Houston Oaks Drive (552)	H-317				H-398	888.748			H-65	896.363			7.615								
C-11	Houston Oaks Drive (442)	H-438	4.181	431.844	186.3972	H-437	-13.659	529.662	0	H-436	0.186	62.499	315.978	13.845	486.663							

Notes
*Water will be flowing from Hydrant #2 to Hydrant #1 to Flow Hydrant
** For Differential survey: Elevation of the Total Station = 0' and record elevation change to the next hydrant
Example: Total Station is set on Residual Hydrant #2, Rod is set on Residual Hydrant #1. Elevation of Total Station (Hyd #2) is 0'. Elevation of Rod (Hyd #1) is recorded with the appropriate sign (negative elevation of rod means Residual Hydrant #1 is below Residual Hydrant #2)
*** We don't need the Elevation of the Flow Hydrant

Figure 26 C-Factor Surveying Data Log

B.2 Fire Flow Surveying

B.2.1 Fire Flow Survey Procedure

During the Fire Flow Testing prescribed for this project, it was necessary to determine the absolute elevations of the hydrants involved in this testing. The following provides an outline of the appropriate procedure for performing a Fire Flow Hydrant Elevation Survey. NOTE: Prior to any surveying activities, the proper care and operation of the total station and its accompanying equipment should be studied and reviewed.

1) In the area where these tests will be performed, it will be necessary to locate Geodetic Benchmarks to determine the elevations. To accomplish this, surveyors should proceed to the website http://benchmarks.scaredycatfilms.com to find possible locations. http://www.ngs.noaa.gov/ should also provide helpful, more detailed descriptions of individual benchmarks.

2) Proceed to the physical areas where the most useful benchmarks have been identified and determine whether they are readily available or accessible. If not, the surveyors may employ the use of a metal detector and/or a shovel to uncover the desired marker if it is determined to be appropriate.

   NOTE: Circumstances involving the actual location of a benchmark vary, so respect and care for private property rights and personal safety should be considered and observed at all times. For instance, if a benchmark is believed to be located in someone's property, surveyors should not continue their search for said benchmark without permission from the property owner. Likewise, if a benchmark is located in the middle of a road or some other similarly hazardous area, practical judgment should be used to avoid placing surveyors or equipment in danger.

3) Once a useable benchmark has been located, surveyors should use standard surveying procedure known as leveling to proceed from the benchmark to the desired hydrant locations. This will involve identifying the most accessible and efficient path to take between the benchmark and the hydrants, keeping in mind that the fewer shots that can be taken, the less error can be introduced into the elevation measurements.

4) Position a Leica TC400NL total station and tripod so that it has a clear line of sight to the benchmark and to a point along the path toward the desired hydrant location where a prism rod can be placed.

5) Place the total station on its tripod and make sure the instrument is level.

6) Once level, the height of the instrument should be measured using a tape measure, yard stick or similar device and should then be duplicated on the prism rods. In situations where it is impractical or undesirable for the instruments and rods to have the same height, record each individual height for use in future calculation.

7) At this point, the instrument can be turned on and the rods can be placed at their desired positions – one on the benchmark and one along the path toward the hydrant.

8) Once the rods are placed and steady, the total station operator can take a measurement by sighting the center of the prism located at the benchmark and pressing the "DISP" button on the instrument.

9) After a few moments, the total station will display the slope distance, horizontal distance, vertical angle and the vertical distance between the prism and the instrument's sight. The vertical distance should be recorded as the "Backsight."

10) Leaving the total station in place and simply turning it towards the second prism, Step 4 should be repeated. The vertical distance here should be recorded as the "Foresight."

11) Subtract the Backsight from the Foresight to determine the difference in elevation between the two points and thus the total elevation of the second prism's location.

12) Repeat steps 4-10 by backsighting to the second prism's location and foresighting to another point further along the path to the desired hydrant's location. This should be repeated as many times as is necessary to reach the final location.

13) Once in position to measure the elevation of the fire flow hydrants, place the rods on top of the nut at the center of the hydrant's desired flow nozzle to approximate the elevation at the center of the flow.

14) Record the elevations of both the flow and residual fire flow hydrants on the Fire Flow Surveying Data Log to use in future calculations.

    NOTE: It is good practice to take accurate field notes throughout this procedure to make interested parties aware of any special circumstances involved in the surveyors' measurements and keep track of any error introduced therein.

B.2.2 Fire Flow Survey Results

Table 28 shows the relevant elevation results needed for fire flow calculations.

Table 28 Fire Flow Surveying Data Log

Fire Flow Surveying Data Log								
Site ID	Location	Flow Hydrant		Residual Hydrant			Residual #2 (if any)	
		Hydrant ID	Elevation (ft)	Hydrant ID	Elevation (ft)	Elevation Difference (ft)	Hydrant ID	Elevation (ft)
FF-2	Shannon Road	H-79	850.73	H-80	842.82	7.902		
FF-3	Clinton Drive near Citation Drive	H-97	895.97	H-90	908.84	12.866		

FF-5	Duncan Ave between Pleasant and Vine St	H-200	861.26	H-278	862.14	0.883		
FF-6	Higgins Ave near Atlas Street	H-174	863.27	H-175	869.26	5.994		
FF-7	Castle Blvd between Meadowview & Clintonville	H-70	883.36	H-71	876.37	6.991		
FF-9	South of Paris By-Pass at WWTP	H-307	799.26	H-308	801.75	2.492	H-4	792.71
FF-11	Houston Oaks Drive (near 552)	H-317	896.36	H-398	888.75	7.615	H-65	880.38
FF-12	Mt. View Drive between Hilltop and Summit	H-41		H-320				
FF-13	Karla Drive	H-149		H-145				
FF-14	High Street between 8th and 10th	H-191	844.86	H-189	845.16	0.304		

Appendix C: Demand Data

A study conducted by Aquacraft, Inc. for the city of Westminster, CO in 1998 was used to approximate the daily demand distribution in Paris, KY. The study identifies the daily demand for each consumer type and how much of that demand is consumed during each hour of the day. The hourly demand is expressed as a percentage of the average daily demand for a peak demand day (Aquacraft, Inc. , 1998). Data used from this study is shown in Table 29.

Table 29 Demand Based on Consumer Type and Time

Time	0	1	2
0	127%	188%	236%
0.5	119%	184%	210%
1	111%	179%	184%
1.5	125%	191%	193%
2	139%	203%	202%
2.5	92%	177%	209%
3	44%	150%	216%
3.5	60%	123%	196%
4	76%	96%	176%
4.5	127%	103%	206%
5	177%	110%	236%
5.5	212%	112%	182%
6	247%	114%	128%
6.5	219%	95%	127%
7	191%	76%	125%
7.5	173%	84%	121%
8	155%	91%	116%
8.5	178%	71%	119%
9	200%	50%	121%
9.5	127%	62%	76%
10	54%	73%	30%
10.5	43%	73%	24%
11	32%	72%	18%
11.5	33%	74%	19%

Time	0	1	2
12	34%	76%	19%
12.5	26%	79%	48%
13	17%	82%	76%
13.5	20%	78%	56%
14	22%	73%	35%
14.5	23%	79%	28%
15	23%	84%	21%
15.5	32%	85%	21%
16	40%	85%	21%
16.5	87%	96%	24%
17	133%	107%	26%
17.5	130%	85%	26%
18	127%	63%	25%
18.5	163%	83%	25%
19	199%	103%	24%
19.5	150%	103%	29%
20	100%	102%	33%
20.5	89%	98%	56%
21	77%	93%	79%
21.5	66%	72%	92%
22	54%	51%	105%
22.5	38%	65%	126%
23	21%	79%	146%
23.5	21%	79%	146%

Appendix D: Data Collection

D.1 C-Factor Test

D.1.1 C-Factor Test Procedure

A step by step procedure for conducting the C-Factor Test is shown below.

Hydrant Testing Crew Instructions

1. Test shall be made during a period of ordinary demand. Before testing begins, the Paris WTP plant will need to be notified of the time of testing. This must occur so the Paris WTP can record the required data regarding tank levels, pump operation schedules, plant flow, etc. during each hydrant flow test.
2. Two hydrants designated the "Residual Hydrants", will be chosen to collect the normal static pressure while the other hydrant in the group, the "Flow Hydrant", is closed. The residual pressure will also be collected while the other hydrant in the group is flowing. Record the length between these hydrants (should range between 400 and 1200 feet). If the hydrants are not at the same elevation, height of the hydrants will need to be recorded.
3. One hydrant, designated the "Flow Hydrant", is chosen to be the hydrant where flow pressure will be observed using a Pitot tube (Hydrant Flow Meter). The Pitot tube to be used for this project is a Pollard P669LF.
4. Once the Flow Hydrant has been selected, a valve directly downstream of the Flow Hydrant should be closed. The valve should be closed slowly to prevent pressure surges and water hammers in the system.
5. At this time the flowing hydrant shall be opened, water should be allowed to flow long enough to clear any debris and foreign substances from stream.
6. A 2 ½" cap with pressure gauge that can read approximately 25 psi greater than the system pressure for the hydrant will be attached to the residual hydrants and each residual hydrant opened full. For this project a Pollard item #P67022LF Hydrant Static Pressure gage will be used. A reading (static pressure) is taken when the needle comes to a rest. Record this reading on the C-Factor Data Collection Log.
7. The Hydrant testing crew members for the residual hydrants will then signal the flowing hydrant crew member using 2 way radio device or cell phone. Attach the Pitot tube to the 2 ½" outlet along with the static pressure gage to a remaining outlet and open hydrant again. The hydrant valve should be opened slowly to prevent pressure surges or water hammer in the system. The hydrant should be flowed approximately 2-5 minutes.

   a. If dechlorination regulations exist for the selected hydrant then dechlorinating diffuser will need to be connected to the flowing hydrant.
8. Observe the Pitot Gauge and static gage reading and record the pressures at the residual hydrants and the flowing hydrant simultaneously (once readings have stabilized). Proper communication will be needed to achieve simultaneous recording.
9. After adequate readings have been recorded, close the flow hydrant to cease flow. Static pressure readings should be recorded at both residual hydrants simultaneously.
10. Complete the other necessary information on the C-Factor Data Collection Log.
11. Make sure to reopen the previously closed valve before leaving the testing site.

Water Treatment Plant Crew Instruction

1. Prior to the start of Hydrant testing, digital pressure gages (Pollard FHGPR325) should be hooked up to the elevated storage tanks to record tank levels. The digital pressure gages were set to record pressure readings at 30 second intervals.

2. After initial parameters have been recorded, real time data should be taken directly before each test is performed. This data will include the tank levels of the Bypass tank and clear well, along with the flow and pressure of pumps. Communication with the WTP will help synchronize when readings should be collected.

D.1.2 C-Factor Calculations

In order to calculate the C-factor, the procedure shown below was followed. The head loss was first calculated using the pressures recorded at the two residual hydrants after the flow hydrant is opened, along with the elevations of each residual hydrant. The equation used to calculate the head loss between the two residual hydrants was found using the Bernoulli Equation (shown in Equation 2). The hydrant labeled Residual Hydrant #2 on the C-Factor Data Collection Log will be the upstream hydrant, while the hydrant labeled Residual Hydrant #1 is located downstream (as shown in Figure 11).

Equation 7

$$\left(\frac{P_2}{\gamma} + Z_2 + \frac{{V_2}^2}{2g}\right) - h_L = \left(\frac{P_1}{\gamma} + Z_1 + \frac{{V_1}^2}{2g}\right)$$

Where,
h_L = Head loss
P_1 = Residual pressure at Hydrant #1 (downstream hydrant)
P_2 = Residual Pressure at Hydrant #2 (upstream hydrant)
Z_1 = Gage elevation at Hydrant #1

Z_2 = Gage elevation at Hydrant #2
V_1 = Velocity in pipe at Residual Hydrant #1
V_2 = Velocity in pipe at Residual Hydrant #2
γ = Specific weight of water
g = Acceleration due to gravity

The difference in velocity heads between the two residual hydrants is considered negligible. Therefore, only the difference in the pressure head and elevation head between the hydrants was considered when calculating the head loss.

Equation 8

$$\boldsymbol{h_L} = \frac{(\boldsymbol{P_2} - \boldsymbol{P_1}) * \left(\mathbf{144}\, \boldsymbol{in^2}/\boldsymbol{ft^2}\right)}{\boldsymbol{\gamma}} + (\boldsymbol{Z_2} - \boldsymbol{Z_1})$$

Where,
h_L = Head loss (ft)
P_1 = Residual pressure at Hydrant #1 (downstream hydrant) in psi
P_2 = Residual Pressure at Hydrant #2 (upstream hydrant) in psi
Z_1 = Gage elevation at Hydrant #1 (downstream hydrant) in feet
Z_2 = Gage elevation at Hydrant #2 (upstream hydrant) in feet
$\gamma = 62.4\ ^{\text{lb}}/_{\text{ft}^3}$

The static pressures recorded at each hydrant prior to flowing the hydrant were also used as a check for the validity of the data. The static pressure head between the two residual hydrants was calculated and compared to the elevation head between the hydrants. The static pressure head should be equal, or relatively close, to the elevation head. The flowrate in the particular pipe was also calculated using the discharge pressure and geometry of the hydrant.

Equation 9

$$\boldsymbol{Q} = \mathbf{29.84} * \boldsymbol{C_d} * \boldsymbol{D_o}^{\mathbf{2}} * \sqrt{\boldsymbol{P_d}}$$

Where,
Q = Flowrate (gpm)
C_d = Coefficient of discharge of hydrant (see Figure 27)
D_o = Diameter of hydrant/reducer opening (in)
P_d = Discharge or pitot pressure (psi)

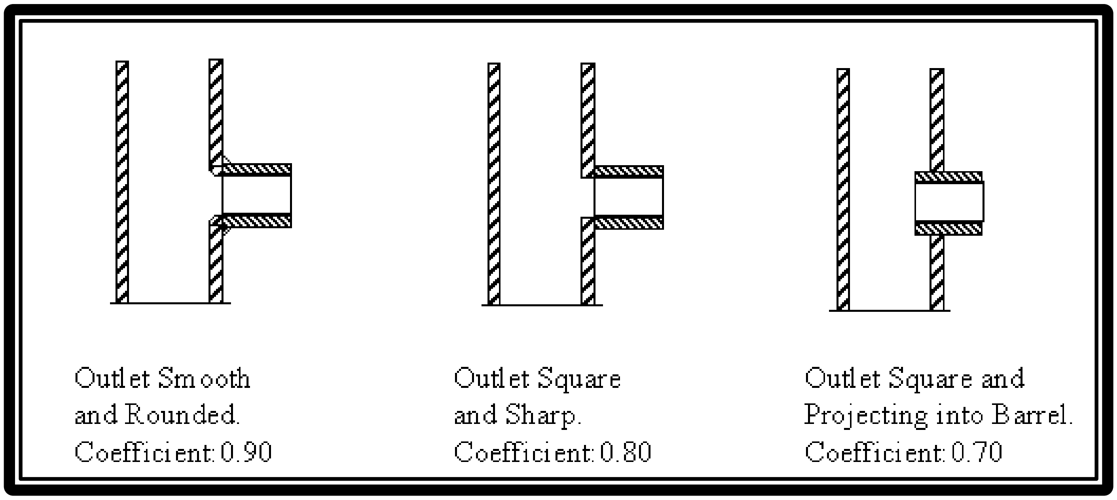

Figure 27 Hydrant Nozzle Discharge Coefficients

The Hazen Williams Equation was used to calculate the C-factor for each C-factor test performed.

Equation 10

$$C = 3.566\frac{L^{0.54} * Q}{{h_L}^{0.54} * D^{2.6277}}$$

Where,
h_L = Head loss (ft)
L = Length of pipe (ft)
Q = Flowrate (gpm)
C = C-Factor
D = Diameter of pipe (in)

D.2 Fire Flow Test

D.2.1 Fire Flow Test Procedure

The AWWA M17 guide- *Installation, Field Testing, and Maintenance of Fire Hydrants* was used to develop the standard operating procedures for the fire flow test.

Hydrant Testing Crew Instructions

1. Test shall be made during a period of ordinary demand. Before testing begins the Paris WTP plant will need to be notified of the time of testing. This is so the Paris WTP can record the

required data regarding tank levels, pump operation schedules, plant flow, etc. during each hydrant flow test.

2. One hydrant designated the “Residual Hydrant”, will be chosen to collect the normal static pressure while the other hydrants in the group, the “Flow Hydrant’, is closed. The residual pressure will also be collected while the other hydrant in the group is flowing. If the hydrants are not at the same elevation, height of the hydrants will need to be recorded.
3. One hydrant, designated the “Flow Hydrant”, is chosen to be the hydrant where flow pressure will be observed, using a Pitot tube (Hydrant Flow Meter). The Pitot tube to be used for this project is a Pollard P669LF.
4. At this time the flowing hydrant shall be opened, water should be allowed to flow long enough to clear any debris and foreign substances from stream.
5. A 2 ½” cap with pressure gauge that can read approximately 25 psi greater than the system pressure for the hydrant will be attached to the residual hydrant and the hydrant opened full. For this project a Pollard item # P67022LF Hydrant Static Pressure gage will be used. A reading (static pressure) is taken when the needle comes to a rest. Record this reading on the Fire Flow Data Collection Log.
6. The hydrant testing crew members for the residual hydrant will then signal the flowing hydrant crew member using 2 way radio device or cell phone. Attach the Pitot tube to the 2 ½” outlet along with the static pressure gage to a remaining outlet and open hydrant again. The hydrant valve should be opened slowly to prevent pressure surges or water hammer in the system. The hydrant should be flowed approximately 2-5 minutes.
    a. If dechlorination regulations exist for the selected hydrant then dechlorinating Diffuser will need to be connected to the flowing hydrant.
7. Observe the Pitot Gauge and static gage reading and record the pressures at the residual hydrant and the flowing hydrants simultaneously (once readings have stabilized). Proper communication will be needed to achieve simultaneous recording.
8. After adequate readings have been recorded, close the flow hydrant to cease flow. Static pressure readings should be recorded at the residual hydrant.
9. Complete the other necessary information on the Fire Flow data Collection Log.

Water Treatment Plant Crew Instruction

1. Prior to the start of Hydrant testing, digital pressure gages (Pollard FHGPR325) should be hooked up to the elevated storage tanks to record tank levels. The digital pressure gages were set to record pressure readings at 30 second intervals.

2. After initial parameters have been recorded, real time data should be taken directly before each test is performed. This data will include the tank levels of the Bypass tank and clear

well, along with the flow and pressure of pumps. Communication with the WTP will help synchronize when readings should be collected.

D.2.2 Fire Flow Calculations

The procedure below shows calculations for the maximum capacity of a hydrant if it is pumped down to a 20 psi residual pressure. The flowrate formula produces a value in gallons per minute (GPM) based on the nozzle diameter and pitot pressure.

Equation 11

$$Q = 29.84 * C_d * {D_o}^2 * \sqrt{P_d}$$

Where,
Q = flowrate (gpm)
C_d = coefficient of discharge
D_o = diameter of hydrant opening (in)
P_d = discharge/pitot pressure (psi)

This formula below calculates available flow based on the readings taken before and during the single outlet flow test (solving for "Q_R".)

Equation 12

$$Q_R = Q_F * \frac{{h_r}^{0.54}}{{h_f}^{0.54}}$$

Where,
Q_F = Observed flow (gpm)
h_r = Pressure drop from the static pressure to the desired residual pressure (psi)
h_f = Pressure drop from the static pressure to the actual residual pressure recorded (psi)

D.3 Fire Flow Validation

Paris also conducted fire flow testing on hydrants throughout the system. When historical hydrant flow data was available for hydrant used in fire flow tests, both sets of data were compared. Data for this verification is included in Table 30, showing percent differences for static pressure between tests. In the event that these results were significantly different, the field crew checked to ensure that there were no closed or partially closed valves upstream of the test area. In the event that such errors were identified, then the fire-flow tests were re-run. In the event that no such valves could be located, the field team noted the discrepancy and attempted to develop a hypothesis for the difference.

Table 30 Fire Flow Validation Results

Test	Model Hyd	Static Pressure	Paris Hyd	Static Pressure	Pressure Diff	Model Hyd	Static Pressure	Flow	Paris Hyd	Stat Pressure	Flow	Pressure Diff	Flow Diff
FF-2	H-80	82.0	22	82.0	0%	H-79	78.0	1300	21	79.0	1272	1%	-2%
FF-3	H-90	54.0	82	51.0	-6%	H-97	61.0	1080	81	57.0	938	-7%	-13%
FF-5	H-278	76.0	235	79.0	4%	H-200	74.0	489	234	81.0	906	9%	85%
FF-6	H-175	68.0	306	74.0	9%	H-174	69.0	650	305	70.0	711	1%	9%
FF-7	H-71	65.0	29	60.0	-8%	H-70	69.5	1220	399	62.0	938	-11%	-23%
FF-9	H-308	98.5	414	102.0	4%	H-307	97.0	1501	415	104.0	1188	7%	-21%
FF-11	H-398	62.0	497	60.0	-3%	H-317	61.0	1107	498	59.0	1152	-3%	4%
FF-12	H-317	64.0	586	70.0	9%	H-41	64.0	780	50	58.0	835	-9%	7%
FF-13	H-145	45.0	67	43.0	-4%	H-149	56.0	645	68	48.0	608	-14%	-6%
FF-14	H-189	86.0	191	84.0	-2%	H-191	83.0	531	471	84.0	608	1%	15%

Appendix E: Data Collection Logs

C-Factor Data Collection Log

Site ID:	C-1		Test Number (if multiple):		1	Date:	6/5/2012
Flowing Hydrant				**Residual Hydrant #1**		**Residual Hydrant #2**	
Project Hydrant ID:		H-78		Project Hydrant ID:	H-77	Project Hydrant ID:	H-76
Hydrant Location:		Glenview Drive		Hydrant Location:	Glenview Drive	Hydrant Location:	Glenview Drive
Gage Elevation:				Gage Elevation:	0.348	Gage Elevation:	4.423
Equipment ID:		#1 (static) and #4 (flow)		Equipment ID:	#2	Equipment ID:	#3
Hydrant Coefficient:		0.9					
Time	**Static Pressure**	**Discharge Pressure (psi)**	**Flowrate (gpm)**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**
11:02	81			82		86	
11:09	39	39	1048		80		64
11:09	39.5	40	1061		80		66
11:10	41	41	1074		80		66
11:10	41	41	1074		80		66.5
11:12	80.5			80		85.5	
:							
:							
:							
:							
:							
:							
Distance between Residual Hydrant #1 and #2:					479.42	ft	
Pipe Diameter (D):					6	in	
Notes:	Flow hydrant leaking				C=		
					C=	3.566*Q*D^-2.6277*(L/HL)^0.53996	
Schematic:						Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3	

C-Factor Data Collection Log

Site ID: C-1 | Test Number (if multiple): 2 | Date: 6/5/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-78	H-77	H-76
Hydrant Location:	Glenview Drive	Glenview Drive	Glenview Drive
Gage Elevation:		0.348	4.423
Equipment ID:	#1 (static) and #4 (flow)	#3	#2
Hydrant Coefficient:	0.9		

Time	Static Pressure	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
11:26	81			84		84	
11:31	40	42	1087		54		84
11:32	39.5	40	1061		54		84
11:32	40.5	41	1074		55		84
11:35	81			84		84	
:							
:							
:							
:							
:							
:							
:							

Distance between Residual Hydrant #1 and #2: 479.42 ft
Pipe Diameter (D): 6 in

Notes:

C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996

Schematic:

Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

C-Factor Data Collection Log

Site ID: C-1 | Test Number (if multiple): 3 | Date: 6/5/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-78	H-77	H-76
Hydrant Location:	Glenview Drive	Glenview Drive	Glenview Drive
Gage Elevation:		0.348	4.423
Equipment ID:	#2 (static) and #4 (flow)	#3	#1
Hydrant Coefficient:	0.9		

Time	Static Pressure	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
11:46	83.5			86		86	
11:51	42	43	1100		56		66
11:51	42	41	1074		55.5		65
11:52	42	42	1087		56		66
11:52	42.5	43	1100		56		67
11:56	83.5			84.5		84	
:							
:							
:							
:							
:							
:							
:							

Distance between Residual Hydrant #1 and #2: 479.42 ft
Pipe Diameter (D): 6 in

Notes:

C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996

Schematic:

Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

C-Factor Data Collection Log

Site ID: C-3 | Test Number (if multiple): 1 | Date: 6/5/2012

	Flowing Hydrant			Residual Hydrant #1		Residual Hydrant #2		Residual Hydrant #3	
	Project Hydrant ID:	H-84		Project Hydrant ID:	H-82	Project Hydrant ID:	H-81	Project Hydrant ID:	H-74
	Hydrant Location:	Redbud Lane		Hydrant Location:	Redbud Lane	Hydrant Location:	Redbud Lane	Hydrant Location:	Redbud Lane
	Near south intersection with Glenview Drive			Near intersection with Crest Court				Near north intersect with Glenview Dr	
	Gage Elevation:			Gage Elevation:	17.857	Gage Elevation:	6.189	Gage Elevation:	3.26
	Equipment ID:	#4 (flow)		Equipment ID:	#2	Equipment ID:	#3	Equipment ID:	#1
	Hydrant Coefficient:	0.9							
Time	**Static Pressure (psi)**	**Discharge Pressure (psi)**	**Flowrate (gpm)**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**
12:43	72			74		80		80	
12:48	51	52	1210		60		68		70
12:49	51.5	52.5	1216		61		68		70.5
12:49	51	52	1210		60		68		70
12:50	51	52	1210		60		68		70
12:53	72			74		80		79	

Distance between Residual Hydrant #1 and #2: 436.037 ft
Pipe Diameter (D): 8 in
Notes: **2.5'' REDUCER USED**
C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996
Schematic:
Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

C-Factor Data Collection Log

Site ID: C-3 | Test Number (if multiple): 2 | Date: 6/5/2012

	Flowing Hydrant			Residual Hydrant #1		Residual Hydrant #2		Residual Hydrant #3	
	Project Hydrant ID:	H-84		Project Hydrant ID:	H-82	Project Hydrant ID:	H-81	Project Hydrant ID:	H-74
	Hydrant Location:	Redbud Lane		Hydrant Location:	Redbud Lane	Hydrant Location:	Redbud Lane	Hydrant Location:	Redbud Lane
	Near south intersection with Glenview Drive			Near intersection with Crest Court				Near north intersect with Glenview Dr	
	Gage Elevation:			Gage Elevation:	17.857	Gage Elevation:	6.189	Gage Elevation:	3.26
	Equipment ID:	#4 (flow)		Equipment ID:	#2	Equipment ID:	#3	Equipment ID:	#1
	Hydrant Coefficient:	0.9							
Time	**Static Pressure (psi)**	**Discharge Pressure (psi)**	**Flowrate (gpm)**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**
1:09				75		80		80	
1:11		24.4	2122		37		50		58
1:11		23.9	2100		36		48		56
1:12		24.7	2135		36		49		55
1:15				74		79		78	

Distance between Residual Hydrant #1 and #2: 436.037 ft
Pipe Diameter (D): 8 in
Notes: **4'' OPENING**
C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996
Schematic:
Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

C-Factor Data Collection Log

Site ID: C-9 | Test Number (if multiple): | Date: 6/5/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-191	H-189	H-190
Hydrant Location:	Corner of 8th and High St		High and 10th
Gage Elevation:		0.998	3.38
Equipment ID:	#1 (static) and #4 (flow)	#2	#3
Hydrant Coefficient:	0.9		

Time	Static Pressure	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
2:57	83			86		84	
3:02		10	531		53.5		75
3:02		10	531		53.5		75.5
3:03		10	531		54		76
3:04	84			86		85	
:							
:							
:							
:							
:							
:							
:							

Distance between Residual Hydrant #1 and #2: 294.953 ft
Pipe Diameter (D): 6 in

Notes: Valve possibly broken

C=

C= 3.566*Q*D^-2.6277*(L/HL)^0.53996

Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

Schematic:

C-Factor Data Collection Log

Site ID: C-10 | Test Number (if multiple): | Date: 6/6/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-317	H-398	H-65
Hydrant Location:	Houston Oaks Drive	Houston Oaks Drive, near intersect. of Pebble Beach Court	552 Houston Oaks Dr
Gage Elevation:		888.748	896.363
Equipment ID:	#1 (static) and #4 (flow)	#2	#3
Hydrant Coefficient:	0.9		

Time	Static Pressure	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
1:39	64.5			63.5		60	
1:42	30.5	32.5	957		32		28
1:42	32	32.5	957		33.5		29
1:43	29.5	30	919		31		27
1:43	31	32.5	957		32		28
				64		60	

Distance between Residual Hydrant #1 and #2: ft
Pipe Diameter (D): 8 in

Notes: New Site

C=

C= 3.566*Q*D^-2.6277*(L/HL)^0.53996

Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

Schematic:

C-Factor Data Collection Log

Site ID: C-11 | Test Number (if multiple): 1 | Date: 6/6/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-438	H-437	H-436
Hydrant Location:	Between 440 and 442 Houston Oaks Drive	Houston Oaks Drive	422 Houston Oaks Dr
Gage Elevation:	4.181	-13.659	0.186
Equipment ID:	#2 (static) and #4 (flow)	#1	#3
Hydrant Coefficient:	0.9		

Time	Static Pressure	Discharge Pressure (psi)	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
2:40	66			65		72	
2:43	52	50	1186		53		63
2:44	52	51	1198		54		63
2:44	52	50.5	1192		54		63
2:44	52	50.5	1192		54		63
				65		73	

Distance between Residual Hydrant #1 and #2: 486.663 ft
Pipe Diameter (D): 10 in

Notes: ONLY WITH REDUCER
New Site

C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996
Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

Schematic:

C-Factor Data Collection Log

Site ID: C-11 | Test Number (if multiple): 2 | Date: 6/6/2012

	Flowing Hydrant	Residual Hydrant #1	Residual Hydrant #2
Project Hydrant ID:	H-438	H-437	H-436
Hydrant Location:	Between 440 and 442 Houston Oaks Drive	Houston Oaks Drive	422 Houston Oaks Dr
Gage Elevation:	4.181	-13.659	0.186
Equipment ID:	#2 (static) and #4 (flow)	#1	#3
Hydrant Coefficient:	0.9		

Time	Static Pressure (psi)	Discharge Pressure (psi) - 2.5'' Reducer	Discharge Pressure (psi) - Paris's Diffuser	Flowrate (gpm)	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
3:03					65		72	
3:06	31	28	24	2993		38		30
3:07	31.5	29	27	3137		37		48
3:08	31.5	29	27	3137		38		49
3:11	65.5				64		72	

Distance between Residual Hydrant #1 and #2: 486.663 ft
Pipe Diameter (D): 10 in

Notes: (#) with our reducer and gage, # with Paris's diffuser
New Site - used Paris's diffuser and our reducer

C=
C= 3.566*Q*D^-2.6277*(L/HL)^0.53996
Q=gpm D=in L=ft Hl=Z2-Z1+(P2-P1)*2.3

Schematic:

Fire Flow Data Collection Log

Site ID: FF-2 | Test #: 1 | Date: 6/6/2012

Flowing Hydrant

Project Hydrant #: H-79
Hydrant Location: Shannon Road
Gage Elevation: 850.726
Equipment ID: #1 (static) and #4 (flow)

Residual Hydrant

Project Hydrant #: H-80
Hydrant Location: Shannon Road
Gage Elevation: 842.824
Equipment ID: #2

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
1:08	78				82	
1:12	60.5	61	1310.95			71.5
1:12	60	59	1289.28			72
1:13	60.5	61	1310.95			72
1:16	78				82.5	

Notes:

Fire Flow Data Collection Log

Site ID: FF-3 | Test #: 1 | Date: 6/6/2012

Flowing Hydrant

Project Hydrant #: H-97
Hydrant Location: Clinton Drive
Gage Elevation: 895.972
Equipment ID: #3 (static) and #4 (flow)

Residual Hydrant

Project Hydrant #: H-90
Hydrant Location: Clinton Drive near Citation Way
Gage Elevation: 908.838
Equipment ID: #1

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
3:32	61				54	
3:36	43	42	1087.79			40.5
3:36	42	41	1074.76			39.5
3:37	42.5	41.5	1081.30			40
3:37	43.5	42	1087.79			40.5
3:40	61				54	

Notes:

Fire Flow Data Collection Log

Site ID: FF-5 Test #: 1 Date: 6/6/2012

Flowing Hydrant		Residual Hydrant	
Project Hydrant #:	H-200	Project Hydrant #:	H-278
Hydrant Location:	Duncan Ave	Hydrant Location:	Duncan Ave near Pleasant Street
Gage Elevation:	861.258	Gage Elevation:	862.141
Equipment ID:	(#1) Static and #4 (flow)	Equipment ID:	#3

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
10:45	74				76	
10:49	7	8 (9)				48
10:49	7	8 (9)				48
10:50	7	8 (9)				48
10:52	74				76	
:						
:						
:						
:						
:						

Notes: (#) diffuser and # Reducer
Flow hydrant difficult to turn

Fire Flow Data Collection Log

Site ID: FF-6 Test #: 1 Date: 6/6/2012

Flowing Hydrant		Residual Hydrant	
Project Hydrant #:	H-174	Project Hydrant #:	H-175
Hydrant Location:	Higgins Ave near Atlas Street	Hydrant Location:	Higgins Ave
Gage Elevation:	863.27	Gage Elevation:	869.264
Equipment ID:	#1 (static) and #4 (flow)	Equipment ID:	#3

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
10:15	69				68	
10:21	13	15	650.08			52
10:21	13	15	650.08			52
10:22	13	15	650.08			52
					68	

Notes: USING PARIS'S DIFFUSER

Fire Flow Data Collection Log

Site ID: FF-6 | Test #: 2 | Date: 6/6/2012

Flowing Hydrant		Residual Hydrant	
Project Hydrant #:	H-174	Project Hydrant #:	H-175
Hydrant Location:	Higgins Ave near Atlas Street	Hydrant Location:	Higgins Ave
Gage Elevation:	863.27	Gage Elevation:	869.264
Equipment ID:	#1 (static) and #4 (flow)	Equipment ID:	#3

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
10:20					68	
10:25	13	17	1771.68			52
10:26	12.5	17	1771.68			52
10:26	12.5	16	1718.78			52
10:28	69.5				68	

Notes: Without DIFFUSER OR REDUCER
NO REDUCER (no steamer on H-174)

Fire Flow Data Collection Log

Site ID: FF-7 | Test #: 1 | Date: 6/6/2012

Flowing Hydrant		Residual Hydrant	
Project Hydrant #:	H-70	Project Hydrant #:	H-71
Hydrant Location:	310 Castle Blvd Near Meadowview Drive	Hydrant Location:	516 Castle Blvd
Gage Elevation:	883.358	Gage Elevation:	876.367
Equipment ID:	#2 (static) and #4 (flow)	Equipment ID:	#1

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
3:54	69.5				65	
3:58	55	54	1233.44			55
3:58	54	53	1221.97			54
3:59	53	51.5	1204.55			55
3:59	53	53	1221.97			55.5
4:03	70				64	
:						
:						
:						
:						

Notes:

Fire Flow Data Collection Log

Site ID: FF-9 Test #: 1 Date: 6/6/2012

	Flowing Hydrant			Residual Hydrant		Residual #2	
Project Hydrant #:	H-307			Project Hydrant #:	H-308	Project Hydrant ID:	H-4
Hydrant Location:	WWTP, Dead End			Hydrant Location:		Hydrant Location:	New hydrant
	South of Paris By-Pass, west of railroad					Located at end of line before turn	
Gage Elevation:	799.257			Gage Elevation:	801.749	Gage Elevation:	792.705
Equipment ID:	#1 (static) and #4 (flow)			Equipment ID:	#2	Equipment ID:	#3

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
9:41	97				98.5		102.5	
9:49	82	80	1501.30			88.5		86
9:50	82	80	1501.30			88.5		86
9:50	81.5	79.5	1496.60			88		86
9:50						88.5		86
9:55	96				98		102	

Notes: Added Residual #2 (not in model)

Fire Flow Data Collection Log

Site ID: FF-11 Test #: 1 Date: 6/6/2012

	Flowing Hydrant			Residual Hydrant		Residual #2	
Project Hydrant #:	H-317			Project Hydrant #:	H-398	Project Hydrant ID:	H-65
Hydrant Location:	552 Houston Oaks Drive			Hydrant Location:	Near intersection of Houston Oaks Drive and Pebble Beach	Hydrant Location:	Houston Oaks Drive
Gage Elevation:	896.363			Gage Elevation:	888.748	Gage Elevation:	880.375
Equipment ID:	#2 (static) and #4 (flow)			Equipment ID:	#3	Equipment ID:	#1

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)	Static Pressure (psi)	Residual Pressure (psi)
2:19	61				62		65	
2:23	46	43.5	1107.05			51		54
2:24	46	43.5	1107.05			51		53.5
2:24	46	43.5	1107.05			51		53.5
2:27	60.5				62		65	

Notes: New Site

Fire Flow Data Collection Log

Site ID: FF-12 | Test #: 1 | Date: 6/6/2012

Flowing Hydrant

Project Hydrant #: H-41
Hydrant Location: 495 Mt. View Drive
Corner of Mt. View Drive and Hilltop
Gage Elevation:
Equipment ID: #2 (static) and #4 (flow)

Residual Hydrant

Project Hydrant #: H-320
Hydrant Location: 405 Mt. View Drive
Corner of Mt. View and Summit
Gage Elevation:
Equipment ID: #1

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
4:13	64				64	
4:17	22	22	787.29			28
4:17	22	22	787.29			28
4:18	21.5	21	769.19			28
4:18	22	21.5	778.29			28
4:21	63.5				64	

Notes: New Site

Fire Flow Data Collection Log

Site ID: FF-13 | Test #: 1 | Date: 6/5/2012

Flowing Hydrant

Project Hydrant #: H-149
Hydrant Location: Karla Drive
Near Northland Drive
Gage Elevation:
Equipment ID: #3 (static) and #4 (flow)

Residual Hydrant

Hydrant Location: H-145
Hydrant Location: Karla Drive
Near Southland Drive
Gage Elevation:
Equipment ID: #2

Time	Static Pressure (psi)	Discharge Pressure (psi)	Flowrate (gpm)	Notes	Static Pressure (psi)	Residual Pressure (psi)
3:43	55				45	
3:45	56				45	
3:47	16	15	650.08			16
3:48	15	14.5	639.15			17
3:48	15	14.5	639.15			16.5
3:53	56.5				52	
					54	

Notes: Was C-4 Site

Fire Flow Data Collection Log

Site ID: FF-14 | Test #: 1 | Date: 6/5/2012

	Flowing Hydrant				Residual Hydrant		Residual #2	
	Project Hydrant #:	H-191			Project Hydrant #: H-189		Project Hydrant ID:	H-190
	Hydrant Location:	Corner of 8th and High			Hydrant Location: High Street		Hydrant Location:	Corner of 10th and High
	Gage Elevation:	844.86			Gage Elevation: 845.164		Gage Elevation:	
	Equipment ID:	#1 (static) and #4 (flow)			Equipment ID: #2		Equipment ID:	#3
Time	**Static Pressure (psi)**	**Discharge Pressure (psi)**	**Flowrate (gpm)**	**Notes**	**Static Pressure (psi)**	**Residual Pressure (psi)**	**Static Pressure (psi)**	**Residual Pressure (psi)**
2:45					86		84	
2:48		10	530.79			54		78
2:48		10	530.79			54		78
2:49		10	530.79			53.5		77.5
2:49		10	530.79			53.5		
2:50					86		84.5	

Notes: Was C-9 Site