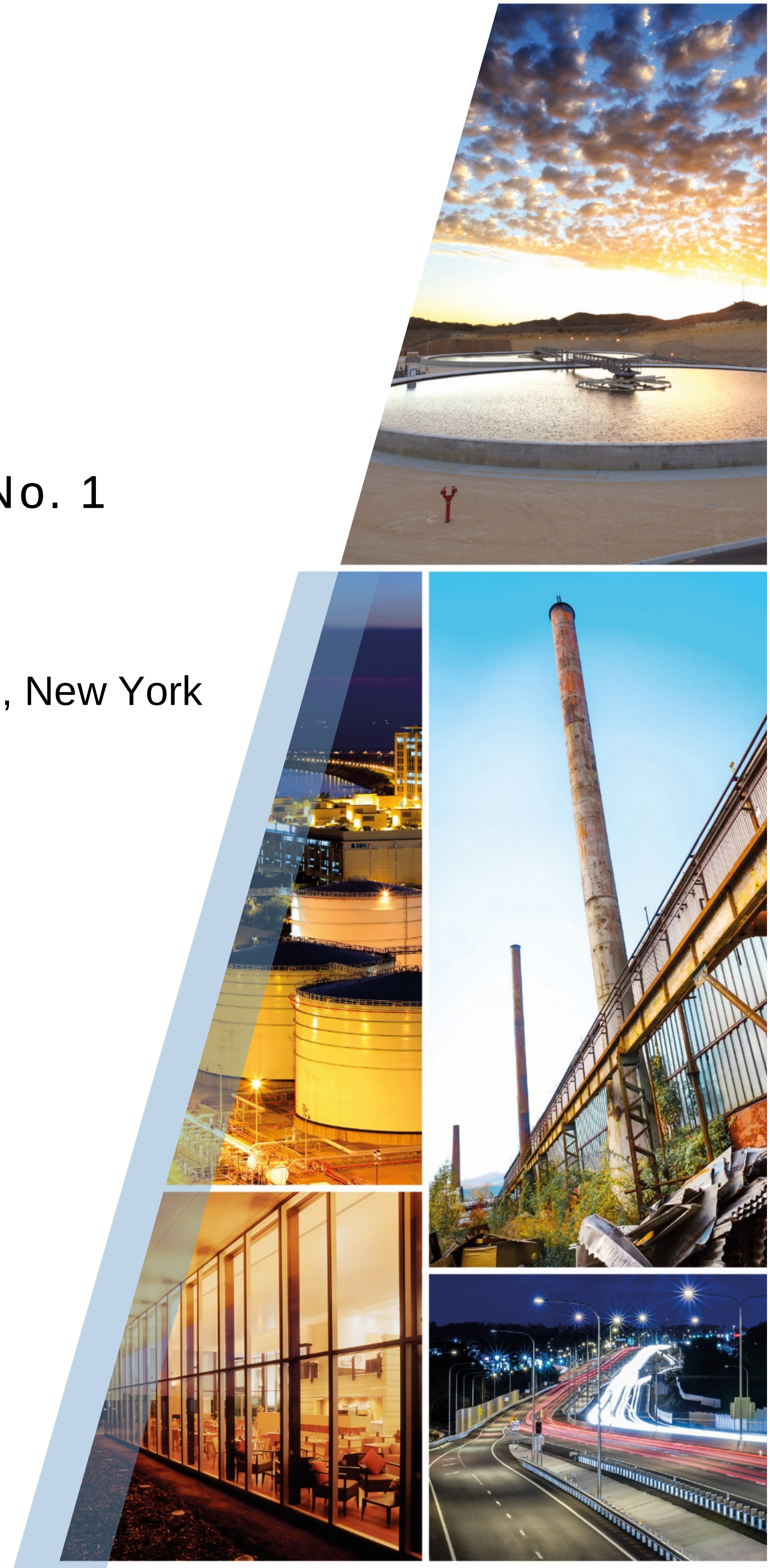
Water District No. 1 Modeling Study

Town of North Castle, New York



WATER DISTRICT NO. 1 MODELING STUDY

TOWN OF NORTH CASTLE, NEW YORK

Prepared for

TOWN OF NORTH CASTLE, NEW YORK

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1. Introduction

Water District No. 1 (WD #1) serves the North White Plains area of the Town of North Castle, NY. The WD #1 distribution system is Town owned and provides potable water and fire protection to 653 service connections and service to about 2,500 people with an average daily demand of 0.23 million gallons per day (mgd).[1] This report presents a hydraulic analysis of the water distribution system serving WD #1.

[1] North Castle Water District No. 1 Annual Water Supply Report for 2018.

2. Purpose of Study

The purpose of the study is to hydraulically analyze the WD #1 distribution system utilizing a computer model. The hydraulic analysis is intended to evaluate the adequacy of the water distribution system to meet demands, provide sufficient pressure and storage, and provide technical guidance for recommended pipe network improvements. The existing water distribution network has been subject to frequent failures that have incurred unplanned service outages and unanticipated repair expenses.

Hydraulic modeling is a cost-effective method of investigating the cause of failures and identifying deficiencies that may lead to a diminished level of service. At the conclusion of the study, a plan for improving the distribution network will be available for discussion and comment.

3. Scope of Services

GHD was retained to develop a computer-based hydraulic model of the Town of North Castle WD #1 distribution system. The model is to be used to evaluate system hydraulic capacity, identify system deficiencies, and develop cost-effective improvement recommendations. Based on the agreement between the Town of North Castle and GHD, the scope of services for this study is as follows:

1. Attend a kickoff meeting with the Town (Owner) to discuss the scope and schedule for the project.
2. Receive and review data provided by the Owner.
3. Develop a computerized model of WD #1 distribution system using WaterCAD.
4. Calibrate the hydraulic model using pressure and flow data from previous hydrant flow testing (or provide hydrant flow testing and pipe condition test as an additional service). (Note: Calibration could not be completed with previous testing data; see Section 5.3.)
5. Evaluate the system by running computer-based simulations for different conditions (i.e., average daily, peak hour, maximum day, and fire flow). (Note: The evaluation could not be completed; see Section 5.4.)
6. Identify and evaluate the system's deficiencies.
7. Prepare a draft report for evaluating the system and proposing improvement recommendations with opinions for cost of construction.

4. Existing Conditions

4.1 Overview

The WD #1 service area is located within the Town of North Castle, Armonk, NY. It is bound on the north by the Kensico Dam, the Bronx River Parkway to the west, and the City of White Plains to the south. The system was constructed between the late 1920s and late 1960s. Potable water is supplied to the system by one supply well (Valhalla well) and the Kensico Reservoir through a connection to the City of White Plains supply transmission main at the Town's North Broadway booster pump station. The Kensico Reservoir is a component of New York City's Catskill-Delaware water supply.

Water from the Kensico Reservoir is pumped into the system by the North Broadway Pump Station. Treated reservoir water is conveyed to the pump via a 36-inch main and then to a District water storage tank on Overlook Road North (Overlook tank) via a 6-inch PVC dedicated transmission main. The water is chlorinated and disinfected with ultraviolet (UV) light at the North Broadway Pump Station. The transmission main serves as a dedicated chlorine contact pipeline. The North Broadway pumps (two at approximately 360 gallons per minute (gpm) per unit) currently provide the Town's primary supply. The invert of the inlet pipe on the Overlook tank (600,000-gallon capacity) is at the maximum elevation of the tank. A second standpipe located off Custis Avenue (the Custis tank, with a 317,000-gallon capacity) also supplies the system and its overflow elevation is the same as that of the Overlook tank.

The Town also has a connection to the New York City Kensico-Bronx pipeline at the Virginia Road booster pump station. At the time of this report, the booster pump was offline due to production water not meeting *Cryptosporidium* disinfection requirements. In the past, the Valhalla well was the Town's primary supply and ran 24 hours per day, drawing from an aquifer. In 2012, the Valhalla well was cleaned and televised. During the process, an abandoned suction end in the borehole was discovered and removed. A new submersible pump and motor were installed at the conclusion of the maintenance but little increase in yield was noted. The yield of the well eventually fell from 82 to 35 gpm by December 2017. In addition to reduced capacity, the Valhalla well was taken offline that month and experienced an electrical service issue as a result of a storm event in March 2018. This will prevent the well from being used again without major repairs to the electrical systems.

WD #1 supplies potable water to approximately 580 residential customers and 110 commercial customers. The estimated population served is 2,500 per the Town's Annual Water Supply Report. New York City uses a service population of 1,894 to determine per capita water use related to water rates. The location of the well house and its discharge main is in an area where the District's property limits are uncertain

WD #1 also serves the Metro North Railroad yard to the southwest of the Town. Interconnections to the City of White Plains water distribution system exist at the end of Cloverdale Avenue and within the Metro North Railroad yard and to the Town of Mount Pleasant on Virginia Road. At the present time, residential development and growth within the District is expected to be limited. It is assumed that no significant increase in water demand will occur in the foreseeable future.

Most of WD #1 was constructed by numerous contractors hired for residential development. It is not known if any formal review or approval of the system was completed by regulatory authorities at the time, and no construction records from such contractors have been provided to GHD. In recent years, pipe failures at various locations in the system have warranted investigation and repair by the Town. Much of the system is older cast iron pipe of various thickness classes. Pipe materials such as those used in WD #1 are often subject to corrosion and deterioration over time.

4.2 System Description

As previously described, the system is presently comprised of two tanks, one booster pump station, and a supply well which supplies potable water to the District. The Overlook and Custis tanks are gradient-stabilized storage tanks and maintain pressure in the system. During the information review, GHD learned that both system tanks had recently undergone rehabilitation including painting.

Table 4.1 presents a summary of the characteristics of the two storage tanks.

Table 4.1 Overlook and Custis Storage Tanks

		Value	
Item	Units	Overlook Tank	Custis Tank
Total capacity	gallons	600,000	317,000
Tank height to overflow	feet	32	95
Inside diameter	feet	60	23
Overflow elevation	feet	525	525
As-built floor elevation	feet	494	431
Volume per depth	gallons/foot	19,354	3,385
Type		Welded steel	Welded steel
Inlet /outlet diameter	inches, pipe material	6 / 12, PVC / ductile iron	10, cast iron

There are a number of homes in the vicinity of the Overlook tank that have low pressure (less than the recommended standard of 35 psi) due to higher elevations.

Disinfection of the water is provided at the North Broadway Pump Station through chlorine addition and UV treatment.

There are two pumps at the North Broadway Pump Station, one for duty and one for backup or standby. Each 28 HP booster pump adds water to the Overlook tank via a 6-inch PVC inlet pipe open to the atmosphere at the top of the tank. Table 4.2 presents details on the pumps.

Table 4.2 North Broadway Pump Data

Criteria	Head (feet)	Discharge (gpm)
Shutoff	236.7	0
Design	220	350
Maximum operating	137.4	571.9

Based on records provided to GHD by the Town, the system consists of over 8 miles of water mains. The two main types of pipe reported are cast iron and ductile iron. Cast iron comprises the majority of the system, whereas ductile iron makes up only a small percentage of new construction added to the northern part of the system near the Overlook tank. The only other reported pipe material is PVC, which is used to connect the North Broadway booster pump station to the Overlook tank.

Table 4.3 presents a summary of the pipes in WD #1.

Table 4.3 Summary of Pipes in WD #1

Pipe Type	Diameter (inches)	Approximate Length (feet)	Percent of WD#1
Cast iron	4	913	2.0%
	6	28,063	61.1%
	8	8,231	17.9%
	10	4,418	9.6%
	12	310	0.7%
Ductile iron	6	456	1.0%
	8	1,520	3.3%
PVC	6	2,000	4.4%
TOTAL		**45,911**	100.0%

Cast iron is a material that is subject to decay and corrosion from constant service in a water supply system over many years of use. Changes in water chemistry and geochemistry (on the outside of the pipe) can corrode cast iron. Internal corrosion will eventually cause phenomena such as tuberculation to reduce pipe condition and capacity. This reduction is manifested as a decrease in internal diameter and an increase in pipe roughness. Pipe roughness is representative of how much friction water experiences as it travels through a pipe. The friction increases as the walls of the pipe become less smooth and more bumpy and the corrosion can eventually lead to pipe failure. Considering the estimated time of installation (approximately 60 years ago, at minimum) and the rise in the number of repairs, much of the cast iron is nearing or at the end of its service life.
Section 5.3.4 provides more information on pipe material, age, and pipe roughness. As provided in the Town's data, there are a total of 93 hydrants in WD #1, manufacturers of which include Darling, Mueller, and Rensselaer.

5. Model Development

The hydraulic model for this analysis was constructed in WaterCAD V8i (Bentley Systems, Inc., Exton, PA). This software package creates a model of a water supply system based upon nodes (or junctions) and pipes. Nodes are set at different elevations in the model and are used to connect the pipes within the network, which puts length between the different nodes. Nodes can be used to represent various system components, such as hydrants, tanks, reservoirs, and pumps.

The data available on the pipe network of WD #1 was presented to GHD in a hard copy Mylar drawing dated 1960 which included pipe diameters and approximate pipe lengths. Additional pipe reaches and diameters and hydrant locations were provided by the Owner on a separate markup. To create the pipe network in WaterCAD, the pipes and junctions for WaterCAD were first mapped manually in ArcGIS v10.5 (ESRI, Redlands, CA). A file containing the approximate locations of each junction and pipe rendered by GHD was then imported into the WaterCAD suite, where the lines and points in the GIS shapefile were used to represent the pipes and nodes.

The model constructed was designed to be run under steady-state conditions. Steady-state assumptions include accumulation of water in the system to be equal to zero (production equal to demand) and possess both constant hydraulic demand and boundary conditions (with respect to time). Steady-state modeling produces results for the system at a single point in time. This steady-state model can return results for average daily, maximum day, peak hour, and fire flow demand conditions.

The incorporation of boundary conditions in this model was based on available data from the Town and information which GHD previously possessed. This data includes approximate pipe length and location; pipe material and age (roughness estimate); tank dimensions, elevations, and levels; hydrant locations; pump curves and sources; and production and sales data for the District. The computerized model was based on:

1. One pressure zone.
2. Distribution mains 6 inches and larger.
3. Two storage tanks.
4. One well pump (in service at the time of past hydrant flow testing) and one booster pump (purchased) supply.
5. No anticipated increase in current demands.

5.1 Initial Model Inputs and Boundary Conditions

Once imported into WaterCAD, the pipe and node data was checked for any unconnected pipes or extraneous junctions. Such instances were resolved on a case-by-case basis. For example, where multiple nodes existed in close proximity, only one was left to join the respective pipes, and where two pipes were close but had no node, a node was placed between the two to join them. Nodes were morphed into representative components (tanks, pumps, etc.) where they existed in the system.

From the GIS file, pipe lengths were made available by node locations. Using USGS topographical maps (as base maps established in the GIS shapefile), elevation data was input into the model from surface elevations read off of these documents. Elevation data is important because it is used by the model to determine pressure differences between the nodes. Pipe material and approximate age were useful in assigning an initial Hazen-Williams C-roughness coefficient for each of the pipes.

The two tanks in WD #1 were constructed in the model based on data such as dimensions and geometry, provided by the Owner. The base elevation (as-built) and maximum elevation of the Overlook tank was known by GHD, and the Owner indicated that both tanks have the same overflow elevation. From this information, the maximum height and base elevation of the Custis tank could be estimated. The Owner also explained that the Overlook tank's inflow pipe was located at the top of the tank and emptied to the atmosphere. This was accounted for in the modeled tank's input.

The two booster pumps were assigned manufacturer pump curves. Pump curves are created by relating discharge flow to pump head. From the Owner, information on the Valhalla well and North Broadway production was used to adjust reservoir and/or pump elevation to match these records. Records and calculations on the North Broadway pump's suction head were available to GHD.

5.2 Demand Data

Customer demand data was distributed evenly across the system. In a drinking water supply, water demand is broken down into two categories: (1) customer sales; and (2) unaccounted-for or non-revenue. Together these two demand categories equal the production of water going into the system. The demand data available featured the total sales in the years 2016 and 2017 as well as the top 10 consumers of water, including Metro North Railroad, Stop & Shop, and Byram Concrete.

Unaccounted-for water is any water produced but not sold by the District. The source of unaccounted-for water includes pipe leakage and breaks, fire flow, water theft, system flushing, and inaccurate metering. The difference between production and sold water is unaccounted-for water. Typically, 10 percent is a normal value for unaccounted-for water in a system; a system should undergo repair or improvement if unaccounted-for water exceeds 25 percent (AWWA).

Table 5.1 presents a summary of production and demand data for 2016 and 2017. Unaccounted-for water in WD #1 is 28 percent on average. This is a high percentage of unaccounted-for water which can be attributed to an aging system (leaks and breaks) and the fact that water meters can under-register as they age. We understand the Town routinely replaces its customer meters.

Table 5.1 Summary of Water Produced and Demanded in WD #1

Water Year	Annual Water Pumped (gal/year)	Annual Water Sales (gal/year)	Annual Unaccounted-for Water (gal/year)	Unaccounted-for Water
2016	113,713,395	84,835,083	28,878,312	25%
2017	122,275,002	85,819,816	36,455,186	30%
Average	**117,994,199**	**85,327,450**	**32,666,749**	**28%**

The source of unaccounted-for water and its distribution within the system are unknown, so for this model, a factor based on the difference between produced water and sold water was evenly distributed throughout the system at all nodes. This factor was applied to all demands as though the demand at each node included unaccounted-for water.

5.3 Model Calibration

Model calibration was performed based on data provided by the Owner and information already with GHD. Insurance Service Offices (ISO) produced reports on hydrant testing performed on six hydrants in the Town on December 10, 2014; September 1, 2004; and June 24, 1999. No additional hydrant flow or pipe condition tests were performed in development of the model due to a concern with the condition of mains in the system and the potential for creating a water main break while operating a hydrant. In the calibration exercise, data from the ISO tests and additional data from Town hydrant testing was used to supplement. The two-step calibration process was done by adjusting different parameters within the model and to model static and residual pressure conditions during past hydrant flow testing. The two parameters adjusted were elevations of nodes, tanks, etc., and internal pipe friction roughness.

5.3.1 Hydrant Test Data Discussion

GHD received and reviewed the four records of test data from the ISO and the Town. The model was calibrated against all three records from the ISO. It was originally decided the test data used would come from the ISO 2014 dataset; however, for the dynamic calibration, all three sets were used due to the challenge presented. It should be noted that both the 2014 and 2004 tests had identical test flows, required flows, and measured pressures.

In general, the model was able to accurately predict static pressures from the ISO test. However, there were significant differences in residual pressures noted from the hydrant tests. From the Town tests, which included all hydrants, many areas in WD #1 have static pressures exceeding 100 psi, which is the upper limit recommended by *Recommended Standards for Water Works* (2012). These Standards recommend the working pressure be between 60 and 80 psi and that in cases where static pressures are greater than 100 psi, pressure-reducing devices be used on the water mains. GHD has not been provided any information indicating that pressure-reducing valves or similar devices exist in WD #1.

5.3.2 Static Calibration

Static calibration is performed by adjusting the node elevations to match the static pressure recorded at each hydrant. Field data is recorded using a meter that attaches to the hydrant and measures the pressure at that location (the hydrant is not flowing). In the model, the system is run at average daily demand. The model is statically calibrated when the hydrant node pressures reasonably match the field data with the corresponding elevations. The Overlook tank's initial elevation was estimated based on the tank water level recorded (single data point) by Supervisory Control and Data Acquisition (SCADA) during the testing date, which was about 24 feet. During this time, pump and reservoir (or well) elevations were adjusted to match resulting flow rates on record and were compared against information collected by GHD and provided by the Owner.

5.3.3 Dynamic Calibration

The dynamic or residual calibration effort is performed by adjusting the pipe's internal friction factor (Hazen C coefficient) until the model accurately outputs the residual pressures at each hydrant as recorded from field testing. During a hydrant fire flow test, one hydrant is opened to determine the maximum flow rate available at that point using a calibrated pressure gage. At an adjacent hydrant, a second calibrated pressure gage is attached and the hydrant is left closed. The pressure read on the closed hydrant is the residual pressure. The ISO data available did not specify which hydrant was being used for each part of the test (one for flow, one for pressure measurement). For practicality, residual pressure was read off of the same hydrant that was flowing. It is expected the residual pressure would be lower than the static pressure.

5.3.4 Hazen C Pipe Roughness and Pipe Material and Age

During the calibration of the model, the Hazen C coefficient is adjusted so the model can accurately predict residual pressures. This C-value is dependent on a number of factors and offers a general representation of the status of the interior of the pipe.

As pipes service the water supply and age, their walls will corrode and deteriorate as a function of environmental parameters like water chemistry, mineral scaling, microbiology, and pipe material. During pipe aging, C-values can drop from over 120 down to 90 and lower. The added friction impacts the system by impeding flows and reducing available pressure. Most of the pipes in WD #1 are unlined cast iron. For new ductile iron pipe, the select default C-value is 150. The mains added to the model started with C-values of 67 for 6-inch mains and 68 for 8-inch mains. These values are based on interpolation of literature values for similar pipes in terms of age and size.

Minor losses also impact friction in the system. Associated with headloss in valves, bends, tees, and other modified pipe sections, minor losses can be accounted for in an equivalent C-value. If any valves or bends in the system existed during the hydrant testing, any reduction in pressure they caused during the test is already reflected in the results. Therefore, there is no need to specifically add minor losses into the model at any location of a valve, fitting, or bend.

Table 5.2 presents ISO hydrant test data used from 2014, 2004, and 1999. Each dataset was used in a separate model, not in the same model.

Table 5.2 ISO Testing Data for WD #1 From 2014, 2004, and 1999

Test No.	Hydrant ID (Model)	Static Pressure (psi)	Residual Pressure (psi)	Flow Needed (gpm @ 20 psi)	Flow Available
2014					
1	H-1	105	34	4,500, 2,500	1,070
2	H-2	110	80	2,000	1,180
3	H-3	127	30	2,500	1,010
4	H-4	126	40	2,000	890
5	H-5	134	125	1,000	710
6	H-6	72	16	1,000	730
2004					
1	H-1	105	34	4,500, 2,500	1,070
2	H-2	110	80	2,000	1,180
3	H-3	127	30	2,500	1,010
4	H-4	126	40	2,000	890
5	H-5	134	125	1,000	710
6	H-6	72	16	1,000	730
1999					
1	H-1	80	49	2,500	1,175
2	H-2	130	85	1,750	1,126
3	H-3	135	80	2,250	1,048
4	H-4	74	25	1,000	530

The ISO testing data indicates there are several areas in the system that do not provide the ISO estimates of needed fire flow.

5.3.5 Calibration Summary

The hydrant test data available appeared to be inadequate for the dynamic calibration of the hydraulic model for WD #1. During the calibration effort, the required Hazen C-values to match field-recorded residual pressures with model output were too low to be reasonable in some places in the model. For this reason, it is believed there is a closed valve(s) somewhere in the pipe network, inaccurate information in the ISO test reports, or pipe sizes that may be different than what Town records indicate. The dynamic calibration was carried out with three different sets of ISO hydrant testing data and none were able to reasonably predict the pressures at many of the test nodes. For some nodes, percent errors exceeded 100 percent. As such, without collecting new hydrant flow test data, the model remains uncalibrated and cannot be used to assess the adequacy of the system under varying demand conditions, or to screen improvements for improved capacity.

If the Town were to embark on a hydrant testing effort, GHD has created a marked-up map of WD #1 of potential candidates that can be used (Appendix E).

5.4 Evaluation of Demand Data

The system was to be evaluated under four different conditions: average daily demand, maximum day demand, peak hour demand, and fire flow demand. However, because the model could not be calibrated, none of these conditions could be evaluated.

6. Conclusions and Recommendations

6.1 Model Calibration Techniques

At the completion of this project, the Town will be given a copy of the hydraulic model; however, it will not be calibrated. Despite numerous simulations and revisiting all of the data provided by the Town and available to GHD at the time of calibrating, it was not possible to reconcile the high percent errors on the test hydrants. Lack of up-to-date hydrant test data from the field was the primary reason for the inability to calibrate the model.

GHD recommends that if this model is to be calibrated at any time in the future, it should be done with recent hydrant testing data. The 2014 data is identical to the 2004 data. We understand that the ISO hydrant test data for 2014 was not collected from field testing. We also understand that hydrant testing cannot be performed on WD #1 because the water mains may not withstand such stresses, and there is a lack of adequate valves in the system to isolate breaks. However, new hydrant testing data would be the only choice for calibrating the model and identifying any closed valves in the system.

6.2 Age and Condition of Existing Mains

Many of the water mains in WD #1 are aging and past their service life as indicated by the lowered system capacity and frequent water main breaks reported by the Owner. The water mains may have developed tuberculation as corrosion occurred along the inner lining of the pipes, especially in cast iron. Over time, this will increase the friction and headloss present in the system. In other cases where pressures may be high, aging pipes may rupture, typically when the line has to be flowed during firefighting or flushing activity. During fire flow or hydrant flushing events, certain parts of the District will experience pressures lower than 20 psi, which is below regulatory limits.

ISO testing records also show that parts of the system cannot supply ISO's recommended amounts of fire flow (see Table 5.2).

6.3 Water Main Improvements

There are a number of improvements that can be made to WD #1, including redundancy (increased pipe looping), adding hydraulic redundancy to the system by adding new main connections to the existing water tanks, increasing the size of water mains, placing mains in parallel, and simply replacing older water mains with new ones. These are good waterworks and engineering practices. It is recommended that all new water mains provided into the system be constructed from cement mortar-lined ductile iron pipe (DIP) and that multiple recommendations suggested by this report be implemented.

It is important to note that some recommendations give minimum pipe diameters for ones involving the replacement or addition of mains. These estimates can be made more accurate by assessing the District with a calibrated model.

The following paragraphs are recommendations for improvement in specific areas of WD #1.

6.3.1 Increase the Size of Water Mains on North Broadway, Virginia Road, and Washington Avenue

The water mains that run along these main roads are considerably undersized, with some sections only having original diameters of 6 inches. This main loop is vital to supplying water to the District and is a good first step in improving system reliability. It is recommended the smallest size of any main in this loop be 12-inch.

6.3.2 Increase the Size of Water Main on Washington Place East

The water main that run along Washington Place East is an important connection between the main roads (North Broadway and Washington Avenue) in the east and west of the District. Bolstering this water main with larger pipe may improve reliability. It is recommended the smallest size of any main in this loop be 12-inch.

6.3.3 Increase the Size of Water Main on Hillandale Avenue

The water main that run along Hillandale Avenue is an important connection between the main roads (North Broadway and Washington Avenue, Custis Avenue) in the east and west of the District. Bolstering this water main with larger pipe may improve reliability. It is recommended the smallest size of any main in this loop be 12-inch.

6.3.4 Connect Dead End Pipe on Palmer Avenue to Main Serving the Shopping Center on Reservoir Road

The 6-inch main on Palmer Avenue can be tied into the 6-inch main on Reservoir Road. GHD understands this has been a recent problem area where the water supply is failing to meet needs, and this is one option to increase looping and reliability of the District. Palmer Avenue directly connects to Reservoir Road; therefore, a new water main should not interfere with any homes or businesses or require an easement. It is recommended this main be at least 8-inch.

6.3.5 Connect Water Main on Grove Road to Palmer Avenue Via Rockledge Road

The 6-inch mains on Grove Road and Palmer Avenue can be connected without the need for an easement. This is one way to increase looping and reliability of the District. It is recommended this main be at least 8-inch.

6.3.6 Replace 10-Inch Mains With Larger Mains

Water mains sized 10 inches are perhaps the oldest, the majority of which are located exclusively in the Custis and Overlook tank areas and can be considered critical to WD #1. Water mains sized 10 inches may be less common in modern installations; however, they are not impossible to obtain.

It is recommended that the oldest and most hydraulically significant mains be replaced to improve system capacity.

6.3.7 Valhalla Well Rehabilitation or Redevelopment

It is important that WD #1 have a redundant water supply that draws from more than one source. Currently, WD #1's only source is the Broadway pump station. To provide the added redundancy, it is recommended that the Valhalla well be rehabilitated, redeveloped, or replaced as necessary so some capacity can return to the well and this source can be utilized again. Over time, as a well is pumped, fines, corrosion byproducts, and microorganism films may build up around the well screen and media. Rehabilitation involves replacing the pump or piping system in the well. Redevelopment may include flushing with muriatic acid and chlorine; redrilling the well; or overpumping, surging, or jetting the well to break up material clogging the media or screen. The option of replacement may mean replacing the entire pump in the well or abandoning the current well for construction and development of a new one.

As mentioned in Section 4.1, the Valhalla well had been rehabilitated and redeveloped in 2012. While the Town has made efforts to redevelop the well, it has not significantly restored capacity and continues to experience rapid yield decline. The capacity of the Valhalla well should be addressed to supplement the North Broadway supply. In addition, the condition of the discharge main would need to be addressed if the Valhalla well is returned to service.

6.3.8 Virginia Road Pump Rehabilitation

The system can receive additional redundancy by rehabilitating the Virginia Road pump station. The Virginia Road pump has been turned off from production because it lacks treatment for removing or inactivating *Cryptosporidium*. UV treatment would need to be added to the station in order to provide the necessary improvement. Further improvements would include replacing the entire pumping system and performing building and facility upgrades.

6.3.9 Tank Volume Adequacy

GHD understands that both tanks serving WD #1 have recently been rehabilitated. The combined volume of the tanks does not have the capacity to provide the volume of storage required to meet the highest ISO recommended fire flow. One of ISO's recommended fire flow rates in WD #1 is 4,500 gpm sustained for four hours. From past records, a maximum day demand has been observed exceeding 700,000 gallons. In a worst case scenario (maximum day demand plus fire), the system could not supply the required 1.1 million gallons from storage for the duration of the fire. The combined volume of both tanks is 917,000 gallons, and not all of that volume is usable to the fire because pressures drop to unacceptable levels at homes in the vicinity of the Overlook tank. It should be noted that, while not relied on as a first option, the various interconnections between WD #1 and adjacent water systems may be opened in an emergency to supplement the District, which would lessen the impacts of tank drawdown during firefighting activity.

6.3.10 Address Low System Pressures

It is apparent that some areas of WD #1 have service pressures less than 35 psi, which falls below 20 psi during peak demands. This is primarily an issue in the residential area immediately adjacent to the Overlook tank. GHD understands the Overlook tank was constructed prior to some of the higher elevation homes in its vicinity and recommends the Town address these low pressure areas. We understand that houses in the vicinity of the tank have booster pumps to address low pressure.Valve Replacement

With the replacement of mains, valves should be provided at all intersections and interconnection points to improve the ability to isolate sections of the system. Insert valves should be added to older mains which will remain.

Appendices

Appendix A – Map of Water District No. 1 (1960)

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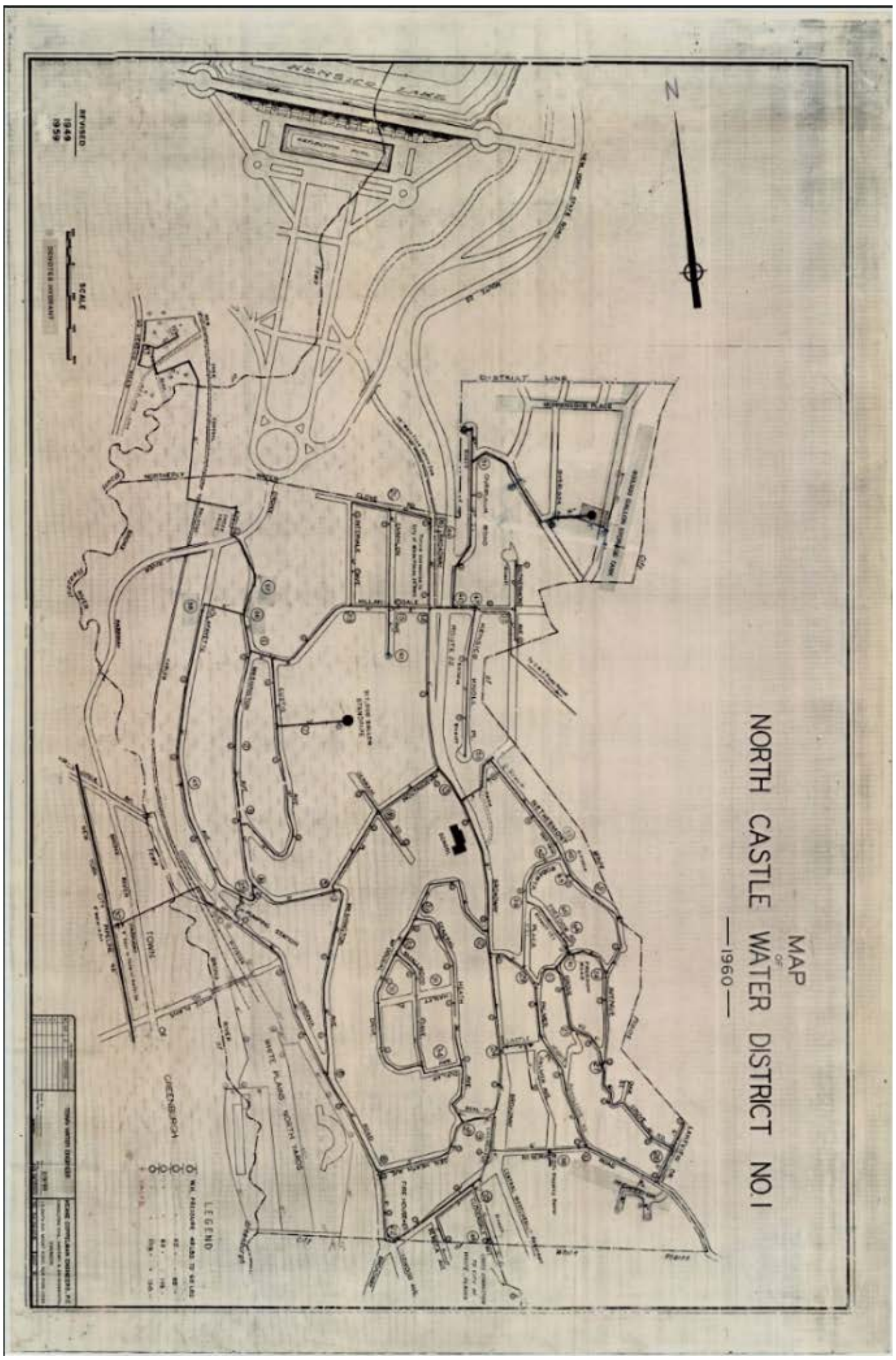

Appendix B - List of All Hydrants in WD #1

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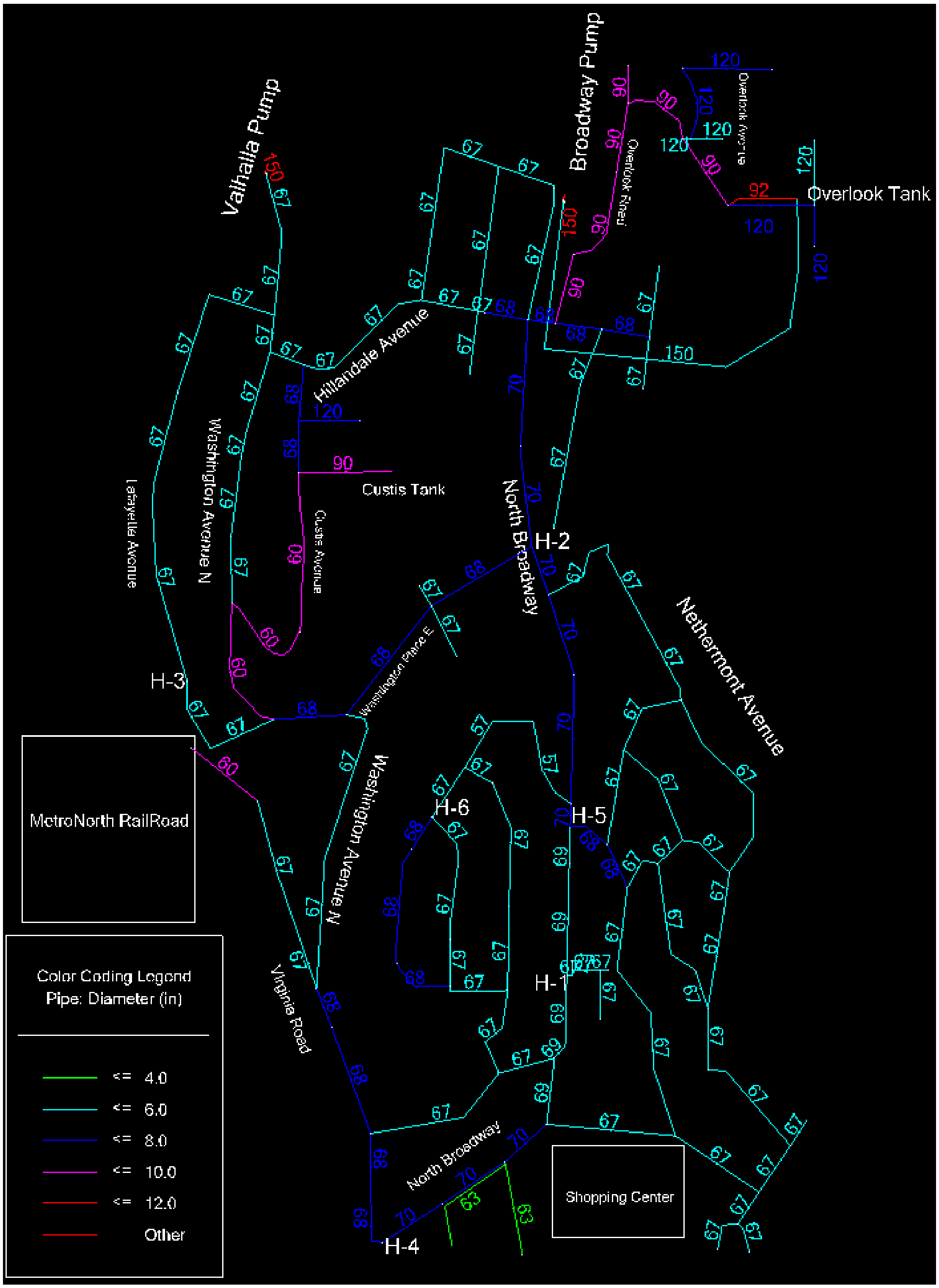
HYD#	St#	Location	Type	Static Pressure (psi)	Cap Color	Main Size (in.)	Dead End	Fire Flow		
								Pressure (psi)	Residual (psi)	Flow (gpm)
1	17	Rockcliff Pl.	Muel. 4-1/2	18	Orange	8	Y	18	11	515
2	54	Overlook Rd./Tank Dwy	Renn.	23	Orange	10		23	15	865
3	3	Overlook Ct.	Renn.	58	Green	6	Y	58	40	1000
4	12	Overlook Rd.	Renn.	73	Green	10		76	75	1365
5	2	Overlook Rd.	Renn.	85	Green	10		85	75	1365
6	128	Nethermont Ave.	Muel. 5-1/4	72	Orange	6	Y	72	10	500
7	110	Nethermont Ave.	Renn.	76	Orange	6	Y	76	13	550
8	12	Hillandale Ave.	Renn.	80	Green	6		76	47	1250
9	19	Kensico Knolls Pl.	Renn.	75	Orange	6	Y	75	22	730
10	9	Kensico Knolls Pl.	Renn.	76	Orange	6	Y	76	20	710
11	1001	North Broadway	Muel. 5-1/4	104	Green	6		104	28	974
12	24	Hillandale Ave.	Renn.	103	Green	6		103	34	1085
13	31	Emmalon Ave.	Darling	116	Green	6		116	44	1218
14	24	Intervale Ave.	Muel. 5-1/4	123	Green	6		123	45	1225
15	8	Intervale Ave.	Renn.	121	Green	6		121	28	975
16		Hillandale & Emmalon	Darling	105	Green	6		105	30	995
17	915	North Broadway/Sir John's	Darling	100	Green	8		100	46	1245
18	41	Hillandale Ave.	Renn.	93	Green	6		93	32	1042
19	53	Custis Ave.	Renn.	73	Orange	8		73	40	1000
20		Custis Tank	Renn.	54	Green	10		54	35	930
21	35	Custis Ave.	Renn.	72	Green	10		72	39	1132
22	20	Custis Ave.	Renn.	75	Green	10		75	37	965
23	105	Washington Ave.	Renn.	100	Green	6		100	24	900
24	89	Washington Ave.	Renn.	99	Green	6		99	38	1132
25	123	Washington Ave.	Darling	91	Green	6		91	39	1132
26		Parkway	Muel. 5-1/4	125	Green	6		125	30	1012
27	160	Lafayette/Turnaround	Muel. 5-1/4	131	Green	6		125	82	1230
28	121	Lafayette Ave.	Darling	127	Green	6		127	29	1000
29	77	Lafayette Ave.	Darling	127	Green	6		127	30	1012
30		Benfield/Lafayette	Darling	127	Green	6		135	80	1048
31	66	Washington Ave.	Muel. 5-1/4	108	Green	8		108	44	1095
32	47	Washington Ave.	Renn.	125	Green	8		125	48	1272
33	31	Washington Ave.	Muel. 5-1/4	114	Green	6		114	22	875
34	11	Washington Ave.	Muel. 5-1/4	120	Green	6		120	24	900
35	95	Virginia Rd.	Renn.	135	Green	6		135	33	1050
36	145	Virginia Rd./Concrete Yard	Muel. 5-1/4	138	Green	6		138	32	1042
37	176	Virginia Rd.	Darling	139	Green	6		139	90	1250
38		Virginia & Washington Ave.	Muel. 5-1/4	127	Green	8		130	85	1126
39		General Heath Ave./Virginia Rd	Darling	130	Green	6		130	35	1095
40	20	Virginia Rd.	Renn. 90-A	140	Green	8		140	36	1102
41	621	North Broadway/Firehouse	Muel. 5-1/4	140	Orange	8		126	40	890
42	88	Seneca Ave.	Renn. 90-A	135	Red	4	Y	135	2	165
43	77	Cloverdale Ave.	Renn. 90-A	136	Red	4	Y	137	6	340
44	647	North Broadway	Renn. 90-A	136	Red	8		129	42	925
45	1	Church St./North Broadway	Renn. 90-A	134	Green	6		134	34	1072
46	20	General Heath Ave.	Renn. 90-A	108	Green	6		108	32	1040
47	34	General Heath Ave.	Renn. 90-A	71	Orange	6		71	12	540
48	51	General Heath Ave.	Renn. 90-A	65	Red	6		65	8	380
49	59	General Heath Ave.	Renn. 90-A	75	Orange	6		49	10	500
50	50	General Heath Ave./McDougal	Renn. 90-A	80	Orange	6		72	16	737
51	24	Smallwood	Renn. 90-A	72	Orange	6		70	24	530
52	51	McDougal Dr.	Renn. 90-A	78	Orange	6		78	11	515
53	14	Smallwood	Renn. 90-A	68	Red	6		68	6	275
54	70	McDougal Dr.	Renn. 90-A	80	Red	6		80	7	300
55	15	McDougal Dr.	Renn. 90-A	94	Orange	6		94	30	875
56	811	North Broadway/McDougal Dr.	Muel. 5-1/4	105	Green	8		105	52	1300
57	755	North Broadway/Dunkin Donut	Muel. 5-1/4	113	Green	6		113	45	1125
58		Church & Beal	Renn. 90-A	118	Green	6		118	34	1070
59		Palmer/Behind Diner	Muel. 5-1/4	125	Orange	6	Y	105	17	750
60	19	Reservoir Rd./Rockledge	Renn. 90-A	126	Orange	6		134	125	720
61	15	Rockledge	Renn. 90-A	97	Orange	6		97	22	740
62	34	Palmer Ave.	Muel. 5-1/4	107	Orange	6		107	24	775
63	43	Grove Rd.	Renn. 90-B	74	Orange	6		74	36	940
64	30	Grove Rd.	Renn. 90-B	65	Orange	6		65	33	920
65		Nethermont Ave./Grove St.	Renn. 90-B	59	Orange	6		59	30	865
66	15	Grove Rd.	Renn. 90-B	72	Orange	6		72	35	930
67	3	Grove Rd.	Renn. 90-B	92	Orange	6		93	17	760
68	15	Lakeview	Renn. 90-B	96	Orange	6	Y	96	13	560
69		Lakeview/Res. Dr.	Renn. 90-B	110	Orange	6		110	17	675
70	11	Nethermont Ave.	Renn. 90-B	45	Orange	6		45	13	560
71	19	Nethermont Ave.	Muel. 5-1/4	39	Orange	6		39	11	515
72	11	Freedom Rd.	Renn. 90-B	60	Orange	6		60	28	810
73	41	Nethermont Ave.	Renn. 90-B	44	Orange	6		44	15	605
74	11	Roberta Pl.	Muel. 5-1/4	62	Orange	6		62	18	670
75	63	Nethermont Ave.	Renn. 90-B	54	Orange	6		54	32	895
76	75	Nethermont Ave.	Renn. 90-B	67	Orange	6		67	35	930
77		Palmer/North Broadway	Renn. 90-B	105	Green	6		105	34	1072
78	845	North Broadway/School	Darling	107	Green	8		107	50	1135
79	877	North Broadway/Washington P	Muel. 5-1/4	104	Orange	8		99	94	790
80	6	Denim Pl.	Muel. 5-1/4	120	Orange	6	Y	120	24	770
81		Denim Pl./Washington Pl.	Muel. 5-1/4	114	Green	8		114	55	1165
82	17	Denim Pl.	Renn.	107	Orange	6	Y	107	25	785
83	1	Pinewood Cir. (Int Pinewood Ci	Darling	135	Orange	8	Y	135	22	735
84	6	Pinewood Cir. (Condos)	Darling	127	Orange	8	Y	127	18	685
85	21	Pinewood Dr. (Condos)	Darling	127	Orange	8	Y	127	20	710
86		Emmalon Circle	Muel. 5-1/4	93	Green	6	Y	83	43	1215
87	67	Overlook Road	Muel. 5-1/4	23	Orange	6	Y	23	10	500
88	20	Overlook Road	Renn.	37	Green	10		37	31	875
89	33	Rockcliff Pl.	Muel. 4-1/2	15	Orange	6	Y	15	9	475
90	3	Valhalla P.	Muel. 5-1/4	32	Orange	8	Y			
91	5	Morning Side Pl.	Muel. 5-1/4	26	Orange	8	Y			
92	10	Morning Side Pl.	Muel. 5-1/4	18	Orange	8	Y			
93	54	Custis Ave.	Muel. 5-1/4	60	Green	8	Y			

Appendix C - Hydraulic Model Map and Pre-Calibration Hazen C-Values Selected for Pipes in Model

Appendix C - Hydraulic Model Map and Pre-Calibration Hazen C-Values Selected for Pipes in Model



Static Calibration Initial C (60 year old pipe)			
		Trend 1	Trend 2
C.I.	4"	93	75
	6"	97	79
	8"	100	80
	10"	105	82
	12"	110	85
D.I.	6"	130	
	8"	130	
	10"	135	

DIP C-values above provided by DIPRA pamphlet (2016)

AWWA Modeling (1995) suggests C is typically 140 for new, lined DIP

Static Calibration Initial C (40 year old pipe)			
		Trend 1	Trend 2
C.I.	4"	103	86
	6"	106	90
	8"	108	92
	10"	110	94
	12"	112	97
D.I.	6"	140	
	8"	140	
	10"	140	

AWWA Modeling (1995) suggests C is typically 140 for new, lined DIP

Appendix D - Static Calibration Data and Dynamic Calibration Data

Appendix D - Static Calibration Data and Dynamic Calibration Data

ISO 2014			
Test No.	Static Pressure (psi)		% Error
	Test Data	Model Output	
1	105	111	-5.4%
2	110	102	7.8%
3	127	119	6.7%
4	126	131	-3.8%
5	105	100	5.0%
6	72	72	0.0%

ISO 2014 (N Broadway pipe shut)			
Test No.	Static Pressure (psi)		% Error
	Test Data	Model Output	
1	105	111	-5.4%
2	110	102	7.8%
3	127	119	6.7%
4	126	131	-3.8%
5	105	100	5.0%
6	72	72	0.0%

ISO 1999			
Test No.	Static Pressure (psi)		% Error
	Test Data	Model Output	
1	80	102	-21.6%
2	130	121	7.4%
3	135	119	13.4%
4	74	66	12.1%

ISO 2014:

ISO 2014 - INITIAL			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	34	68	-50.0%
2	80	89	-10.1%
3	30	95	-68.4%
4	40	105	-61.9%
5	34	75	-54.7%
6	16	46	-65.2%

ISO 2014 - IN CALIBRATION			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	34	59	-42.4%
2	80	79	1.3%
3	30	74	-59.5%
4	40	96	-58.3%
5	34	66	-48.5%
6	16	36	-55.6%

ISO 2004:

ISO 2004 - INITIAL			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	34	68	-50.0%
2	80	89	-10.1%
3	30	95	-68.4%
4	40	105	-61.9%
5	34	71	-52.1%
6	16	46	-65.2%

ISO 2004 - IN CALIBRATION			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	34	59	-42.4%
2	80	79	1.3%
3	30	75	-60.0%
4	40	95	-57.9%
5	34	62	-45.2%
6	16	36	-55.6%

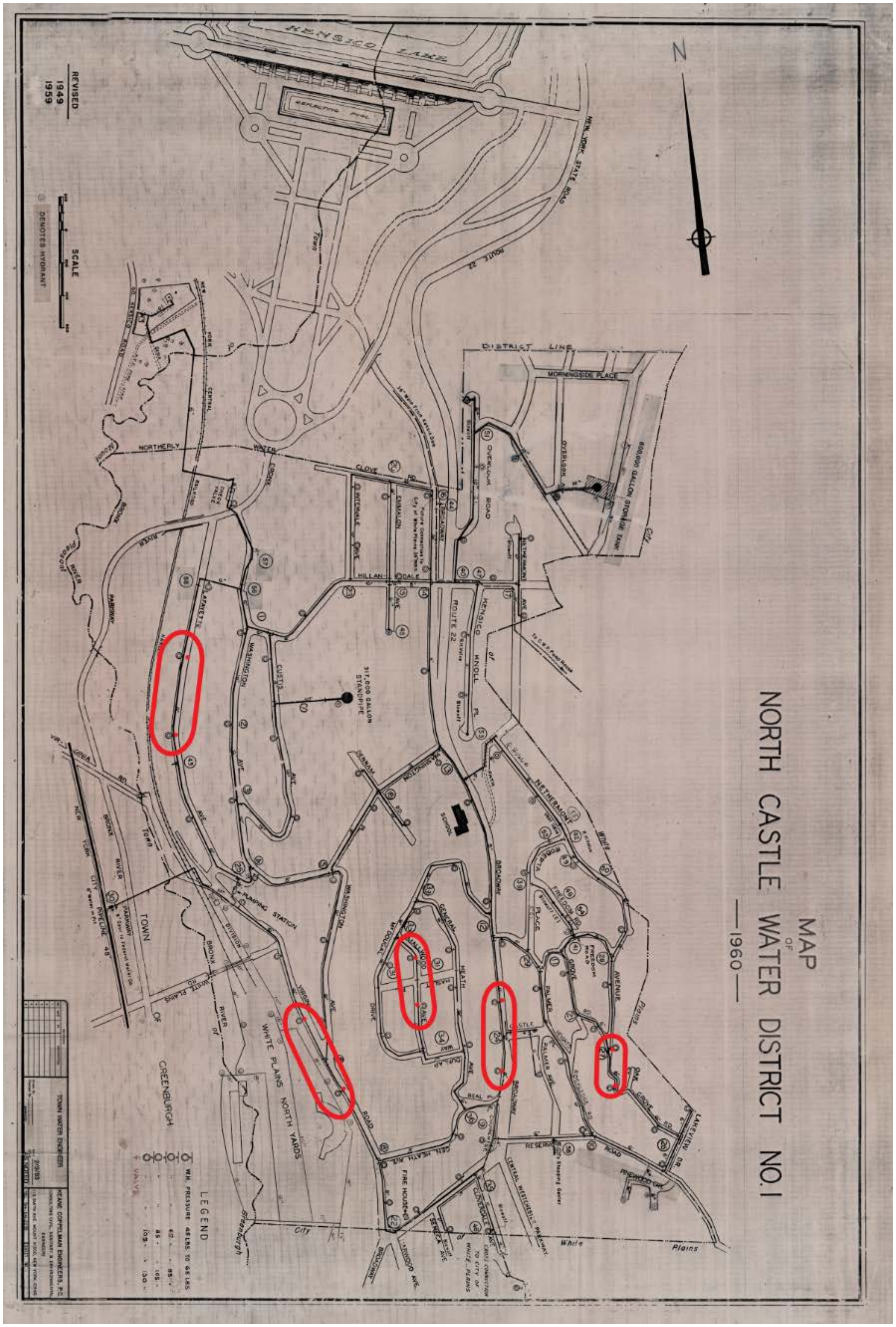
ISO 1999:

ISO 1999			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	49	90	-45.6%
2	85	83	2.4%
3	80	96	-16.7%
4	25	50	-50.0%

ISO 1999 - IN CALIBRATION			
Test No.	Dynamic Pressure (psi)		% Error
	Test Data	Model Output	
1	49	84	-41.7%
2	85	74	14.9%
3	80	82	-2.4%
4	25	45	-44.4%

Appendix E - WD #1 Map, Test Hydrant Candidates

Appendix E - WD #1 Map, Test Hydrant Candidates



about GHD

GHD is one of the world's leading professional services companies operating in the global markets of water, energy and resources, environment, property and buildings, and transportation. We provide engineering, environmental, and construction services to private and public sector clients.

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