APPENDIX H

HYDRAULIC MODELING TECHNICAL MEMORANDUM

City of Flint, Michigan

HYDRAULIC MODELING TECHNICAL MEMORANDUM

Water Distribution System Optimization

January 2018

HYDRAULIC MODELING TECHNICAL MEMORANDUM

Water Distribution System Optimization

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ACRONYMS AND ABBREVIATIONS

ADD – average day demand

AFD – automatic flushing device

BTX – back trace extension

CS2 – Control Station No. 2

CSR – Cedar Street Reservoir

DI – ductile iron pipe

ft – feet

GIS – geographic information system

GLWA – Great Lakes Water Authority

gpm – gallons per minute

HGL – hydraulic grade line

HPR – hydrant pressure recorder

hr – hour

Ln - lane

MDD – maximum day demand

MG – million gallons

MGD – million gallons per day

PS – pump station

psi – pounds per square inch

RMSE – root-mean-square error

SCADA - Supervisory Control and Data Acquisition

St - street

USEPA – United States Environmental Protection Agency

WTP – Water Treatment Plant

WSR – West Side Reservoir

1 INTRODUCTION

The City of Flint (City) distributes drinking water to a population of approximately 98,310 through approximately 580 miles of distribution system mains. The City currently purchases finished water from the Great Lakes Water Authority (GLWA), boosting the concentration of chlorine and orthophosphate for corrosion control prior to distribution. Additionally, the City owns and operates the Flint Water Treatment Plant (WTP) as a backup supply with the ability to intake from the Flint River.

The City of Flint has retained a team led by Arcadis of Michigan, LLC (Arcadis) and including Environmental Engineering & Technology, Inc. (EE&T), Confluence Engineering Group, LLC, and McConnell Communications, Inc.to perform an analysis of system components and organizational practices compared to industry standards and best practices to identify and prioritize necessary improvements to optimize the distribution system.

The purpose of this Technical Memorandum is to document the approach and results of the water distribution system hydraulic model update, calibration, and analysis.

1.1 Hydraulic Modeling Background

Water systems often maintain a hydraulic model to predict performance of the system and to solve a wide variety of design, operational and water quality problems. For example, a hydraulic model can predict pressures and flow rates through the system for comparison to design standards, a model can track flow through a system to determine water age and water quality areas of concern, or a model can represent system impacts of various operating schemes and adjustments.

In 2009, the City of Flint contracted with various professional services firms to develop and calibrate a hydraulic model representing the City's water distribution system. Since that time, the model was periodically updated, but additional calibration was not performed.

In 2016, the United States Environmental Protection Agency (USEPA) and CitiLogics, LLC collected field pressures during typical system conditions, the latest information available within the City's geographical information system (GIS), Supervisory Control and Data Acquisition (SCADA) system and customer billing systems to update and calibrate the model to represent current system conditions. The USEPA visited all tanks, reservoirs, pump stations, and control stations and performed model updates to reflect valve size and type, pipe lengths and diameters, pump curves and valve loss coefficients. The USEPA also performed an assessment of model performance during the period of August – November 2016, and error statistics for predicted tank levels, flows, hydraulic grade, and system demand have been generated.

As part of the *Assessment of Current Practices and Gap Analysis Technical Memorandum, January 2017,* by the Arcadis team, a copy of the latest hydraulic model was provided for our review and audit of the model's capability and alignment with currently industry standard practices and guidelines. While significant improvements to the model had recently been performed, the model still lacked the level of calibration necessary for system evaluation.

As the City's Water Distribution Optimization Project developed, it was clear that a calibrated hydraulic model was necessary for answering questions such as identifying the correct volume of storage needed in the system to maintain adequate hydraulic performance and balance with a lower water age. Arcadis then began a detailed model update and calibration effort coordinating with the USEPA team, such that sufficient calibration and confidence in the model existed to answer these questions.

Following completion of an update and calibration to the model, the calibrated model was utilized to evaluate multiple objectives associated with the Water Distribution System Optimization Project.

1.2 Modeling Objectives

Multiple objectives were identified to use the hydraulic model for the purpose of better understanding the system, and ultimately for evaluating potential changes to the system for the purpose of system optimization. This Technical Memorandum summarizes the following tasks:

- Updating and calibrating the model to adequately represent current system conditions for the purpose of system evaluations.
- Analysis of distribution system storage facilities to determine the hydraulics and water age impacts of taking various facilities offline, or bringing facilities online that are not currently in service.
- Evaluation of potential system pressure transients, or surges, as a result of rapid pump and/or valve startup and shutdown. The results are compared to historical main breaks to identify any correlation.
- Identify best locations for online water quality monitoring and sensor placement that balance adequate coverage of the entire system, yet are sufficiently downstream to capture the impact of changes to water age.
- Evaluate the impact of various system and operational changes on water age within the system. While water age does not necessarily correlate to water quality, it is often used as a surrogate to water quality and it is best practice to minimize water age.
- Using operational data from the calibrated model, identify which pipes within the system are most critical to ensure uninterrupted service to customers. The results will be used as input for evaluating risk during development of the Asset Management Plan.

2 MODEL IMPROVEMENTS AND CALIBRATION

The USEPA and CitiLogics were updating and calibrating the model in a real-time modeling environment. Various versions of the model were provided to Arcadis with complex controls in order to adequately represent changing conditions. A “snapshot” model was provided by the USEPA and CitiLogics which served as the basis for the Arcadis model update and calibration effort. The model was an export from the real-time model and contained all real-time controls and operations during the period of field data collection and testing performed by Arcadis (Section 2.2).

2.1 Model Revisions and Improvements

2.1.1 Infrastructure Revisions

A number of infrastructure related revisions were made to the model prior to calibration. These changes were deemed necessary based on the initial model review and feedback received from the City. First were updates to junction elevations. In the model as received, elevation accuracy was questionable. For example, most elevations near the downtown area were a single value before suddenly changing by several feet in a neighboring area. Therefore, all elevations in the model were updated with publicly-available topographic geographic information system (GIS) data.

Spatially, the model was inconsistent and contained several configuration issues. Frequent jagged pipes were identified in the model. Though these do not affect hydraulics, they do present challenges with interpreting model results. Model pipes would frequently not align with roadways or traverse private property. In addition, GIS data received from the City did not align exactly with the modeled pipes. As part of asset management task, spatial data collection associated with the Water Distribution System Optimization Plan was performed. This additional data was used to correlate and align the model and GIS data sets. A common relationship was determined between the model and GIS which allowed the two data sets to be directly linked (it is possible that the previous model was built using the original GIS in some form). The model junction X-Y coordinates and pipe vertices were updated based on the preferable and more consistent Flint GIS data (NAD 83 International Feet). Figure 2.1 shows an example of piping before and after the coordinate updates. While none of these effected the model hydraulics, the relationship did have major benefits: the model is now spatially consistent which improves model-based recommendations; and GIS data can be exchanged with the model to provide model updates or to extract model results into the GIS.

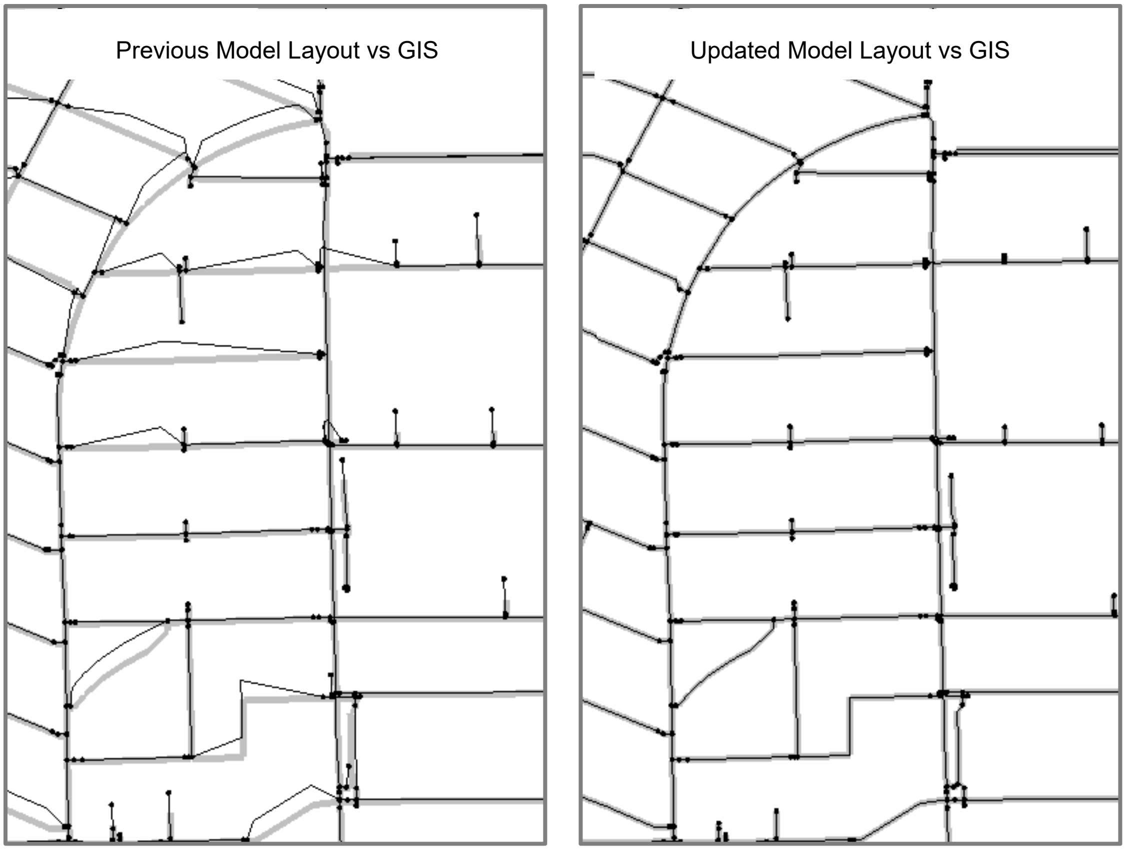
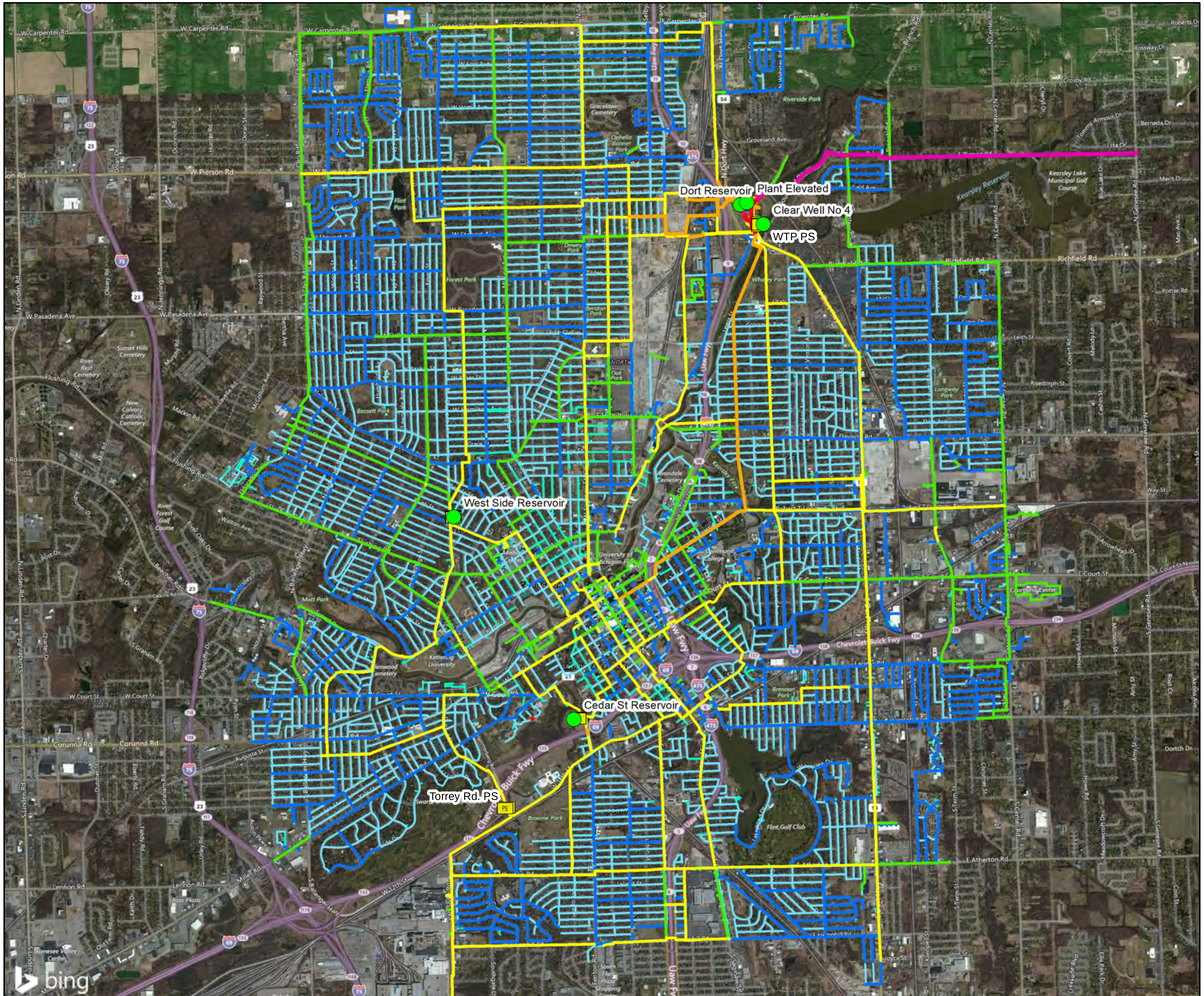


Figure 2.1 Previous Network to Updated Network Comparison

Finally, many large diameter pipes were identified in the model as incorrect by the City. Therefore, a review between the model, GIS, system-wide maps, and local field atlas maps was performed. A number of pipe diameters were revised in various locations within the model (most in the 16” to 24” range). Figure 2.2 shows the complete City of Flint model network and final pipe diameters that were used for calibration and analysis.

2.1.2 Demand Allocation Revisions

USEPA and CitiLogics, as part of their model update, obtained the latest billing data from the City and reallocated water system demands through a geocoding process prior to providing the model to Arcadis. During calibration, a large area near the middle of the network was identified as having negative pressures. Further investigation revealed an exceptionally large demand at a single location in this area. Through coordination with USEPA and CitiLogics, it was determined that this was a demand allocation error in the model: multiple demand locations that could not be located were incorrectly placed on a single junction. Arcadis worked with CitiLogics to correct this demand error, and the new demand distribution developed by CitiLogics was updated in the calibration model. Figure 2.3 shows a before and after comparison of the demands in the model. Generally, the adjustments for the majority of the network were minor with the exception of the region near the reallocated large demand.



Legend

- Model Tanks
- Model Pumps

Model Pipes (Diameter)

- < 6"
- 6"
- 8"
- 10 - 12"
- 16 - 24"
- 24" - 36"
- 36" - 48"
- > 48"

N

0 5,000 10,000 Feet

City of Flint, MI

Hydraulic Modeling Calibration

Flint Water Model Network

ARCADIS Design & Consultancy for natural and built assets

FIGURE **2.2**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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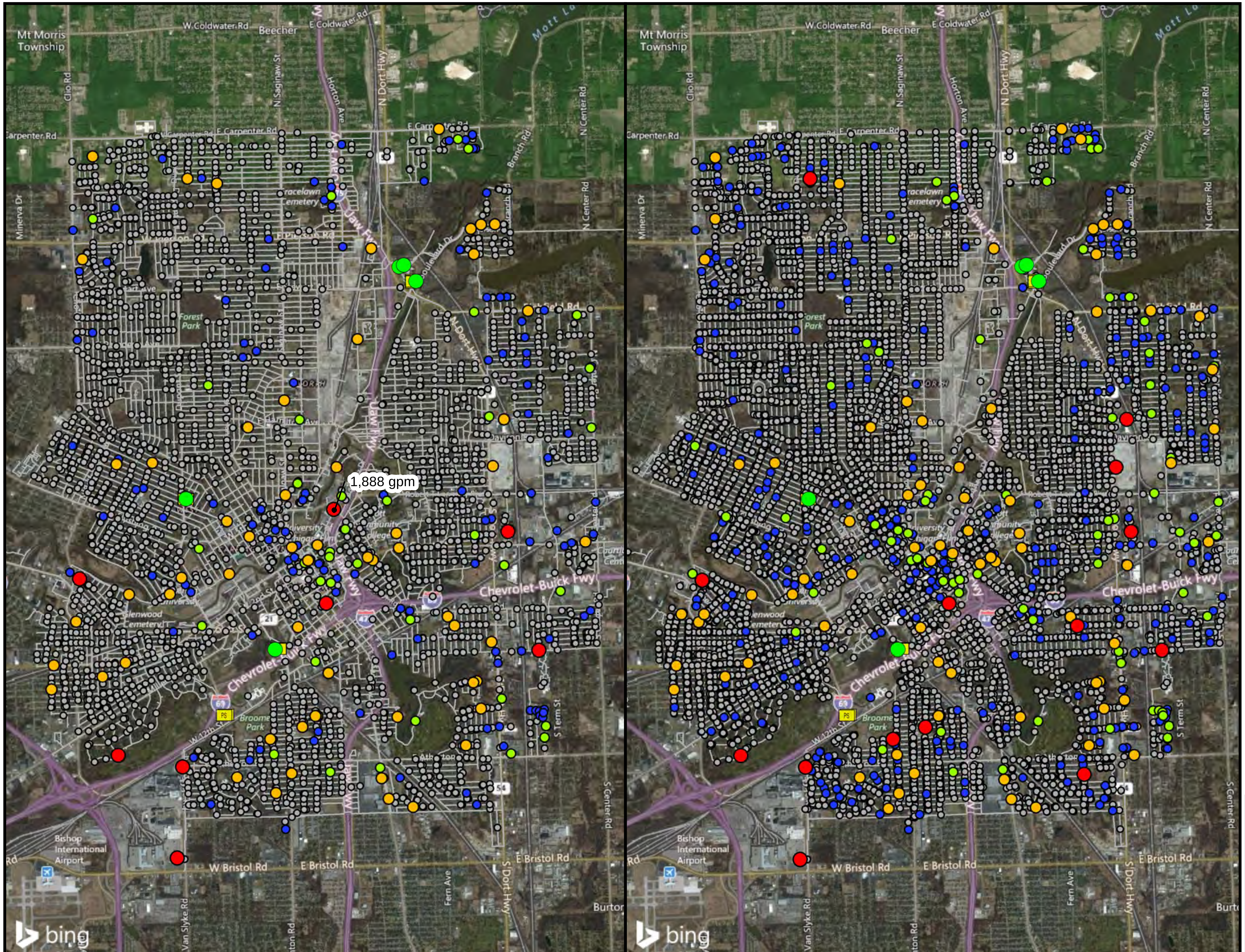
Service Layer Credits: © 2017 DigitalGlobe ©CNES (2017) Distribution Airbus DS © 2017 HERE © 2017 Microsoft Corporation

Original Demand Distribution

Updated Demand Distribution



Legend

- Model Tanks
- Model Pumps

Demand (gpm)

- 0 - 2
- 2 - 5
- 5 - 10
- 10 - 30
- > 30
- Existing Pipes

N

0 0.5 1 2 Miles

City of Flint, MI

Hydraulic Modeling Calibration

Demand Distribution Comparison

ARCADIS Design & Consultancy for natural and built assets

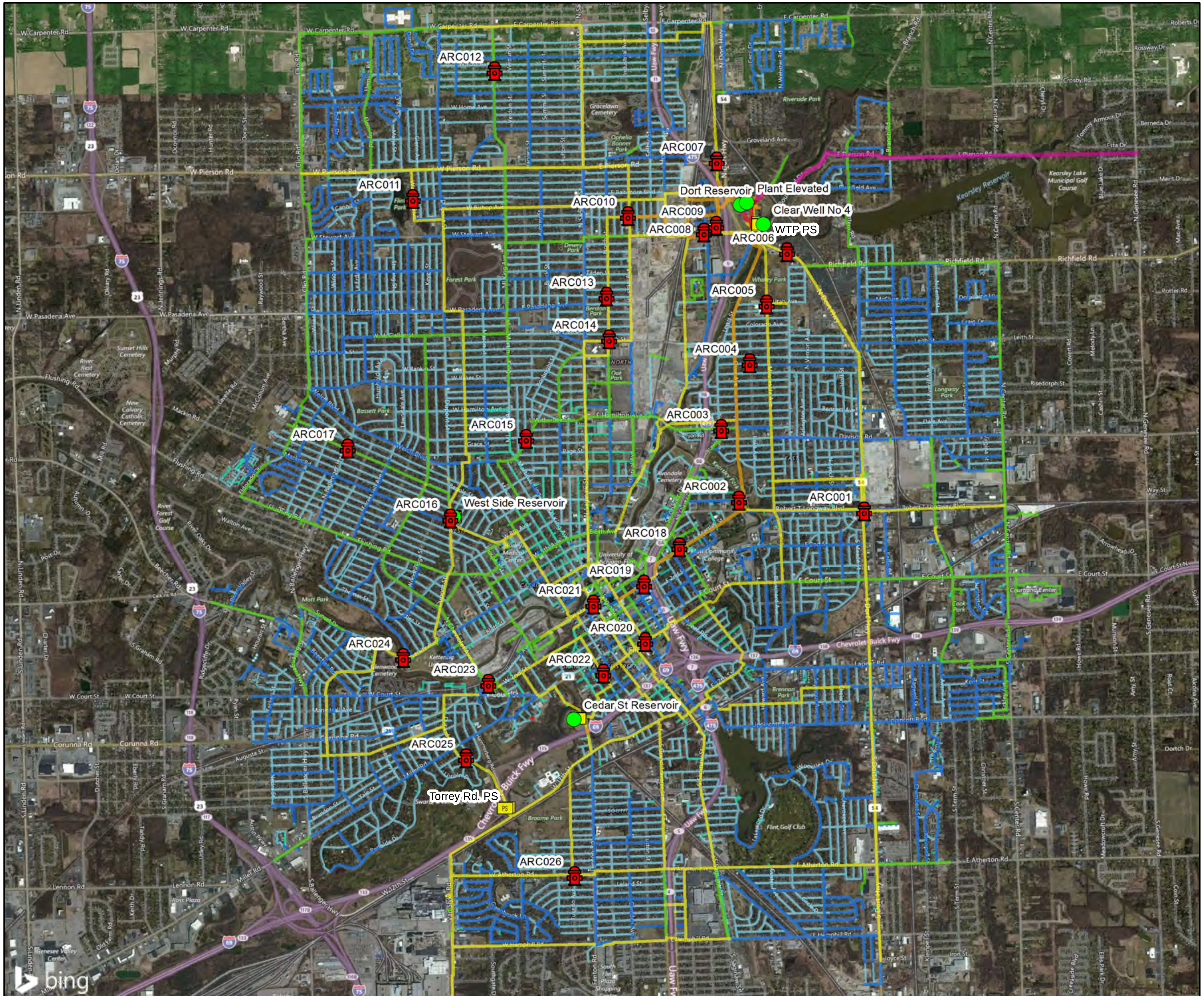
FIGURE **2.3**

2.2 Calibration Data Collection

Arcadis performed an extensive field effort in support of recalibration of the model. Appendix A provides the complete data collection plan that was developed for this effort. Twenty-six hydrant pressure recorders (HPRs) were installed on hydrants throughout the system. They remained on hydrants for approximately one week while pressures were recorded every minute. One of the goals of this field effort was to understand the evolution of the hydraulic grade line (HGL) and how it changed within the system. The model could be adjusted accordingly if HGL degraded suddenly versus gradually as water moved into the system. Locations of all installed HPRs are found in Figure 2.4 and Table 2.1, and collected data reports are presented in Appendix B.

Table 2.1 Locations of HPRs

ID	Type	HPR	Elev. (ft)	Model ID	Location / Intersection
ARC001	Pressure	206197	754	3510	Dort & Robert Longway
ARC002	Pressure	206215	731	3379	Poblar & Kearsly Park
ARC003	Pressure	206196	729	9990	Broadway Blvd & Lewis St
ARC004	Pressure	206223	728	10355	Iowa Ave & Maryland Ave
ARC005	Pressure	206202	731	12020	Utah & Minnesota Ave
ARC006	Pressure	206211	725	11798	N Dort Hwy & Franklin Ave
ARC007	Pressure	206201	750	15465	Piersons Rd & Thetford Rd
ARC008	Pressure	206213	751	11534	E Stewart Ave & James P Cole Blvd
ARC009	Pressure	206216	749	11827	1401 E Stewart St (Parking Lot)
ARC010	Pressure	206222	765	10182	Black Ave & Industrial Ave
ARC011	Pressure	206172	770	12513	Baltimore & Winthrop Blvd
ARC012	Pressure	206224	776	14998	Lorado & Martin Luther King Ave
ARC013	Pressure	206193	757	10718	Gillespie Ave & North St
ARC014	Pressure	206209	747	10040	Lieth & North St
ARC015	Pressure	206217	800	13847	Oren Ave & Paternson St
ARC016	Pressure	206210	765	8398	Dupont St & Jean Ave
ARC017	Pressure	206198	778	9469	Ballenger Hwy & Mallery St
ARC018	Pressure	206219	746	4260	Crapo St & Kearsley St
ARC019	Pressure	206218	738	5842	1st St & Chavez Dr
ARC020	Pressure	206220	752	5914	5th St & Harrison
ARC021	Pressure	206194	717	5386	Beach St & Kearsley St
ARC022	Pressure	206208	757	5050	Oak St (dead end)
ARC023	Pressure	206199	737	6681	Glenwood & Fox
ARC024	Pressure	206221	698	8012	University Ave (between Nolan Ave & Bridge)
ARC025	Pressure	206207	749	7758	Durand St & Ramsay Blvd
ARC026	Pressure	206195	763	2684	Atherton Rd & Tuxedo Ave



Legend

- Pressure Metering
- Model Tanks
- Model Pumps

Model Pipes (Diameter)

- < 6"
- 6"
- 8"
- 10 - 12"
- 16 - 24"
- 24" - 36"
- 36" - 48"
- > 48"

N

0 5,000 10,000 Feet

City of Flint, MI

Hydraulic Modeling Calibration

Installed Hydrant Pressure Recorders

ARCADIS Design & Consultancy for natural and built assets

FIGURE **2.4**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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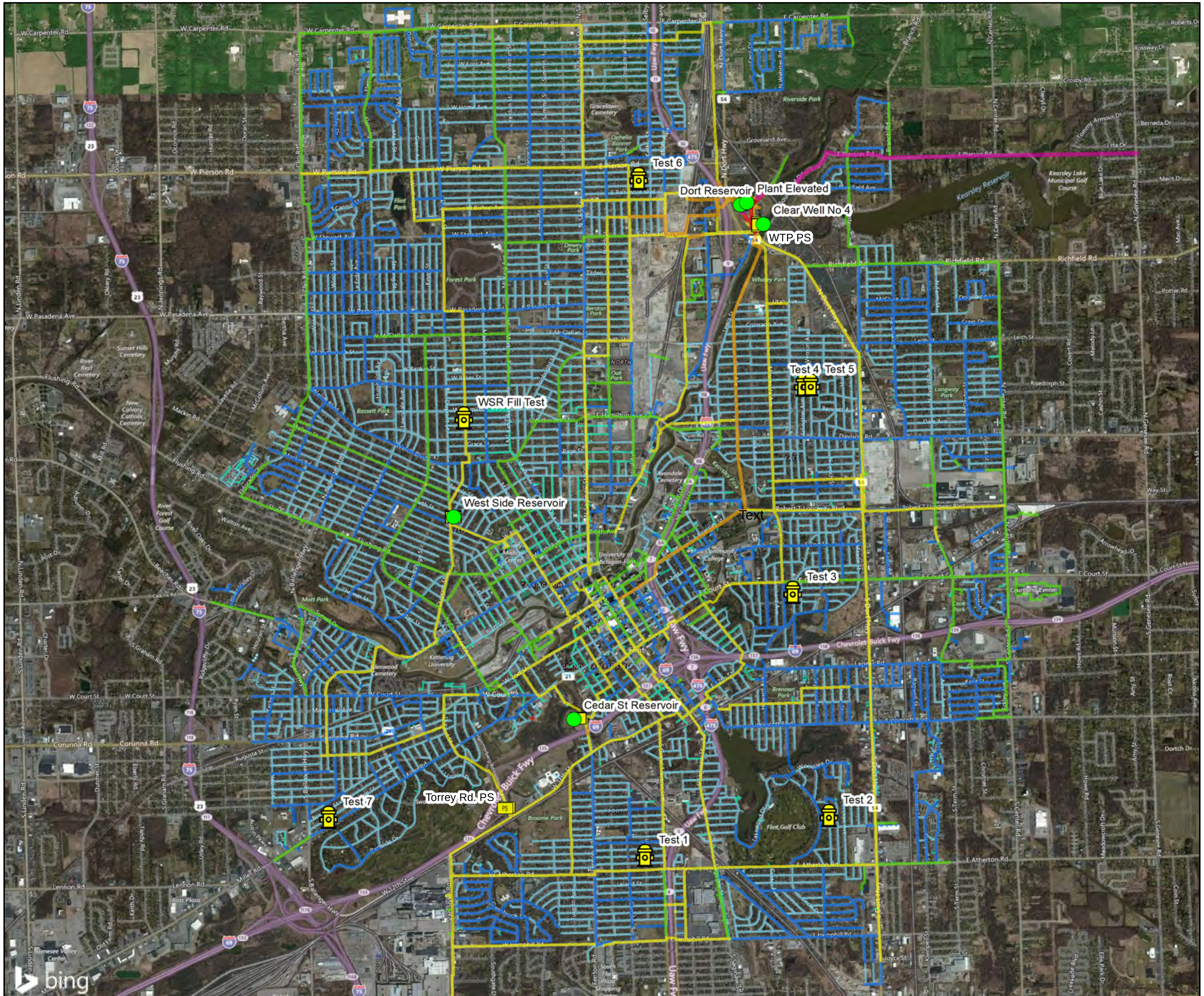
Several hydrant flow tests were also performed on the City of Flint system. Several locations were tested both for available fire flow as well as pipe roughness, or Hazen-Williams C-factor. The goal with these tests was to test the local capacity of pipes, as well as to determine C-factors that would be used during calibration. An additional test was also performed to simulate a West Side Reservoir fill cycle. This facility is currently offline, but it was important to capture system dynamics to the point that those conditions could be accurately represented. Poor valve and hydrant conditions caused several flow test location adjustments, but final locations for each test are found in Figure 2.5 and Table 2.2. Collected flow tests data are presented in Appendix C.

Table 2.2 Flow Test Locations

Test #	Test Type	Model ID	Flow Hydrant Intersection
1	C-factor & Fire flow	6312	Pettibone & Grand Traverse St
2	C-factor & Fire flow	7440	Dearborn & Country Club Ln
3	C-factor & Fire flow	8571	Franklin & Court St
4	Fire flow	1562	Arlington & Deleware
5	C-factor	1546	Vernon & Deleware
6	C-factor & Fire flow	4670	Marengo & Selby
7	C-factor & Fire flow	9111	Yale between Barney & Knapp
8	WSR Fill Test	3765	Iroquois & Odette, Josephine, & Grace



Legend

- Tested Hydrants
- Model Tanks
- Model Pumps

Model Pipes (Diameter)

- < 6"
- 6"
- 8"
- 10 - 12"
- 16 - 24"
- 24" - 36"
- 36" - 48"
- > 48"

N

0 5,000 10,000 Feet

City of Flint, MI

Hydraulic Modeling Calibration

Hydrant Flow Test Locations

ARCADIS Design & Consultancy for natural and built assets

FIGURE **2.5**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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2.3 Model Calibration

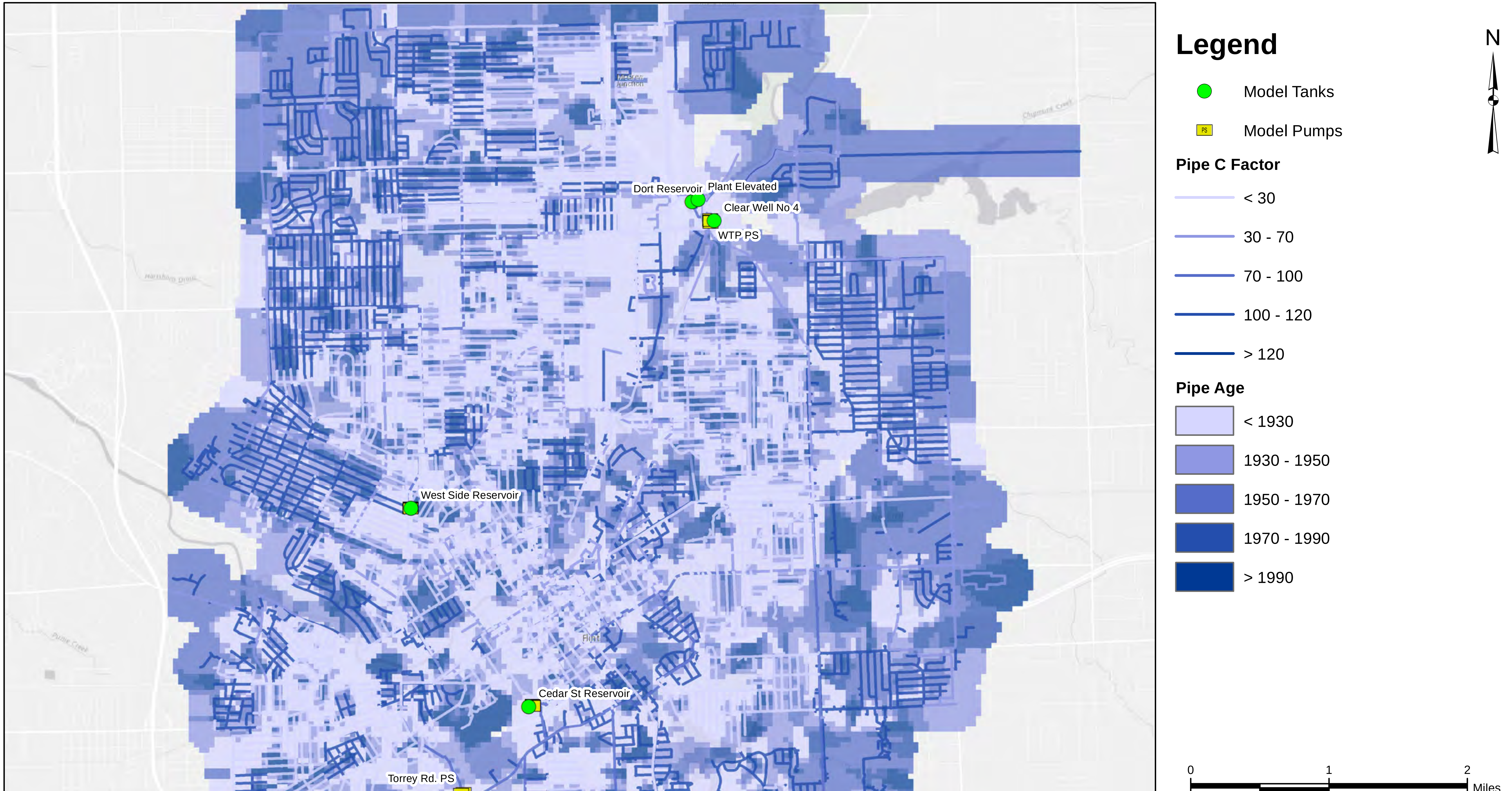
System-wide adjustments were first made based on flow tests performed in the system. These flow tests showed significant degradation of tested pipes, with a low C-factor of nearly 15 (compared to typical values of 130 for new pipes in good hydraulic condition). Based on these flow test results, widespread adjustment of C-factors was required. A scale of pipe age to C-factor was established based on field results (Table 2.3). Since exact pipe ages are not known, pipe ages were approximated based on available hydrant installation dates. At the time of the model calibration, a full survey of hydrant install dates was not available. This data was collected prior to 2017 for the west portion of the system only, so these previous data were used to create approximate pipe age regions. Gaps in the east area were filled in with hydrant data collected during the flow tests.

Table 2.3 Revised Pipe Roughness Values

Age	Cutoff Year	C-factor
< 15	2002	130
15 – 75		110
> 75	1942	30

The model C-factors for the distribution mains less than or equal to 8-inches were updated based on Table 2.3. For transmission lines greater than 8-inches, C-factors were adjusted so that modeled HPR data matched metered data. As shown in Figure 2.6, the oldest water mains align with the lowest C-factors in the model, and similarly align for the newest water mains and highest C-factors. The hydraulic grade line was used as a calibration parameter to minimize some of the uncertainties with model and hydrant elevations. In addition to C-factor adjustments some valves near the plant were closed and a check valve was added to the model near Durand St. and Brown St. These operational changes were verified with Atlas maps when possible.

During calibration, it was determined that select locations near the Water Treatment Plant (WTP) could not be matched to measured data. This persistent issue near the WTP could not be resolved with pipe closure or C-factor adjustment. It is possible that additional testing or information further upstream or at the WTP would be required to resolve these specific issues. However, since most locations downstream and otherwise have a very close correlation with metered results, calibration proceeded past these locations.



City of Flint, MI

Hydraulic Modeling Calibration

Pipe Age versus C-factors

ARCADIS

FIGURE 2.6

The flow tests were also used to calibrate the model by simulating each of the flow tests in the model. Tests 1 through 7 were simulated in the model by adding demand to the tested hydrant and measuring the difference between initial (static) pressure and residual pressure. Some local adjustments were required so that the modeled pressure decrease was within 2 psi of measured values. Additionally, Test 4 had a valve that could not be located in the field. Based on calibration results, it was assumed that this valve was broken and/or partially closed. The West Side Reservoir (WSR) fill test performed in the field did require a higher level of accuracy because of its impact to local hydraulics during WSR fill stages. Therefore, C-factor adjustments were required between the WTP and WSR to closer align these test results. This adjustment did result in one HPR (ARC024) south of WSR being out of alignment, but it was more important to accurately represent extreme system events like the reservoir fill cycles.

Figure 2.7 shows the final scatter graph of modeled versus metered pressures. Most locations are very well calibrated and within +/- 15%; the exceptions are anomaly points for location ARC014 where the hydrant was out of service for valving repair during the data collection period.

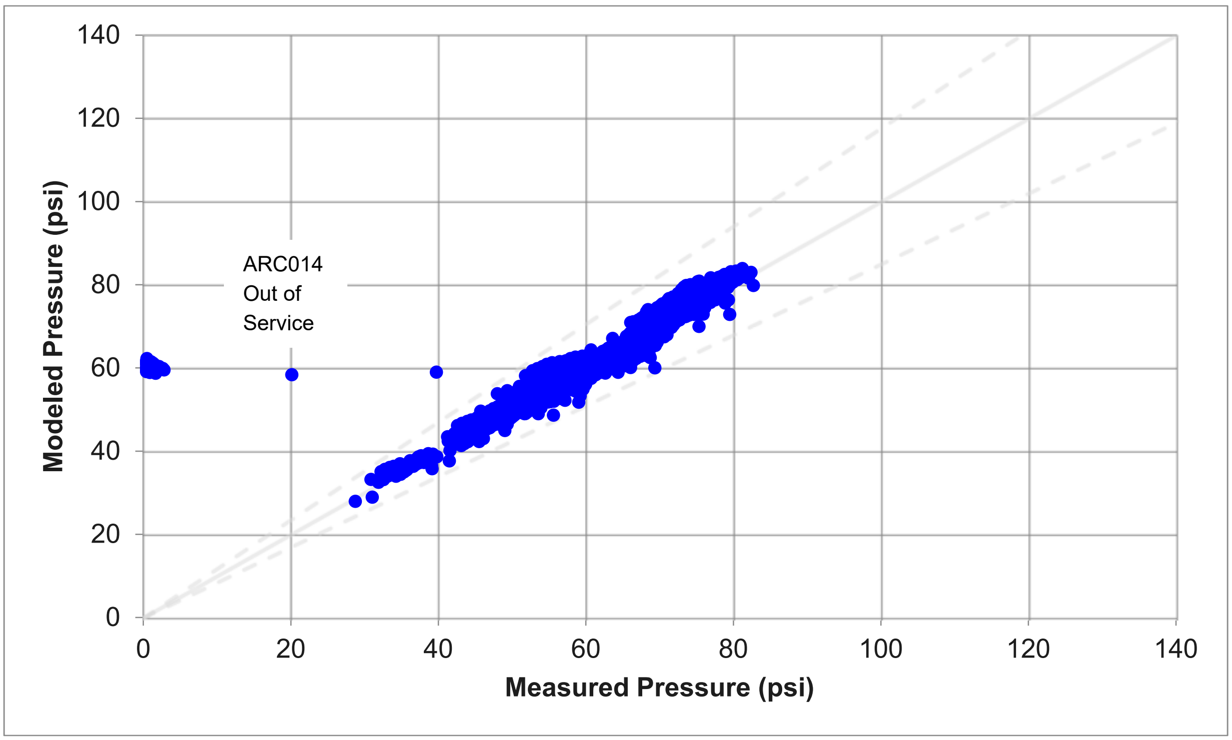


Figure 2.7 Pressure Calibration Scatter Graph

Table 2.4 shows the average modeled and measured HGLs for each location during the calibration day as well as the root-mean-square error (RMSE) for each site over the calibration period. Table 2.5 compares the field flow test with modeled results which all show very good correlation. Appendix D provides detailed calibration graphs for all HPR locations as well as available flow and level data from the City's SCADA data.

Table 2.4 HPR Model Calibration HGL Results

Title	Avg Model (ft)	Avg Measured (ft)	RMSE (ft)	Avg Diff (ft)
ARC001	878.9	873.0	2.16	0.1
ARC002	880.2	880.0	2.01	-0.2
ARC003	883.0	883.9	1.76	0.9
ARC004	881.6	881.9	1.58	0.3
ARC005	883.1	884.5	1.92	1.4
ARC006	884.8	886.7	2.21	1.9
ARC007	885.3	881.3	4.59	-4.0
ARC008	884.9	876.6	8.67	-8.3
ARC009	885.2	880.5	5.05	-4.7
ARC010	882.8	883.6	1.97	0.8
ARC011	880.9	882.7	2.82	1.8
ARC012	881.1	879.4	2.72	-1.7
ARC013	881.7	879.2	3.20	-2.5
ARC014*	881.2	857.5	58.07	-23.5
ARC015	880.5	879.7	2.20	-0.8
ARC016	880.3	878.9	2.57	-1.4
ARC017	880.1	880.8	2.43	0.8
ARC018	879.4	881.2	2.95	1.9
ARC019	875.5	878.5	4.97	3.1
ARC020	875.2	877.3	4.41	2.1
ARC021	875.9	879.5	5.41	3.6
ARC022	874.2	875.0	3.09	0.8
ARC023	880.4	881.1	3.02	0.7
ARC024	880.5	873.8	7.42	-6.7
ARC025	915.6	917.2	3.03	1.6
ARC026	871.6	875.1	4.56	3.6

* Hydrant temporarily out of service during calibration period

Table 2.5 Flow Test Calibration Results

Test Number	Test Flow (gpm)	Test Pressure Drop (psi)	Model Pressure Drop (psi)	Difference (psi)
1	186	3.8	2.9	0.9
2	713	8.7	6.3	2.4
3	699	3.5	1.3	2.2
4	516	32.5	31.2	1.3
6	638	7.4	5.3	2.1
7	676	15.5	16.3	-0.8
WSR Fill	2075	3.9	4.1	-0.2

2.4 Summary of Calibrated Model

The calibrated model was finalized and provided to USEPA for extended use during real-time simulations. However, some additional revisions to the model were necessary before it could be used for the analysis described in the following sections.

2.4.1 Operational Controls Revisions

The "Calibration Model" contained time-based controls from the real-time (USEPA) model based on specific operations during that time. While this was well-suited for calibration activities, time-based controls limit the usability of the model for system analysis. Therefore, the operational controls were revised after calibration was complete. In this way, the system was operated similarly to the calibration day, but controls were based on levels rather than times. Controls were set to adjust Control Station No. 2 (CS2) flow based on Cedar Street Reservoir (CSR) levels, CSR pumps were operated based on the elevated tank and CSR levels, and the CSR inflow valve was controlled based on the elevated tank and CSR levels.

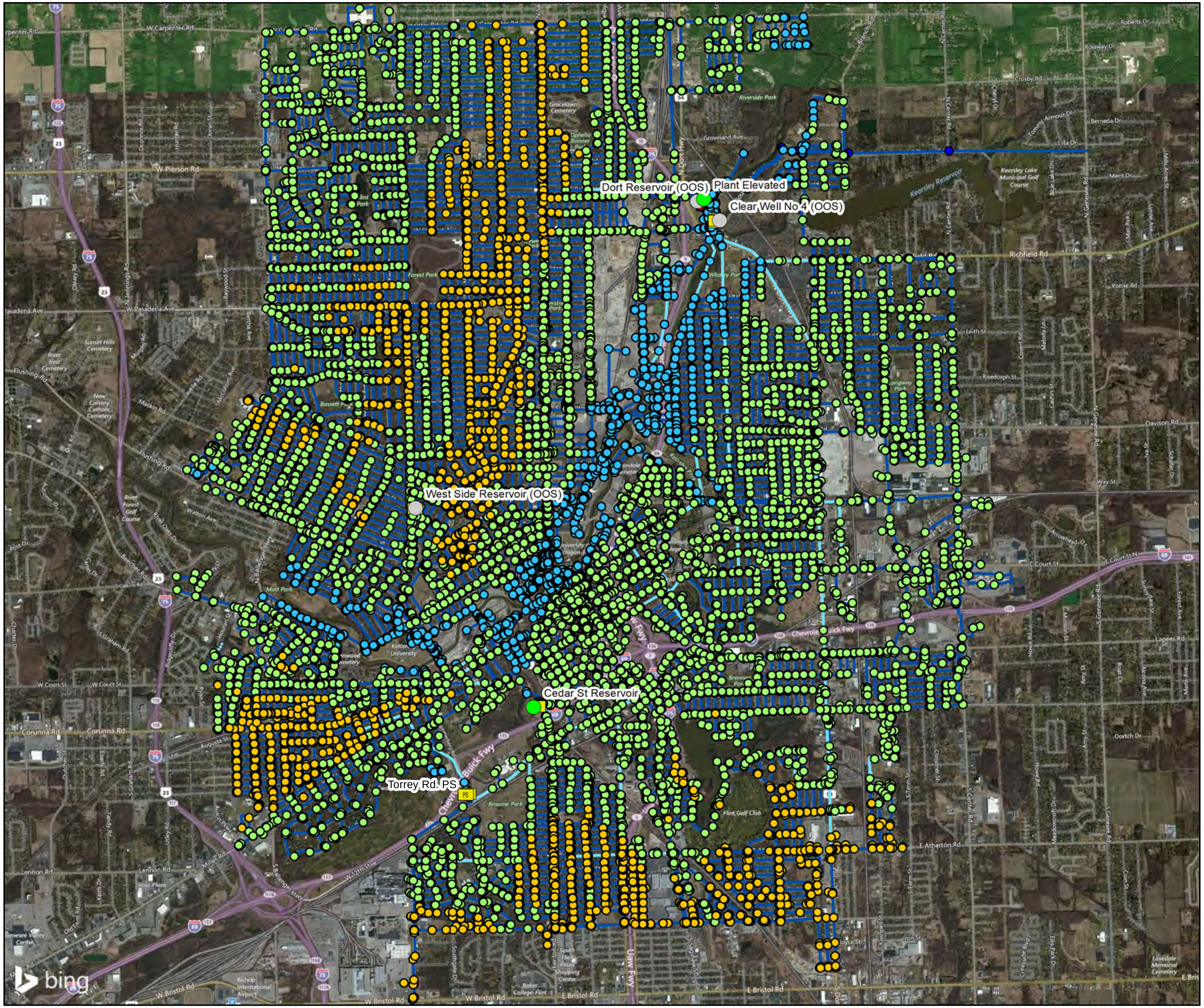
2.4.2 Analysis Model Results

Since operational controls were revised, this model was identified as the "Analysis Model" versus the Calibration Model that contained the time-based controls based on the Real-Time Model. Both models provided similar results, but the Analysis Model results best represent the typical average day demand (ADD) of the system with current conditions. In addition to the controls revisions, the analysis model represents multiple system demand conditions within the model. Throughout the analysis, demands are referred to as average day demands (ADD), maximum day demands (MDD), or winter maximum day demands. The annual average and maximum day demands were determined by analyzing data over the period June 2016 to May 2017. Additional insight on available past situations from the City indicated a higher maximum day demand during excessive main breaks in the winter. The winter maximum day demand represents this historical peak demand. These demands are summarized in Table 2.6 below.

Table 2.6 System Demand Conditions

Scenario	Demand (MGD)
ADD	12.4
MDD	14.6
Winter MDD	24.0

Figures 2.8 and 2.9 show system pressures and available fire flow results for the Analysis Model under existing average day conditions. A shown in Figure 2.8, all system pressures are above 20 psi with the highest pressures along the Flint River. Figure 2.9 indicates low fire flow capacities across the entire system. For the analyses presented in the following sections, this model was used as a base.



Legend

N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Minimum Pressure (psi)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- > 80

Maximum Velocity (ft/s)

- < 1
- 1 - 5
- > 5

0 1 2 Miles

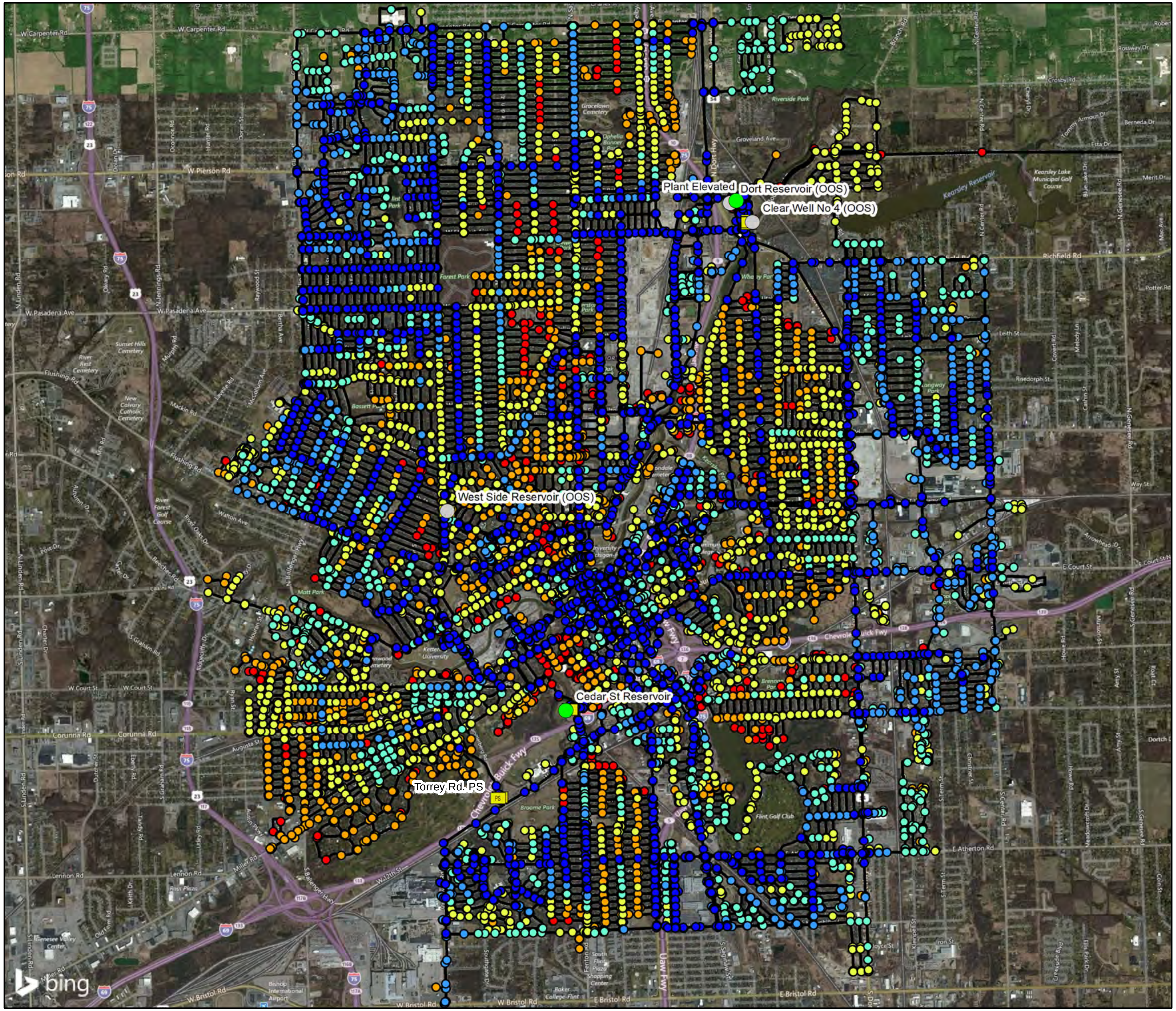
City of Flint, MI

Hydraulic Modeling Calibration

Calibrated Model Results: Existing Conditions ADD

ARCADIS Design & Consultancy for natural and built assets

FIGURE **2.8**



Legend

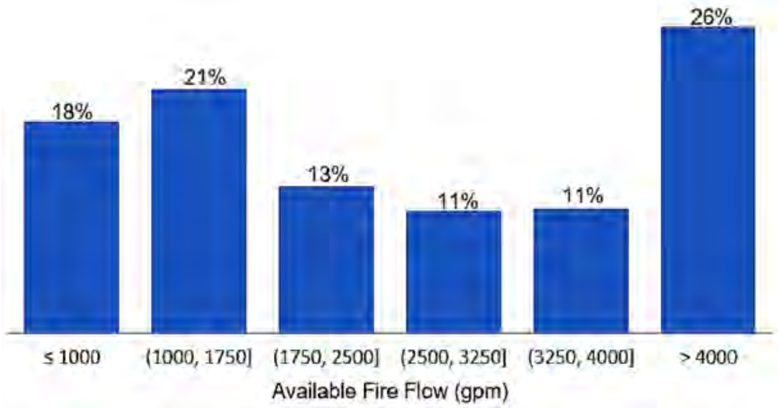
N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Available Fire Flow (gpm)

- < 500
- 500 -1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- > 4,000

Existing Pipes



0 1 2 Miles

City of Flint, MI

Hydraulic Modeling Calibration

Calibrated Model Results: Available Fire Flow ADD

ARCADIS Design & Consultancy for natural and built assets

FIGURE **2.9**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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3 DISTRIBUTION STORAGE ANALYSIS

3.1 Objectives

Storage facilities within a distribution system serve many purposes. These include: providing adequate volume of water for fire protection, water supply during an emergency such as a power outage or main break, maintaining system hydraulic grade, and allowing treatment and pumping facilities to deliver at a more consistent flow rate while storage supplies are utilized during peaks in diurnal demands. The distribution storage analysis consisted of two tasks: a storage gap analysis and storage modifications model simulations. The gap analysis was performed based on general industry best practices to determine the appropriate total storage volume for current system demands. The storage simulations took storage facilities out of service and evaluated the impacts on available fire flow rates, system pressure, and distribution velocity for typical system conditions and winter conditions.

3.2 Approach

The first step in the analysis was to determine the maximum and minimum existing storage capabilities of the distribution system. Five storage facilities were considered in the evaluation: Cedar Street Reservoir, West Side Reservoir, Dort Reservoir, Clear Well No. 4 and the Water Treatment Plant Elevated Tank. For maximum storage (capacity), all storage facilities were assumed to be completely full. The total volume of each facility was calculated using the dimensions and elevations in the model. The WTP Elevated Tank volume was provided because of its specialized spheroid shape. The volume of each facility was converted to gallons and the sum of the results was taken. The potential (maximum) existing storage is 53.6 million gallons. (Note that calculated / modeled capacity for each facility and the total storage volume do not match the capacities provided by the City. However, the calculated capacities are similar or slightly smaller than the reported capacity in every case. As such, utilizing the slightly smaller, in some cases, calculated capacity results in a conservative analysis. The facility volumes were adjusted by the USEPA and CitiLogics prior to providing the model to Arcadis as a result of real-time data calibration). The minimum existing storage is also known as the minimum operating storage or volume. The minimum operating volumes for CSR and WSR were calculated using the given dimensions and the lowest water level based on field readings. The WTP Elevated Tank utilized a volume to depth ratio to calculate volume. Dort Reservoir and Clear Well No. 4 volumes were not calculated because they are both out of service and no recent operational readings were available (this does not impact the analysis since minimum operating storage is used just as a reference). The summation of the three facility volumes yielded a minimum volume of 15.8 million gallons. Individual results for both the system storage capacity and minimum volume are given in Table 3.1.

Table 3.1 Storage Tank Characteristics

Tank Name	Type	Reported Capacity (MG)	Model Capacity (MG)	Minimum Volume * (MG)
Cedar St.	Ground Storage Reservoir	20.0	17.4	12.1
West Side	Ground Storage Reservoir	12.0	11.3	2.7
Water Treatment Plant	Elevated Tank	2.0	1.9	1.0
Dort	Ground Storage Reservoir	20.0	20.0	Unknown **
Clearwell No. 4	Buried Tank	4.0	3.0	Unknown **
Total		58.0	53.6	15.8

* Based on current operating range
** Operating range not available due to facility not currently in operation

Once the operational range for storage was established, the required storage was determined using the following relationships. Typical required total water storage volume is comprised of three components: (1) equalization storage, (2) emergency storage and (3) fire storage. Equalization storage is a storage allocation that provides water supply during peak hourly demand times that occur as a result of the variation in water usage during a 24-hour period. Emergency storage is water that is allocated to satisfy system demand during an event that disrupts supply. Such events would include temporary source contamination, equipment failure, power supply interruption, and main breaks. Fire storage is water that is allocated to mitigate facility fires. The fire flow rating within the service area and fire flow duration period are considered when calculating this volume. A balance must be reached when sizing elevated tank capacity so that an oversized tank is not selected to avoid higher construction cost and degradation of stored water quality due to increased water age.

The systemwide components (equalization, emergency and fire storage) of total storage volume were calculated based on system demands and fire protection ratings. Once the required total storage volume was determined, model simulations were performed to reach equilibrium between available and required volumes while maintaining system stability and operation.

3.3 Results

Water supply data was reviewed to identify the average day demand and maximum day demand for the City's service area. Based on flow rates through the CS2 36" system supply main, annual average day demands are approximately 12.4 million gallons per day (MGD); the highest recorded demand was 14.55 MGD which was obtained from a weekly-normalized, average-daily flow calculation. The highest previous demand was 24.0 MGD under past winter conditions. Based on industry standards, the typical equalization storage volume needed is approximately 20% of the system's maximum day demand. The equalization storage for the service area at 20% of the maximum day demand is approximately 2.91 million gallons and 20% of the winter MDD is 4.8 million gallons.

The required fire flow storage is based on the existing physical structures being primarily residential units with a spacing no closer than 31 to 100 feet within the service area. This criterion suggests an applicable fire flow rating of 1,000 gallons per minute for a duration of at least 3 hours. This fire flow rating and duration requires approximately 180,000 gallons of storage.

The criteria for determining the needed emergency storage volume is more subjective than for equalization or fire storage. Often, sustaining supply during a power outage is the basis for defining emergency storage volume. A catastrophic main break or source water contamination event are other purposes of providing emergency storage. A general practice is for emergency storage to be designed as 4 hours of supply during maximum day demands. Four hours of supply during the forecasted maximum day demand of 14.55 MGD is approximately 2.43 million gallons. At 24 MGD, the required emergency volume is 4.0 million gallons,

Table 3.2 summarizes the storage volume requirements for the City of Flint. Based on this analysis, the total minimum required storage for the system is 5.52 million gallons. Using the winter maximum day demands the minimum required storage is 8.98 million gallons.

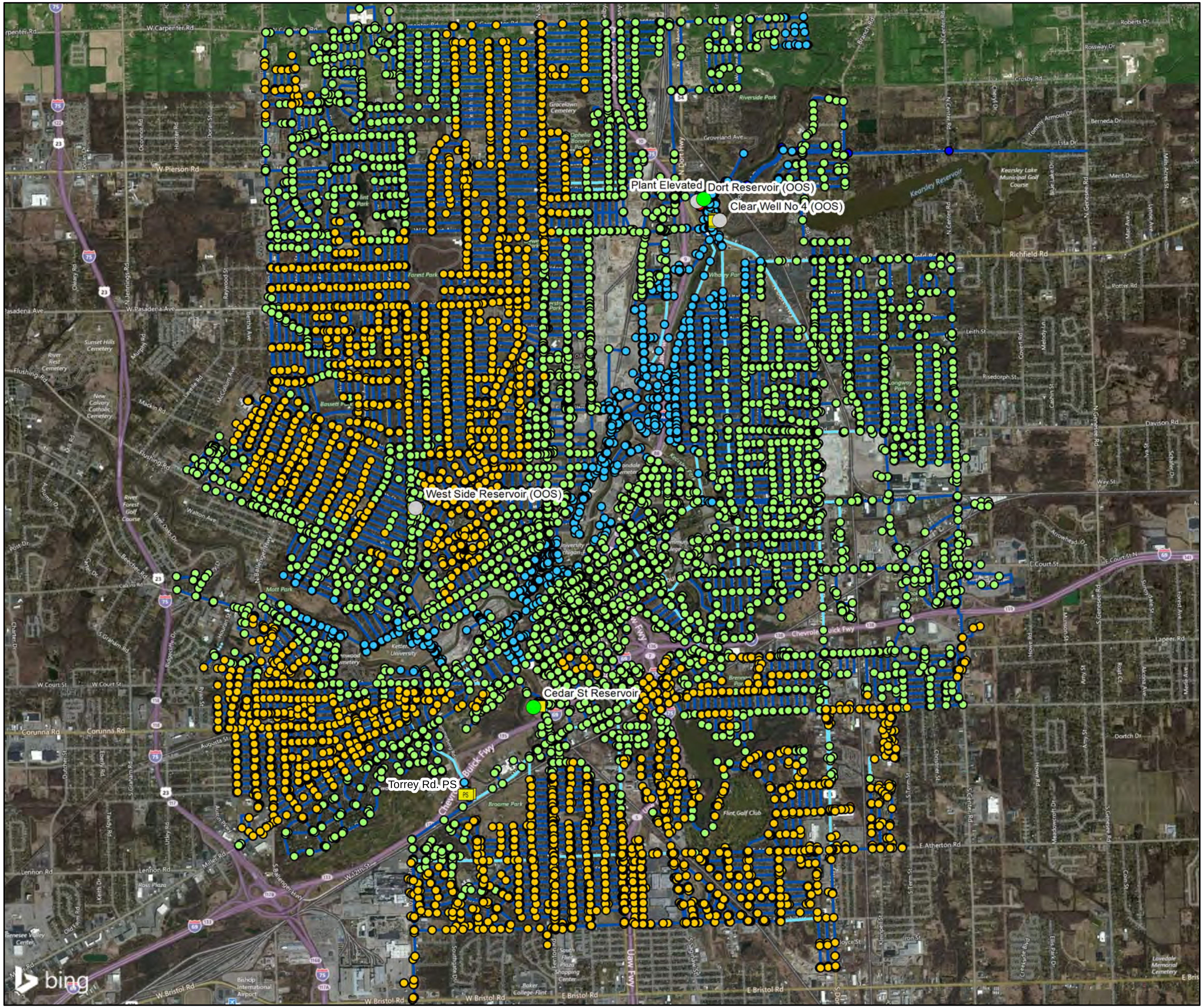
Table 3.2 Required Storage Analysis Results

Analysis Conditions	Maximum Demand (MGD)	Equalization Volume (MG)	Fire Storage Volume (MG)	Emergency Volume (MG)	Total Min. Required Volume (MG)
Normal	**14.55**	**2.91**	**0.18**	**2.43**	**5.52**
Past Winter	**24.0**	**4.80**	**0.18**	**4.00**	**8.98**

The next phase of the analysis focused on improving storage operations and overall system efficiency. The analysis examined six different scenarios (the first three being typical operations, and the second three being special cases):

1. Maximum day demand with the WTP Elevated Tank and CSR online (i.e., existing configuration, current operations).
2. Maximum day demand with the WTP Elevated Tank and WSR online.
3. Maximum day demand with the WTP Elevated Tank, Dort Reservoir, and Clearwell No. 4 online.
4. Maximum day demand with the WTP Elevated Tank online.
5. “Winter” maximum day demand with the WTP Elevated Tank and CSR online.
6. “Winter” maximum day demand with the WTP Elevated Tank, CSR, Dort and Clearwell No. 4 online.

The first three scenarios were evaluated using an extended period simulation to determine system pressures, velocities, and available fire flows. The second three scenarios were also evaluated using an extended period simulation, but these scenarios examined system operations and duration of system integrity. The maximum supply from CS2 was not allowed to exceed 15 MGD during the peak hour in accordance with the pending contract with the Great Lakes Water Authority (GLWA) during any simulation. Figures 3.1 and 3.2 show model results for the current system configuration (WTP Elevated Tank and CSR online). Figures 3.3 and 3.4 show results for scenario 2 (WTP Elevated Tank and WSR online), and Figures 3.5 and 3.6 show results for scenario 3 (WTP Elevated Tank, Dort Reservoir and Clearwell No. 4 online).



Legend

N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Minimum Pressure (psi)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- > 80

Maximum Velocity (ft/s)

- < 1
- 1 - 5
- > 5

0 1 2 Miles

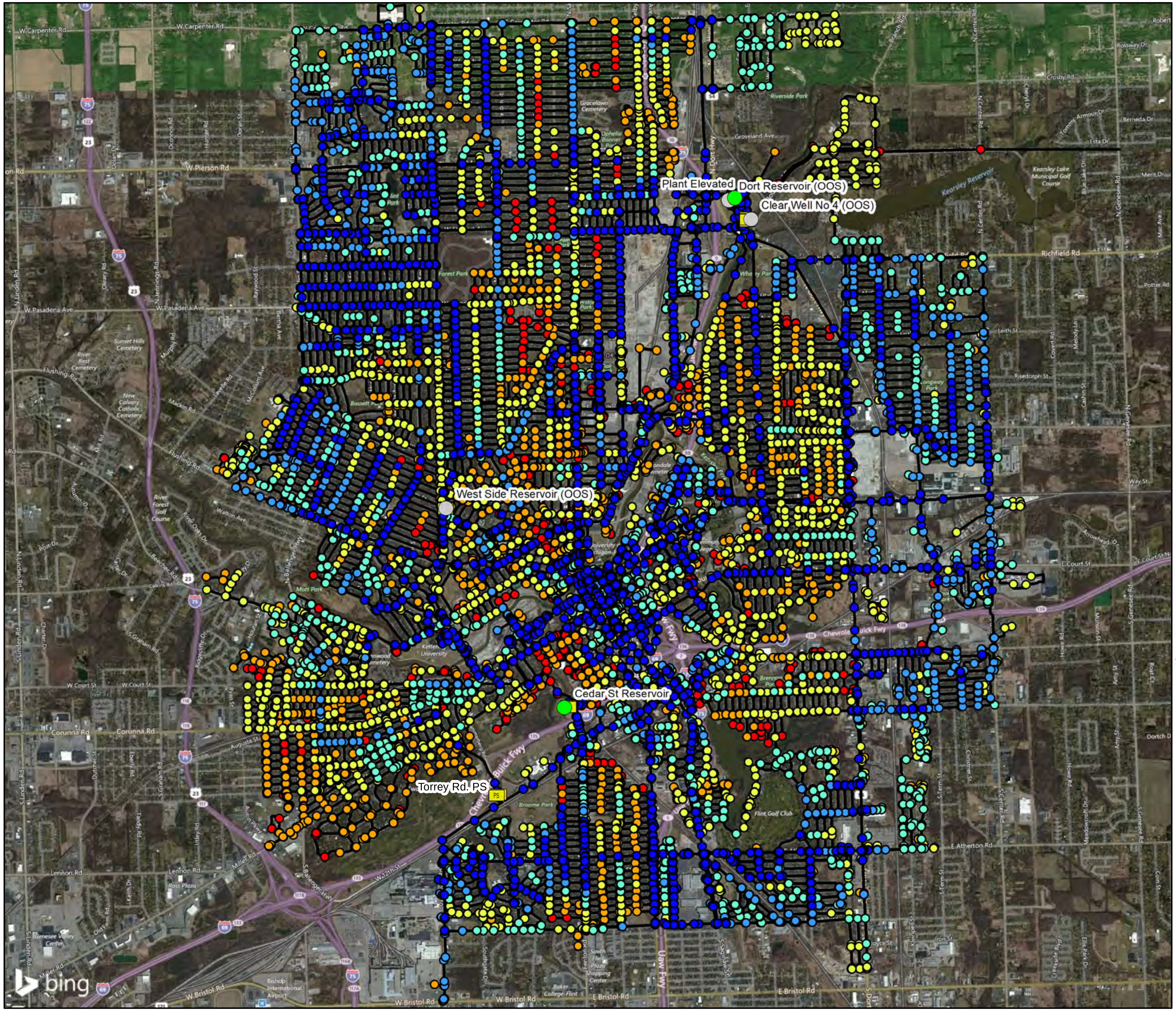
City of Flint, MI

Hydraulic Modeling Analysis

Flint Storage Analysis: Existing Conditions MDD

ARCADIS Design & Consultancy for natural and built assets

FIGURE **3.1**



Legend

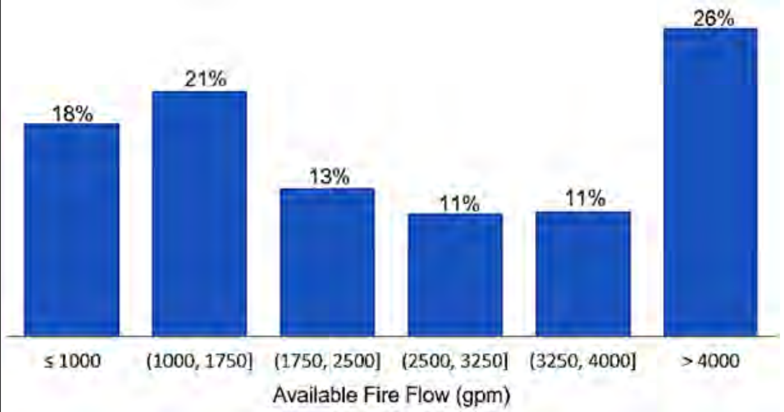
N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Available Fire Flow (gpm)

- < 500
- 500 -1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- > 4,000

Existing Pipes



0 1 2 Miles

City of Flint, MI

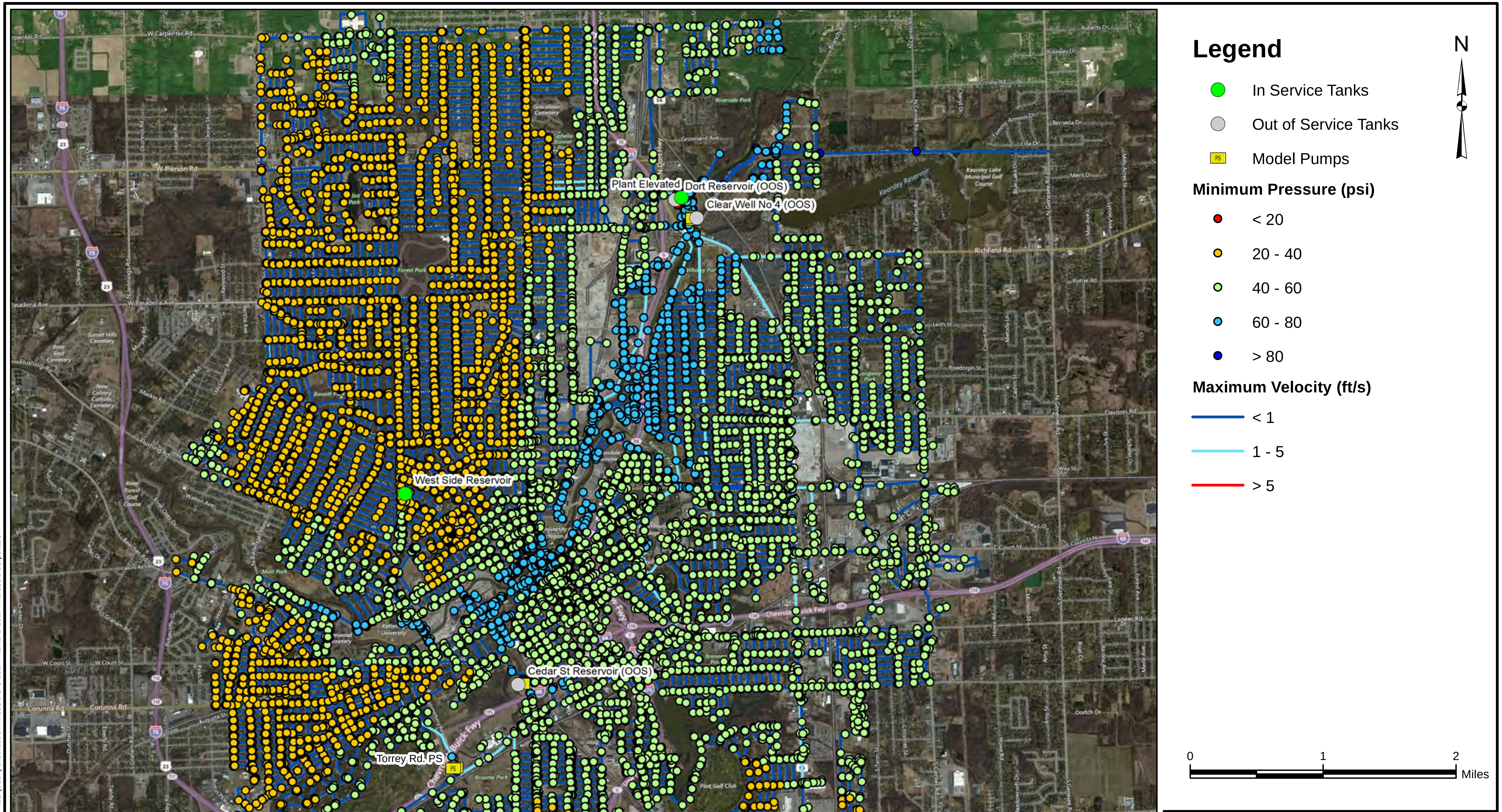
Hydraulic Modeling Analysis

Flint Storage Analysis: Available Fire Flow MDD

ARCADIS Design & Consultancy for natural and built assets

FIGURE **3.2**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
G:\PROJECTS\20616-Flint_MI\001-DistSysOpt\00900-HydraulicModel\Maps\Flint_Storage_CSR_MDD_Fireflow.mxd 12/1/2017 3:35:49 PM



City of Flint, MI

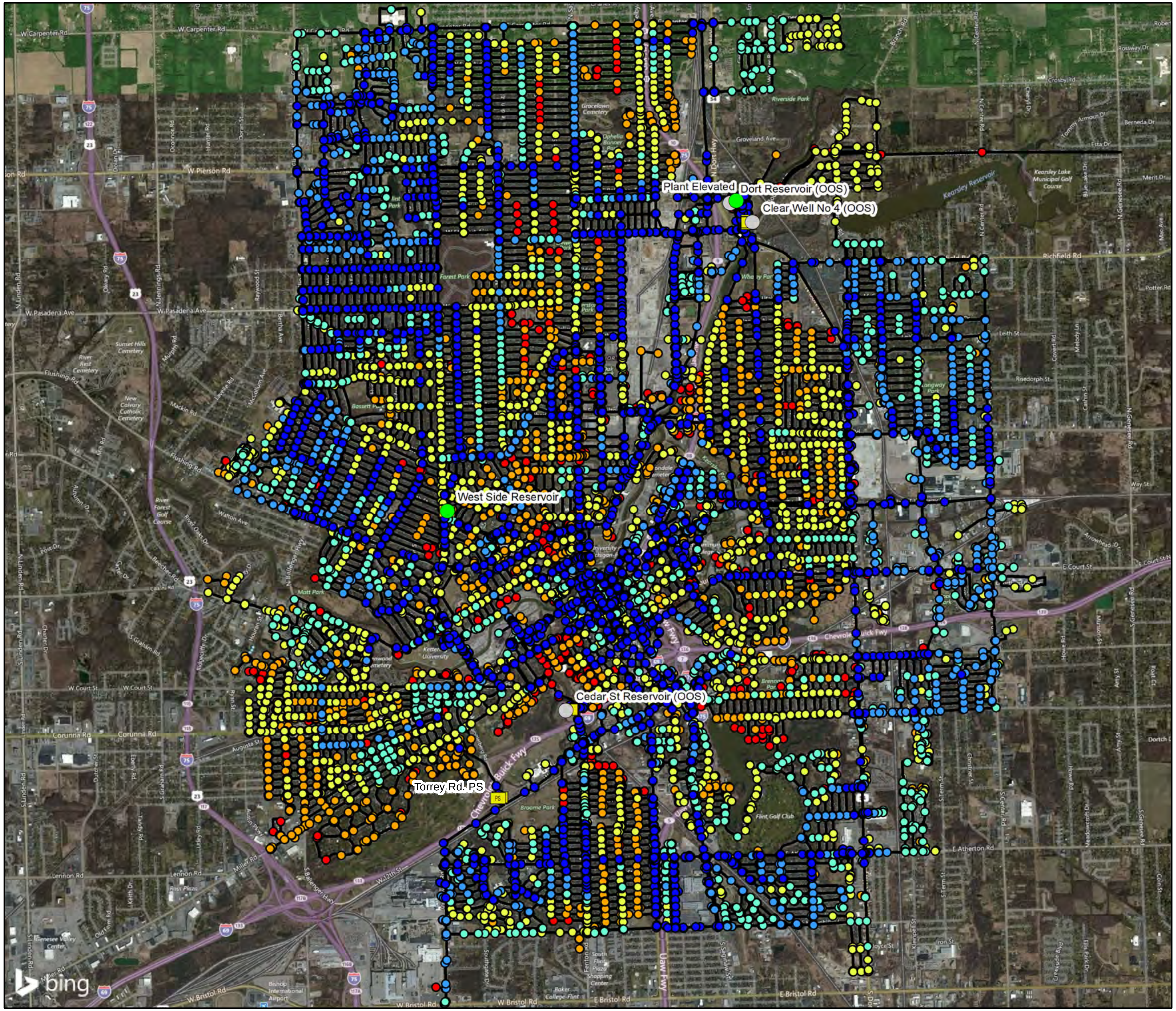
Hydraulic Modeling Analysis

Flint Storage Analysis: WSR MDD Scenario Model Results

ARCADIS Design & Consultancy for natural and built assets

FIGURE 3.3

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
G:\PROJECTS\20616-Flint_MI\001-DistSysOpt\00900-HydraulicModel\Maps\Flint_Storage_WSR_MDD_Pressure_Velocity.mxd 12/1/2017 3:38:52 PM



Legend

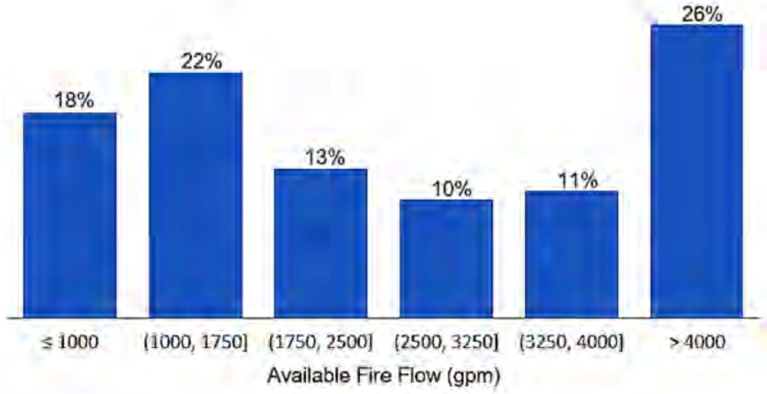
N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Available Fire Flow (gpm)

- < 500
- 500 -1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- > 4,000

Existing Pipes



0 1 2 Miles

City of Flint, MI

Hydraulic Modeling Analysis

Flint Storage Analysis: WSR MDD Scenario Available Fire Flow

ARCADIS Design & Consultancy for natural and built assets

FIGURE **3.4**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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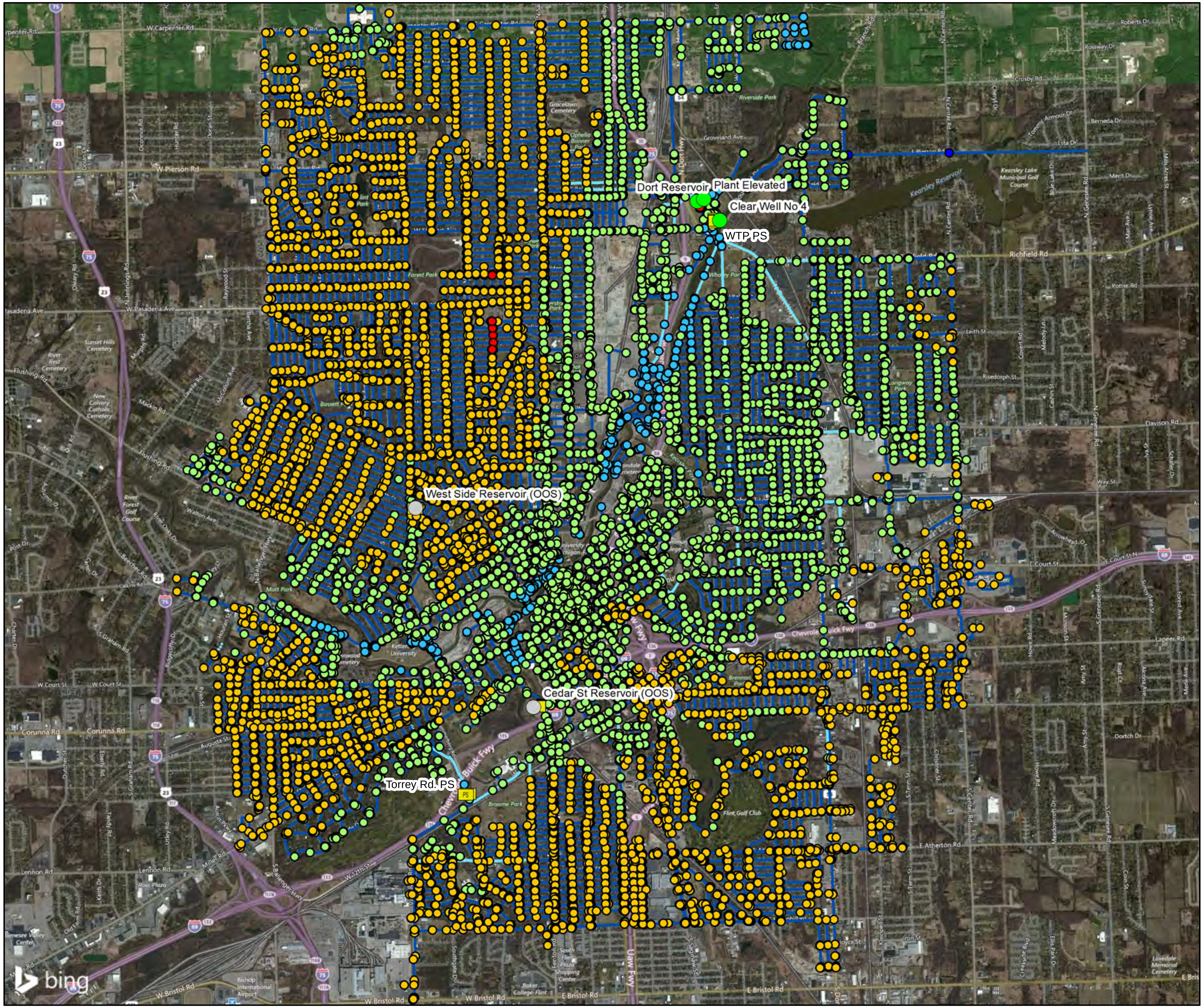
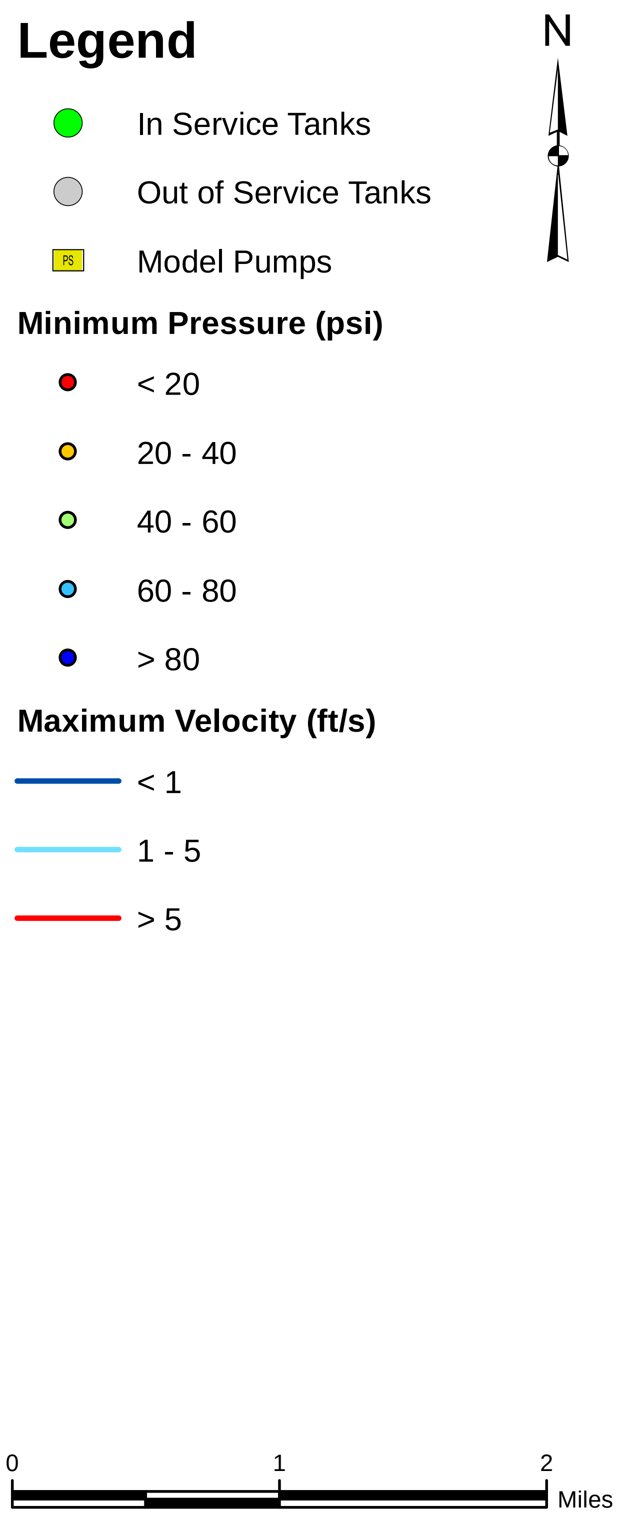




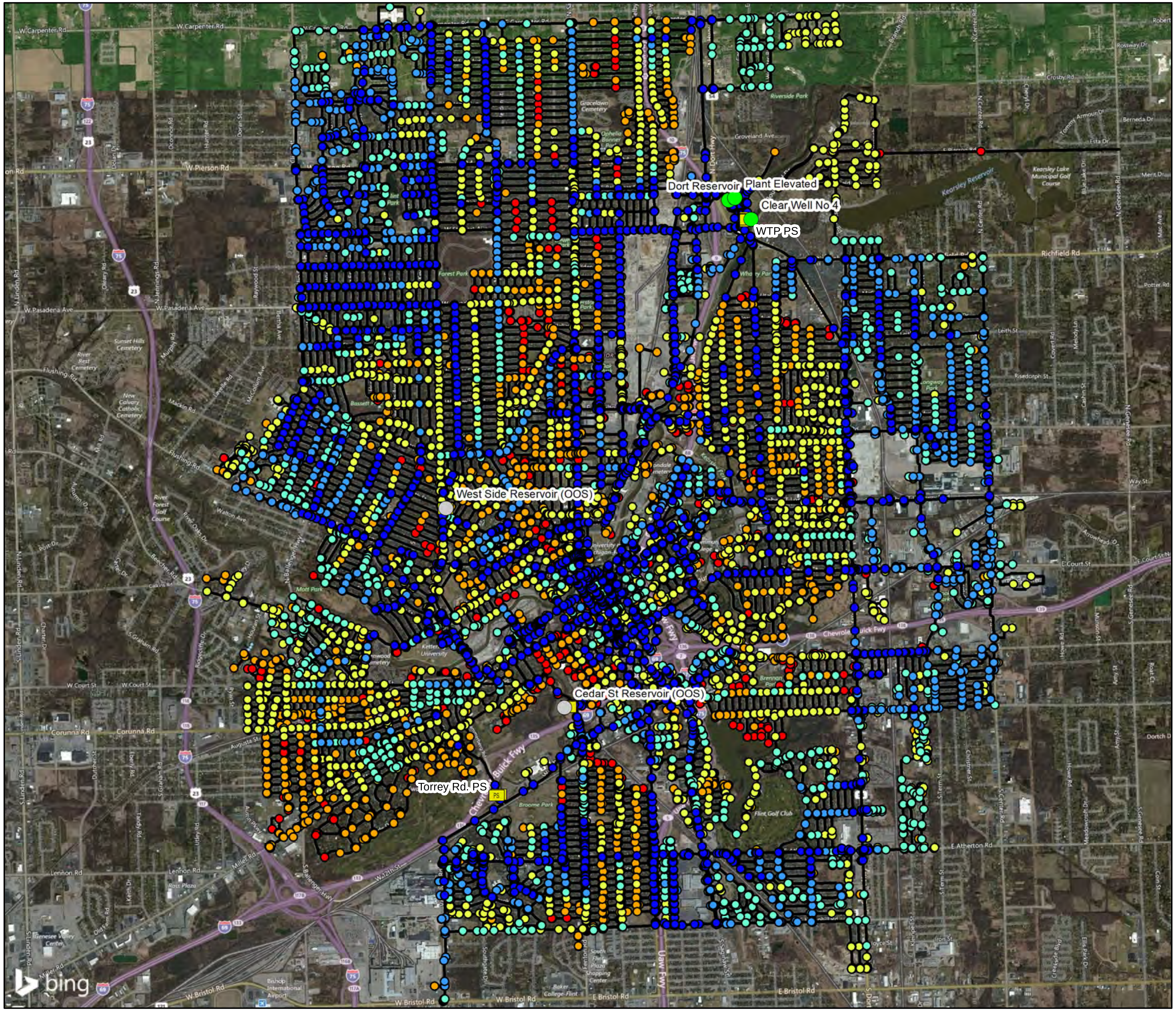
City of Flint, MI

Hydraulic Modeling Analysis

Flint Storage Analysis: Dort MDD Scenario Model Results

ARCADIS Design & Consultancy for natural and built assets

FIGURE 3.5



Legend

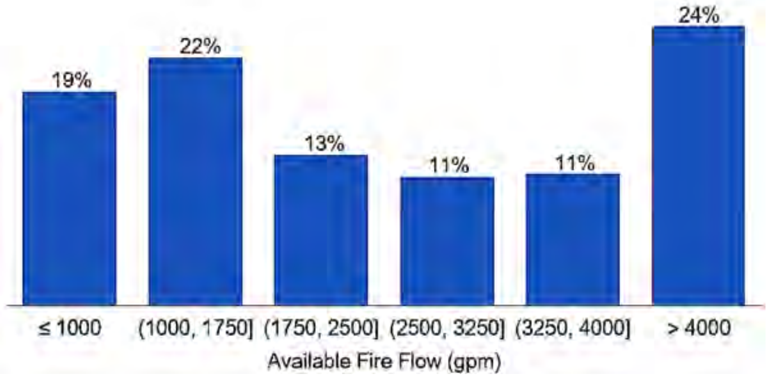
N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

Available Fire Flow (gpm)

- < 500
- 500 -1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- > 4,000

Existing Pipes



0 1 2 Miles

City of Flint, MI

Hydraulic Modeling Analysis

Flint Storage Analysis: Dort MDD Scenario Available Fire Flow

ARCADIS Design & Consultancy for natural and built assets

FIGURE 3.6

Additional special case model evaluations were requested by the city for non-routine situations that could occur in the system. At times during service or upgrades, the system may need to be operated temporarily with only the elevated tank in service. Based on the storage evaluation calculations, the elevated tank cannot provide necessary volumes for continuous system stability and emergency conditions. However, the system could be operated temporarily with just the elevated tank in place. Figure 3.7 shows how the elevated tank behaves in the model when all other storage is out of service. While levels trend downward over the three simulated days, the system is still stable, pressures throughout the system remain similar to current values, and the CS2 inflow does not reach above 15 MGD. Therefore, this operating strategy could be used during temporary service outages in the future. Notice the water level in the Elevated Tank, and subsequently the system the system HGL, is reduced when operating temporarily. An approximate 3 psi decrease is experienced throughout the system when compared to existing average day conditions.

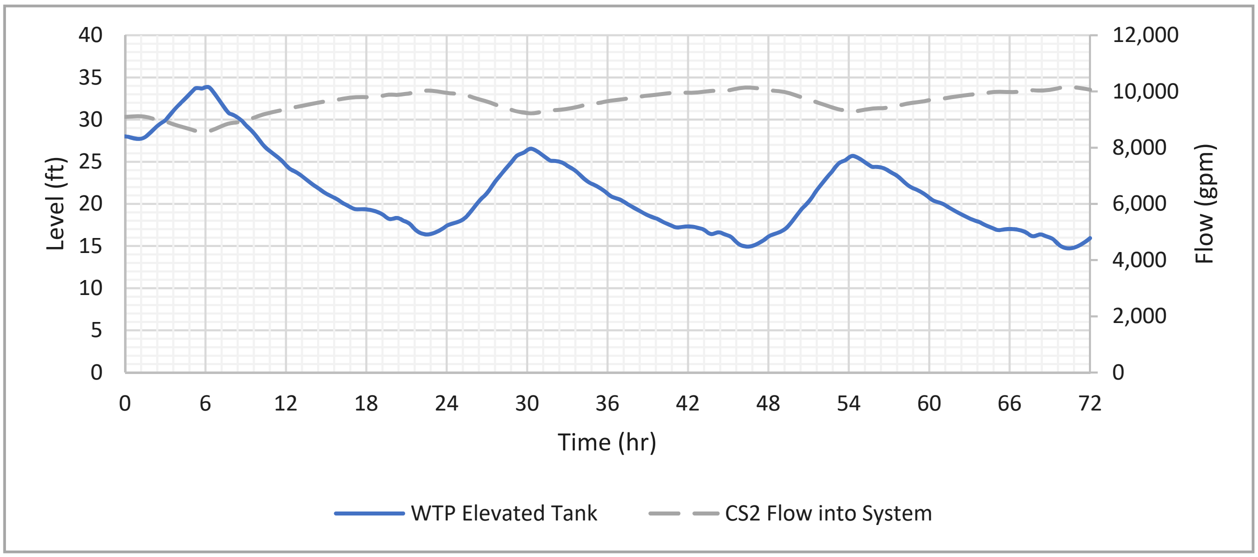


Figure 3.7 Model Results for WTP Elevated Tank Only MDD Scenario

Additional model runs were made for high demand scenarios. Historically, large main break water losses have resulted in exceptionally high water demands in the winter. Information from the city stated that system demand could be around 24 MGD in these types of conditions. Therefore, multiple scenarios were run with these “winter” demands to help evaluate required storage in these cases. The first model runs were made for current operational conditions with the elevated tank and CSR online. Model parameters were adjusted to force a maximum flow limit through CS2. Flow through CS2 was limited to 15 MGD, and because of the large deficit between supplied water and water demand, the tanks eventually drained, and the model failed. Based on tank and flow results in Figure 3.8, the system storage is depleted after 42 hours. Time beyond this would need to be offset by increasing source water flow from CS2 in excess of 15 MGD to meet total system demands.

The final simulation was performed with current operational conditions plus Dort Reservoir being in service. The storage added by Dort can sustain the system for an additional twenty-four hours beyond the previous scenario (Figure 3.9). While the end result would still increase CS2 flow, having Dort online does extend network stability, providing the city with more time to repair or address the issues that are resulting in these elevated system demands.

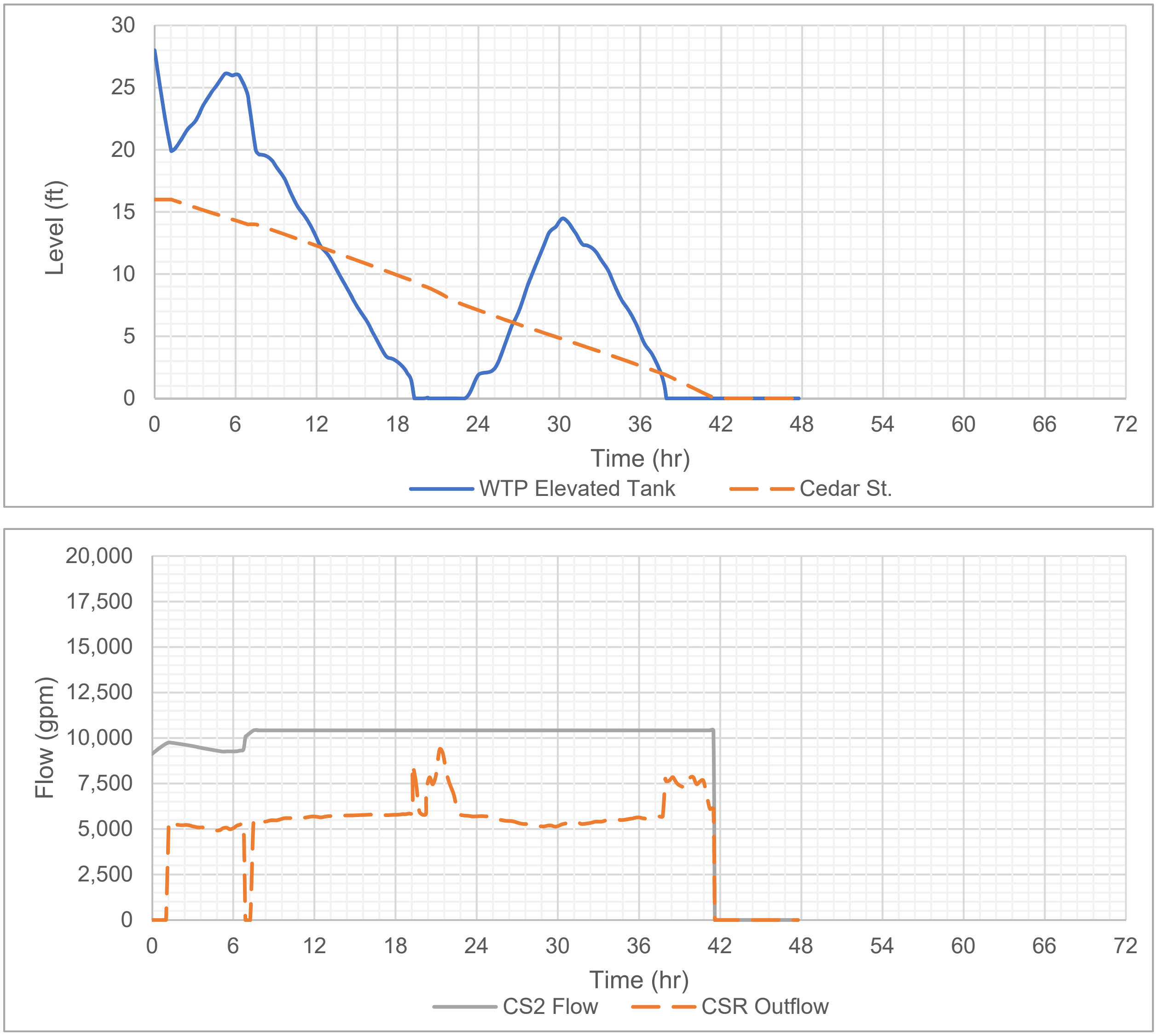


Figure 3.8 Model Results for CSR Winter Conditions Scenario

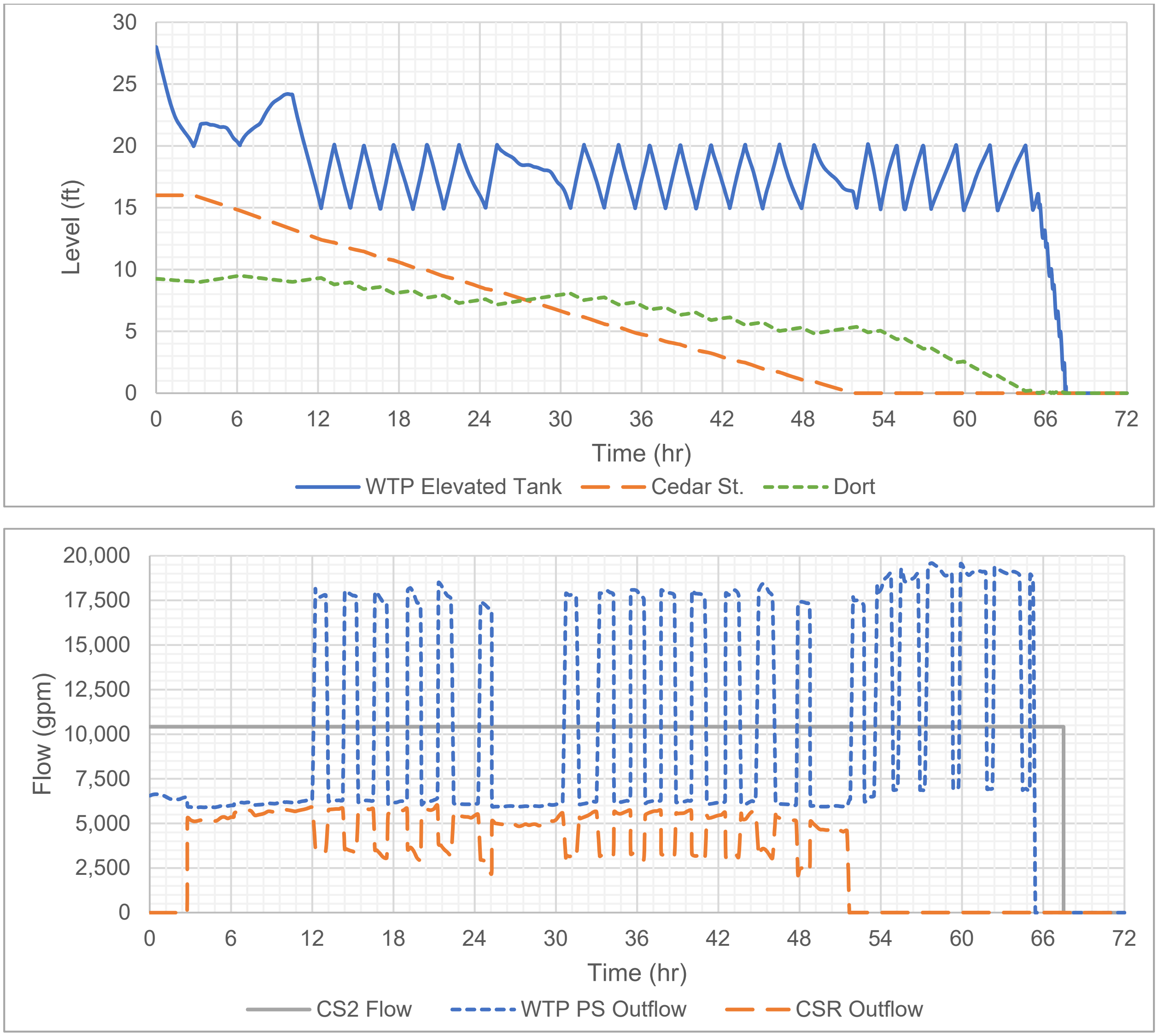


Figure 3.9 Model Results for CSR & Dort Winter Conditions Scenario

3.4 Recommendations

Based on the storage evaluation described above, Flint currently has an excess amount of available storage compared to the required total volume based on current demands considering industry standard evaluation criteria. It is therefore desirable to reduce storage to improve water quality in the system. However, most of the available storage facilities in the system are at similar volume ranges, except for the elevated tank. The elevated tank is desirable for emergency situations, but is not sufficiently large to sustain the required operations of the system during emergency conditions. Therefore, in addition to this tank some combination of additional storage is necessary in the system.

A number of evaluations using the calibrated Analysis Model were performed considering different storage scenarios. Based on the first three simulations, the pressure, velocity and available fire flow in the system do not change significantly between scenarios. However, the Dort and Clearwell No. 4 scenario does show some pressures in the system drop below 20 psi. These results, combined with model results from the water age analysis and transient analysis suggest that current operation of CSR and the elevated tank should continue. However, based on results from potential large winter demands due to numerous main breaks, having Dort Reservoir also in operation during certain periods could allow the city more flexibility when repairing main breaks. In the future, the City should consider new replacement facilities with reduced storage, or a modification of existing facilities to reduce the excess available storage in the system.

Table 3.3 Storage Evaluation Summary

Scenario	Meet Typical Conditions (Pressure)	Extend Winter Demand Capacity	Surge Reduction	Water Age Reduction
Elev. Tank & CSR	X	-	X	X
Elev. Tank & WSR	X	-	-	X
Elev. Tank & Dort	X	-	X	X
Elev. Tank	X	-	X	X
Winter Elev. Tank & CSR	N/A	-	X	X
Winter Elev. Tank, CSR & Dort	N/A	X	X	-

4 SURGE ANALYSIS/PRESSURE MEASUREMENT

4.1 Objectives

A common cause of water main breaks is significant pressure fluctuations often resulting from pump and control valve operations. The hydraulic model was utilized to perform a transient analysis focused at system storage facilities. The analysis simulated current conditions to determine if transients are potentially resulting from system operations, particularly pump start-up and shutdown. If significant transients are observed, model parameters can be adjusted to reduce the effect of a transient event and advise how the system should be operated.

4.2 Approach

The transient analysis used Bentley HAMMER software in conjunction with the calibrated Analysis Model. The analysis focused on the pumps at Cedar Street and West Side Reservoirs, and the outflow pumps were identified as the most probable sites for transient causing events because of the frequency of pump operations. Four events were modeled: single pump start-up at CSR, single pump start-up at WSR, single pump shutdown at CSR, and single pump shutdown at WSR. Each simulation was set to run for two minutes at a very small timestep to allow for wave propagation and system stability after a given transient causing event was triggered. Pressure wave speed and vapor pressure were assumed to be 4,000 ft/s and -14.20 psi respectively.

Transient analysis requires more detailed information than for a standard hydraulic model such as pump and motor moments of inertia. Unfortunately, this detailed information on the pumps at CSR and WSR was not readily available; therefore, many transient parameters had to be assumed. The pumps for both sites were set to ramp up to full speed within one second (assuming a worst-case scenario). Modeled start-up was controlled by speed rather than torque, and the time for pump valve operation was set to zero seconds to simulate a check valve slamming closed. Pump shutdown was determined based on assumed pump inertia. Table 4.1 summarizes pump parameters used for transient modeling for both sites. The pump valve diameters were set based on the adjacent downstream pipe diameter. Flow and head were taken from the hydraulic model simulation. Motor and pump inertia and speed were based on typical pump characteristics. For the pump shutdown, inertia was reduced to half of the original value so the change in flow would be more of a worst-case scenario. Specific speed was calculated using available modeled flow, head and speed.

Table 4.1 Surge Analysis Pump Characteristics

Pump Label	Pump Valve Diameter (in)	Flow (gpm)	Head (ft)	Motor & Pump Inertia (lb-ft^2)	Speed (rpm)	Specific Speed
CSR Pump 1	16	4,500	140	500	1,700	3,300
WSR Pump 2	12	2,100	120	400	1,700	2,155

Once the pump operations were set up, data collection areas within the model were defined including report points and profile paths. Results can only be gathered for the specified report points, but limited points were selected because of computation limitations. Report points were selected from locations in close proximity to the given reservoir. The profile paths were established to begin at the transient source (the pump) and continue through pipes and junctions leading away from the source. Five pathways were monitored, extending in multiple directions away from each site; the paths varied in length from 500 feet to 2,000 feet.

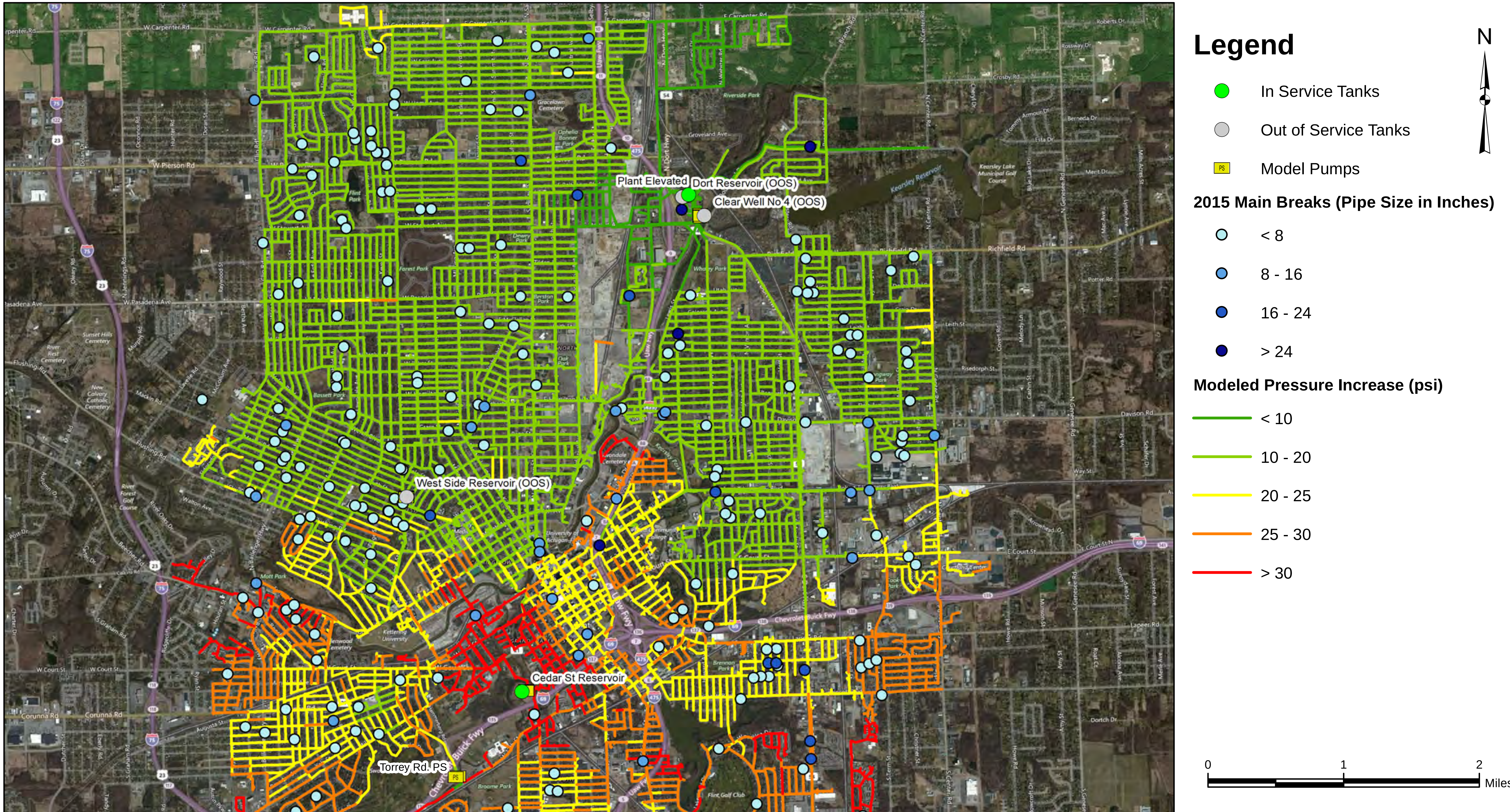
Before transient simulations could be performed, some additional model adjustments were required. The calibrated hydraulic model has many pipes with low roughness factors, which prevented the transient analysis from being computed because of internal software computations and limitations. Therefore, pipe roughness was adjusted to an average value of 90 which allowed computations to proceed. While not ideal, these increases in C-factors are conservative since smoother pipes allow faster pressure wave propagation speeds. When all necessary adjustments were made, each simulation was computed, and the results were viewed through path profiles and time history plots. Internal model results examined the hydraulic grade line, pressure and air/vapor volume along the defined path or at each report point.

4.3 Results

The results from each simulation showed the pressure increases experienced in the system caused by the start-up or shut down event. Modeled pressure increases, and maximum transient pressures were correlated to historic pipe breaks. Based on these results, the pressure effects of start-up and shut down were mostly localized around the pump in question. Significant transient pressures were most evident with the pump start-up at CSR and to a lesser degree with pump start-up at WSR. No scenario profile path displayed typical wave-like transients and most were more muted responses. Figures 4.1 to 4.4 depict the increase in pressure within the system pipes and the location of main breaks in 2015 as a comparison. Based on the comparison of modeled results and historic main breaks, CSR does not show a strong correlation but WSR does. During pump start-up simulations for WSR the area that witnessed the largest pressure increases also had a large concentration of pipe breaks.

4.4 Recommendations

Based on this transient analysis, some correlation exists between pump operation and main breaks. Specifically, WSR pumps turning on resulted in large pressures near a large cluster of historic breaks. However, this does not explain all main breaks in the system as the area of influence from these operations is relatively small. Because of this, it is recommended to not utilize WSR without a thorough investigation of operation and equipment that could be leading to this positive correlation. Because CSR results do not show the same historic break correlation, it is likely that operation of this facility is not causing significant strain on the system. Therefore, it is recommended to continue to operate CSR as normal.



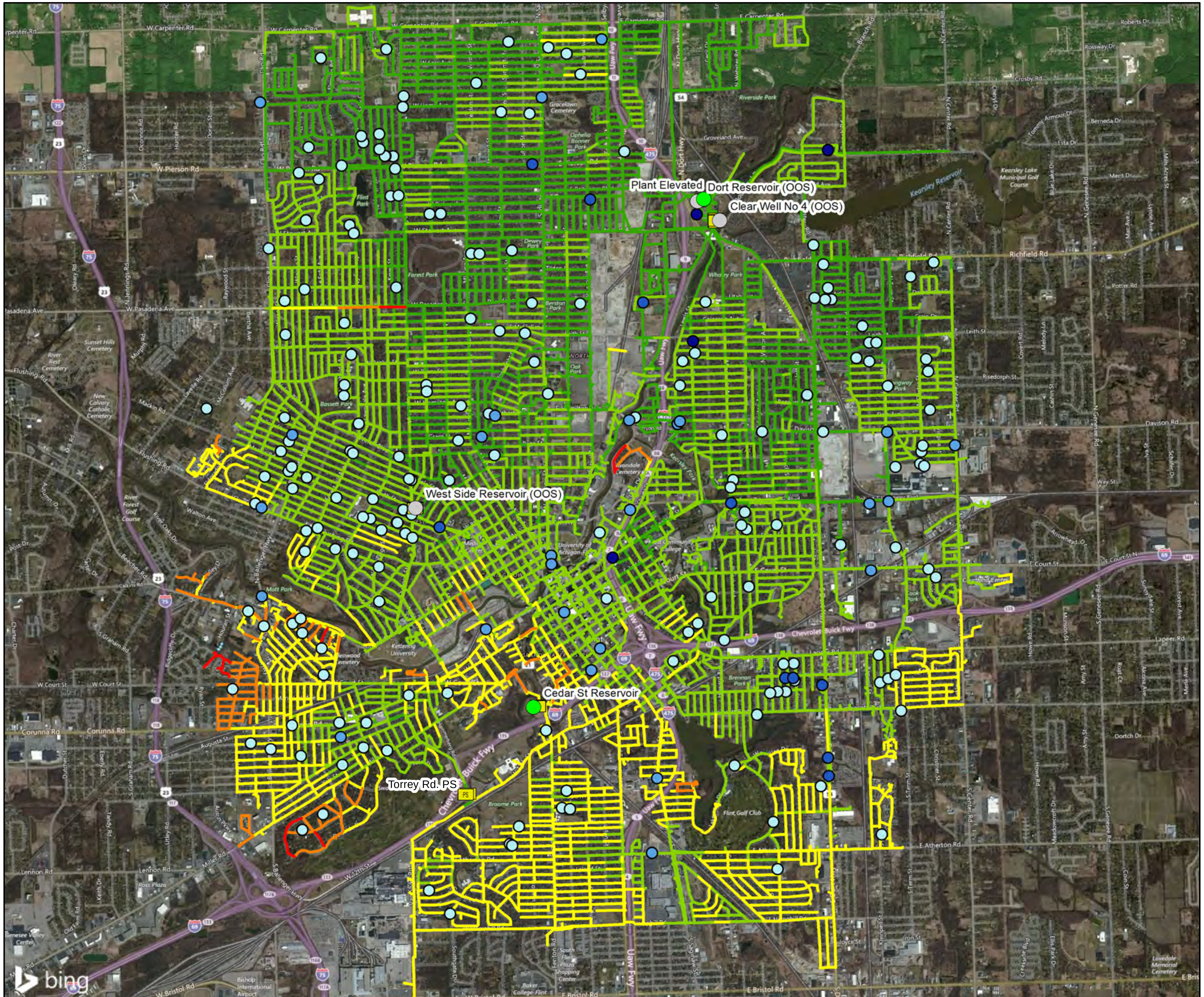
City of Flint, MI

Hydraulic Modeling Analysis

Surge Analysis: CSR Pump Start-up

ARCADIS Design & Consultancy for natural and built assets

FIGURE 4.1



Legend

N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

2015 Main Breaks (Pipe Size in Inches)

- < 8
- 8 - 16
- 16 - 24
- > 24

Modeled Pressure Increase (psi)

- < 10
- 10 - 15
- 15 - 20
- 20 - 25
- > 25

0 1 2 Miles

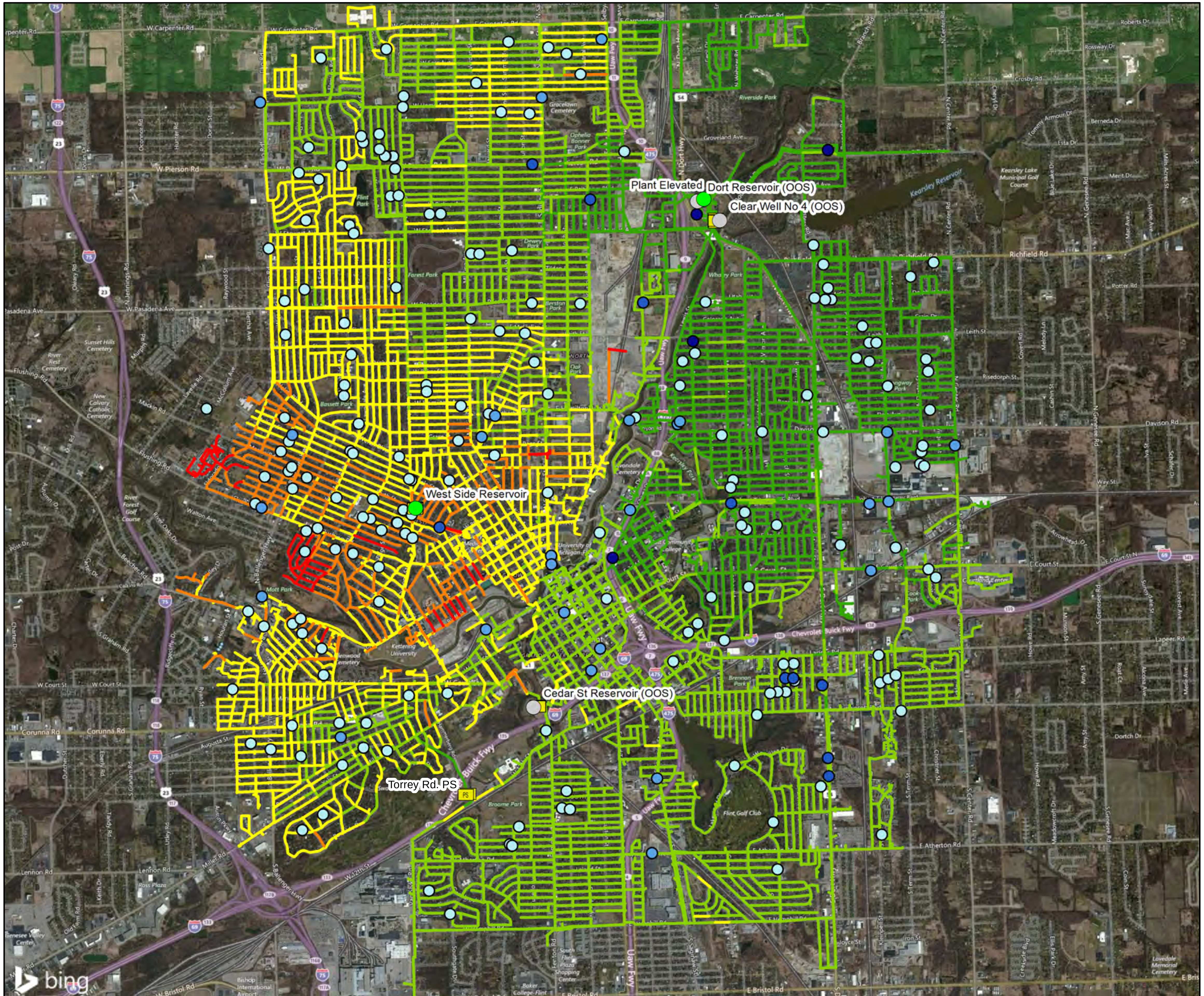
City of Flint, MI

Hydraulic Modeling Analysis

Surge Analysis:
CSR Pump Shutdown

ARCADIS Design & Consultancy for natural and built assets

FIGURE
4.2



Legend

N

- In Service Tanks
- Out of Service Tanks
- Model Pumps

2015 Main Breaks (Pipe Size in Inches)

- < 8
- 8 - 16
- 16 - 24
- > 24

Modeled Pressure Increase (psi)

- < 10
- 11 - 15
- 15 - 20
- 20 - 25
- > 25

0 1 2 Miles

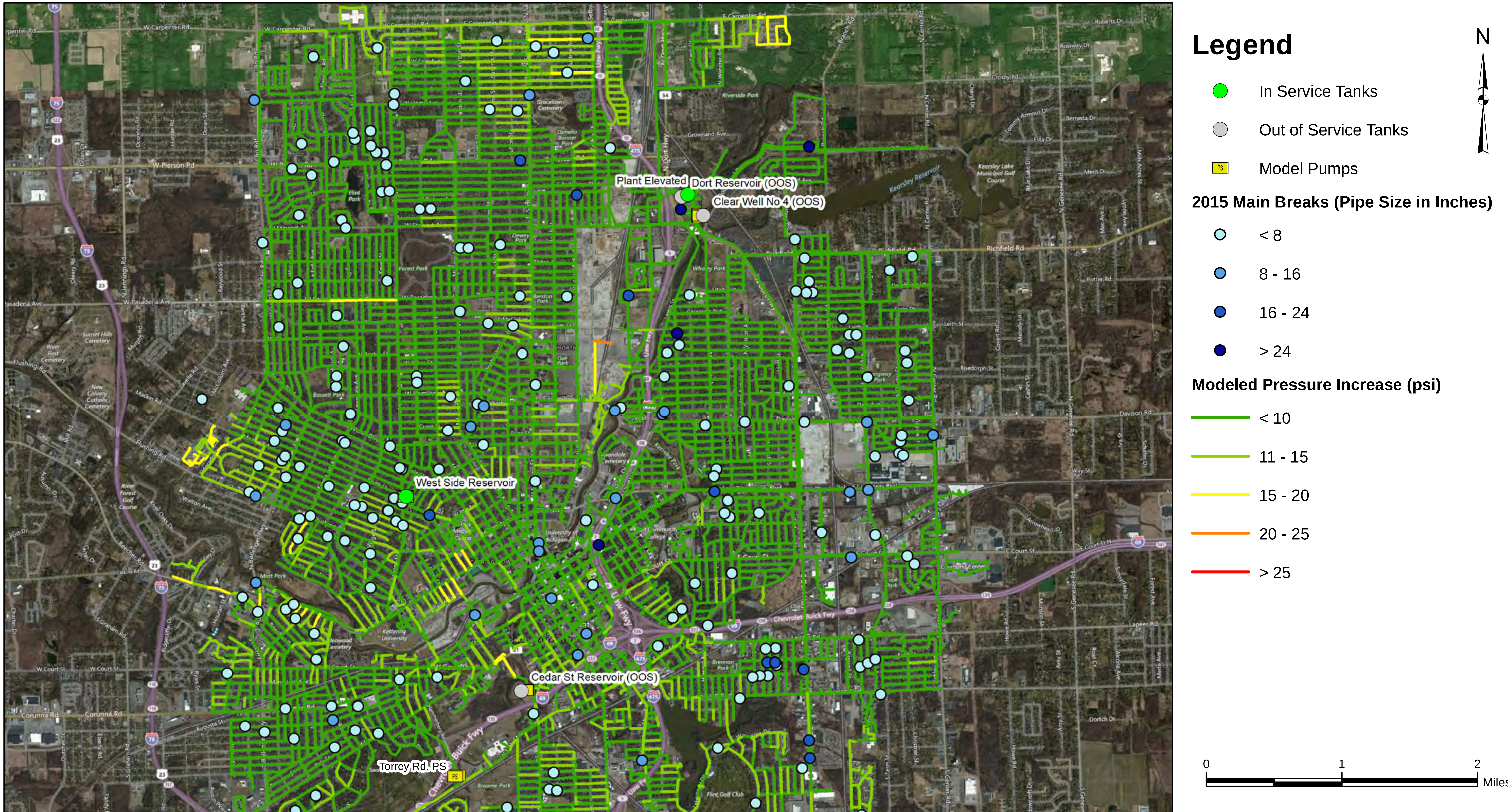
City of Flint, MI

Hydraulic Modeling Analysis

Surge Analysis:
WSR Pump Start-up

ARCADIS Design & Consultancy for natural and built assets

FIGURE **4.3**



City of Flint, MI

Hydraulic Modeling Analysis

Surge Analysis: WSR Pump Shutdown

ARCADIS Design & Consultancy for natural and built assets

FIGURE **4.4**

5 WATER QUALITY SENSOR PLACEMENT

5.1 Objectives

The primary objective of this analysis is to identify the optimal location for water quality sensors such that they support typical operations and provide large anomaly detection coverage. The calibrated hydraulic model was used to evaluate flow paths of water throughout the system. Using this information, sensor placement locations were proposed that align with the objectives of the data collection and with the results of the modeling.

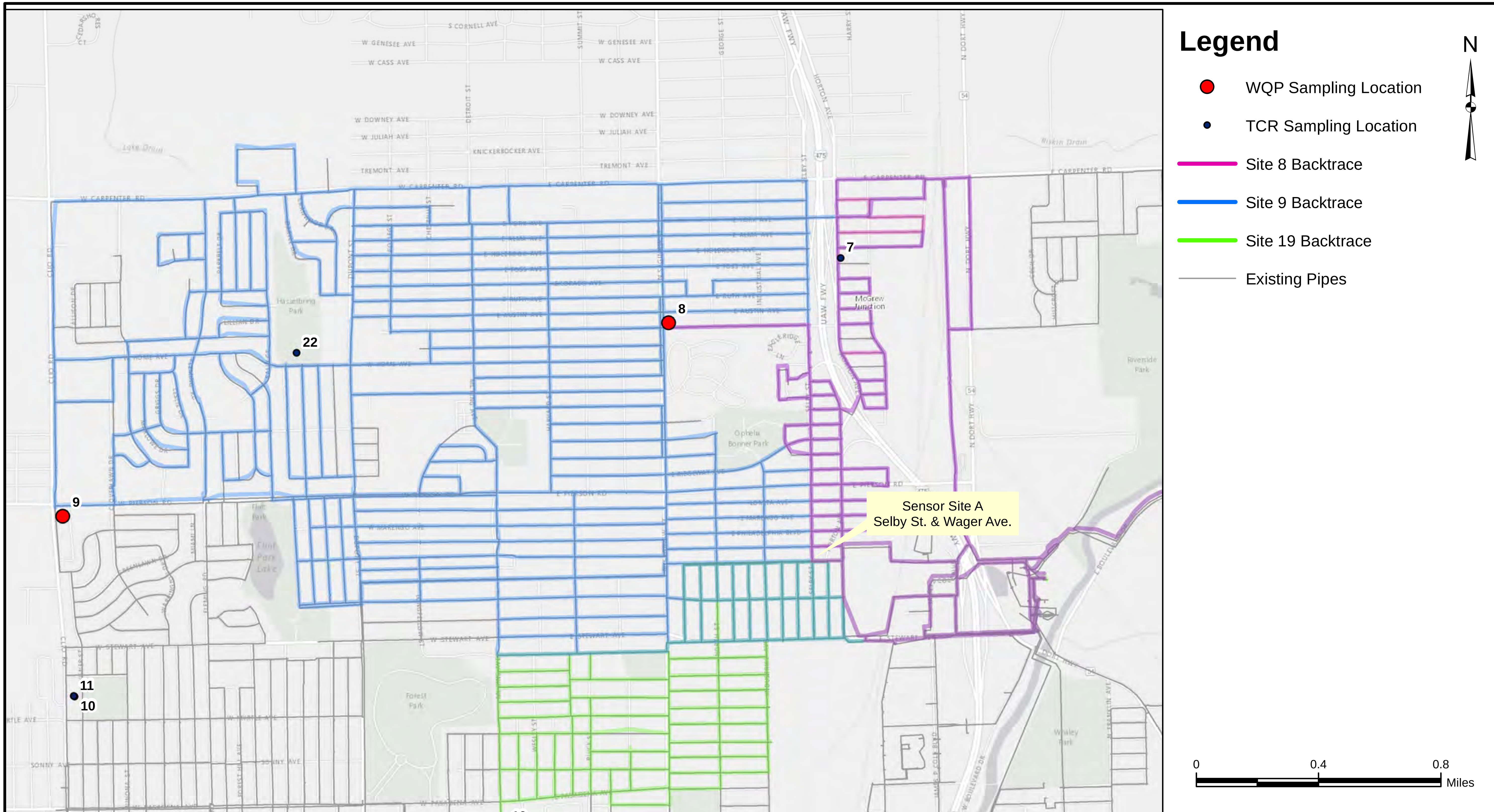
5.2 Approach

This analysis examined existing water quality monitoring points and the upstream flow paths from these locations. The analysis used the calibrated model and the back-trace extension (BTX) add-on inside InfoWater modeling software.

First, existing water quality sampling points were reviewed, and twenty-five corresponding model junctions were selected. These junctions are the starting points of the BTX back-tracing program. The calibrated model (in WaterGEMS) was exported into InfoWater so that the BTX add-on could be utilized. For each location, an event was identified at hour 36 and back-traced 24 hours (to allow for adequate coverage). Results from multiple back-traces were grouped together and potential sensor locations were selected where upstream back-traces overlapped. Within each overlapping area, model junctions were identified for a given sensor location, and separate downstream traces were performed. These trace simulations represent the approximate downstream coverage areas for each sensor location.

5.3 Results

Figures 5.1 – 5.5 show five sets of grouped back trace results. Overlapping regions are identified in each figure as potential sensor placement areas. The overall coverage area of each of these proposed sensor locations is shown in Figure 5.6.



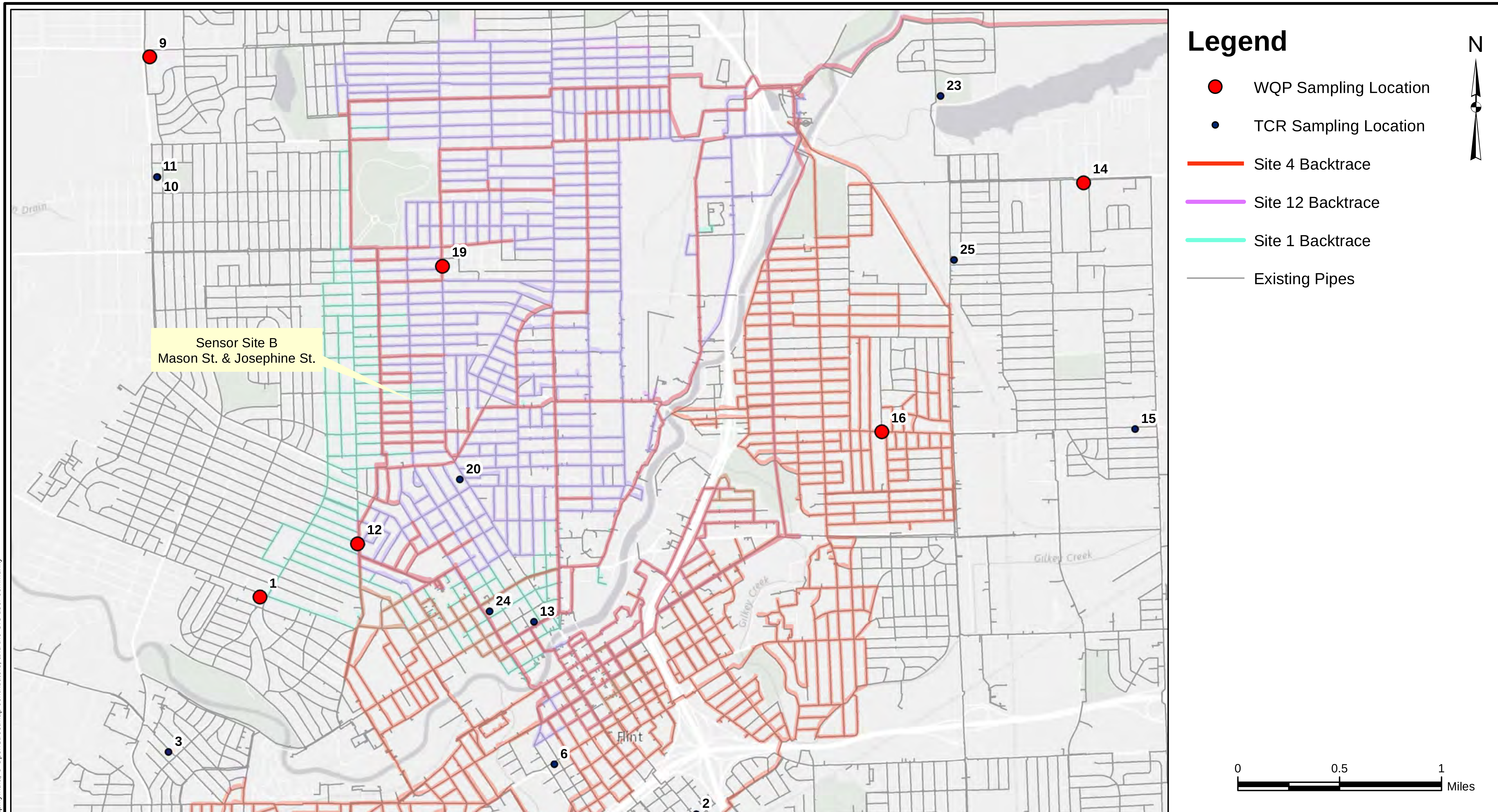
City of Flint, MI

Hydraulic Modeling Analysis

Sensor Site A
Water Quality Sampling Back-Trace

ARCADIS

FIGURE **5.1**



City of Flint, MI
Hydraulic Modeling Analysis

Sensor Site B
Water Quality Sampling Back-Trace

ARCADIS Design & Consultancy for natural and built assets

FIGURE **5.2**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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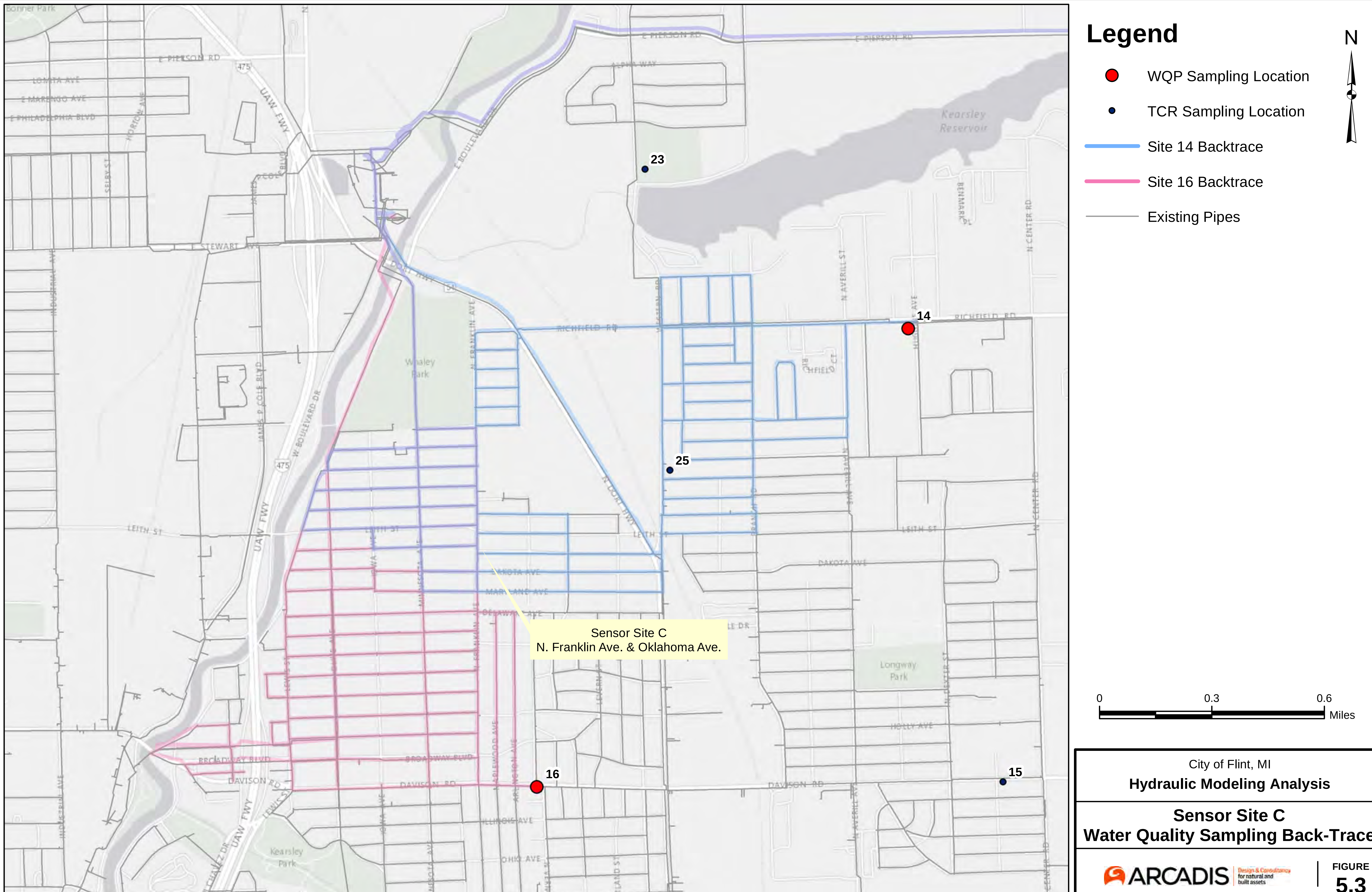
Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community



City of Flint, MI

Hydraulic Modeling Analysis

Sensor Site C
Water Quality Sampling Back-Trace

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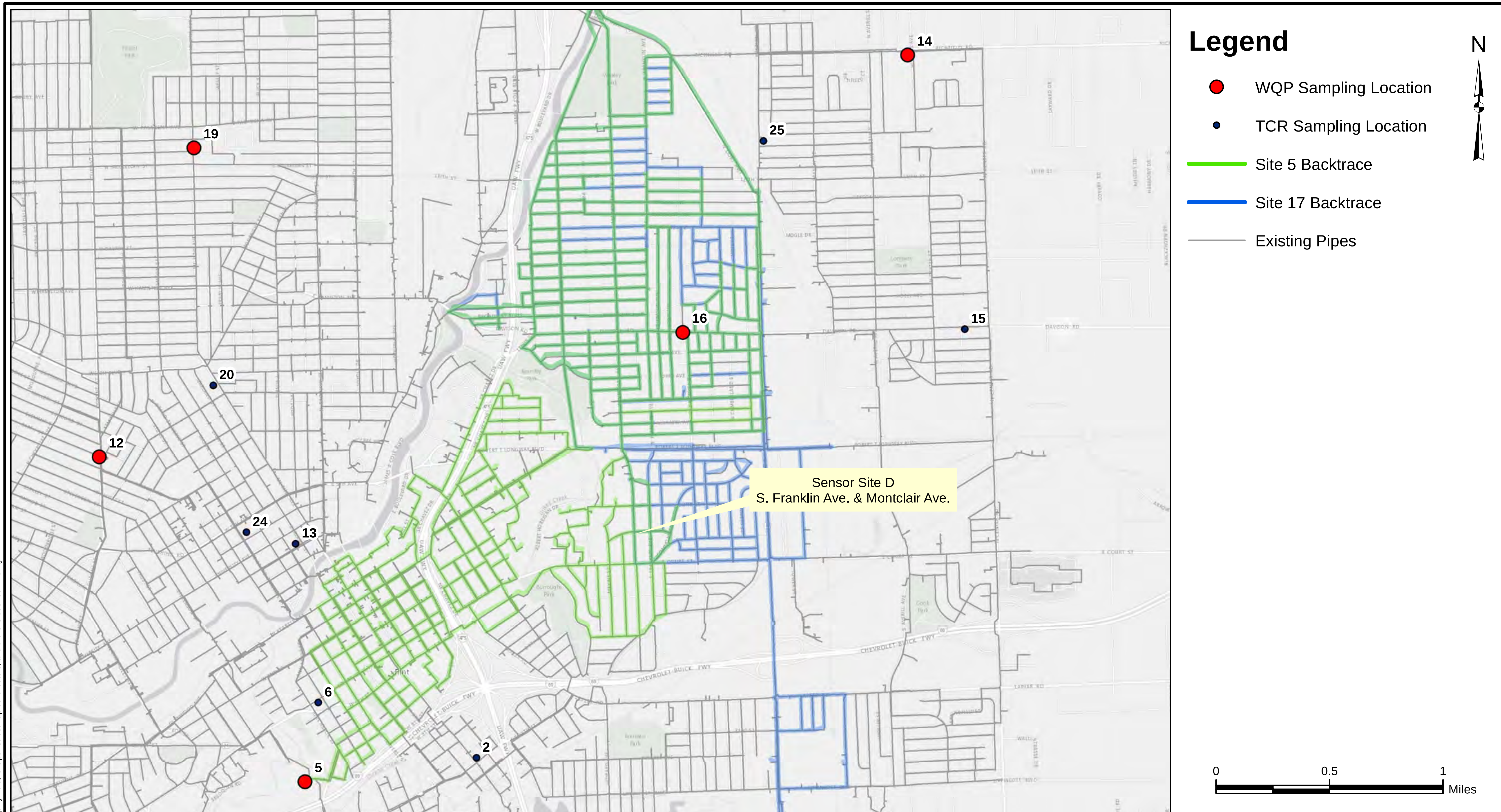
FIGURE **5.3**



City of Flint, MI
Hydraulic Modeling Analysis

Sensor Site D
Water Quality Sampling Back-Trace

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FIGURE
5.4

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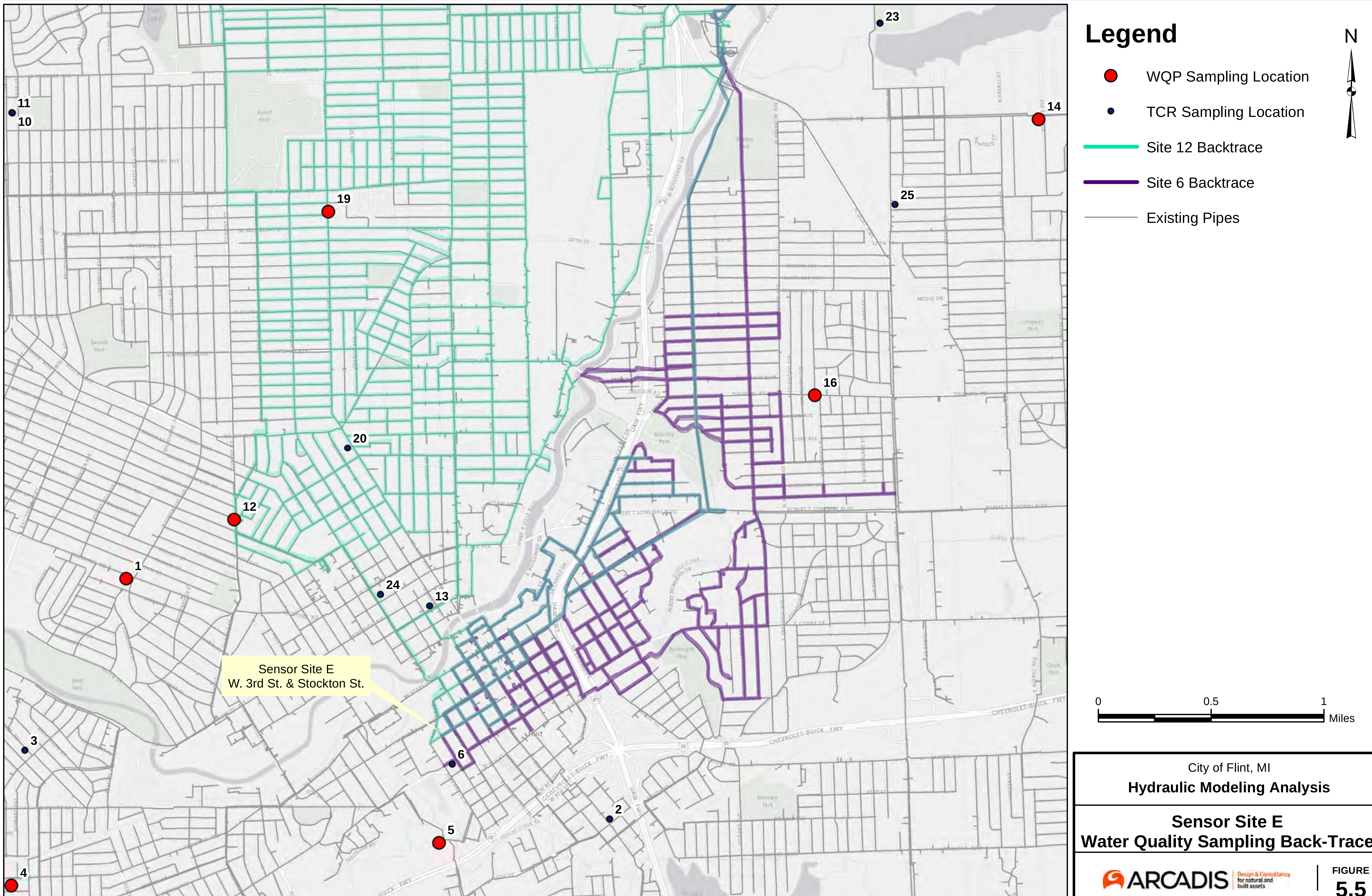

City of Flint, MI

Hydraulic Modeling Analysis

Sensor Site E
Water Quality Sampling Back-Trace

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FIGURE **5.5**

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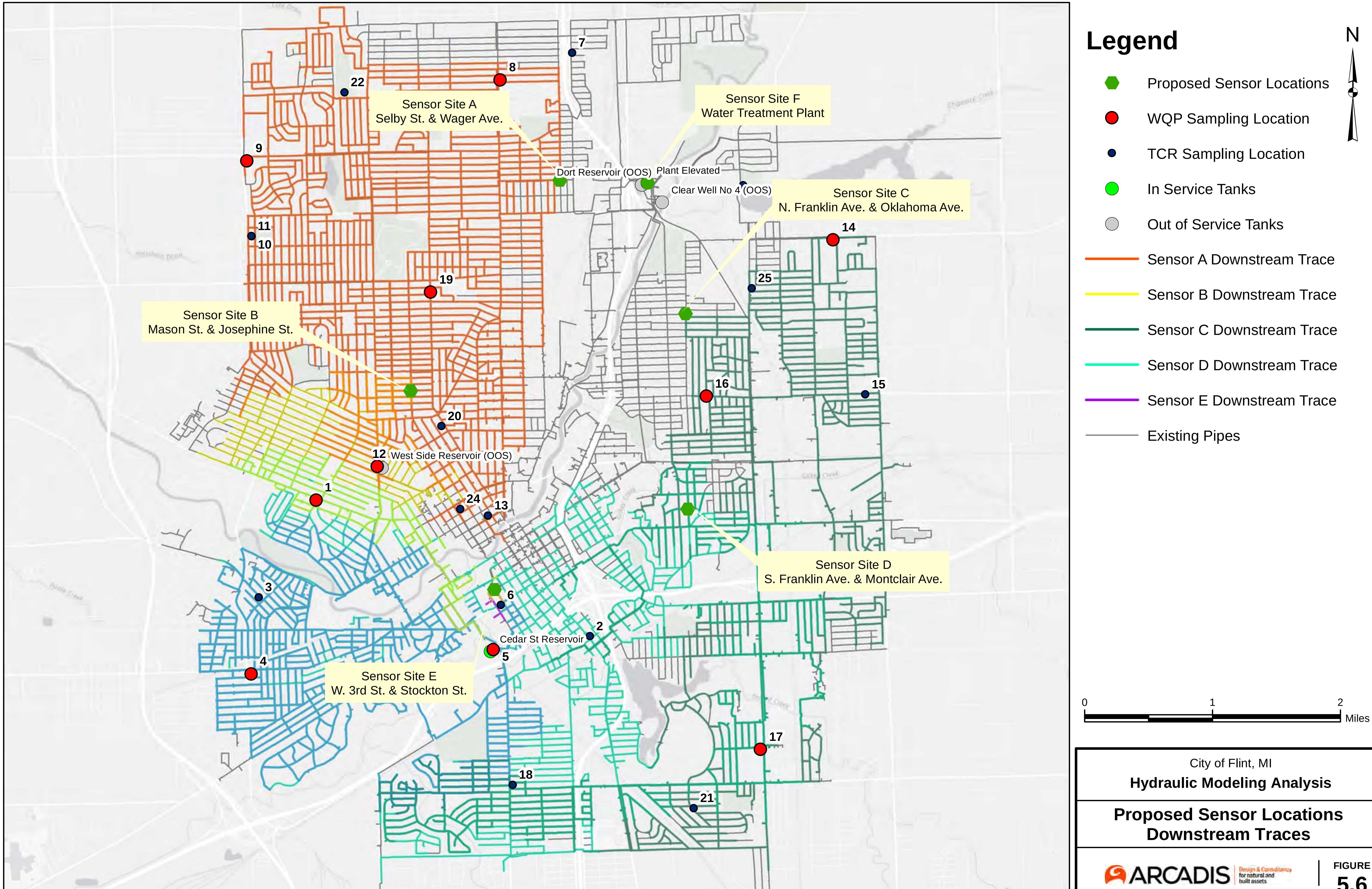

City of Flint, MI
Hydraulic Modeling Analysis

Proposed Sensor Locations Downstream Traces

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FIGURE 5.6

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

5.4 Recommendations

Six recommended sensor locations are identified in Table 5.1; five were determined from the back-tracing analysis with a sixth site assumed at the water source. Nearly the entire network can be monitored based on these locations which significantly bolsters water quality tracking and anomaly detection capabilities. These locations are optimal locations based on system hydraulics. As the City identifies where sensors can be practically located and the exact quantity, revising this analysis is recommended to confirm coverage area for any locations other than as recommended below.

Table 5.1 Recommended Sensor Installation Locations

Sensor Site	Model ID	Area	Location / Intersection
A	11564	North	Selby St. & Wager Ave.
B	13557	West	Mason St. & Josephine St.
C	11133	East	N. Franklin Ave. & Oklahoma Ave.
D	3869	Southeast	S. Franklin Ave. & Montclair Ave.
E	4991	South	W. 3rd St. & Stockton St.
F	--	Northeast	CS2 / WTP

6 WATER AGE ANALYSIS

6.1 Objectives

When a water system is producing consistent-quality water, the hydraulic residence time of water within the system, or water age, is often a reliable predictor of general water quality. This is validated by most disinfectant decay curves and generally aligns with first-order reaction kinetics. A water age analysis was performed to evaluate the overall system water age and to identify areas within the distribution system characterized by the highest water age. Select methods to mitigate areas of greatest concern were simulated which included storage modification, scheduled flushing, or pipe looping.

6.2 Approach

This analysis used the calibrated Analysis Model to simulate water age for average day conditions under current system operating conditions (WTP Elevated Tank and CSR online). The extended period was set at 1,000 hours simulation time so equilibrium water age was reached within the system. After the model simulation completed, water age results for the final 100 hours were averaged and reported in days. After base water age conditions for the system were determined, alternative runs were performed to help improve water age. The first alternative was to evaluate system water ages if Cedar St. and Dort Reservoir were utilized; the model and operation from Section 3 was used for this simulation and results were compared with current conditions. The second alternative added eight automatic flushing devices (AFDs) to the southwest area which had the highest water age. Seven AFDs were set to run continuously at a flow rate of 20 gpm, and one was set at 50 gpm. Existing AFDs have a maximum flow of 20 gpm. Water age results were again compared with current conditions. A third alternative increased the flow through the Torrey Rd. PS to potentially recirculate water in the southwest area.

6.3 Results

Results for the entire system show high water age, especially at dead ends near the system boundaries and near the Flint River. The south and southwest regions of the system show higher water age than northern areas. Because of the large number of dead ends in the system, the model results show an exceptionally high-water age for much of the system. Realistically, these dead ends may not fully represent the quality of water that is delivered to customers in the system. Therefore, the results for modeled water age was represented by only considering locations with demands in the model. This removed the dead-end “noise” and presents clearer results.

Base water age simulation results are given in Figure 6.1; current conditions show a distinct separated wave pattern with the newest water in the system near CS2 and the oldest water in the southwest portion of the system. Water age results using CSR and Dort Reservoir are given in Figure 6.2. Water age trends are not similar between the two storage scenarios, the combined scenario showed higher water age in the south and southwest areas. Conversely, an overall decrease in water age is apparent with the proposed improvements in the system (Figure 6.3). The system improvements showed improved water ages locally surrounding the areas of interest, however high water age still exists in the southwestern portion of the city. Table 6.1 provides a comparison of the scenarios using several metrics. For the final alternative, water age results were not substantially improved by increasing the flow through the Torrey Road PS. The increased flow to the southwest area resulted in higher water age being pushed just north of the southwest area. Because of this, Torrey Road PS modification is not recommended as part of water age mitigation strategies.

Table 6.1 Water Age Statistics Limited to Demand Nodes

#	Scenario	Mean Age (days)	Median Age (days)	Cumulative 95% (days)
1	Existing Conditions	6	5	10
2	CSR & Dort Scenario	7	7	12
3	Improvements Scenario	5	5	10

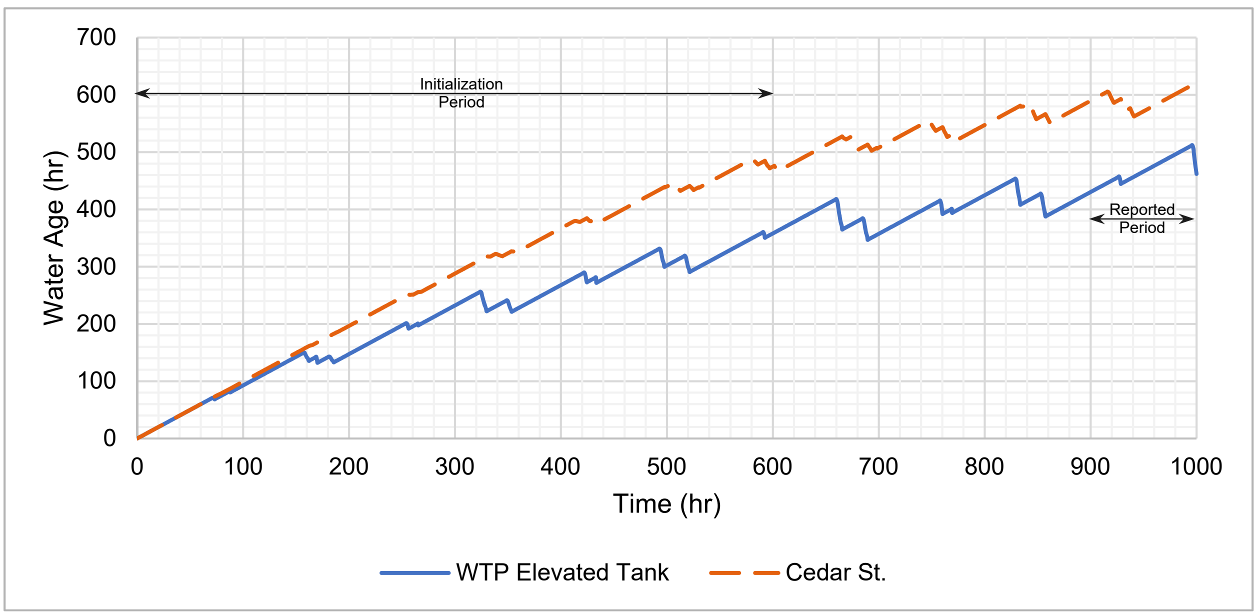
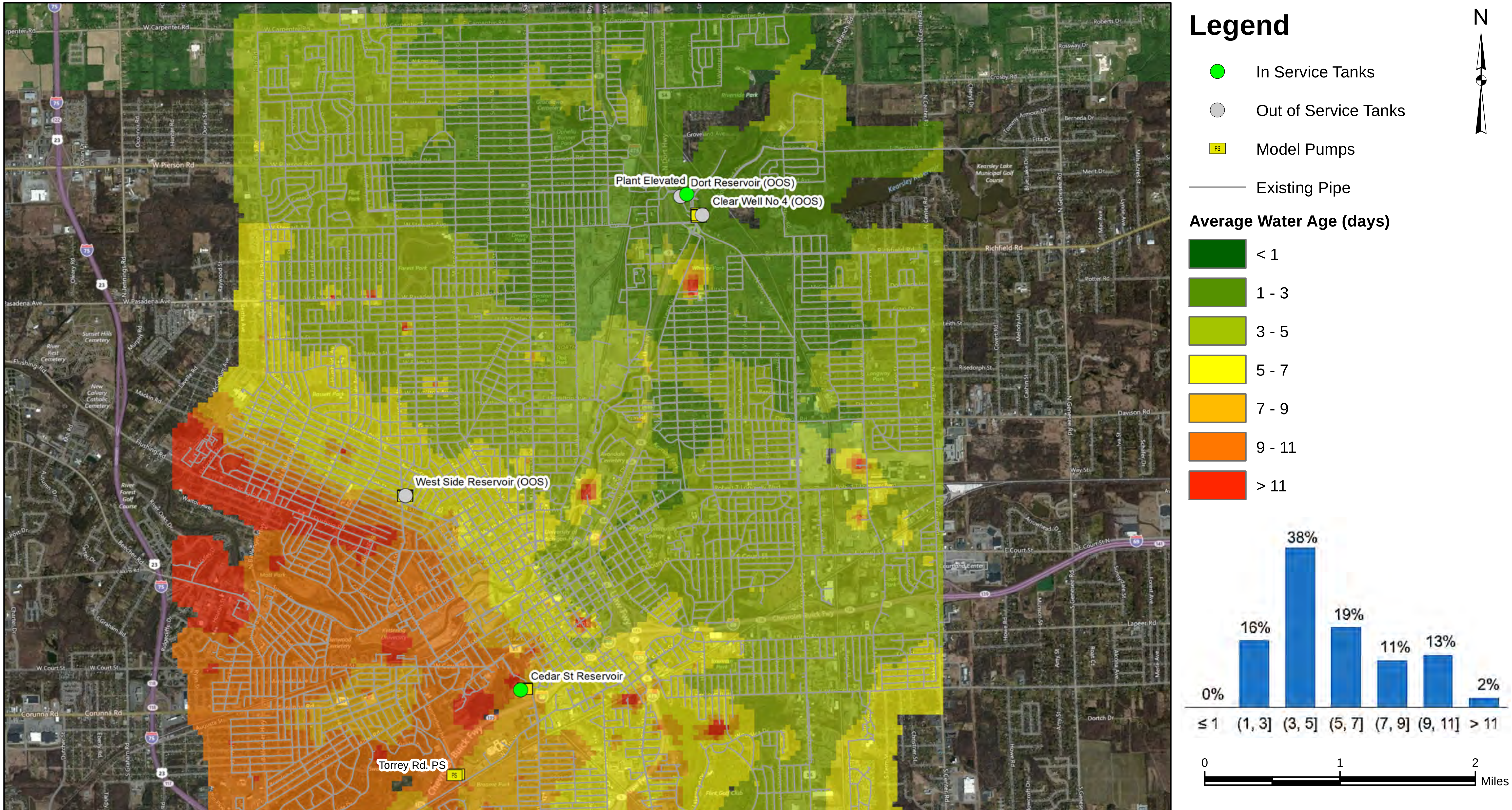


Figure 6.1 Storage Facilities Water Age Existing System ADD



City of Flint, MI

Hydraulic Modeling Analysis

Existing Conditions ADD: Water Age Results

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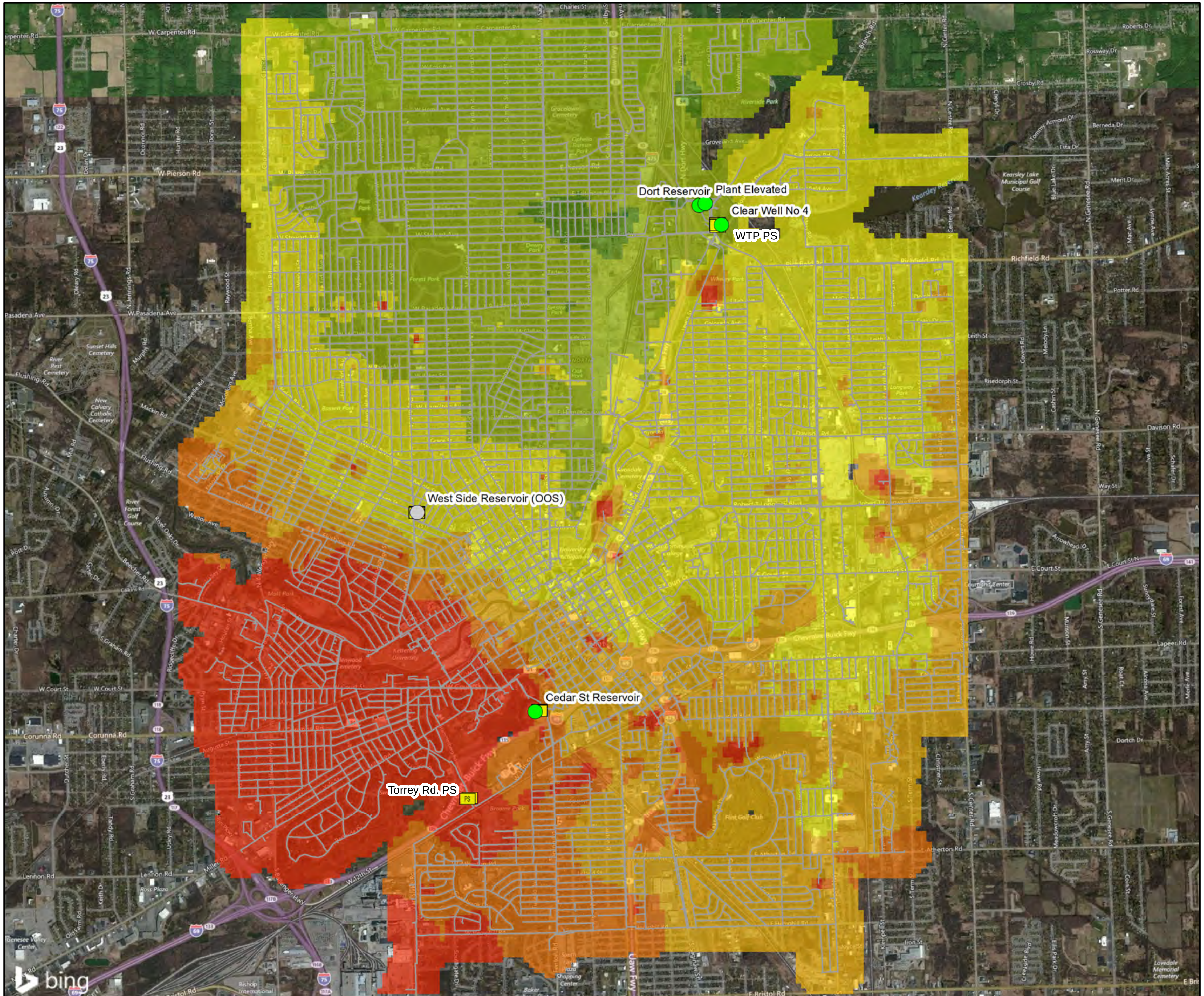
FIGURE **6.2**

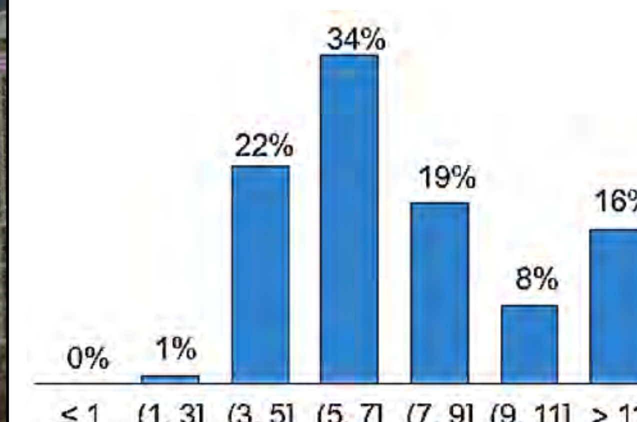


Legend

- In Service Tanks
- Out of Service Tanks
- Model Pumps
- Existing Pipe

Average Water Age (days)

- < 1
- 1 - 3
- 3 - 5
- 5 - 7
- 7 - 9
- 9 - 11
- > 11



0 1 2 Miles

N

City of Flint, MI

Hydraulic Modeling Analysis

CSR & Dort ADD Scenario: Water Age Results

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FIGURE **6.3**

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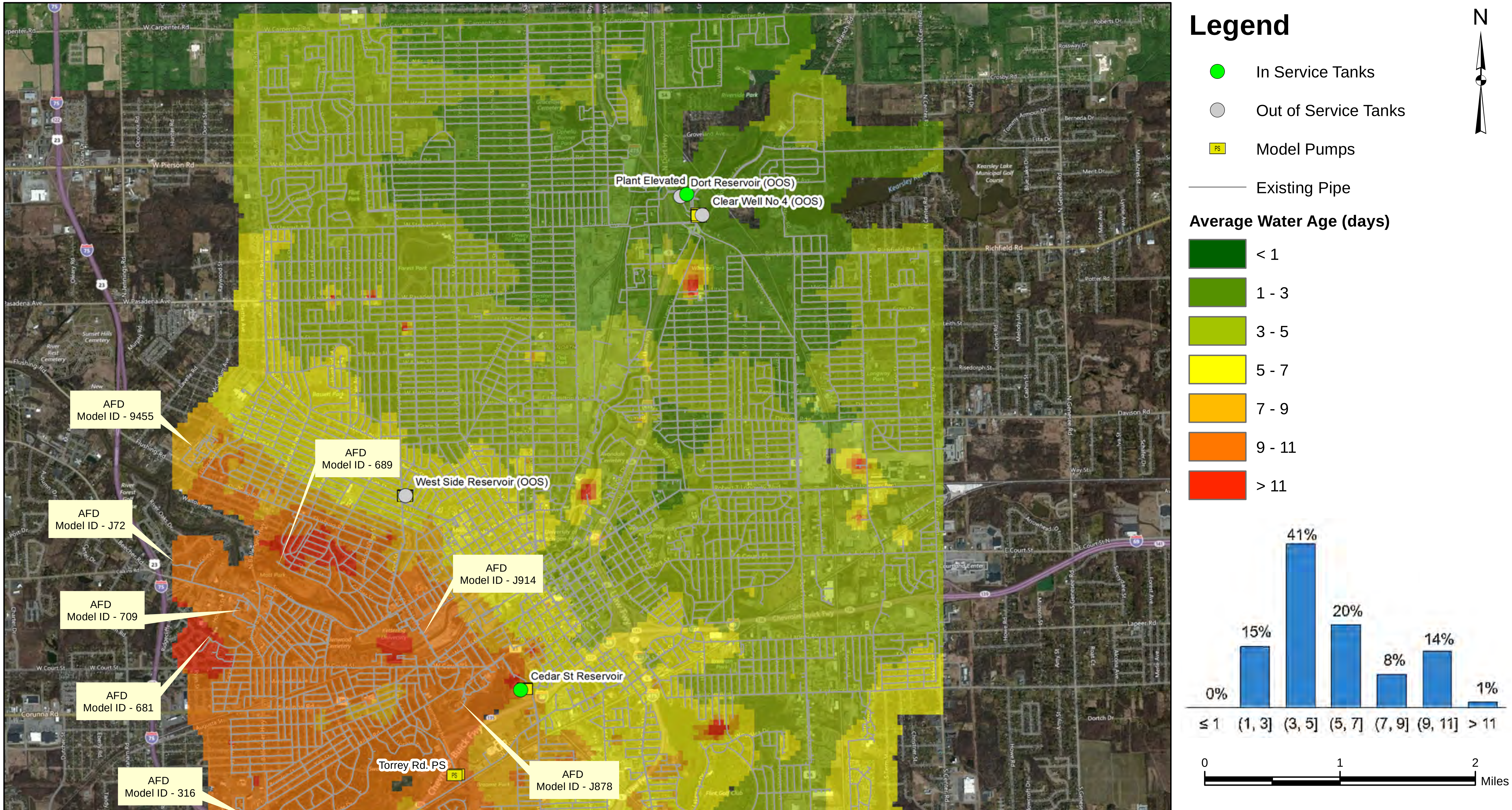

City of Flint, MI

Hydraulic Modeling Analysis

Improvements ADD Scenario: Water Age Results

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FIGURE **6.4**

6.4 Recommendations

Based on the water age modeling results found above, is recommended that Cedar St. and Dort Reservoir not be utilized together. Water age in the system is negatively impacted by using both storage facilities with an overall increase in the water age throughout the system by several days. Short term usage of both Dort and Cedar St. during certain time periods, as discussed in the storage evaluation, is possible, but care should be taken in operation of Dort to promote turnover.

AFDs are recommended in the system to improve the overall water age of the system. Because of Flint's low customer demands and large number of dead ends, widespread solutions for high water age may not be possible. However, the small enhancements found in Table 6.2 do show local and regional improvements to water age.

Table 6.2 Proposed System Improvements

Type	Flow Rate (gpm)	Model ID	Location
AFD	20	9455	Drummond Rd.
AFD	20	J72	River Hill Dr.
AFD	20	316	Austin Pkwy. & Miller Rd.
AFD	20	J914	N. Chevrolet Ave. & Flint River
AFD	20	709	Beecher Rd. & Houran St.
AFD	20	J878	Segoquen Rd. & Foster Dr.
AFD	50	689	Nolen Dr.
AFD	20	681	Jacque St. & Thornfield Ln.

7 CRITICALITY ASSESSMENT

7.1 Objectives

Hydraulic models support asset management in determining both the likelihood of failure and the consequence of failure for each modeled pipe segment within the system. Hydraulic models support evaluating the likelihood of failure by identifying pipes with high pressures, pipes with a wide range of pressures and velocities, pipes with varying flow direction and pipes with high head loss which is indicative of pipe condition. Models support evaluating the consequence of failure by performing a pipe failure impact analysis also known as a criticality analysis. A criticality analysis is performed within the modeling software to determine the impact to minimum pressure requirements, the ability to meet all demands, and operations concerns (e.g. pump running off curve) as each pipe segment is taken out of service individually. The likelihood and consequence of failure results will serve as operational data input into the broader asset management methodology. The primary objective of this analysis is to identify pipe segments within the distribution system that are the most critical in supplying demand to service customers.

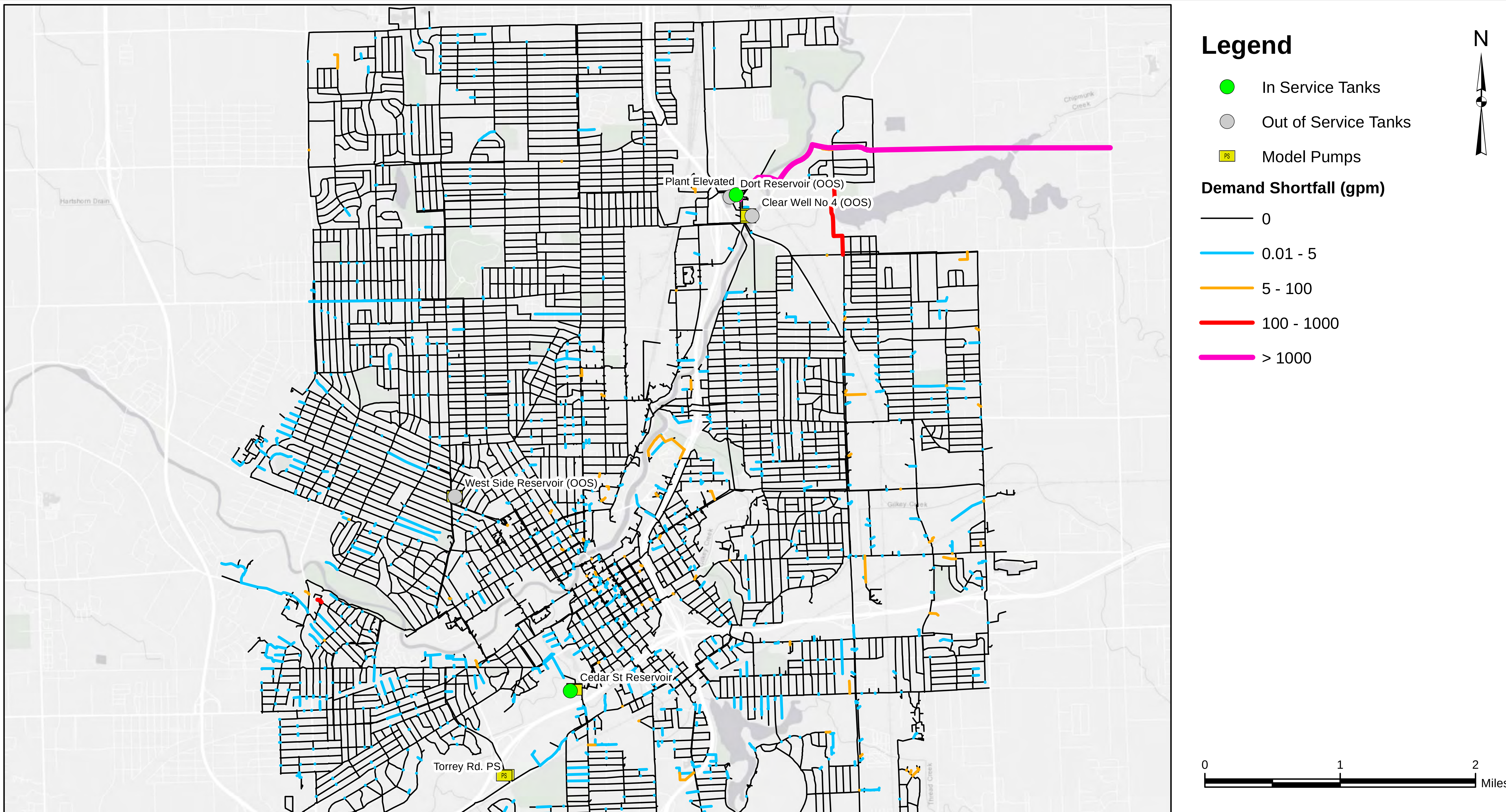
7.2 Approach

This analysis exclusively used the criticality routine within WaterGEMS modeling software using the calibrated Analysis Model. Criticality was run using current maximum day conditions, and a steady state scenario representing a CSR fill cycle was used for the criticality simulations.

The criticality routine had two distinct phases, segmentation and criticality. The segmentation phase splits the entire distribution system into segments either by pipe element or by the divisions between isolation valves. Valves were not considered in this evaluation because of limited valving data within the calibrated model. Each segment has the potential to be taken out of service; therefore, it is essential to identify the length and location of each pipe segment. This phase used a special selection set of pipes and junctions which excluded elements within or close to pump stations or storage facilities. Once the system was properly partitioned, the criticality program was set up to evaluate the system using calculated hydraulics while trying to maintain a minimum pressure at each demand location of 20 psi. After the routine is run, results show pipe segment pressure issues and unmet demands as each pipe was taken out of service one by one.

7.3 Results

The results for each criticality segment were reported as demand shortfall in gallons per minute (or percent of total) and the lowest junction pressure in psi. For the simulated system demand of approximately 12 MGD, only seventeen-hundred pipes out of fifteen thousand caused a decrease in total system demand (see Figure 7.1). Twenty-five pipe segments registered above 0.5% demand shortfall with the highest shortfall at 27%. Segments that result in minimal demand shortfall are often dead-end pipes where only a few customers are affected by a pipe break or replacement. Based on these results, there are relatively few critical segments; this could be based on the poor condition of many pipes as well as the highly looped nature of the system.



City of Flint, MI
Hydraulic Modeling Analysis

Existing Conditions: Model Criticality Results

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FIGURE 7.1

7.4 Recommendations

While it's impossible to eliminate or provide complete redundancy to all highly critical pipes, some improvements to the system can be made based on the criticality results for the model. For example, Figure 7.1 shows a highly critical pipeline providing water to a community to the northeast portion of the system. Since this is the only pipeline providing water to this community, a break here will render the entire area without water. Therefore, a secondary pipe will provide redundancy and reduce the criticality of this pipeline.

It is also important to consider that criticality is not the only component to consider when addressing consequence of failure. A full analysis of consequence (and likelihood) of failure is an important part of utility planning. A complete pipeline assessment and rehabilitation plan is being developed as a part of the asset management efforts associated with the Distribution System Optimization Plan. The model criticality results will feed directly into this analysis and help produce a comprehensive plan for the system.

8 SUMMARY AND RECOMMENDATIONS

The modeling associated with this analysis can be divided into four distinct phases: revision, data collection, calibration and analysis. The revision phase improved the physical accuracy of the model compared to the existing system, including junction elevations, point locations, pipe sizes, and system demands. Next, a comprehensive field data collection effort was performed to assist with model calibration. Twenty-six hydrant pressure recorders were installed to monitor system pressures over time, and seven flow tests were also performed to determine local capacity and C-factors. The calibration phase focused on closely matching model and metered pressures. The flow tests indicated severe degradation of the tested piping which lead to system-wide C-factor adjustments based on pipe ages. The final calibration step was to prepare the model for analysis by adjusting operational controls to allow for alternative and extended simulations.

The analysis phase can be further broken down into five separate evaluations: storage, surge, sensor placement, water age, and criticality. The storage analysis examined capacity and operations, and it compared the existing available storage volume with the theoretical minimum volume required. Operational evaluations compared three storage configurations (Dort/Clearwell, CSR and WSR) at maximum day demands to current conditions with CSR in operation. The model simulation results showed that maximum water velocity, minimum junction pressure and available fire flow were very similar between scenarios.

The purpose of the surge analysis was to determine if pump or valve operations were the cause of historic main breaks. Transient events at CSR and WSR were simulated using a transient model, and rapid pump start-up and sudden pump shutdown were evaluated at each reservoir. Model results show pressure fluctuations are localized around the reservoirs, and there are some correlations to historic main breaks for the WSR scenarios.

For the water quality sensor placement analysis, existing water quality sampling points were used as a starting point. Upstream traces were performed for each existing water quality point, and flow paths were visually inspected to determine overlapping locations that could house sensors. Downstream traces from each of these monitor locations were used to determine the overall monitoring coverage area. To help evaluate water quality, water age scenarios were simulated for the Flint network. Current condition results were compared to a scenario where Dort was the primary storage facility and another scenario with the addition of flushing devices and pipe looping. Water age for all the scenarios was elevated with Dort showing a slightly larger area of high water age and the improved conditions showing a slightly smaller area compared to existing conditions.

The final analysis for the Flint system was a criticality assessment, which will help support the asset management task by identifying critical pipe segments within the distribution system. The criticality tool within the model was utilized to systematically take each pipe out of service and determining the resulting demand shortfall. The most critical pipes were identified based on how much demand was not met when out of service. Based on a steady state evaluation of the entire system, only a small fraction of the pipes caused significant loss in demand supplied.

A number of recommendations were determined based on the analysis presented above. Multiple analyses were performed that looked at water storage configurations. The consensus between all analyses that were performed seemed to point at the continuation of utilizing CSR and the plant elevated tank for system storage. Storage analysis showed excess storage in the system above the required amount, which points to not increasing system storage and instead possible decreases. The storage analysis and water age analysis both showed that using Dort Reservoir presents worse system conditions; pressures are slightly lower in the middle of the network and water age is worse throughout the system. Additionally, the transient analysis showed some correlation of pipe breaks with WSR operation. The abandonment of WSR negligibly impacts minimum pressures in the southwest region of the system during high demand conditions such as in the winter with a maximum simulated demand of 24 MGD. When evaluating daily minimum pressures throughout the system, the lowest pressures typically correspond to filling operations of Cedar St. and West Side Reservoir. The continued usage of only CSR and the plant elevated tank is recommended for normal system conditions as this presents the best results from these analyses.

Based on the complete storage analysis, the recommended long-term operating strategy should balance attenuating peak supply flow rates from GLWA while minimizing storage for water quality benefit. It is recommended for the plant elevated tank, Dort Reservoir and Cedar St. Reservoir to be operated during the winter months (with peak demands of 24 MGD due to main breaks); and, for the plant elevated tank and Cedar St. Reservoir to be operated in the summer months when there are lower demands and higher reaction rates. Although not expected, if the City experiences significant demand growth in the future, Dort Reservoir should be returned to always-on operations.

The recommended operating strategy during non-peak seasonal demands or typical conditions is to return to deep cycling of the ground storage facilities in order to maintain adequate water quality. This is necessary to prevent an excessive amount of continuous flushing that would otherwise be necessary to reduce water age in the areas of the system with the highest age. This does not afford the flexibility to modify storage operations from current practices such that operations reduce peak water supply rates from GLWA (e.g. peak shaving). However, Dort Reservoir and Cedar St. Reservoir filling should not occur simultaneously to minimize peak water supply rates for filling operations; and, reservoir filling should occur during daily diurnal periods of minimum customer consumption to reduce peaks and also reduce the impact of pressure decreases during filling.

Due to the lack of operating data on Dort Reservoir and the High Service Pumping Station at the WTP, it is unclear if any additional infrastructure changes are necessary to successfully operate with Dort and the Elevated Tank both in service. Model simulations suggest changes (valving, etc.) may be necessary to adequately turn over Dort and the Elevated Tank when supplied through Control Station 2.

In addition to storage recommendations, several system improvements were identified in Table 6.2 as part of the water age analysis. These improvements include automatic flushing devices. Implementation of these recommendations should improve overall water age in the system as discussed above. Finally, water quality sensor locations were determined and can be found in Table 5.1; these should be installed to provide optimal monitoring coverage area of the system.

APPENDIX A

Field Data Collection Plan

City of Flint, Michigan

CALIBRATION DATA COLLECTION PLAN

Water Distribution System Model Calibration

April 2017

1 INTRODUCTION

This Calibration Data Collection Plan provides details for our collection of current distribution system pressure and pipe network capacities, aligning with other data from the City's SCADA system, in order to obtain sufficient data to complete calibration of the City's water distribution system hydraulic model. This effort is part of the Flint Drinking Water Distribution System Optimization project being performed by the Arcadis Team, and in collaboration with the previous model development and calibration progress performed by the USEPA and CitiLogics modeling team. Included in this Plan are the following:

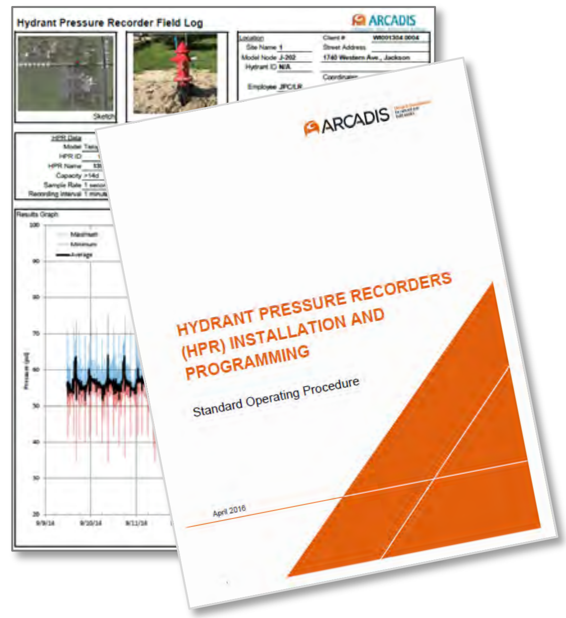
1. Data Collection Approach / Need
2. Proposed Hydrant Pressure Recorder (HPR) and flow test locations.
3. Methods to achieve maximum "uptime" of HPRs collecting data.
4. Dates of installs, data collection periods and recording intervals.
5. Project Health and Safety Plan (HASP).

2 APPROACH

This Plan is established to collect data for the purpose of supplementing any available SCADA data from the City of Flint as well as previously measured data within the distribution system. The purpose of this additional data collection is to perform pipe roughness testing to sufficiently calibrate the model for storage evaluations and other system modeling analysis. Hydrant Pressure Recorders (HPRs) will be temporarily installed to understand the magnitude of hydraulic grade line variation from the source to test locations and through storage and pumping facility operations.

The proposed hydrant survey locations were identified based on primary inflow facility locations, previous data collected, and site accessibility. At the time of this data collection, the West Side Reservoir is out of service, therefore hydraulic grade line variation when West Side Reservoir is filling will not be observed. A total of 30 HPRs will be used to collect data throughout the system. These electronic recorders are used to obtain system static and residual pressure measurements, and collect pilot pressure measurements to calculate field test flow rates.

Pressure measurements will be obtained via field testing occurring over approximately one week in April/May 2017. Arcadis representatives will lead the installation and management of pressure recorders on hydrants and fire flow testing. City representatives will assist Arcadis by operating hydrants and valves as well as providing additional system insight during the testing.



Throughout the installation week, Arcadis representatives will travel from site to site to install HPR's and take live readings. Installed HPR's will be locked in place with a security cover. After the meters have been in place for approximately one week, they will be uninstalled by Arcadis representatives. All pressure data collected will be provided in test reports to the project team.

Detailed information on the proposed metering locations, routing and scheduling details and additional information on the meters themselves are contained within the following sections.

3 PROPOSED TEST LOCATIONS

Test locations were determined for the specific purpose of observing hydraulic grade line degradation during distribution reservoir filling observations. Recorders were placed nearby major facilities to capture boundary conditions entering each system. Other recorders were distributed throughout the system being cognizant of pipe network connectivity, larger diameter transmission mains, and hydrant access. Roadways with apparent ongoing construction were removed from consideration during location selections.

Overview maps for all the proposed metering locations are attached to this Calibration Data Collection Plan. All proposed locations are subject to change based on field conditions observed at the time of testing. Detailed mapbooks were developed for field crews that highlight each location. Recorded field data will include install team, install date & time, meter ID, hydrant location GPS point, live pressure reading, and hydrant photo.

4 SCHEDULE

The following testing schedule is proposed for performing the field testing. This schedule is to be confirmed by representatives at the City of Flint with respect to the availability of City resources.

Monday, May 1, 2017

1. Conduct a Calibration Data Collection Kickoff Meeting at City offices at 3:00 p.m. with project and field representatives.
    a. Review this Plan, discuss project procedures (including the Health and Safety Plan), and staffing for the week.
    b. Exchange contact information and determine procedure for obtaining SCADA data following test week.

Tuesday, May 2, 2017

1. Arcadis will conduct a daily Tailgate Health and Safety discussion for the day's planned field activities.
2. Arcadis field crew will install hydrant pressure recorders throughout the City system in locations identified in the attached figures. These will remain temporarily installed and be removed next week.

Wednesday, May 3, 2017

1. Arcadis and City field crews meet at the City operations facility at 8:00 a.m.
2. Arcadis will conduct a brief Tailgate Health and Safety discussion for the day's planned activities.
3. Arcadis and City field crews conduct hydrant flow tests and pipe roughness tests as indicated in the attached figures.

Thursday, May 4, 2017

1. Arcadis and City field crews meet at the City operations facility at 8:00 a.m.
2. Arcadis will conduct a brief Tailgate Health and Safety discussion for the day's planned activities.
3. Arcadis and City field crews conduct hydrant flow tests and pipe roughness tests as indicated in the attached figures.

Tuesday, May 9, 2017 – Wednesday, May 10, 2017

1. Arcadis will arrive on site for removal of hydrant pressure recorders.
2. Arcadis will conduct a brief Tailgate Health and Safety discussion for the day's planned activities.
3. Arcadis and City field crews will remove hydrant pressure recorders.

5 PRESSURE RECORDER DETAILS

Hydrant Pressure Recorders, Model HPR-31, by Telog (now owned by Trimble) will be the pressure measurement device utilized to perform the pressure survey. Telog HPR-31 equipment is superior field data collection equipment, which does not require frequent recalibration (often required of other hydrant pressure recorders) and has long-term batteries. The HPRs allow for custom programming to meet the needs of this project. The HPRs will be programmed to sample the pressure every 5 seconds then record the minimum, average and maximum pressure values every 1 minute. A data sheet for the equipment that will be installed is attached to this Calibration Data Collection Plan for reference.

The fleet of Arcadis-owned HPRs include units with 200 psi maximum pressure and units with 300 psi maximum pressure. It is our understanding that no points within the City's system exceed 200 psi, therefore all 200 psi maximum pressure units will be installed.

Each HPR attaches with national standard thread to the 2.5-inch port of a hydrant and will be secured with a lockable security cover which prevents tampering/removal of the recorder on the pressurized hydrant port. The security cover will have a label attached noting the hydrant is pressurized and the equipment is owned by Arcadis for a test in progress.

6 ADDITIONAL DOCUMENTATION

The Arcadis Team regularly performs field work for model calibration, and often trains utility operators in performing pressure surveys and fire flow testing. The following documents, attached to this Plan, provide standard processes which will be followed throughout the project to ensure adequate data and operator safety:

- Hydrant Pressure Recorder Installation and Programming Standard Operating Procedure
- Pipe Roughness Testing Standard Operating Procedure
- Project Health and Safety Plan (HASP)

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HYDRANT PRESSURE RECORDERS (HPR) INSTALLATION AND PROGRAMMING

Standard Operating Procedure

April 2016

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CONTENTS

1 PURPOSE AND GOAL

The purpose of this Standard Operating Protocol (SOP) is to establish the steps for the installation of hydrant pressure recorders.

Hydrant pressure recorders can be used for the collection of pressure data and fire flow testing. The data obtained with a hydrant pressure recorder can then be used to calibrate a water distribution model.

2 EQUIPMENT

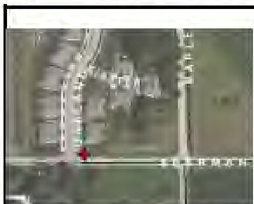
The majority of the necessary equipment is included in the hard carrying cases.

- Telog Hydrant Pressure Recorders (minimum of two if performing a fire flow test)
  - HPR 21 - serial port and normal 9V battery (short life)
  - HPR 31 - round port and 3.6V Lithium Battery (5-year life)
  - Both models come in two versions:
    1. 100 psi – higher accuracy, lower range
    2. 200 psi – lower accuracy, higher range
- Data transfer cable
  - Black → Serial Cord to connect HPR 21 to computer
  - Blue → USB to serial adaptor (will need drivers to use on computer)
  - Yellow → round connector to serial adaptor (for HPR 31)
- Diffuser
- Garden hose adapter
- Fire hydrant wrench

3 INSTALLATION

1. Take detailed notes and fill out initial portion of *Hydrant Pressure Recorder Field Log*.

Hydrant Pressure Recorder Field Log ARCADIS



Sketch

Photo

Location		Client #	CL001000.X001
Site Name	1	Street Address	
Model Node	J3882	Sherman at Oakland	
Hydrant ID	N/A		
		Coordinates	
Employee	JPC/LR		

HPR Data		Notes			
Model	Telog HPR31	Pressure monitoring while system is still being implemented. All mains installed, service connections remain to be installed.	Install Date/Time	9/9/2014	11:52am
HPR ID	2		Install Pressure	71 psi	
HPR Name	1113		Remove Date/Time	9/16/2014	10:32am
Capacity	> 14d		Remove Presure	72 psi	
Sample Rate	1 second		Local FD Notified?	Yes	
Recording Interval	1 minute				

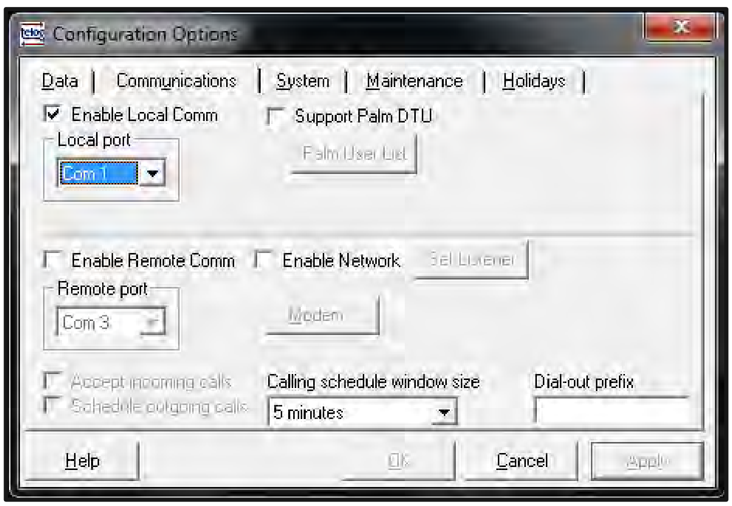
2. Verify that the hydrant is closed and remove side cap. Unless special circumstances exist, a utility representative must present to perform actions pertaining to operating the hydrant and installing the HPR.
3. Slowly open hydrant to perform an initial flush. Initial flush will remove rust and grit from hydrant.
4. Attach the HPR to side cap and ensure seal is tight. Check that all other caps are tight.
5. Fully open the hydrant at an extremely slow speed so as to limit the amount of water hammer.
6. Check for large leaks. If leaks are present, a new gasket may be required to prevent leaking. If leaking continues, a different hydrant location will be required.
7. Connect computer via data cable and ensure the HPR is programmed correctly and recording data. Disconnect the HPR after performing verifications.
8. Attach security cover and hasp. Then, secure with the padlock.

9. Confirm if it is necessary to notify the Fire Department that the hydrant is active/on. Frequently the utility will add an "out of service" tag to the hydrant or a "not in service" bag.

4 TELOG SOFTWARE

Telogers for Window is used for both HPR-31 and 21 devices. Current released version is 6.30, however it has a bug that doesn't allow programing HPR-21 devices. Beta release 6.31 fixes this issue.

Telog will not automatically recognize when cords (serial or USB) are plugged in. By default, local communication is not enabled, so after most Telog startups go to ***Setup→Options→Communications*** tab and click the "***Enable Local Communications***" option.

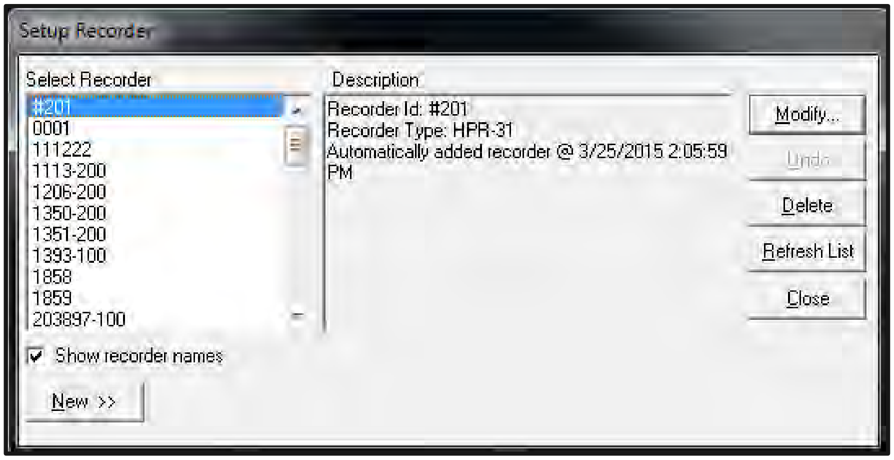


The local port dropdown lists all active communication ports for the computer. Com 1 is the serial port, and USB can be any number between 3 and 9 (check device manager if unsure). Note: if the right port doesn't display, restart the software (must be plugged in when the software is started or else Telog cannot see).

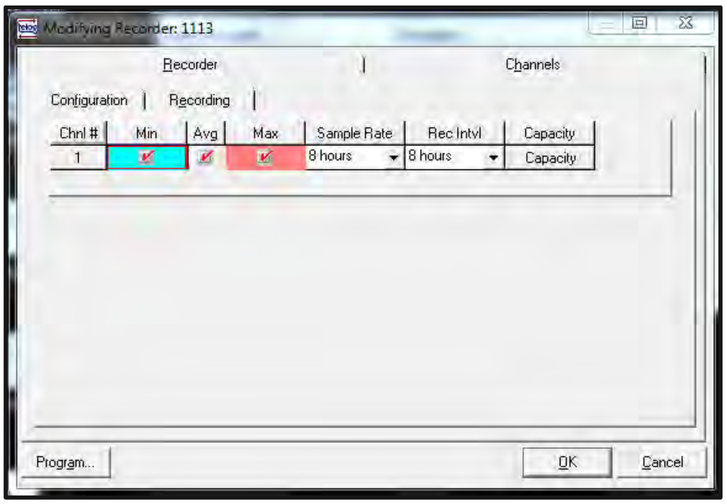
4.1 HPR Programming

HPR devices will need to be programed before and after field work.

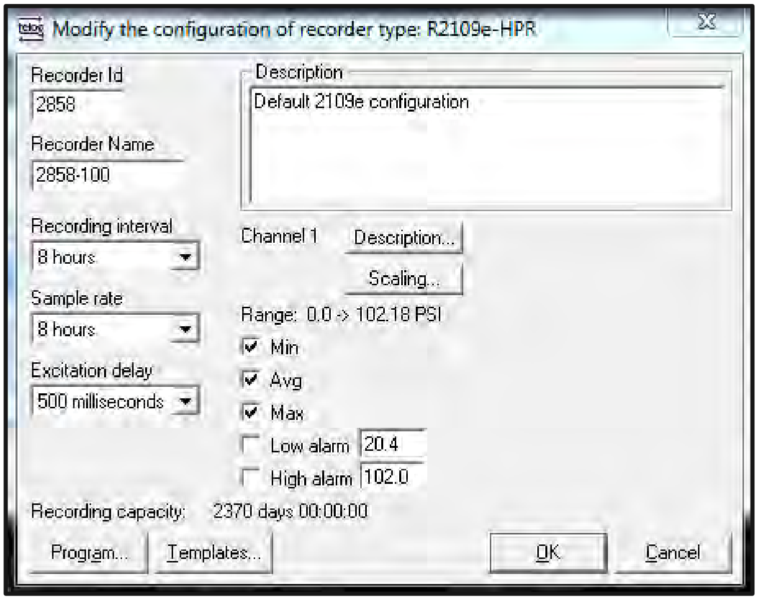
1. Go to ***Setup→ Recorders***
2. Selected the connected recorder and hit ***Modify*** (or hit ***New→Attached Recorder***)



3. HPR-21 and 31 have slightly different programing.
   - HPR-31 has tab based options. Primary options of interest are in the ***Channels*** Tab, under ***Recording*** subtab.



   - HPR-21's have a single main screen where all options are present.



4. Check the ***Recording Interval*** and the ***Sampling Rate*** options.
   - **Storage**: 8 hour sampling rate and 8 hour recording rate
   - **Usage**: 5 second sample rate and 1 minute recording rate

5. You have to hit the ***Program*** button to save the changes to the device. (Note this may delete data off the device).

4.2 HPR Data

Data can be gathered from the HPR in two modes. "***Display latest readings***" for testing the equipment, and "***Collect Data***" for downloading all data present on the device.

4.2.1 Current Readings

- ***Communicate→ Local Recorder***
- For HPR-21's, click on ***RTU Type*** and choose Unknown or HPR-21 option (otherwise it will not connect). For HPR-31's leave as is or select Unknown.
- Note: if start option is greyed out, must enable location communication (see section 5.0)
- Hit "***Display Latest Readings***" - allows the user to view current readings during field deployment and equipment testing (hit stop or close to end the session)

- o If device won't connect: check local communication option, check set COM port, restart software with cables plugged in, check RTU type, check chords, replace HPR battery.

4.2.2 Data Download

- o ***Communicate→ Local Recorder***
- o Select ***RTU Type*** as noted above
- o Hit ***Collect Data***
  - ▪ Won't have pop-up when complete; see main program footer for download progress
- o To view data: ***File→Analyze data from database*** or database button
  - ▪ Check the specific HPR in "Select data to analyze" tab
  - ▪ Change start/end times in "Data Set Properties" tab
  - ▪ Data will display graphically and tabular
  - ▪ Copy data to excel or export file to CSV (file→export)

5 NOTES

5.1 General

- Most hydrants are "dry barrel" and not active. This prevents water from being released/flooding if the hydrant were to be damaged.
- Most hydrants are standard thread and can connect with the HPRs
  - o Non-standard threads require an adaptor to connect the HPRs
- Use the side opening of a hydrant for pressure recording and flow tests
  - o Reduce risk of injury by not standing in front of caps when pressurizing hydrant. Caps can unexpectedly burst off and cause injuries.

- Hydrant's, typically, have manufacturing dates which can indicate approximate water main age.
- Security cases are easily damaged while transporting. Be sure to keep in secure containers.

5.2 HPR Projects

- HPRs are utilized for pipe roughness testing (C-factor), fire flow testing and general pressure measurement.
- Remember to coordinate with utility for installation. Also, notify the fire department.
- Weekly Rental Fee for equipment is $75 per unit. Daily fee is $15/day per unit.
  - Fill out Unit Billing form for project charging
  - O107 Unit Code for HPR usage

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PIPE ROUGHNESS FIELD TESTING

Standard Operating Procedure

April 2016

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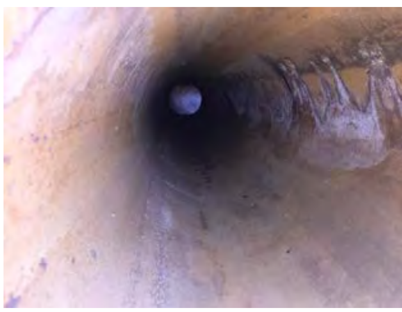
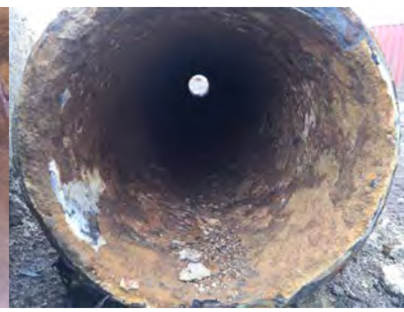
CONTENTS

1 PURPOSE

A primary method of performing calibration on a water distribution system hydraulic model is by adjusting the pipe roughness coefficients. Adjusting the roughness coefficient of pipes will increase or decrease the amount of friction loss induced as water is conveyed through the system. Pipes of varying material, interior wall lining, age and diameter can exhibit a wide range of roughness coefficients. Biofilm, scaling and iron oxide formation can inhibit the hydraulic performance of the pipes as shown in the following project photos.

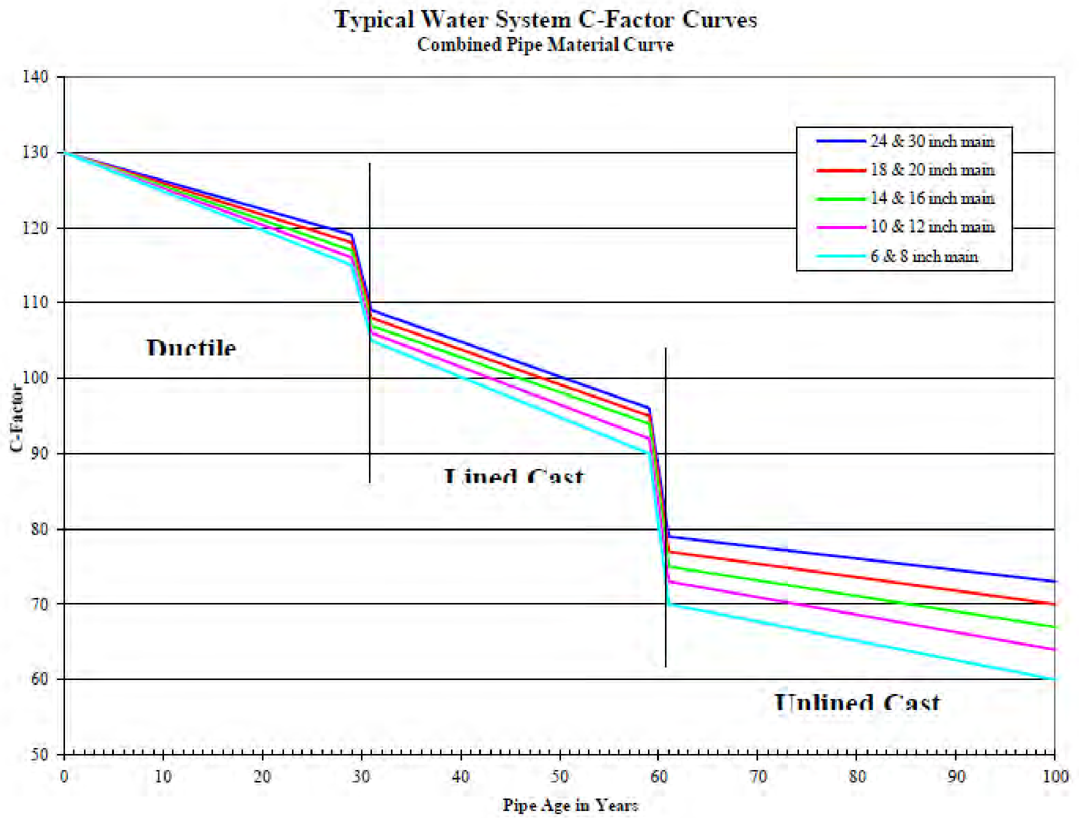

Hydraulic models commonly use the Hazen-Williams method of calculating friction loss in pressurized pipe applications. The pipe roughness coefficient, or C-factor, is adjusted to reflect the varying roughness within pipes.

A pipe roughness field test is performed at select locations throughout a water distribution system for the purpose of estimating the pipe roughness for use in a hydraulic model. This SOP will provide the calculations for determining a C-factor from field pressure and flow measurements, general C-factors for comparison to measured data, and an overview of test equipment and test procedures.

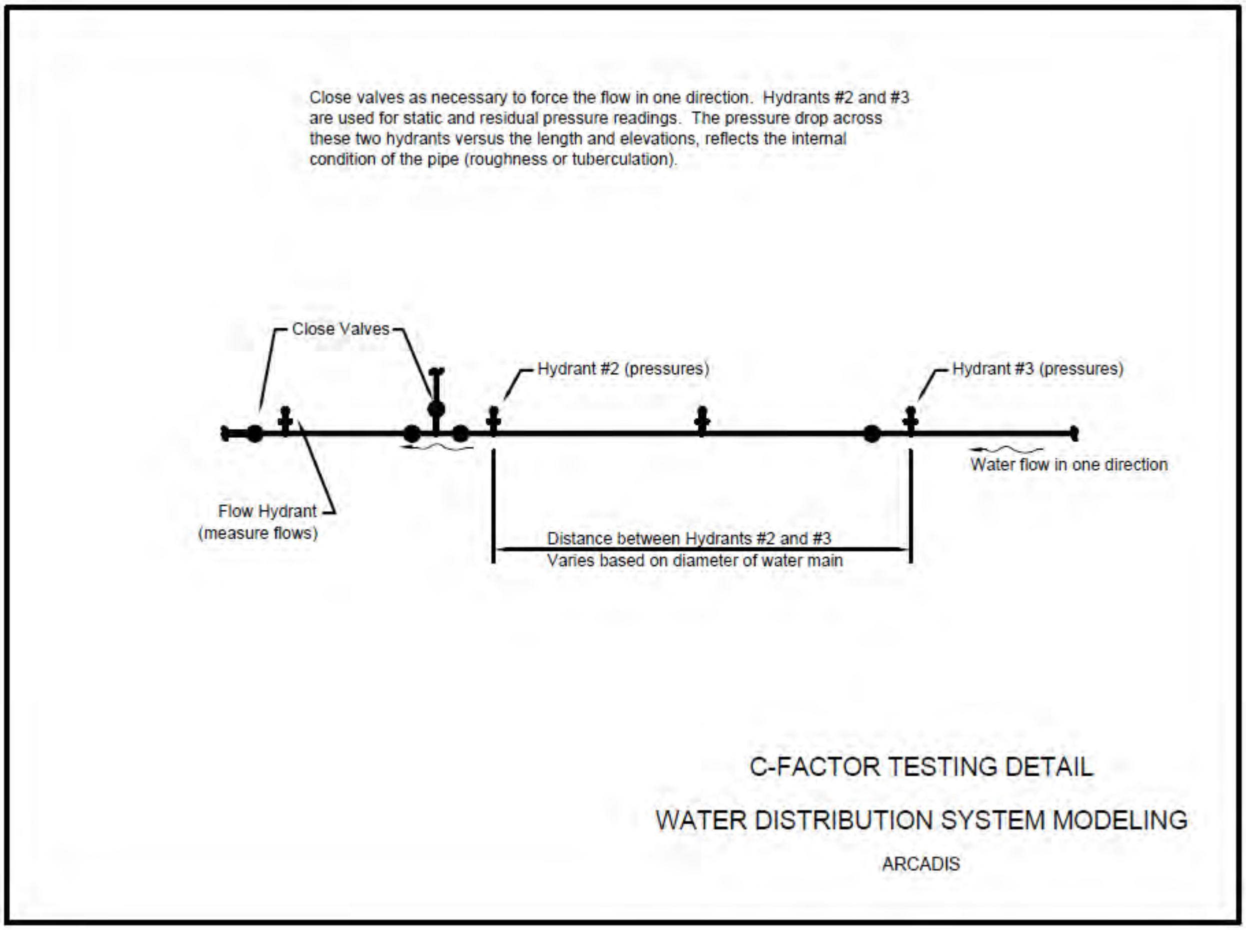
2 CALCULATIONS AND GUIDELINES

Various guidelines exist to set initial pipe roughness coefficients, however any model should have field data measured and used to confirm and adjust pipe roughness coefficients. Two examples of roughness coefficient guidelines are shown below.

Material	Hazen-Williams Coefficient - *C* -
Asbestos Cement	140
Brass	130 - 140
Brick sewer	100
Cast-Iron - new unlined (CIP)	130
Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100
Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83
Concrete	120 - 140
Copper	130 - 140
Ductile Iron Pipe (DIP)	120
Galvanized iron	120
Glass	140
Lead	130 - 140
Plastic	140 - 150
PVC, CPVC	150
Smooth Pipes	140
Steel new unlined	140 - 150
Steel	130
Steel riveted	110
Tin	130
Wood Stave	120



A variation of the Hazen-Williams equation is used to calculate the C-factor from field test data. The field data is a measurement of pressure from three hydrants and distance between hydrants as shown in the following figure. In addition, length of pipe between hydrants must be considered to achieve sufficient test accuracy.



Water Distribution System Modelling
Field Work for C-Factor Testing

$$HL = \frac{10.44 x L x Q^{1.85}}{C^{1.85} * D^{4.8655}} \qquad C^{1.85} = \frac{10.44 x L x Q^{1.85}}{HL x D^{4.8655}}$$

HL (head loss) feet — C (friction factor) Hazen Williams coefficient
L (length) feet — D (diameter) inches
Q (flow) gpm

HL is the pressure loss between two hydrants; converted from psi to feet by multiplying by 2.31

$$HL = (P2-P3)x2.31$$

$$C^{1.85} = \frac{10.44 x L x Q^{1.85}}{(P2-P3)x2.31 x D^{4.8655}}$$

The higher C factor, the smoother pipe, and the lower pressure difference between hydrants
For testing purposes, we want to see as large of a pressure drop and flow as possible.
How long must the run between hydrants 2 and 3 be to achieve more accuracy?

Main Size	Flow Rate	Pressure Drop	"C" Factor	**Min. L Desired**
4	200	4.62	120	**146**
6	400	4.62	120	**292**
8	600	4.62	120	**558**
10	800	4.62	120	**971**
12	1,000	4.62	120	**1,560**
14	1,100	4.62	120	**2,769**
16	1,200	4.62	120	**4,514**
20	1,300	4.62	120	**11,529**
30	2,500	4.62	110	**21,050**
48	2,500	4.62	110	**207,209**
Inches	gpm	(2 psi)		**feet**

Main Size	Flow Rate	Pressure Drop	"C" Factor	**Min. L Desired**
4	300	4.62	120	**69**
6	500	4.62	120	**193**
8	750	4.62	120	**369**
10	1,000	4.62	120	**643**
12	1,100	4.62	120	**1,308**
14	1,200	4.62	120	**2,357**
16	1,300	4.62	120	**3,893**
20	1,500	4.62	120	**8,847**
30	3,000	4.62	110	**15,024**
48	3,000	4.62	110	**147,885**
Inches	gpm	(2 psi)		**feet**

Main Size	Flow Rate	Pressure Drop	"C" Factor	**Min. L Desired**
4	200	4.62	60	**41**
6	400	4.62	60	**81**
8	600	4.62	60	**155**
10	800	4.62	60	**269**
12	1,000	4.62	60	**433**
14	1,100	4.62	60	**768**
16	1,200	4.62	60	**1,252**
20	1,300	4.62	60	**3,198**
30	1,300	4.62	110	**70,576**
48	1,300	4.62	110	**694,707**
Inches	gpm	(2 psi)		**feet**

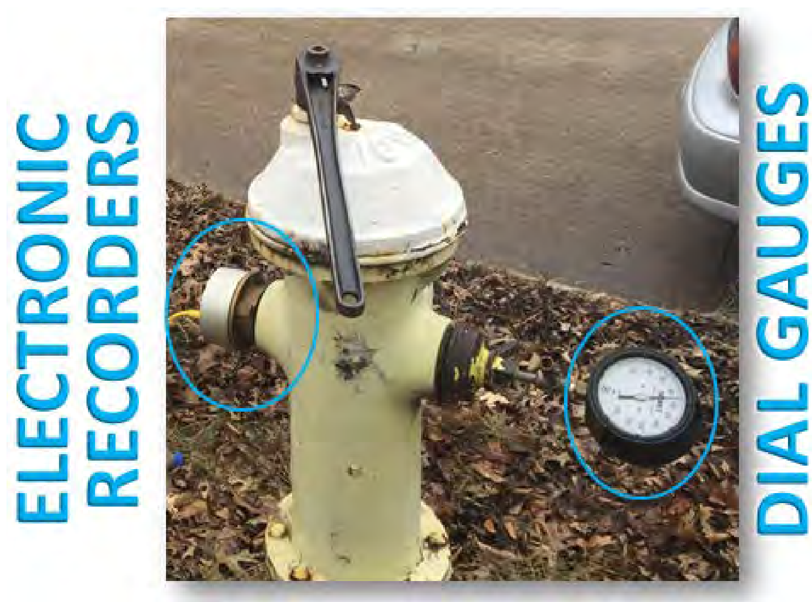
Main Size	Flow Rate	Pressure Drop	"C" Factor	**Min. L Desired**
4	100	4.62	60	**146**
6	250	4.62	60	**193**
8	400	4.62	60	**328**
10	600	4.62	60	**459**
12	800	4.62	60	**654**
14	1,000	4.62	60	**916**
16	1,100	4.62	60	**1,471**
20	1,200	4.62	60	**3,708**
30	1,500	4.62	110	**54,160**
48	1,500	4.62	110	**533,124**
Inches	gpm	(2 psi)		**feet**

A spreadsheet in Excel is programmed with the above calculations and is utilized as input for field data when performing pipe roughness testing in the field.

In addition to calculated C-factors from field test data, any photos or documentation of pipe interior condition, such as those shown in Section 1, can further support the C-factor input for hydraulic model development and/or calibration.

3 TEST EQUIPMENT

A pipe roughness test per the procedure described in Section 4 utilizes pressure measurement to determine a hydrant flow rate and pressure changes between two hydrants of known length. Dial gauges allow for ease of viewing the data whereas electronic gauges more accurately and more frequently measure and record the pressure.



Arcadis maintains dial gauges and electronic recorders. The electronic recorders are predominately utilized for model calibration. In addition to pressure recorders, the apparatus used to measure pitot pressure can be a straight-tube pitot device with varying orifice diameters or a rotatable diffuser with integral pitot assembly.

4 TEST PROCEDURE

A pipe roughness test requires the isolation of a section of water main such that flow is being provided by one direction and one water main. The closing of valves and operation of hydrants is always performed by the system owner, not by Arcadis. The test procedure can be summarized in the following 5 tasks:

1. Preparation
2. Close Valves
3. Install Pressure Recorders
4. Perform Test
5. Documentation

4.1 Preparation

Preparation consists of identifying each test setup – the closed valves and accessible hydrants, evaluating any traffic control needs, confirming test equipment condition and availability, and assigning staffing roles and responsibilities. Test preparation includes preparing maps of each test area prior to entering the field with consideration of safety when selecting test locations.

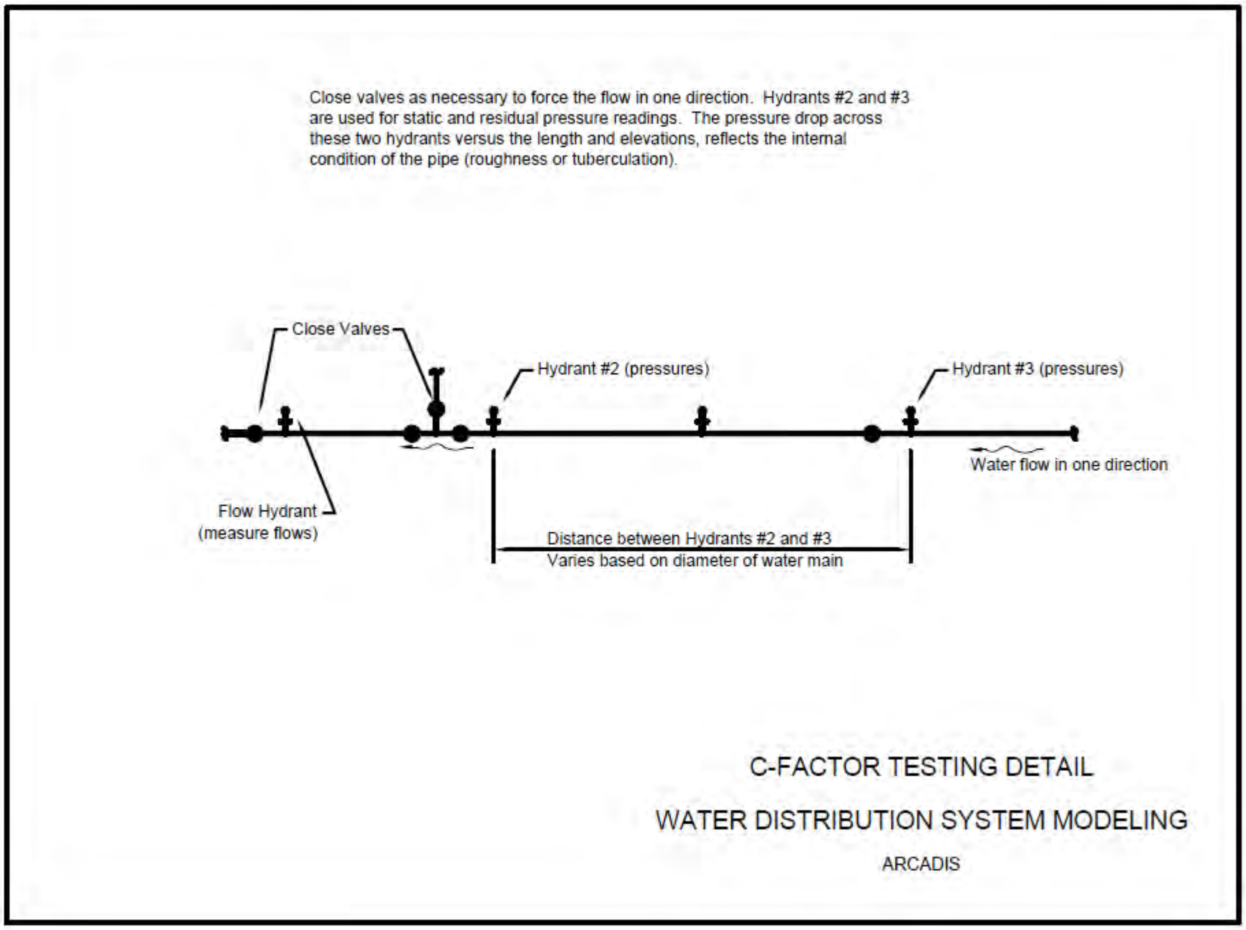
Site selection is a key component of the preparation task. If testing is performed for the purpose of model calibration, tests should be performed on a various areas of the system where conditions may result in changing pipe roughness coefficients. Characteristics to consider when selecting test locations include: Pipe material, pipe install year or age, interior pipe lining, amount of demands along pipe segment, pipe diameter, and presence of any hydraulic restrictions within test area.

4.2 Close Valves

Arcadis will initially identify valves to be closed (if any) to allow for a single flow path to the water main being tested. The identified valves will be confirmed as acceptable by the water distribution system owner and also be closed by the owner. Any changes to the actual valves closes are to be documented for model calibration purposes. If a straight segment of pipe with only one direction of flow source (i.e. a dead end main) exists, then no valves are necessary to be closed.

4.3 Install Pressure Recorders

Hydrant pressure recorders are installed on the hydrants identified in the test setup as shown in the following figure. Hydrants shall always be operated by water distribution system owners and not by Arcadis. Upon arrival to each hydrant, the hydrant should be briefly flushed to remove particulate material within the hydrant barrel so that it doesn't impact pressure sensor measurements. The hydrant pressure recorder must be adequately sealed and other ports of the hydrant also sealed during the test. Slight dripping leakage from other ports has minimal effect on test. Refer to Hydrant Pressure Recorders SOP for additonal procedures and information. Measure the distance between hydrants as shown in the following figure as well when traveling from test to test. Any adaptors required due to special local hydrant thread patterns must be provided by the system owner. All hydrant pressure recorders owned by Arcadis have National Standard Threads.



4.4 Perform Test

With all equipment installed and the system isolated, it is time to perform the flow test. Consider estimated discharge stream of the flowing hydrant and establish proper traffic control. The test begins when the flowing hydrant is opened. Test duration must be sufficient enough for the system hydraulics to equilibrate while flowing and is usually anywhere from 1 minute to 3 minutes of flowing. Continuously evaluate the system hydraulics, expelled water flow path and traffic control and make adjustments as necessary. Abandon the test if the residual pressure nears or falls below 20 psi.

4.5 Documentation

Following completion of the test, record all test information. Notes will include any manual measurements taken, any information on asset condition (such as the manufacture date on the hydrants), record any lessons learned and unusual test conditions. Obtaining photos of the test setup and operation can be useful for test reports as well as a reminder of the test conditions.

5 SUMMARY

Data collected for a pipe roughness test is a key component of hydraulic model calibration. Proper testing, recording all observation and safe conditions are necessary for a successful test. This SOP is to be used as a guide to Arcadis staff who have performed pipe roughness testing and is not all-inclusive of the requirements for a test. Items such as hydrant flow testing and programming of electronic recorders are addressed in other SOPs.

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APPENDIX B

Field Data Reports

City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID: Cfactor Test1
Location: Pettibone Ave
Performed By: BMC & JPC
Date & Time: 5/2/17 4:30 PM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Pettibone Ave & S Grand Traverse St (manual diffuser/pitot)

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Pettibone Ave & Euston St - HPR 206212
Hyd. #3: Pettibone Ave & Brunswick Ave - HPR 206206

TEST INFORMATION

Test Pipe		Elevation		Other	
Distance (ft):	1300	HYD # 1		Orifice Size:	**1 1/8**
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: C-factor testing @ 4:29 PM (normal diffuser low flow, so used manual smaller pitot)
Fireflow Testing @ 4:31 PM (valve opened during test)

ROUGHNESS TEST RESULTS

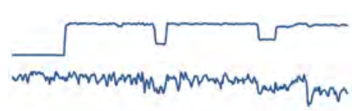
Average Hydrant Flow (gpm)	95
Avg Hyd #2 Pressure (psi)	23.78
Avg Hyd #3 Pressure (psi)	44.51

Fire Flow Test

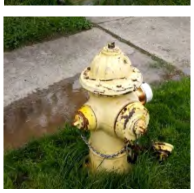
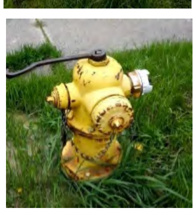
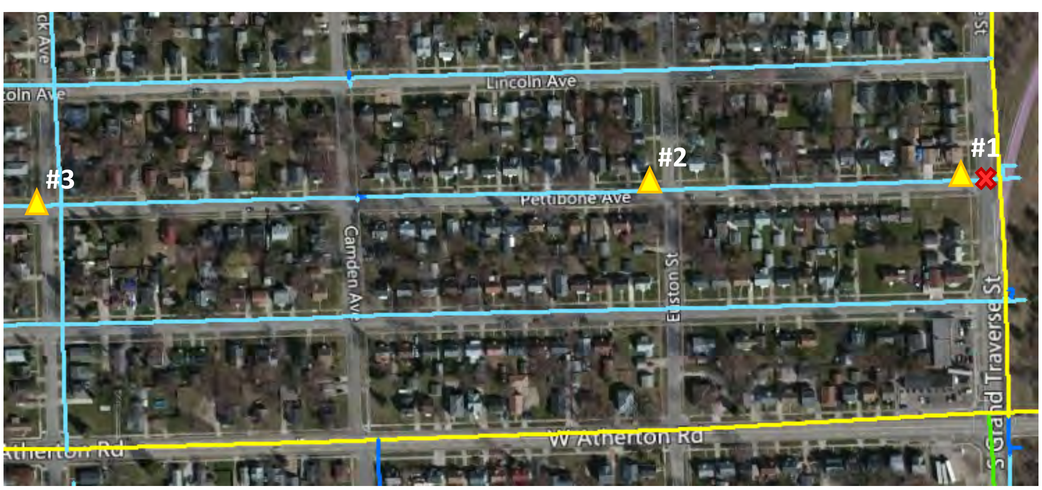
Available Fire Flow (gpm)	536
Static Pressure (psi)	47.0

Calculated C-Value ***17.62***

Hyd 1
Hyd 2
Hyd 3



LOCATION MAP

City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID:	Cfactor Test2	**Performed By:**	BMC & JPC
Location:	Dearborn Ave	**Date & Time:**	5/2/17 5:00 PM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Dearborn Ave & Country Club Ln - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Dearborn Ave between Eldon Baker & Country Club - HPR 206212

Hyd. #3: Dearborn Ave & Algonquin Ave - HPR 206206

TEST INFORMATION

Test Pipe		Elevation		Other	
Distance (ft):	1300	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: C-factor testing @ 5:20 PM

Modified Fireflow Testing @ 5:23 PM (side valves near #2 still closed)

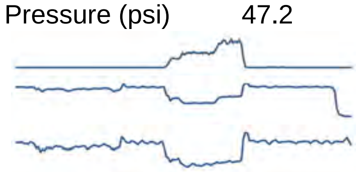
ROUGHNESS TEST RESULTS

Average Hydrant Flow (gpm)	537
Avg Hyd #2 Pressure (psi)	21.36
Avg Hyd #3 Pressure (psi)	33.94

Fire Flow Test

Available Fire Flow (gpm)	969
Static Pressure (psi)	47.2

Hyd 1
Hyd 2
Hyd 3



Calculated C-Value ***117.31***

LOCATION MAP

City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID:	Cfactor Test3	**Performed By:**	BMC & JPC
Location:	Franklin Ave	**Date & Time:**	5/4/17 9:00 AM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Franklin & E. Court St - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Franklin between Calumet & Court - HPR 206212

Hyd. #3: Franklin and Brookside Drive - HPR 206206

TEST INFORMATION

Test Pipe		Elevation		Other	
Distance (ft):	860	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

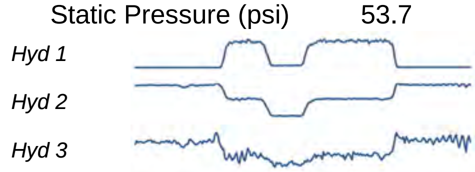
Other Notes: Fireflow testing @ 9:05 (valve opened)

Cfactor testing @ 9:12 (valve closed, then reopened after a minute)

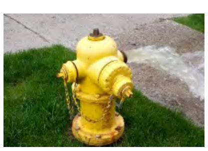
ROUGHNESS TEST RESULTS

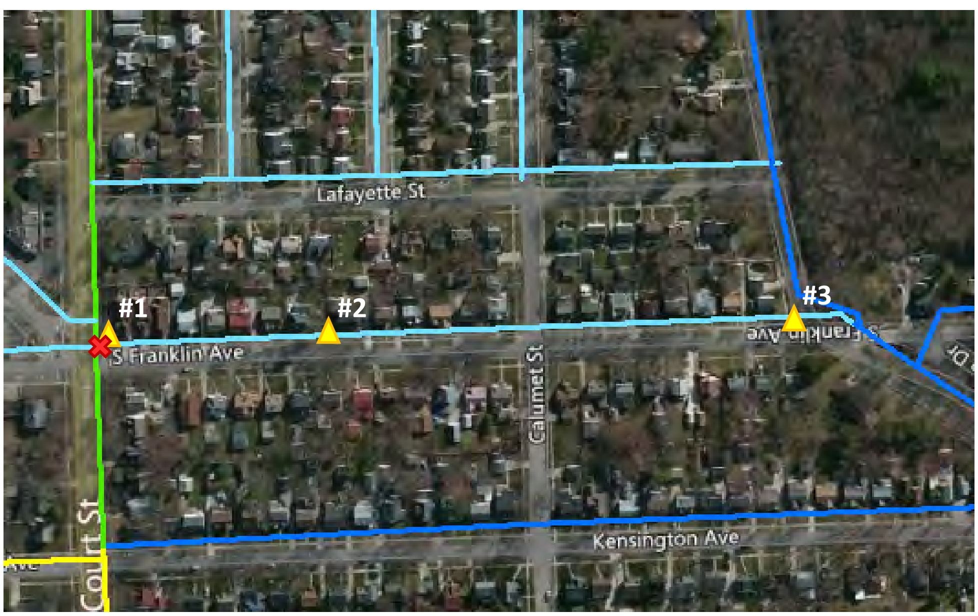
Average Hydrant Flow (gpm)	216	**Fire Flow Test**	
Avg Hyd #2 Pressure (psi)	14.78	Available Fire Flow (gpm)	996
Avg Hyd #3 Pressure (psi)	52.57	Static Pressure (psi)	53.7

Calculated C-Value ***25.33***



LOCATION MAP





City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID: Cfactor Test4
Performed By: BMC & JPC
Location: Arlington Ave
Date & Time: 5/4/17 10:00 AM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Arlington Ave & Deleware Ave - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Arlington Ave & Roseland Ave - HPR 206212
Hyd. #3: Arlington Ave & Broadway - HPR 206206

TEST INFORMATION

Test Pipe		Elevation		Other	
Distance (ft):	1400	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: Fireflow Testing @ 9:58 AM
Could not find valve (burried?) so no Cfactor test

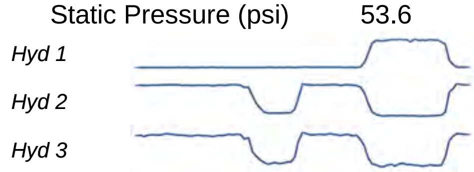
ROUGHNESS TEST RESULTS

Average Hydrant Flow (gpm)	516
Avg Hyd #2 Pressure (psi)	21.25
Avg Hyd #3 Pressure (psi)	45.78

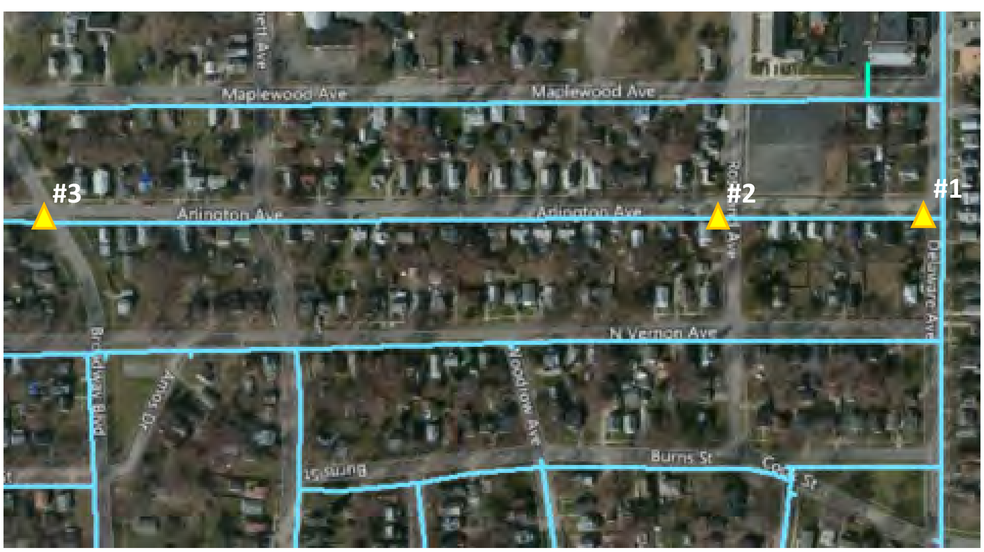
Fire Flow Test

Available Fire Flow (gpm)	527
Static Pressure (psi)	53.6

Available Fireflow ***527*** **(gpm)**



LOCATION MAP



City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID: Cfactor Test5 | **Performed By:** BMC & JPC
Location: Vernon Ave | **Date & Time:** 5/4/17 10:30 AM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Vernon Ave & Deleware Ave - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Vernon Ave & Roseland Ave - HPR 206212
Hyd. #3: Vernon Ave & Woodrow - HPR 206206

TEST INFORMATION

Test Pipe		Elevation		Other	
Distance (ft):	400	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: C-factor testing @ 10:29 AM
Kept valve closed (no FF) because last test was next road over

ROUGHNESS TEST RESULTS

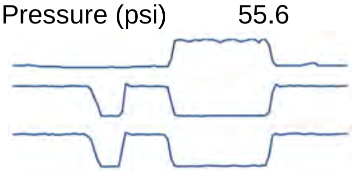
Average Hydrant Flow (gpm)	193
Avg Hyd #2 Pressure (psi)	19.60
Avg Hyd #3 Pressure (psi)	33.33

Fire Flow Test

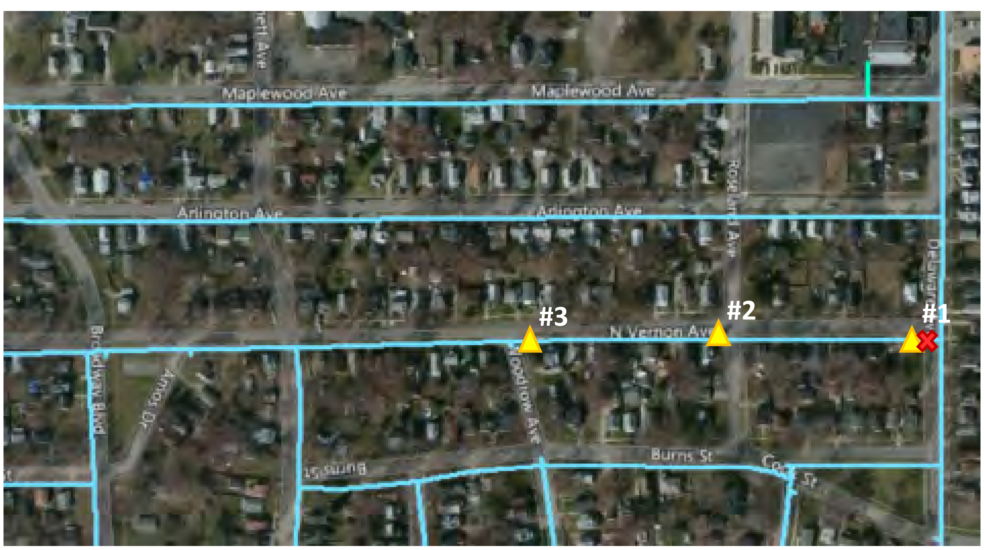
Available Fire Flow (gpm)	N/A
Static Pressure (psi)	55.6

Calculated C-Value ***26.38***

Hyd 1
Hyd 2
Hyd 3



LOCATION MAP



City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID: Cfactor Test6 **Performed By:** BMC & JPC
Location: Marengo Ave **Date & Time:** 5/4/17 11:00 AM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Marengo & Selby St - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Marengo between Selby & Industrial - HPR 206212

Hyd. #3: Marengo between North & Industrial - HPR 206206

TEST INFORMATION

	Test Pipe		Elevation		Other
Distance (ft):	850	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: Fireflow testing @ 11:15 AM

Cfactor testing @ 11:30 AM (had to close 3 surronding valves since closest would not operate)

ROUGHNESS TEST RESULTS

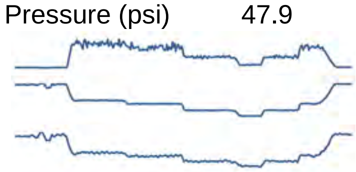
Average Hydrant Flow (gpm)	225
Avg Hyd #2 Pressure (psi)	8.94
Avg Hyd #3 Pressure (psi)	27.42

Fire Flow Test

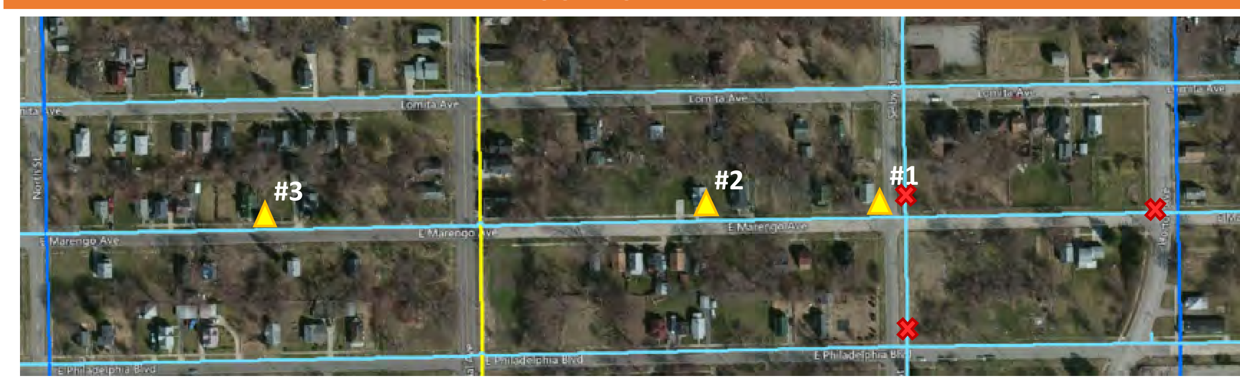
Available Fire Flow (gpm)	775
Static Pressure (psi)	47.9

Calculated C-Value ***30.33***

Hyd 1
Hyd 2
Hyd 3



LOCATION MAP



City of Flint, Michigan
Roughness Coefficient Tests

ARCADIS

Test ID: Cfactor Test1 **Performed By:** BMC & JPC
Location: Yale St **Date & Time:** 5/4/17 12:00 PM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Yale St between Barney & Knapp - HPR 206214

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #2: Yale St & Barney - HPR 206212
Hyd. #3: Yale St & Ballenger HWY - HPR 206206

TEST INFORMATION

	Test Pipe		Elevation		Other
Distance (ft):	830	HYD # 1		Orifice Size:	2 1/2
Diameter (in):	6	HYD # 2		Tank Height:	
Material:		HYD # 3			
Age:					

Other Notes: Fireflow Testing & 12:12 PM
Cfactor testing at 12:17 PM (valve closed during test)

ROUGHNESS TEST RESULTS

Average Hydrant Flow (gpm)	470
Avg Hyd #2 Pressure (psi)	19.26
Avg Hyd #3 Pressure (psi)	26.33

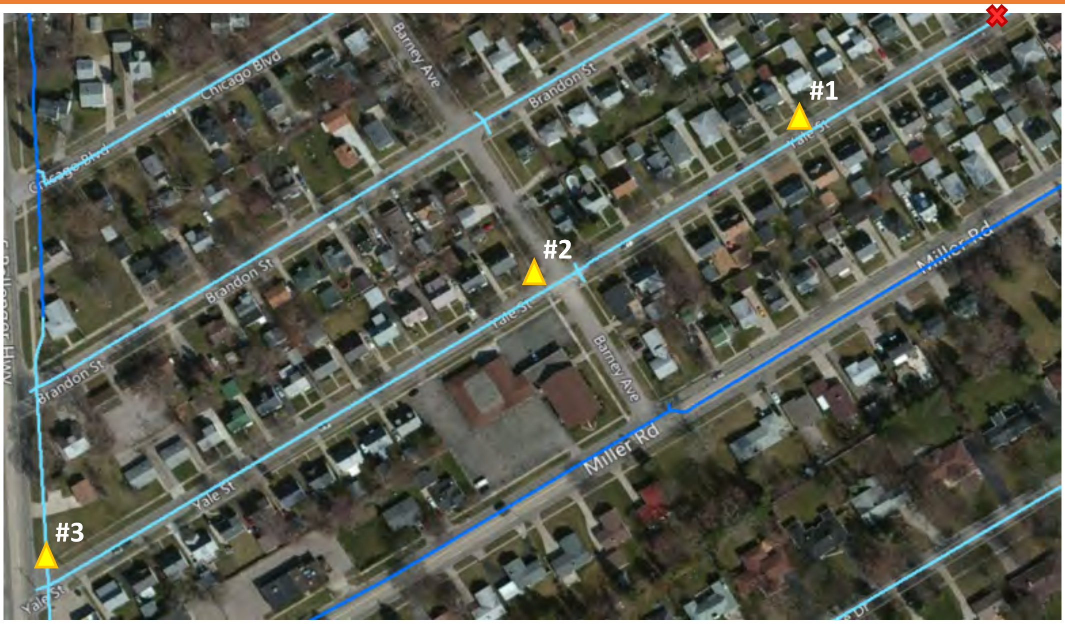
Fire Flow Test

Available Fire Flow (gpm)	851
Static Pressure (psi)	47.3

Calculated C-Value ***109.11***

LOCATION MAP





City of Flint, Michigan
West Side Reservoir Fill Test

ARCADIS

Test ID:	WSR1	**Performed By:**	BMC & JPC
Location:	Iroquois Ave	**Date & Time:**	5/3/17 9:00 AM

FLOWING HYDRANT

Location/Notes: Hyd. #1: Iroquois Ave & Grace St - Two Manual Pitot Difusers
Hyd. #2: Iroquois Ave & Josephine St - Two Manual Pitot Difusers
Hyd. #3: Iroquois Ave & Odette St - HPR 206212

RESIDUAL PRESSURE HYDRANTS

Locations/Notes: Hyd. #4: Iroquois Ave & Witherbee St - HPR 206206

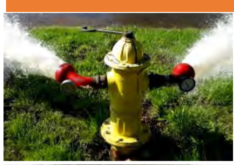
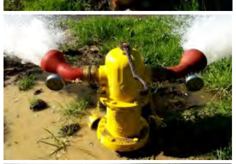
TEST FLOW INFORMATION

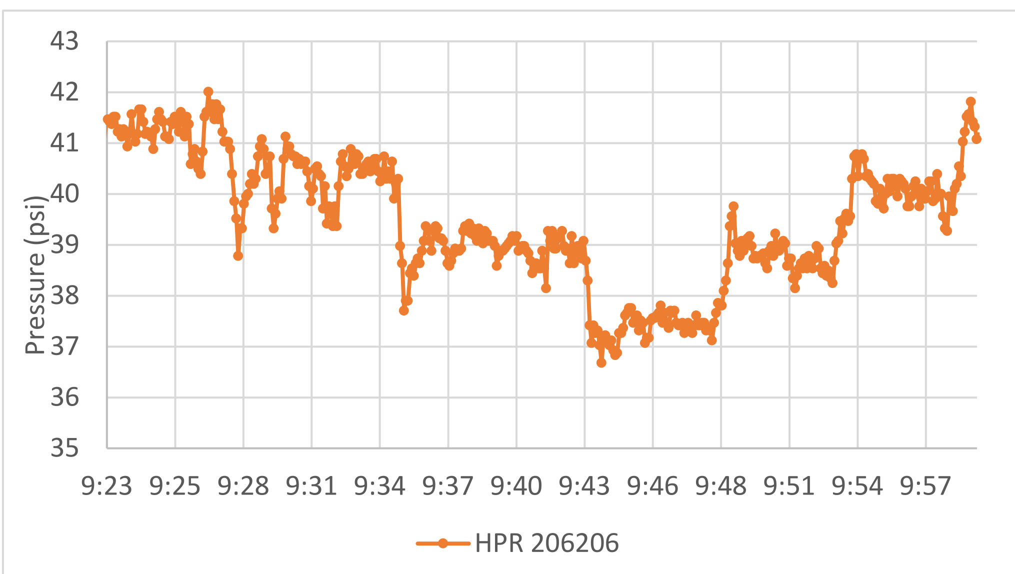
	PSI #1	PSI #2	Total Flow		Orifice Size:
Hyd #1	5	5	667		2 1/2
Hyd #2	6	10	837		
Hyd #3	14.7		571		
			2075	**gpm**	

Pressure Drop
3.86 **psi**

Other Notes: Test to simulate west side reservoir fill cycle and pressure drops
Hydrants Opened from #3 to #2 to #1

RESIDUAL TEST RESULTS

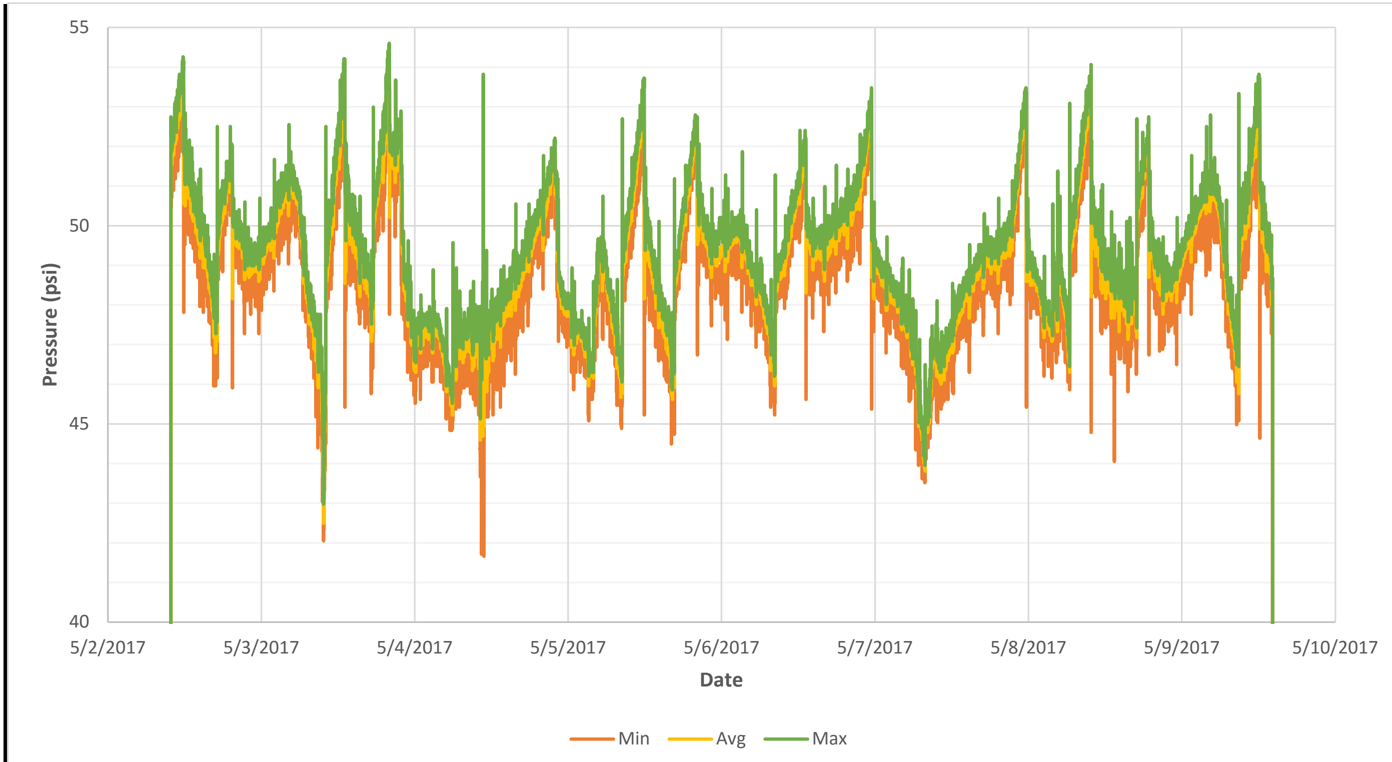





Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC011**	Street Address	
Model Node		Baltimore & Winthrop Blvd	
Hydrant Age	1989		
		Coordinates	
Employee	**BC/JC**		

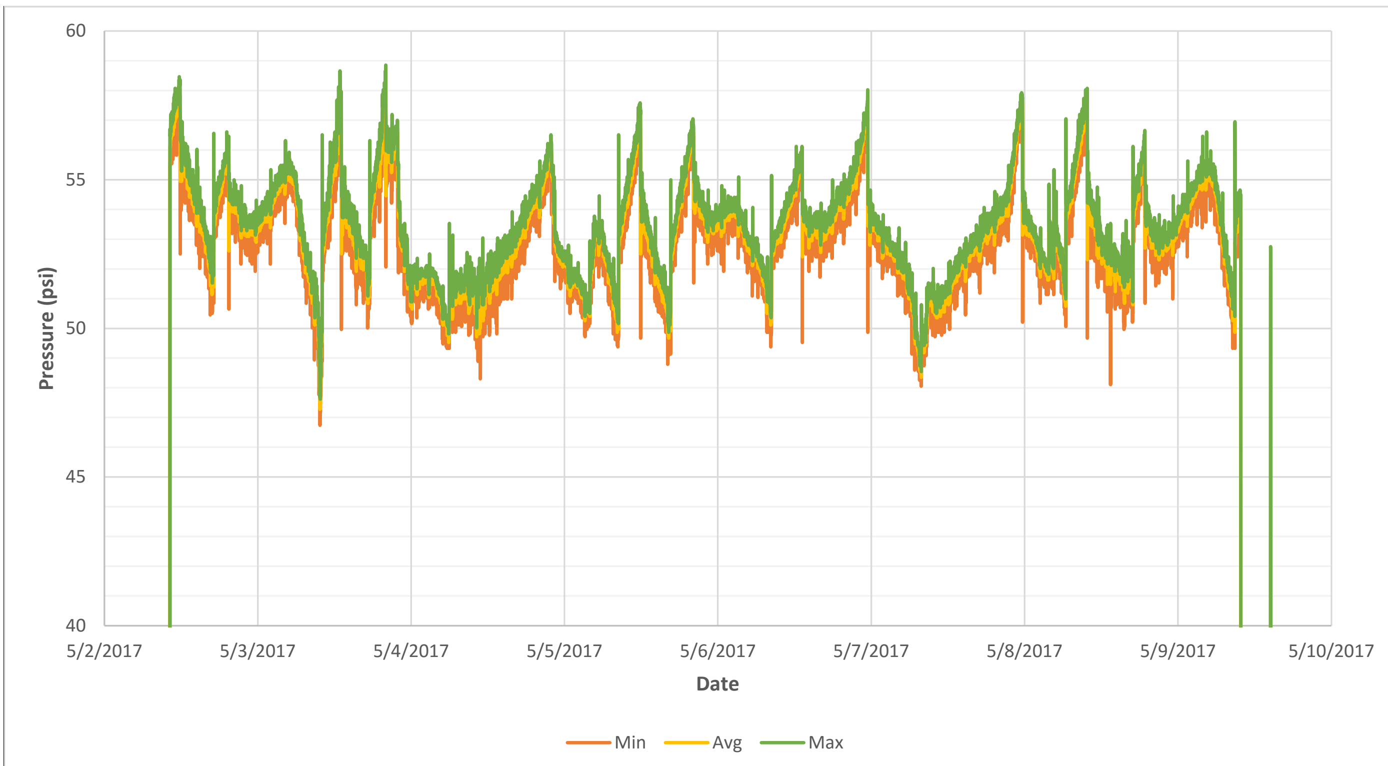
HPR Data		Notes		
Model	HPR-31	Location 14	Install Date/Time	5/2/2017 13:51
HPR ID	**206172**		Install Pressure	**52 psi**
HPR Name	**206172-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC013**	Street Address	
Model Node		Gillespie Ave & North St	
Hydrant Age	-		
		Coordinates	
Employee	**BC/JC**		

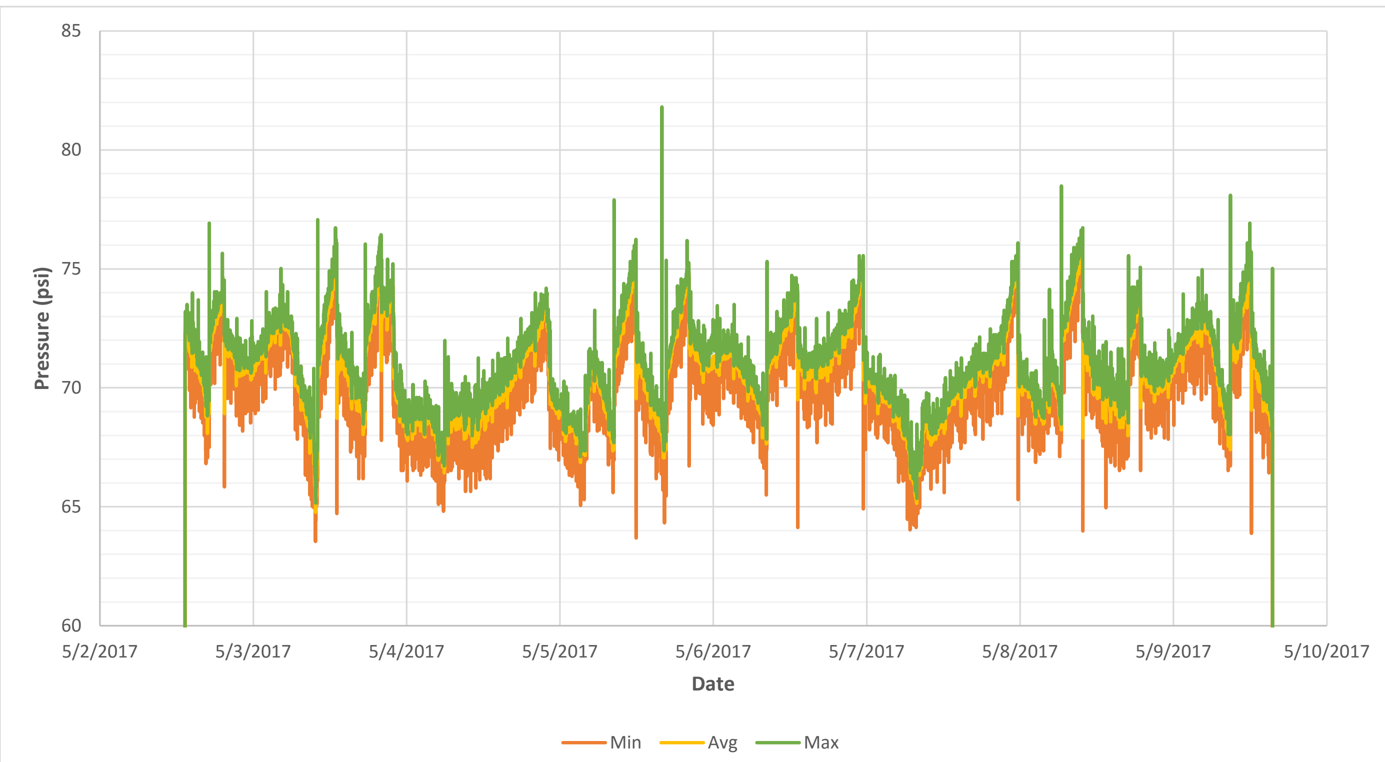
HPR Data		Notes		
Model	HPR-31	Location 21	Install Date/Time	5/2/2017 14:15
HPR ID	**206193**		Install Pressure	**56 psi**
HPR Name	**206193-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC021**	Street Address	
Model Node		Beach St & Kearsley St	
Hydrant Age	2012		
		Coordinates	
Employee	**BC/JC**		

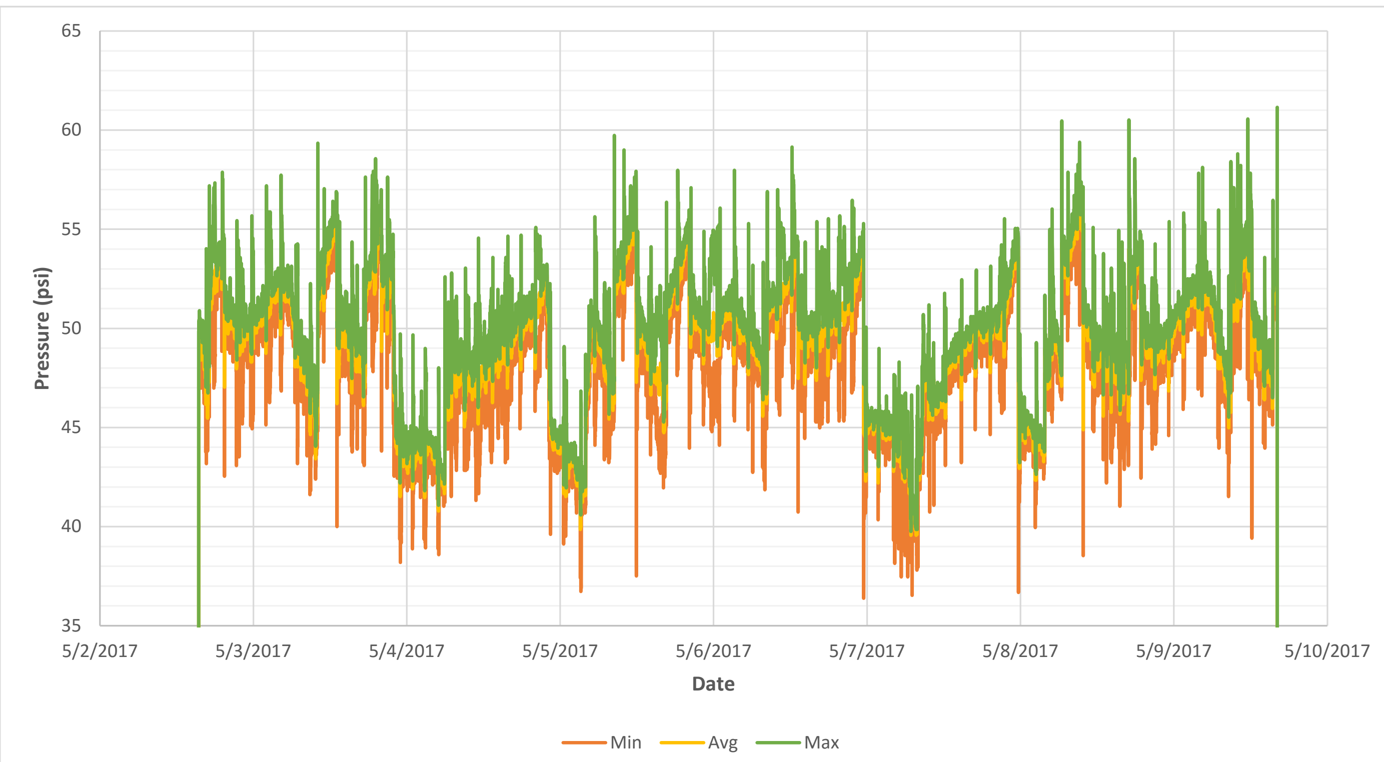
HPR Data		Notes		
Model	HPR-31	Location 10 (moved because original had bad bolts)	Install Date/Time	5/2/2017 17:10
HPR ID	**206194**		Install Pressure	**72 psi**
HPR Name	**206194-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



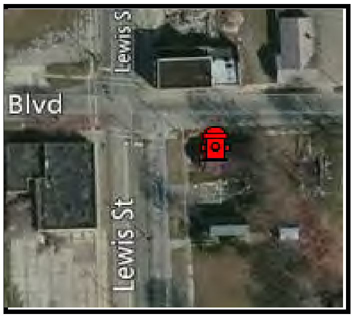
Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC026**	Street Address	
Model Node		Atherton Rd & Tuxedo Ave	
Hydrant Age	-		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 26	Install Date/Time	5/2/2017 19:26
HPR ID	**206195**		Install Pressure	**50 psi**
HPR Name	**206195-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			

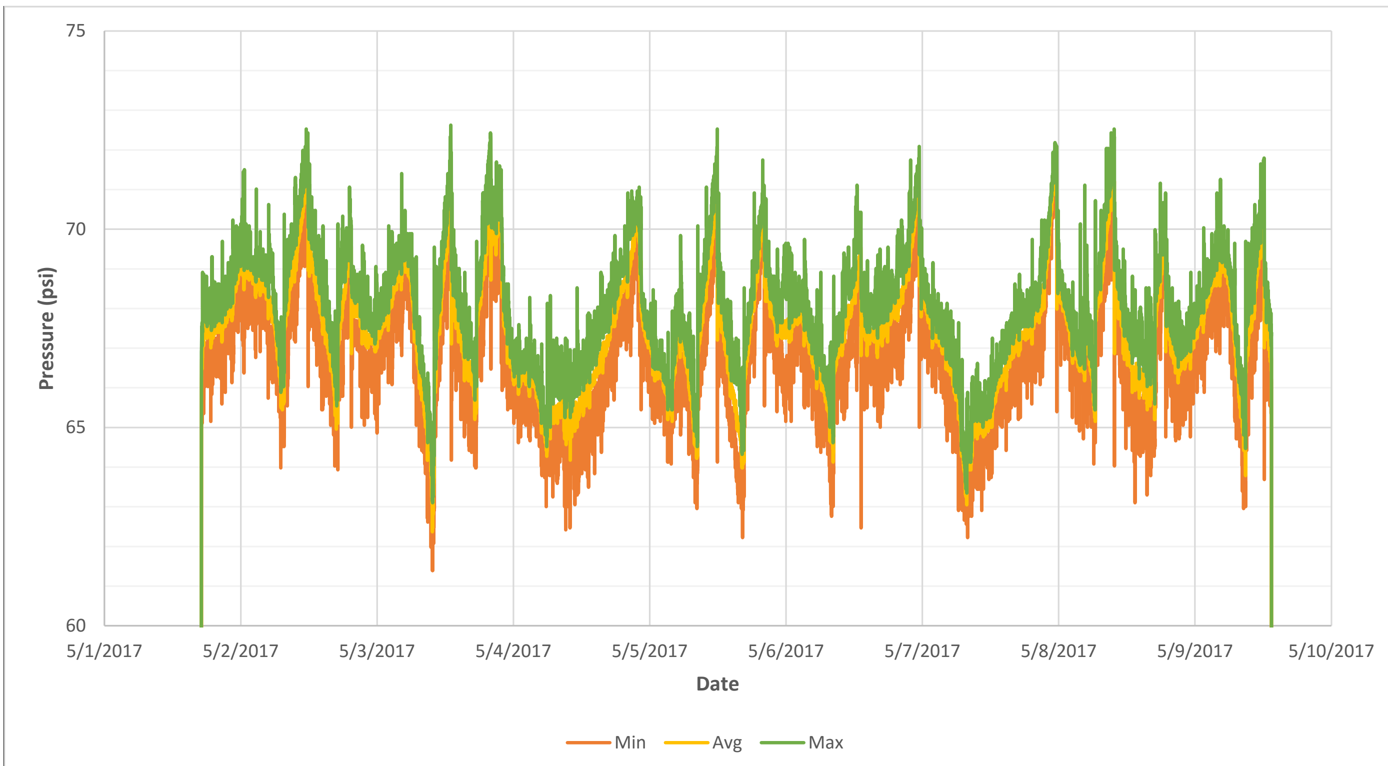


Hydrant Pressure Recorder Field Log



Location		Client #	20616
Site Name	ARC003	Street Address	
Model Node		Broadway Blvd & Lewis St	
Hydrant Age	1908		
		Coordinates	
Employee	BC/JC		

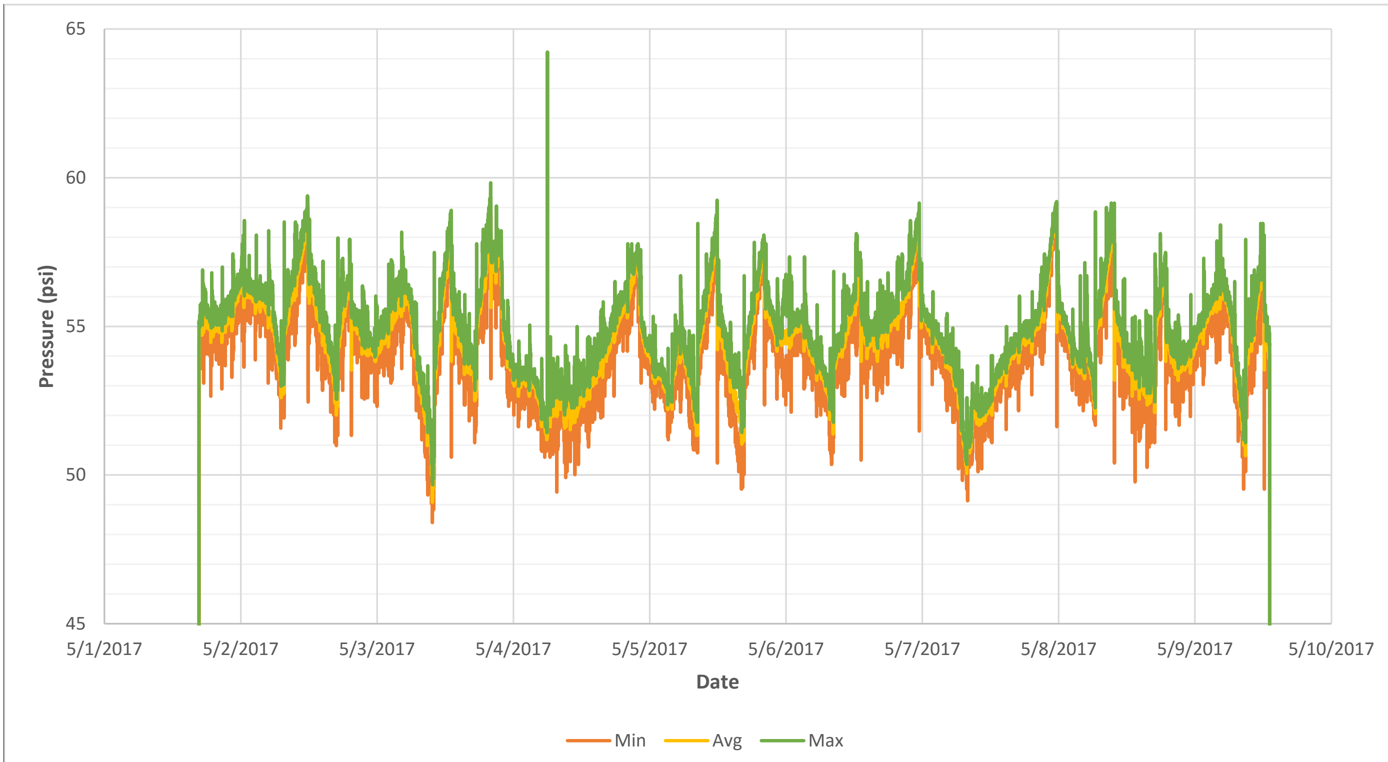
HPR Data		Notes		
Model	HPR-31	Location 4	Install Date/Time	5/1/2017 21:04
HPR ID	206196		Install Pressure	67 psi
HPR Name	206196-200		Remove Date/Time	5/9/2017
Capacity			Remove Presure	-
Sample Rate	5 seconds		Local FD Notified?	Yes
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC001**	Street Address	
Model Node		Dort & Robert Longway	
Hydrant Age	2009		
		Coordinates	
Employee	**BC/JC**		

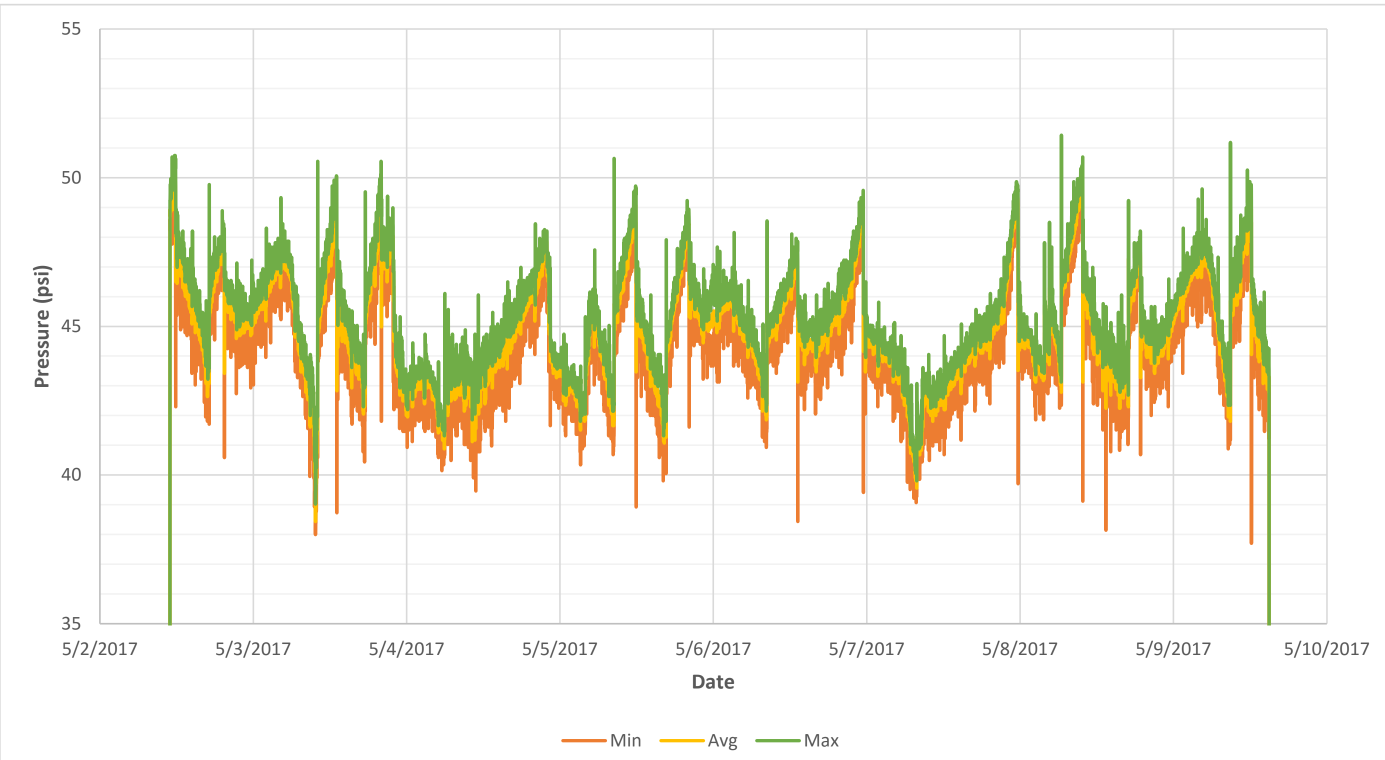
HPR Data		Notes		
Model	HPR-31	Location 6	Install Date/Time	5/1/2017 20:39
HPR ID	**206197**		Install Pressure	**55 psi**
HPR Name	**206197-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC017**	Street Address	
Model Node		Ballenger Hwy & Mallery St	
Hydrant Age	1999		
		Coordinates	
Employee	**BC/JC**		

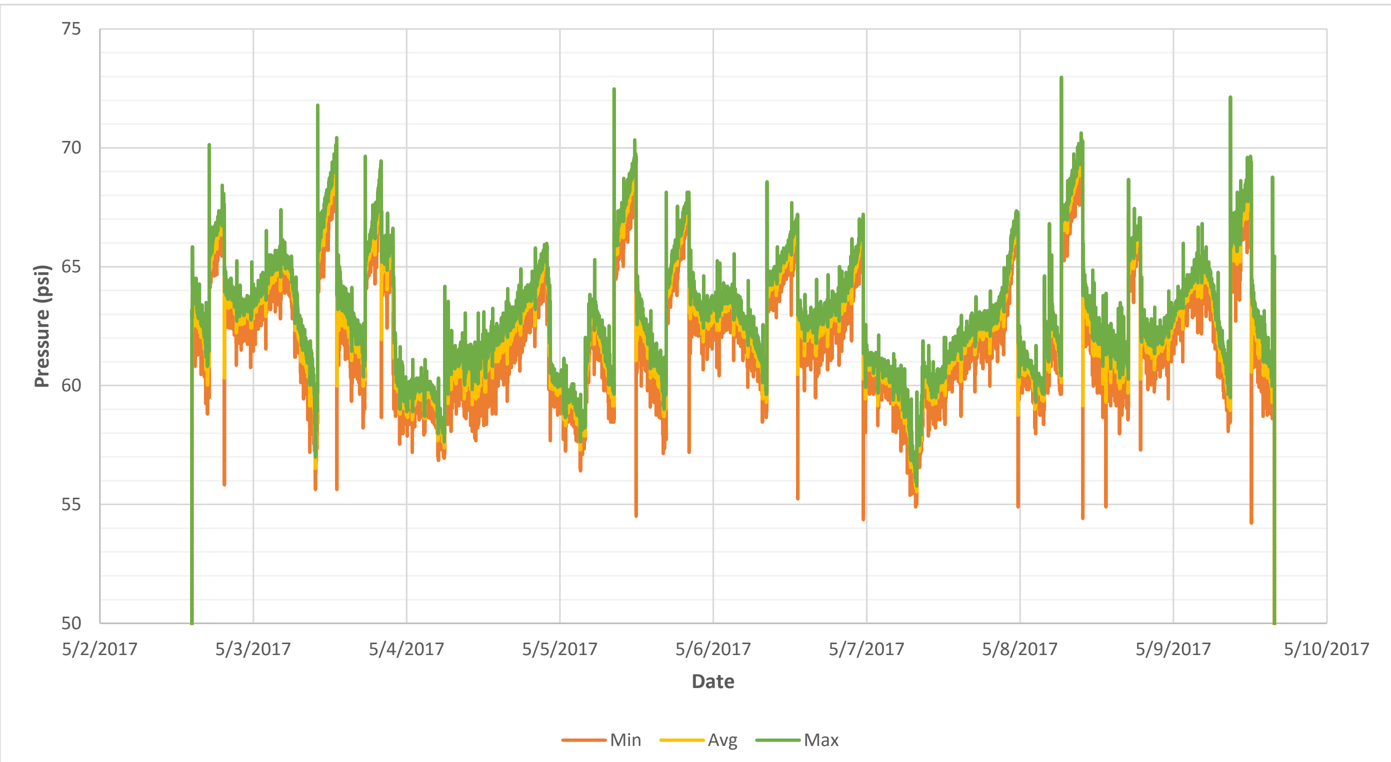
HPR Data		Notes		
Model	HPR-31	Location 23	Install Date/Time	5/2/2017 14:57
HPR ID	**206198**		Install Pressure	**48 psi**
HPR Name	**206198-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



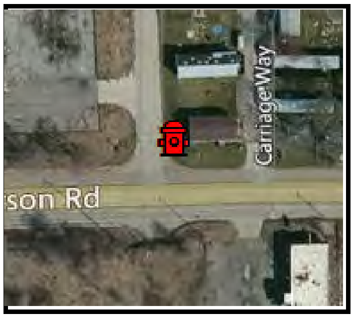
Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC023**	Street Address	
Model Node		Glenwood & Fox	
Hydrant Age	2010		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 19 (construction and changes forced move)	Install Date/Time	5/2/2017 18:23
HPR ID	**206199**		Install Pressure	**62 psi**
HPR Name	**206199-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			

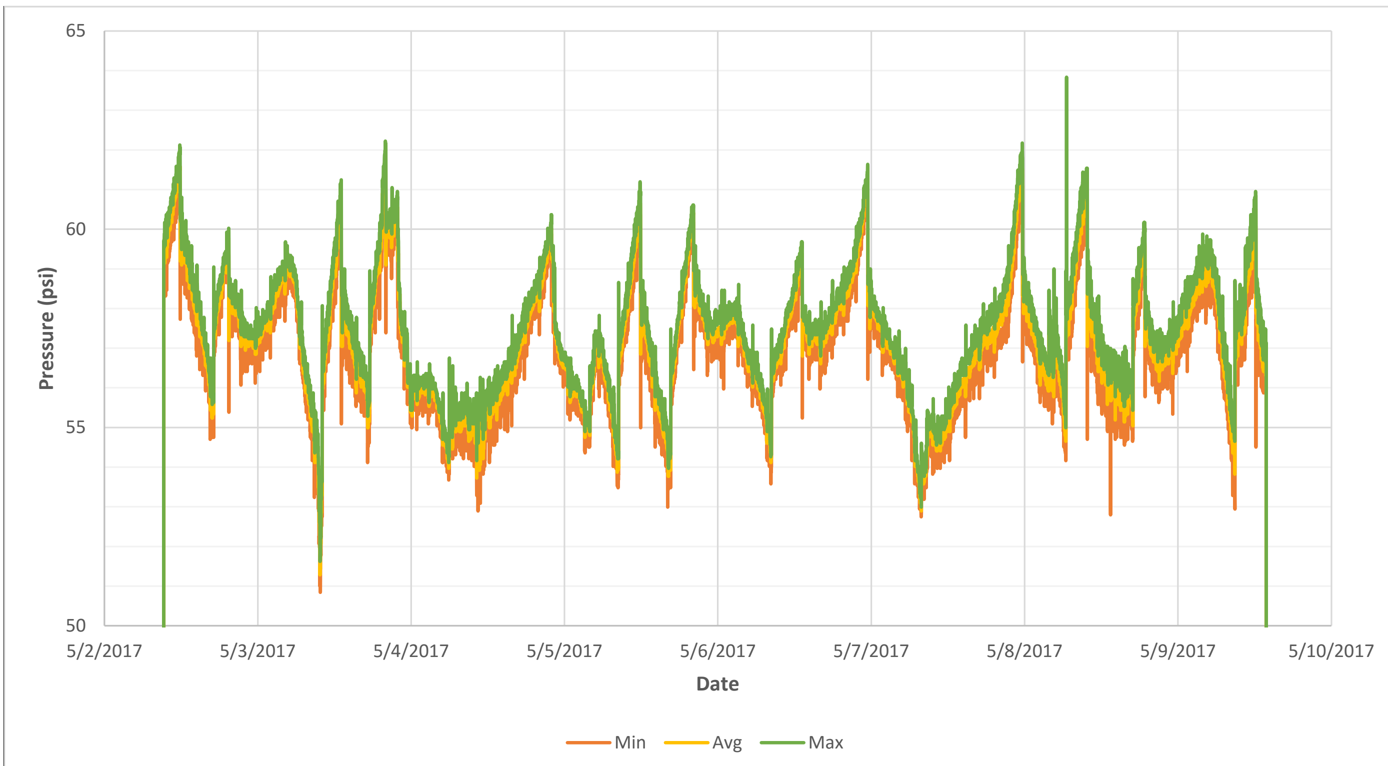


Hydrant Pressure Recorder Field Log



Location		Client #	20616
Site Name	ARC007	Street Address	
Model Node		Piersons Rd & Thetford Rd	
Hydrant Age	1976		
		Coordinates	
Employee	BC/JC		

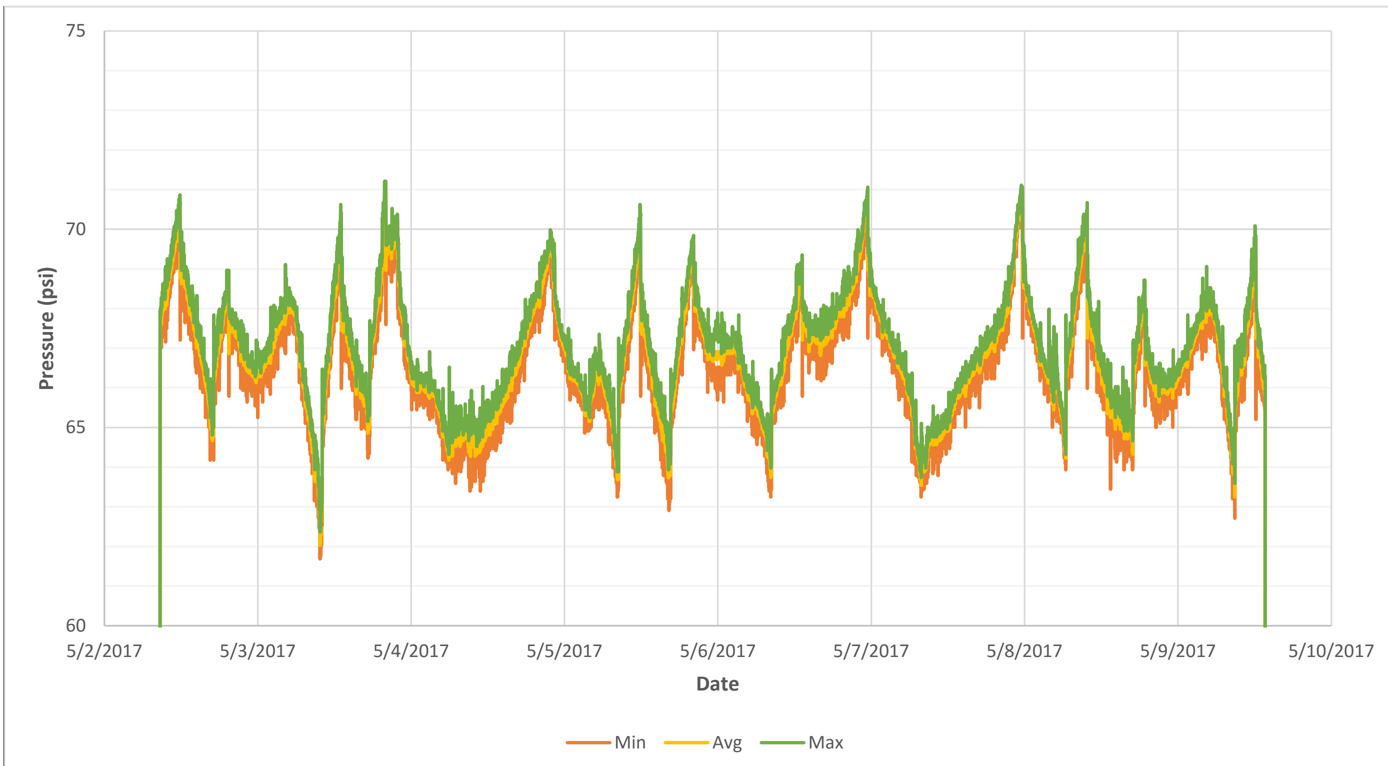
HPR Data		Notes	
Model	HPR-31	Location 12	
		Install Date/Time	5/2/2017 13:17
HPR ID	206201	Install Pressure	60 psi
HPR Name	206201-200	Remove Date/Time	5/9/2017
Capacity		Remove Presure	-
Sample Rate	5 seconds	Local FD Notified?	Yes
Recording Interval	1 minute		



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC005**	Street Address	
Model Node		Utah & Minnesota Ave	
Hydrant Age	1908		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 3	Install Date/Time	5/2/2017 12:42
HPR ID	**206202**		Install Pressure	**67 psi**
HPR Name	**206202-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

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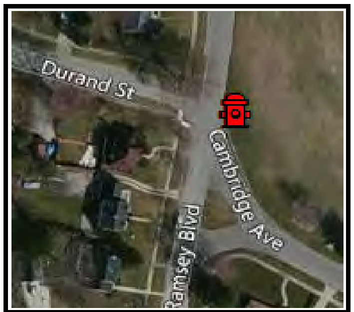
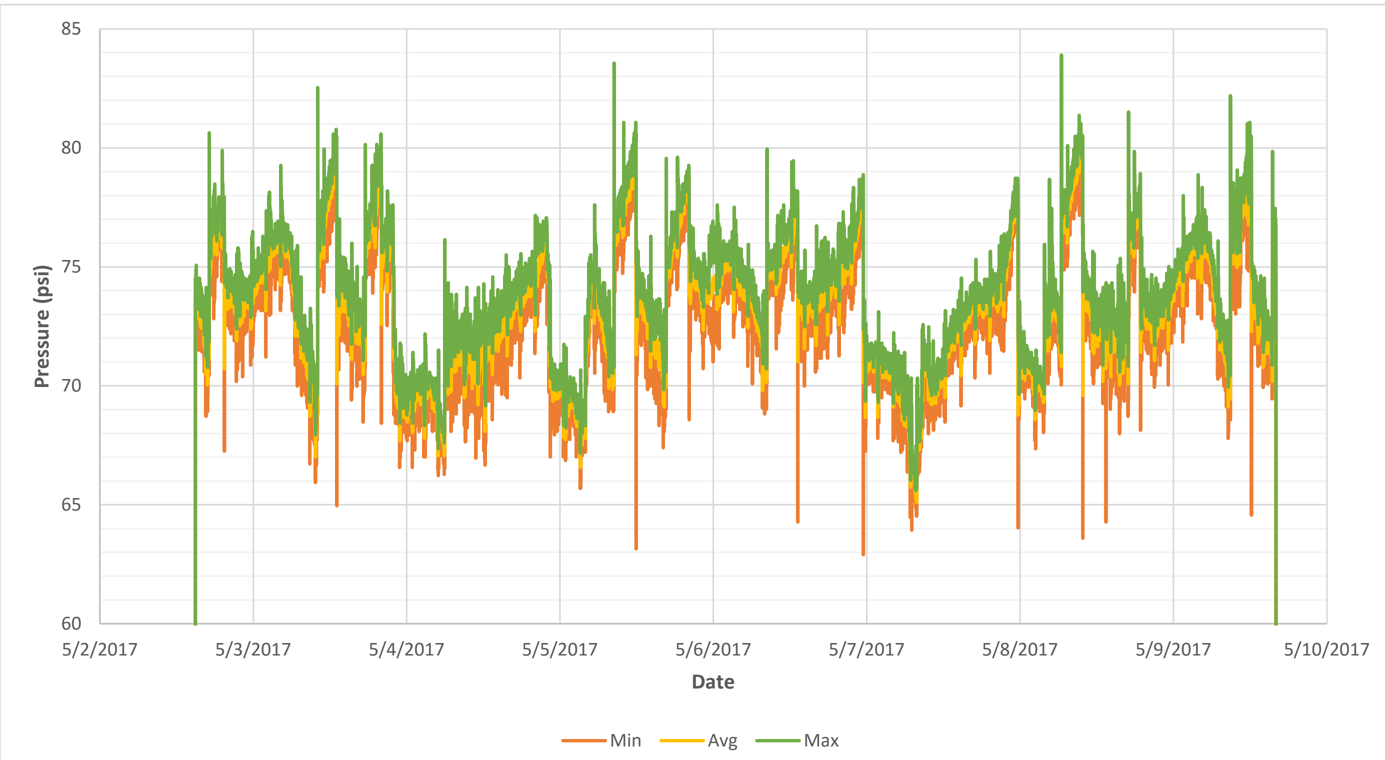


Location		Client #	20616
Site Name	**ARC025**	Street Address	
Model Node		Durand St & Ramsay Blvd	
Hydrant Age	1924		
		Coordinates	
Employee	**BC/JC**		

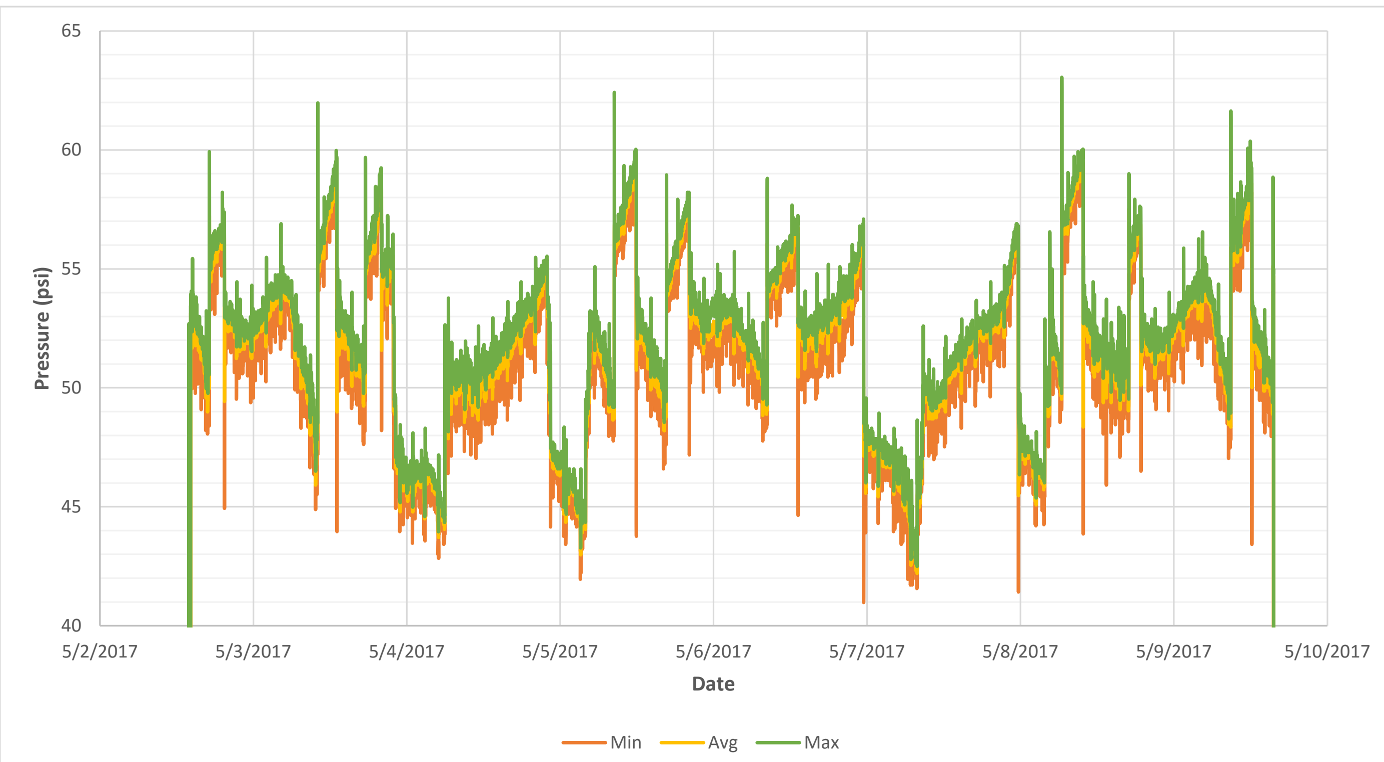
HPR Data		Notes		
Model	HPR-31	Location 17 (moved closer to ps)	Install Date/Time	5/2/2017 18:56
HPR ID	**206207**		Install Pressure	**74 psi**
HPR Name	**206207-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC022**	Street Address	
Model Node		Oak St (dead end)	
Hydrant Age	1947		
		Coordinates	
Employee	**BC/JC**		

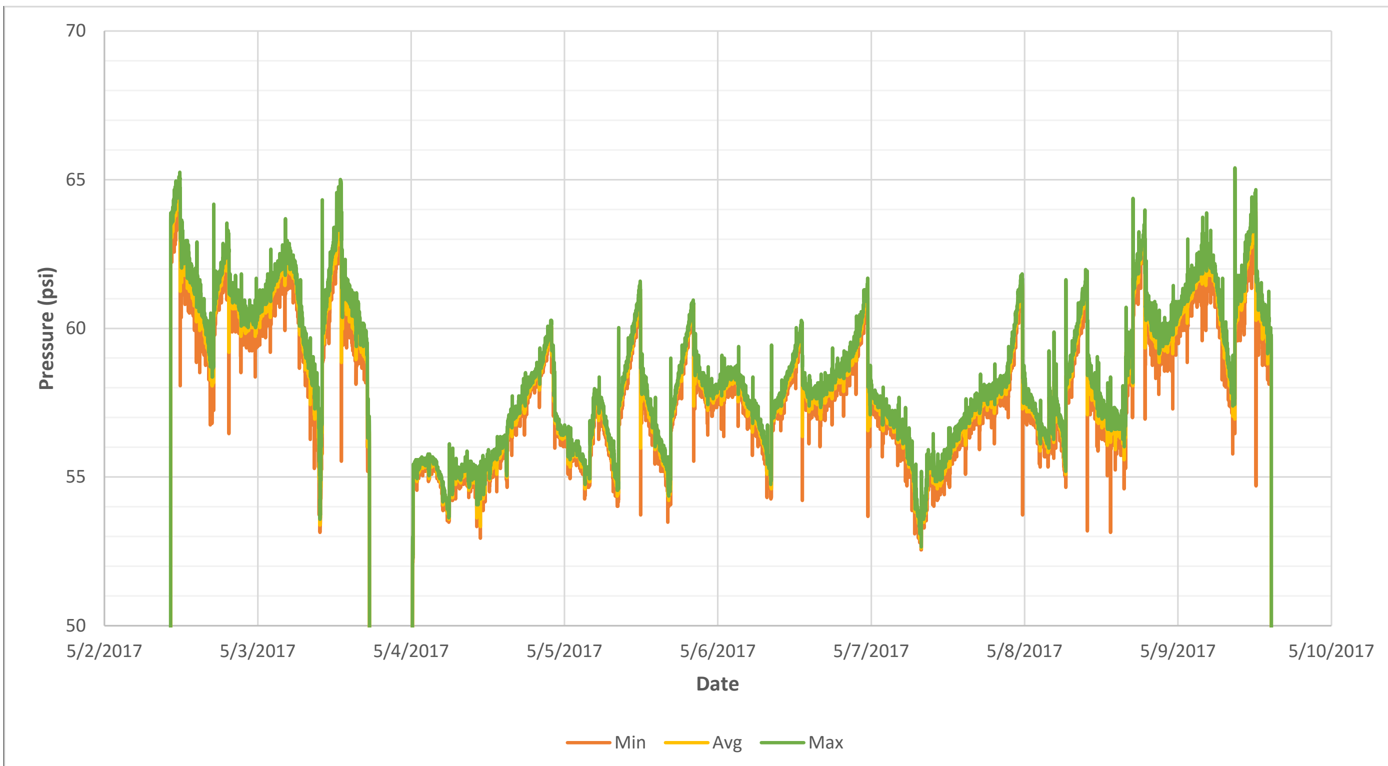
HPR Data		Notes		
Model	HPR-31	Location 8 (could not find original)	Install Date/Time	5/2/2017 17:50
HPR ID	**206208**		Install Pressure	**52 psi**
HPR Name	**206208-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location			
Site Name	**ARC014**	Client #	**20616**
Model Node		Street Address	
Hydrant Age	1937	Lieth & North St	
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 15	Install Date/Time	5/2/2017 14:22
HPR ID	**206209**		Install Pressure	**63 psi**
HPR Name	**206209-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

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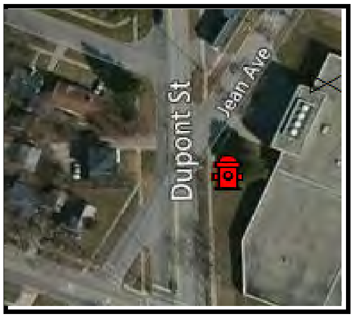
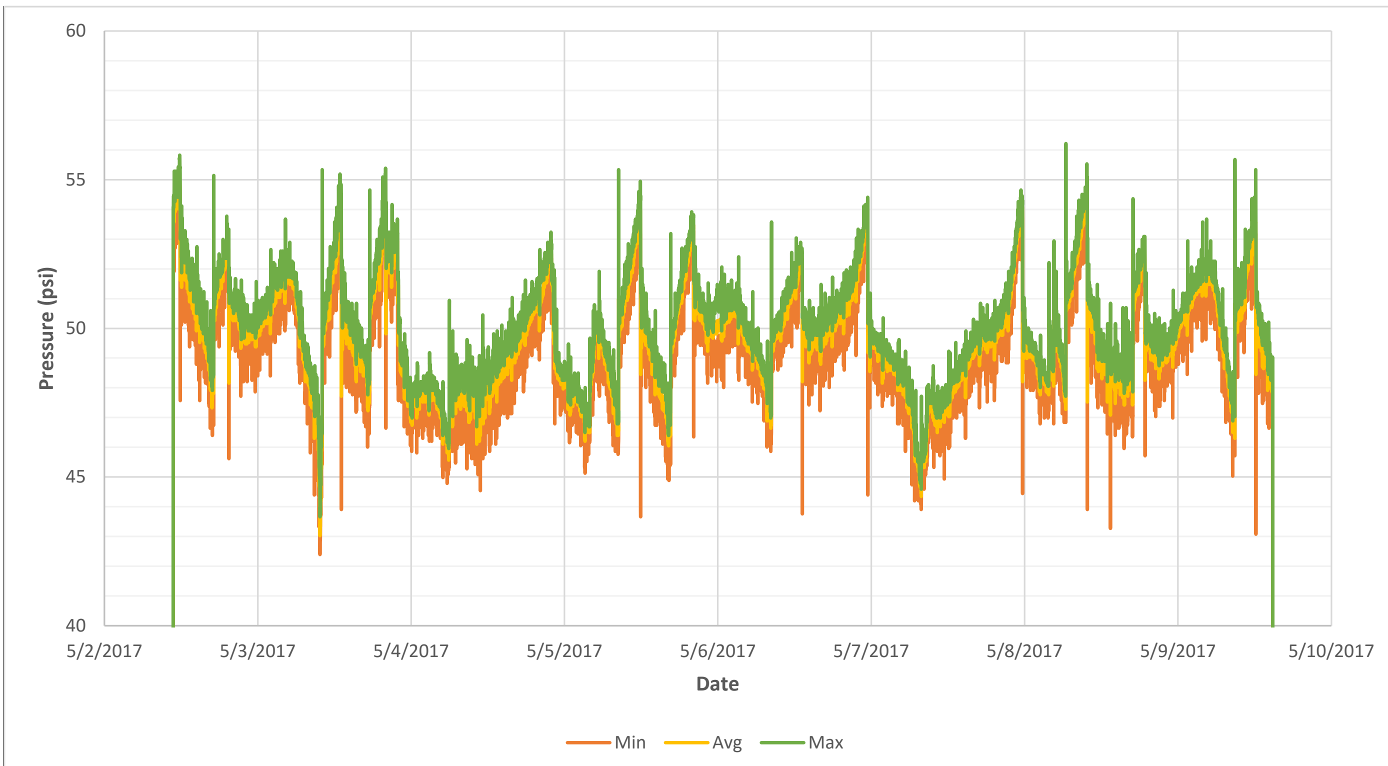


Location		Client #	20616
Site Name	**ARC016**	Street Address	
Model Node		Dupont St & Jean Ave	
Hydrant Age	1970		
		Coordinates	
Employee	**BC/JC**		

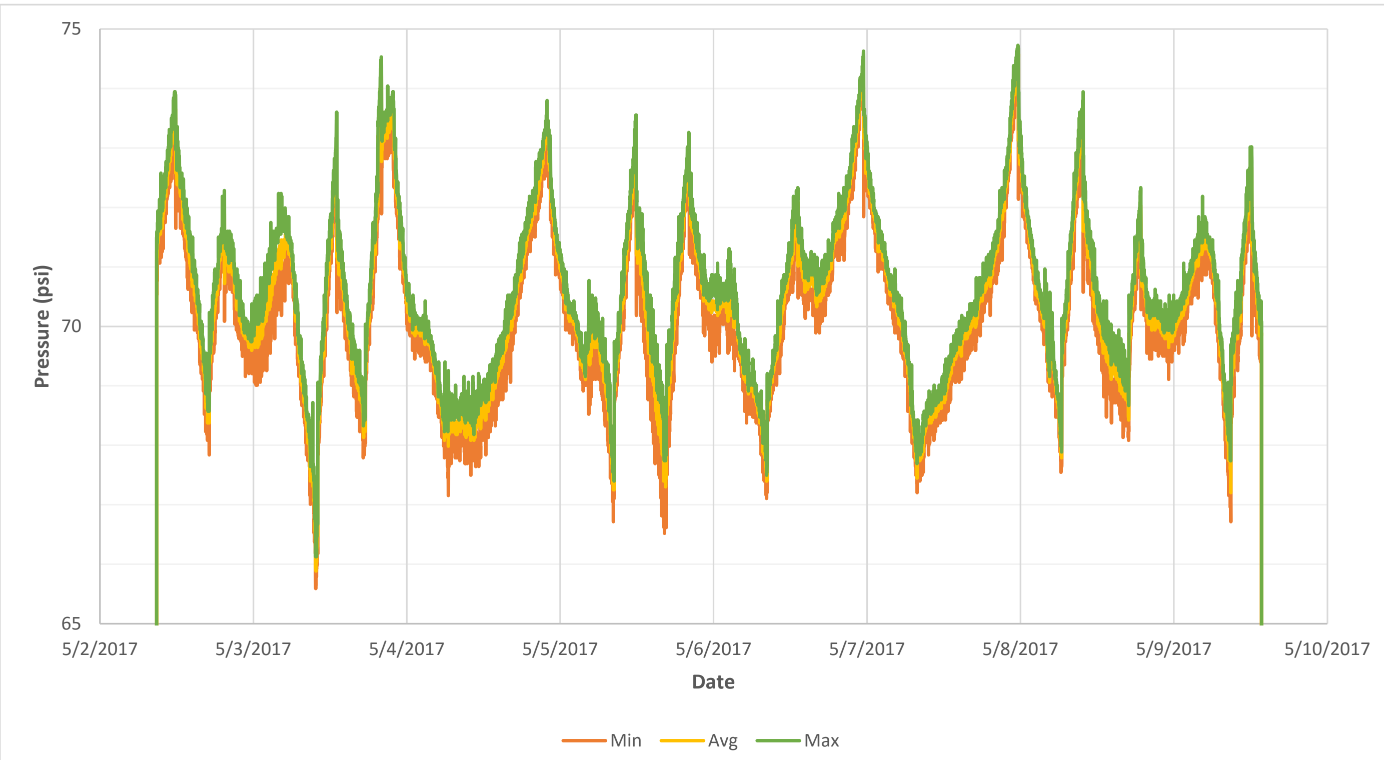
HPR Data		Notes		
Model	HPR-31	Location 16	Install Date/Time	5/2/2017 14:46
HPR ID	**206210**		Install Pressure	**53 psi**
HPR Name	**206210-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	ARC006	Street Address	
Model Node		N Dort Hwy & Franklin Ave	
Hydrant Age	-		
		Coordinates	
Employee	BC/JC		

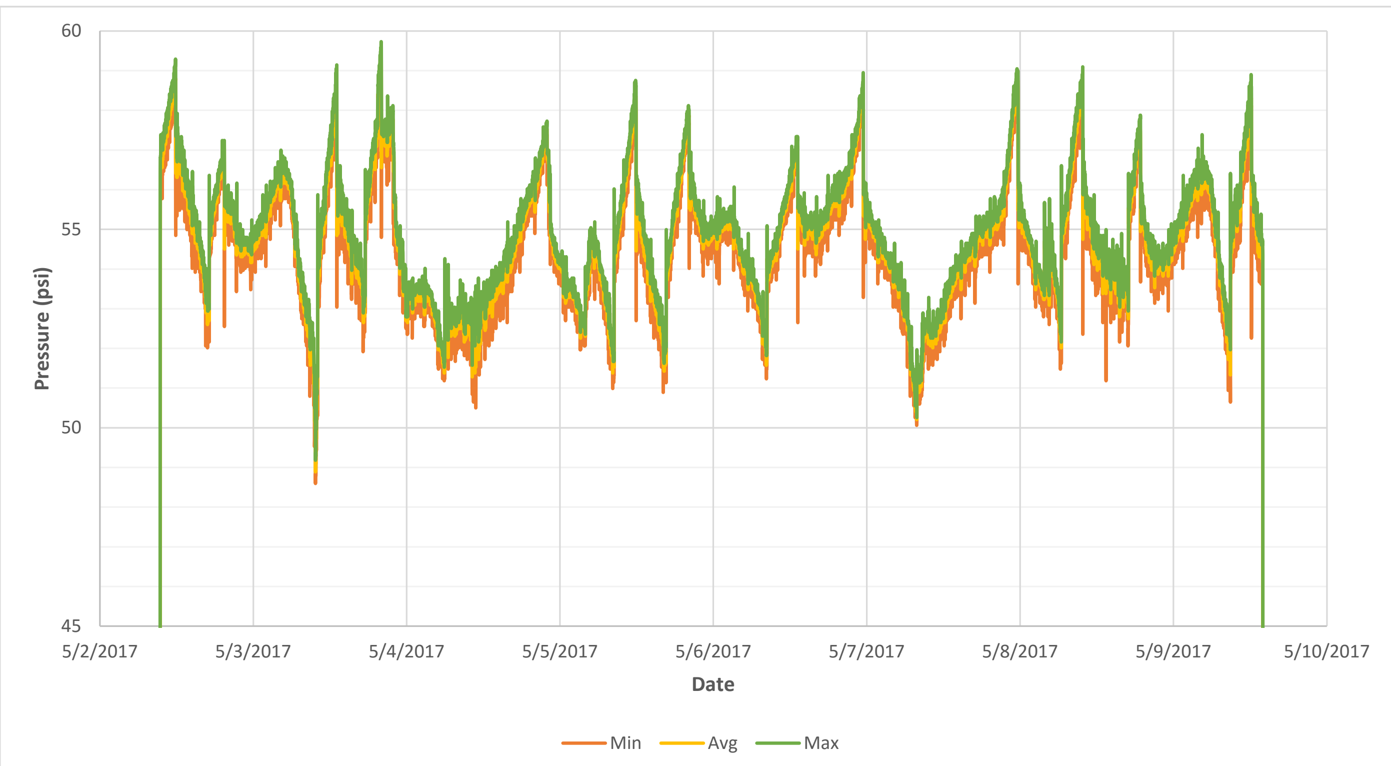
HPR Data		Notes		
Model	HPR-31	Location 2	Install Date/Time	5/2/2017 12:51
HPR ID	206211		Install Pressure	71 psi
HPR Name	206211-200		Remove Date/Time	5/9/2017
Capacity			Remove Presure	-
Sample Rate	5 seconds		Local FD Notified?	Yes
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC008**	Street Address	
Model Node		E Stewart Ave & James P Cole	
Hydrant Age	1978	Blvd	
		Coordinates	
Employee	**BC/JC**		

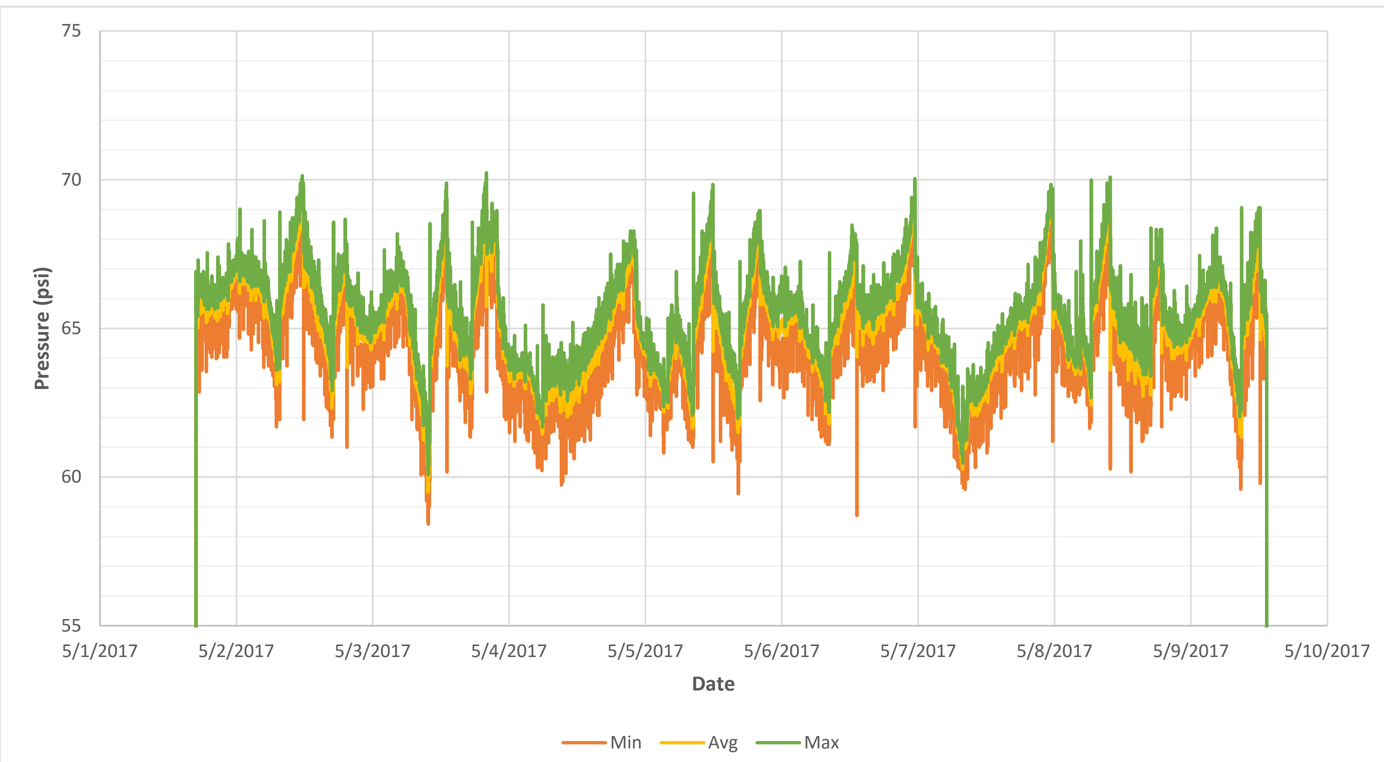
HPR Data		Notes		
Model	HPR-31	Location 11	Install Date/Time	5/2/2017 13:26
HPR ID	**206213**		Install Pressure	**56 psi**
HPR Name	**206213-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	ARC002	Street Address	
Model Node		Poblar & Kearsly Park	
Hydrant Age	1995		
		Coordinates	
Employee	BC/JC		

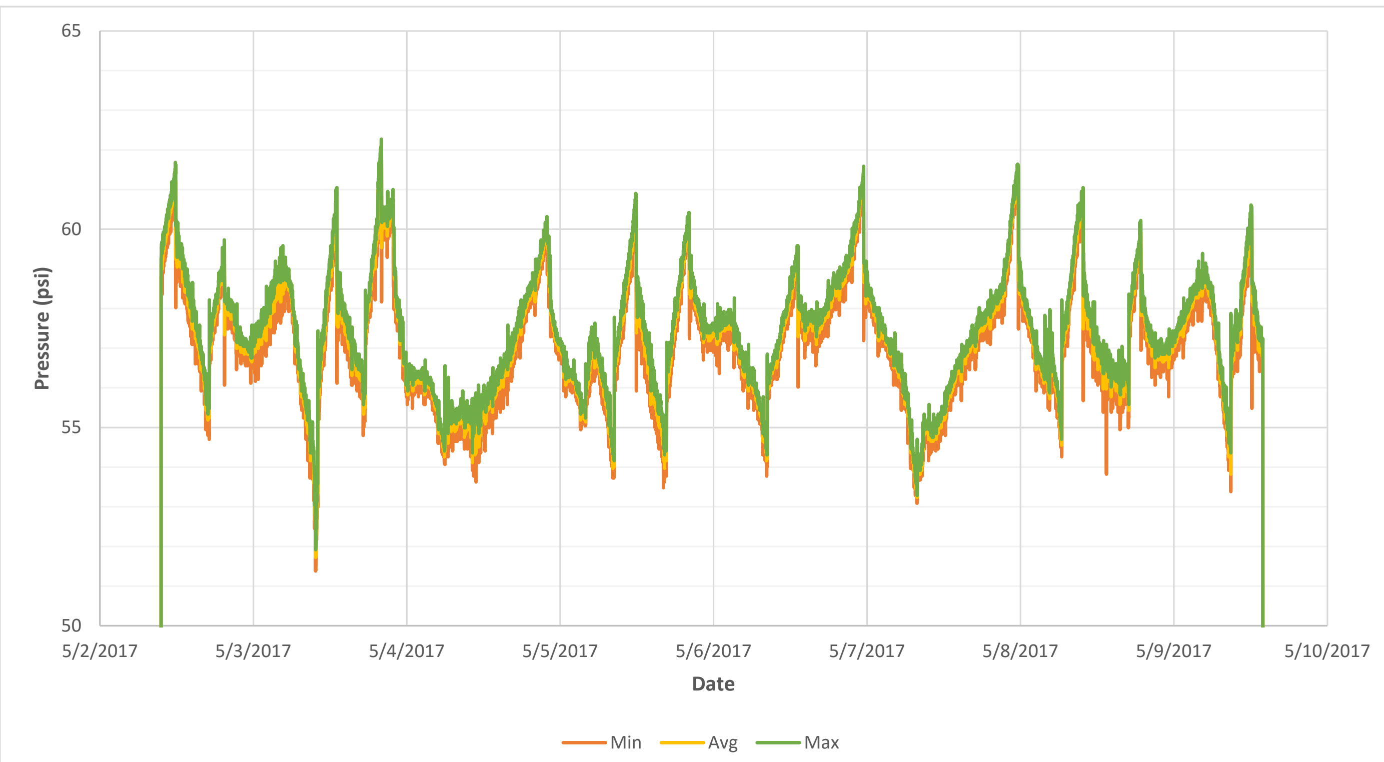
HPR Data		Notes		
Model	HPR-31	Location 5	Install Date/Time	5/1/2017 20:54
HPR ID	206215		Install Pressure	65 psi
HPR Name	206215-200		Remove Date/Time	5/9/2017
Capacity			Remove Presure	-
Sample Rate	5 seconds		Local FD Notified?	Yes
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC009**	Street Address	
Model Node		1401 E Stewart St (Parking Lot)	
Hydrant Age	2015		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 1 (original would not thread)	Install Date/Time	5/2/2017 13:34
HPR ID	**206216**		Install Pressure	**59 psi**
HPR Name	**206216-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

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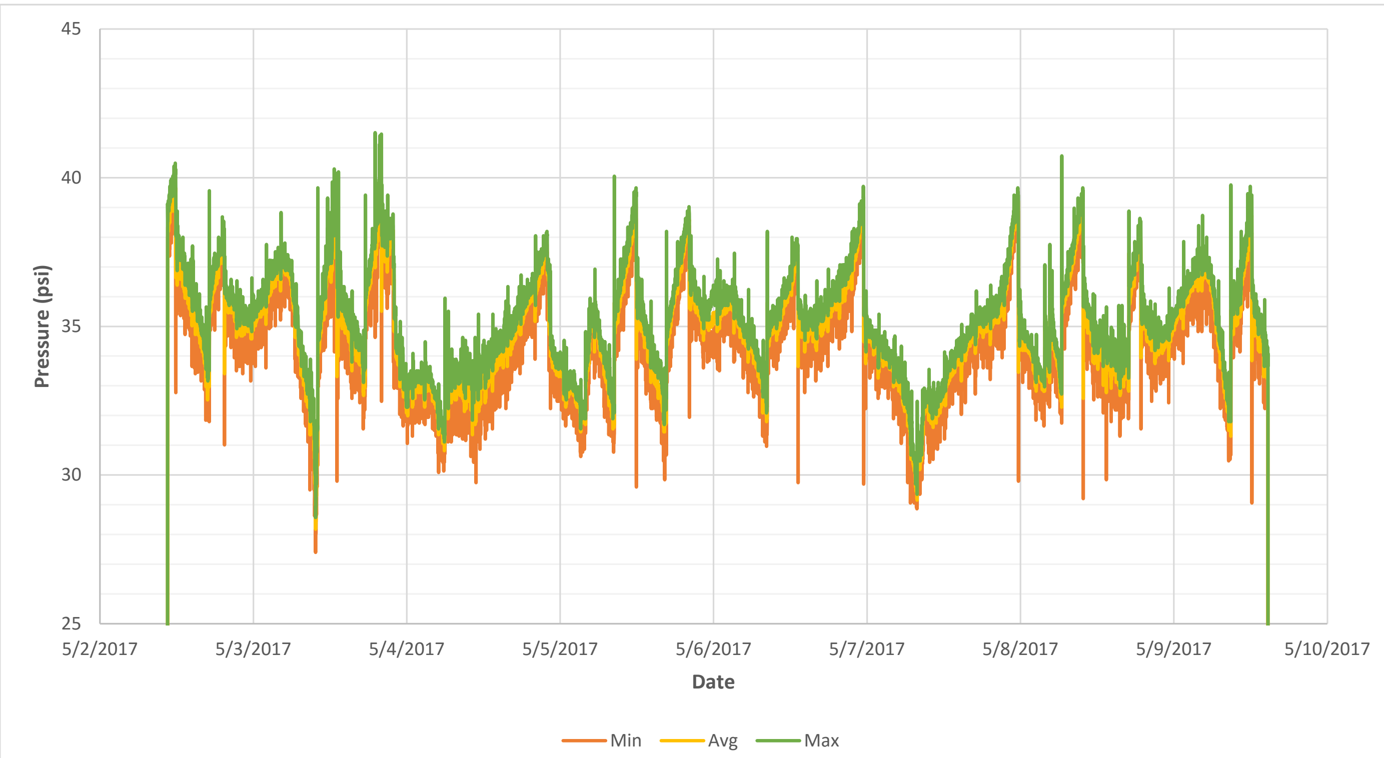
Location		Client #	**20616**
Site Name	**ARC015**	Street Address	
Model Node		Oren Ave & Paternson St	
Hydrant Age	1964		
		Coordinates	
Employee	**BC/JC**		

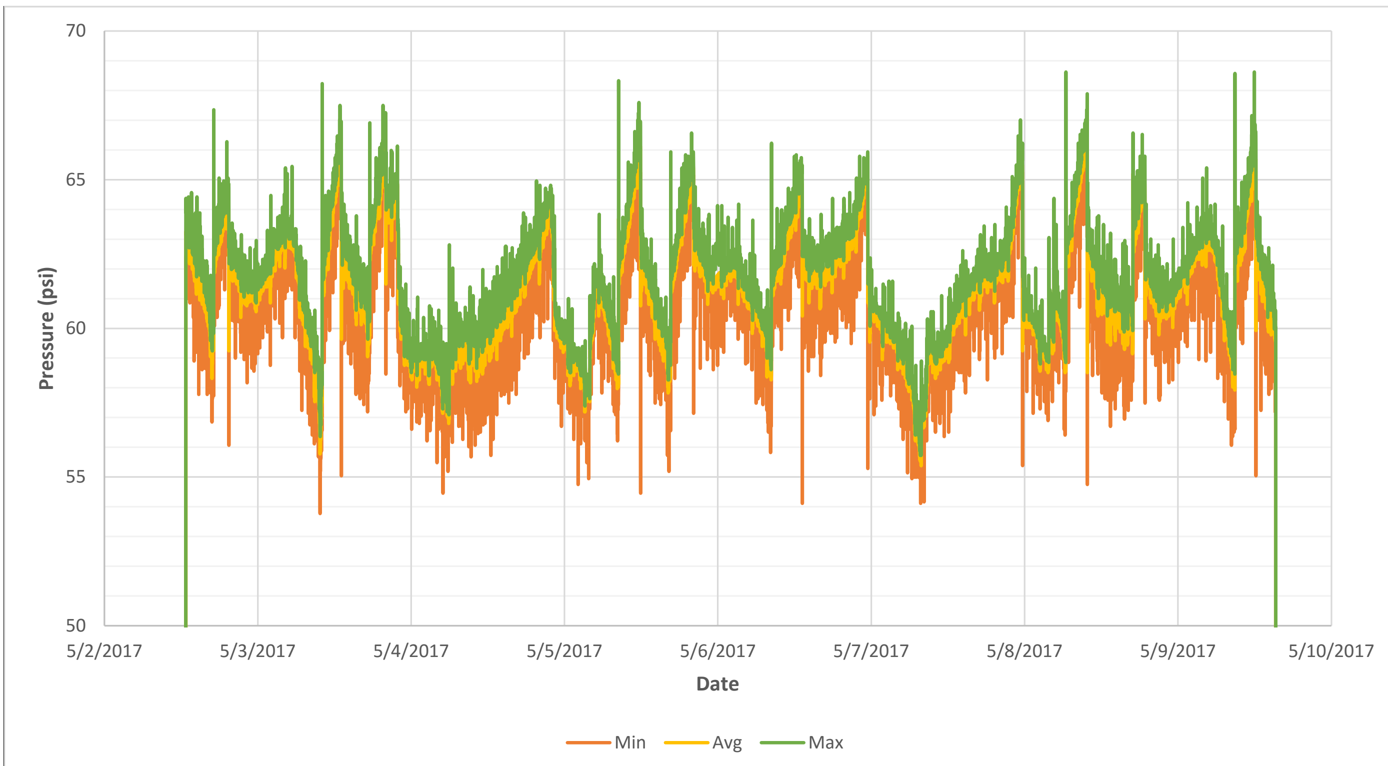
HPR Data		Notes		
Model	HPR-31	Location 22	Install Date/Time	5/2/2017 14:31
HPR ID	**206217**		Install Pressure	**38 psi**
HPR Name	**206217-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



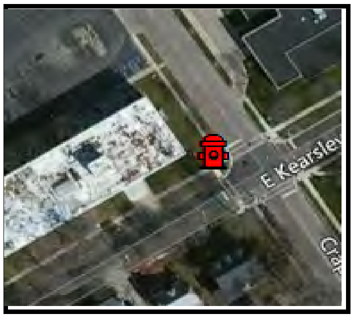
Hydrant Pressure Recorder Field Log

Location		Client #	**20616**
Site Name	**ARC019**	Street Address	
Model Node		1st St & Chavez Dr	
Hydrant Age	1971		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 7	Install Date/Time	5/2/2017 16:44
HPR ID	**206218**		Install Pressure	**63 psi**
HPR Name	**206218-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			

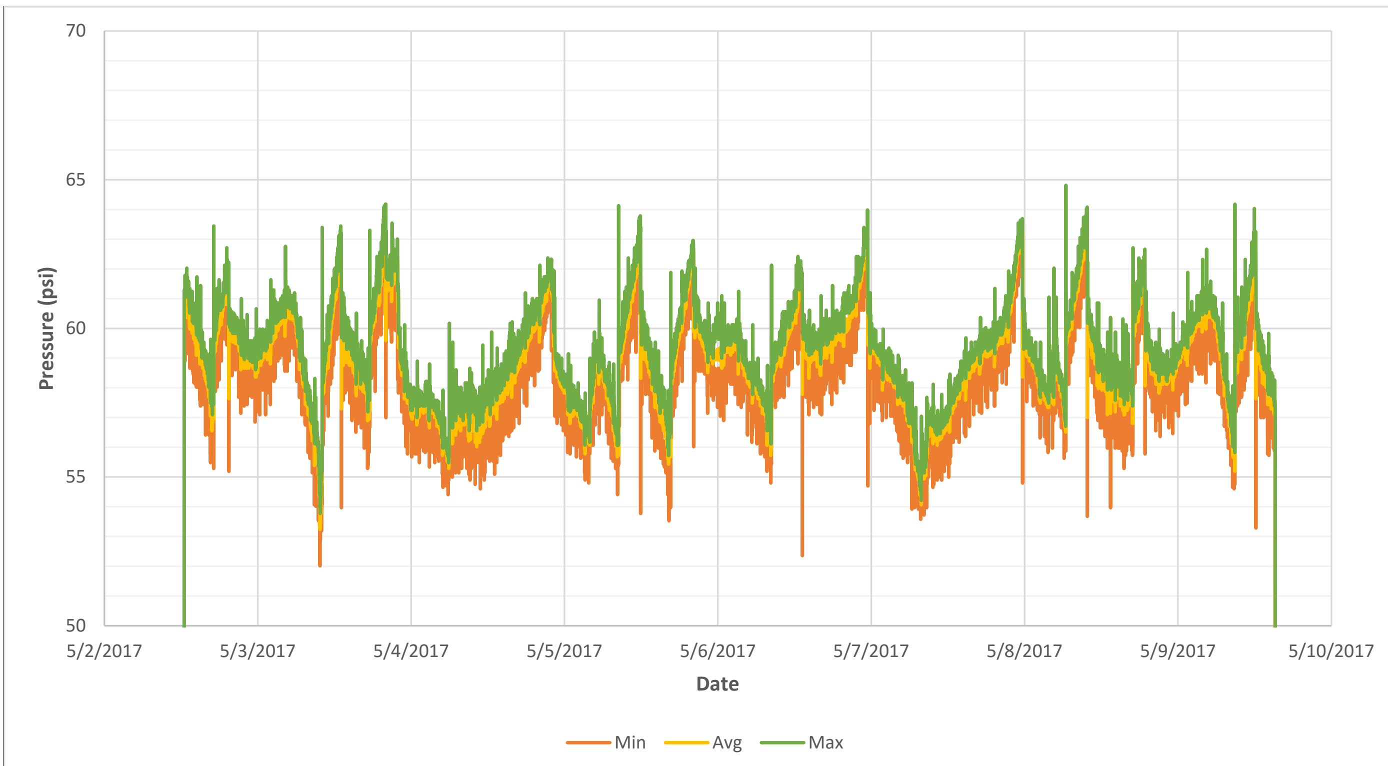


Hydrant Pressure Recorder Field Log



Location		Client #	20616
Site Name	**ARC018**	Street Address	
Model Node		Crapo St & Kearsley	
Hydrant Age	2011	St	
		Coordinates	
Employee	**BC/JC**		

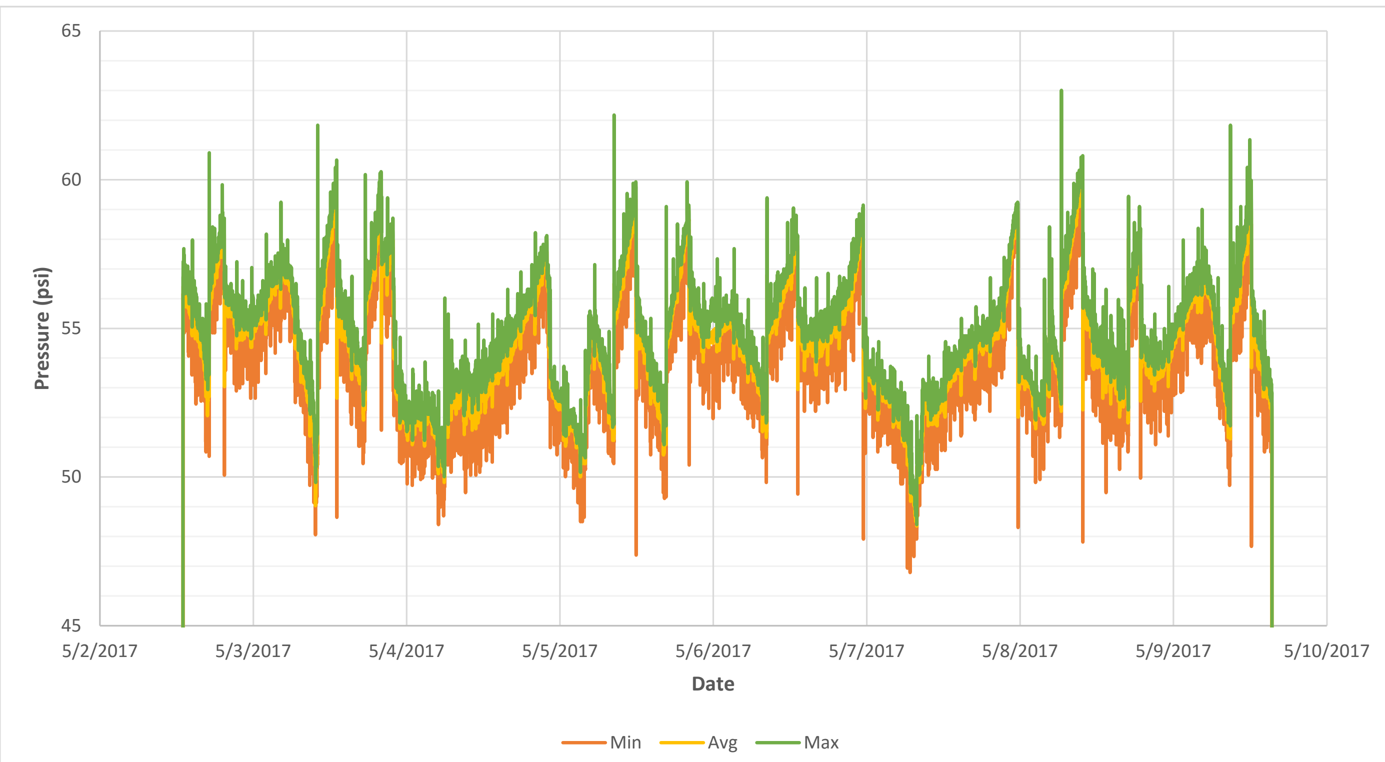
HPR Data		Notes		
Model	HPR-31	Location 25	Install Date/Time	5/2/2017 16:30
HPR ID	**206219**		Install Pressure	**61 psi**
HPR Name	**206219-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location		Client #	20616
Site Name	**ARC020**	Street Address	
Model Node		5th St & Harrison	
Hydrant Age	1938		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 9	Install Date/Time	5/2/2017 16:59
HPR ID	**206220**		Install Pressure	**56 psi**
HPR Name	**206220-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

Location

Site Name	**ARC024**	Client #	**20616**
Model Node		Street Address	
Hydrant Age	2007	University Ave (between Nolan Ave & Bridge)	
		Coordinates	
Employee	**BC/JC**		

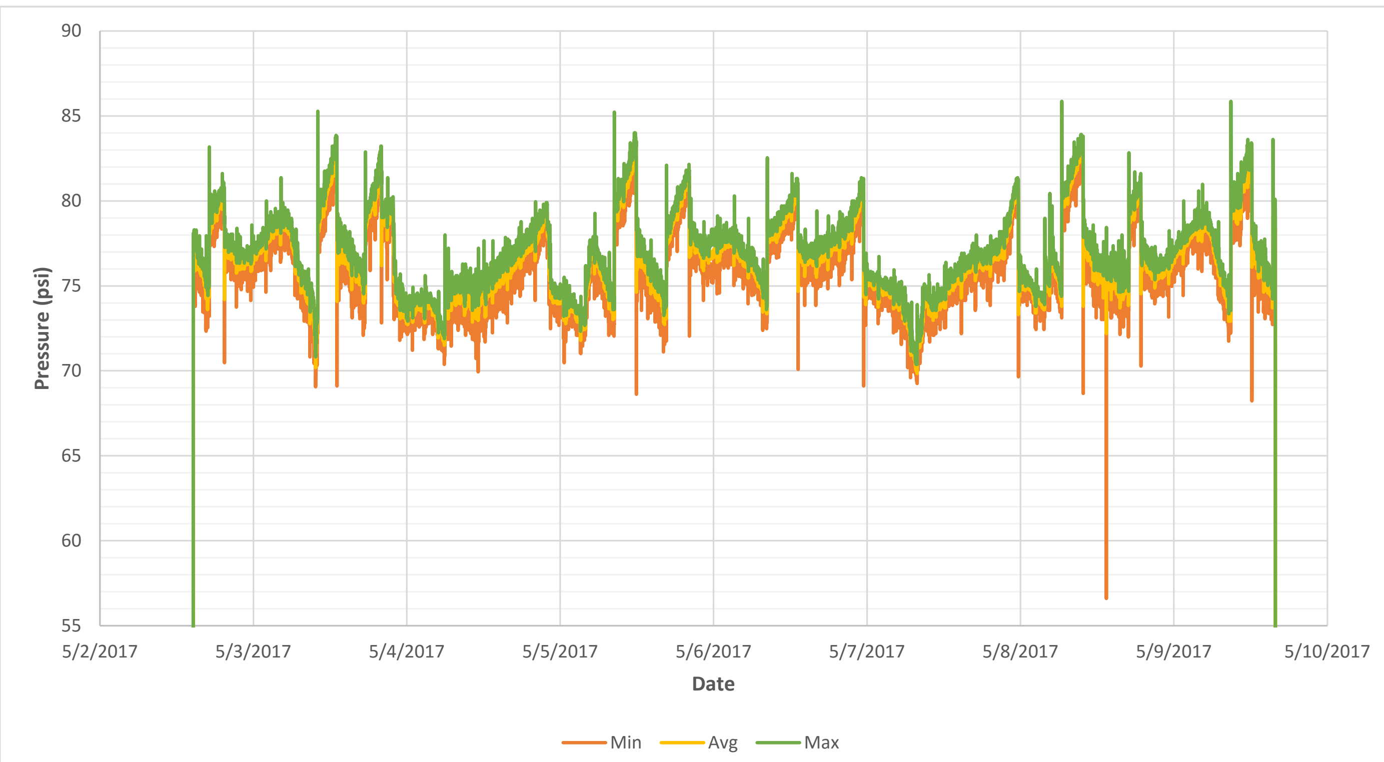
HPR Data

Model	HPR-31
HPR ID	**206221**
HPR Name	**206221-200**
Capacity	
Sample Rate	5 seconds
Recording Interval	1 minute

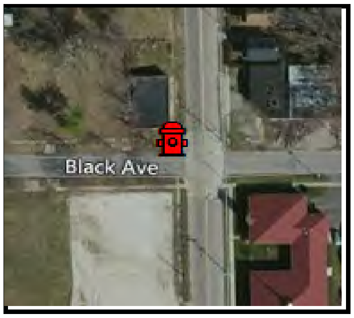
Notes

Location 18 (better location on main)

Install Date/Time	5/2/2017 18:36
Install Pressure	**76 psi**
Remove Date/Time	**5/9/2017**
Remove Presure	**-**
Local FD Notified?	**Yes**

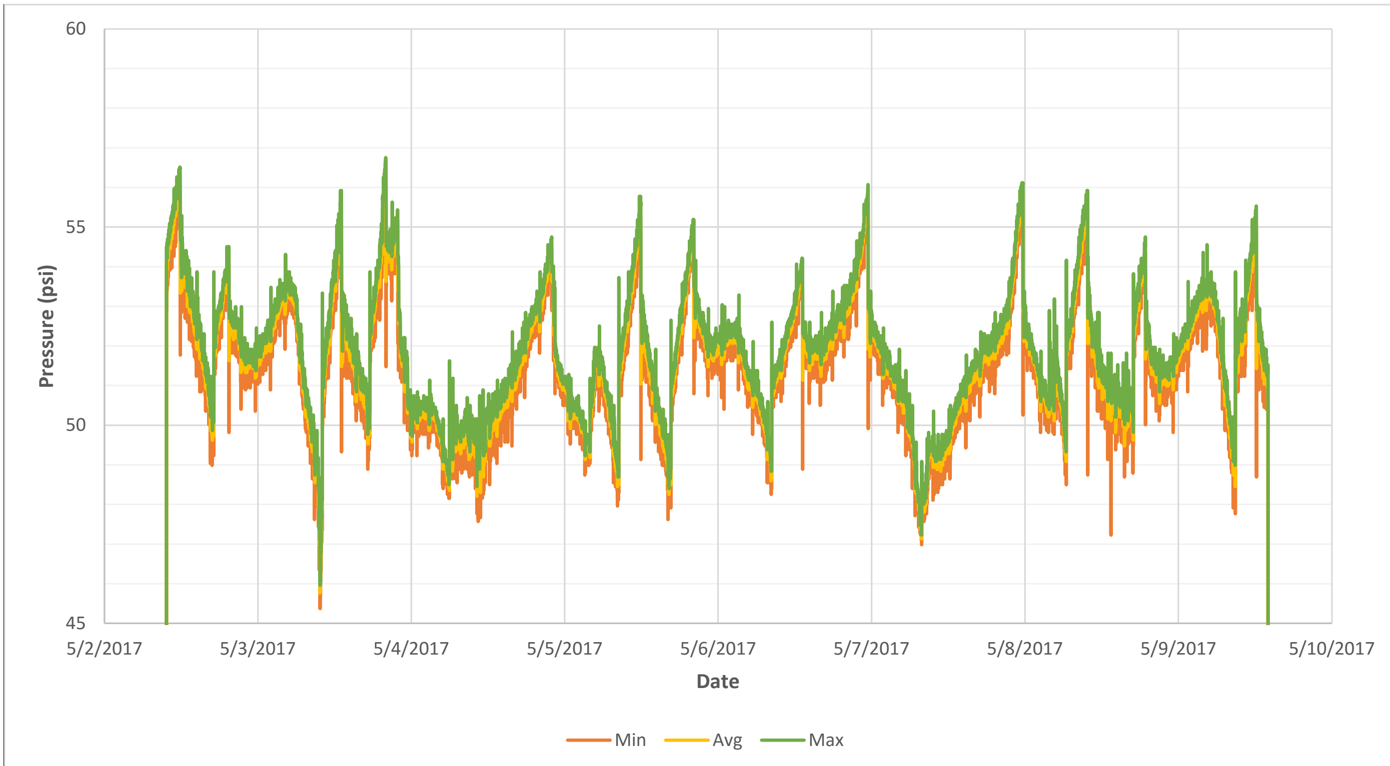


Hydrant Pressure Recorder Field Log



Location		Client #	20616
Site Name	**ARC010**	Street Address	
Model Node		Black Ave & Industrial Ave	
Hydrant Age	1958		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 13	Install Date/Time	5/2/2017 13:41
HPR ID	**206222**		Install Pressure	**54 psi**
HPR Name	**206222-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			

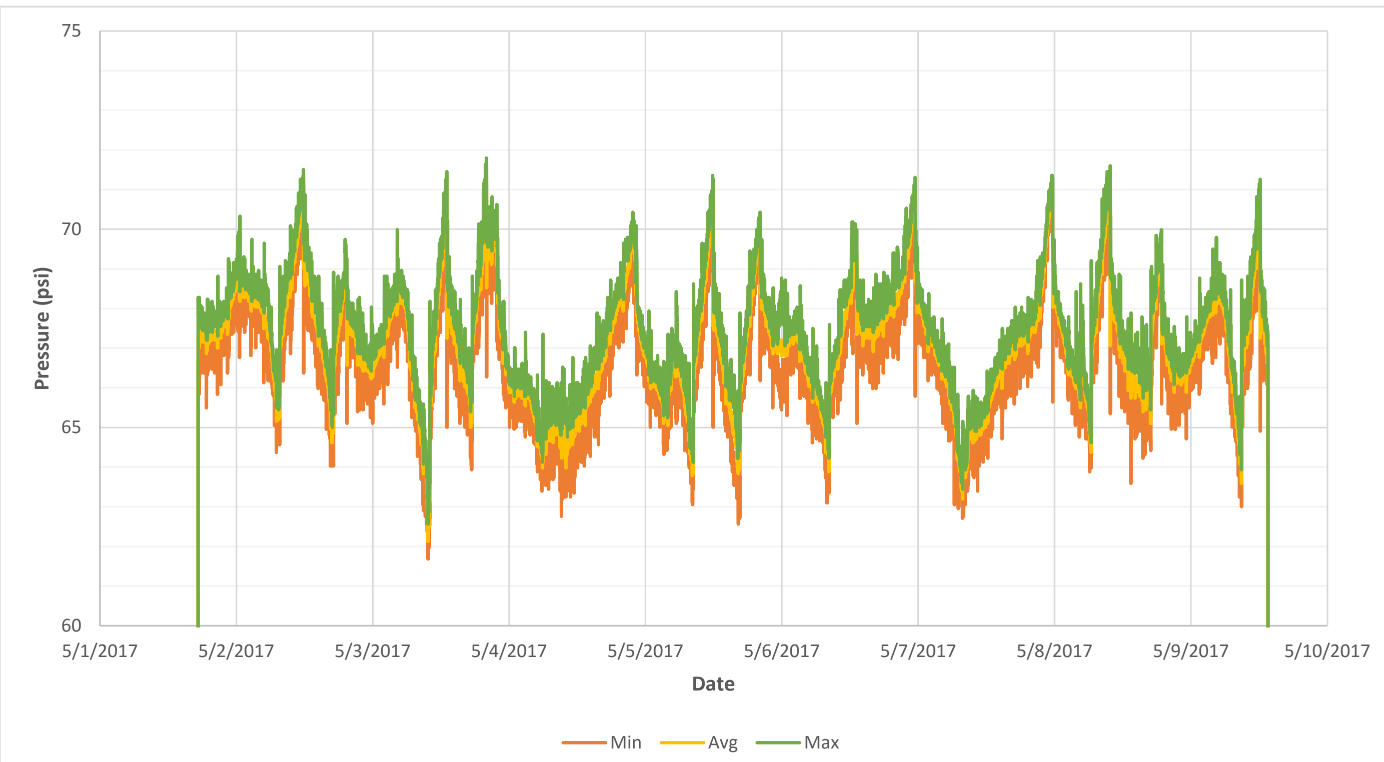


Hydrant Pressure Recorder Field Log

ARCADIS Design & Consultancy for natural and built assets

Location		Client #	20616
Site Name	**ARC004**	Street Address	
Model Node		Iowa Ave & Maryland Ave	
Hydrant Age	2008		
		Coordinates	
Employee	**BC/JC**		

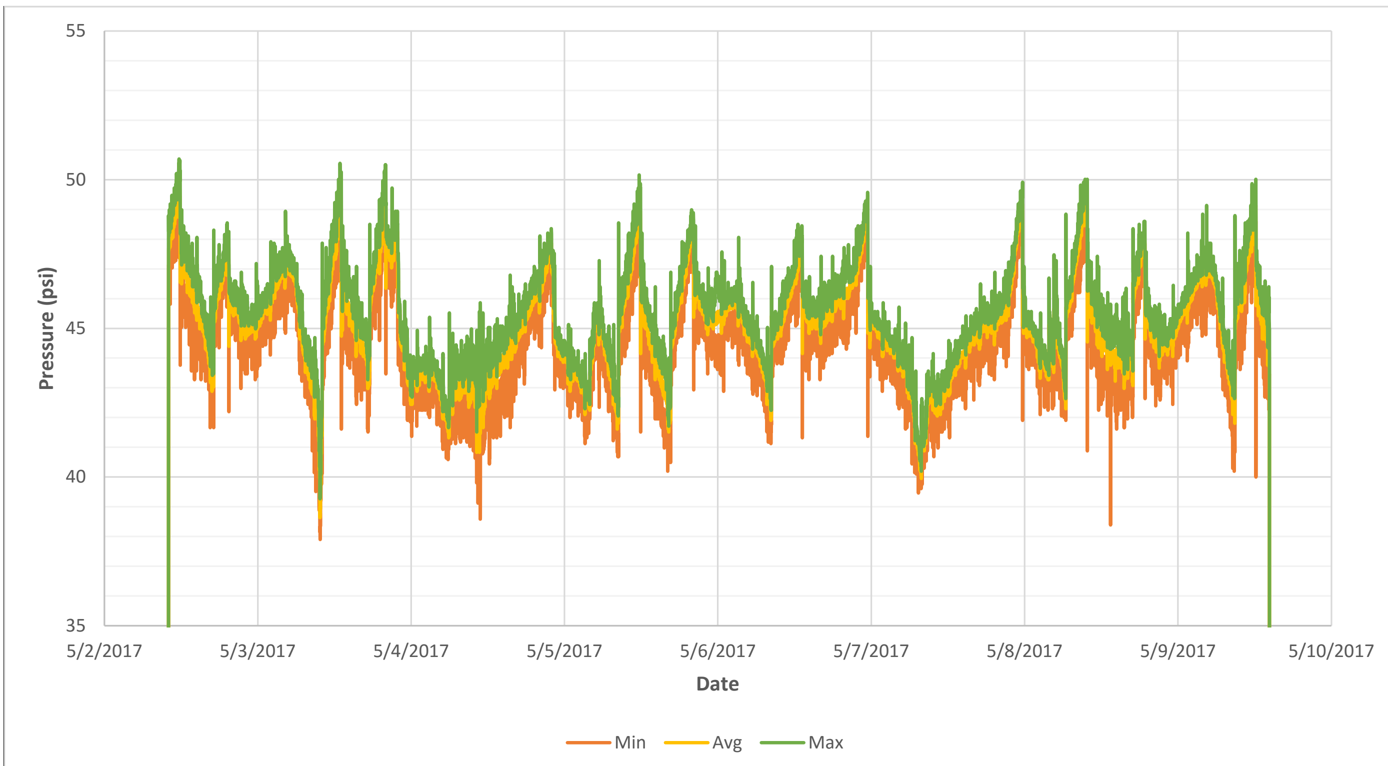
HPR Data		Notes		
Model	HPR-31	Location 24	Install Date/Time	5/1/2017 21:16
HPR ID	**206223**		Install Pressure	**68 psi**
HPR Name	**206223-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	-
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			



Hydrant Pressure Recorder Field Log

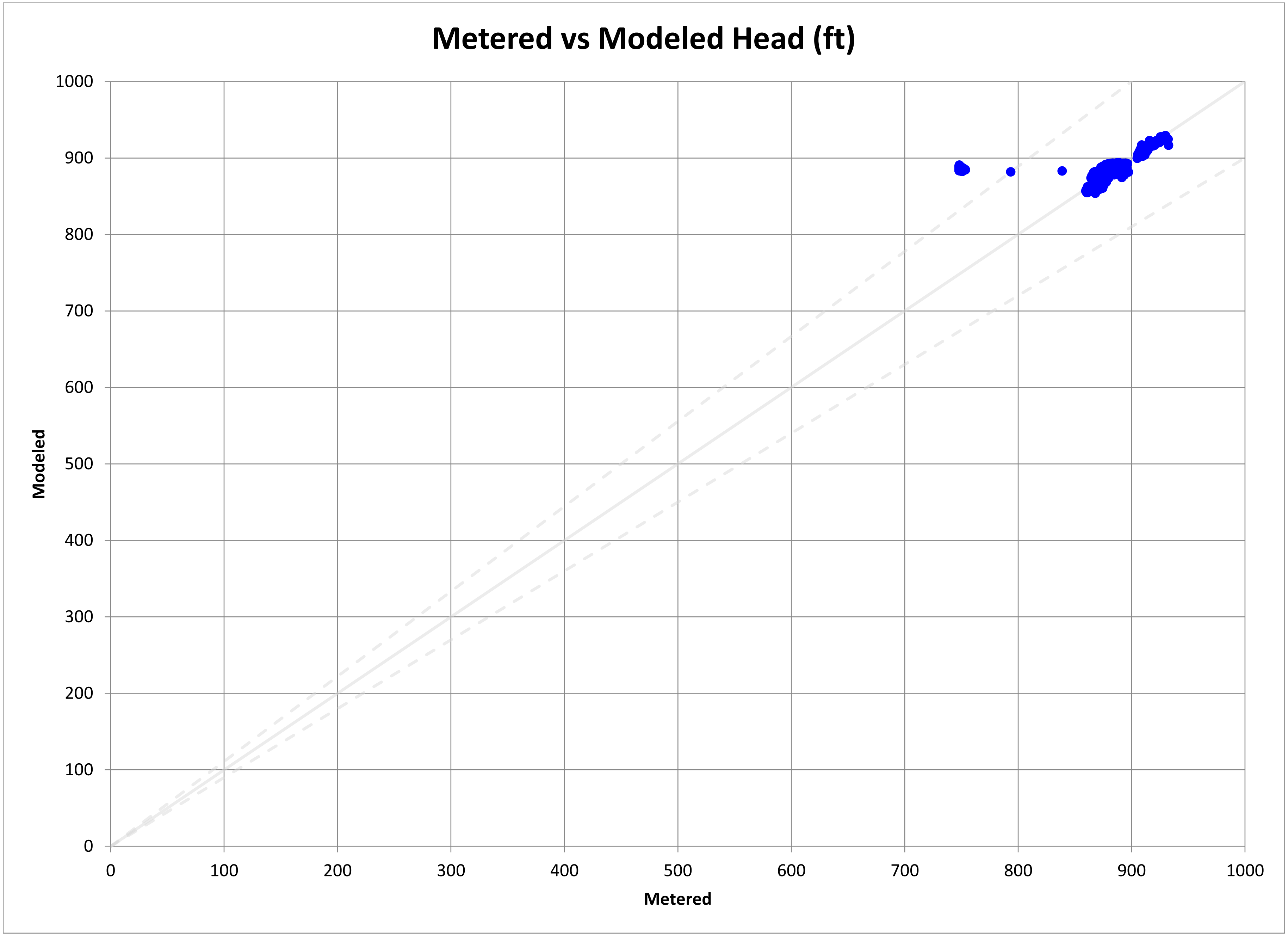
Location		Client #	20616
Site Name	**ARC012**	Street Address	
Model Node		Lorado & Martin Luther King Ave	
Hydrant Age	2011		
		Coordinates	
Employee	**BC/JC**		

HPR Data		Notes		
Model	HPR-31	Location 20	Install Date/Time	5/2/2017 14:01
HPR ID	**206224**		Install Pressure	**48 psi**
HPR Name	**206224-200**		Remove Date/Time	**5/9/2017**
Capacity			Remove Presure	**-**
Sample Rate	5 seconds		Local FD Notified?	**Yes**
Recording Interval	1 minute			

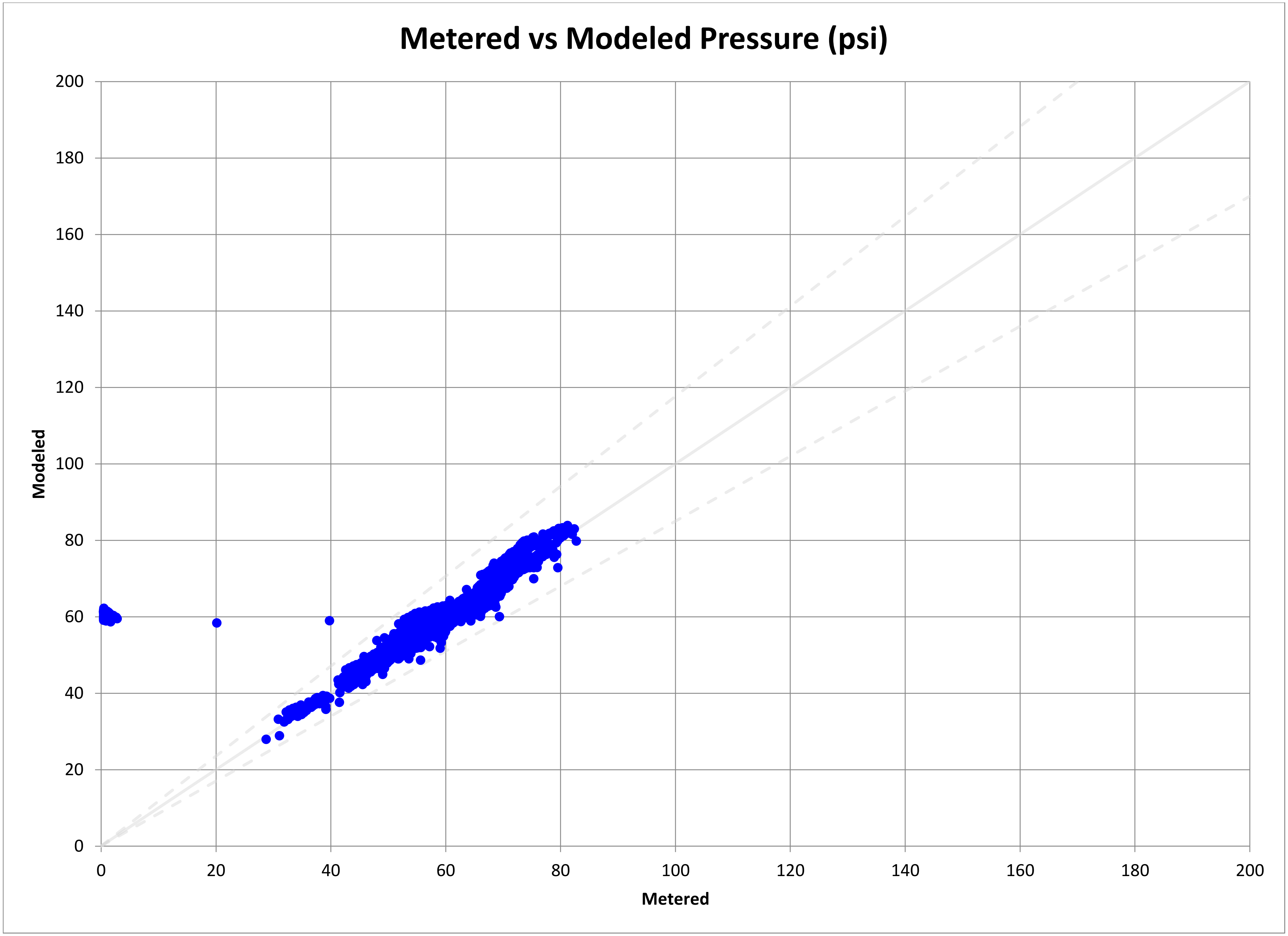


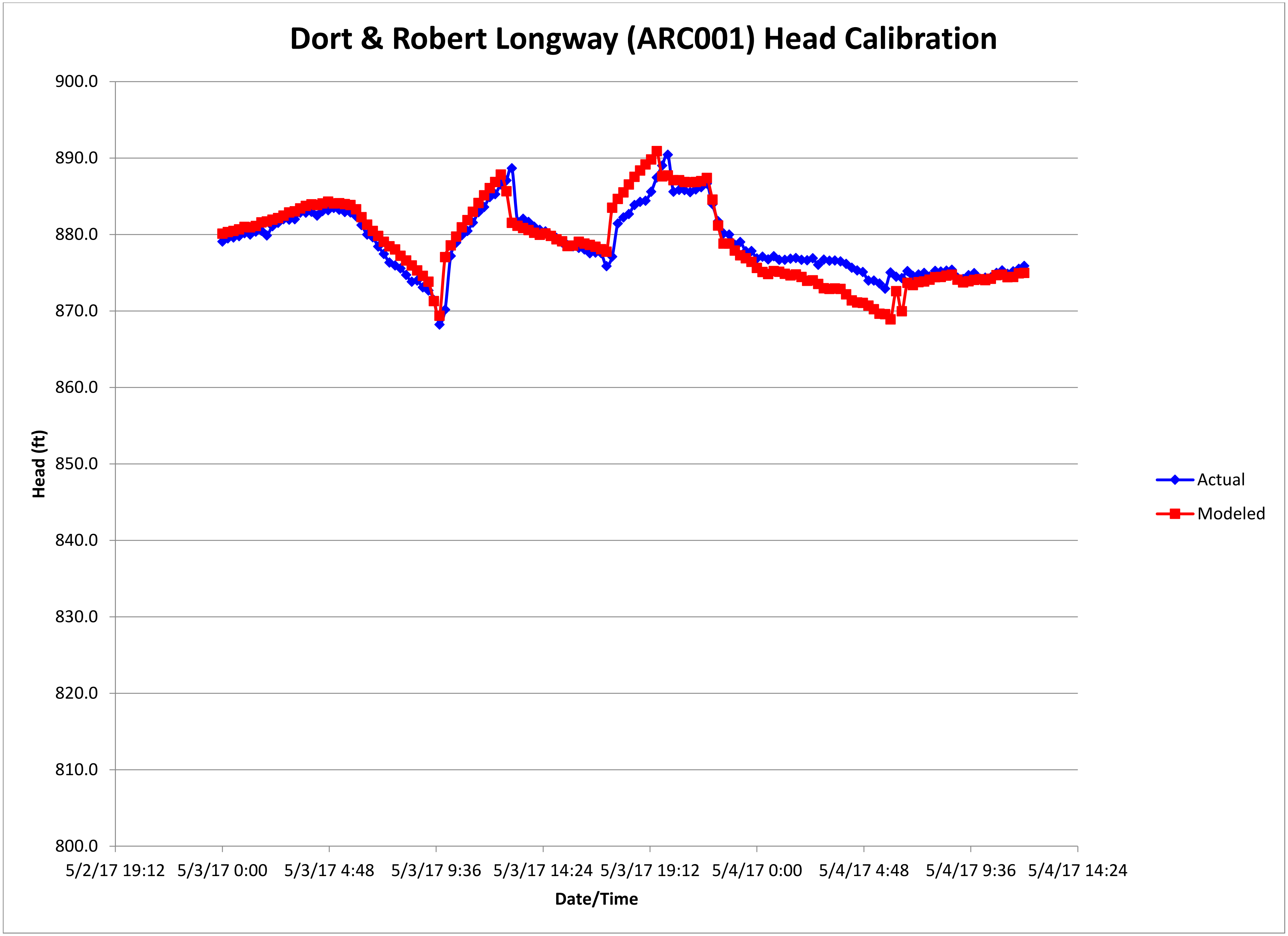
APPENDIX C

Calibration Reports

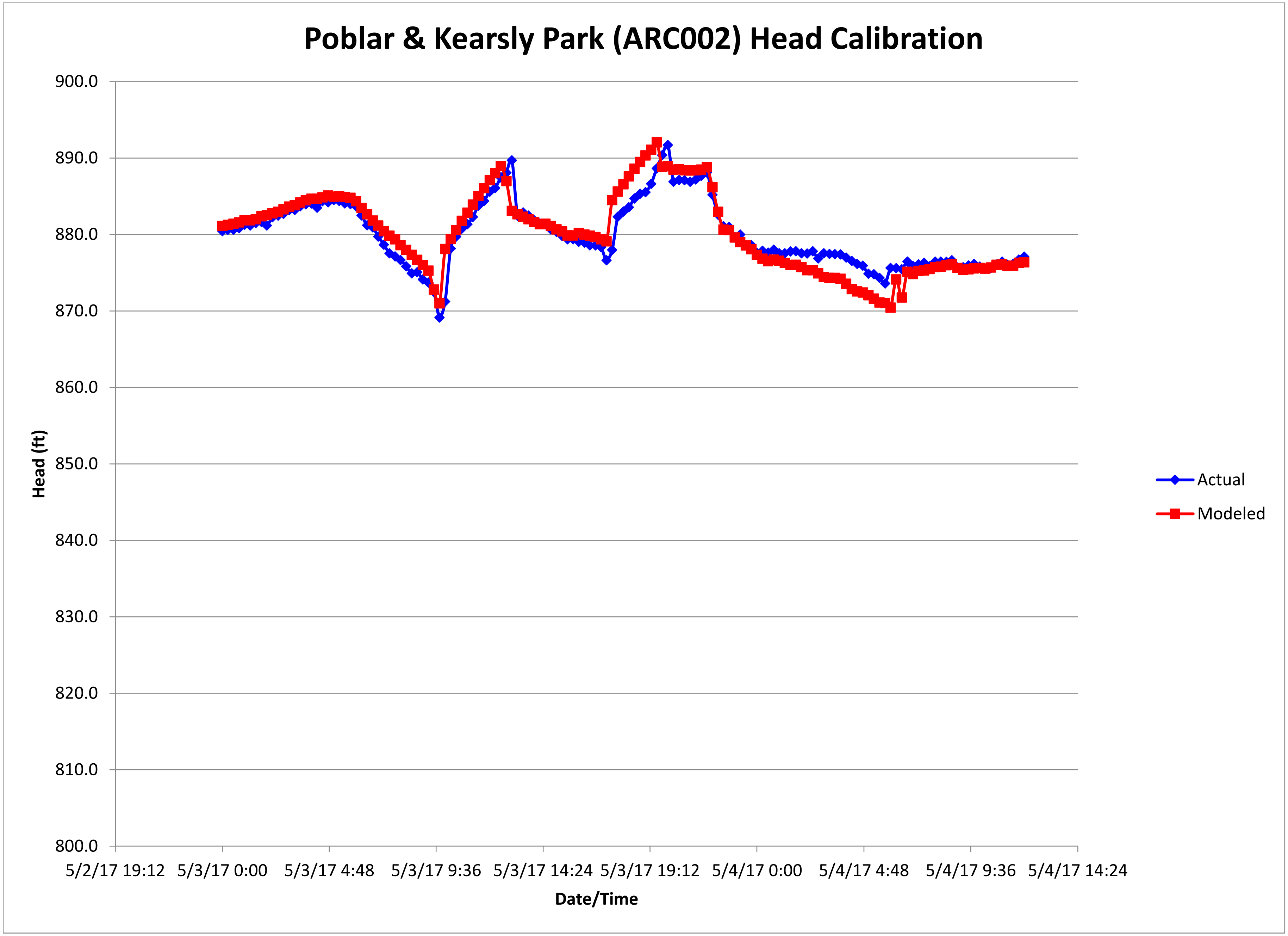


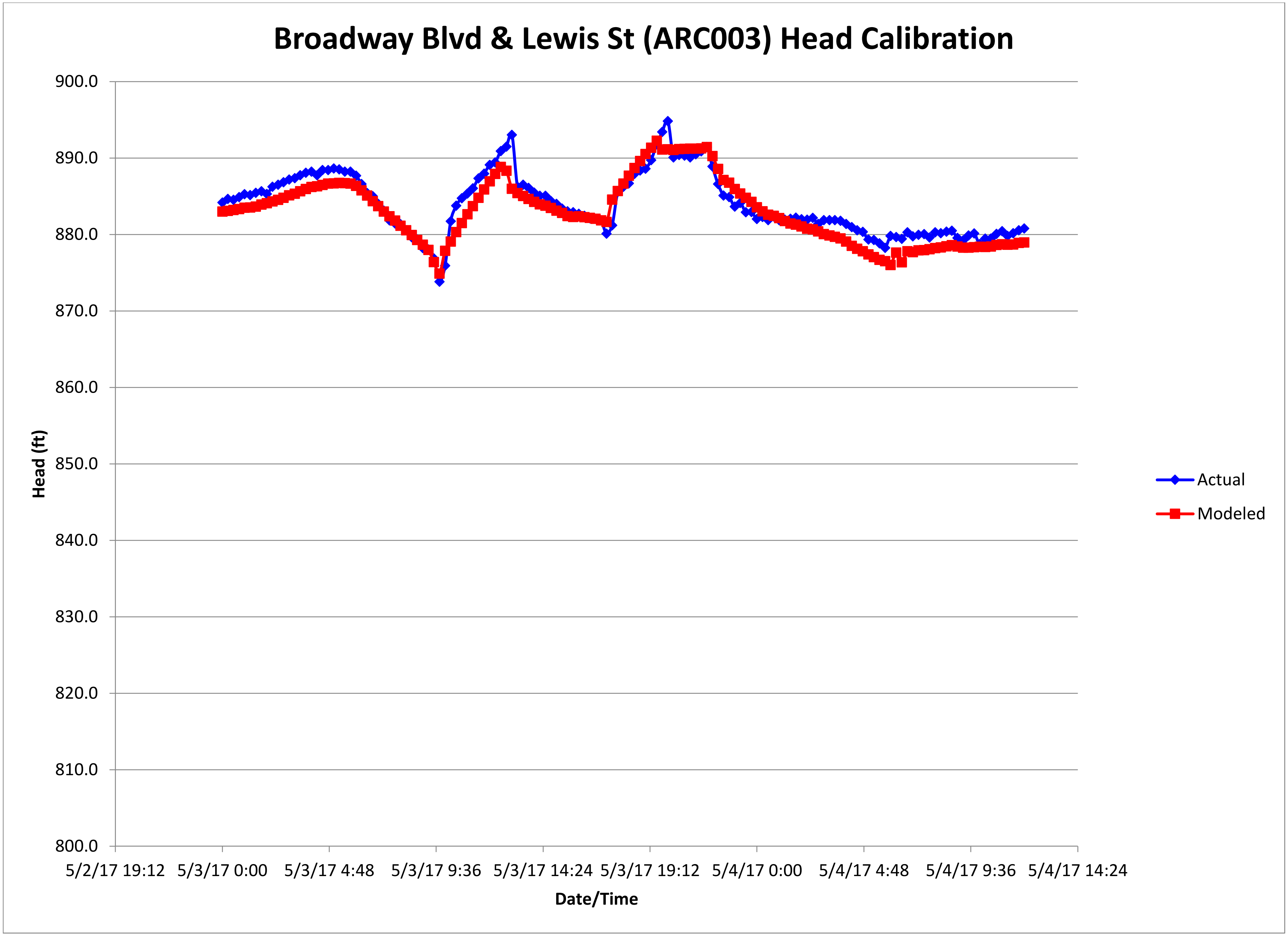
Metered vs Modeled Head (ft)
Modeled
Metered
0
100
200
300
400
500
600
700
800
900
1000

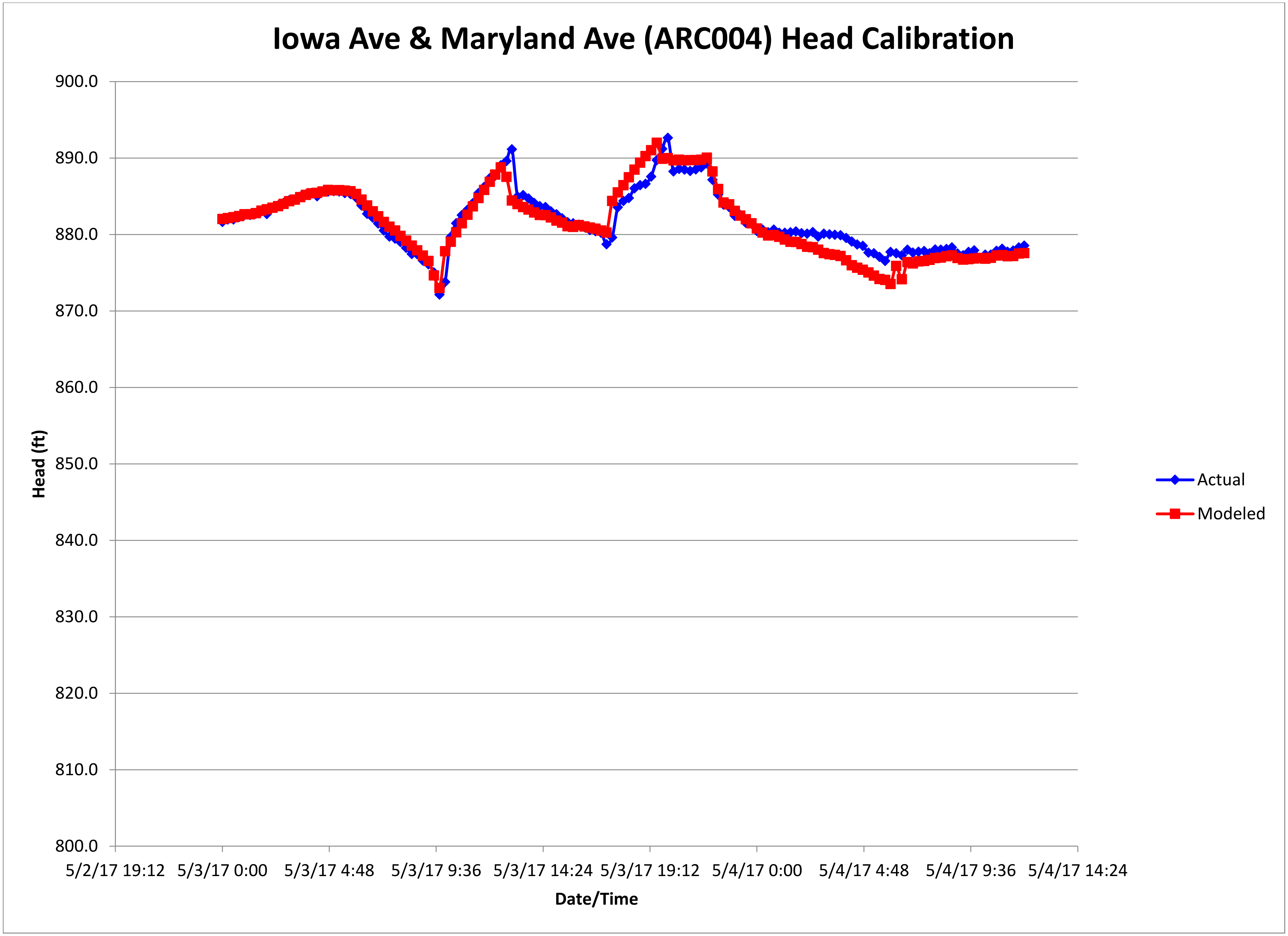

Metered vs Modeled Pressure (psi)
Modeled
Metered
0
20
40
60
80
100
120
140
160
180
200

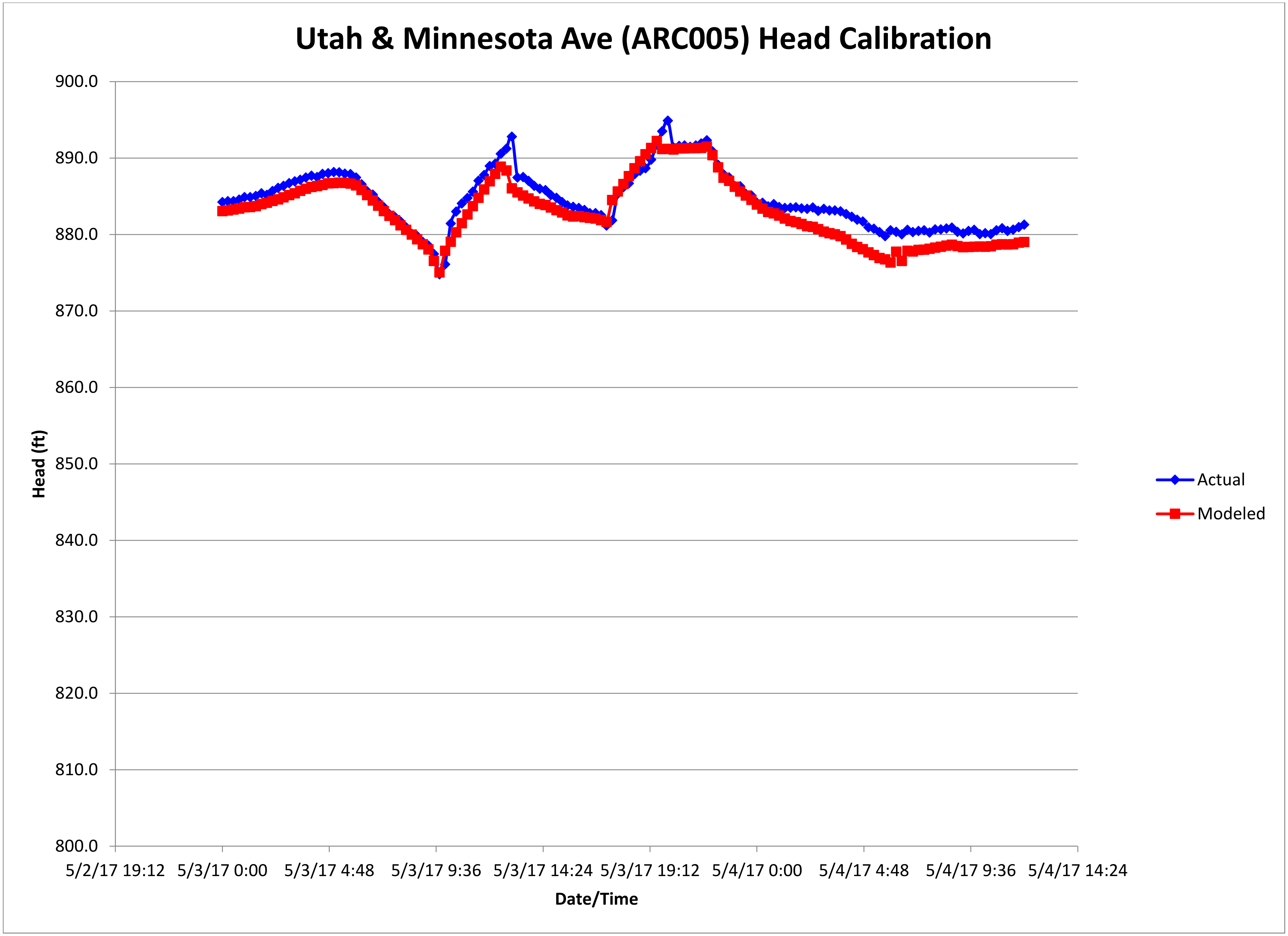


Dort & Robert Longway (ARC001) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

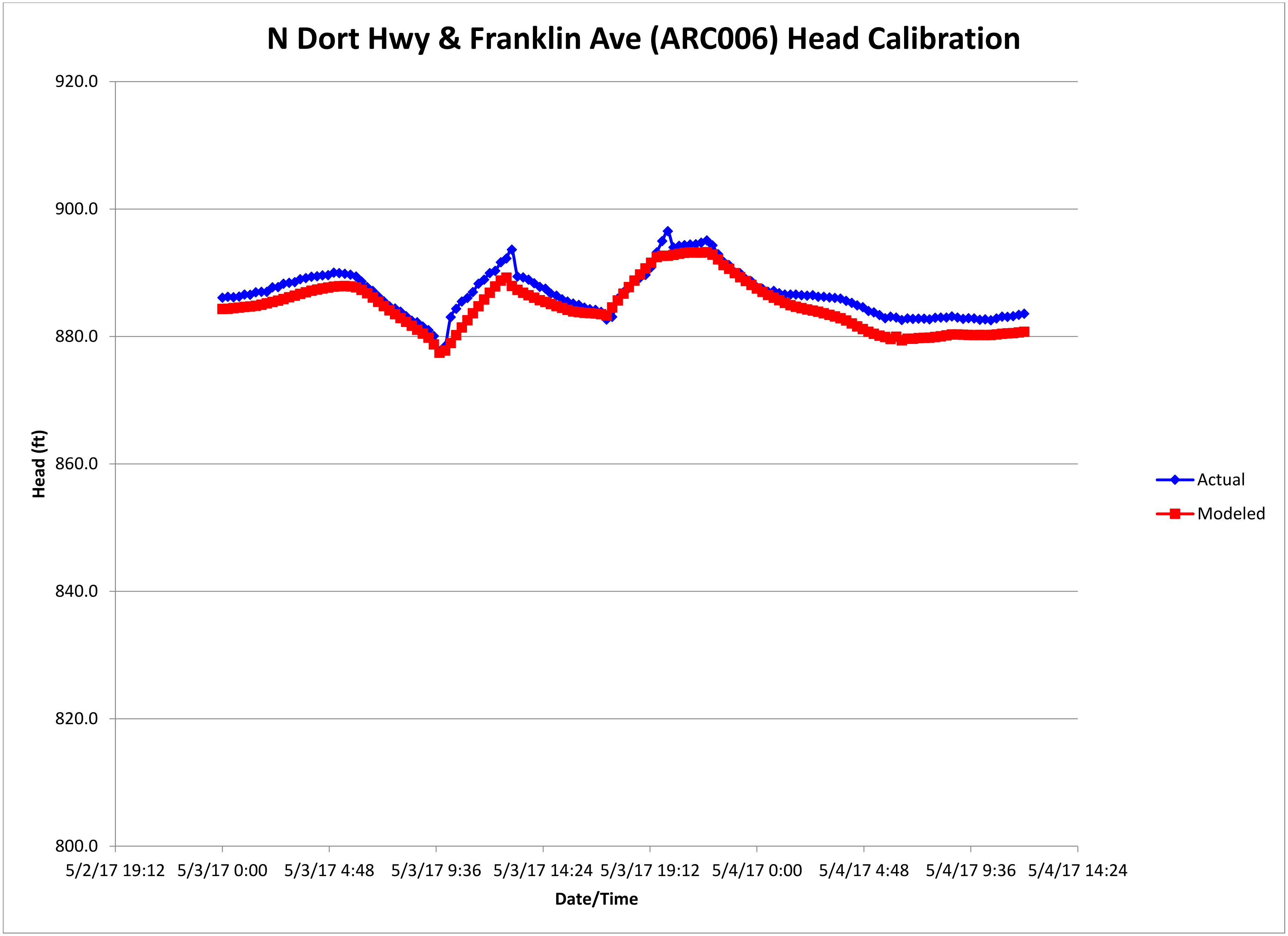

Poblar & Kearsly Park (ARC002) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled


Broadway Blvd & Lewis St (ARC003) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

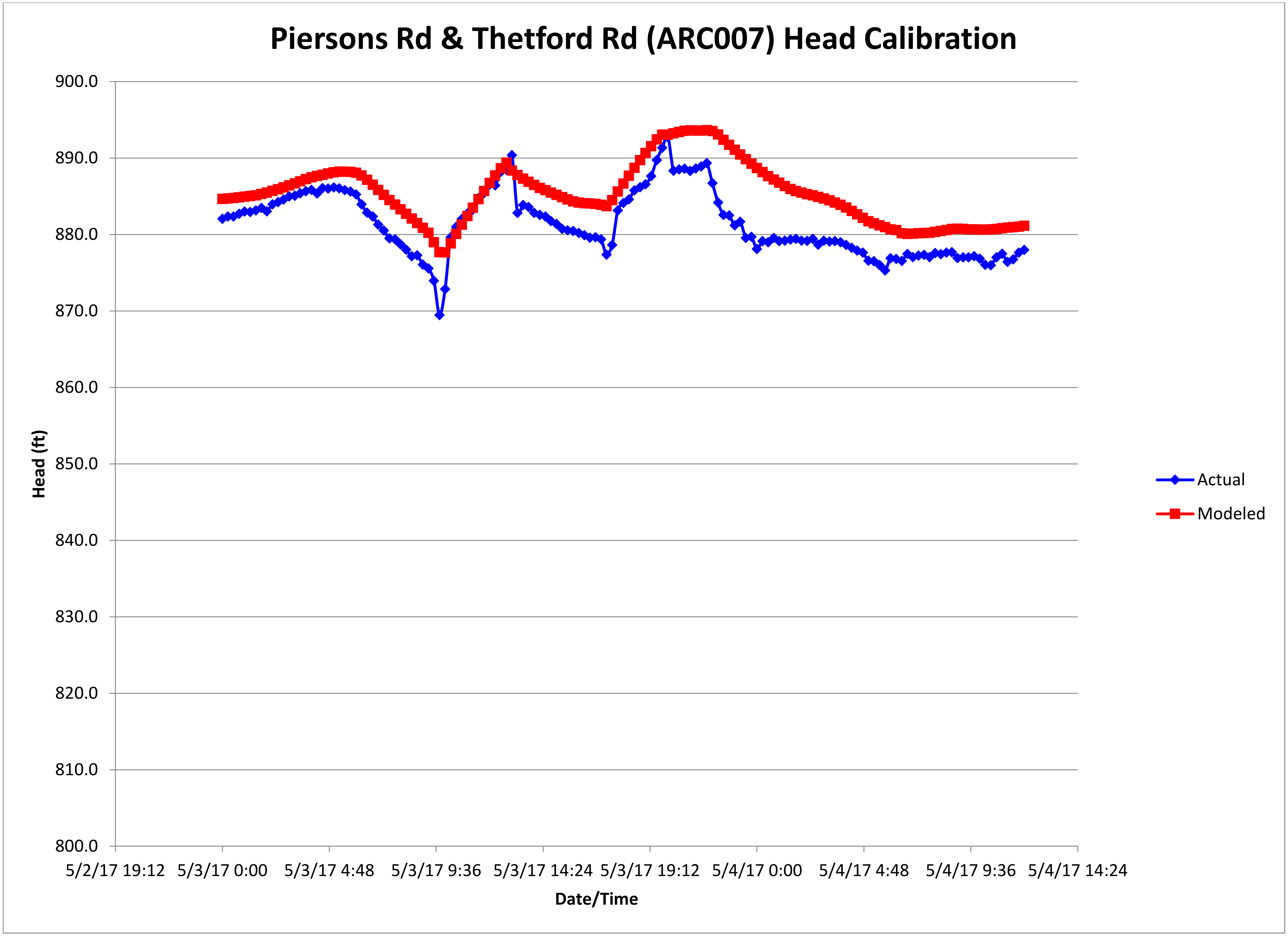

Iowa Ave & Maryland Ave (ARC004) Head Calibration
Head (ft)
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



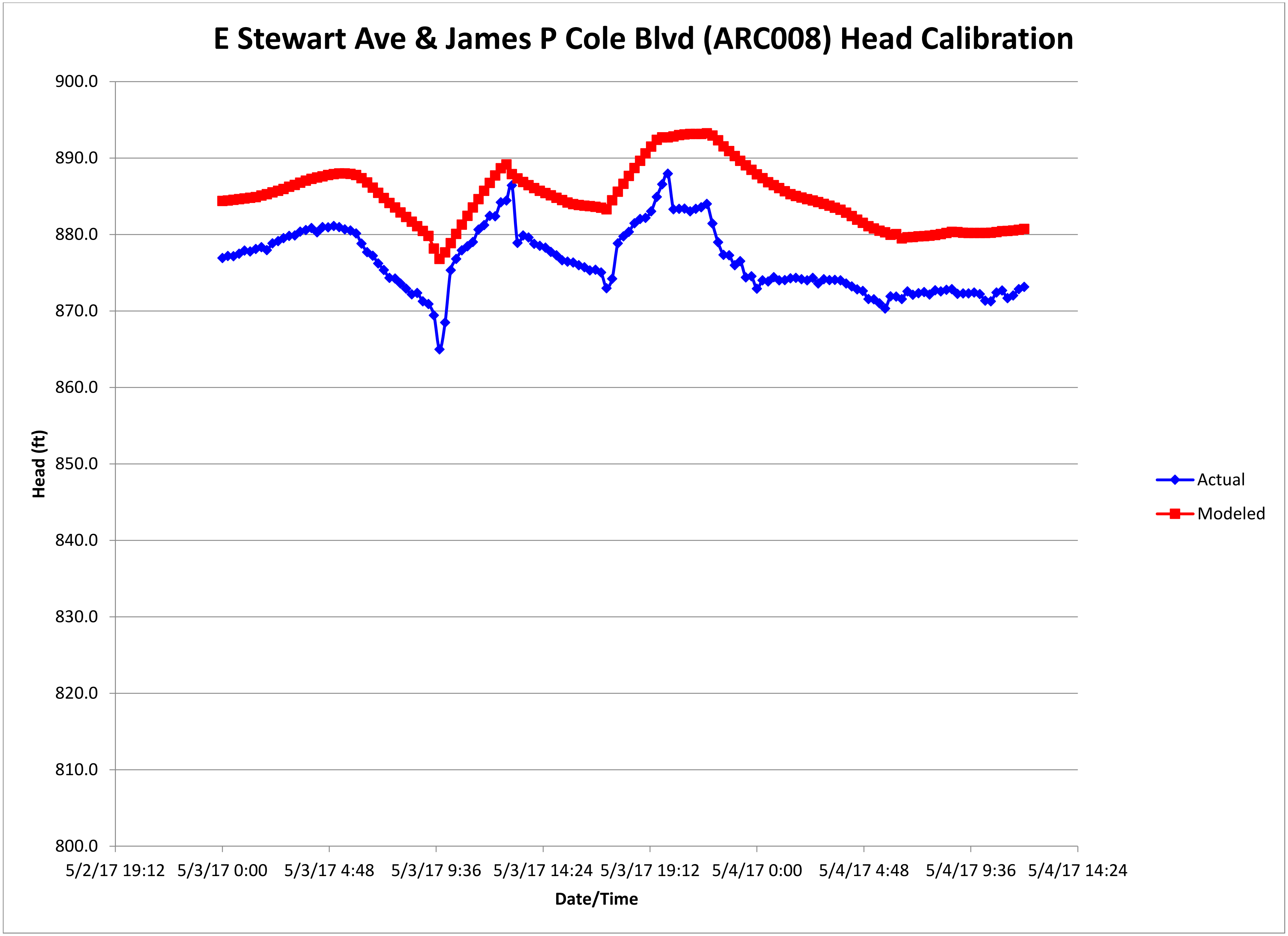
Utah & Minnesota Ave (ARC005) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



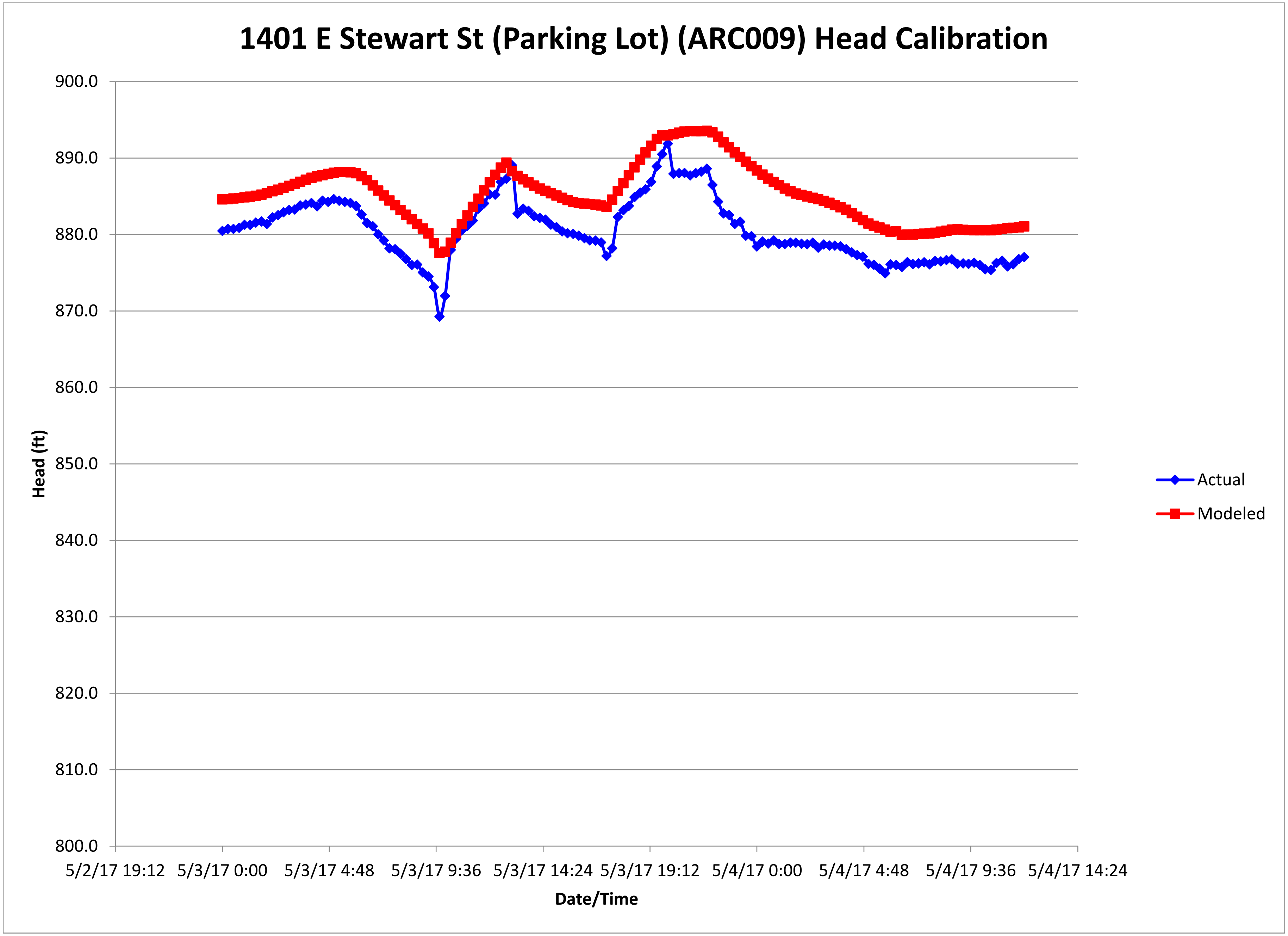
N Dort Hwy & Franklin Ave (ARC006) Head Calibration
920.0
900.0
880.0
860.0
840.0
820.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



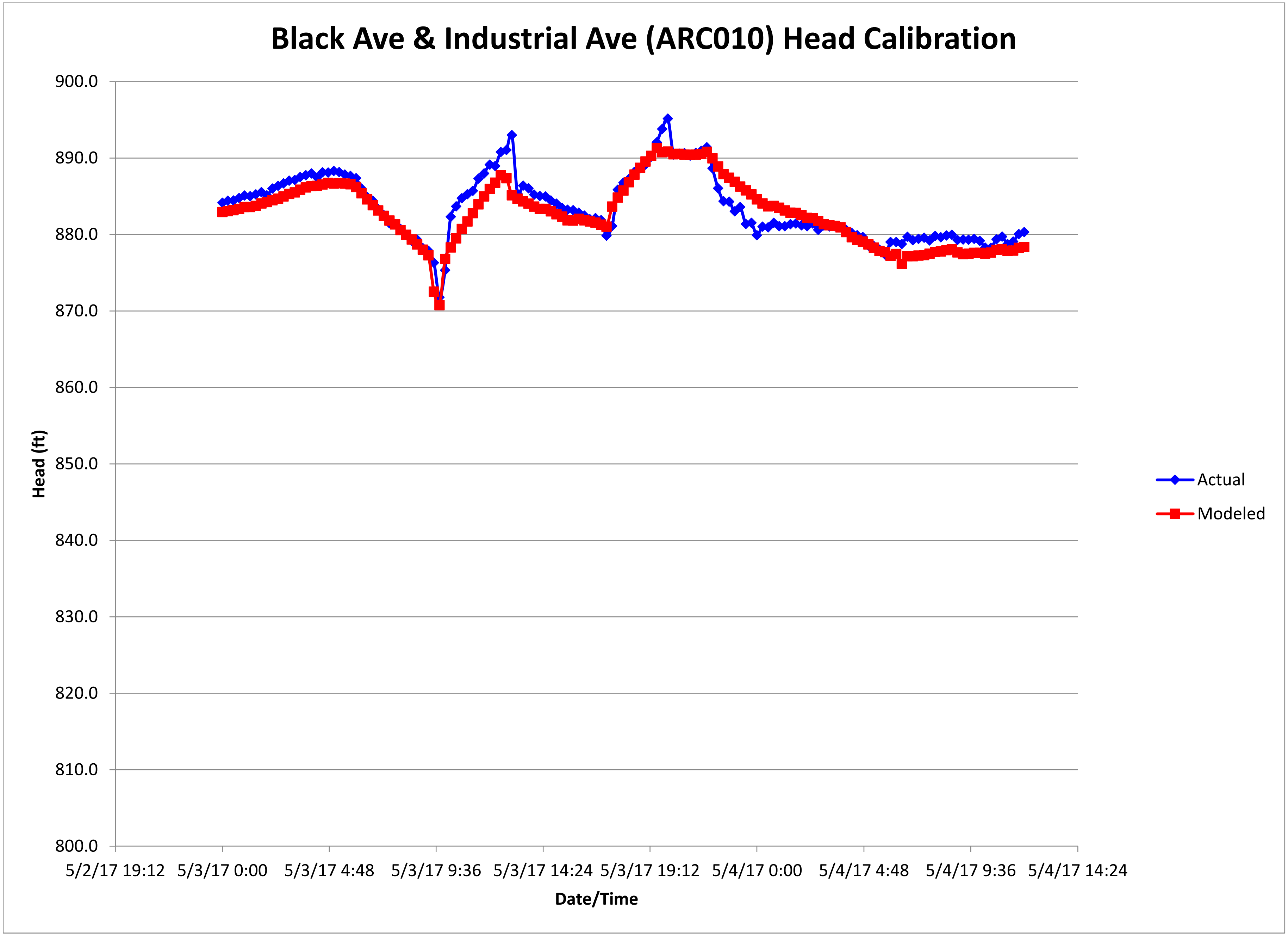
Piersons Rd & Thetford Rd (ARC007) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



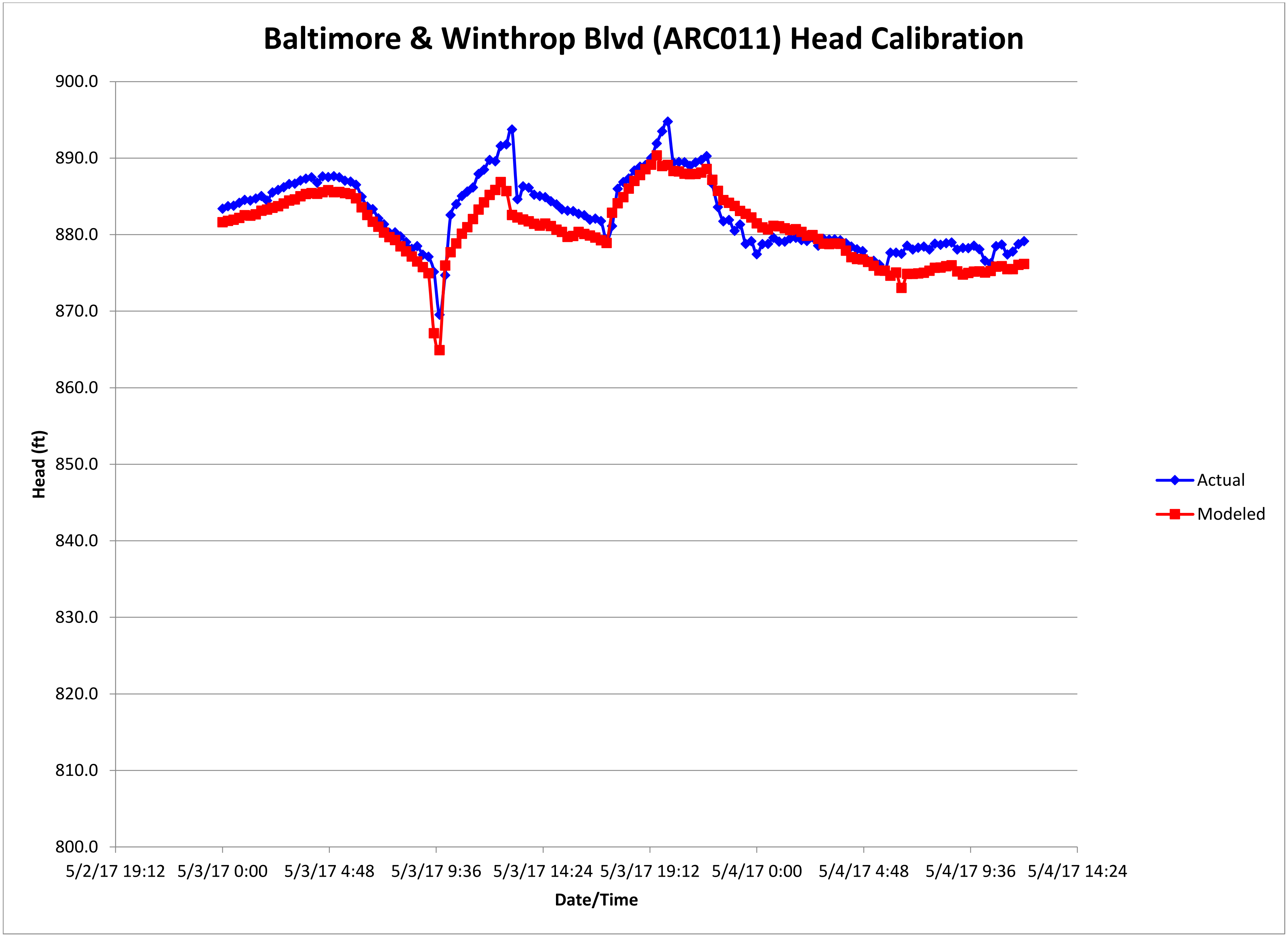
E Stewart Ave & James P Cole Blvd (ARC008) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



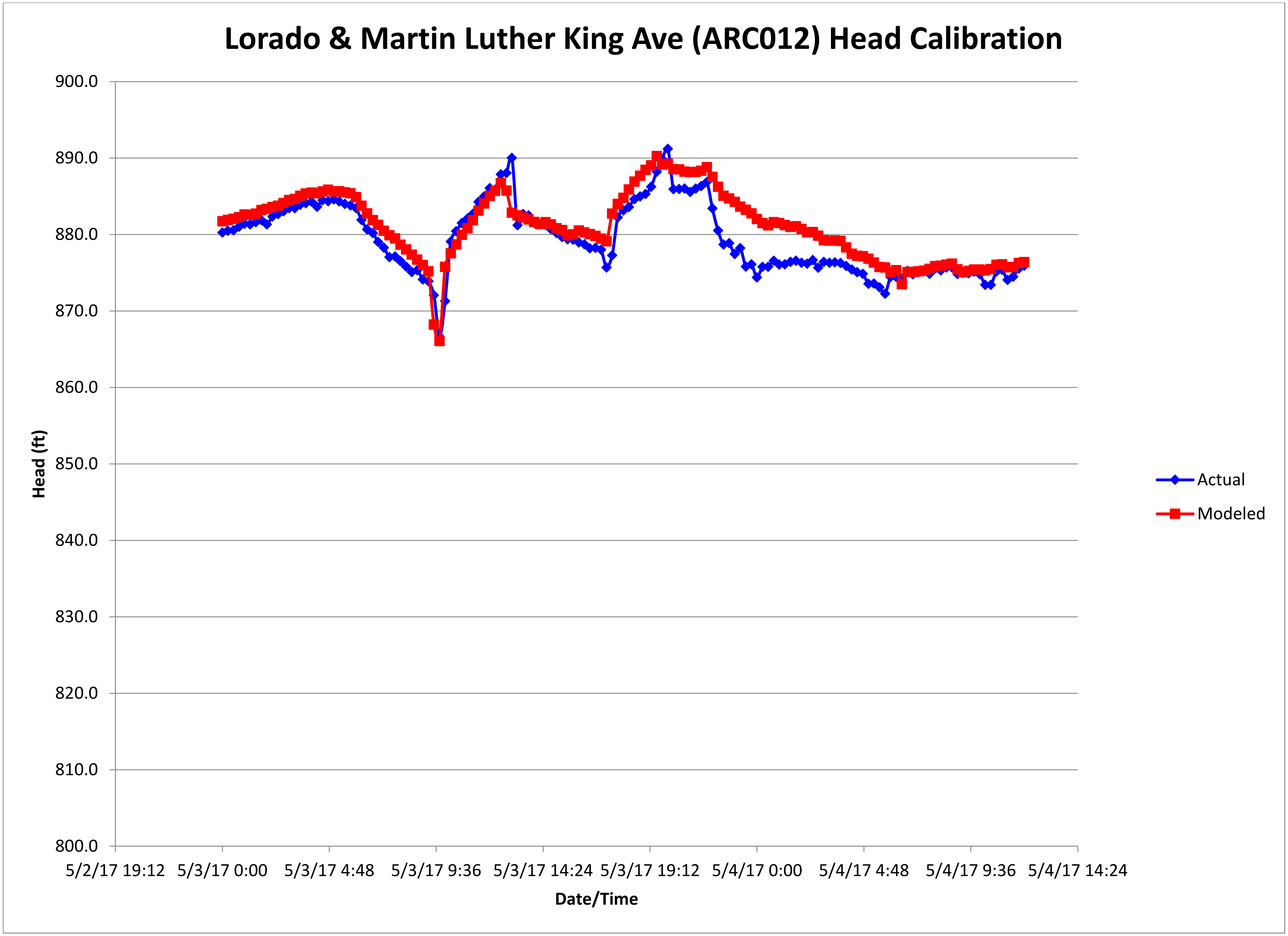
1401 E Stewart St (Parking Lot) (ARC009) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



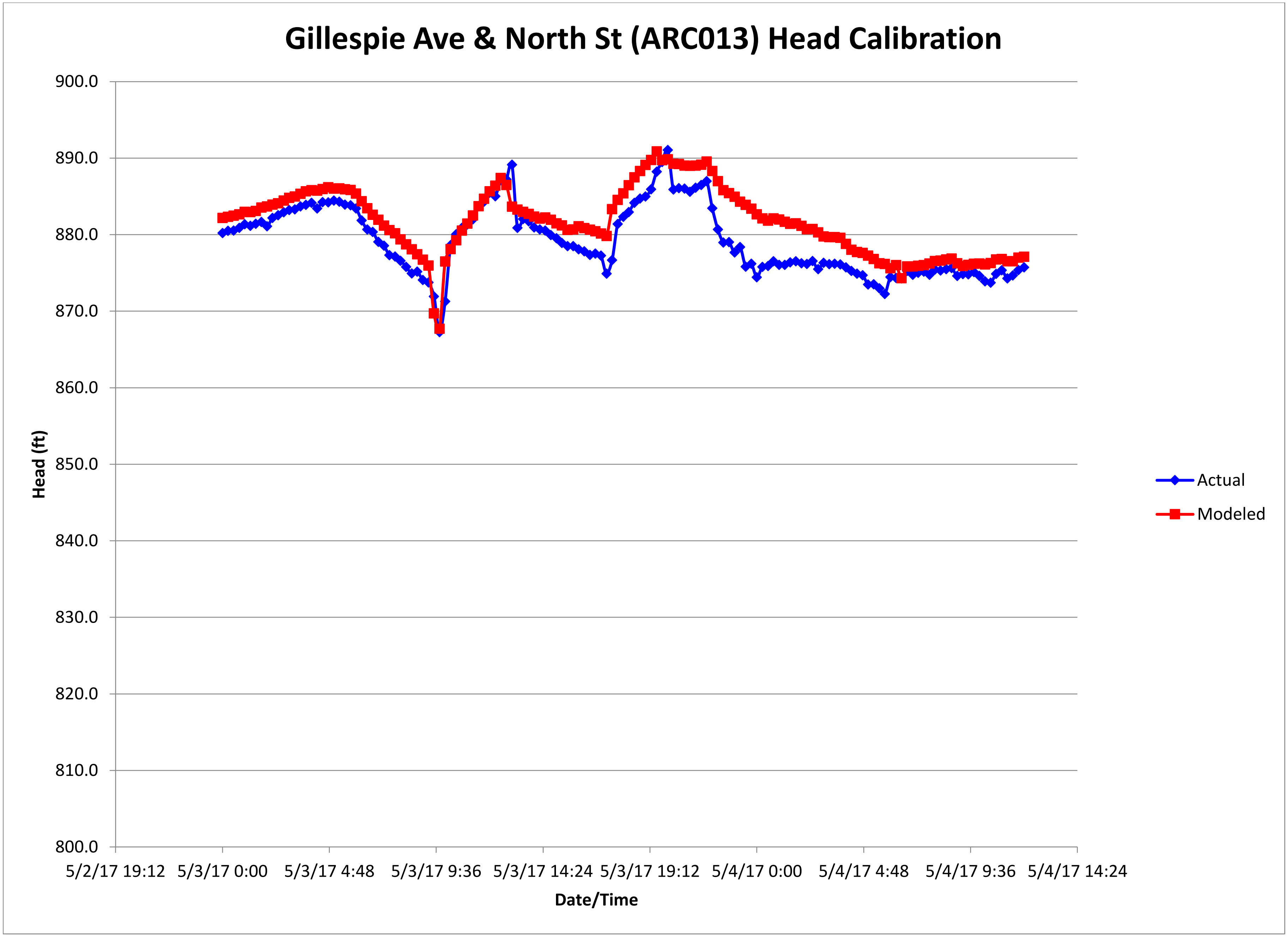
Black Ave & Industrial Ave (ARC010) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

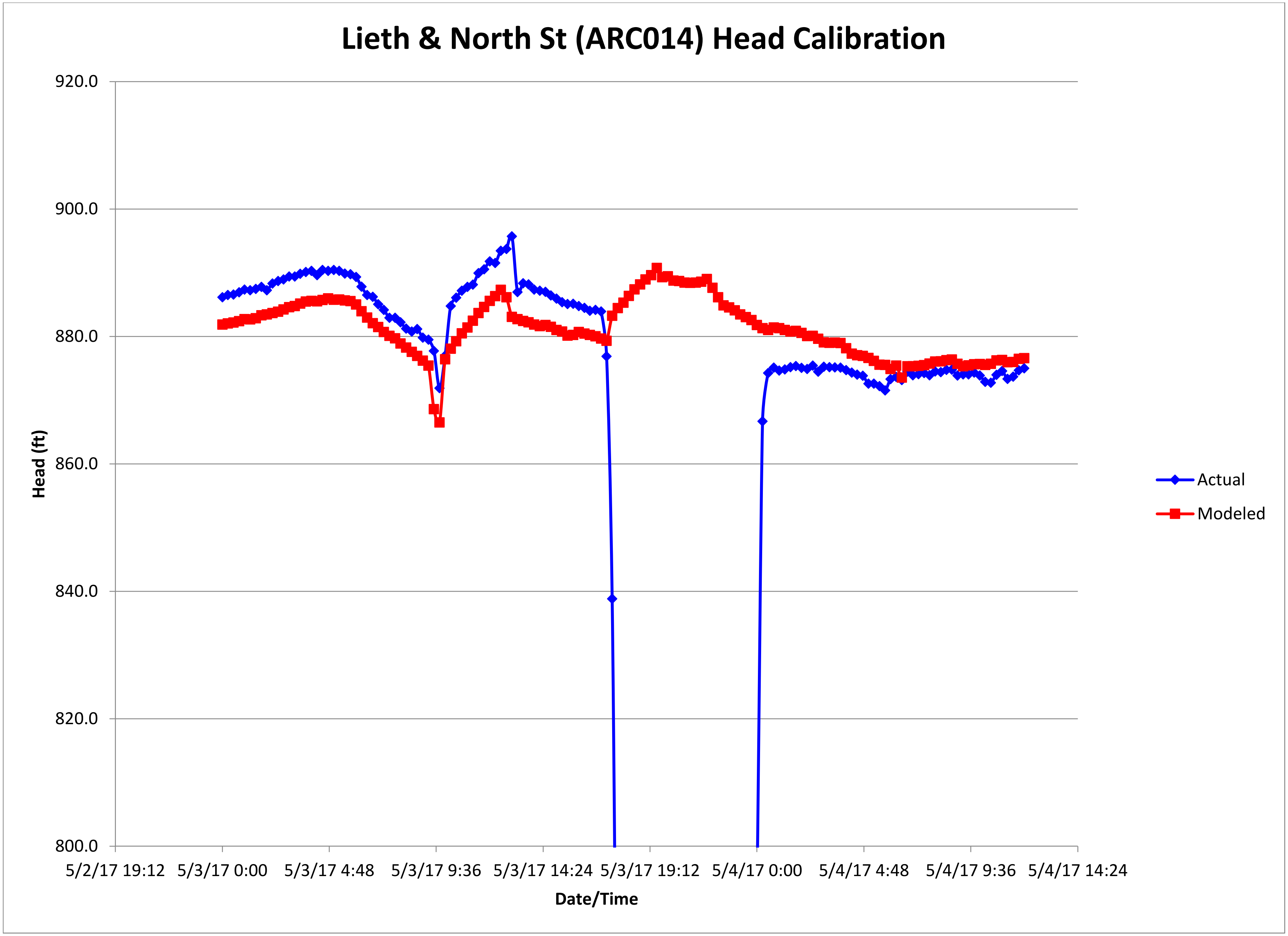


Baltimore & Winthrop Blvd (ARC011) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

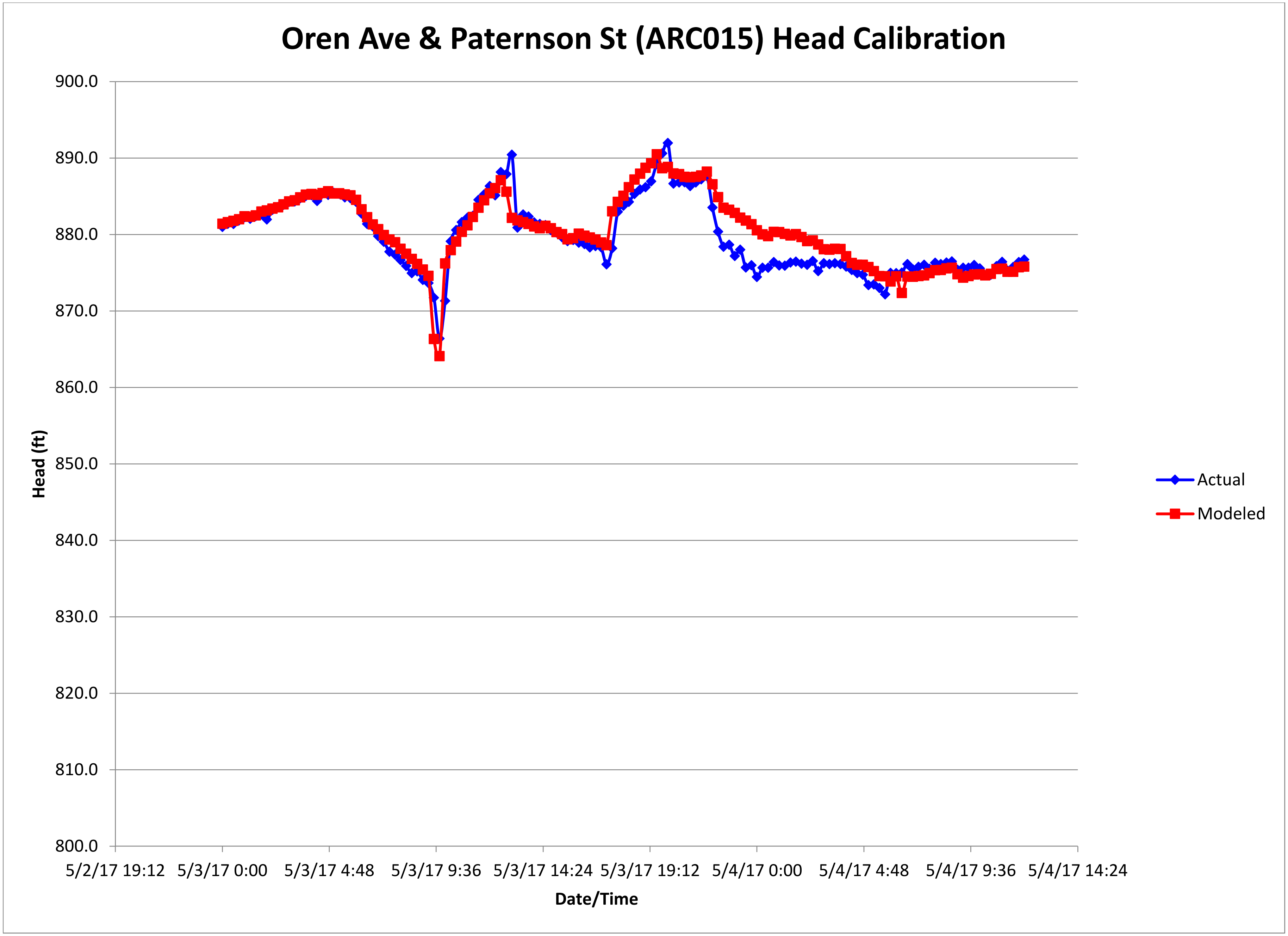


Lorado & Martin Luther King Ave (ARC012) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

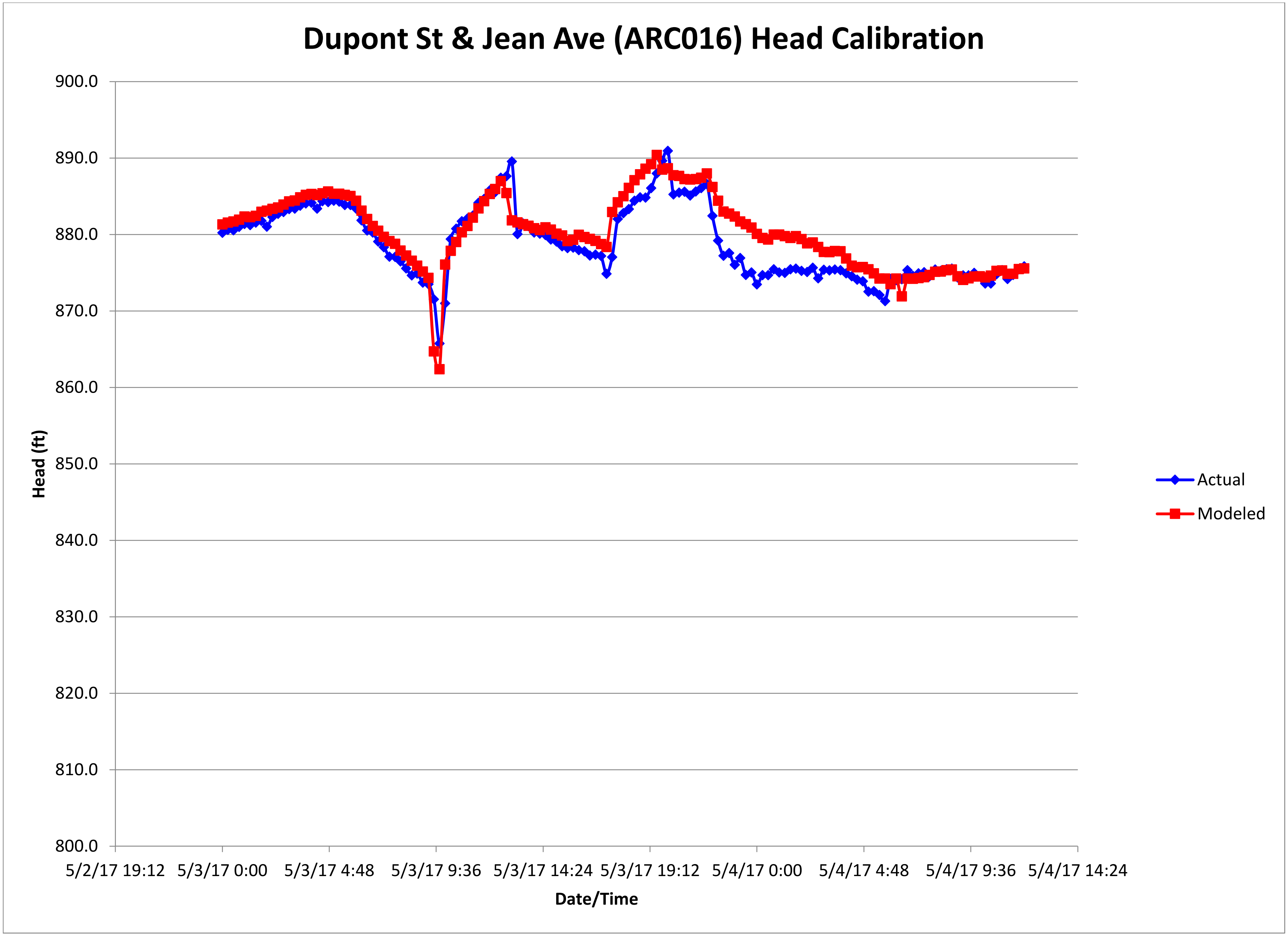

Gillespie Ave & North St (ARC013) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



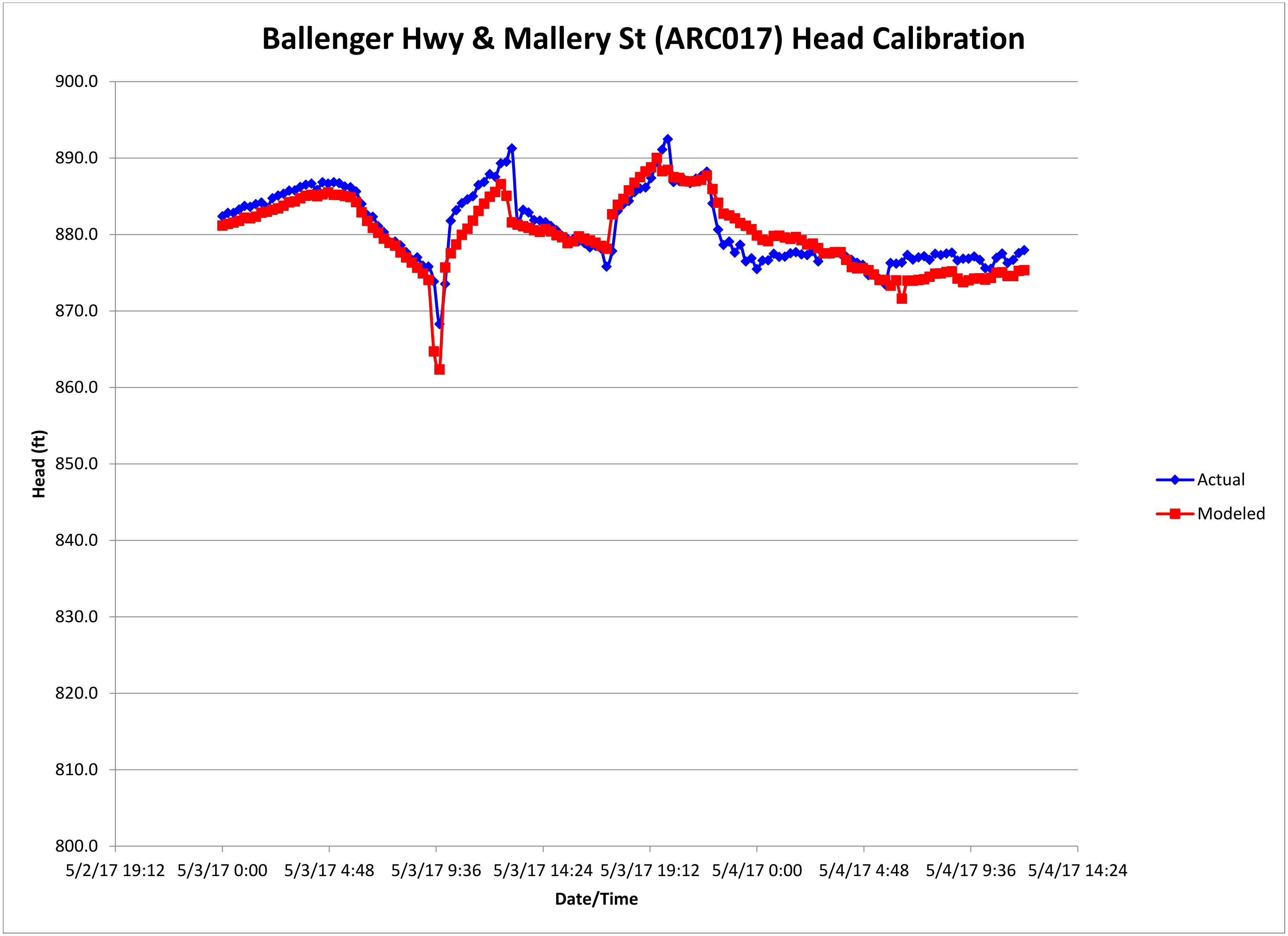
Lieth & North St (ARC014) Head Calibration
920.0
900.0
880.0
860.0
840.0
820.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



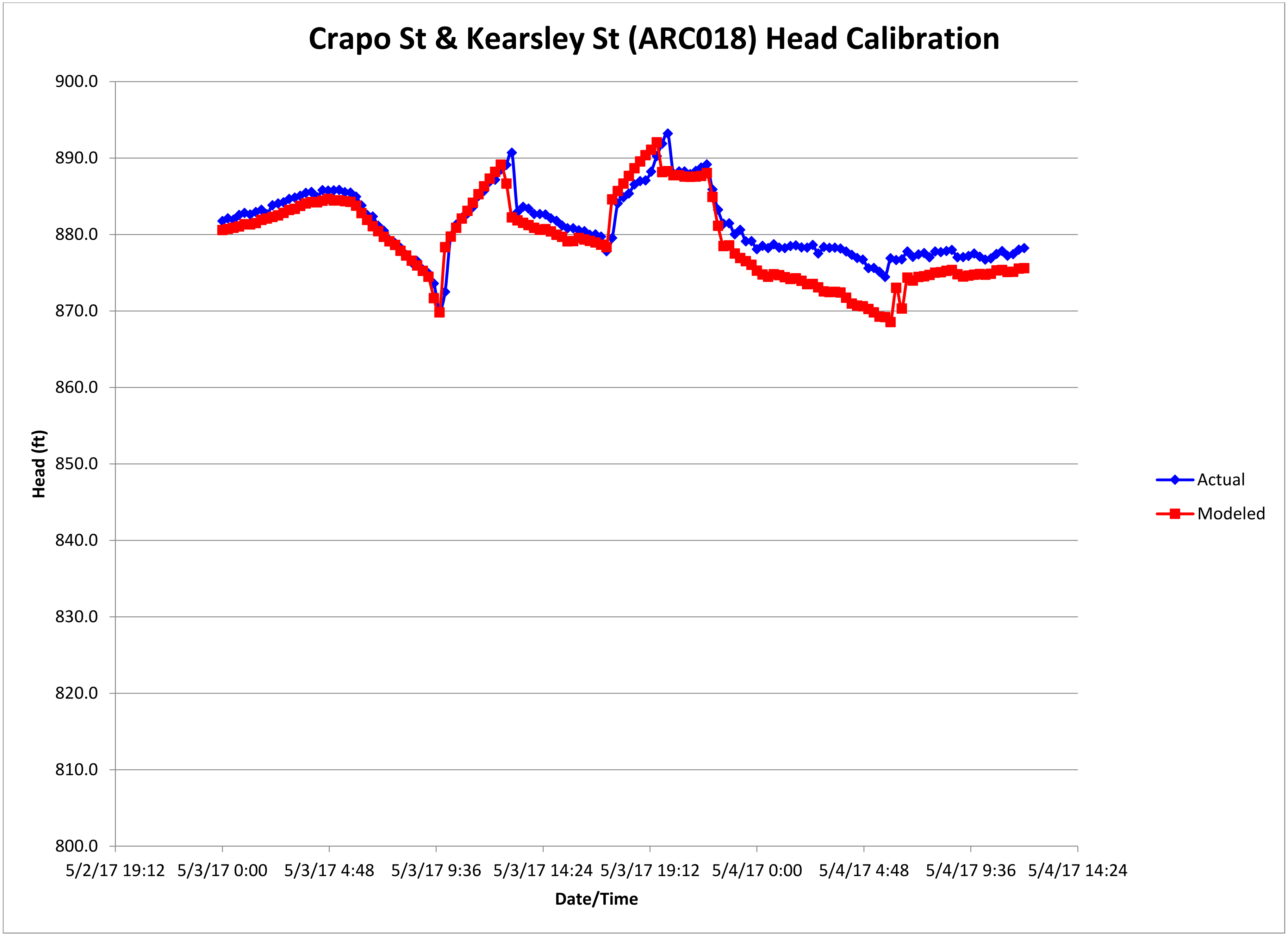
Oren Ave & Paternson St (ARC015) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



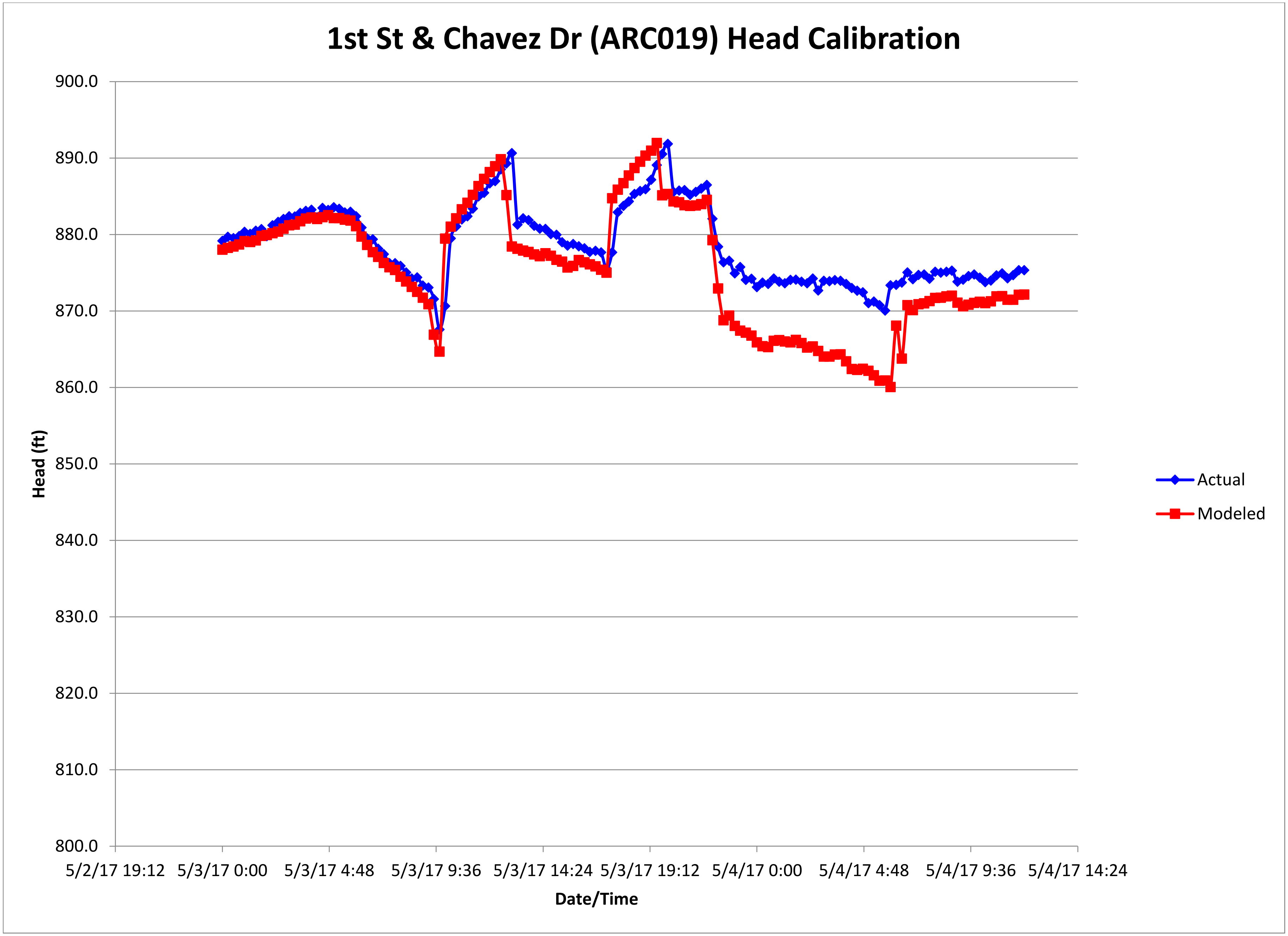
Dupont St & Jean Ave (ARC016) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



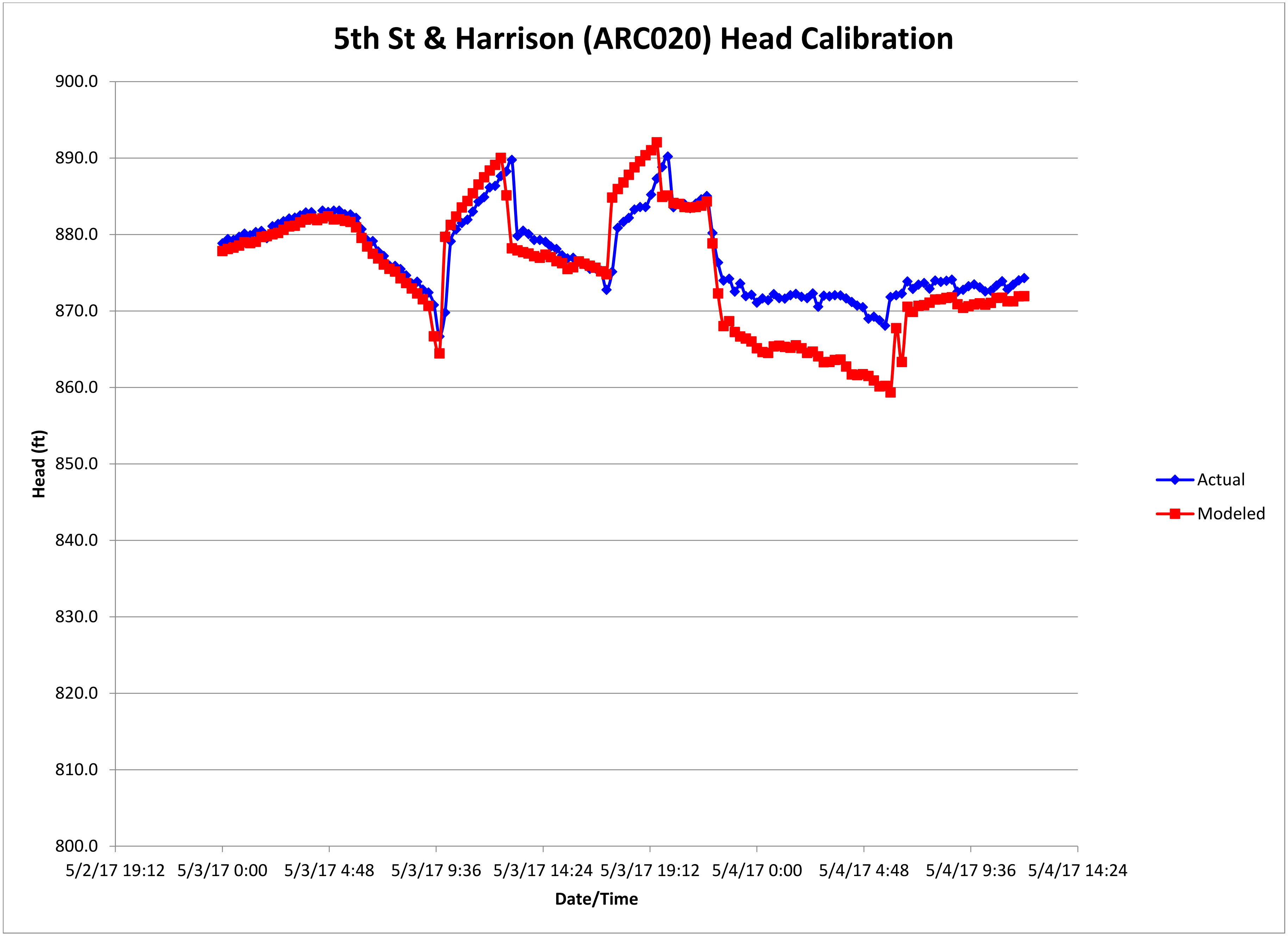
Ballenger Hwy & Mallery St (ARC017) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



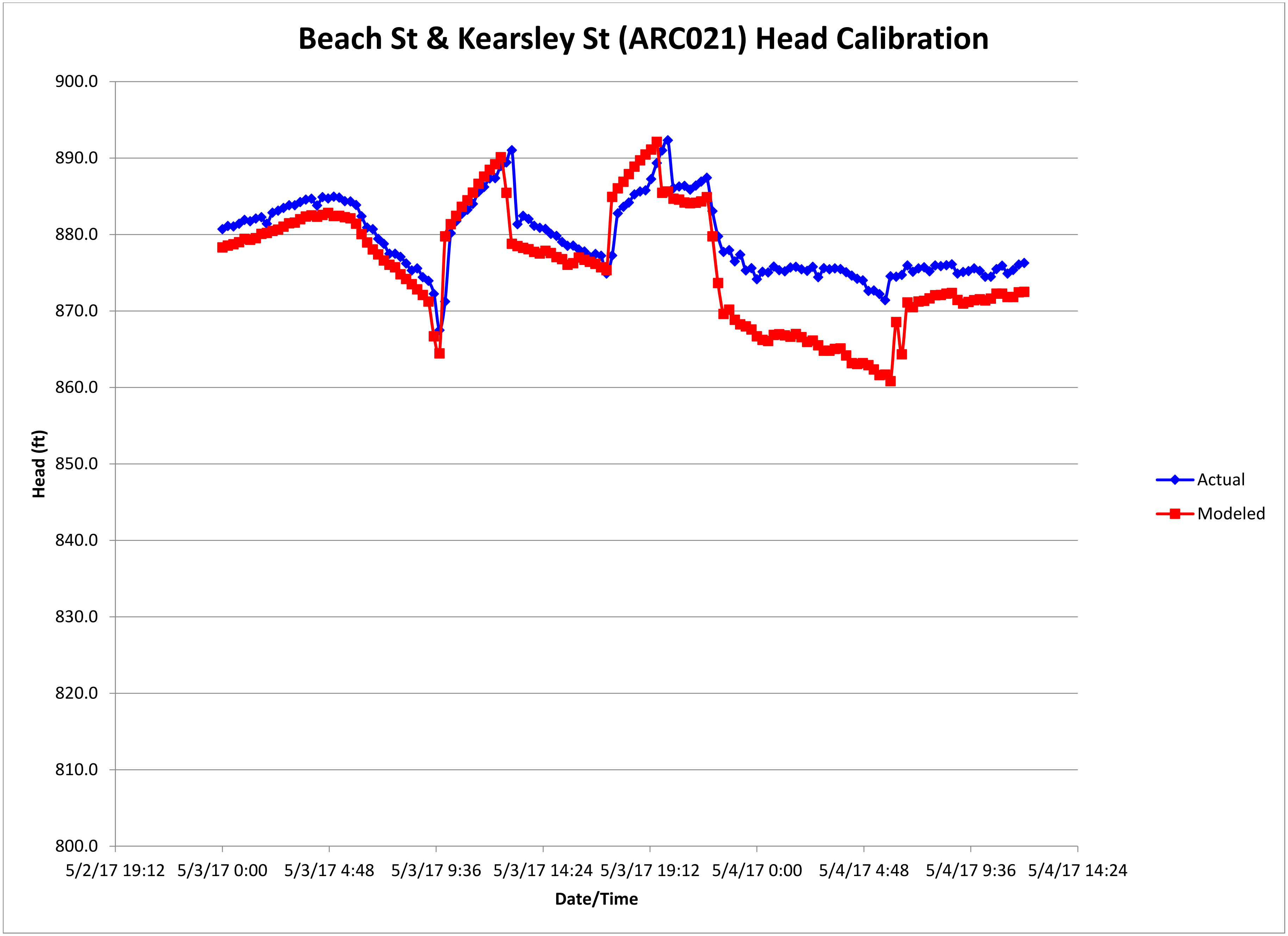
Crapo St & Kearsley St (ARC018) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



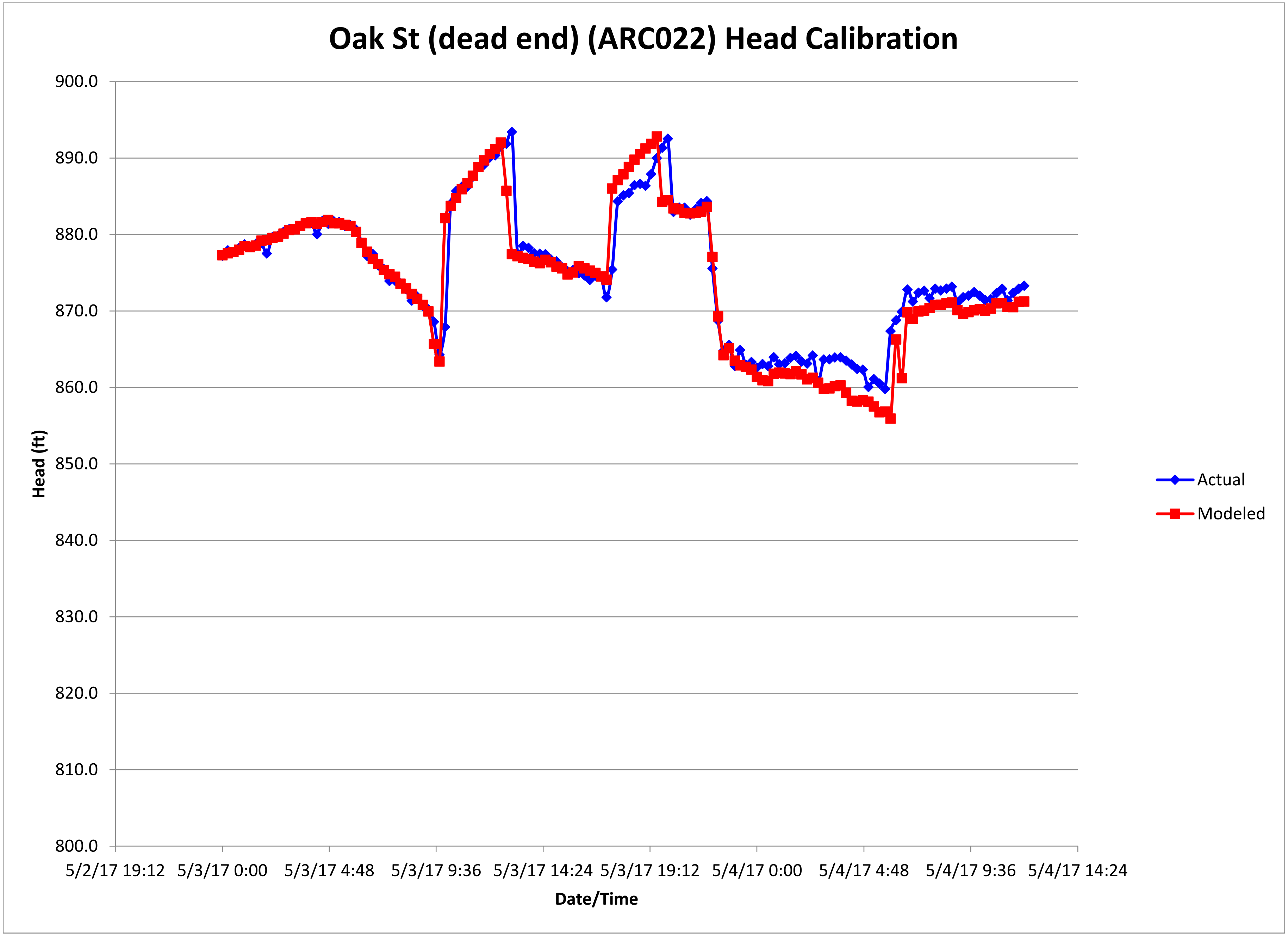
1st St & Chavez Dr (ARC019) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



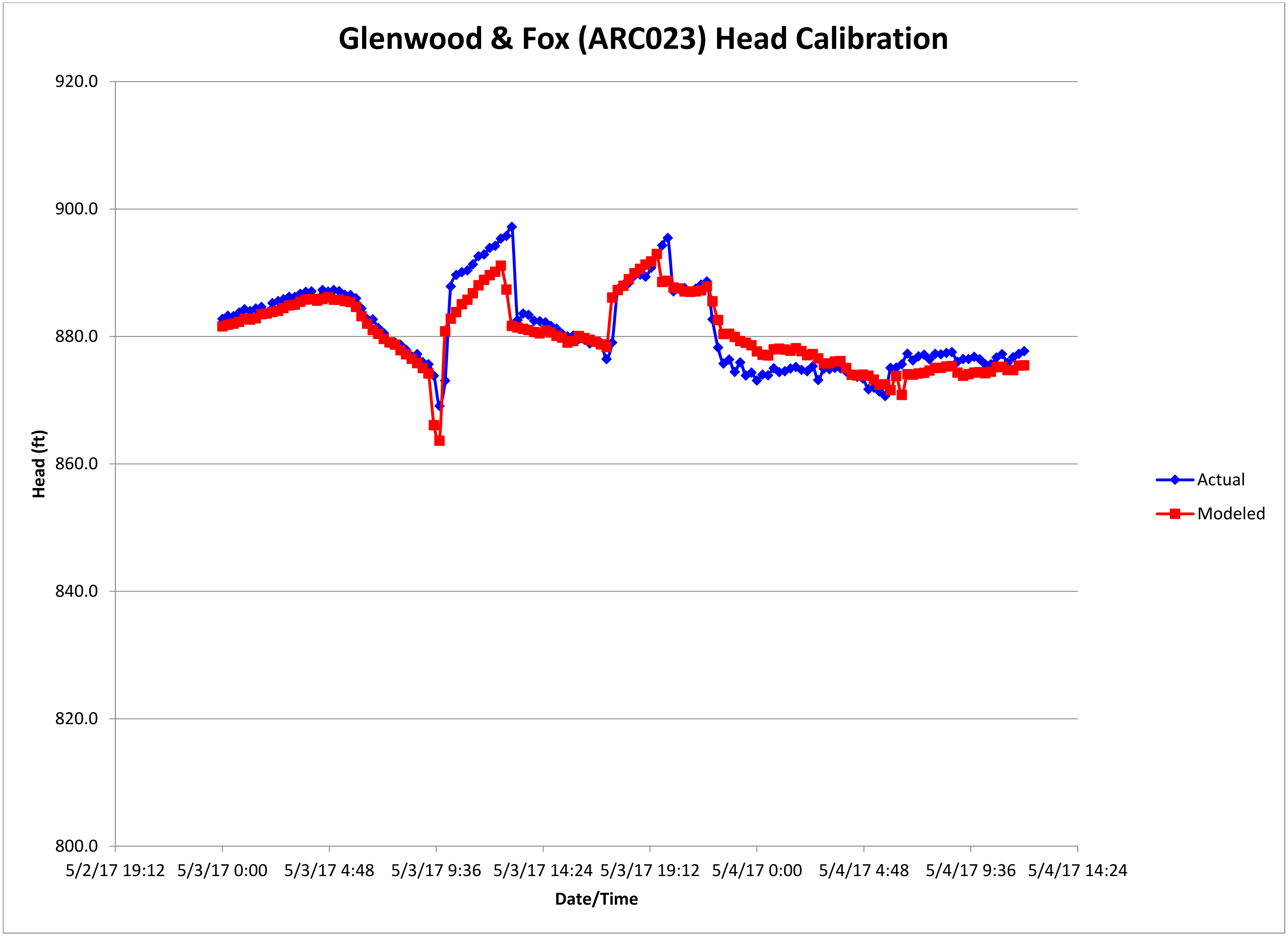
5th St & Harrison (ARC020) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

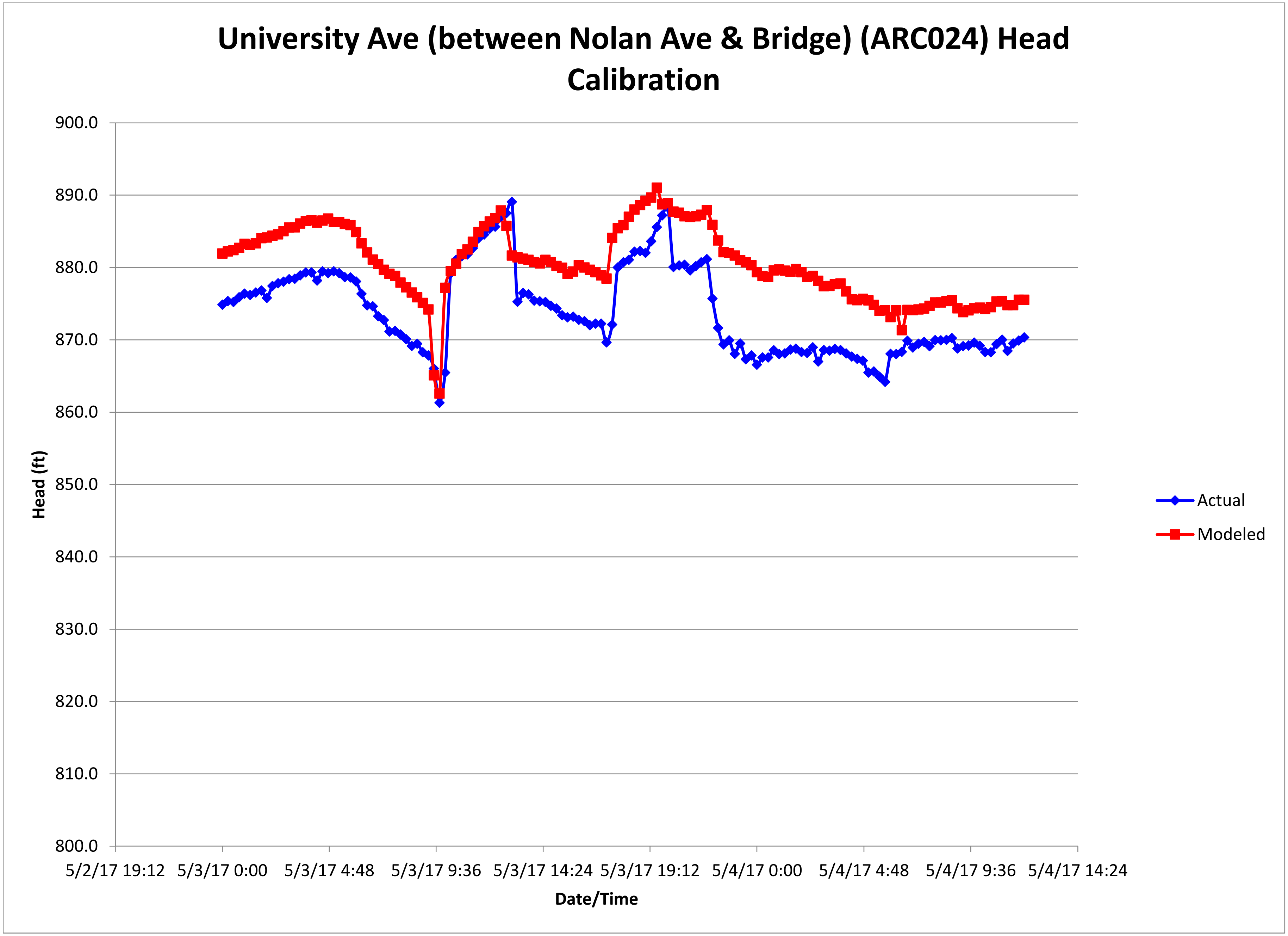


Beach St & Kearsley St (ARC021) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

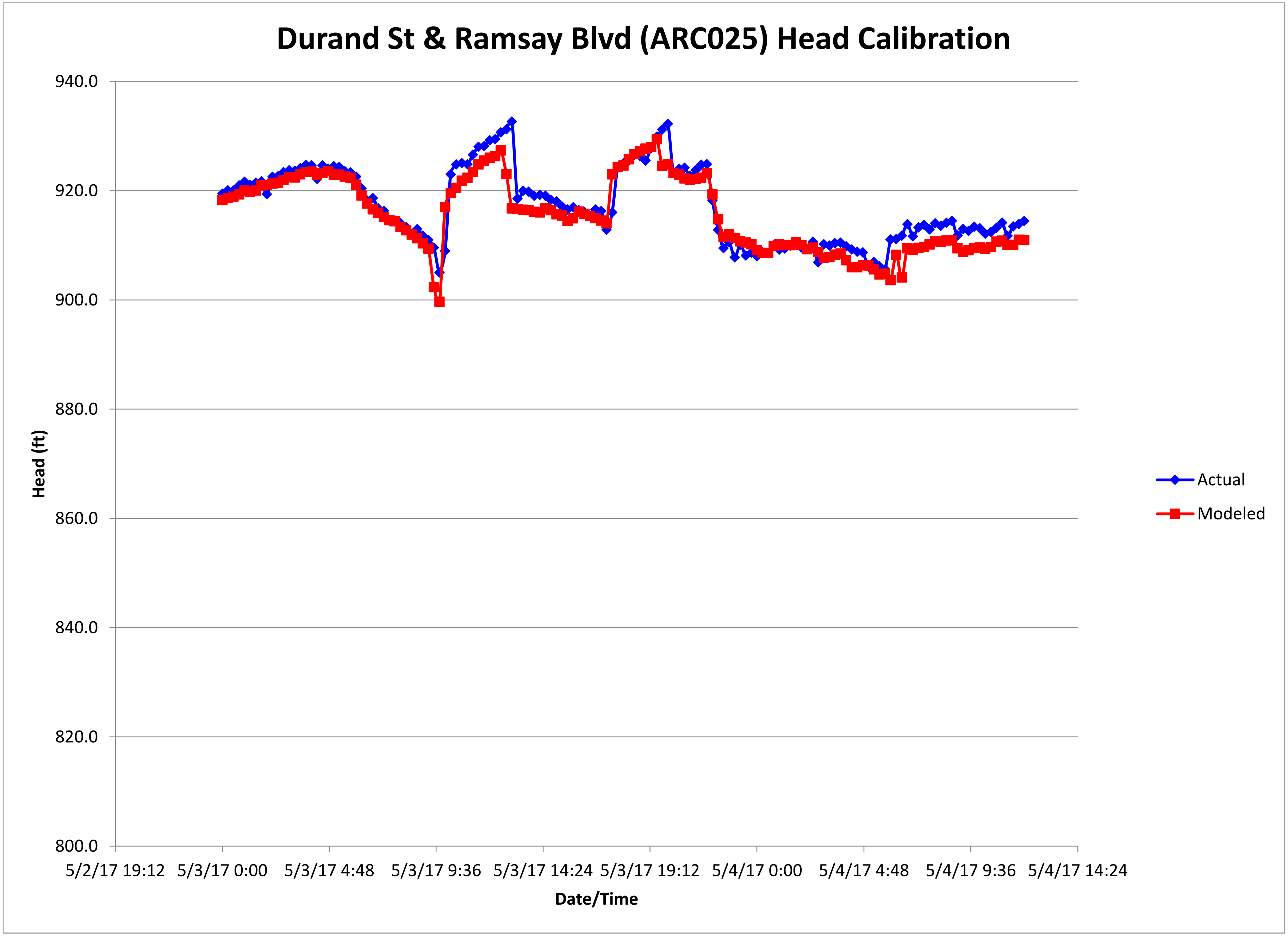


Oak St (dead end) (ARC022) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

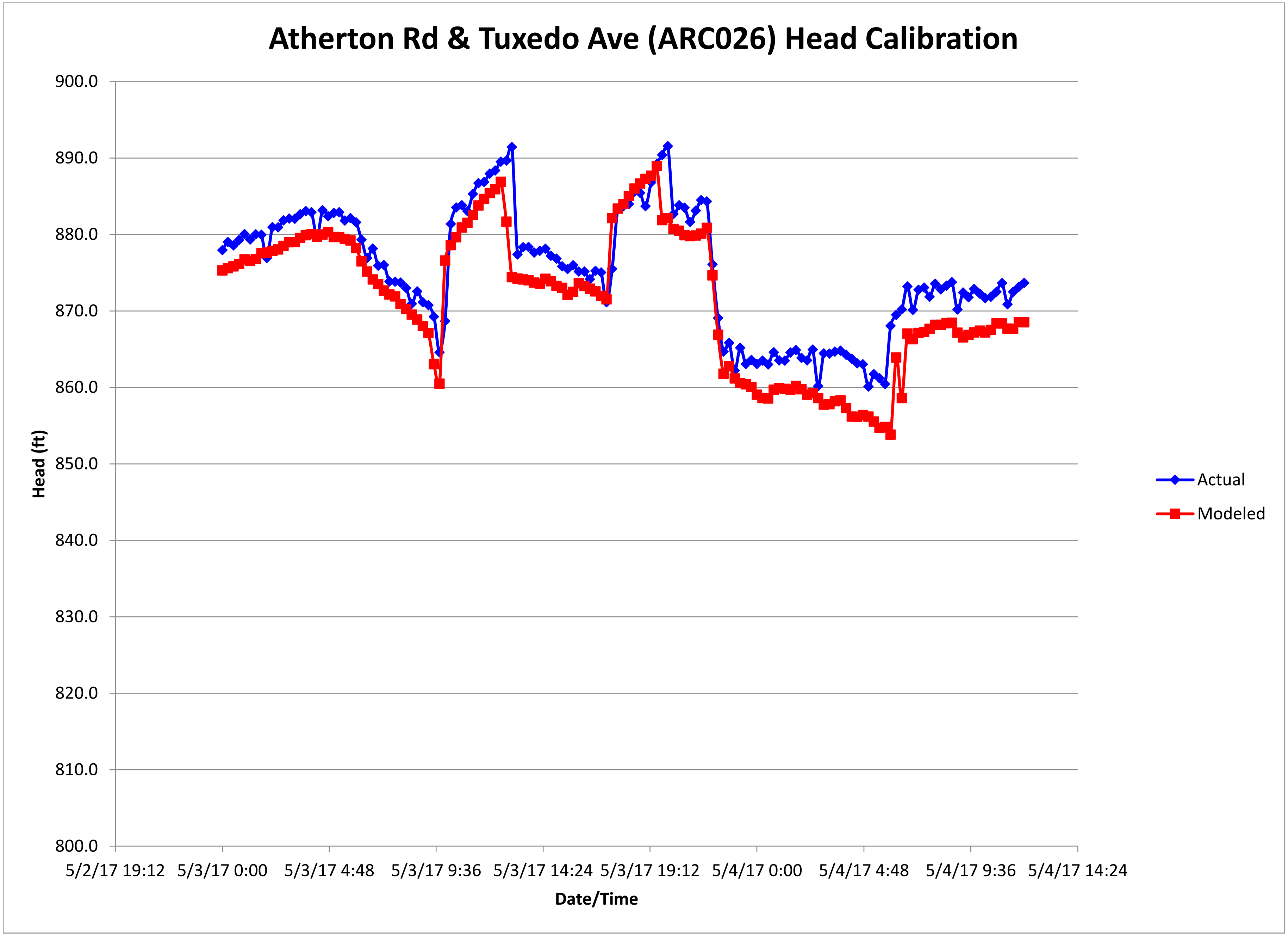

Glenwood & Fox (ARC023) Head Calibration
920.0
900.0
880.0
860.0
840.0
820.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled



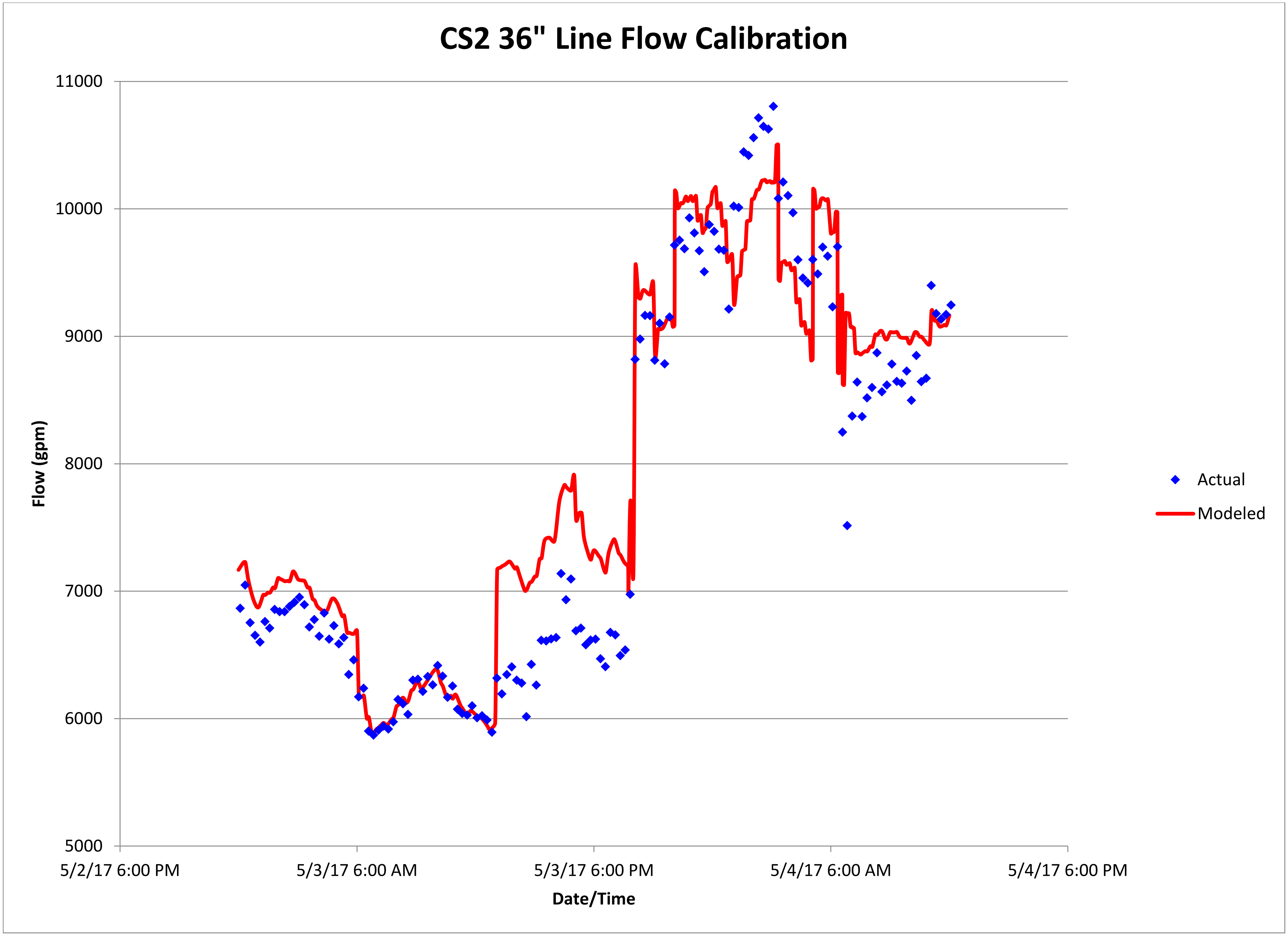
University Ave (between Nolan Ave & Bridge) (ARC024) Head Calibration
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

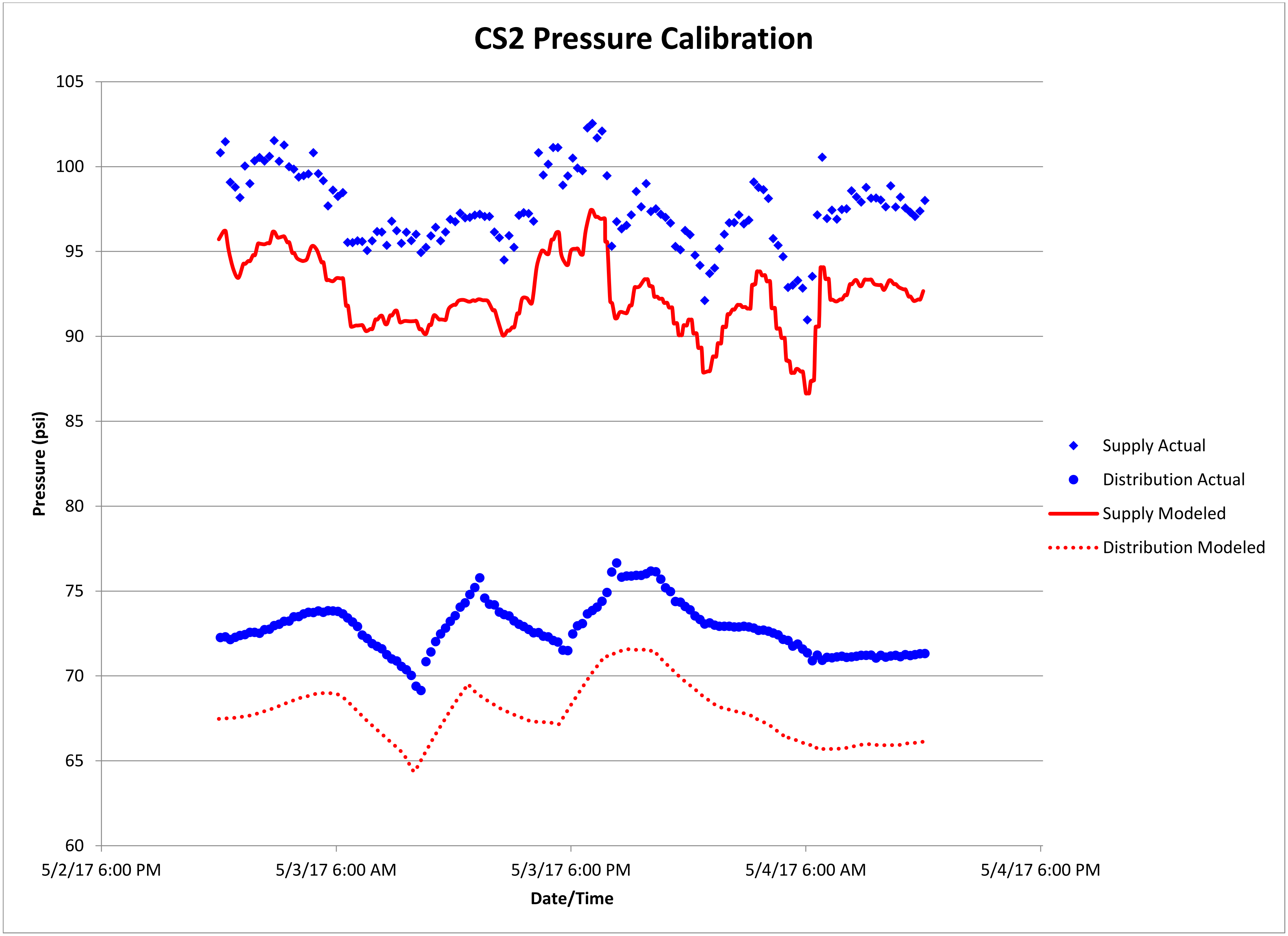


Durand St & Ramsay Blvd (ARC025) Head Calibration
940.0
920.0
900.0
880.0
860.0
840.0
820.0
800.0
Head (ft)
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

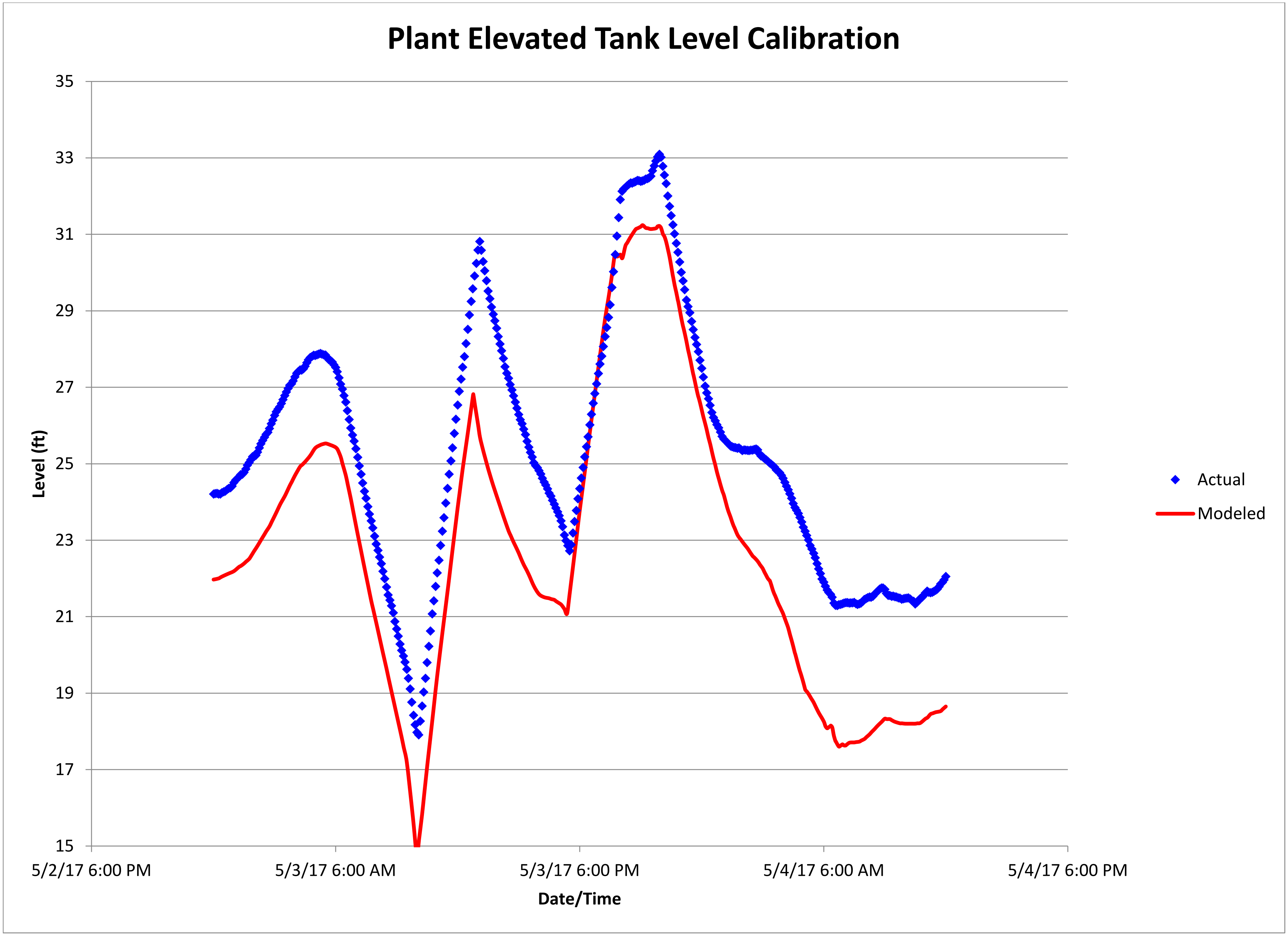


Atherton Rd & Tuxedo Ave (ARC026) Head Calibration
Head (ft)
900.0
890.0
880.0
870.0
860.0
850.0
840.0
830.0
820.0
810.0
800.0
5/2/17 19:12
5/3/17 0:00
5/3/17 4:48
5/3/17 9:36
5/3/17 14:24
5/3/17 19:12
5/4/17 0:00
5/4/17 4:48
5/4/17 9:36
5/4/17 14:24
Date/Time
Actual
Modeled

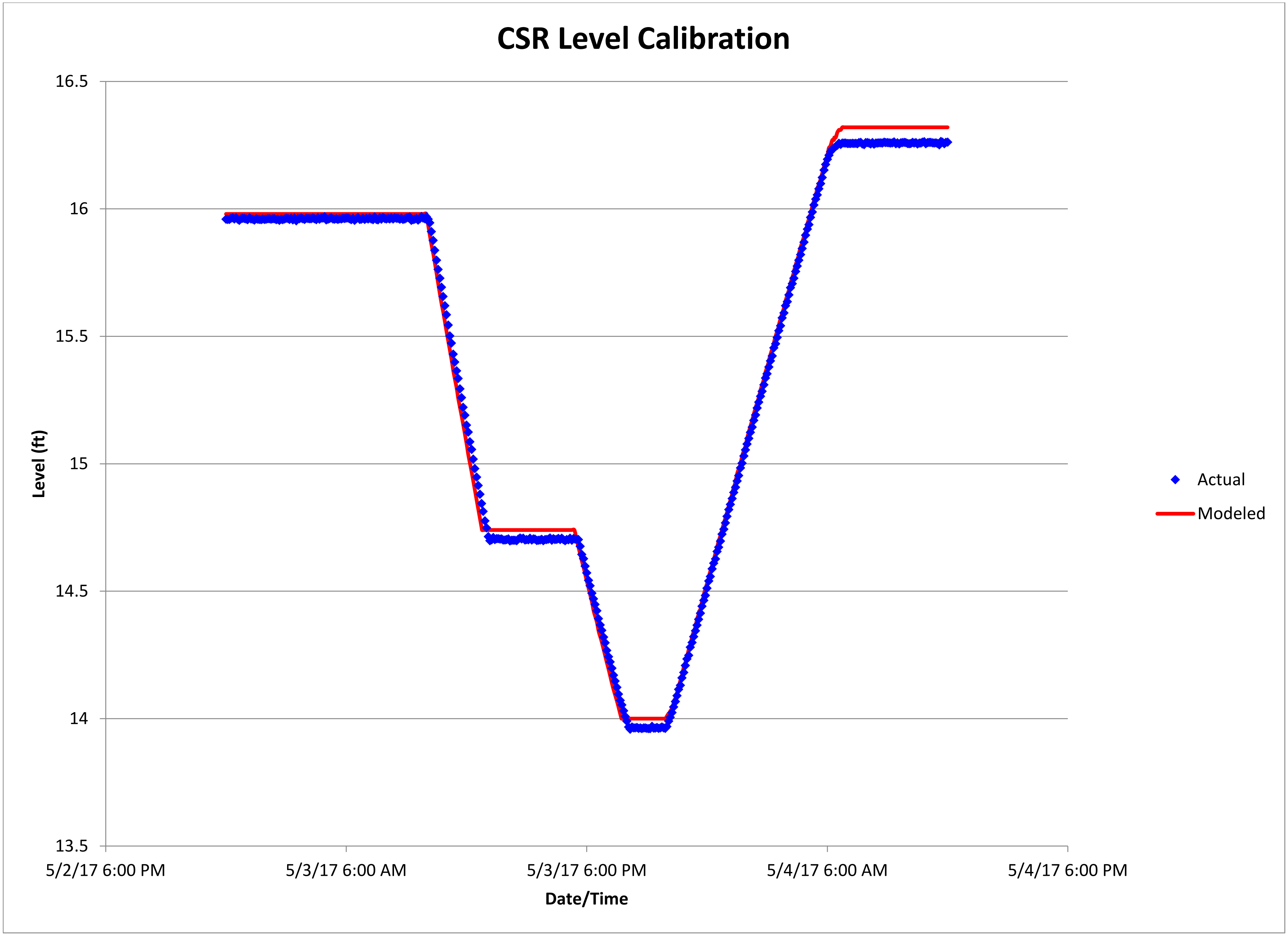

CS2 36" Line Flow Calibration
11000
10000
9000
8000
7000
6000
5000
Flow (gpm)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Actual
Modeled



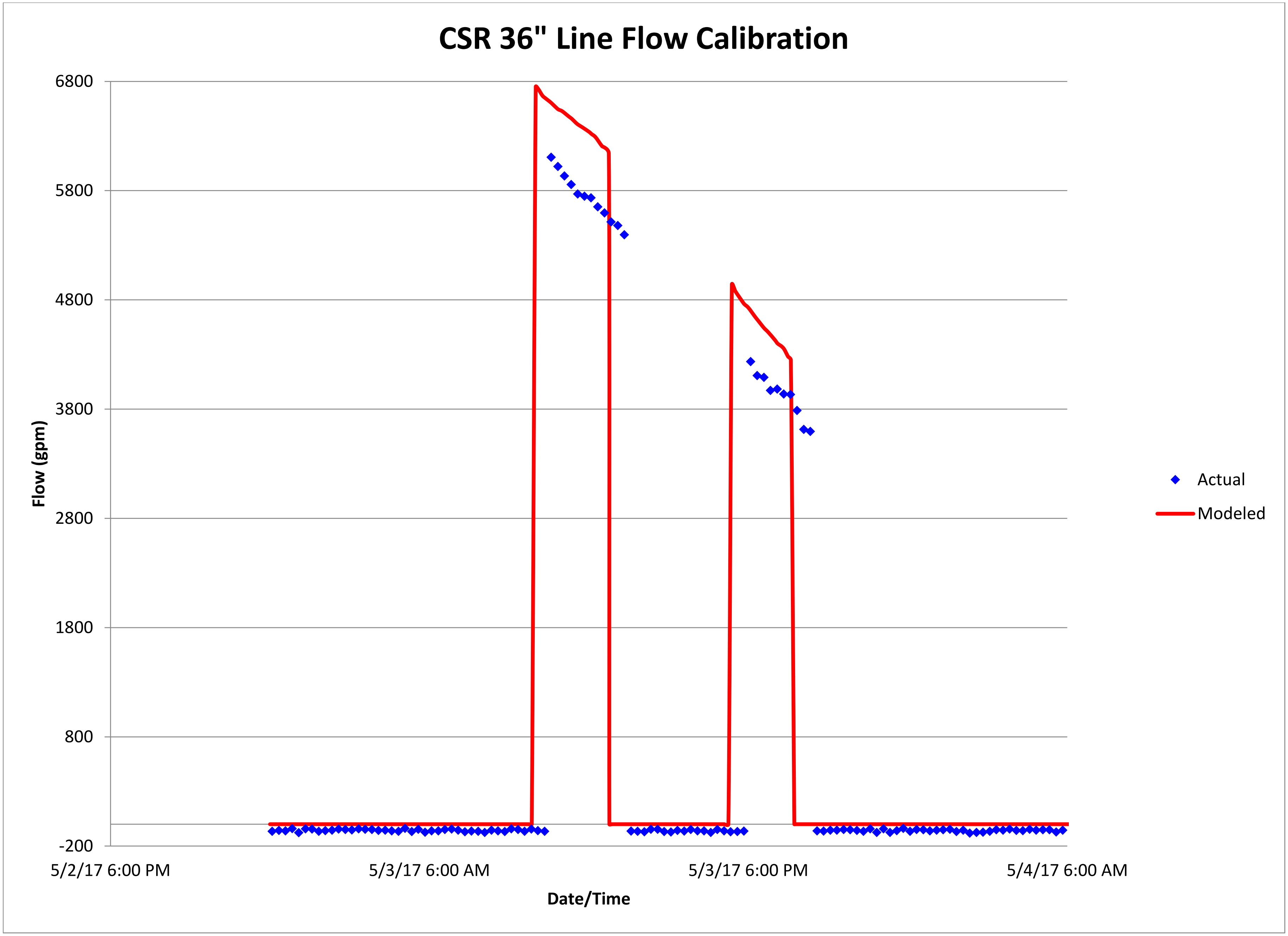
CS2 Pressure Calibration
105
100
95
90
85
80
75
70
65
60
Pressure (psi)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Supply Actual
Distribution Actual
Supply Modeled
Distribution Modeled



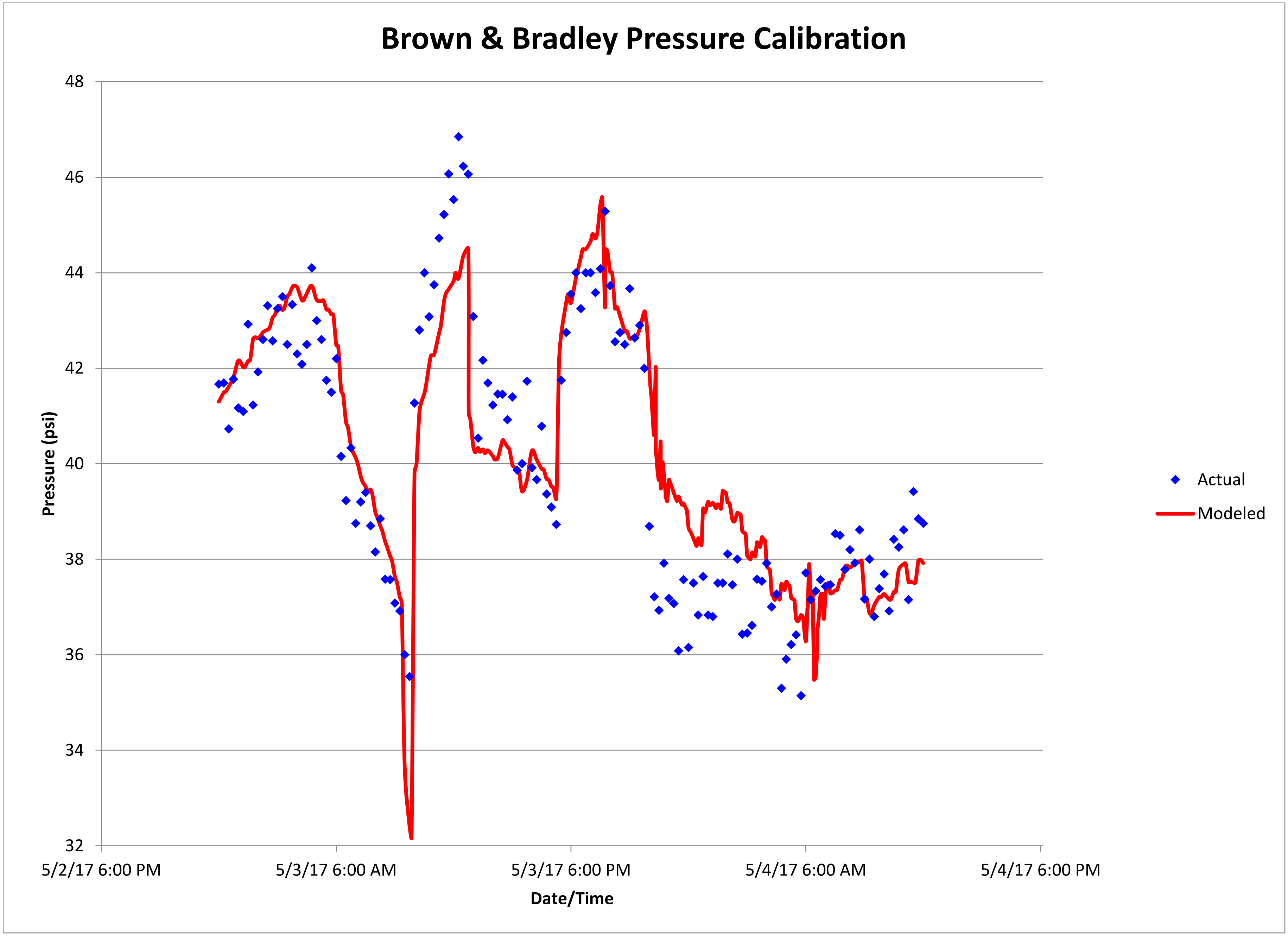
Plant Elevated Tank Level Calibration
35
33
31
29
27
25
23
21
19
17
15
Level (ft)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Actual
Modeled



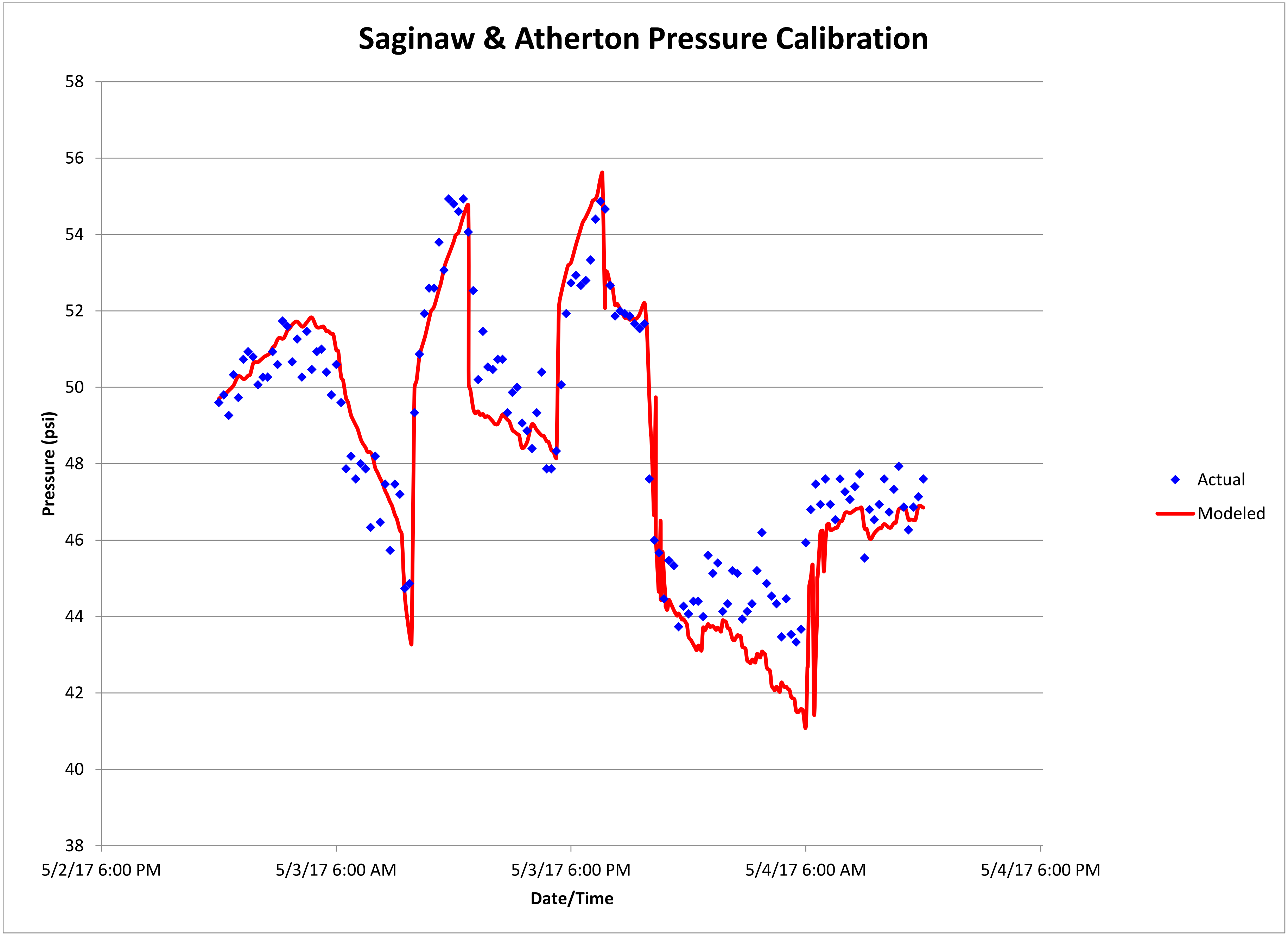
CSR Level Calibration
16.5
16
15.5
15
14.5
14
13.5
Level (ft)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Actual
Modeled



CSR 36" Line Flow Calibration
6800
5800
4800
3800
2800
1800
800
-200
Flow (gpm)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
Date/Time
Actual
Modeled



Brown & Bradley Pressure Calibration
48
46
44
42
40
38
36
34
32
Pressure (psi)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Actual
Modeled


Saginaw & Atherton Pressure Calibration
58
56
54
52
50
48
46
44
42
40
38
Pressure (psi)
5/2/17 6:00 PM
5/3/17 6:00 AM
5/3/17 6:00 PM
5/4/17 6:00 AM
5/4/17 6:00 PM
Date/Time
Actual
Modeled

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ADDENDUM 1

STORAGE ANALYSIS UPDATE

MEMO

To:

City of Flint, MI

From:

Arcadis of Michigan, LLC

Arcadis of Michigan, LLC
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Suite 500
Novi
Michigan 48377
Tel 248 994 2240
Fax 248 994 2241

Date:

April 4, 2018

Arcadis Project No.:

20616001.0000

Subject:

Addendum No. 1 to the *Hydraulic Modeling Technical Memorandum, January 2018*

Per the City's request, an additional model scenario was developed to help analyze specific conditions that were outside the original scope of work. This new scenario examines the operation of both Dort Reservoir and Cedar Street Reservoir at half capacity (by volume) to reduce water age in the system during seasons of low demands. Findings and recommendations from this additional scenario are summarized below.

Storage Analysis

Approach

The operation of Cedar Street Reservoir in conjunction with Dort Reservoir was modeled as part of a winter main break scenario, and was presented in the *Hydraulic Modeling Technical Memorandum, January 2018*. The winter main break scenario assumed a maximum daily demand of 24 million gallons per day (MGD), which reflects historical demands that result from excessive main breaks that have occurred during winter. An average day demand simulation of 12.4 million gallons per day was also performed to evaluate water ages. For the revised scenarios, the tank diameters were reduced by half (this assumes the total storage in each reservoir could be divided in half) while the supply flow from the Great Lakes Water Authority (GLWA) continued to be limited to 15 MGD. Modeling Dort Reservoir or both Reservoirs at half capacity by altering operating water levels (as opposed to smaller diameter tanks) would be expected to produce similar hydraulic and water age results due to the pumping operations at these facilities. As revisions to reservoir operations progress, additional modeling of the reservoirs should be performed during detailed design of the upcoming pump station improvements. Key results of the additional simulations are presented below.

Results

For the winter demand scenario, the deficit in supply versus demand causes all tanks (Cedar Street Reservoir, Dort Reservoir and the Water Treatment Plant Elevated Tank (West Side Reservoir is offline per previous recommendations)) to completely drain within 38 hours or less (see Figures A1 and A2). Hydraulic grade line, available pressures and available fire flow rates during this time were not evaluated for this scenario because these are atypical conditions and service would not be available once the tanks drained completely. Additionally, the results for both parameters at the start of the simulation would be the same as base results presented in the original technical memorandum.

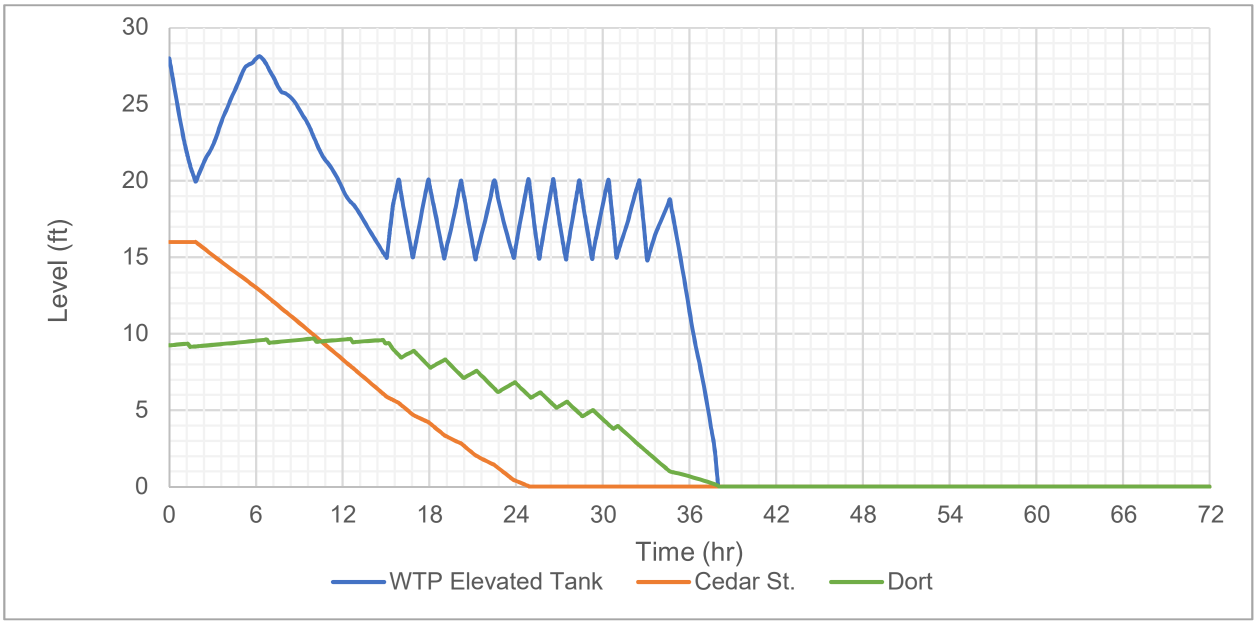


Figure A1. Modeled Tank Water Levels during Winter Conditions with Dort and Cedar Street Reservoirs at Half Capacity

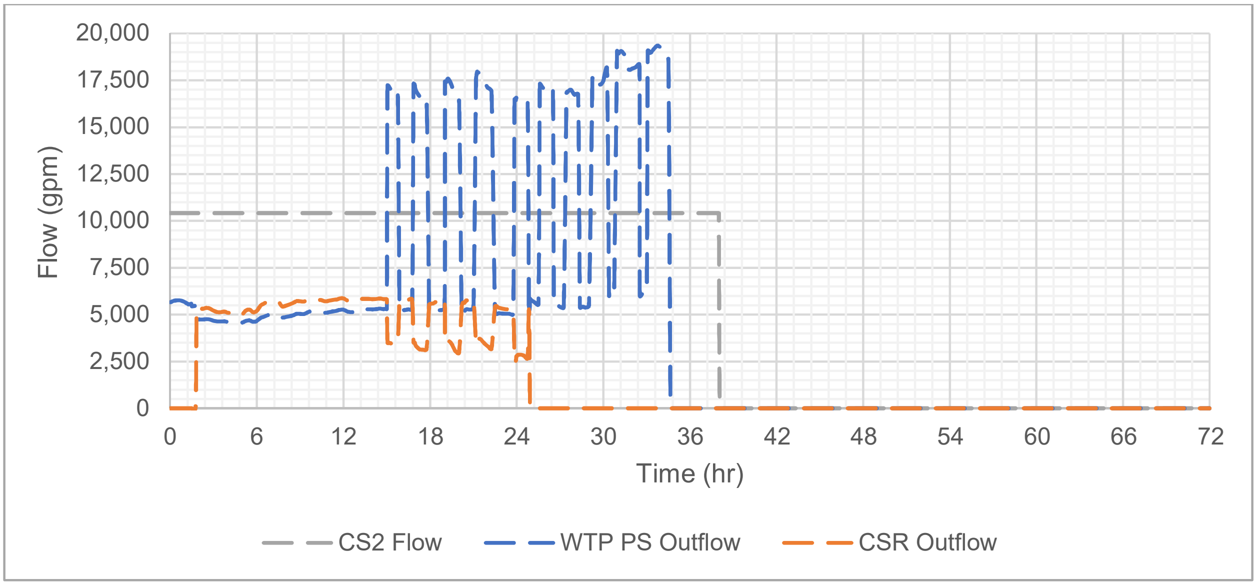
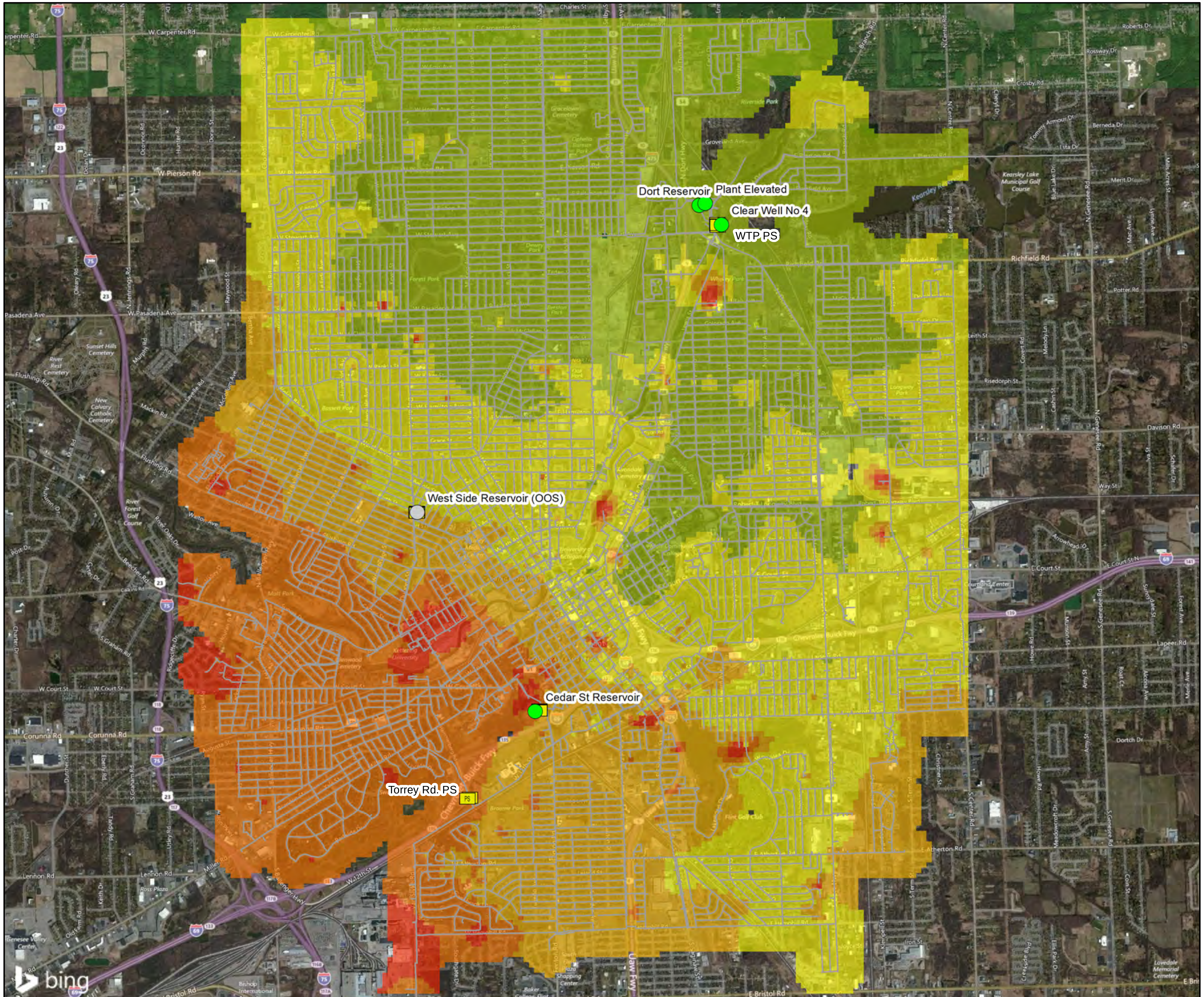


Figure A2. Modeled Pump Station Flow Rates during Winter Conditions with Dort and Cedar Street Reservoirs at Half Capacity

System water age was evaluated using the reduced capacity scenario described above. The analysis kept Cedar Street Reservoir and Dort Reservoir online at half capacity each while the system experienced average day demands of 12.4 MGD. Model results are presented in Figure A3 and show an overall lower water age throughout the system as compared to the water age modeled under the original full capacity scenario with both reservoirs online. The highest water ages in the southwest portion of the distribution system would be less than 11 days and the system would see a slight reduction in water age with more areas seeing water ages less than 5 days.

Based on these model simulations, the temporary reduction in storage volume appears feasible. During extreme winter demands, the available supply time is reduced by almost half compared to having full storage volume. However, this scenario still results in greater storage volume compared with having Dort Reservoir offline during this time (as is presently operated). Additionally, reduced storage during average demands shows a reduction in water age across the City compared to operating Dort Reservoir at full capacity. Having flexibility in operations to bring a larger portion of the storage capacity online may allow this to be a feasible full-time operating strategy (e.g. filling Dort Reservoir above half capacity if possible during the lowest time within the diurnal demands until extreme demands from main breaks are reduced).

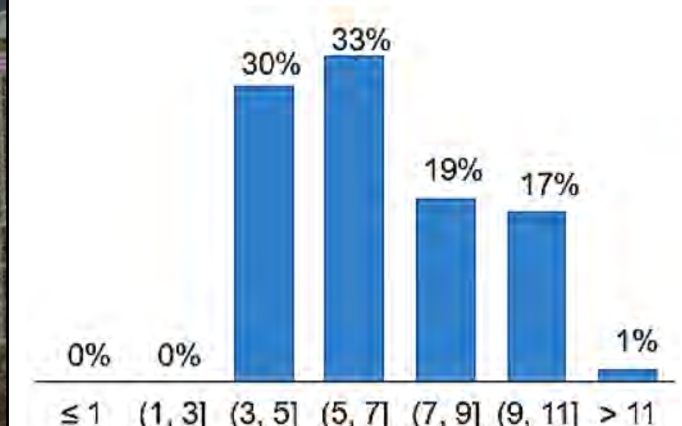


Legend

- In Service Tanks
- Out of Service Tanks
- Model Pumps
- Existing Pipe

Average Water Age (days)

- < 1
- 1 - 3
- 3 - 5
- 5 - 7
- 7 - 9
- 9 - 11
- > 11



0 1 2 Miles

N

City of Flint, MI

Hydraulic Modeling Analysis

CSR & Dort ADD Scenario: Water Age Reduced Tank Capacity

ARCADIS Design & Consultancy for natural and built assets

FIGURE **A3**

City: Flint, MI Div/Group:Water Created By:Arcadis Last Saved By: DMann
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