TM-11: Modeling Approach

1.0 Introduction

A hydraulic model is the major engineering tool used to analyze a water system for master planning efforts. Using a model allows for multiple "what if" scenarios to be analyzed for current and future demand conditions and development of alternatives to address problems and challenges identified for the planning period. Not only can the model be used to provide preliminary sizing of water mains, volume and location of reservoirs, and pumping capacity; it can also be used to characterize and assess transmission system water quality, and energy requirements for pumping.

The purpose of this technical memorandum is to describe the modeling approach used for the DWSD Water Master Plan Update. The modeling approach for this project was divided into two phases.

The modeling efforts for Phase 1 were performed to identify near term solutions (within the next 5 years). This analysis is required to be completed within the first nine months of the project to address specific concerns identified by DWSD and its customers.

In Phase 2, the model analyses centered on identifying improvements through the entire 20 year planning period. The work included identifying capital needs to supply existing and new customers and evaluating operations and potential new efficiencies. Additionally, efforts were focused on reducing regional booster pumping and transmission mains, and distribution mains in Detroit to address the contraction of the population in city and new demands at the outer boundaries of the service area.

2.0 Terminology

Modeling Term	Definition and Application in the Master Plan Update
Real-time Model	Models used to analyze day-to-day operations. The model provided from Metco was built for this type of modeling and the master plan team used it for the Phase 1 work.
Planning Model	Models used to estimate and quantify capital improvements for future needs. The model provided by Metco was revised to a level appropriate for planning purposes. This is the model that will be used for the Phase 2 work.
Model Geometry	Model components that represent the physical water system (pipes, pumps, reservoirs, etc.).
Base Demand	The average day demand of the respective modeling day. The base demand will be multiplied by the hourly demand factors to determine the hourly demands in the models.
Diurnal Patterns	The hourly demand patterns of the each customer community. The pattern represents the average use of water throughout the demand day.
Hourly Demand Factors	The factors that are applied to the base demands to represent the diurnal demand patterns of each community.

3.0 Modeling Tool

In accordance with the CS-1528 contract scope of work, the CDM Smith team used the model provided by DWSD as the base model for the planning study work. This model was developed by Metco under DWSD's Contract No. CS-1499 and is an Extended Period Simulation (EPS) model using the Innovyze software, InfoWater.

The master planning team converted the InfoWater files to Bentley's WaterGEMS model. Both are comparable in capabilities and both use the EPANet algorithms to perform the hydraulic and water quality analyses. All input files used will be provided back to DWSD in both InfoWater and EPANet formats.

An extended period simulation can be used to determine whether the system has the ability to provide acceptable levels of service over a period of minutes, hours, or days. An EPS model analyzes the system demands at designated time intervals (or time steps) throughout the analysis period. Time steps may vary depending on the type of model that is being used. For example, if the model is being used to analyze actual operations, then time steps can be set to match when pumps are turned on and off.

The model developed by Metco used 5 minute time steps and 15 minute report intervals. These models were calibrated to three separate demand days in 2011; a minimum day demand model (12/15/11), an average demand day model (9/15/11) and a maximum day demand model (7/21/11).

For each demand day, the models were calibrated to actual recorded pressures at remote sites in the system. By way of example, the calibration results for the reservoirs for each model are shown in **Table 3-1**.

The Average Mean Error (AME) for each site was calculated for each site based on subtracting the model results for a given time from the measured value corresponding to that time and then taking the average of these differences over all time steps for each date. Negative values mean the model results are generally higher than the measured values.

Model results are presented in 15 minute intervals while the measured values do not necessarily have a regular time interval. The following types of data were considered:

- Measured Pressures at Pump Stations and WTPs
- Measured Pressures at System Monitoring Points (SMPs)
- Measured Water Levels at System Reservoirs
- Measured Pressures at Master Meters (WAMR)

These models were provided to the CDM Smith team during the summer of 2013. A review of the models was conducted by the CDM Smith team with regards to the model geometry and system operations.

Table 3-1: Calibration Results for Phase 1 Hydraulic Model

Reservoir Name	Average Day AME* (psi)	Minimum Day AME (psi)	Maximum Day AME (psi)
Adams Road Pump Station Reservoir Level	-1.23	0.95	1.06
East Side Pump Station Reservoir Level	-0.84	0.04	-0.79
Electric Avenue Pump Station Reservoir Level	-0.22	0.08	0.15
Haggerty Pump Station Reservoir Level	-0.88	0.08	0.55
Ford Road Pump Station Reservoir Level	0.36	0.04	-0.02
Franklin Pump Station Reservoir Level	0.02	0.33	0.55
Michigan Avenue Pump Station Reservoir Level	0	-0.47	-0.5
Imlay City Pump Station Reservoir Level	-0.79	-0.02	0.56
Joy Road Pump Station Reservoir Level	-0.18	0.51	-0.01
Northwest Pump Station Reservoir Level	0.64	-0.2	-0.08
West Service Center Pump Station Reservoir 2 Levels	0.32	-0.71	0.03
Schoolcraft Pump Station Reservoir Level	2.48	-0.01	0.55
West Chicago Pump Station Reservoir Level	1.16	-0.07	0.05
Wick Road Pump Station Reservoir Level	-0.28	1.05	-0.77

* - AME is Average Mean Error of Measured - Calculated

The data used to model the pumps in the system were in agreement with the pump curve information that the CDM Smith team received from DWSD. Furthermore, the reservoir configurations and size and the transmission pipe network appeared to match prior system models used to simulate system operations.

The C-factors in the model simulating the pipe friction and minor losses varied from 50 to 140 throughout the entire transmission system. Lower C-factors are an indication of pipes with rougher surfaces and resulting higher head losses, while higher C-factors are an indication of relatively newer pipelines. The factors in the model appear to be appropriate for the size and age of the system with the lower C-factors typically found in the older mains in and around the City of Detroit and higher C-factors in the suburban transmission system. Nonrevenue water allocations were adjusted by the master planning team based on new information from the Water Audit project, and these adjustments are described below in Section 4.2.

After the review of the model was completed, the CDM Smith team met with the Metco to discuss any questions or findings that were still outstanding. The meeting generated a few additional revisions that were incorporated into the models prior to their use on this project.

4.0 Planning Model Development

For the purposes of system planning, the model geometry provided by DWSD was simplified so that multiple planning scenarios could be completed more efficiently. Additionally, the real losses were re-apportioned in the model based on more current information from DWSD's CS-1396 Comprehensive Water Audit and adjustments to master meter operating ranges were made based on the Metco model accuracy. Each of these is described further below.

4.1 Geometry Revisions

The Metco model is being used for Phase 1 and is being developed for DWSD to provide real-time system control planning that will be integrated with the Ovation SCADA system. Since the models for this project will be used for planning, modifications to the pump curve data and their control valves will be made during Phase 2.

The model contains all of the individual pumps (over 150) and control valves. Although this is necessary for a real-time model that evaluates hour-to-hour pump operations based on actual system use at the time, it is not necessary for a planning model. The planning models will be evaluating the total pumping station and high-lift plant pumping needs based on future demands. Therefore, the planning model will create composite pump curves from the individual pump curves and use a station PRV to simulate station throttling.

DWSD's pumping facilities use pumps arranged for parallel operations. A typical layout is shown in Figure 4-1. Parallel pumps share a common suction (suction header or reservoir) and discharge (header) condition.

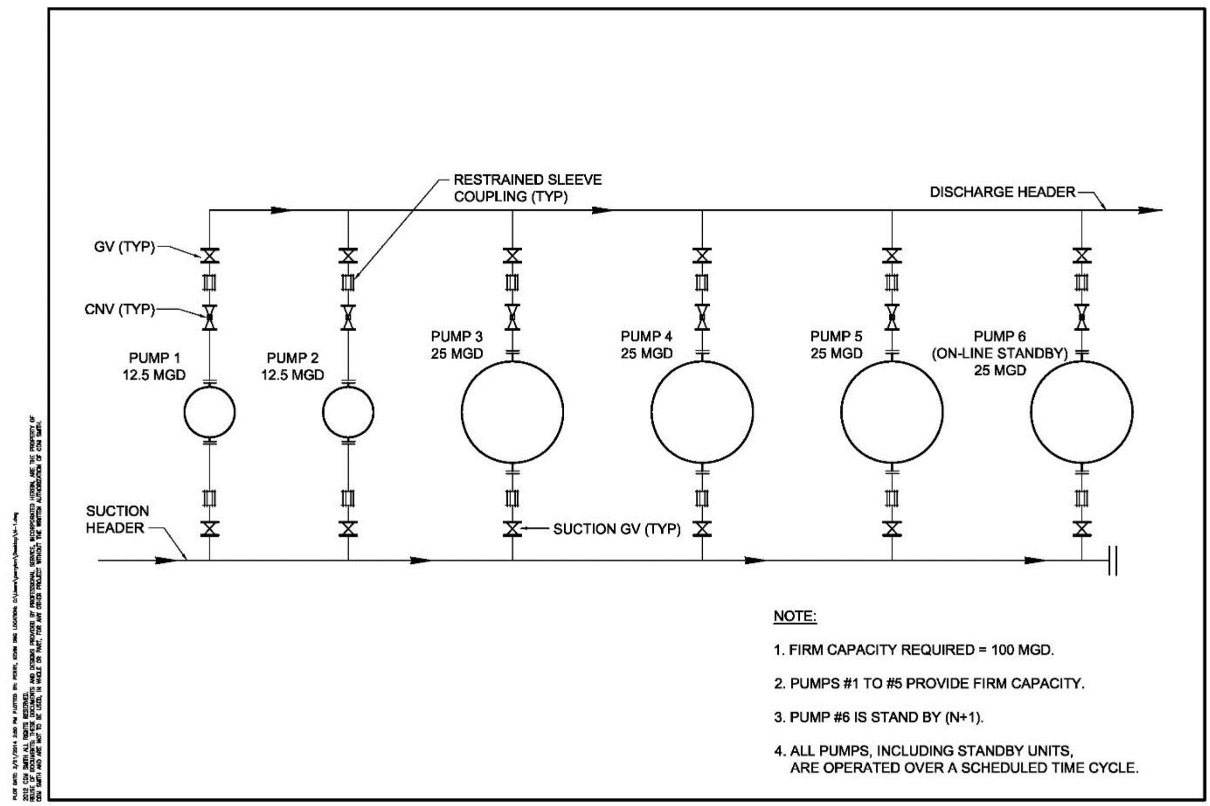

Figure 4-1: Typical Pumping Station Schematic

4.2 Distribution of Real Losses

In the Metco model demands simulating real losses were distributed throughout the model at nodes in a more evenly fashion. This approach tends to overestimate the water loss in the suburban system and under estimate the losses within the City of Detroit. **Table 4-1** summarizes the real losses documented in the water audit report. The Real Losses shown in the transmission systems are estimated based on joint leakage using the Smith Method developed by Jeffery Smith in 1987.

This method is based on pipe age, number of joints, number of valves, pipe diameter, pressure, number of connections, and pipe material in its calculation of leakage. Smith's formula is shown below:

$$L = \frac{(AF)\,[N + F + V + 0 + (1.5 \times S)]\; D \times P \times 0.5}{TF}$$

Where:

L = unavoidable leakage from a given category of transmission main in gph

AF = age factor

N = number of joints

F = number hydrants

V = number valves

O = number other appurtenances

S = number of services

D = nominal diameter in inches

P = average pressure in psi – 55 psi

TF = pipe material type adjustment factor

The input data was collected from DWSD's Summary of Operating Statistics and based on typical design criteria for DWSD's transmission system. The number of pipe joints was estimated based on an average pipe section length of 20 feet.

The number of valves and appurtenances was quantified based on an average of one valve every half mile and other appurtenance every quarter mile. The number of valves or other connections does not significantly affect the water loss calculations because the quantities are relatively small in comparison to the large number of pipe joints.

The Real Losses in the Detroit distribution system were estimated based on water loss associated with leaks and abandoned services.

Table 4-1 DWSD Water System Real Losses

Location	2012 Real Water Loss Volume (MG)	2012 Real Water Loss Volume Percentage (%)
Detroit Retail	87	92
Detroit Transmission System	3	3
Suburban Transmission System	5	5
Total	95	100

The planning model depicting Detroit is comprised only of the transmission mains within the City. Therefore, the real losses associated with Detroit Retail and Detroit Transmission were distributed equally amongst the Detroit nodal demands in the model. The suburban transmission losses were computed as gallons/foot and distributed based on the pipe diameter and pipe length. The demands associated with the Real Losses were applied at the nodes representing the master meters along the pipe routes.

Apparent Losses at the plants, master meters and demands associated with retail use were not accounted for in the model. This is because the pump curves were used at the plants and the demands were built based on categorical uses. Since Apparent Losses are associated with inaccuracies of the recording devices, these demands were not considered applicable to the modeling of the real demands developed for the master plan.

4.3 Master Meter Operating Ranges

The planning model results are based on providing pressures within each customer's contract ranges at the master meters. During the hydraulic modeling analyses conducted for the 2035 planning year it was discovered that many master meter pressures could not be maintained within the contract limits without the use of a PRV. Since many of the future demands were not markedly different than the current demands and PRV's are not located at these master meters additional investigations were conducted.

Further evaluation of the Metco model found that calibration of the model days were based on the measured pressures at pump stations, water treatment plants and at the remote system monitoring points. However, the models were not calibrated based on the pressures at the wholesale customer meters.

Therefore, to account for this discrepancy, the Metco model was further evaluated based on the differences in the model results versus the individual pressure contract ranges. The wholesale customer meter contract ranges were then adjusted based on these findings. Each wholesale customer meter was evaluated and allowing for typical anomalies in modeling, a simulated pressure range was considered acceptable if less than 15% of the 24 one hour pressures fell outside the contract range.

For wholesale meters that did exceed 15% hourly pressure threshold, an average pressure was computed based on the difference between the model pressure and contract range and the number of times the event occurred. An example of the computation for wholesale customer meters requiring an adjustment is shown below in **Tables 4-2 and 4-3**.

Table 4-2: Example: AH03 Master Meter from METCO MDD model (psi)

	Metco Model Pressure by Hour*																									
Master Meter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Lower Contract Limit	Upper Contract Limit
AH03	97	79	78	86	82	88	100	110	102	116	116	101	109	109	110	85	102	99	96	102	94	111	111	94	83	107

Pressure difference in case of excess pressure (psi) = Model pressure - Upper contract limit
Pressure difference in case of insufficient pressure (psi) = Lower contract limit - Model Pressure

Table 4-3: Difference between Metco Model Pressure and Lower/Upper Contract Limit*

Master Meter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
AH03	0	4	5	0	1	0	0	3	0	9	9	0	2	2	3	0	0	0	0	0	0	4	4	0

Duration of day with low pressure = 3 hours
Duration of day with excess pressure = 8 hours
Duration of day with pressure violation = 3 + 8 = 11 hours
When there is more than 3 hours with pressure violation (>15%):

Average low pressure difference = sum (low pressure violation of all hours) / Number of hours with insufficient pressure = 10 / 3 = 3.3 psi
Average excess pressure difference = sum (excess pressure violation of all hours) / Number of hours with excess pressure = 36 / 8 = 4.5 psi

Simulation lower contract limit = Lower contract limit - Average insufficient pressure violation = 83 – 3.3 = 79.7 (psi)
Simulation upper contract limit = Lower contract limit + Average excess pressure violation = 107 + 4.5 = 111.5 (psi)

* Blue shading represents difference of excess pressure; pink represents difference of insufficient pressure

It should be noted that these simulated contract limits are only used for modeling purposes in identifying whether capital improvements are required. A summary of the average pressure adjustments by DWSD Operating Zone are shown in **Table 4-4**. The adjustments for each individual master meter are provided in Appendix A.

Table 4-4: Average Pressure Simulation Adjustment by Operating Zone - METCO MDD Model

Operating Zone	Average Low Pressure Violation (psi)	Average Excess Pressure Violation (psi)
2	0.3	0.0
3	1.0	2.6
4	2.5	1.3
5	0.6	1.6
6	0.4	1.0
7	3.9	1.3
8	1.9	3.1
9	1.3	2.8
10	5.0	5.8
11	2.9	0.7
12	1.2	1.3
13	0.4	0.2
14	2.0	2.7

The average difference in pressure varied by approximately 2 psi for both the upper and lower limits and approximately 85% of the differences were less than 5%. During the first 5-year review of the upcoming planning period, new data on demands, nonrevenue water, and actual performance in meeting wholesale customer contract limits should be reviewed and factored into an update and continuing refinement of the hydraulic model.

Appendix A: Pressure Adjustments at Master Meters

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
AC01	68.9	137.3	0.0	0.0	0%	0%	69	137
AH02	127	149	0.0	6.1	0%	4%	127	155
AH03	83	107	3.3	4.5	4%	4%	80	112
AH04	104	126	2.0	5.9	2%	5%	102	132
AH05	55	87	17.3	8.9	32%	10%	38	96
AH06	69	100	1.0	4.4	1%	4%	68	104
AP04	55	79	0.0	0.0	0%	0%	55	79
AP05	56	78	0.0	0.0	0%	0%	56	78
AP06	56	76	0.0	0.0	0%	0%	56	76
AP07	51	74	0.0	0.0	0%	0%	51	74
AP08	49	71	0.0	0.0	0%	0%	49	71
AP09	54	74	0.0	0.0	0%	0%	54	74
AP11	53	73	0.0	0.0	0%	0%	53	73
AP12	54	73	0.0	0.0	0%	0%	54	73
BC01	137	194	0.0	0.0	0%	0%	137	194
BL01	56	79	2.5	1.5	4%	2%	54	81
BL02	55	78	3.0	1.5	5%	2%	52	80
BR01	59.7	74.4	3.0	7.6	5%	10%	57	82
BR04	55	77	0.0	0.0	0%	0%	55	77
BR05	56	80	0.0	0.0	0%	0%	56	80

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
BR06	49	71	0.0	0.0	0%	0%	49	71
CA03	123	150	1.0	10.3	1%	7%	122	160
CA04	124	151	4.0	9.0	3%	6%	120	160
CA05	72	99	1.0	9.4	1%	10%	71	108
CA06	102	128	2.0	10.3	2%	8%	100	138
CA07	105	130	0.0	17.6	0%	14%	105	148
CH01	69.2	144.8	11.7	0.0	17%	0%	58	145
CH02	69.1	144.7	11.4	0.0	17%	0%	58	145
CH03	55.7	132.2	10.2	0.0	18%	0%	46	132
CH04	41.1	129	0.0	0.0	0%	0%	41	129
CH05	56.5	140.8	0.0	0.0	0%	0%	57	141
CM01	71	99	0.0	0.0	0%	0%	71	99
CM02	76	105	0.0	0.0	0%	0%	76	105
CM03	82	111	0.0	0.0	0%	0%	82	111
CT01	62	85	0.0	3.2	0%	4%	62	88
CT02	71	95	1.5	1.4	2%	1%	70	96
CT03	65	86	0.0	3.6	0%	4%	65	90
CT04	69	90	0.0	3.5	0%	4%	69	94
CT05	55	88	0.0	3.8	0%	4%	55	92
DH01	39	62	4.5	0.0	12%	0%	35	62
DH02	34	55	5.5	0.0	16%	0%	29	55
DH03	44	64	0.0	0.0	0%	0%	44	64
DH10	33	62	0.0	0.0	0%	0%	33	62
DH11	45	68	0.0	0.0	0%	0%	45	68

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
DH12	49	65	0.0	0.0	0%	0%	49	65
EC01	51	73	0.0	0.0	0%	0%	51	73
ED01	62	93	0.0	0.0	0%	0%	62	93
ED02	41	52	0.0	38.8	0%	75%	41	91
FA01	48	73	0.0	3.0	0%	4%	48	76
FE02	50	75	0.0	0.0	0%	0%	50	75
FE03	50	75	0.0	0.0	0%	0%	50	75
FK01	56	79	3.0	1.0	5%	1%	53	80
FL01	39.8	59.7	0.0	0.0	0%	0%	40	60
FR01	64	84	0.0	6.4	0%	8%	64	90
FR02	64	86	0.0	3.0	0%	3%	64	89
FR03	63	84	0.0	5.5	0%	7%	63	90
FT02	61	87	0.0	3.8	0%	4%	61	91
FT03	68	94	0.0	4.0	0%	4%	68	98
FT04	49	75	0.0	0.0	0%	0%	49	75
FT05	81	109	5.5	6.0	7%	6%	76	115
FT06	86	117	0.0	0.0	0%	0%	86	117
FT07	55	83	10.8	4.3	20%	5%	44	87
FT08	123	143	2.0	5.2	2%	4%	121	148
FT09	93	122	0.0	2.3	0%	2%	93	124
FT10	101	131	0.0	0.0	0%	0%	101	131
FT11	100	131	5.8	4.7	6%	4%	94	136
GC04	66	86	0.0	3.1	0%	4%	66	89
GC05	61	82	0.0	0.0	0%	0%	61	82

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
GI01	56.1	76.2	0.0	0.0	0%	0%	56	76
GI03	56.3	79.8	0.0	5.7	0%	7%	56	86
GK01	58.5	77.3	0.0	0.0	0%	0%	59	77
GK02	59.2	77.8	0.0	0.0	0%	0%	59	78
GK03	60	82	0.0	0.0	0%	0%	60	82
GR02	60.8	102.5	3.8	0.0	6%	0%	57	103
GR03	56.5	79.1	2.0	1.4	4%	2%	55	81
GW01	53	74	0.0	0.0	0%	0%	53	74
GW02	45	55	0.0	0.0	0%	0%	45	55
GW03	43	55	0.0	0.0	0%	0%	43	55
HK01	40	57	0.0	0.0	0%	0%	40	57
HK02	39	58	0.0	0.0	0%	0%	39	58
HK03	31	65	0.0	0.0	0%	0%	31	65
HK04	37	55	0.0	0.0	0%	0%	37	55
HK05	34	55	0.0	0.0	0%	0%	34	55
HK06	41	64	0.0	0.0	0%	0%	41	64
HK08	38	55	0.0	0.0	0%	0%	38	55
HK10	39	58	0.0	0.0	0%	0%	39	58
HN01	60	96	0.0	0.0	0%	0%	60	96
HN02	34	68	0.0	0.0	0%	0%	34	68
HR01	71	94	2.0	2.7	3%	3%	69	97
HR02	73	97	4.7	1.0	6%	1%	68	98
HW03	50	72	0.0	0.0	0%	0%	50	72
HW05	50	71	0.0	0.0	0%	0%	50	71

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
HW06	45	55	1.5	0.0	3%	0%	44	55
HZ01	48	73	0.0	0.0	0%	0%	48	73
HZ02	48	73	0.0	0.0	0%	0%	48	73
HZ04	47	71	0.0	0.0	0%	0%	47	71
HZ05	57	94	0.0	0.0	0%	0%	57	94
IC01	31.8	54.6	0.0	0.0	0%	0%	32	55
IK01	43.3	62.9	0.0	0.0	0%	0%	43	63
IK02	66.3	91.8	11.9	0.0	18%	0%	54	92
IK04	47.8	65.3	0.0	0.0	0%	0%	48	65
IT01	55.4	121.7	0.0	10.7	0%	9%	55	132
KH01	92	110	1.0	5.5	1%	5%	91	116
LA01	56	76.1	0.0	0.0	0%	0%	56	76
LA02	59.5	83.6	0.0	0.0	0%	0%	60	84
LA03	41	61.6	0.0	0.0	0%	0%	41	62
LP02	55.7	74.9	0.0	0.0	0%	0%	56	75
LP03	49.1	80.9	0.0	0.0	0%	0%	49	81
LP05	52.7	64.9	0.0	4.2	0%	7%	53	69
LV02	68	93	0.0	4.3	0%	5%	68	97
LV03	61	92	0.0	0.0	0%	0%	61	92
LV04	73	98	0.0	4.7	0%	5%	73	103
LV12	102	131	4.5	5.2	4%	4%	98	136
LV13	50	70	0.0	0.0	0%	0%	50	70
LV14	56	79	0.0	0.0	0%	0%	56	79
LV15	59	86	0.0	0.0	0%	0%	59	86

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
LV16	88	117	5.5	6.3	6%	5%	83	123
LX01	70	143	11.6	0.0	17%	0%	58	143
LX02	70	142	13.7	0.0	20%	0%	56	142
MA01	80	145	17.0	0.0	21%	0%	63	145
MA02	67	139	18.9	0.0	28%	0%	48	139
MA03	57	135	4.4	0.0	8%	0%	53	135
ME01	52	74	0.0	0.0	0%	0%	52	74
ME02	47	74	0.0	0.0	0%	0%	47	74
ME03	52	71	0.0	0.0	0%	0%	52	71
MF01	57.5	78.2	0.0	0.0	0%	0%	58	78
MH01	51	78	0.0	0.0	0%	0%	51	78
MH02	53	80	0.0	0.0	0%	0%	53	80
NE01	68	100	5.7	5.5	8%	6%	62	106
NE03	52	76	8.8	6.5	17%	9%	43	83
NE04	59	80	8.4	5.8	14%	7%	51	86
NE05	58	90	7.3	3.0	13%	3%	51	93
NE08	71	94	6.5	7.5	9%	8%	65	102
NH01	69	144	12.3	0.0	18%	0%	57	144
NL01	60	83	9.5	6.7	16%	8%	51	90
NL02	80	94	12.5	10.5	16%	11%	68	105
NV01	54	82	8.0	7.4	15%	9%	46	89
NV02	52	79	7.0	7.0	13%	9%	45	86
NV03	52	82	7.3	6.0	14%	7%	45	88
NV04	81	109	0.0	0.0	0%	0%	81	109

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
NV05	72	100	0.0	0.0	0%	0%	72	100
OC01	58	80	0.0	0.0	0%	0%	58	80
OP02	35	60	0.0	0.0	0%	0%	35	60
OT01	54	95	18.3	6.5	34%	7%	36	102
PL01	120	145	6.0	9.3	5%	6%	114	154
PL02	93	121	2.5	7.7	3%	6%	91	129
PO01	37	59	5.4	3.0	15%	5%	32	62
PO02	83	107	2.5	7.3	3%	7%	81	114
PT02	65	94	3.5	7.5	5%	8%	62	102
PT03	125	150	0.0	10.5	0%	7%	125	160
PT04	75	100	4.0	8.7	5%	9%	71	109
RC01	87	109	5.2	3.0	6%	3%	82	112
RC02	95	120	5.2	3.0	5%	3%	90	123
RC03	125	148	0.0	6.2	0%	4%	125	154
RC04	55	135	0.0	3.4	0%	3%	55	138
RD01	41	64	0.0	0.0	0%	0%	41	64
RD02	51	74	0.0	5.3	0%	7%	51	79
RD03	42	64	0.0	2.0	0%	3%	42	66
RD04	34	62	0.0	0.0	0%	0%	34	62
RD05	31	60	0.0	0.0	0%	0%	31	60
RD06	48	68	0.0	4.2	0%	6%	48	72
RD07	45	68	0.0	2.2	0%	3%	45	70
RD08	50	71	0.0	5.8	0%	8%	50	77
RD09	51	98	0.0	5.3	0%	5%	51	103

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
RD10	43	67	0.0	2.6	0%	4%	43	70
RE01	67	93	0.0	0.0	0%	0%	67	93
RE03	62	84	0.0	3.1	0%	4%	62	87
RH01	56	136	0.0	0.0	0%	0%	56	136
RK01	54	81	0.0	0.0	0%	0%	54	81
RM01	51	113	0.0	0.0	0%	0%	51	113
RR01	58	77	0.0	0.0	0%	0%	58	77
RR02	54	76	0.0	0.0	0%	0%	54	76
RR03	53	74	0.0	0.0	0%	0%	53	74
RS01	60.5	81.7	9.7	0.0	16%	0%	51	82
RS04	40	61	0.0	0.0	0%	0%	40	61
RS06	67	97	0.0	0.0	0%	0%	67	97
RS07	41	62	0.0	0.0	0%	0%	41	62
RT01	42	59	0.0	0.0	0%	0%	42	59
RT02	42	55	4.2	1.0	10%	2%	38	56
RW01	36.5	76.3	0.0	0.0	0%	0%	37	76
RW04	55.9	77.5	0.0	0.0	0%	0%	56	78
SE05	31	55	0.0	0.0	0%	0%	31	55
SE06	40	63	0.0	0.0	0%	0%	40	63
SE07	40	62	3.0	0.0	8%	0%	37	62
SE08	71	103	0.0	0.0	0%	0%	71	103
SE09	90	120	0.0	0.0	0%	0%	90	120
SE10	88	115	4.0	0.0	5%	0%	84	115
SE11	92	113	0.0	7.5	0%	7%	92	121

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
SE12	110	131	0.0	8.2	0%	6%	110	139
SE13	81	102	0.0	5.9	0%	6%	81	108
SE14	116	136	0.0	6.5	0%	5%	116	143
SE15	66	95	4.0	0.0	6%	0%	62	95
SG01	52	77	0.0	0.0	0%	0%	52	77
SG03	57	79	0.0	0.0	0%	0%	57	79
SG04	54	76	0.0	0.0	0%	0%	54	76
SL01	93	111	0.0	5.8	0%	5%	93	117
SN01	69.9	126	0.0	0.0	0%	0%	70	126
SR01	60	83	2.3	1.0	4%	1%	58	84
SS02	74	96	1.0	2.0	1%	2%	73	98
SS03	45	55	0.0	0.0	0%	0%	45	55
SS04	44	54	1.9	0.0	4%	0%	42	54
SS05	46	56	0.0	0.0	0%	0%	46	56
ST02	55	77	0.0	2.2	0%	3%	55	79
ST03	59	90	0.0	3.7	0%	4%	59	94
ST04	49	79	0.0	0.0	0%	0%	49	79
ST05	56	82	0.0	0.0	0%	0%	56	82
ST06	68	89	0.0	3.2	0%	4%	68	92
ST07	69	90	0.0	2.9	0%	3%	69	93
ST08	61	83	0.0	3.0	0%	4%	61	86
ST09	50	73	0.0	0.0	0%	0%	50	73
ST10	65	86	0.0	0.0	0%	0%	65	86
ST11	31	54	0.0	4.8	0%	9%	31	59

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
SU01	58	93	0.0	0.0	0%	0%	58	93
SY01	95	126	0.0	0.0	0%	0%	95	126
SY02	67	116	0.0	0.0	0%	0%	67	116
SY03	61	139	0.0	6.9	0%	5%	61	146
SY04	83	136	0.0	0.0	0%	0%	83	136
SY05	94	139	15.6	0.0	17%	0%	78	139
SY06	96	121	0.0	0.0	0%	0%	96	121
TA03	40	64	0.0	0.0	0%	0%	40	64
TA04	52.8	64.4	0.0	3.2	0%	5%	53	68
TA05	45	67	0.0	0.0	0%	0%	45	67
TA06	55	78	0.0	0.0	0%	0%	55	78
TA07	52	75	0.0	0.0	0%	0%	52	75
TN01	50.8	72.5	0.0	0.0	0%	0%	51	73
TN03	54.9	79.5	0.0	0.0	0%	0%	55	80
TY01	50	75	0.0	0.0	0%	0%	50	75
TY03	51	77	0.0	0.0	0%	0%	51	77
TY04	114	149	0.0	0.0	0%	0%	114	149
TY06	87	111	0.0	4.6	0%	4%	87	116
TY07	72	96	4.5	1.0	6%	1%	68	97
TY08	104	134	0.0	8.4	0%	6%	104	142
UT01	107	135	0.0	0.0	0%	0%	107	135
VB01	61	95	0.0	0.0	0%	0%	61	95
VB02	61	87	0.0	0.0	0%	0%	61	87
VB04	67	93	8.0	0.0	12%	0%	59	93

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
VB05	67	93	0.0	0.0	0%	0%	67	93
VB06	100	140	0.0	10.6	0%	8%	100	151
VB07	54	76	0.0	0.0	0%	0%	54	76
WA01	80	107	2.7	1.5	3%	1%	77	109
WB01	85	110	0.0	5.1	0%	5%	85	115
WB02	95	118	1.0	2.8	1%	2%	94	121
WB03	125	145	2.5	2.8	2%	2%	123	148
WB04	102	138	0.0	0.0	0%	0%	102	138
WB05	84	103	2.5	3.4	3%	3%	82	106
WB06	108	137	0.0	0.0	0%	0%	108	137
WB07	80	108	0.0	0.0	0%	0%	80	108
WB08	97	116	4.0	4.2	4%	4%	93	120
WG01	52	111	0.0	0.0	0%	0%	52	111
WG02	69	120	0.0	0.0	0%	0%	69	120
WL01	60.7	79.7	9.7	3.1	16%	4%	51	83
WL03	61.3	83.1	10.0	0.0	16%	0%	51	83
WL06	62.3	78.4	0.3	7.2	0%	9%	62	86
WL07	53	73	0.0	0.0	0%	0%	53	73
WL08	56.4	76.7	10.1	0.3	18%	0%	46	77
WL09	48	70	0.0	0.0	0%	0%	48	70
WL10	49	68	0.0	0.0	0%	0%	49	68
WL12	59.6	81.1	10.0	0.0	17%	0%	50	81
WN03	63	91	0.0	0.0	0%	0%	63	91
WN04	60	91	0.0	0.0	0%	0%	60	91

Average pressure exceedance simulated pressure limits of master meters of METCO MDD model

Master Meter	Lower Current Contract Limit (psi)	Upper Current Contract Limit (psi)	Average Insufficient Pressure Violation (psi)	Average Excess Pressure Violation (psi)	Average Lower Pressure limit Violation (%)	Average Upper Pressure limit Violation (%)	Simulated Lower Contract Limit (by Average Pressure Violation) (psi)	Simulated Upper Contract Limit (by Average Pressure Violation) (psi)
WN05	64	92	0.0	0.0	0%	0%	64	92
WN07	63	92	16.4	0.0	26%	0%	47	92
WN10	55	80	0.0	0.0	0%	0%	55	80
WN11	64	88	0.0	4.5	0%	5%	64	92
WN12	58	79	0.0	0.0	0%	0%	58	79
WN13	67	89	4.2	0.0	6%	0%	63	89
WO01	56	79	0.0	0.0	0%	0%	56	79
WO02	54	76	0.0	0.0	0%	0%	54	76
WX01	80	120	0.0	0.0	0%	0%	80	120
WY01	55	81	9.1	2.3	17%	3%	46	83
YT01	110	145	4.0	3.0	4%	2%	106	148
YT02	115	145	0.0	9.8	0%	7%	115	155

Appendix B: Analysis of Water Age in the Transmission System

To assess water quality in the transmission system, a water age modeling analysis was performed. The 2035 average day demand (ADD) model was used because travel times are longer and therefore water age is older under average day demand conditions rather than under maximum day demand conditions. The travel time is based on velocity, so the time it takes the water to get from the water plants to the customer is dependent on the demand from the customers and the pipe diameter.

Chlorine residual and water age are related. The longer water remains in a system the likelihood that the chlorine concentrations in the pipes will drop to unacceptable levels increases. For water in the DWSD system, the water quality goal is to keep water age less than 10 days, including wholesale customer distribution systems. Therefore, the goal in the analyzing the transmission system is to provide water to the master meters that does not exceed 5 days. This provides for an additional 5 days for the water to travel through the customer's distribution system before it gets to the end user.

The 2035 ADD model includes the proposed improvements in the system as well as Flint no longer being served by DWSD. However, the GLCUA is still supplied, which represents the customer furthest west on the 72-inch main.

The results of the water quality analysis is shown in Figure B-1. Typical reservoir operations were assumed based on DWSD's Ovation system automatically turning over reservoirs every three days.

As shown there are areas in the system that exceeds 5 days water age. Some of these locations (shown as a purple) are associated with system dead-ends due to isolation valves or valves that are typically closed during average day operations. Operation of these valves or small bypasses around the isolations would be required to promote lower water age.

The water age of 5 days in the transmission system is also exceeded along the 72-inch main. This is because the remaining demand from GLCUA is small relative to the size of the transmission main. As a result of this, DWSD is conducting chlorine demand tests to design chlorine booster stations for the potential water age problem.

There are also a few locations where master meters (purple circles) have water age greater than 5days. This is due to either a small demand at the master meter or that the meter is at the end of a dead-end main. In all cases however, the water age is less than 6 days.

Finally, since this analysis is for the transmission system, water age associated with the Detroit distribution system was not analyzed. Water mains in sparsety populated areas of the City have the potential for excessive water age. It is recommended that DWSD-Retail conduct this analysis as part of inventory of distribution mains discussed in Chapter 8.

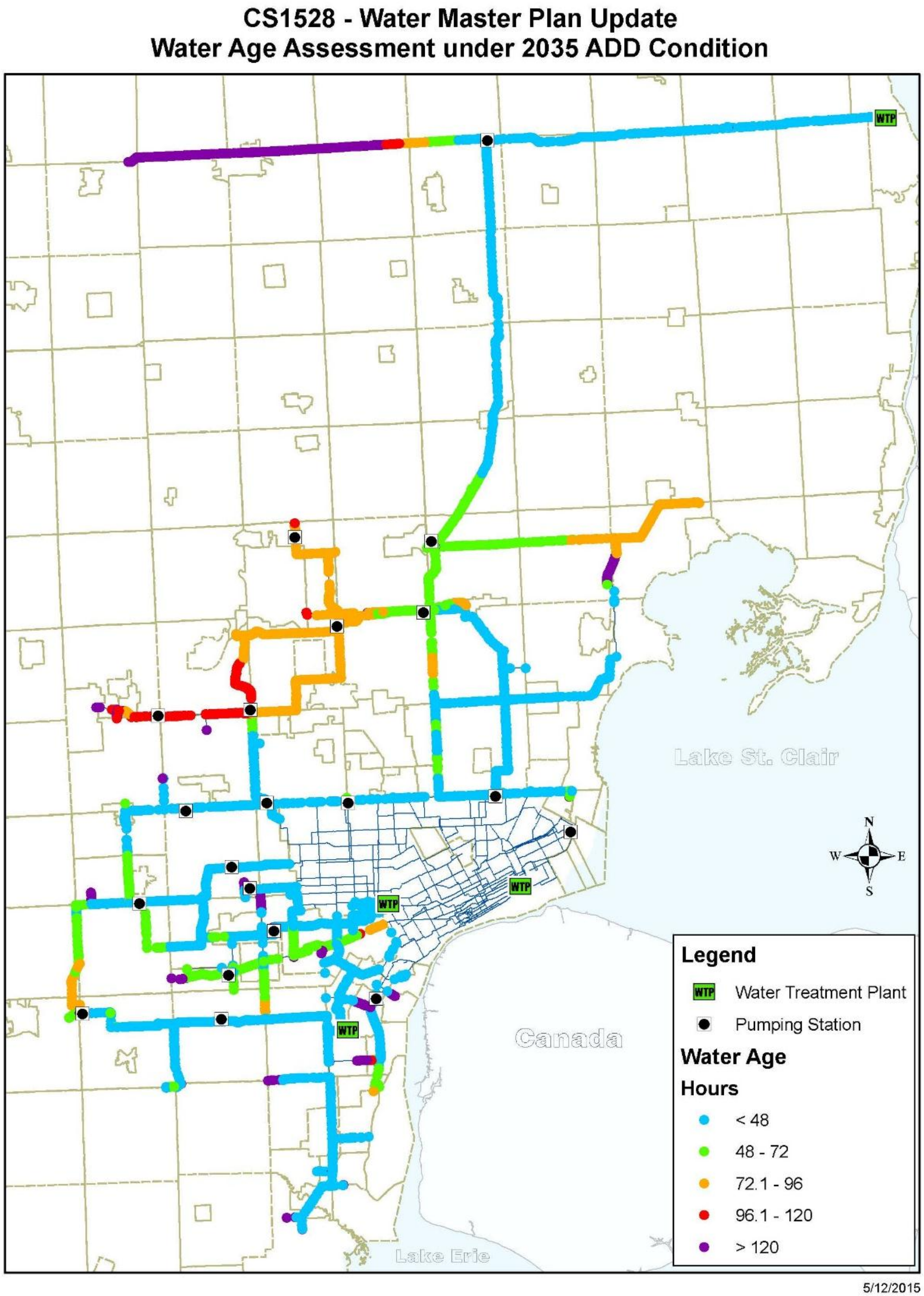

Figure B-1. Water Age Analysis