CHAPTER 9. WATER MODEL PRESENTATION AND ASSUMPTIONS

9.1 Introduction and Background

The City of Lincoln has a long history of providing water to its residents – likely dating back before its incorporation in 1890. In providing water, the City became responsible for the development and upkeep of water conveyance system. The City still manages and operates a potable water system with pieces of infrastructure that date back to at least 1929.[1] The water system contains pipes from every construction era since that time all coalesced into a single conveyance arrangement. The pipe materials include: concrete, iron, steel, and PVC with the oldest redwood pipes having been fully removed. The City has continued to grow expanding from a small town to a City with over 45,000 residents. The miles of pipe, number of valves, pressure settings, and infrastructure locations all require maps, spreadsheets, and databases to monitor and service. Furthermore, the additions to the system must be carefully engineered to comply with the newest fire flow and design standards as well as tested and verified to keep the existing City water system in compliance with applicable law and regulations.

Since the 1970's, universities and private companies have been writing computer software to process engineering complexities in urban water systems. Computers are now capable enough to store all of a City's water system details and display the impacts of system changes in advance of problems arising. In the early 2000's, the City of Lincoln was tracking water system expansions and maintenance projects in a Geographic Information System (GIS) format and had developed a water system model. With the housing crisis of the late 2000's, City growth substantially slowed and the need for modeling additions to the water system essentially ended. Coupling the downturn with a lack of funding, the GIS database was mothballed. Fast forward to the mid 2010's, development has returned to the City of Lincoln as well as the need for an accurate, scalable, and robust water system model and comprehensive GIS database. The primary purpose of this chapter is to provide an overview of the City's updated model and explain its functional utility.

The City's water system has been capably operated since the City's last water model update. With the downturn in City development, the system operations could be

[1] 1929 is the oldest category of infrastructure cataloged in the City GIS system in 2009 by Ecologic. Much of the raw water systems controlled by the PCWA and NID date back to the gold rush days. As described in **Chapter 1**, these systems provided water to the City in its earliest years.

maintained to meet status quo standards. However, the system saw several instances when it was nearly exhausted and vulnerabilities in the system, although suspected, have not yet been fully vetted. In short, the old water model technology was insufficient to meet the City's expansive development needs.

Specifically, the City's previous water model of the existing system was last updated in 2011 to derive some early infrastructure sizing and available number of new connection estimates for the proposed Village 1 development. **Figure 9-1** presents an example of the 2011 model and the details provided in that model. Similar early phased development service capacity from the existing City water system was also completed for Village 7 in 2013 using the 2011 model. Since then, only minor changes have occurred within the City for new pipes as well as in the operations of Pressure Reducing Valves (PRVs), tanks, and wells. With over 200 miles of pipe and nearly 3,000 pipe sections, there was a significant amount of work involved with updating the model representation of the City's constructed infrastructure and cross-checking infrastructure assumptions against the field maps to make necessary corrections. Minor corrections to the new model will be ongoing in the future as updated drawings are reviewed and analyzed. These corrections will have negligible impact on the overall results of the model and will not change the validity of the results drawn from the model.

Figure 9-1 – 2011 Legacy Water System Model Example

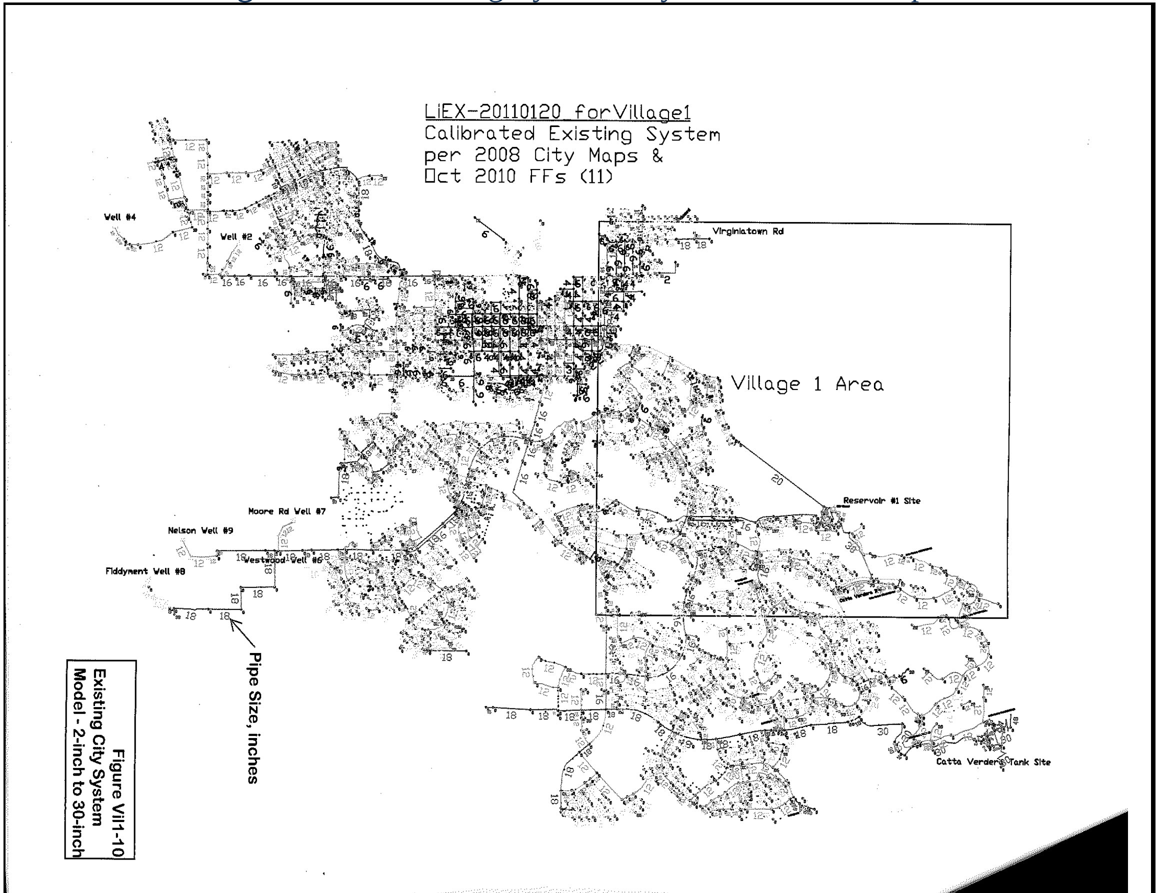

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Image Sources:
2011 Village 1 Water System Constraint Analysis

Recently, growth in computer processing power has allowed for water system information to be stored in complex mapping environments rather than simple computerized system blueprints. **Figure 9-2** presents and example of the detail to be found in the new modeling software. Unlike the earlier model that is limited to a simple wire frame model, the new software is capable of changing the way the system is projected as well as working with interactive background layers including street maps, satellite photos, and interactive parcel maps.

Figure 9-2 – 2016 Water System Model Example

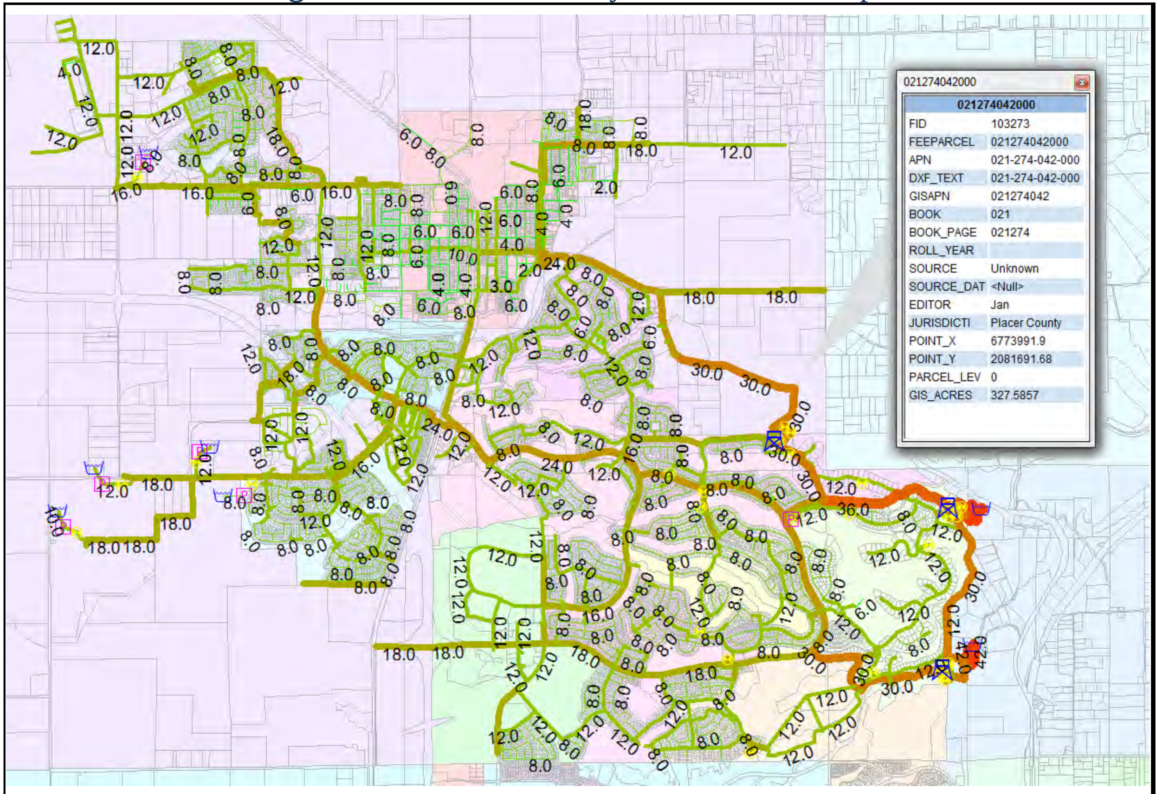

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Plumbing Codes and Fire Codes have become more stringent, requiring less water per house on a daily basis yet requiring larger service lines to supply fire sprinklers. This chapter discusses the process of updating the water model, the key assumptions used in the model, and the results and recommendations resulting from the model update process.

9.2 Model Conversion and Update

Before the revised and refined water demand allocations and model validation were built into the system, the existing model required model platform conversion in order to work in the new software purchased from Innovyze.[2] Specifically, the new Innovyze software runs on top of an ArcGIS environment. The older software ran on top of an AutoCAD environment. This switch in base environment is necessary and logical because

[2] Innovyze was not the only software option for modeling the City's water system. The decision to go with Innovyze rather than another software vender for modeling software was due to a number of factors including consultant familiarity with the software, inverted compatibility of some files from the old model, and recommendations from neighboring agencies.

AutoCAD has shifted away from large infrastructure modeling and ArcGIS has become the industry standard in utilities modeling.

Raw data file conversion was an independent step required to run the new model. Consulting Staff with Innovyze assisted in executing the data files and platform conversions. There were no significant issues with the conversion and once compiled into the new software, additional analytical tools were available to troubleshoot the new City model. Following the software conversion, the new model was updated with additional information. Specifically, the model is using 2013 metered and measured flow data to represent the best available information for model execution.

9.2.1 Data Collection

The City's old H2ONET model (old model) was used as the base for planning future infrastructure upgrades. The old model had last been updated prior to the establishment of new City-wide planning demand numbers which significantly impacted the projected buildout demands.

The City and other City Consultants provided Tully & Young the following data for model update purposes:

- Old H2ONET-AutoCAD based model.
- Latest GIS database for comparison and use in updating the old model regarding infrastructure locations and corresponding elevations.
- City water system base maps showing water infrastructure on top of parcel maps and aerial photo layers. Where differences between the projected drawings and base maps were found, the City was consulted and location resolutions were finalized.
- SCADA screenshots for system pressures, flows, tank levels, and control valve settings for the key period of about a week in July 2013 when the peak system flow occurred.
- SCADA data and handwritten records as available.
- Valve Information.
- System hydraulic grade information.
- Storage Tank information.
- Well production information.
- Blueprints and as-builts of key infrastructure within the City's system.

9.2.2 Pipelines

Based on staff and consultant assessments, the pipes in the old model were compared to the field maps and GIS pipe layers. Any differences were noted and clarified with City staff, developers, and consultants. The new Innovyze software features displayed disconnected pipes and that resulted from the file conversion process. The pipes input into the new model contained lengths and diameters obtained from the old model. Since the old model was not spatially-referenced, all pipes were updated from the GIS database in order to give proper lengths and connections. While some existing pipes in the old model had material information, it was not always consistent with that listed in the GIS database. Spot checks in several identified areas in the City's water system are ongoing with City staff and should be completed in the near future.

Table 9-1 below shows the total length and counts of pipelines by diameter in both the 2013 Model and the build-out Model. The build-out model represents the pipe systems that would be necessary to meet the long-term City demands. The location of these pipes in the model represents a placeholder for pipe sizing in the future that may not be located in these exact locations. The 2013 model pipe locations are shown in **Figure 9-3** and the build-out model is shown in **Figure 9-4**.

Table 9-1 – Summary of Pipe Data

	2013 Model		Buildout Model	
Pipe Diameter	Sum of Length (ft)	Number of Pipes	Sum of Length (ft)	Number of Pipes
2	2,884	6	2,884	6
3	374	1	374	1
4	33,686	73	29,541	72
6	72,410	223	72,410	223
8	517,230	1,279	515,826	1,277
10	14,734	47	15,031	42
12	360,298	785	603,731	881
14	9,968	33	10,063	34
16	48,664	89	63,131	93
18	72,375	117	227,696	172
24	50,898	83	72,717	89
30	11,909	23	24,938	21
36	458	2	9,535	4
Grand Total	1,195,889	2,761	1,647,877	2,915
	226	Miles	312	Miles

Both the old and new models use the Hazen-Williams head-loss equation for calculating head-loss in pipes and have assigned C factors ranging from 80 to 140.[3] The C factor is the coefficient used in the Hazen-Williams equation that is based on the material type and condition. However, considering that the values from the old model were calibrated and that the lower C values were more conservative and realistic, the values from the old model were used in the new model in most places except for where specific errors were identified. Newer sections of pipe were also checked for uncharacteristic low values and updated with realistic numbers. The C factors for added pipes were estimated using the C factor from adjacent pipes or from industry standards depending on likely age, material, and location within the City. These C factor values will be updated following future fire flow analysis and corresponding model calibration with the analysis.

[3] The Hazen-Williams equation is an empirical formula used to calculate the pressure drop in a pipe based on the physical properties of the pipe. The material and age of the pipe determine the roughness of the pipe and through the equation, how much energy is lost in the pipe due to friction and measured as a pressure drop.

Figure 9-3 – 2013 Water System Model

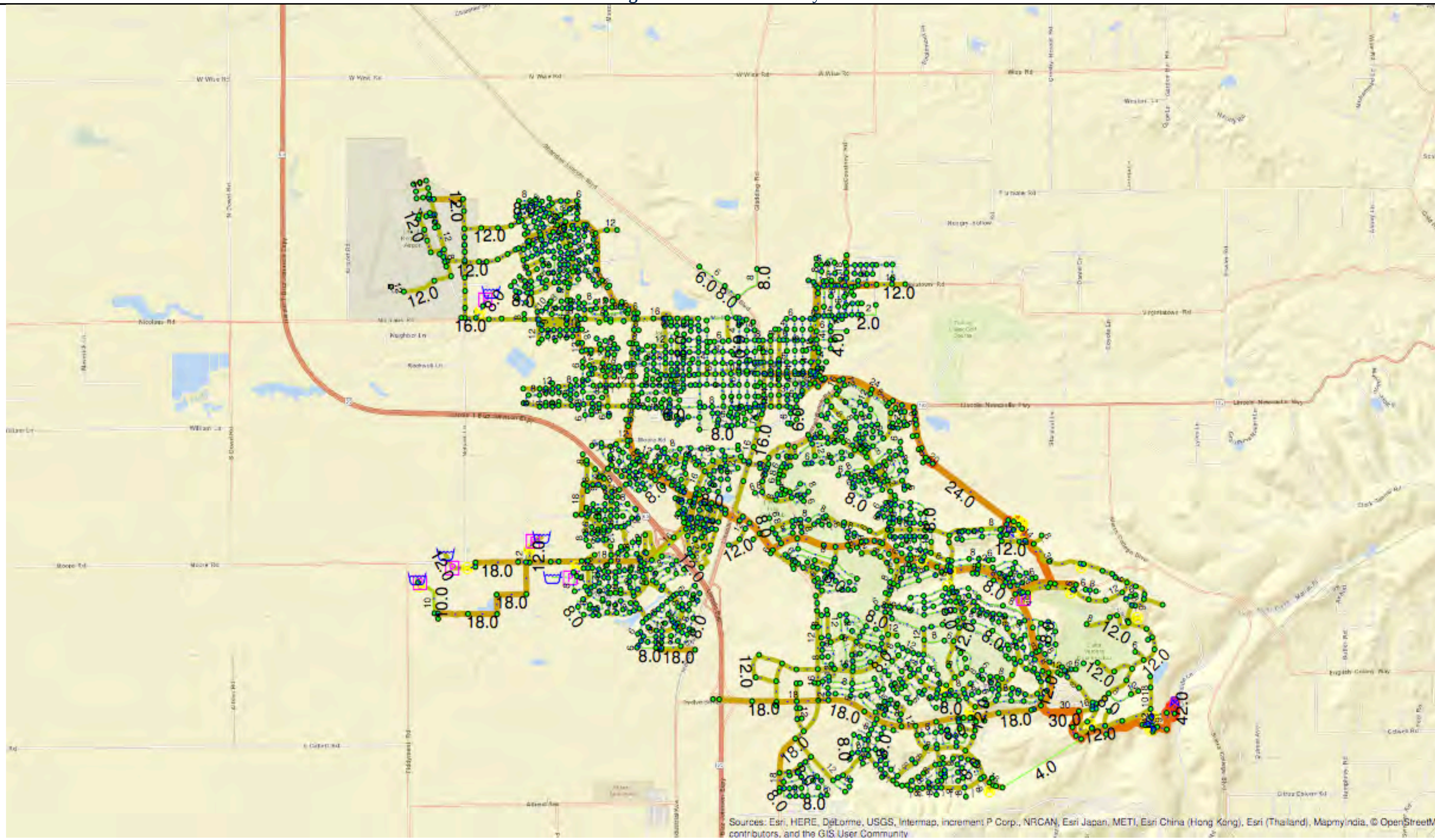

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Image Sources:

City Water System GIS, Licensed ESRI ArcGIS

City Water Model, Innovyze InfoWater

Figure 9-4 – Build-out Water System Model

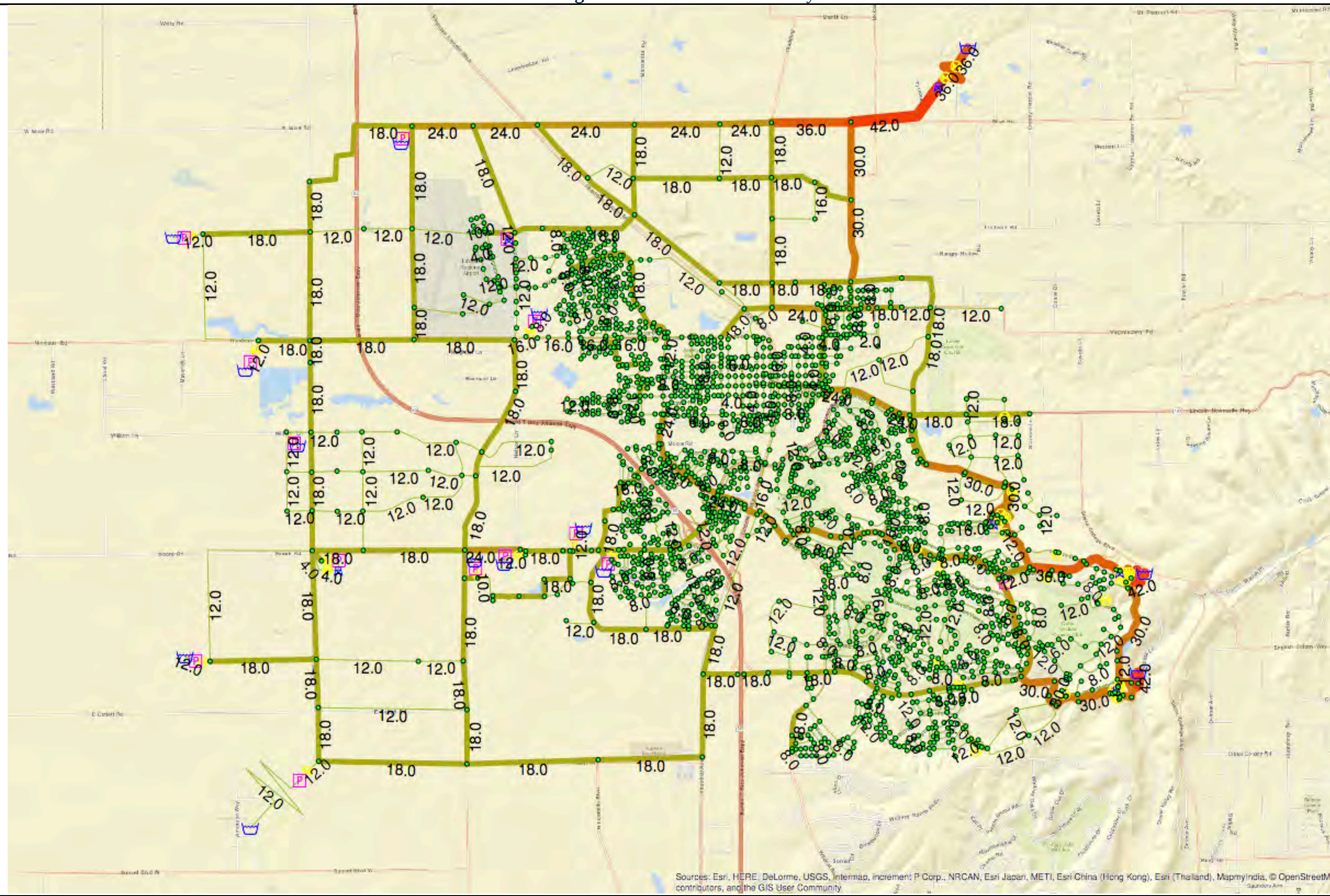

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

9.2.3 Junctions

Junctions, also referred to as nodes, are located at the end of each pipeline segment in the model. Additional junction information, including approximate locations and elevations, was assigned manually in the model based on GIS data and staff observations. Elevation data was derived from multiple sources. The best available data was found to be 20-foot contour maps available from the Placer County GIS Clearing House online. Updated elevations were plotted for junctions and compared to the 20-foot contour maps, with corrections made as necessary. In areas with significant topography, USGS topographic maps were used as the default source for elevation data. Developed areas with significant grading were set using as-built maps where available and reasonable judgment after consultation with City Staff. These junctions relying on reasonable judgment and staff consultation have been noted for future confirmation and updating.

Additional elevation checks were necessary after new model expansions or changes due to new junctions defaulting under the model parameters to zero feet elevation. The pressure spikes caused by the zero feet elevations were easy to identify and correct in the model.

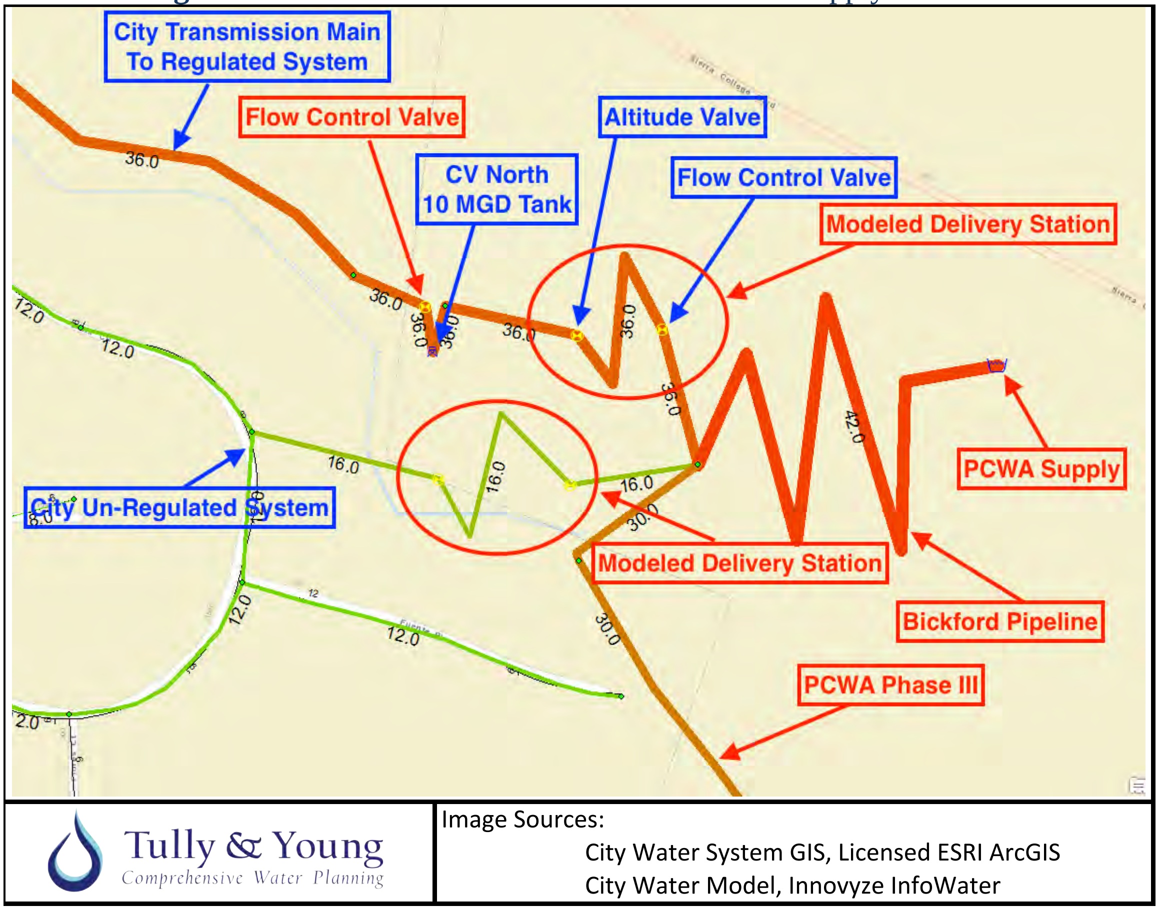
9.2.4 Tanks and Reservoirs

City Storage tanks and theoretical reservoirs related to the well configurations and the Placer County Water Agency (PCWA) treated surface supply were modeled as junction nodes in the old model. As part of the new model update, tank sites in the system were modeled as gravity tanks. The PCWA and Nevada Irrigation District (NID) water treatment plants (both existing and planned) for the treated surface water supplies were modeled as source points with fixed head. Tank elevation information was derived from the old model and checked against as-built schematics when available. **Table 9-2** shows tank elevations, operating levels, capacities, and dimensions necessary for the existing system model. **Figure 9-5** presents a modeled example of a water storage tank and a surface water supply source.

Table 9-2 – Summary of Tank Data

ID	Type	Elevation (ft)	Minimum Level (ft)	Maximum Level (ft)	Initial Level (ft)	Diameter (ft)	Minimum Volume (ft3)
T-4-CATTAVERDERAPT	0: Cylindrical	565	2	30	21	170	0
T-3-3MGHGL385	0: Cylindrical	365	2	30	23	127	62667
T-7-PCWAFOOTHILL (Imaginary tank for modeling purposes)	0: Cylindrical	755	10	55	30	175	0

Figure 9-5 – Catta Verdera North Modeled Water Supply and Tank



9.2.5 Pump Stations

Pump station locations, pump curves, and operational logic were developed based on information in the old model and additional available information. Pump controls were adjusted to meet necessary flows and the software was allowed to "self balance" these flows as necessary. This effort was performed because the majority of water demands are met from surface water and critical pipe infrastructure is related to these surface water connections. A summary of pumps and pump status needed for existing system model is shown in **Table 9-3**. **Figure 9-6** presents a modeled example of a well water supply source.

Table 9-3 – Summary of Pump Station Status

ID	Type	Elevation (ft)	Diameter (in)	Constant Power (hp)	Shutoff Head (ft)	Design Head (ft)	Design Flow (gpm)	High Head (ft)	High Flow (gpm)
WELL7-MOORERDPUMP	2: Exponential 3-Point Curve	120	12		310	240	1200	0	1500
WELL6-WSTWDWELLPUMP	2: Exponential 3-Point Curve	120	10	0	306	235	900	0	1100
WELL8-FIDDYMNTA-PUMP	2: Exponential 3-Point Curve	120	10	0	306.7	286	1400	0	1800
WELL2-PUMP	2: Exponential 3-Point Curve	120	10		310	230	800	0	1200
WELL9-NELSON-PUMP	2: Exponential 3-Point Curve	120	10	0	306	245	2100	0	2400
PMP-7006 (Catta Verdera Pump)	2: Exponential 3-Point Curve	320	12	300	400	360	2500	270	3000

Figure 9-6 – Fiddyment Modeled Water Supply Well

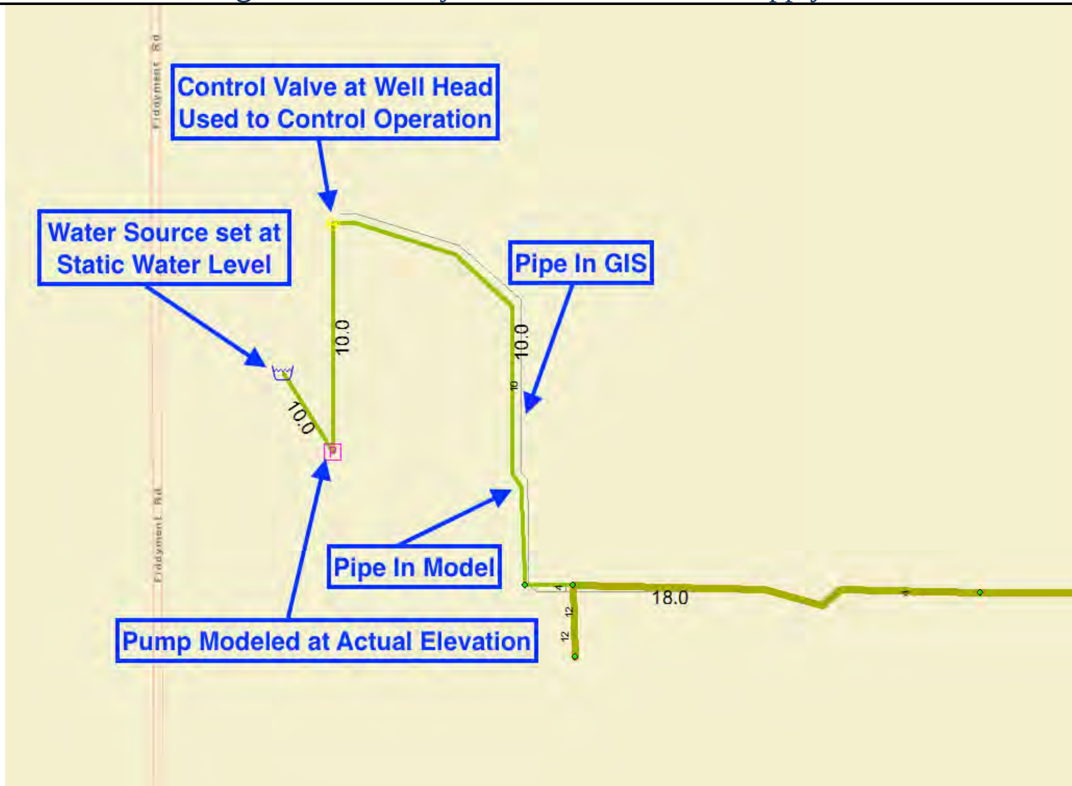


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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

9.2.6 Valves

All valves were revised to match 2013 summer operations status. Inlet tank valves were set and adjusted to maintain the proper system inflow to match data from PCWA. PRVs located on Twelve Bridges Drive (south 18-inch transmission line) and on Stoneridge Drive (north 24-inch transmission line) were adjusted from summer 2013 numbers as necessary to balance flow conditions between the north and south transmission lines. The sensitivity in the system to changes in these PRVs allowed adjustments of 1 to 2 psi to make significant changes that would be within the level of accuracy of the recording data at each of these PRVs. For future operations, with additional demands and system infrastructure, it was assumed that these PRVs would be adjusted to necessary settings in the field so no set number was used in controlling them. Currently, typical system operation requires the adjustment of some PRV setting multiple times per year to keep flows balanced. For modeling, the team is focused upon the PRV setting in a peak flow period. The actual field setting will vary from time to time. **Figure 9-7** presents an example schematic of a PVR setup and **Figure 9-8** presents a modeled PRV.

Figure 9-7 – Example PRV Schematic

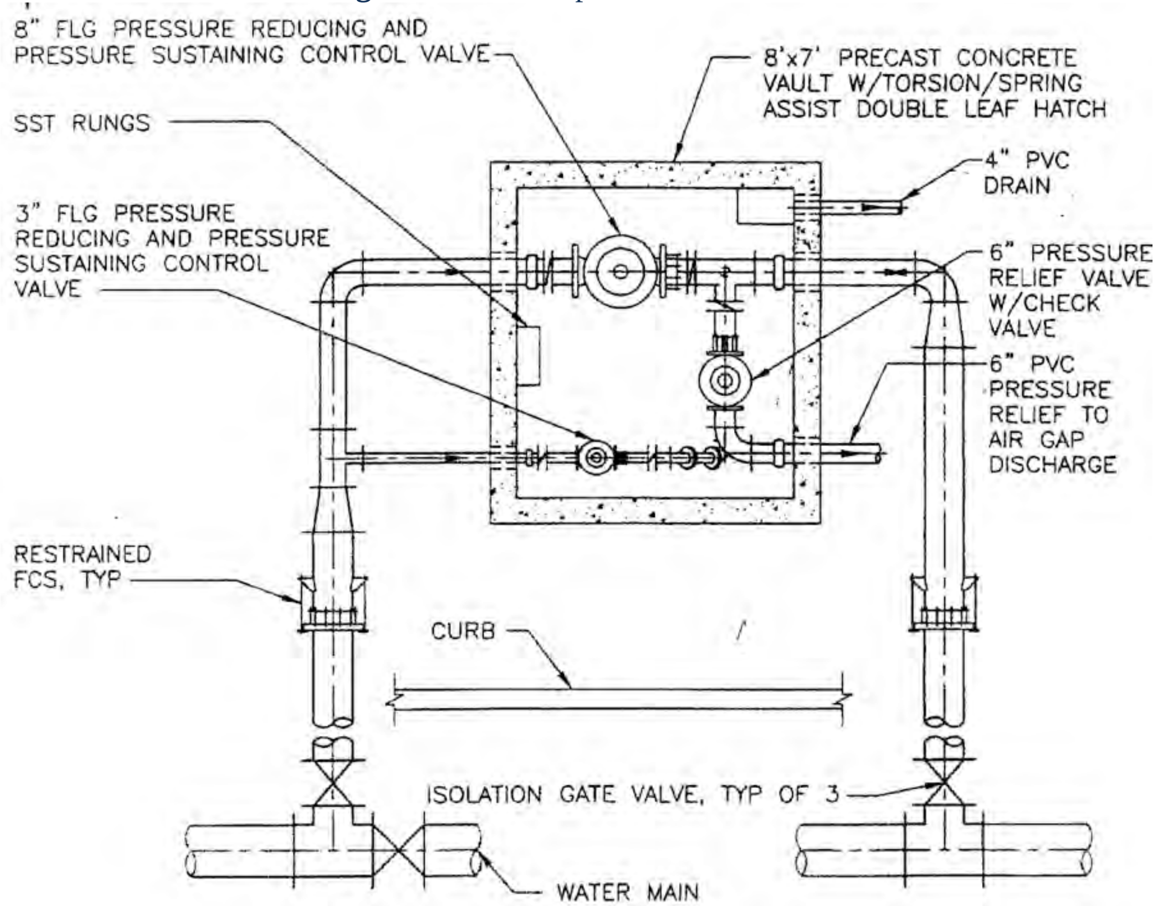

Figure 9-8 – Example Modeled PRV

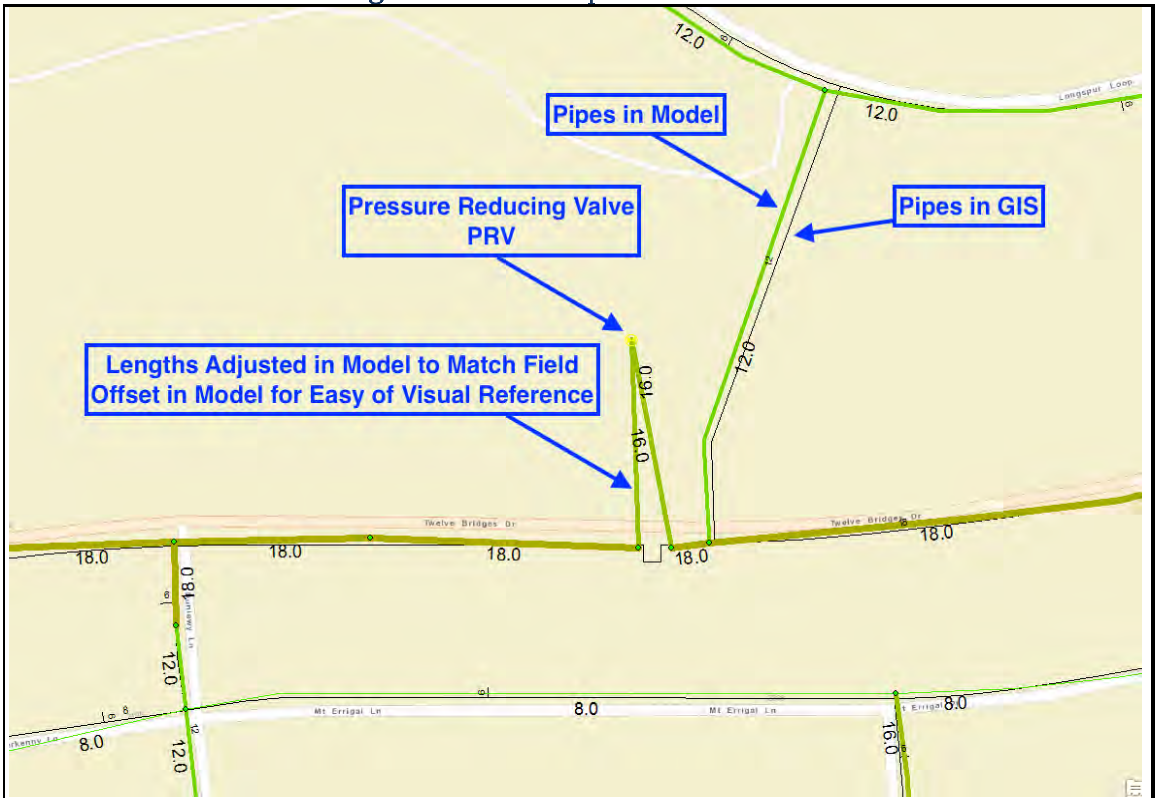

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

It should be noted that the PRV schematic presents a more complex system than what is represented in the model. This is simply because the valves in a PRV can only operate efficiently within a certain range of flows whereas a computer has no such limits. In reality, the PRV system has one smaller PRV for typical water use or nighttime flows and a parallel larger PRV for peak use time and fire flow needs.

9.3 Demand Allocation

Demand allocation was conducted based on 2013 meter data using tools built into the new Innovyze and underlying ArcGIS software. With the new software, demands are mapped using the address data in the City's meter database through a process called geo-coding. In this process the ArcGIS base software uses the internet to search for the meter's address (its location), much like someone would look up directions to a residential location, and then places a dot on the City map at that approximate location. Once this was complete for all 18,000+ City water meters, the meter demand is assigned to the nearest junction in the new model through the Innovyze software. **Figure 9-9** shows the meter to node assignment as performed by the Innovyze software. A few hundred City meter addresses were found to be without results and were adjusted as necessary, or eliminated if deemed insignificant. Note that of the 18,000+ City water meters available in the 2013 data file, less than 2% were eliminated.

Figure 9-9 – Innovyze Meter Assignment

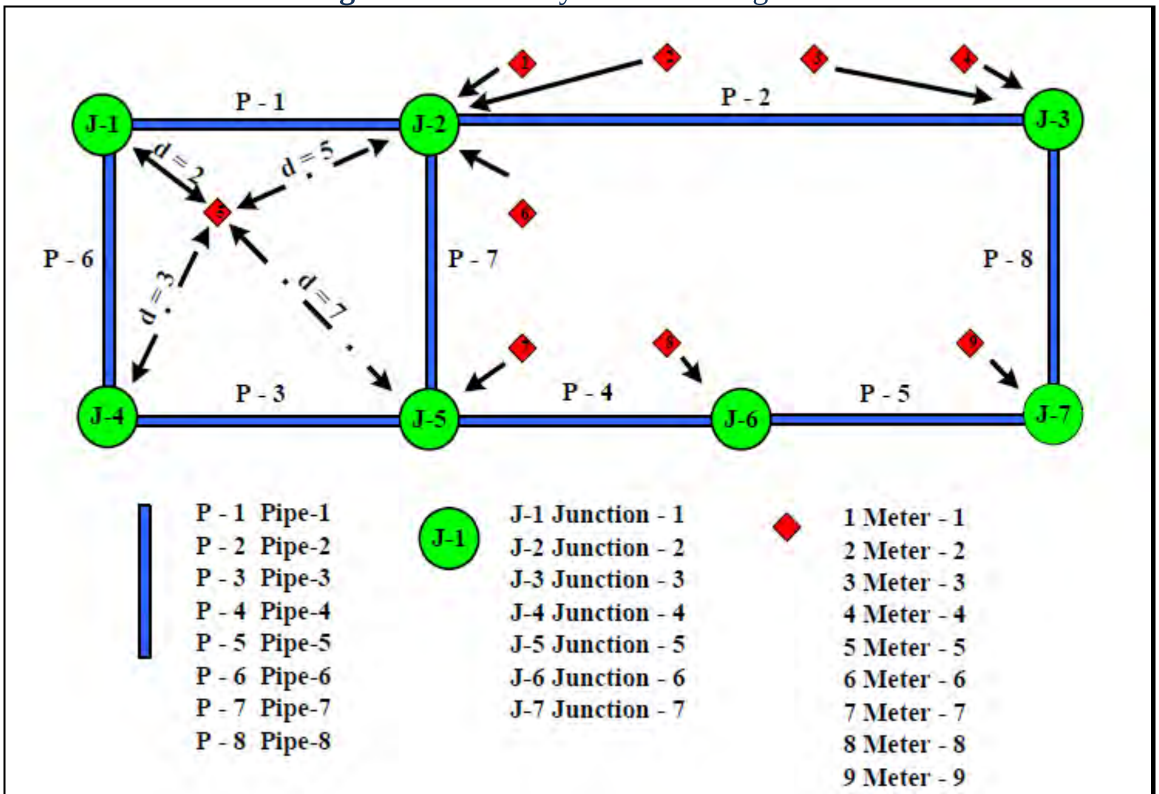

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Image Sources:
Innovyze Meter Allocation Guide

9.3.1 Selection of Supply and Infrastructure Scenarios

Over the course of eight City Council Workshops, information was presented with staff to assist the Lincoln City Council to formally give direction on desired future goals for the City's short and long-term water supplies. Since the previous 2008 General Plan, the projected build-out maximum day demand for potable water has been reduced from about 118 Million Gallons per Day (MGD) down to 67 MGD. This demand reduction is driven primarily by the reduction in projected per acre and per dwelling unit demands as discussed in detail in **Chapter 4**.[4] By substituting potential raw and reclaimed supplies

[4] The demand factors used in the 2008 General Plan were based on meter records from the late 1980s which were prior to the efficient plumbing codes of the early 1990s or later landscape and water efficient codes.

for potable supplies, the total potable demand could be further reduced to a maximum day demand of 47 MGD. As a conservative approach, a maximum day of 57 MGD potable demand was chosen by the City Council as the target build-out demand for future modeling and Public Facilities Element planning. Additional discussions were conducted and a City Council decision was made to plan on treated surface supplies from the two existing PCWA connections at the 5 million gallon Catta Verdera South Tank site and through two future PCWA connections at the former City Pond site now known as Catta Verdera North, and a future connection from the proposed NID regional water treatment plant and pipeline near McCourtney and Wise Roads. **Figure 9-10** shows the future water supply sources as used in various water supply scenarios.

Figure 9-10 – Future Modeled Water Supplies

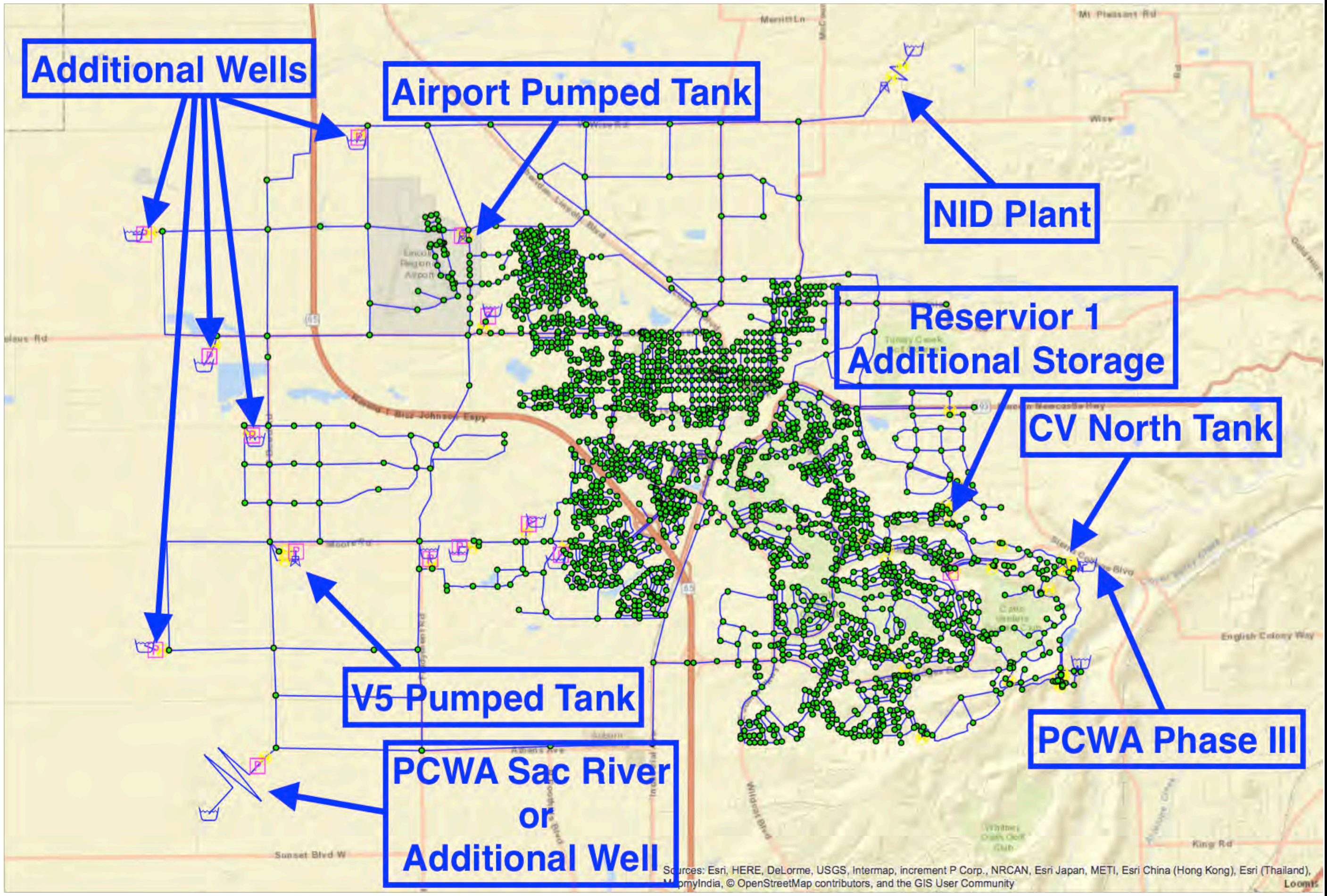

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

During the course of the eight workshops, a number of explanatory model runs were completed to check if individual supply and piping scenarios would be viable. Since the workshop in December 2015, updates and corrections have been completed to the model scenarios, with focus concentrated on a few scenarios and additional model runs relevant to long-term planning have been undertaken at the request of engineering staff. The bullet list below summarizes the model scenarios completed and saved, including those superseded and abandoned, and those updated to continue further analyses as requested. This list is not meant to be exhaustive and will be modified with additional inputs or requested changes in the future.

Early Model Runs:

- 2013 Model A – Used for initial calibration, superseded and abandoned
- 2013 Model B – Used for initial calibration, superseded and abandoned
- 67 MGD build-out – Used to check sources and main infrastructure, superseded and abandoned
- 67 MGD build-out – Version with PCWA only, superseded and abandoned
- 67 MGD build-out – Version with NID only, superseded and abandoned
- 47 MGD build-out – Used to minimize infrastructure, superseded and abandoned

Primary Model Runs in use:

- 57 MGD build-out – Updated and in use, primary model for long term planning decisions
- Existing City with Phase III – Updated and in use, primary model for near term planning decisions

Temporary Planning and Engineering Model Runs[5]:

- Existing City with Phase III, V1, and Village 5 Phase 1 – Completed and key results recorded, to be abandoned

[5] The details of these model runs will be summarized in an engineering memo for later use by City Staff. The results of these runs were used in the planning for build-out as presented in this document.

- Existing City with Phase III, V1, V5 – Completed and key results recorded, to be abandoned
- Existing City with Phase III, V1, V5 and V7 – Completed and key results recorded, to be abandoned
- Existing City with Phase III, V1, and Max V5 without V7 intertie – Completed and key results recorded, to be abandoned
- Model run for City Engineering Staff, build-out emergency with NID treatment offline – Completed and key results recorded, to be abandoned
- Model run for City Engineering Staff, build-out emergency with PCWA treatment severely impacted – Completed and key results recorded, to be abandoned
- Model run for City Engineering Staff, near build-out with NID treatment online before Villages 2 and 3 have built, single NID delivery line on McCourtney Rd. – Completed and key results recorded, to be abandoned
- Model run for City Engineering Staff, capacity for build-out of west side without Village 2 and Village 3 east to west transmission mains – Completed and key results recorded, to be abandoned
- Model run for City Engineering Staff, capacity for build-out with existing system and Phase III – Completed and key results recorded, to be abandoned
- 2016 Fireflow Calibration Model – In development, early results used to verify model accuracy, final results to update BO and Existing Models, to be abandoned

9.3.2 Peaking Factors

Industry standard peaking factors for potable water use in similar sized systems in the region use a 2.5 to 1.0 ratio for the maximum day of a year to the average day of the same year (max day to average day ratio, or max day demand factor) and a 1.6 to 1.0 ratio for the peak hour of the maximum day of the year to the maximum day of the same year (peak hour to max day ratio, or peak hour demand factor). Before redeveloping the model, City Staff and consultants surveyed neighboring agencies and assess relevant reference materials to establish appropriate factors to be considered in the modeling efforts. The previous modeling information prepared in 2010 has a table, **Table 9-4** below, tracking the max day to average day ratio. As can be seen in **Table 9-4**, the trend of this max day to average day ratio since 2004 has been about 2.0. The 2013 City meter data is consistent with 2.0 to 1.0 ratio of max day to average day.

Table 9-4 – Maximum Day to Average Day Demand Factors

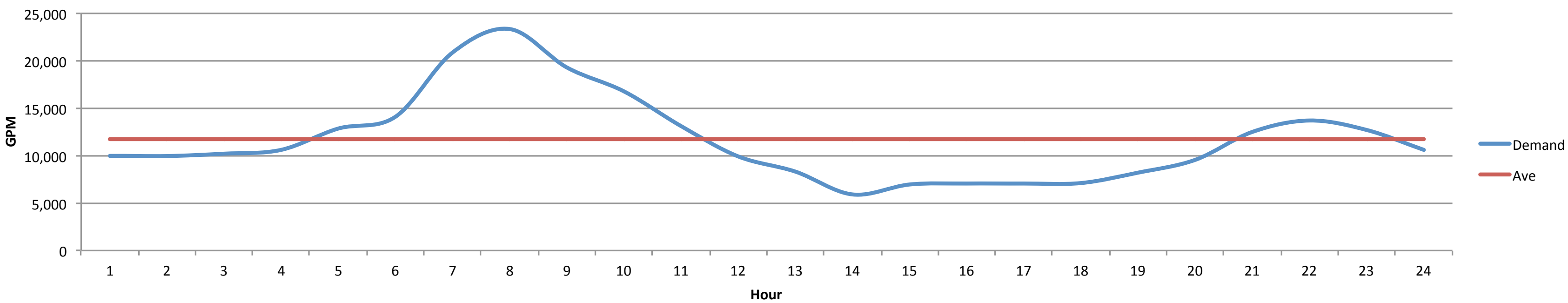
Table VIl1-5
City Historical Municipal Water Deliveries & Demand Factors
per
City of Lincoln California Department of Health Services Annual Report Data
1996 - 2009

Year	Estimated Population	# of Services	Annual Potable Surface Water Delivered by PCWA* (AFY)	Max Day Potable Surface Water Delivered (MGD)	Annual Ground Water Delivered (AFY)	Total Annual Potable Water Delivered (AFY)	Average Daily Potable Water Delivered (MGD)	Max Day Ground Water Delivered (MGD)	Max Day Demand Surface & Ground Water (MGD)	Max Day to Ave Day Ratio	Ground water to Total Annual **	Increase in Potable Demand from Prior Year
1996	8,500	2,536	1,338	3.1	516	1,853	1.7	0.9	4.0	2.4	28%	
1997	8,500	2,602	1,678	3.2	484	2,162	1.9	1.1	4.3	2.2	22%	17%
1998	8,600	2,933	1,421	3.2	433	1,854	1.7	0.9	4.1	2.5	23%	-14%
1999	7,224	2,408	1,783	3.8	469	2,252	2.0	0.9	4.7	2.3	21%	21%
2000	12,500	5,035	2,041	3.6	569	2,610	2.3	1.2	4.8	2.1	22%	16%
2001	14,510	6,413	3,326	5.1	408	3,734	3.3	2.1	7.2	2.2	11%	43%
2002	20,141	7,619	4,063	6.7	713	4,776	4.3	1.4	8.1	1.9	15%	28%
2003	26,000	9,767	4,845	8.8	543	5,388	4.8	1.9	10.7	2.2	10%	13%
2004	27,000	11,794	7,243	11.5	298	7,541	6.7	2.0	13.5	2.0	4%	40%
2005	33,513	13,681	7,828	12.9	515	8,343	7.4	2.0	14.9	2.0	6%	11%
2006	36,277	15,541	8,780	14.3	1,789	10,569	9.4	1.4	15.7	1.7	17%	27%
2007	37,000	16,238	9,017	14.7	924	9,941	8.9	1.3	16.0	1.8	9%	-6%
2008	37,000	16,483	9,097	14.3	1,084	10,181	9.1	1.3	15.6	1.7	11%	2%
2009	40,157	16,584	8,851	14.3	837	9,688	8.6	2.7	17.0	2.0	9%	-5%
					Average Annual Values			1996-2009		2.1	15%	
								2005-2009		1.8	10%	

For the peak hour to max day ratio, it was noted as early as 2009 that this ratio was increasing from the old, estimated 1.6 multiplier. For this 2016 modeling effort, data was collected from 2013 SCADA data by City staff to verify the peak hour demand factor. **Figure 9-11** below presents the hourly cycle of demand within the City on the maximum day of demand, July 8, 2013. The 2013 data is being used due to drought-related restrictions on potable water use in the state. The drought related conditions in Lincoln render similar data for 2014 and 2015 moot. The hourly data that establishes the curve in **Figure 9-11** is what allows for running the model demands on an hourly demand basis for the twenty-four hours of the maximum day (extended period modeling), as well as identifying the peak hour demand factor.

Figure 9-11 – Max Day Hourly Analysis

Hour	1:00	2:00	3:00	4:00	5:00	6:00	7:00	**8:00**	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
Demand	10,000	9,950	10,200	10,600	12,850	14,090	20,870	23,350	19,300	16,775	13,110	9,910	8,310	5,900	6,950	7,050	7,050	7,100	8,200	9,550	12,500	13,700	12,700	10,600
Ave	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692	11,692
Ratio	0.855	0.851	0.872	0.907	1.099	1.205	1.785	**1.997**	1.651	1.435	1.121	0.848	0.711	0.505	0.594	0.603	0.603	0.607	0.701	0.817	1.069	1.172	1.086	0.907



9.4 Model Validation

In order for the model to run correctly and provide accurate results, the model must be validated. The model was validated by using system conditions from the old 2010 model and 2010 field fire flow results. Additional 2016 fire flow results are being assessed in the model but were not incorporated at the time of this drafting. The City's previous model was prepared in 2010-2011 to derive some early infrastructure sizing estimates for the Village 1 development. Since then only minor changes have occurred within the City for new pipes and minor changes were made in the operations of Pressure Reducing Valves (PRVs), tanks, and wells. With over 200 miles of and nearly 3,000 sections of pipe in the model, differences were expected due to base environment conversion. Two versions were created in 2015, referred to as 2013 Model A and 2013 Model B, based on the year of the demand data and system configuration. These initial models have been superseded as discussed in **Section 3.2.1**. **Table 9-5** presents a comparison across models for the selected hydrant locations.

Table 9-5 – Fire Flow Comparison Table

	Field Tests		2010 Model	2010 Model	2010 Model
Junction	Measured Flow	Measured Pressure	2010 Pressure	2013 Upgrade A	2013 Upgrade B
J-5374	915	95	90.4	98.6	105.9
J-5395	1280	96	82.1	90.8	98.1
J-5429	990	96	86.9	87.7	105.3
J-5193	1280	92	76.6	95.1	103.5
J-5203	990	89	88.8	105.3	113.7
J-5454	1338	99	93.4	101.9	109.5
J-5257	959	85	78.7	89.8	98.4
J-5493	1091	95	77.7	87.1	94.3
J-DW-1682	915	54	55.3	47.2	56.5
J-5069	1021	75	65.3	93.9	102.5
J-212	1289	105	103.0	113.4	120.1

2013 Upgrade A - Changed a few demand and pump curves, 2010 Calibration Day demand
2013 Upgrade B - Upgrade A + significant elevation adjustments, 2010 Calibration Day demand
2013 Model A- Updated piping, pump & valve set points, 2010 Calibration Day demand
2013 Model B - Updated piping, pump & valve set points, 2013 Ave Day demand

The 2010 Model had pressures an average of 8% lower than measured in the field. With Upgrade A, the average was 3% higher than measured but there was variability both higher and lower and the absolute error being 9%. The 2013 Upgrade B resulted in an average of 13% higher than measured flows but with improved consistency than 2013 Upgrade A. To account for this higher flow result, a fire flow limit above the state mandate is used when sizing City infrastructure.

Once the 2013 Upgrade B model was calibrated to the best available data, it was used as the basis for all subsequent model scenarios. Drought-related restrictions were minimal in 2016 so the City completed fire flow testing in August of 2016. The newest pipe information available has been included in a new 2016 Calibration Model.

The locations of desired fireflow test results were provided to staff for discussion. Staff concluded that it was appropriate to conduct fireflow testing at a number of the locations including all locations used for the 2013 Model Calibration. Some locations were not tested due to know pipe issues and risks of breakage. The results of the fireflow analysis were compared to the latest pipe system with calibration data from the 2013 Update Model with the results presented in **Table 9-6**.

Table 9-6 – 2016 Calibration Table

	2016 Field Tests		2016 Model in Use Pressure
Junction	Measured Flow	Measured Pressure	
J-5374	944	95	94.4
J-5395	1269	96	95.2
J-5429	1026	96	95.5
J-5193	1269	92	100.7
J-5203	1026	89	100.6
J-5454	1310	99	94.7
J-5257	1000	85	85.3
J-5493	1121	95	90.8
J-DW-1682	944	60	56.9
J-5069	1182	82	76.1
J-212	1253	107	99.7

The 2016 Model in use was found to be much more accurate than the previous calibration runs. Average pressures were found to be only 1% lower than field measured pressures. Individual error was generally around 5% with one hydrant pressure being 13% over actual. Additional fireflow tests were conducted in other locations throughout the City. The results of this testing show that newer parts of the City are generally better modeled than older areas. This is consistent with known details about the system and the condition of GIS records.

The results of this 2016 fireflow testing support the results developed out of the buildout and current models. Results concerning legacy areas of town including the downtown area are subject to more error however the modeled results are still useful for planning and engineering decisions. Field testing is risky in older pipes and breakage as a result of testing would be expensive. By modeling the old areas of town and applying a conservative safety factor usable numbers can be generated.

As the large FRP projects in the old parts of the system are completed it will be necessary to preform ongoing checks of the model to verify the impacts of pipe replacement actions. As the 2016 fireflow testing established a high level of accuracy for the current model, these checks need only be preformed every few years. The model still has minor correction and sizing errors that will be caught as part of ongoing reviews and edits which will likely improve the model accuracy further.

9.5 Model Limits, Operational Standards, and Future Infrastructure Design Criteria for Model

In the production of the system water model, some basic limits and rules must be followed. System Operational Standards relate to the conditions and limits in system operations including pressures, pipe velocities, tank operations, PRV settings, maximum day exceptions, and well operation. System Design Standards or City design criteria relates to a number of details used in the design of the City's potable water system including minimum pipe sizes, looping of mains, tank sizing, well redundancy, and pipe materials. The pertinent details of these items are presented in the sections described below. For the City of Lincoln these come from City policies set in the Design Criteria & Procedures Manual from June 2004, additional industry standard engineering assumptions, and practical field operations. The City's design criteria that are presented in this chapter include applicable current regulatory and engineering standards references as follows: SWRCB-Division of Drinking Water (DDW) standards, Uniform Fire Code, and American Water Works Association (AWWA) standards. Other non-policy and standards based operations determined in the field by operations staff are still a necessary part of the operations standards for modeling purposes. This section presents these limits, operational settings, rules and assumptions, as well as provides the reasoning for their inclusion in existing and future City policy where appropriate.

9.5.1 Pipes

Pipe sizing is determined by the operational criteria, follows fire code requirements, and complies with some general engineering standards related to minimum sizing. For instance, no mains are sized smaller than 8-inch and no looped mains are smaller than 12 inches.

Pipe materials, standard sizes, and roughness calculations for new pipe shall comply with the following table.

Table 9-7 – Pipeline Criteria

Pipeline Criteria (as applied to Computer modeling)	
Hazen-William roughness coefficient for pipes less than 16 inches in diameter	120-130
Hazen-William roughness coefficient for pipes 16 inches in diameter and larger	140
Approved Pipe Materials	Ductile Iron Pipe, PVC, Motar-lined Steel Pipe
Approved Pipe Sizes in Inches Diameter	8, 12, 16, 18, 24, 30, 36, 42, 48

The purpose of these rules is to maintain the performance of the water system in peak demand situations that include operational water, fire flow, and emergency needs. The 12-inch looped mains provide significantly better total water transmission capacity in the event of a fire and provide redundancy in the event of a pipe failure. On non-looped sections of main, an 8" line provides adequate supply for fire hydrants so long as the pipe is not too long.[6] Pipe materials listed are the current industry standard and are selected based on a balance of cost, operational performance, and longevity.

9.5.2 Storage

Storage Reservoirs (Tanks) shall be sized to provide 50% of average day capacity, plus fireflow storage, as well as an emergency storage volume while leaving 10% of average day minimum head space. Fireflow storage shall be defined as the water needed to serve the largest fireflow and duration as defined by the California Fire Code. Emergency storage shall be defined as 24 hours water for every resident at California Health and Safety minimums, currently 55 gallons per day per person. Head space in the storage tanks shall be defined as the unused capacity on a maximum day.

This tank sizing differs from previous City design standards for the purpose of complying with modern industry standards. This sizing criteria differs from that presently defined in the City General Plan documents, and is more conservative – meaning it meets industry baselines. This conservative sizing also allows the City a buffer time to bring other supplies online in the event of an emergency. Head space is required in the tanks due to the need to accommodate the fluctuating City demands and the operation of and distance from source water PCWA treatment plants. Previous tank sizing standards did not expressly identify then need or operational impacts of head space.

9.5.3 Wells

Well criteria set in this section does not account for the impacts of new groundwater regulation and agreements within the western placer groundwater basin. Future City wells shall have a production capacity of at least 1 mgd (1,400 gpm for 12 hours of operation per day). Total well pumping capacity was historically equal to 75% of

[6] A proposed limit of 2,000ft foot for non-looped mains has been presented in the standards recommendations at the end of this chapter.

average day demand. This pumping capacity may be modified when multiple surface water sources and delivery systems are available to the City. Wells shall be operational during maximum day demands with 1 well offline as backup for every 3 in operation. Total annual production target is limited to 10% of average annual total of treated surface water deliveries and groundwater production. The average annual production total is based upon a 10 year running average.

These criteria serve the purpose of creating a reliable potable water supply for the City of Lincoln. The benefits of this type of conjunctive use program were seen in 2011 with the Bear River Canal outage. The City was able to rely on water stored in the aquifer to augment reduced PCWA deliveries to the City until the PCWA supplies were back online, minimizing impacts to City customers. The utility of the conjunctive use system also avoided lasting impacts to the underlying aquifer.

9.5.4 Demand Multipliers

Demand multipliers are monitored and updated as system operations change. Currently the average day of the year to maximum day for the same year multiplier is 2.0. Currently the peak hour of the maximum day to the maximum day multiplier is 2.0. This represents a shift in the proportions of the multipliers since the early 1990s (2.5 and 1.6 respectively). This follows the documented trend from meter records of reducing the maximum day multiplier and increasing the peak hour multiplier and is consistent with trends seen by other water purveyors in the region.

Current multipliers are as follows:

- Max Day Demand (MDD) = Average Day Demand (ADD) x 2
- Peak Hour Demand (PHD) = MDD x 2

9.5.5 System Pressures

Normal System pressures shall be operated between 50 and 130 psi. Minimum pressures during peak hour of maximum day shall not drop to 40 psi. Minimum pressure during a maximum day fire flow event is 20 psi. (Note that the current water model is using 25 psi (minimum residual pressure during fire flow as a conservative buffer until normal year fire flow calibrations can be performed). These pressures are within the limits of current regulatory and industry standards.

9.5.6 Pipe Velocities

Pipes are designed and operated so velocities are maintained below 7 ft/sec during maximum day demands. Maximum day fire flows may allow for 10 ft/sec in key delivery pipes. Maximum day peak hour flows shall be allowed to exceed the 7ft/sec limit so long as the hour before and the hour after do not exceed the 7 ft/sec limit and the single peak hour does not exceed 10 ft/sec.

These pipe velocities are in line with industry standards and balance the cost of pipe upsizing with longevity, while maintaining acceptable minimum system pressures and related piping head losses. Some local agencies use lower valves for maximum velocity standards but the City of Lincoln lacks the extreme elevation changes or rugged conditions to necessitate lower limits.

9.5.7 Tank Operations

Tank operations are gravity fed except where future pumped storage is planned. Tank levels are managed as operations staff deems necessary. Tanks should not drop below emergency and fire flow storage levels during maximum day use. As operational limits are observed, additional storage should be constructed to maintain storage levels and system security prior to new demands coming online.

9.5.8 PRV Settings

Pressure Reducing Valves (PRV) settings at City PRV stations maintain pressure and flow from; 1) the higher storage tanks in the Catta Verdera area to the remainder of the system, and 2) higher pressure zones to lower zones. PRV setting adjustments are at the discretion of operations staff to provide the best possible service to customers. These settings are adjusted in the field seasonally and for varying operational conditions. System designs shall not rely on frequent field PRV setting adjustments or regular remote adjustments through SCADA for proper maximum day operation.

9.5.9 Well Operations

Seasonally, in order to maximize the benefit of City wells and minimize PCWA contract limit increases, the City production wells shall be operated as much as possible in peak months and minimized on shoulder months around the peak months. Daily well operations for the model have been assumed to be no more than 12 hours per day. Based on City experience, this goal for normal operation reduces potential for stress on the aquifer, mechanical equipment, and effects on nearby private wells. This seasonal goal will result in real savings in terms of contract and surface water treatment plants capacity needs, with the added benefit of regular utilization of backup supply infrastructure.

9.5.10 Extended Period Model Operation

Previous City water models only represented an instantaneous look at the water system performance. This representation was mainly due to insufficient data to accurately represent dynamic system performance. Although the scope of work for this study called for a modeling of 24-hour periods related to the average day and maximum day, the models developed utilize data that allows modeling the system for up to 60 hours. The purpose for simulating the longer period is to be able to graphically illustrate the abilities of well operation to help maintain tank storage levels with fixed delivery rates from PCWA and NID source supplies. This longer model time allows for the verification that the system is balanced and not just operating on stored water.

9.5.11 California Fire Code Requirements

The State of California Fire Code includes more detail since the last model update. The Fire Code is updated every three years. The City's current water model, as required by law, followed the design and operational criteria set in the most recent version of the California Fire Code available at the time of development, dated 2013. When a revised Fire Code was adopted for 2016, all applicable design standard changes were recognized. As new codes are adopted the model will continue to be updated where necessary.

With new residences having fire sprinkler requirements, some fire hydrant flow code requirements have potentially been reduced. However, in practice of development design, hydrant flows still require analysis in residential as well as non-residential areas. This analysis is due to mixed use along the pipeline routes and new fire sprinkler flow requirements that increase with home square footage. Some larger homes may have fire sprinkler flow requirements similar to commercial buildings.

City fire flow testing (for system model calibration) was postponed until August of 2016 due to reduced maximum day demand on the water system during the peak usage months in 2014 and 2015 largely due to drought restrictions. The results of the 2016 fireflow testing only served to verify the accuracy of the model. As a result, the model serves as a tool for the City engineering staff to use to identify areas of deficient fireflow capacity. Some older areas of the City are served by aged pipes that as undersized for modern fireflow requirements. These areas have been identified for replacement as part of the City's FRP program. **Chapter 10** of this document provides more details on the individual FRP projects including some that are already underway.

9.5.12 Improved Security

This section is discusses the impact of the input assumptions and policy goals on the water model and on the City water system as a whole.

Many of the details in this section are carried from previous City standards but some received key changes that will result in significant changes in the future water system.

Details on the policy and standards changes can be found in **Section 9.8.6**. By increasing the tank size requirements, the City will create more emergency storage and will give City staff additional flexibility in system operations in order to conduct much needed maintenance and repairs. Pipe looping requirements serve to improve the redundancy within the system and ensure fire protection is not restricted by a single pipe outage or closed valve.

9.6 Modeled System Evaluation Criteria

The system evaluation criteria were based on Lincoln design criteria taken from the adopted City standards and recommended standards presented and agreed upon by staff. In order to ensure compliance with the policies and standards, some more conservative limits were used in the model to analyze system operations. The following criteria are used to assess the system capacity:[7]

- Source Water Balance. A source (i.e., WTP) is deficient if the water demand exceeds the source capacity.
- Tank Water Balance. A tank is deficient if the outflow is greater than the inflow (i.e., a negative water balance) or tank levels decline significantly in extended period modeling. **Figure 9-12** presents an example of water tanks cycling in an EPS model.
- Velocity. The transmission pipelines are flagged if the velocity exceeds 10 feet per second (fps) during peak hour demand, or for fireflows during max day demand, and 7fps on Max Day.
- Pressure. Junction pressures greater than 125 psi or below 40 psi are flagged, and 25 psi is the minimum system pressure allowed during max day demand plus a single fire flow (20% has been added to the State minimum requirement for existing infrastructure to be conservative until such time as the model has been re-calibrated with new fire flow testing). New development is to maintain 45 psi (about 10% above the State minimum requirement of 40 psi) in the system at all times except during a fire flow. **Figure 9-13** presents and example of peak hour pressure mapping.
- Areas with chronic legacy issues are flagged and continually checked. The circled area in **Figure 9-13** represents an example of a legacy issue.

[7] The limits and criteria in this list may differ from actual policy or design standards.

Figure 9-12 – Modeled Water Tank Operation

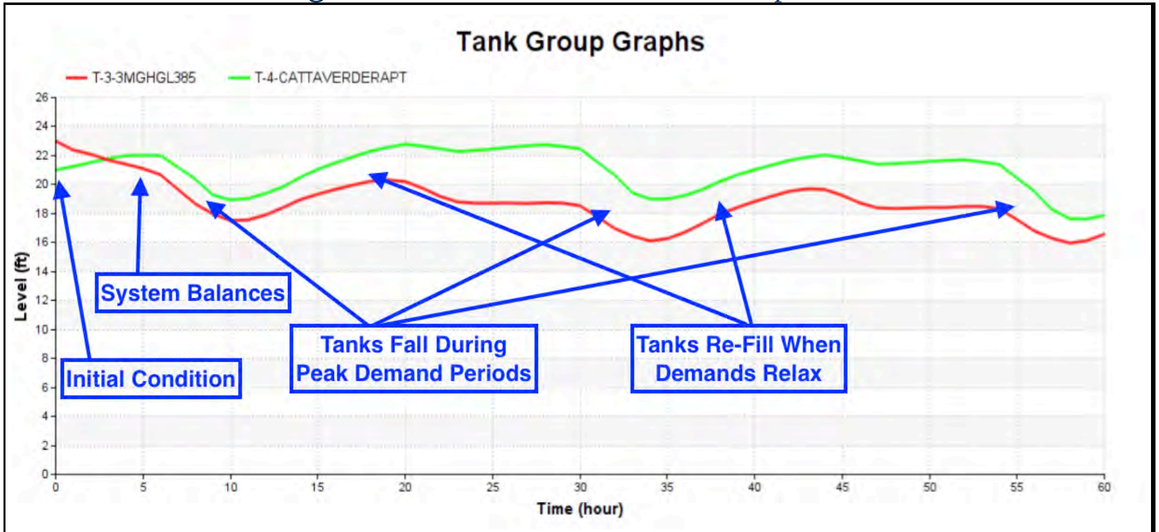


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Image Sources:
City Water Model, Innovyze InfoWater

Figure 9-13 – Pressure Mapping Example

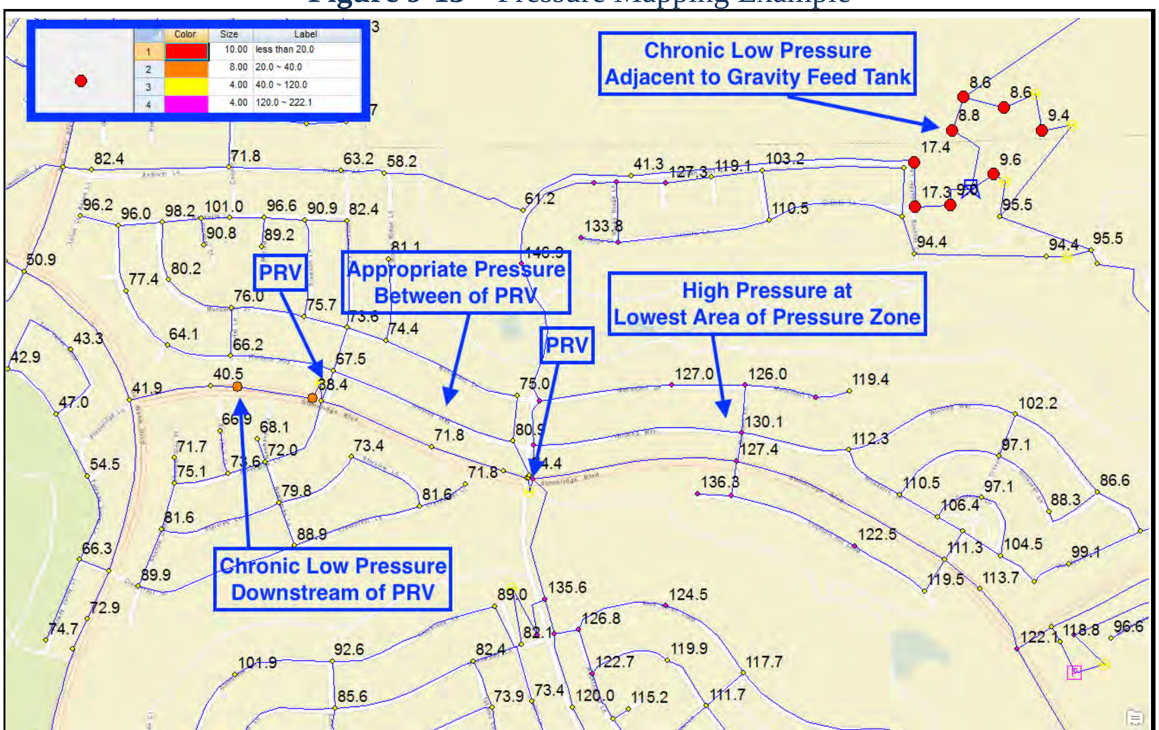

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

9.7 System Analysis

The objective of the system analysis is to determine the maximum capacity of the existing system and capacity of proposed future system improvements. The assumptions and analysis are described below.[8]

9.7.1 Model Assumptions

The following assumptions are made during the system capacity analysis:

- All storage tanks are assumed to use the same approximate starting level of about 22 feet in depth and operated to cycle but refill to approximately 2/3s or to a 28 foot maximum.
- Only the gravity option is examined for treated surface water supplies to the City. There is no pumping except from City wells, the Catta Verdera Booster Pumping Station, and at dedicated City pumped storage locations where applicable in future models.
- Low pressures: Chronically low pressures near storage tanks and pressure regulating valves are identified, but not included in the analysis. Since the pressures at the tanks are controlled by the tank level and pressures at pressure regulating valves by the valve setting, it is assumed that these values are correct. Pressures below zero are identified as possible problems to be rectified with the analysis.
- High pressures: Pressures over 125 psi are flagged and re-checked for confirmation. Pressures adjacent to well pumps are chronic defaults, and are ignored as each well has a downstream flow control valve connected to the system and used to balance system flows.
- Low pressures: Chronic low pressure issues such as in the legacy area of old town and at high points in the easterly edge of the Del Webb development are ignored but flagged for future improvements.
- High velocities: Chronic high-velocity areas such as in undersized road crossings and at undersides PRVs are ignored but flagged for future improvements.

9.7.2 Initial System Evaluation

Once the 2013 B model was calibrated with available tools and information, the now completed 67 MGD model was started.[9] Numerous steps were taken to improve the

[8] The limits and criteria in this list may differ from actual policy or design standards.

speed with which subsequent models could be derived from this ultimate build-out scenario including standard naming conventions, variable feature settings, and a control structure which allowed for easy changes to total supplies entering the system, as well as changes in sources of supplies.

Once the 67 MGD model was complete, multiple rounds of trouble shooting were conducted to identify disconnected pipes, correct elevation errors, correct valve direction issues, develop realistic pressure reducing valve and pump settings, and sizing of mains to allow 4 separate in-City tank locations to operate in conjunction with each other, as well as the surface water supplies. Some operational issues required the temporary inclusion of flow control valves that do not exist in the real system to eliminate variable flows from the 67 MGD model and allow the system to solve correctly. Once the system was balanced, these "imaginary" valves were removed.

The result was a 67 MGD model that allowed for operation at the planned maximum or with a focus on PCWA or NID supplies with no infrastructure changes necessary in the existing system. It should be noted that areas with chronic pressure and flow limitations were not significantly improved but new developments could be met with pipes smaller than those identified in the previous 2010-118 MGD max day model.

Since the completion of the 67 MGD model, the City Council has agreed that a diversified supply involving 10 MGD from raw water supplies and 57 MGD from treated supplies should be the City's target at build-out. To accommodate this a version of the 67 MGD model was modified to meet the lower 57 MGD requirement with the benefit of smaller pipes, fewer tanks, and fewer new wells which all result in savings to the City.

9.8 Conclusion

This section addresses the results of the model update and the purposes of the model moving forward.

9.8.1 Model Limitations

Currently the 2016 57 MGD model is only limited to the quality of the data available to input into it. Software limitations exist but the current issue regarding the accuracy of the 2016 model is quality data to calibrate it. Specifically, fire flow tests during a drought year would provide less meaningful data than tests rendered in normal water years. The current level of accuracy is sufficient to develop large-scale system wide projects and to

[9] As discussed later in this section, the 67 MGD model has been replaced with the current 57 MGD model. The 67 MGD model is only referenced to maintain accuracy in telling the story of the model update process.

assess fire flows for pending development projects. Any model result, when taken with the conservative buffers presented in the assumptions section, is the best current information available for decision makers.

As previously discussed, new fire flow tests were conducted in August of 2016. The results of those tests shows an improvement in model accuracy from the 2013 Model updates. As seen from the 2016 fireflow testing, the model accuracy is lacking in the older areas of the system where the condition and details of the pipes in the ground is largely unknown. As the FRP projects begin to replace these older and functionally deficient pipes, model accuracy will continue to improve. Further, assumptions related to external drivers of water use such as conservation and future codes can impact the results of the model.

9.8.2 Data Limitations

As discussed earlier, the accuracy of the 2016 model is only as good as the data used to build and calibrate it. The 2016 model is based on GIS data of the water system that lacks detail in some areas of the City. Numerous developments adjacent to each other prior to the use of GIS systems have unclear records of interconnection. This lack of complete records is most notable in the older parts of City where the water lines dating back to the 1920s are infrequently connected to the newer pipes of 1990s developments.

The lack of recent fire flow data, a limited fire flow location sample set, and limited fire flow tests approximating maximum day demand conditions contribute to reduced accuracies and increased uncertainties in the 2016 model performance. This limitation has been discussed with City staff in modeling presentation meetings. Additional fire flow testing was conducted and showed the accuracy of the model in areas were the system data was best. In the older areas of the City and in areas with known functionally deficient pipes, the accuracy of the model suffers.

9.8.3 System Limitations

As derived from the modeling process and in the process of updating the 2016 model, the City's water system appears deficient in a number of geographical and functional areas.

Physical limitations exist throughout the City but with the updated demands and demand factors, areas not meeting the operating assumptions for minimum pressure and maximum pipe velocities are isolated. Examples of these limitations include older areas of the City with undersized laterals, phased pipe segments with varying diameters, undersized pipes in overpasses, undersized connecting pipes to City production wells, and lack of current above ground storage capacity. All of these issues can be either individually addressed or mitigated to meet build-out demands without extensive replacement.

The current SCADA control system for the treated water system is functional but lacks many features of the newer systems. The limits of the current SCADA system make water system model updates cumbersome but do allow for extended period modeling without issue. As the treated water system expands and complete utilization of the second supply source as part of the PCWA Phase III Pipeline and Metering Station Project, City water system operations will become difficult to manage without expanded SCADA based pressure and flow controls.

9.8.4 Summary of Phased Planned Build-out of the City Treated Water System

Currently the 2016 model is being used to establish the number of new services that can be provided to pending developments prior to key treated water system infrastructure having to be online. The areas of Village 1, Village 5, SUD B and Village 7 are the largest pending developments for the City. These developments, as well as smaller potential development areas within the existing City limits, have been analyzed as part of the Lincoln Water Master Plan modeling process as the first major phase of City expansion as the City approaches build-out.

The remainder of the City's Sphere of Influence developable areas are on the northern and western edges of the City. As no detailed information is currently available for these areas and there is no clear indication as to which area will develop first, the next phases of planned City expansion require multiple models. Models are being prepared to establish the limits of growth under two primary scenarios, the first being west side development fed primarily through the existing service mains with PCWA as the primary surface supply, and the second being north side development prior to the NID treatment plant coming online.

The final treated water model for phased build-out is the "Buildout Model." A number of models have been created to represent build-out conditions and the current 2016 model will be revised many times before build-out is reached. The purpose of this final treated water model is to set the sizing of key infrastructure needed at build-out so that new waterlines that are needed immediately will not be undersized before meeting final build-out conditions.

Additional versions of this build out model and some interim models were completed to identify key infrastructure segments and inform decision-making. Options for redundancy and the capacity of the system in emergency situations are also helpful planning tools for the water system engineers and land planners. The information gained from these other model runs will be used to determine the best option for the City water system based on the path development actually takes and will be updated as new information becomes available.

9.8.5 Summary of Recommended Corrective and Continued Actions

This section details the recommended actions to maintain the quality of the City's treated water model and improve accuracy over time.

- Conduct normal year max day fire flow tests and re-calibrate the model to within 10% (completed for August 2016, recommend repeating every few years)
- Continue O&M operations and update the model with system changes created in this process.
- Continue to update model with as-built and maps of areas in question, especially in regards to components of the existing system.
- Establish records of areas without redundancy or fireflow capacity and plan for field upgrades.
- Update the model incrementally with each new development to document needed infrastructure to meet supply criteria.
- Integrate new operations technologies such as AMI or advanced SCADA into the model as they become available.
- Check alternate pipe alignments and pipe designs against build-out and intermediate phase models to identify potential impacts.
- Ensure treated water models reflect all City-planned Capital Improvements and Facility Replacements for the treated water system.
- The City should formally review, update, adopt and codify updated system design and engineering standards for the water system.
- The City should require developers to perform and submit development specific water modeling with defining parameters and product expectations
- Siting, design, and construction of City Capital Improvement Projects involving storage tank, well production and booster pump station facilities, along with PCWA and NID water supply contracts should be handled solely by staff and not subject to the control of outside developer-related entities via development agreements

9.8.6 Summary of City Policy and Design Standard Update Actions

This section details the recommended updates to City Policies and the Engineering and Design Standards.

- Revise the language so that the deign standards, as required by law, follows the design and operational criteria set in the most recent version of the California Fire Code, dated 2016. (update every 3 years along with the California Fire Code.)
- Establish a City Policy of well use for peaking and minimized use in non-peak demand periods.
- Establish a City Policy of total well pumping capacity to be greater than or equal to 75% of average day demand.
- Establish a City Policy that well pumping capacity must account for 1 well to be offline as backup for every 3 in operation.
- Establish a City Policy that well pumping target should be 10% of average annual demand as seen on a 10 year running average.
- Establish a Design Standard that City Wells should be capable of producing at least 1 MGD (1,400 GPM for 12 hours per day).
- Establish a Design Standard that new City Well shall operate on VFD.
- Establish a City Policy that minimum storage shall provide 50% of average day capacity, plus fireflow storage, as well as an emergency storage volume while leaving 10% of average day minimum head space.
- Establish a City Policy that additional storage facilities shall be constructed as additional demands are placed on the system.
- Establish a Design Standard of no mains smaller than 8 inches.
- Establish a Design Standard of no non-looped mains longer than 2,000 feet.
- Establish a Design Standard of no looped mains are smaller than 12 inches.
- Establish a Design Standard that pipes shall follow the criteria set **Section 9.5.2**
- Establish a City Policy that demand multipliers shall be monitored yearly and updated as system operations change.
- Establish a City Policy that future system infrastructure shall not require frequent PRV adjustment in order for the system to remain balanced.

- Establish a Design Standard of operating pressures between 50 and 130 psi.
- Establish a Design Standard of operating pressures during peak hour of maximum day shall not drop below 40 psi.
- Establish a Design Standard of operating pressures during a maximum day fire flow event shall not drop below 20 psi.
- Establish a Design Standard of operating velocities maintained below 7 ft/sec during maximum day demands.
- Establish a Design Standard of operating velocities maintained below 10 ft/sec in maximum day fireflow demands.
- Establish a Design Standard of operating velocities maintained below 10 ft/sec in maximum day peak hour so long as all other hours follow the 7 ft/sec standard.

CHAPTER 10. FACILITY REPLACEMENT PROGRAM

The purpose of this chapter is to discuss the potable water supply projects identified as part of the Facility Replacement Program (FRP) for the City of Lincoln based on water system infrastructure ages, materials, known conditions, and modeling results. The recommended FRP projects will assist the City in meeting build-out demand as well as current fire flow conditions. This chapter was developed in consultation with City Staff and ongoing projects and recommended projects are based upon conditions known as of Summer, 2016.

10.1 Introduction

Unlike the CIP program where projects are tied to specific developments and milestones within the water system, the FRP deviates from the modeled hypothetical schematics and addresses acute conditions that actually exist in the current water delivery system. The City of Lincoln operates a water system that has changed water supply sources multiple times and, therefore, relies on many incongruent engineering and operational improvements to maintain service. With some pipes being cataloged in the database as installed as early as 1929, the FRP is as much of an information tracking program as it is a repair program. Moreover, the variety of pipe materials incorporated into the City system may cause unforeseen issues not predicted by the infrastructure records relating to dates alone.

"Spot Repairs" – repairs that occur in specific areas on an as needed basis – occur regularly in many parts of the City and occasionally involve up-sizing pipes. Specifically, if a spot repair is needed and the Capital Improvement Program (CIP is discussed in **Chapter 11**) identifies the location as needing a pipe up-sizing, the City takes actions to accommodate the CIP in making the spot repair. As the spot repairs grow in number, due to the age and materials of the older water system, engineers and operators anticipate related issues that may arise in other parts of the system and try to make adjustments. Unlike CIP project planning and construction, FRP planning is an ongoing effort that spans decades with continued system assessment and infrastructure upgrades. City employees that identify and report issues need to prioritize projects so that the most problematic and far-reaching projects are addressed ahead of lesser projects. Accordingly, this chapter develops a critical list of Facility Replacement Program projects to address current water delivery system issues.

The projects listed below cover the main FRP issues identified in coordination with City Staff. Many of these FRPs are not yet disaggregated into individual projects but represent potential existing vulnerabilities in the system. **Section 10.2** identifies projects underway while **Section 10.3** identifies the specific projects ready for repair. **Section 10.4** identifies the longer-term projects with broader implications to the City's overall water system.

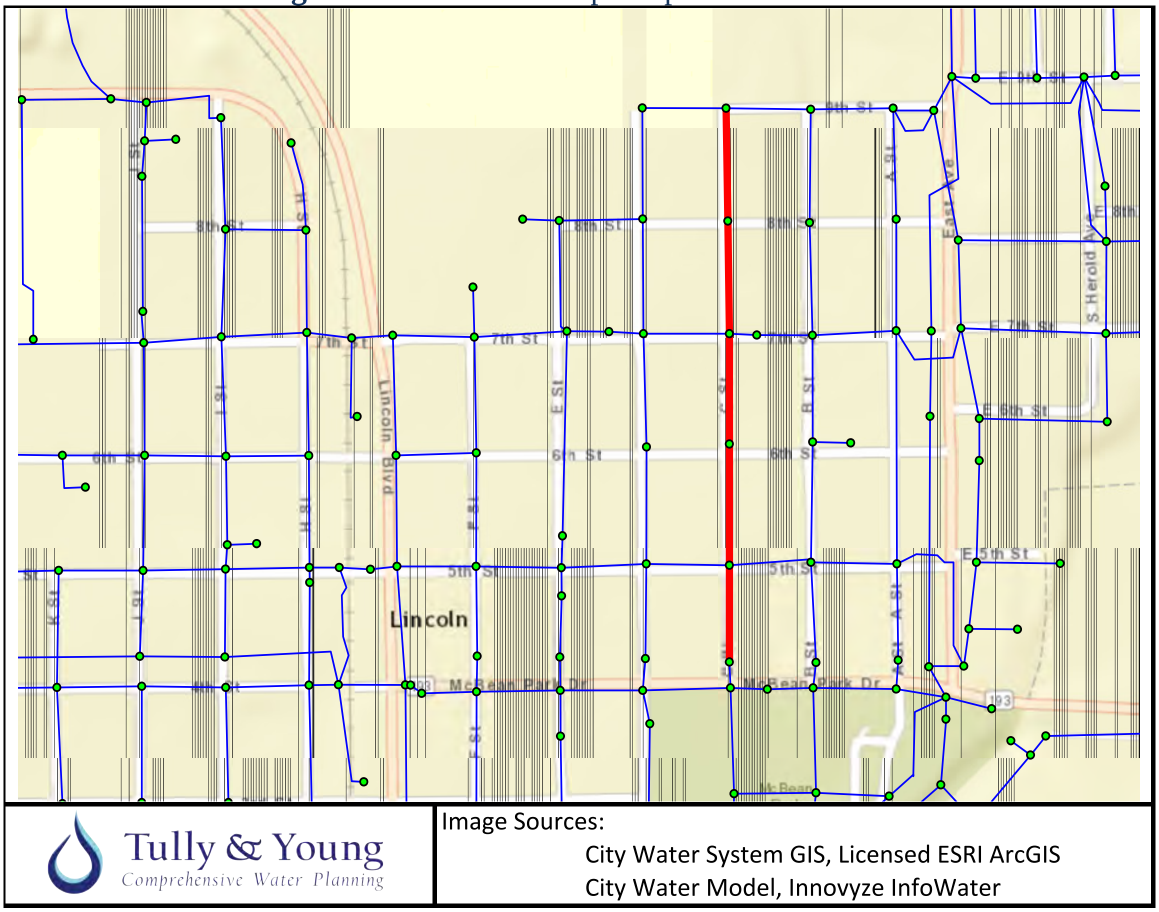
10.2 Projects Underway

The projects noted in the following subsections are underway as of the Summer of 2016. Projects currently underway are generally related to smaller single pipe projects ranging from a few hundred feet to a few blocks (approximately 3/10ths of a mile). Current system operations staff and engineering staff worked together to identify the key infrastructure needing replacement and prioritized the projects that have been initiated. The following subsections are not an exhaustive list of the projects underway. The subsections describe the system benefits resulting from their completion.

10.2.1 C Street from McBean Park to 9th Street

The City is currently replacing the 4-inch CIP pipe along C Street with new 8-inch PVC line. The section of pipe currently serves 6 fire hydrants, 2 of which are only capable of fire flow around 750 gpm prior to hitting design velocity limits. In addition, the 4-inch pipe is labeled in the GIS as being installed in 1929 or earlier meaning the pipes are over 85 years old. The replacement pipe measures approximately 2,400 feet as shown below in **Figure 10-1**. Following the completion of this replacement project, all fire flows in this area should be above about 2,000 gpm.

Figure 10-1 – C Street Pipe Replacement



10.3 Projects Currently Identified

These projects listed in the subsections below are anticipated to begin shortly. The projects currently identified are generally related to smaller single pipe projects ranging from a few hundred feet to about a half-mile but also include some system-wide general replacement projects. System operations staff and engineering staff worked together to identify the key infrastructure needing replacement and prioritized the projects listed below. The following subsections detail the projects identified and the benefits resulting from their completion.

10.3.1 East 9th Street

The City is currently replacing the 4-inch CIP pipe along East 9th Street with new 8-inch PVC line. The section of pipe currently serves 2 fire hydrants, one of which is only capable of fire flow around 750 gpm prior to hitting design velocity limits. In addition, the pipe in question is labeled in the GIS system as being installed in 1929 – making the pipe over 85 years old. The replacement pipe measures approximately 700 feet as shown below in **Figure 10-2** in green. Following the completion of this replacement project all fire flows in this area should be above about 2,900 gpm. This project is anticipated to be completed in Spring of 2017.

Figure 10-2 – East 9th Street Pipe Replacement

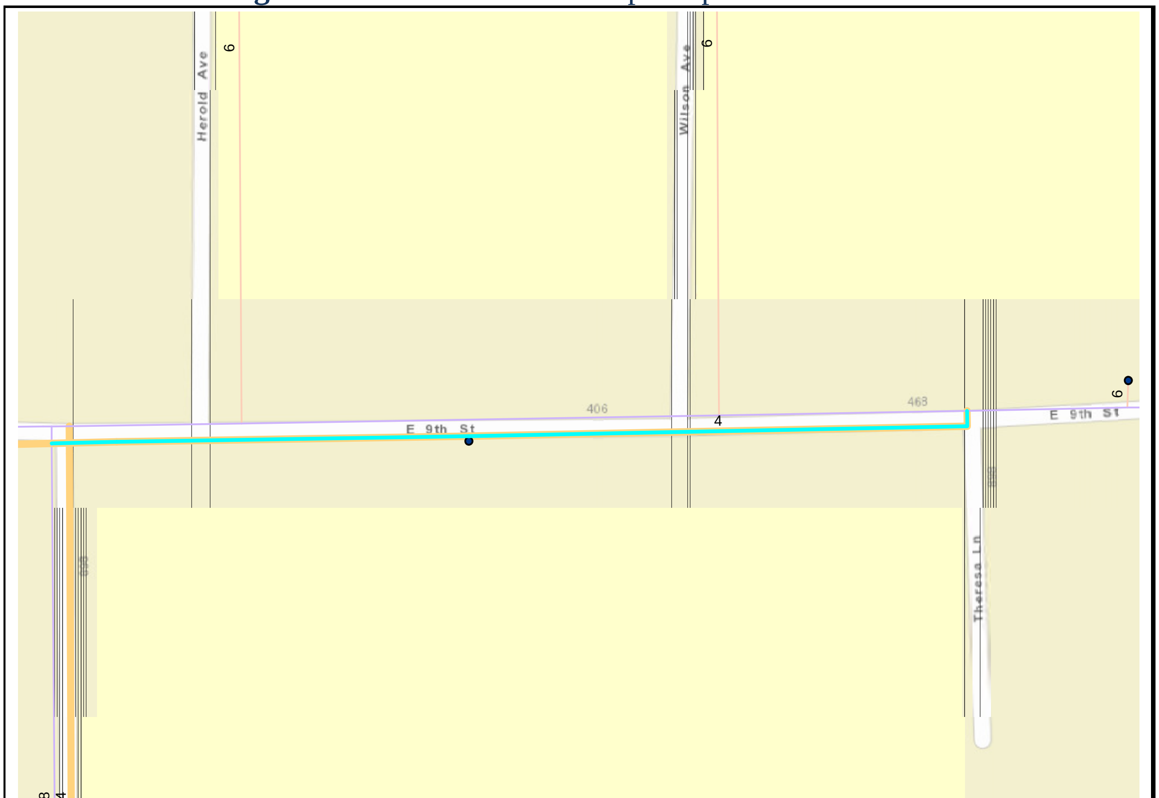


Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

10.3.2 East 5th Street

The City is currently replacing the 4-inch CIP pipe along East 5th Street with new 6-inch PVC line. The section of pipe currently serves 1 fire hydrant that is only capable of fire flow around 400 gpm prior to hitting design velocity limits and is the only fire protection available for a number of houses. In addition, the identified pipe is listed in the GIS system as installed in 1929, exceeding 85 years old. The replacement pipe measures approximately 260 feet as shown below in **Figure 10-3**. Following the completion of this replacement project all fire flows in this area should be above about 2,300 gpm.[1] This project is anticipated to be completed in Summer of 2017.

[1] This 2,300 ft. value exceeds the 10 ft/sec limit in the 6 inch pipe but due to the unique location is being treated as a hydrant lateral in terms of design consideration. Fireflow velocity considerations are only

Figure 10-3 – East 5th Street Pipe Replacement

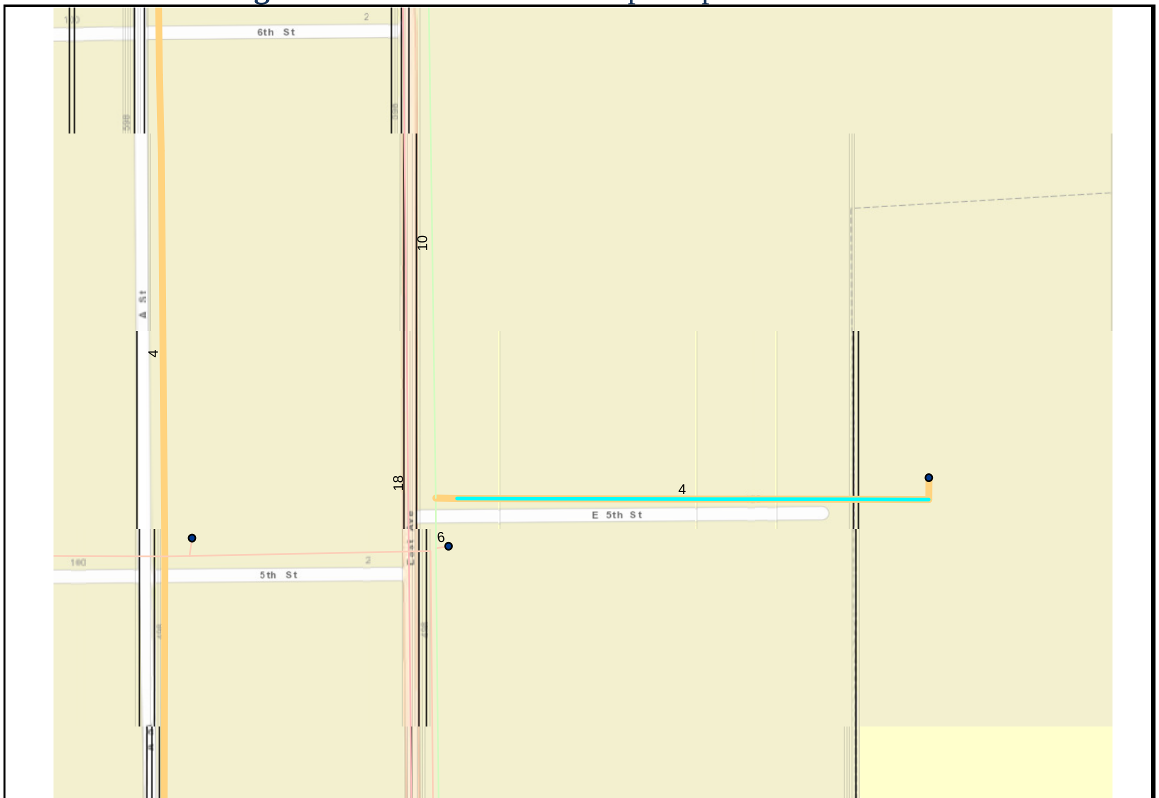


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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

10.3.3 LDS

The City is installing new 8-inch and 12-inch PVC pipes along Red Leaf Way and Liberty Lane of the LDS parcel. This section of the City's current service area is currently only served by a single 2-inch non-looped water line. Although the water line is PVC and was installed in 1990, it is only capable of about 50 gpm. The existing pipe is shown below in **Figure 10-4**. Following the completion of this resupply project, all fire flows should be above suitable for residential and commercial services. This project is anticipated to be completed in 2017.

applied to system mains for design purposes. The velocity in a hydrant lateral may exceed the 10 ft/sec design limit.

Figure 10-4 – LDS Resupply Installation

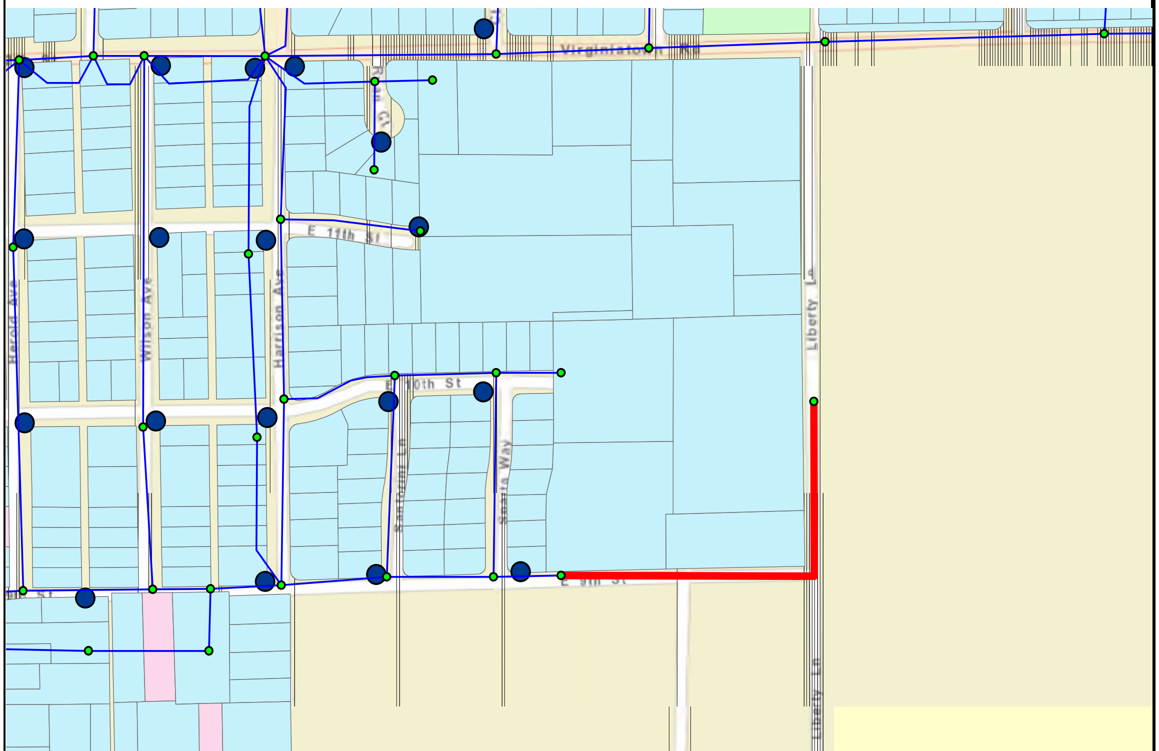

Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

10.3.4 SummerPlace

The City is installing new 8-inch and 12-inch PVC pipes along Red Rock Road to provide fire protection and water service to the SummerPlace project. Adjacent waterlines were installed in 2004 and can provide fireflows around 3,500 gpm. The new 12-inch main pipe measures approximately 650 feet as shown below in **Figure 10-5**.[2] Following the completion of this replacement project all fire flows in this area should be above about 6,500 gpm and the 12-inch line will loop the water system on Red Rock Road. This project is anticipated to be completed in 2017.

[2]For the purposed of this analysis the 8-inch waterlines on site are considered laterals in fire flow modeling.

Figure 10-5 – SummerPlace Pipe Installation

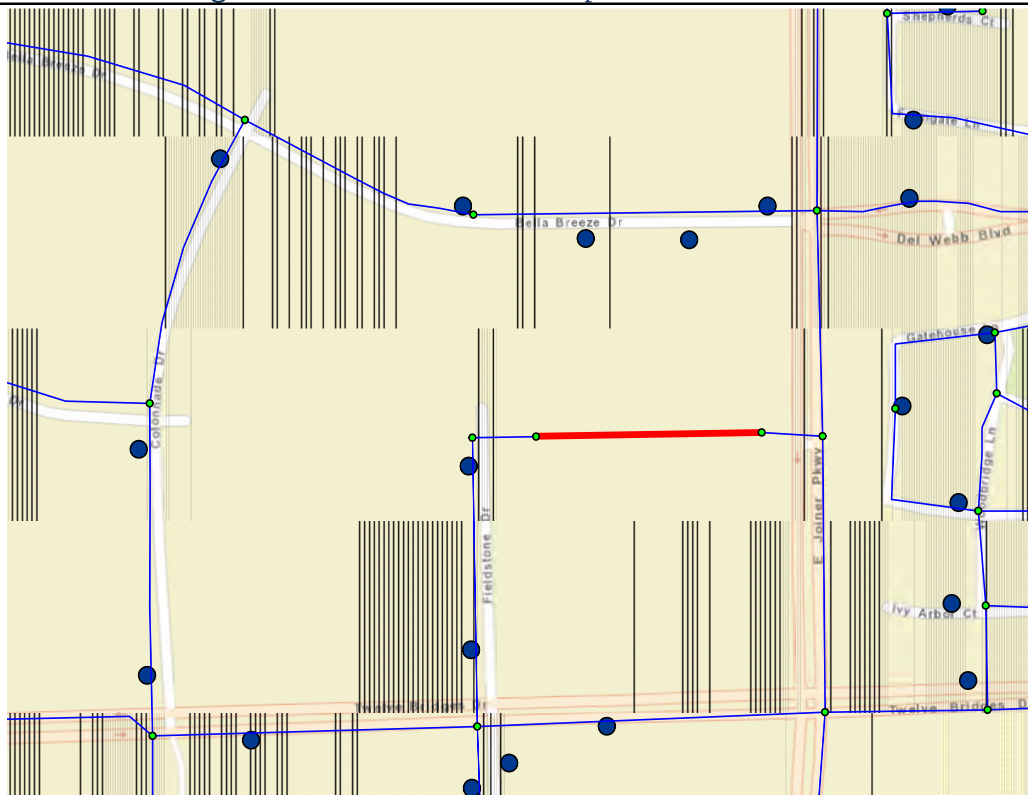

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

10.3.5 Summerset – F Street

The City is currently replacing the 4-inch CIP pipe along F Street between 2nd and 3rd Streets with new 12-inch PVC line. The section of pipe is only capable of fire flow around 700 gpm prior to hitting design velocity limits. In addition, the pipe in question is approximately 90 years old with an install year listed in the GIS system of 1929. The replacement pipe measures approximately 400 feet as shown below in **Figure 10-6**. Following the completion of this replacement project all fire flows in this area should be above about 6,500 gpm. This project should be completed in 2017.

Figure 10-6 – Summerset - F Street Pipe Replacement

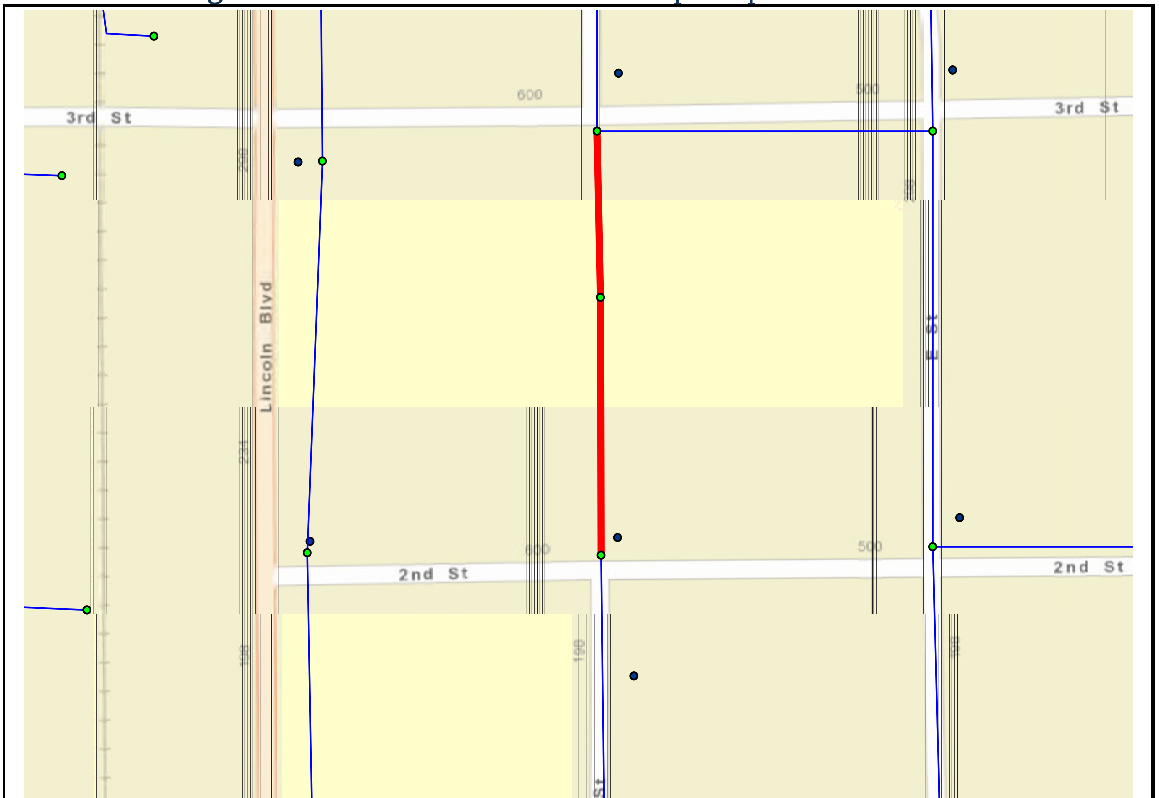

Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

10.3.6 Greater 4-Inch CIP Replacement

Many of the projects listed above are related to water mains constructed of 4-inch Cast Iron Pipe (IP). This pipe is too small to effectively serve fire flows without violating the 10 ft/sec design standard and has suffered from corrosion. The City is currently in the process of identifying key sections of and replacing all of the 4-inch IP pipe along with new PVC line. The size of the new PVC line is determined by the engineering staff but will generally be an 8-inch water line. The 147 sections remaining of this IP totals 3.6 miles and together with 1.7 miles of 4-inch ACP pipe currently serves about 60 fire hydrants, many of which are only capable of fire flow around 700 gpm prior to hitting design velocity limits. In addition, the pipes identified were all installed between 1929 and 1960. The pipes to be replaced are shown below in **Figure 10-7**.[3] Following the replacement of the 4-inch pipes, looped fire flows in this area will all be above at least

[3] The pipes in this table include some pipes labeled as ACP in the GIS system. The City is awaiting some field verifications as ACP pipe was far more common in 6-inch diameters

about 2,000 gpm. These projects are anticipated to be completed in approximately 5 years.

Figure 10-7 – 4-inch IP Pipe Replacement

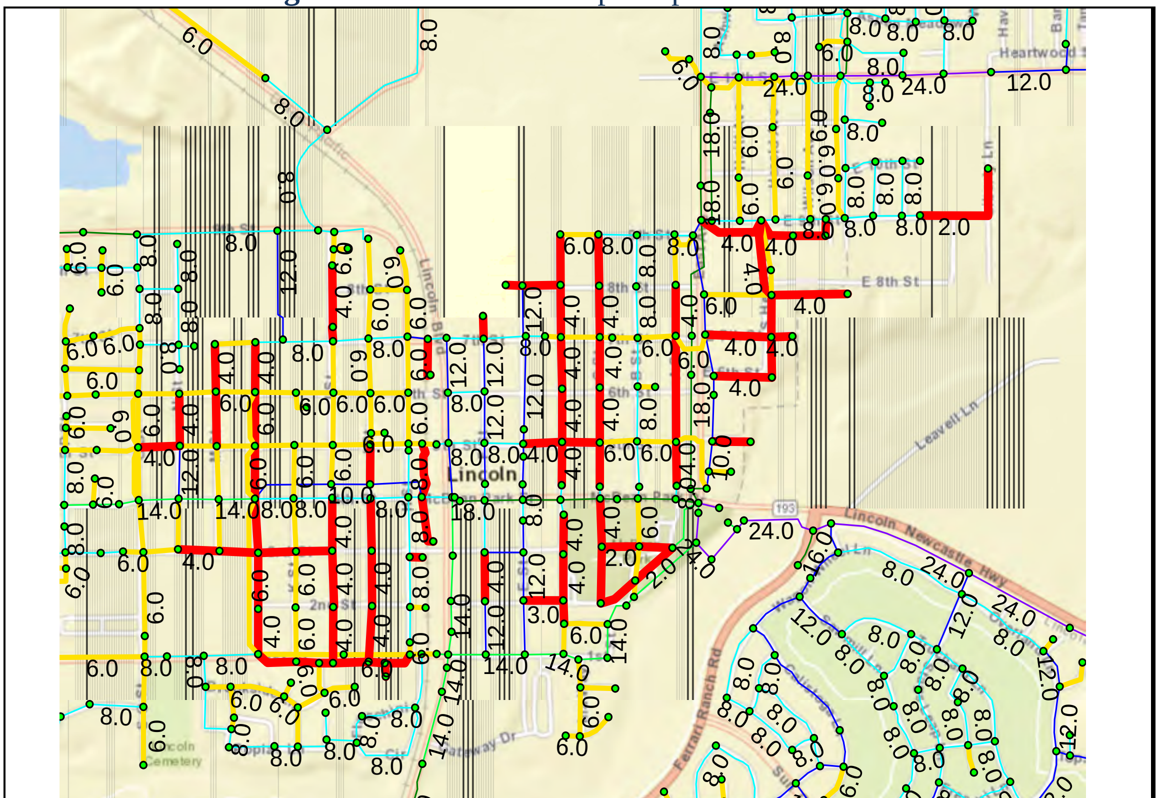

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Table 10-1 – Example Table of all 4inch IP Pipes

OBJECTID_1	OBJECTID	comment	dia	type	material	pipe_id	status	year_	Shape_Length	source	year_install	precon_date	material_class	subdivision
5874	1,573		4	wtpi	CIP	5874	existing	1929	570.8	nolte data	1929	1929	CL 150	First St.
6116	528		4	wtpi	STEEL	6116	existing	1929	527.3	Sectional Map of Water Distribution System Showing Proposed Improvements	1929	1929	CL 150	Herold Ave.
6799	434		4	wtpi	CIP	6799	existing	1929	516.6	Lincoln East E Ninth-Herold-E Eighth pgs 2,3,4 of 10 Jan 1987.pdf	1929	1929	CL 150	E. Ninth St.
3555	625		4	wtpi	CIP	3555	existing	1929	501.1	nolte data	1929	1929	CL 150	J St.
5962	762		4	wtpi	CIP	5962	existing	1929	485.2	nolte data	1929	1929	CL 150	M St.
11512	536		4	wtpi	CIP	11512	existing	1929	478.3	av-water.dwg	1929	1929	CL 150	D St.
3584	628	material taken from water leak record	4	wtpi	STEEL	3584	existing	1929	463.5	nolte data	1929	1929	CL 150	I St.
11522	510		4	wtpi	CIP	11522	existing	1929	454.1	nolte data	1929	1929	CL 150	A St.
6044	536		4	wtpi	CIP	6044	existing	1929	453.6	nolte data	1929	1929	CL 150	D St.
11506	508		4	wtpi	CIP	11506	existing	1929	453.2	nolte data	1929	1929	CL 150	C St.
11508	536		4	wtpi	CIP	11508	existing	1929	452.6	nolte data	1929	1929	CL 150	D St.
20428	615		4	wtpi	CIP	20428	existing	1929	435.7	nolte data	1929	1929	CL 150	D St.
6747	558		4	wtpi	STEEL	6747	existing	1929	429.8	nolte data	1929	1929	CL 150	Fifth St.
6197	461		4	wtpi	CIP	6197	existing	1929	428.4	nolte data	1929	1929	CL 150	C St.
6159	461		4	wtpi	CIP	6159	existing	1929	425.4	nolte data	1929	1929	CL 150	C St.
30594	615		4	wtpi	CIP	20428	existing	1929	424.8	nolte data	1929	1929	CL 150	D St.
5960	742		4	wtpi	CIP	5960	existing	1929	417.8	nolte data	1929	1929	CL 150	M St.
23276	510		4	wtpi	CIP	11523	existing	1929	408.8	nolte data	1929	1929	CL 150	A St.
11502	470		4	wtpi	CIP	11502	existing	1929	403.4	nolte data	1929	1929	CL 150	C St.
6236	628		4	wtpi	CIP	6236	existing	1929	401.2	nolte data	1929	1929	CL 150	I St.
6256	625		4	wtpi	CIP	6256	existing	1929	393.3	nolte data	1929	1929	CL 150	J St.
23290	621		4	wtpi	CIP	11494	existing	1929	392.4	nolte data	1929	1929	CL 150	F St.
11456	628		4	wtpi	CIP	11456	existing	1929	391.5	legacy gps	1929	1929	CL 150	I St.
23373	528		4	wtpi	STEEL	11541	existing	1929	383.9	av-water.dwg	1929	1929	CL 150	Herold Ave.
6648	888		4	wtpi	STEEL	6648	existing	1929	382.9	nolte data	1929	1929	CL 150	D St.
5771	601		4	wtpi	CIP	5771	existing	1929	373.4	nolte data	1929	1929	CL 150	Third St.
6262	1,360		4	wtpi	CIP	6262	existing	1929	359.0	nolte data	1929	1929	CL 150	First St.
6137	464		4	wtpi	CIP	6137	existing	1929	358.9	nolte data	1929	1929	CL 150	A St.
6820	434		4	wtpi	CIP	6820	existing	1929	353.7	Lincoln East E Ninth-Herold-E Eighth pgs 2,3,4 of 10 Jan 1987.pdf	1929	1929	CL 150	E. Ninth St.
5775	601		4	wtpi	CIP	5775	existing	1929	342.6	nolte data	1929	1929	CL 150	Third St.
11510	644		4	wtpi	CIP	11510	existing	1929	335.4	nolte data	1929	1929	CL 150	Eighth St.
5790	601		4	wtpi	CIP	5790	existing	1929	334.2	nolte data	1929	1929	CL 150	Third St.
6171	664		4	wtpi	CIP	6171	existing	1929	326.8	nolte data	1929	1929	CL 150	Fifth St.
6163	566		4	wtpi	CIP	6163	existing	1929	324.1	nolte data	1929	1929	CL 150	Fifth St.
6344	604		4	wtpi	CIP	6241	existing	1929	319.0	nolte data	1929	1929	CL 150	K St.
3632	639		4	wtpi	CIP	3632	existing	1929	298.6	nolte data	1929	1929	CL 150	Lincoln Offsite
6666	888		4	wtpi	CIP	6666	existing	1929	291.9	nolte data	1929	1929	CL 150	D St.
5782	601		4	wtpi	CIP	5782	existing	1929	282.8	nolte data	1929	1929	CL 150	Third St.
23071	1,614	diameter from water leak record	4	wtpi	CIP	5979	existing	1929	280.9	nolte data	1929	1929	CL 150	Fifth St.
5931	675		4	wtpi	CIP	5931	existing	1929	275.4	nolte data	1929	1929	CL 150	Eighth St.
28287	464		4	wtpi	CIP	6137	existing	1929	274.7	nolte data	1929	1929	CL 150	A St.
28339	445		4	wtpi	STEEL	6122	existing	1929	248.6	Sectional Map of Water Distribution System Showing Proposed Improvements	1929	1929	CL 150	E. Eighth St.
6819	434		4	wtpi	CIP	6819	existing	1929	243.0	Lincoln East E Ninth-Herold-E Eighth pgs 2,3,4 of 10 Jan 1987.pdf	1929	1929	CL 150	E. Ninth St.
6136	464		4	wtpi	CIP	6136	existing	1929	164.1	nolte data	1929	1929	CL 150	A St.

10.4 General Long-Term Projects

The general long-term projects described in the subsections below are underway as of the Summer of 2016. Projects currently underway are generally related to smaller single pipe projects ranging from a few hundred feet to a few blocks. Current system operations staff and engineering staff worked together to identify the key infrastructure needing replacement and prioritized the projects currently underway. The following subsections detail the projects underway and the benefits resulting from their completion.

10.4.1 Pipes Exceeding Their Design Lives

The City GIS database lists a number of pipes dating from as far back as 1929. All of these pipes are well beyond their useful design life and commonly undersized for current City demands and legally required fire flows. Repairs performed in areas of the City with these older pipelines typically call for replacing smaller pipe sections. While this replacement works over time, it does lead to some remnant pipeline sections that are older and less reliable. These pipe sections are shown in **Figure 10-8**. For the purposes of this subsection, pipes older than 1960 have been identified in the GIS system and have generally exceeded their design limits.[4] This age-limit tags 815 separate pipes in the GIS system with a total length of 17.9 miles. As the FRP will be an ongoing effort between operations and engineering, the age-limit details determined to be outside of the useful design life will be adjusted as more information about the condition of pipes in the

[4] The current choice of a 1960 design life threshold is arbitrary and is to be adjusted before specific projects are identified.

ground is collected. It is anticipated that location and material will result in modification to the design life threshold.

Figure 10-8 – Map of all Pipes older than 1960

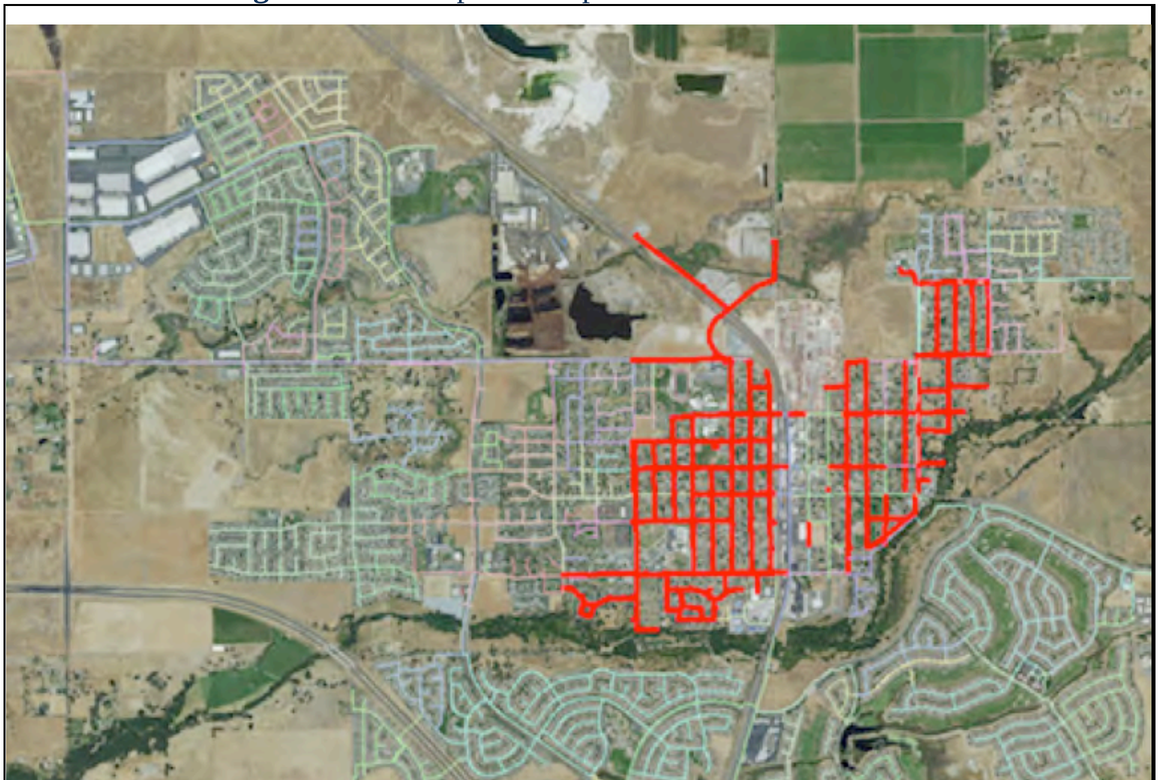

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Table 10-2 – Summary Table of all Pipes older than 1960

Diameter (inches)	Count	Total Length (miles)	Median Year Installed
2	6	0.3	1929
4	225	5.3	1929
6	445	8.2	1959
8	115	3.4	1959
10	24	0.6	1959

10.4.2 ACP Pipe

Through the course of water system design, pipe materials have greatly varied – as engineering and infrastructure preferences as well as technology have changed. One such pipe is the Asbestos Cement Pipe (ACP). This pipe was used widely in the middle of the 20th century and presented a significant cost savings over the iron pipe of the era. Today, ACP is considered brittle and leak-prone compared to modern Iron and PCV pipes. The City of Lincoln has a number of ACP water mains scheduled for replacement but many still remain and are not yet identified specifically for replacement. With the newest of these pipes being approximately 30 years old, these pipes are more than half way through their useful design life. As the pipe becomes more brittle with age, repairing and connecting new pipes to this ACP pipe has become more difficult. The City considers this type of pipe functional but has identified them for replacement. In total, the City has 937 individual ACP pipes identified in the GIS system with a total length of nearly 21 miles. **Figure 10-9** shows the distribution of these pipes in the older parts of the City.

Figure 10-9 – Map of all ACP pipe in the City

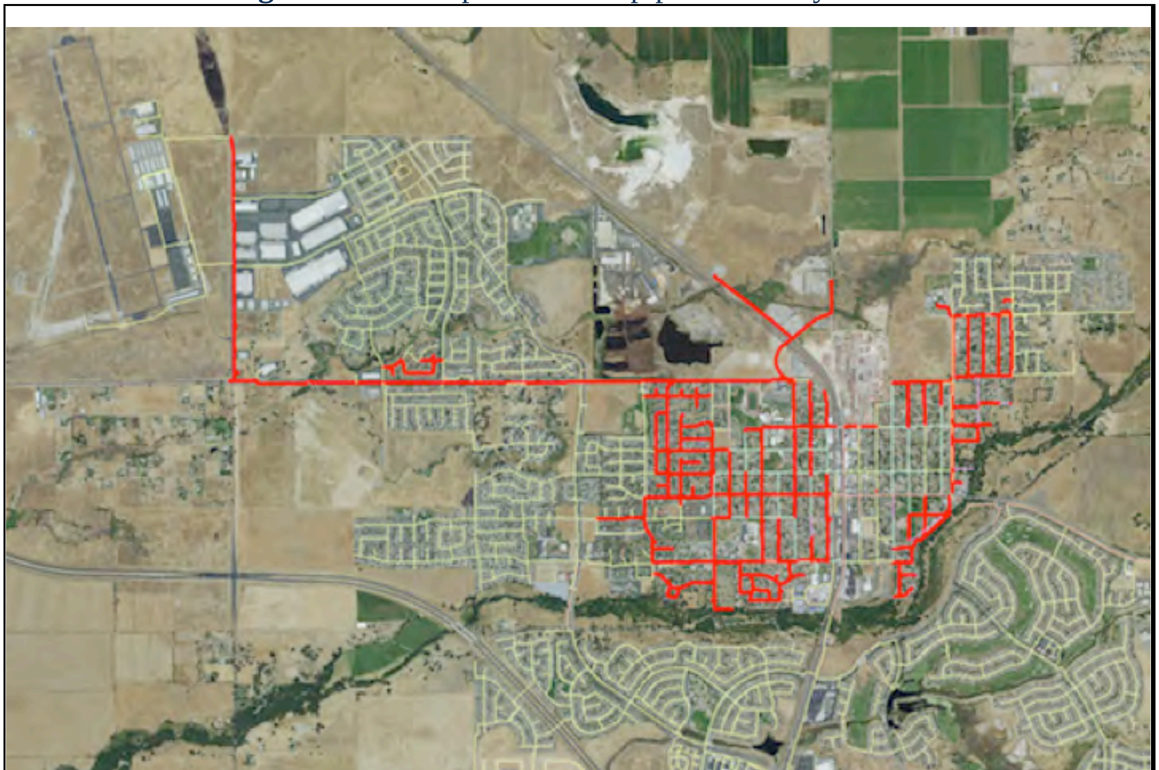

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Table 10-3 – Summary Table of all ACP Pipes

Diameter (inches)	Count	Total Length (miles)	Median Year Installed
2	4	0.2	1929
4	81	1.7	1929
6	489	8.4	1960
8	183	5.3	1960
10	71	1.5	1978
12	50	1.1	1984
14	25	0.8	1978
16	33	1.9	1984

10.4.3 Older Rail Undercrossings

The City of Lincoln grew out of what is today called "Old Town." This area straddled old Highway 65 and the railroad tracks near the current City Hall. Pipes located in and around old Highway 65 and the railroad tracks are difficult and expensive to maintain, repair and replace. Old Town currently has 5 of the 7 rail undercrossings. Most pipelines imbedded in the undercrossings are generally small and many of those pipelines have exceeded their useful design life. With the newly constructed Highway 65 bypass that circumnavigates Old Town, the cost of replacing one of these crossings has fallen and become less procedurally burdensome. Maintaining, repairing, and replacing pipelines that transverse the railroad tracks is still expensive due to the complexities of railway management issues. **Figure 10-10** shows the distribution of rail undercrossing pipes in the older parts of the City.

Figure 10-10 – Map of Old Town Rail Undercrossings

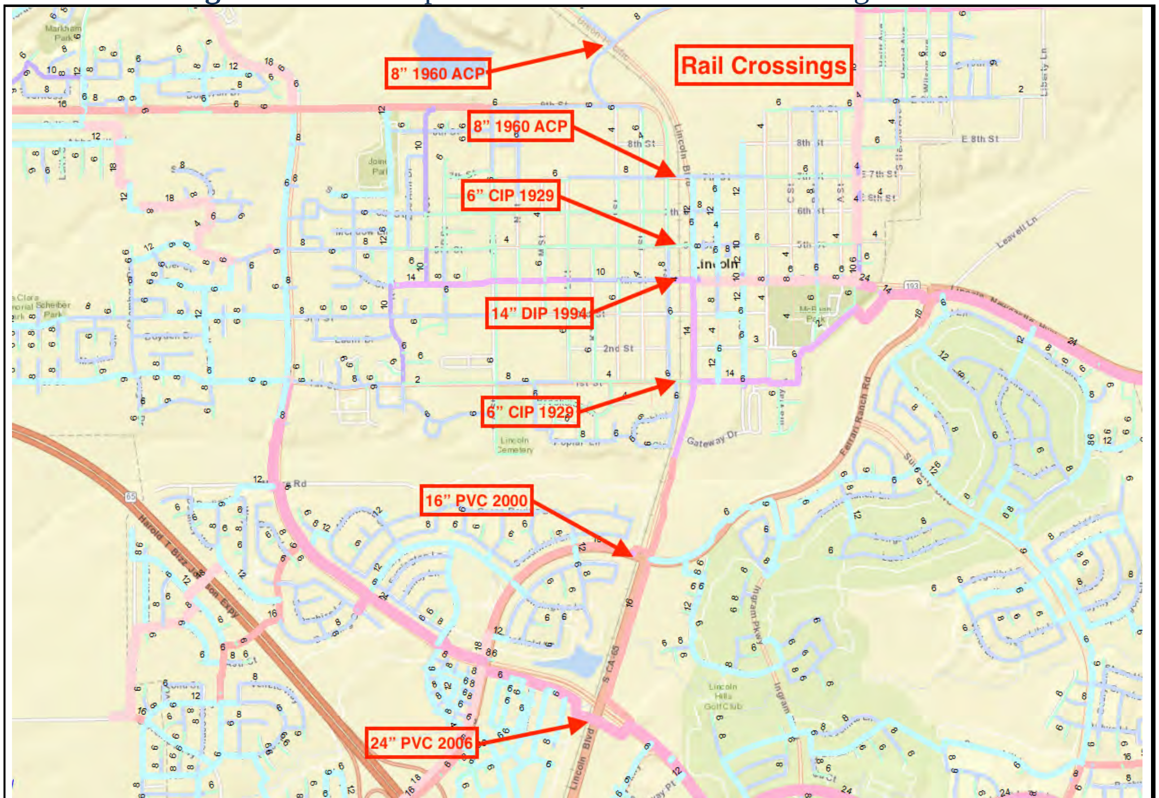

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Table 10-4 – Table of Undercrossings

Location	Diameter	Material	Year
Gladding & 9th	8”	ACP	1960
7th	8”	ACP	1959
5th	6”	CIP	1929
4th	14”	DIP	1994
1st	6”	CIP	1929
Ferrari Ranch	16”	PVC	2000
Joiner Parkway	24”	PVC	2006

10.4.4 Current Fire Flow Issues

The City of Lincoln has a number of areas that are supplied by older pipe infrastructure that cannot handle the flows required under todays Fire Code. As most of these areas will see replacement under the larger 4-inch CIP program and later by the ACP replacement program, areas still not satisfying Fire Code requirements will need to be addressed. With the completion of the 4-inch CIP and ACP pipe replacement, all current areas will be able to serve at least 1,500 gpm fire flows needed to serve residential areas. Some areas may be short of commercial and industrial fire flows but these will be addressed on a case by case basis by City staff as this development progresses.

Figure 10-11 – Map of Current Fire Flow Issues

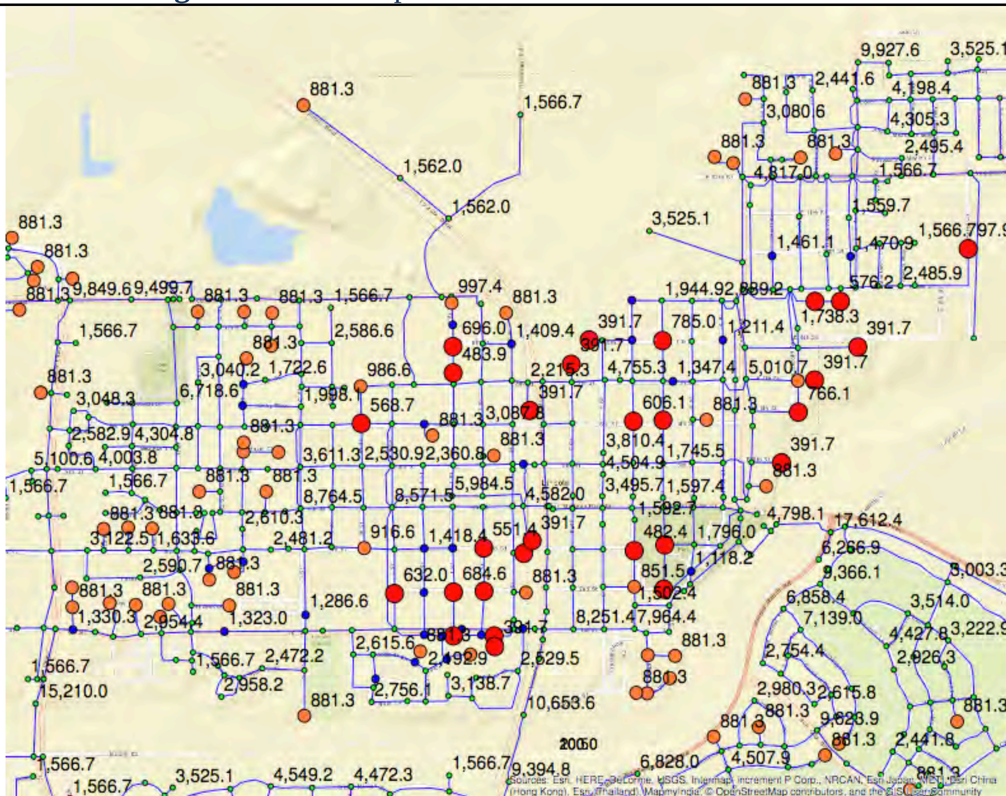

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Image Sources:
City Water System GIS, Licensed ESRI ArcGIS
City Water Model, Innovyze InfoWater

Figure 10-12 – Impact of 4-inch CIP Replacement to Fire Flows

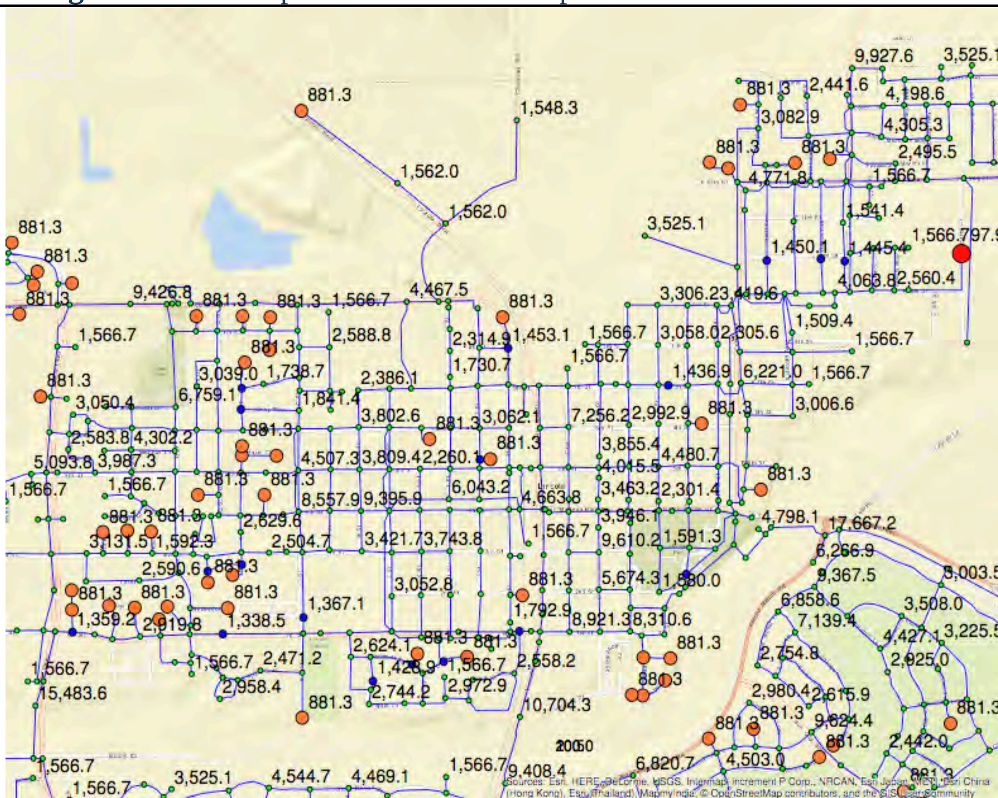

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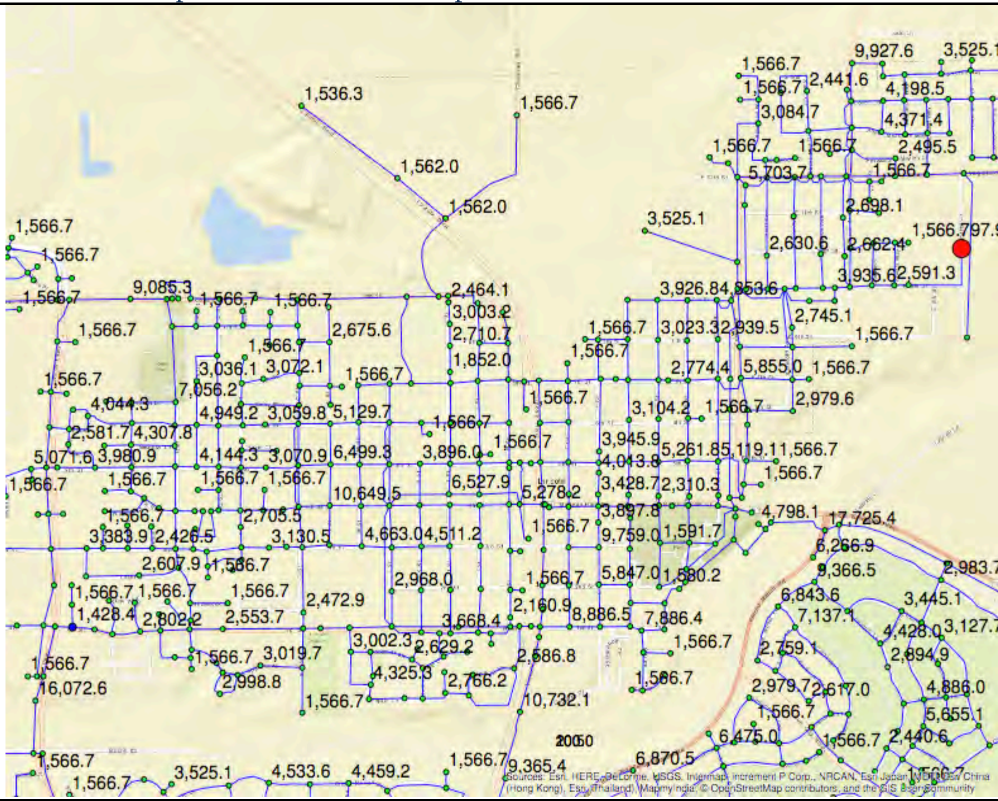
Figure 10-13 – Impact of 4-inch CIP Replacement and 6-inch ACP to Fire Flows



Tully & Young Comprehensive Water Planning	Image Sources: City Water System GIS, Licensed ESRI ArcGIS City Water Model, Innovyze InfoWater