Optimatics

optimizing water systems

Water System Master Plan Update Optimization Study

City of Bend, Oregon, Project No. WA09FA

Consequence of Failure Analysis

FINAL MEMORANDUM

March 2010

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Executive Summary

As part of the Water System Master Plan Update Optimization Study, Optimatics performed a consequence of failure analysis on all the distribution pipes in the Bend network. Optimatics' pipe criticality program OptiCritical ™ was combined with Bend's updated and calibrated steady-state hydraulic model to develop the criticality results.

The pipe criticality results provide valuable insight into where the system is most vulnerable with respect to the effects of pipe breaks and pipe isolation. The City can add this information to the body of knowledge it uses to prioritize where to spend its capital improvement dollars to strengthen the system.

After analyzing the criticality results, Optimatics developed a method for ranking the most vulnerable areas, leading to which pipes should be paralleled or replaced in order to strengthen these locations in the network. Criticality "metrics" such as the number of valve closures for isolation; the severity of pipe breaks and isolation with respect to the isolation of the two most critical customers identified by Bend (St. Charles Medical Center and the Deschutes Brewery); isolation of the greatest number of customers; and resulting low pressures under simulated break and simulated isolation conditions were studied and used in the priority ranking. The table below shows the top 7 critical areas, prioritized in terms of those metrics deemed to be most important.

Metrics used to prioritize the top 7 critical areas

Priority Number	Location	Cause vulnerability near St. Charles Medical Center	Cause vulnerability near Deschutes Brewery	Cause vulnerability due to low pressures during break	Cause vulnerability due to many customers isolated during break or isolation
1	**Zone 5 - NE Neff Road and NE Purcell Boulevard / St. Charles Medical Center**	✓		✓	✓
2	**Zone 5 - Deschutes Brewery area off SW Simpson Ave and SW Colorado Ave**		✓	✓	
3	**Zone 4 East (4B) – pipes on Reed Market Road and other streets**			✓	
4	**Zone 3 – pipes on and off Mt. Washington Drive south of Skyliners Road**			✓	✓
5	**Westwood Zone (3C) – Mt. Bachelor Drive / Mammoth Drive area**			✓	✓
6	**Zone 4 East (4B) – Brosterhous Road / American Lane / Fox Run Road**			✓	
7	**Zone 3 – Intersection of Mt. Washington Drive and Shevlin Park Road**				✓

An additional six areas beyond these seven were given Second Priority status based on the number of customers isolated during an isolation of a pipe for repair. These are the locations listed below; between 130 and 310 customers could be isolated:

1. Pipes in Zone 6 and 7B at the intersection of Butler Market Road and Purcell Boulevard, and north along Purcell
2. Zone 4 East (4B) pipes along Bronzewood Avenue off SE 15th Street
3. Pipes in the far southeast end of Zone 3 near the intersection of Fairway Ridge Lane and Devil's Lake Drive
4. Zone 4 East (4B) pipes supplying the zone from Pilot Butte Reservoir #2 to the north and west
5. Zone 6 and 7C pipes along Butler Market Road near the eastern edge of the system
6. Zone 4 East pipes at and just west of the intersection of NE Bear Creek Road and 15th Street

The City can use the criticality information contained in this document to assist in their capital improvement plans over the next 10 years.

1 Introduction

The aim of a pipe criticality analysis is to identify the most critical pipes in the water system in terms of the risks associated with failure of each pipe. Risk can be defined as follows:

Risk = Consequence of Failure x Likelihood of Failure

Conventional planning efforts for pipe replacement and rehabilitation (R&R) involve collecting information on pipe age, material, break history, leak history and other factors and creating an R&R prioritization list based on probability or likelihood of failure of a pipe. A pipe criticality analysis takes the evaluation further by identifying those pipes which, if broken or isolated, will cause the greatest consequence of failure. Factors related to consequence of failure include loss of supply to critical customers or to a large number of customers, low service pressure, flooding, high repair costs, and reputation damage to the utility. Understanding where consequence of failure is greatest in the system leads to a greater understanding of risk and vulnerability. A utility can then use this information to refine its existing R&R strategy, including adding new mains, new pressure reducing valves (PRVs), or other capital improvements as well as operational modifications to strengthen vulnerable areas of the system.

2 Background

Optimatics and MSA are currently carrying out a Water System Master Plan Update Optimization Study for the City. The study includes evaluation of current system operations under typical summertime and typical wintertime operating conditions, the development of an optimized master plan of improvements for target year 2030 maximum day conditions, and a prioritized capital improvement plan for the next 10 years as a subset of the overall master plan.

As part of the overall study scope, Bend also desired to have a pipe criticality analysis performed on the system using Optimatics' software program OptiCritical. The City will use this criticality information to prioritize the implementation of improvements to strengthen the system in selected areas, thereby reducing its vulnerability to pipe breaks and pipe isolation in the event of a break.

The minimum information required by the program for the consequence of failure analysis is a calibrated steady state model and details of shutoff valves (location and operability). The analysis generates a database containing a large number of results metrics related to the impact of pipe breaks and isolation of breaks on system pressures, flow velocities, and supply to customers. The criticality analysis results enable an assessment of the relative consequence of failure for each pipe in the network based on a number of different metrics of most concern to Bend.

It is important to note that the pipes in the Bend system are not particularly old and have not suffered from significant tuberculation. The City has not experienced issues with discolored water due to excessive velocities or reverse flows. The primary issues with respect to pipe criticality in the system are essentially loss of supply and low service pressure in certain areas which would occur during a pipe break or isolation, which reveals where the system is vulnerable in terms of reliability and back-up supply (redundancy). Therefore, the particular pipe criticality metrics of concern to Bend staff include those related to supply issues (customers affected), hydraulic performance (low pressures), and maintenance issues (valves required to isolate a break).

At the same time, Optimatics took into account several factors that the City identified which could affect likelihood of failure of certain mains in the system. These include the following:

Year of installation – the City has some older mains that may have a higher likelihood of failure.

Quality of installation – the quality of pipe installations can significantly affect the likelihood of failure of a particular main. In the Bend system, some cast iron mains laid before 1950 are proving to be particularly problematic due to poor installation techniques. Similarly, poor construction techniques in the South Bend area have led to significant issues with pipe breaks and leaks.

Pipe Material – this information is likely to overlap with the two risk factors above. Bend has advised that cast iron was the primary pipe material up to the 1980's. As mentioned above, some older cast iron mains were poorly installed and have been problematic. Since the 1980's, ductile iron has been used almost exclusively. The exception is the acquired South Bend area to the far southeast where PVC pipe was installed. Some small diameter galvanized steel pipe was installed in the 1960's and has been targeted for replacement. Also, the South Bend area has a number of shallow buried pipes that are being targeted for replacement.

Bend's current GIS database includes material information for many pipes, as shown in Figure 2.1.

With the results of the criticality analysis, the most critical locations/pipes have been ranked based primarily on system vulnerability. The additional step was then taken to compare the critical pipes with the City's age and pipe material data as well as the recommendations for pipe replacement and new pipe in the 2007 Master Plan Update. Any pipes/locations which were identified as priority from the criticality analysis but also identified in these additional databases have been called out. This provides the City with important information as it weighs how to best invest its capital improvement dollars toward strengthening the distribution system.

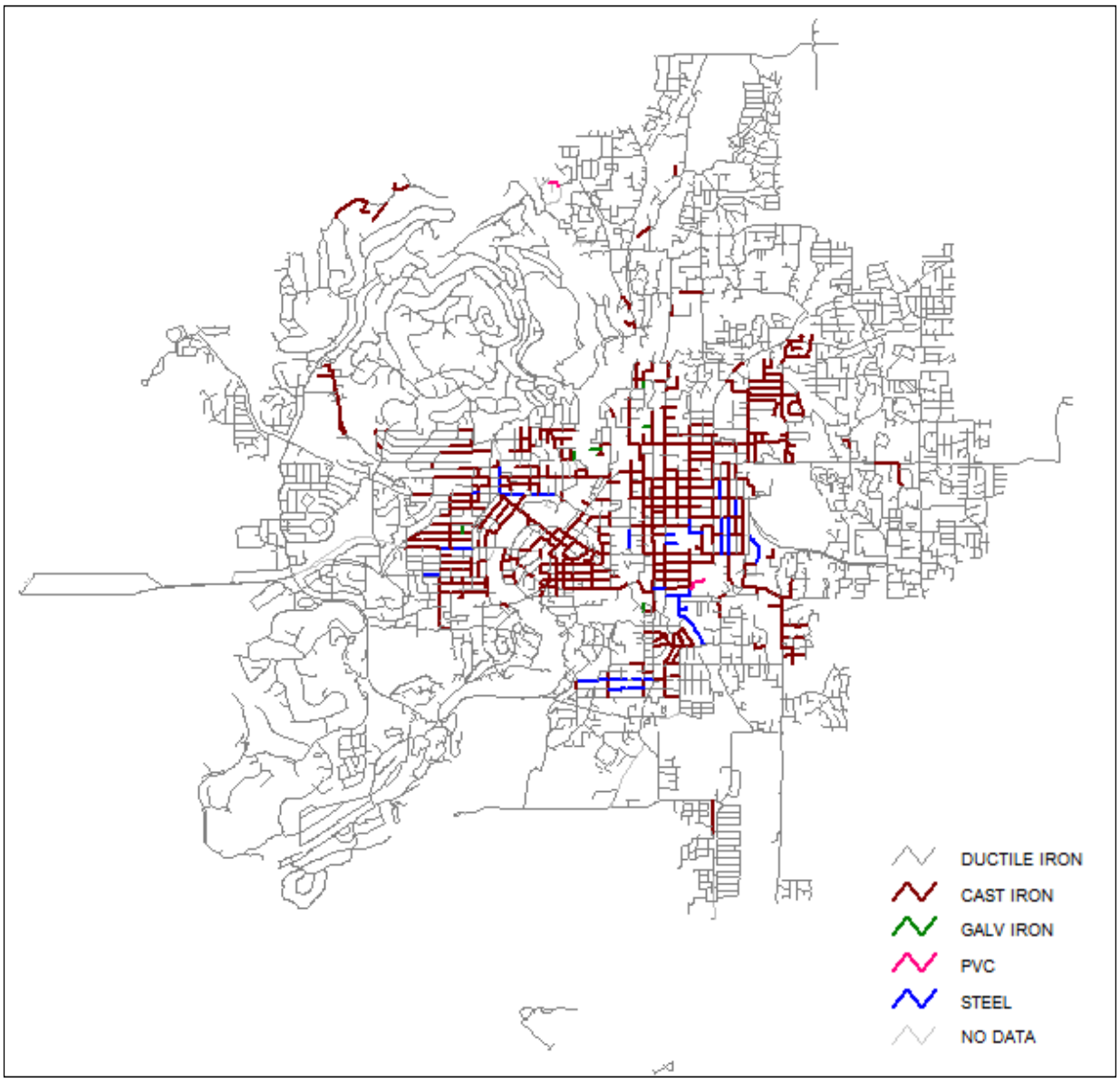

Figure 2.1 – Pipe Material Data in Bend GIS

3 Study Steps

Optimatics performed the following steps for the pipe consequence of failure analyses.

1. Ran a pipe criticality analysis based on current demand conditions using the Optimatics' software program OptiCritical ™ and the existing calibrated steady-state hydraulic model.
   - Determined consequence of failure measures that are most important for Bend considering the list of measures currently provided in OptiCritical.
   - Took the existing model and inserted all shut off valves (from the City's most up-to-date GIS files) using OptiCritical's automated tools.
   - Ran the criticality analysis, breaking every pipe to determine consequence of failure including consideration of the effect on critical customers or sensitive areas.
2. Identified the most critical pipes in the system based on the consequence of failure results.
   - Analyzed the results of both the pipe break and pipe isolation cases and identified the pipes which isolated the greatest number of customers, caused significantly low pressures, and/or adversely affected the St. Charles Medical Center or the Deschutes Brewery.
   - Created screen shots from EPANET and OptiCritical ™ of these areas of the system and inserted them into this memorandum.
   - Developed a prioritized ranking of the most critical pipes based on number of isolated customers and low pressures due to break and isolation.
   - Correlated criticality information with the pipe information database and identified any locations which turned up on multiple lists.
3. Developed this memorandum summarizing the analyses and results.

4 Criticality Analysis

The criticality analysis assessed the consequence of failure of all pipes in the system, simulating both break and isolation.

Critical customers can be tracked in the analysis in terms of which pipes are most critical to supply these customers. The City stated that there are two critical customers – the St. Charles Medical Center (north of NE Neff Road between NE Purcell Boulevard and NE 27th Street – model node JCT-6609) and the Deschutes Brewery (near Colorado and Simpson – model node JCT-1455). The Brewery is deemed a significant customer since its sophisticated equipment relies on water pressure being maintained. These two customers are highlighted on Figure 4.1.

After discussion with Bend staff, the criticality metrics that were deemed most important for the system include the following:

1. Number of valves needing to be closed to isolate a pipe for repair
2. Number of demand nodes isolated
3. Number of customers isolated
4. Number of low pressure customers during a pipe break
5. Minimum pressure after isolation
6. Number of low pressure customers during a pipe isolation

These were the metrics that were sorted and analyzed from the criticality results, and which are summarized in the Results section of this memorandum.

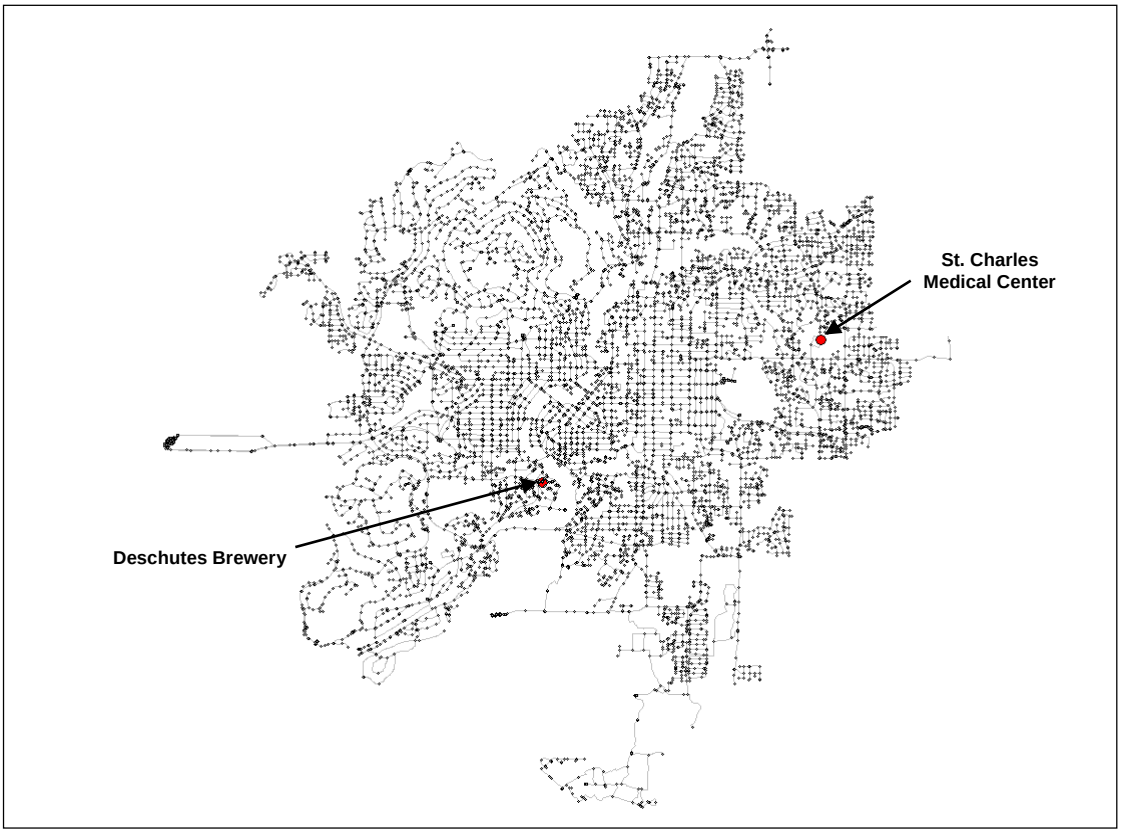

Figure 4.1 – Critical Customers - St. Charles Hospital and Deschutes Brewery

4.1 Importing shut-off valves into the hydraulic model

The first step in the pipe criticality analysis is to import all relevant shut-off valves into the hydraulic model. These valves are generally not present in a hydraulic model, expect perhaps at boundary locations. Subconsultant MSA, who was responsible for updating and calibrating the hydraulic model for this project, provided Optimatics with GIS shapefiles of the system. The valve layer contains details of all system valves. The valve import was largely successful on the first attempt due in large part to the investment made by Bend to update the hydraulic model to a 1:1 relationship to the GIS data. Some valve locations were questionable, but the criticality program proposes locations for these valves based on user-defined distance tolerances from the closest mains to the valves. Optimatics completed the minor effort of manually assigning these questionable valves to the proper pipes.

For the purposes of this study, which is a planning effort, it was assumed that all valves (aside from normally closed zone valves) are open and operable. Although there may be valves that are broken in the open or closed position, they should be scheduled for repair in the near future, so it is an appropriate assumption that all valves are operable.

4.2 Additional considerations

As noted above, low pressure locations are called out by OptiCritical. In the Bend system, as in most systems, there are certain locations that have borderline low pressure under normal conditions – due to their locations and/or elevation – but which are not of concern to the Utility. Prior to the criticality analysis OptiCritical ™ allows the user to exclude these locations from the pressure calculations so they do not show up on the results list as problem nodes. For Bend, these nodes are located at the well sites, reservoirs, on the suction side of certain pump stations, at Outback, and some specific nodes in Zone 1.

5 Results

This section describes the results of the consequence of failure analyses for those criticality metrics most important to Bend. The signifiers 'A8', 'B1', 'B2', etc. are their titles in the criticality program.

It should be noted that the South Bend service area did not show a sufficient number of shutoff valves to properly assess the criticality of pipes in this part of the network. Bend is making improvements in this section of the system and is currently assessing different ways of supplying the area in the future. Once the improvements and operating strategies are in place a pipe criticality assessment can be performed to include this area. As it stands, the statistics described in the following sections which stem from the criticality analysis do not include the pipes in the South Bend area.

5.1 A8 – Break discharge

This parameter reports the expected rate of discharge from a pipe break. This is a function of pressure head at the break location and the break size. Break size is specified in the software by setting a break severity or discharge coefficient. Each pipe break is modelled as an emitter, placed at the simulated location of the break. The break severity is the discharge coefficient used to calculate the emitter flow using the following equation:

$Q = Cp^E$

Where

Q = flow through the break

C = discharge coefficient/break severity

p = pressure at the break

E = emitter exponent (0.5)

The relationship between discharge coefficient value and break discharge is therefore an exponential relationship incorporating the resulting pressure at the node. This means that the relationship between break discharge and emitter coefficient is related to the resistance of the system upstream of the break. As a result, break discharge is influenced by pipe diameter (system resistance) to a certain extent. The example below shows how diameter can affect the simulated discharge, but if the break severity coefficient is set high enough the pipe diameter no longer affects the simulated rate of discharge.

24-inch diameter pipeline

Break Severity	Pressure	Discharge from Model
No break	48.80	0
20	47.85	138
200	21.17	920
2000	0.39	1251
4000	0.1	1255
10000	0.016	1256
100000	0.00016	1256

6-inch diameter pipeline

Break Severity	Pressure	Discharge from Model
No break	48.80	0
20	41.56	126
200	2.26	300
2000	0.024	309
4000	0.006	309
10000	0.00096	309
100000	0.0000096	309

Given the impact of pipe diameter on break discharge, and the fact that the analysis is being used to compare the relative consequence of each pipe failing, Optimatics ran the analysis using a high discharge coefficient. This means severe break conditions are simulated on each pipe and reduces the influence of pipe diameter on the results.

5.2 B1 – Number of valves to isolate a break

The analysis indicates that most pipe breaks in the Bend system could be isolated by closing 4 or fewer valves. Table 5.1 summarizes the valve closure statistics. Nearly 96% of the pipes in the system can be isolated by closing 4 or fewer valves. Just over 2.1% of pipes can be isolated by closing either 5 or 6 valves. Less than 0.2% of the pipes in the system require 7 or more valves to close.

Table 5.1 – Statistics for number of valves to close to isolate pipes

Number of valves to close	Total number of pipes with this many valves to close	Percentage of pipes this represents in system
8	10	0.10%
7	8	0.08%
6	59	0.59%
5	153	1.53%
4 or fewer	9,538	95.6%

Figure 5.1 highlights the two locations in the center of the system, as represented by the model, with pipes that require more than 6 valves to close. These locations are Nashville Avenue just northwest of the river (see Figure 5.2, a screenshot from OptiCritical), with 7 valves to close on these mains, and Louisiana Avenue just southeast of the river (Figure 5.3), with 8 valves to close. Based on the pipe information provided to Optimatics, eight is the maximum number of valves required to be closed to isolate a pipe.

These are favorable figures for the system. Presuming all valves are in good working condition, Bend distribution personnel can isolate any main break by closing 8 or fewer valves.

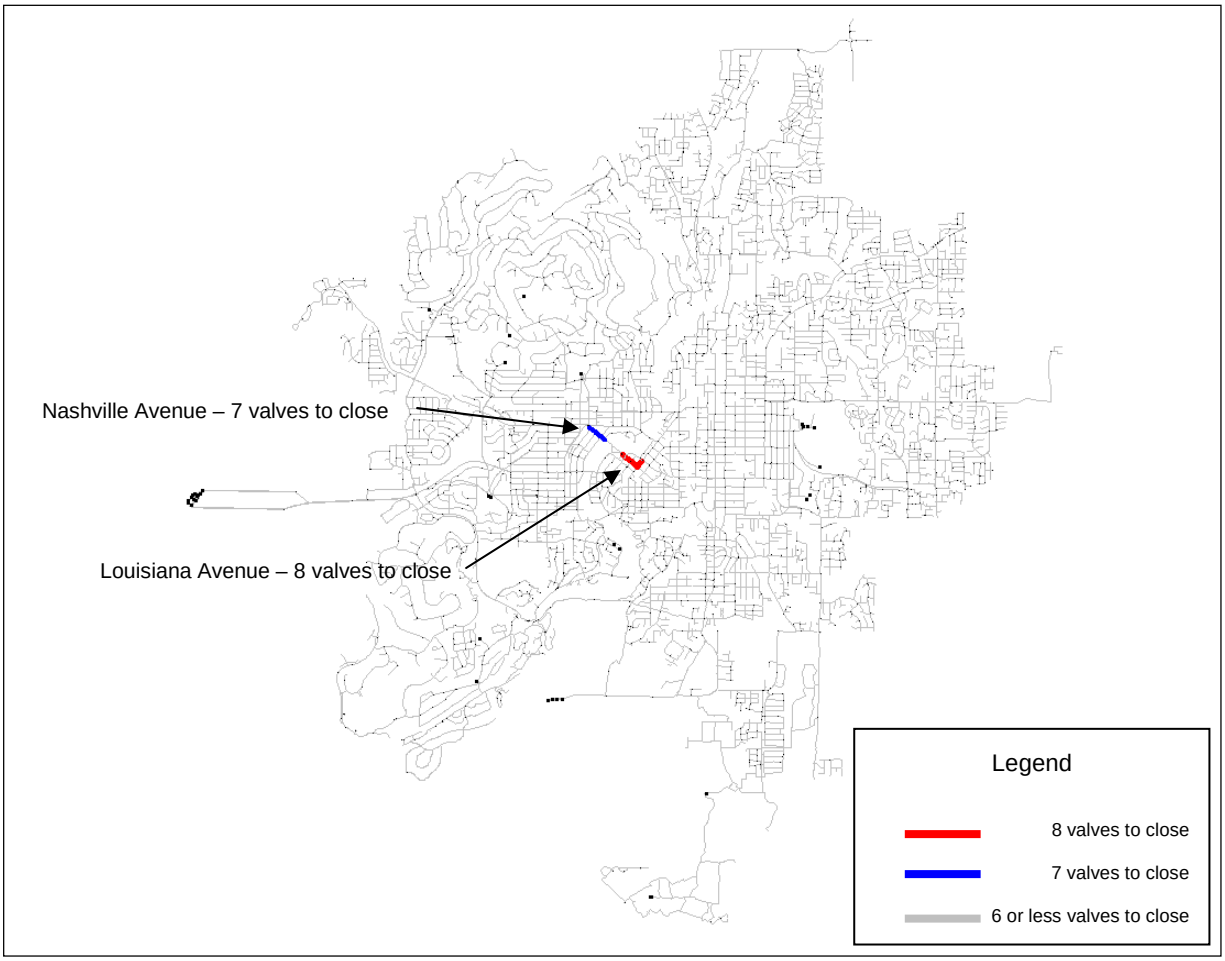

Figure 5.1 - Number of valves that must be closed to isolate a pipe break

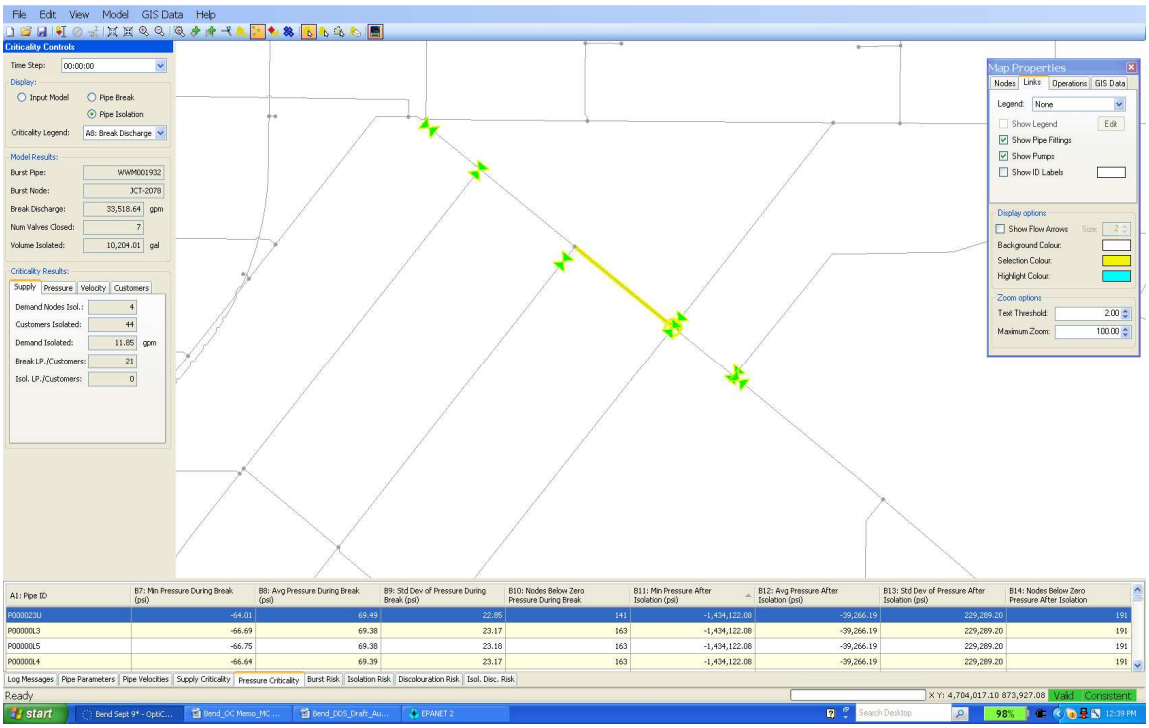

Figure 5.2 – Nashville Avenue location – 7 valves to close

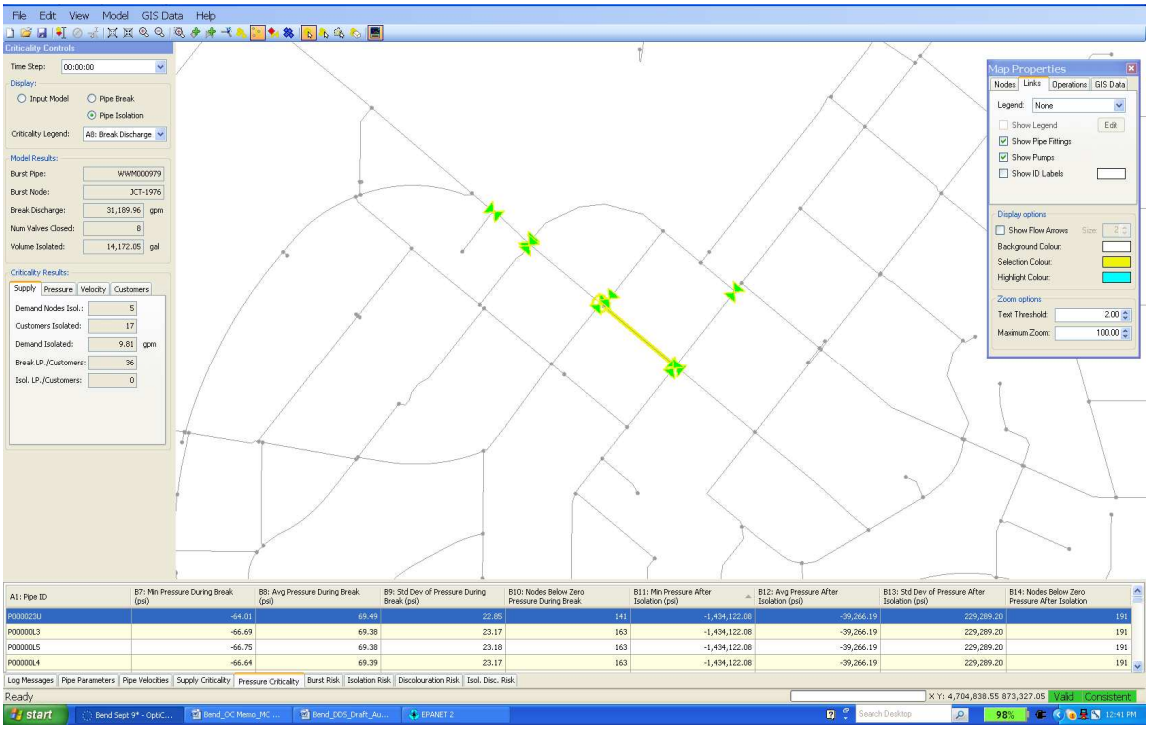

Figure 5.3 – Louisiana Avenue location – 8 valves to close

5.3 Critical pipes near the two identified critical customers

The pipes surrounding the two critical customers– the St. Charles Medical Center and the Deschutes Brewery – which could affect supply to these customers in the event of a break or isolation are shown in the following figures and in Table 5.2. The highlighted pipes are those that:

1. If broken would cause pressure at the critical customer node to drop below 20 psi; or
2. When isolated it would cause pressure at the critical customer node to drop below 20 psi; or
3. If broken or isolated it would completely isolate the critical customer node.

This information should be useful to the City as they weigh options for ensuring uninterrupted supply to these customers.

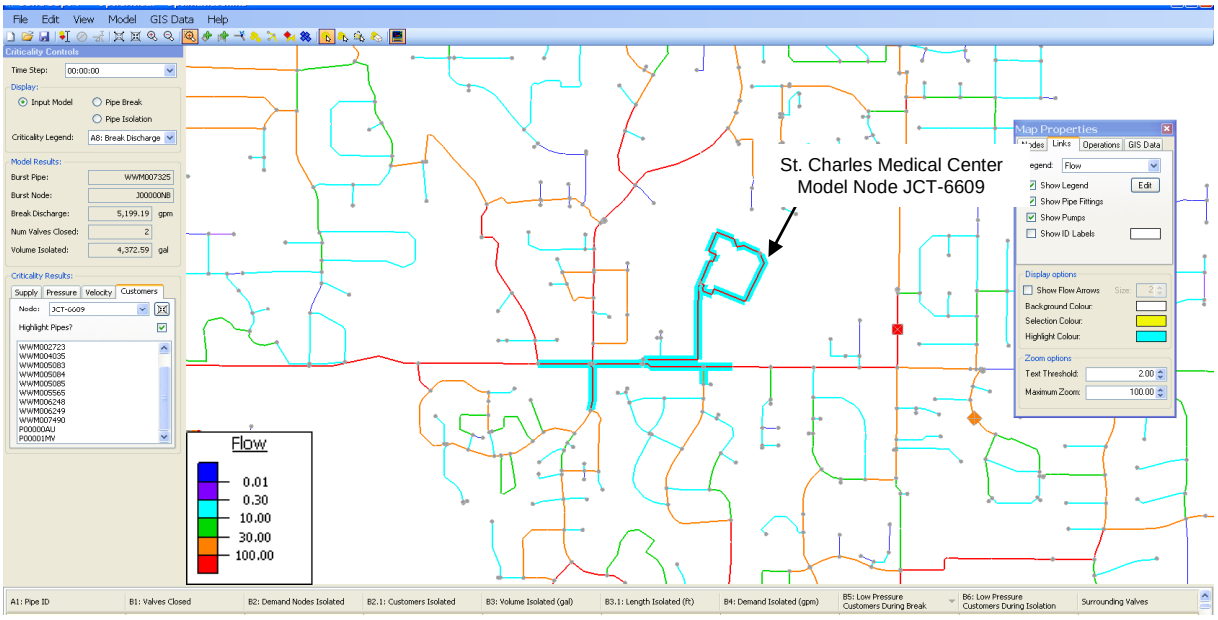

Figure 5.4 – Critical pipes identified and highlighted near St. Charles Medical Center location

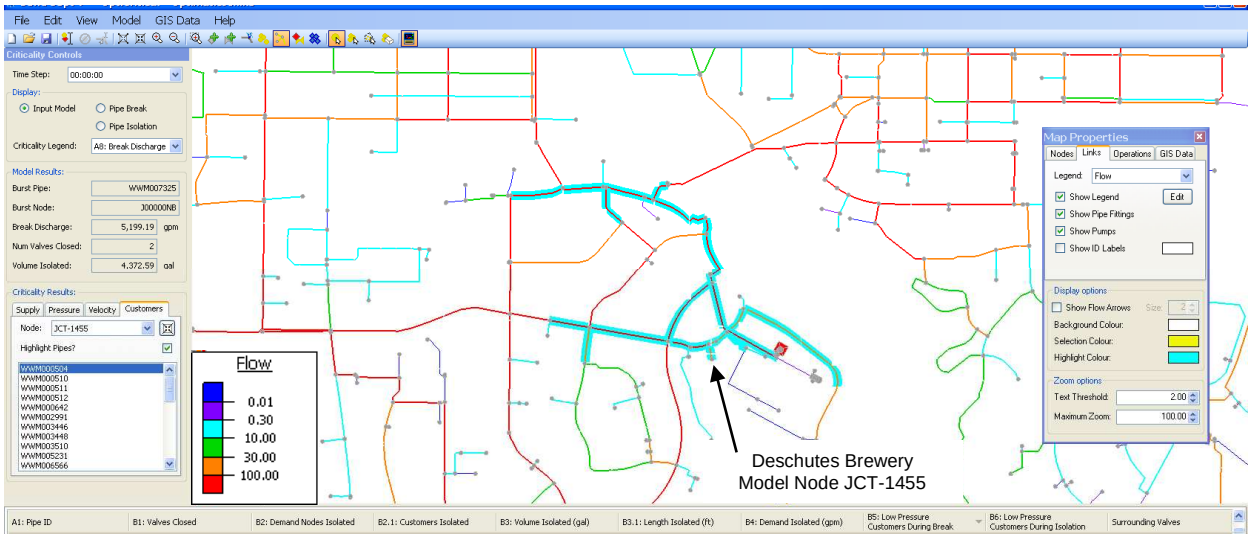

Figure 5.5 – Critical pipes identified and highlighted near Deschutes Brewery location

Table 5.2 – Critical pipes identified near St. Charles Medical Center and Deschutes Brewery locations

Critical Pipes surrounding St. Charles Medical Center (Model JCT-6609) – streets include NE Neff Road, NE Purcell Boulevard, and the mains entering and surrounding the Medical Center	Critical Pipes surrounding Deschutes Brewery (Model JCT-1455) – streets include W. Commerce, SW Shevlin Hixon, SW Colorado, SW Simpson, SW Cyber
WWM001465	WWM000504
WWM001466	WWM000510
WWM002723	WWM000511
WWM004035	WWM000512
WWM005083	WWM000642
WWM005084	WWM002991
WWM005085	WWM003446
WWM005565	WWM003448
WWM006248	WWM003510
WWM006249	WWM005231
WWM007490	WWM006566
P00000AU	WWM006567
P00001MV	WWM006568
	WWM006569
	WWM006570
	WWM006577
	WWM006578
	WWM006581
	WWM006613
	WWM006617
	WWM006620
	WWM006749
	WWM006750
	WWM006751
	WWM007293
	WWM007294
	WWM007318
	P000007T
	P000007U
	P0000088
	P0000089
	P000008A
	P0000118
	P0000119

5.4 B2 – Number of demand nodes isolated / number of customers isolated

The highest number of demand nodes isolated and the number of customers isolated are related metrics. In many cases the results show a direct correlation between them, that is, high isolation figures resulted for both. But there are some locations in the system where one node represents a fairly large number of customers. Therefore the focus of the results was the number of customers isolated, keeping an eye on the corresponding number of demand nodes isolated. Note – a 'customer' refers to a metered service connection and is not a population figure.

The results showed that the estimated number of customers isolated as a result of isolating a pipe for repair ranged from zero to 549. As shown in Table 5.3, the vast majority of system pipes – approximately 97% – isolate 50 customers or less when isolated for repair. This translates to just under 3% of total pipes in the system which isolate greater than 50 customers when isolated for repair. Those pipes that affect a significantly high number of customers are described in further detail below.

Table 5.3 – Statistics for number of customers isolated in the event of a pipe break

Number of customers isolated	Total number of pipes, when broken, isolates this many customers	Percentage of pipes this represents in system
Greater than 500	8	0.08%
Between 401 and 500	0	0.00%
Between 301 and 400	14	0.14%
Between 201 and 300	42	0.42%
Between 101 and 200	98	0.98%
Between 51 and 100	123	1.23%
50 or less	9,695	97.1%

After reviewing the criticality results for this metric, Optimatics determined that a cut-off number of approximately 130 isolated customers captures the most critical pipes. This translates to 8 locations in the model/system. These locations are described in the list below and shown in the figures and Table 5.4 that follow.

1. Westwood Zone (3C) pipes in the Mt. Bachelor Drive / Mammoth Drive area south of the reservoir and pump
2. Zone 3 pipes along Mt. Washington Drive and Shevlin Park Road
3. Pipes in Zone 6 and 7B at the intersection of Butler Market Road and Purcell Boulevard, and north along Purcell
4. Zone 4 East (4B) pipes along Bronzewood Avenue off SE 15th Street
5. Pipes in the far southeast end of Zone 3 near the intersection of Fairway Ridge Lane and Devil's Lake Drive

6. Zone 4 East (4B) pipes supplying the zone from Pilot Butte Reservoir #2 to the north and west
7. Pipes in Zones 3, 5A, and 4D along Mt. Washington Drive north of Shevlin Park Road
8. Zone 6 and 7C pipes along Butler Market Road near the eastern edge of the system

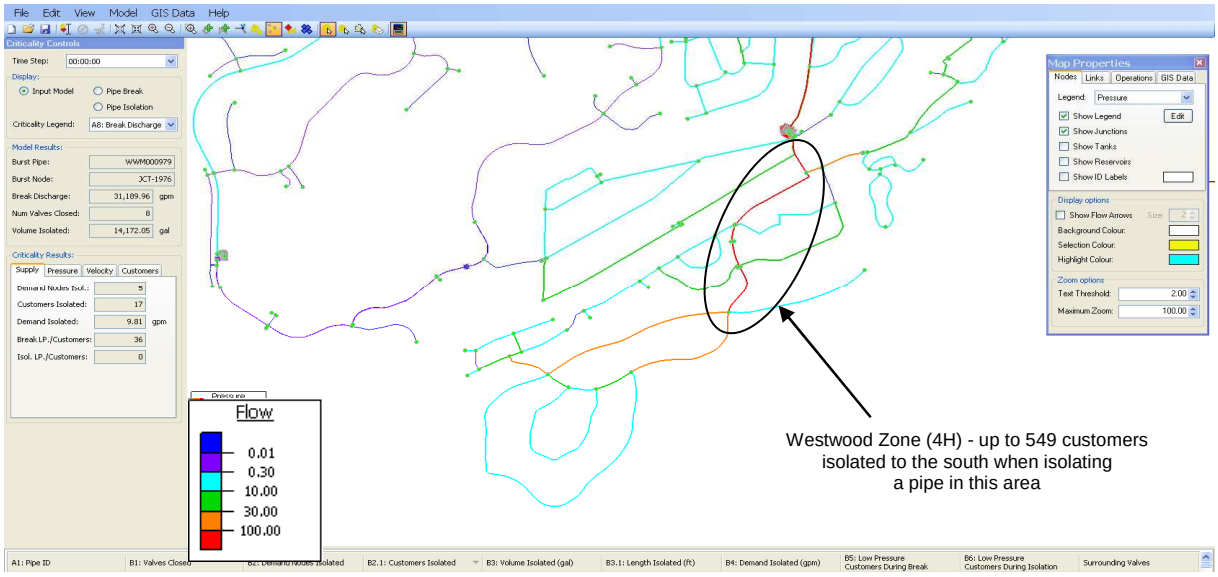

Figure 5.6 – Westwood Zone (3C) – Mt. Bachelor Drive / Mammoth Drive area – customer isolation

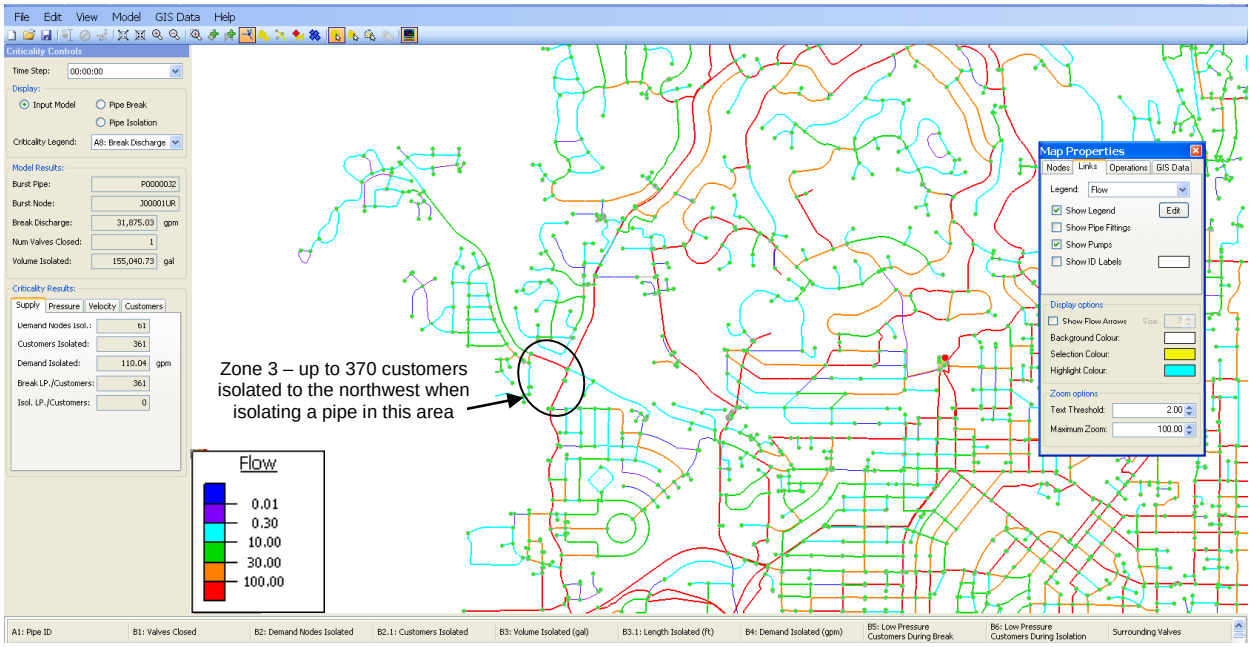

Figure 5.7 – Zone 3 – Mt. Washington Drive & Shevlin Park Road – customer isolation

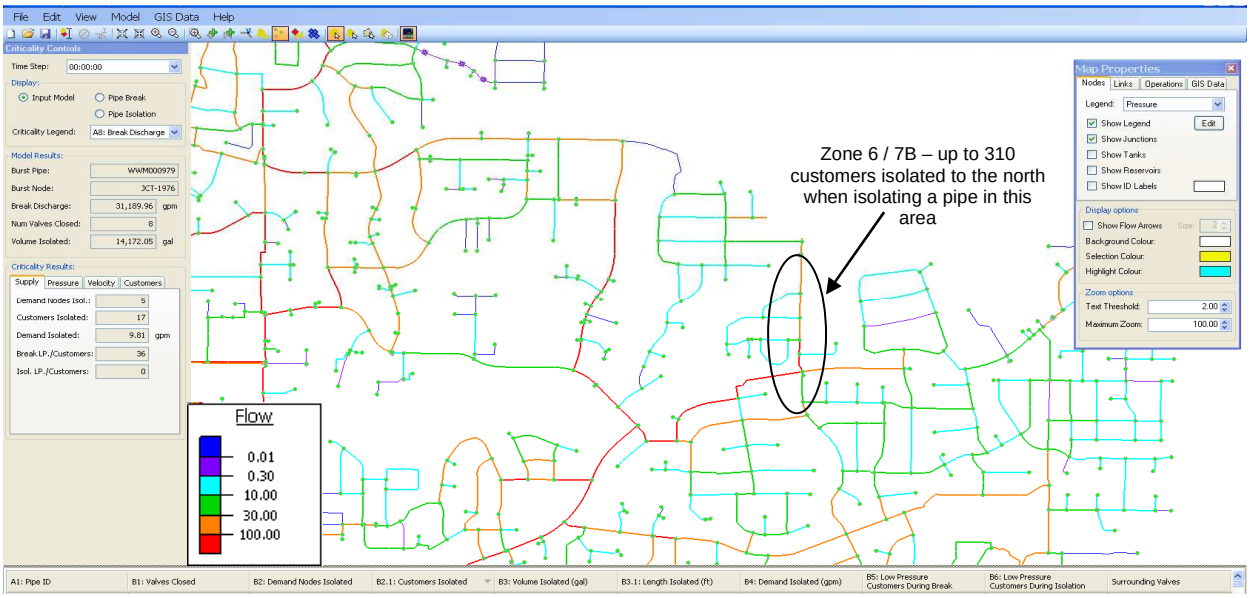

Figure 5.8 – Zones 6 & 7B – Butler Market Road and Purcell Boulevard – customer isolation

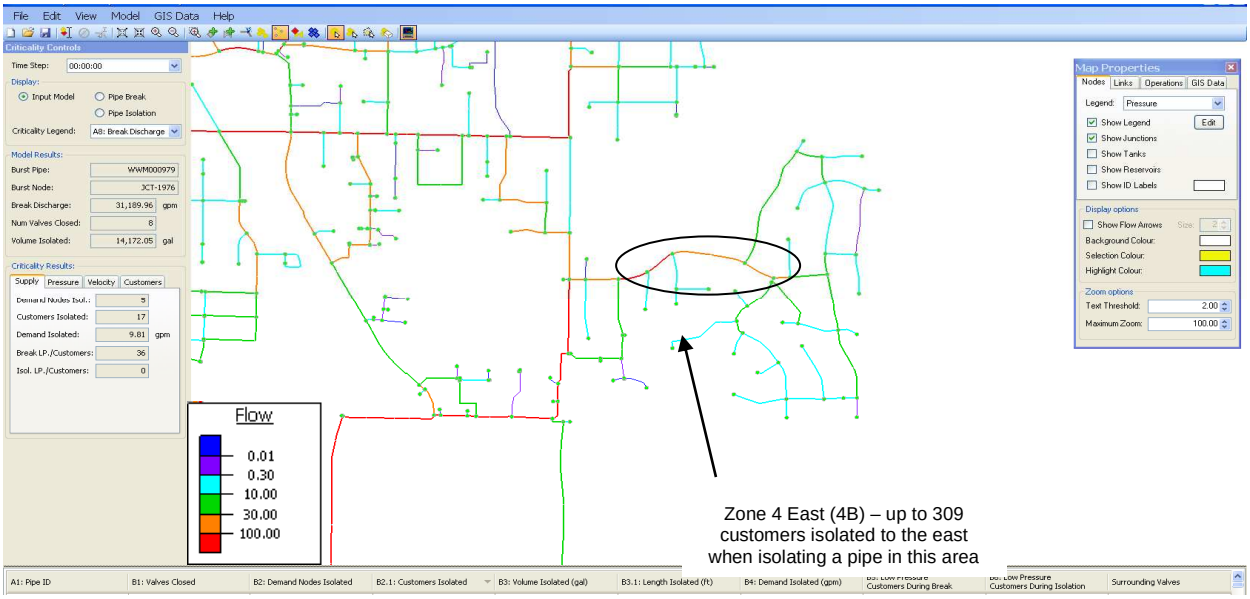

Figure 5.9 – Zone 4 East (4B) – SE Bronzewood Ave -E- SE Castlewood – customer isolation

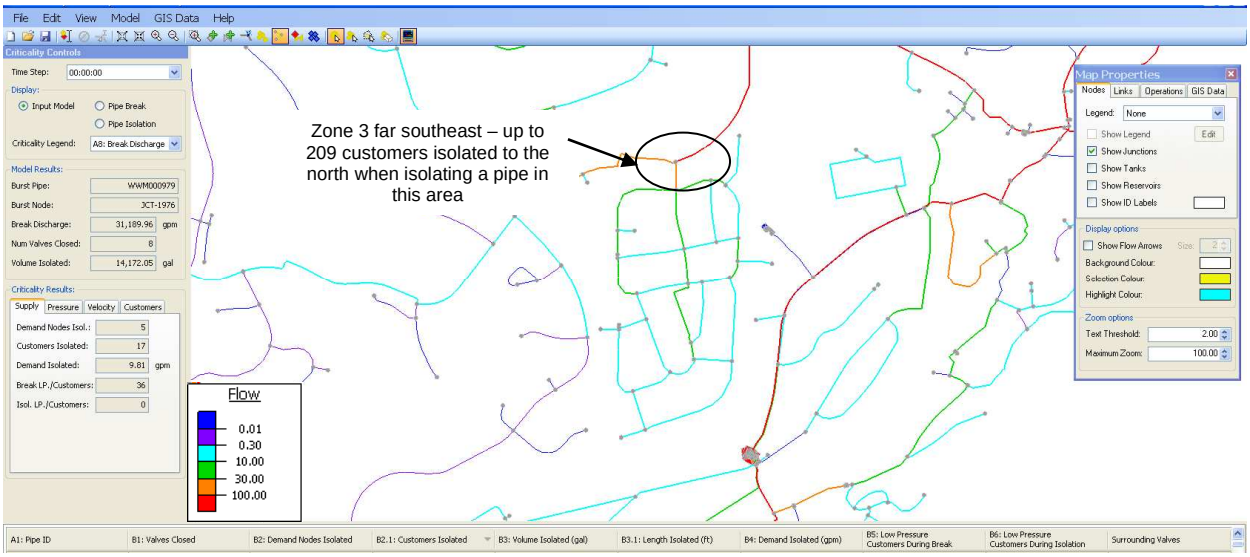

Figure 5.10 – Zone 3 far southeast – Fairway Ridge Lane & Devil's Lake Drive – customer isolation

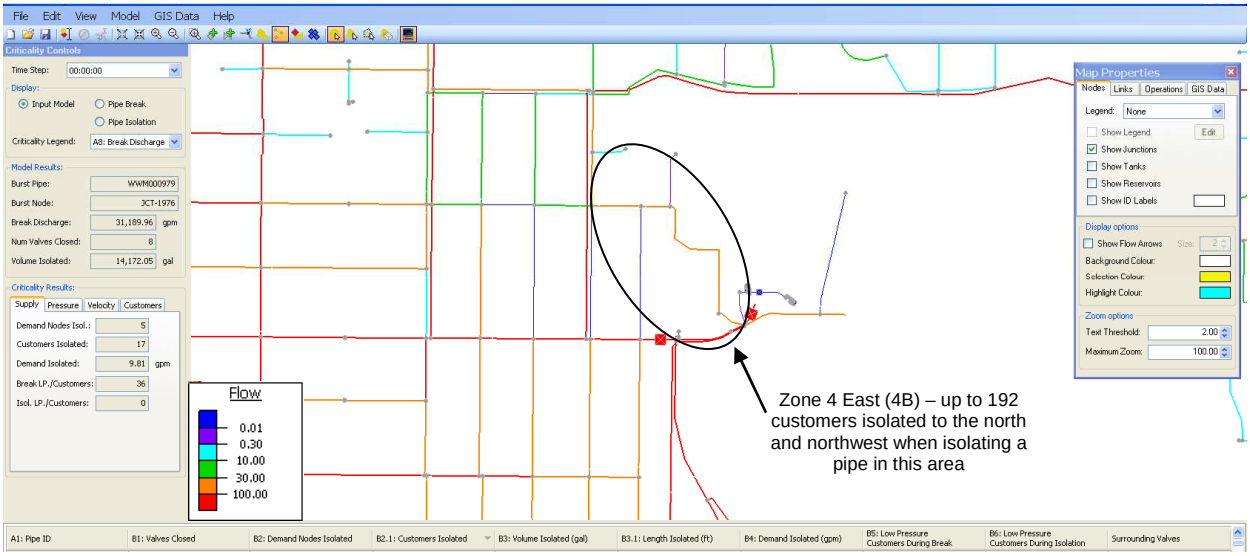

Figure 5.11 – Zone 4 East (4B) – pipes supplying from Pilot Butte Reservoir #2 – customer isolation

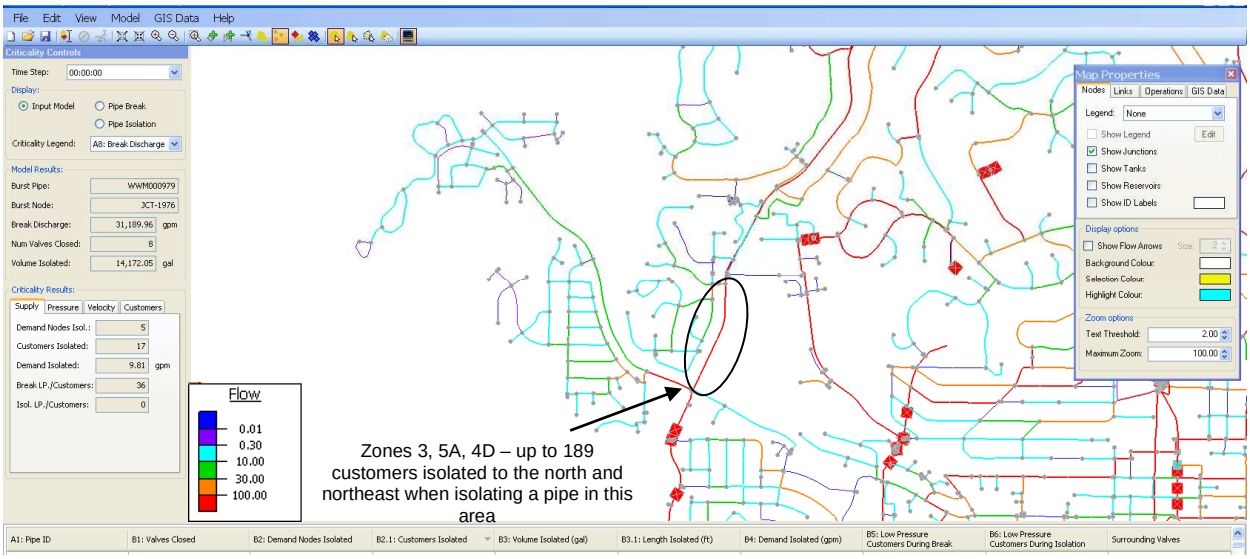

Figure 5.12 – Zones 3, 5A, 4D – Mt. Washington Dr -N- Shevlin Park Rd – customer isolation

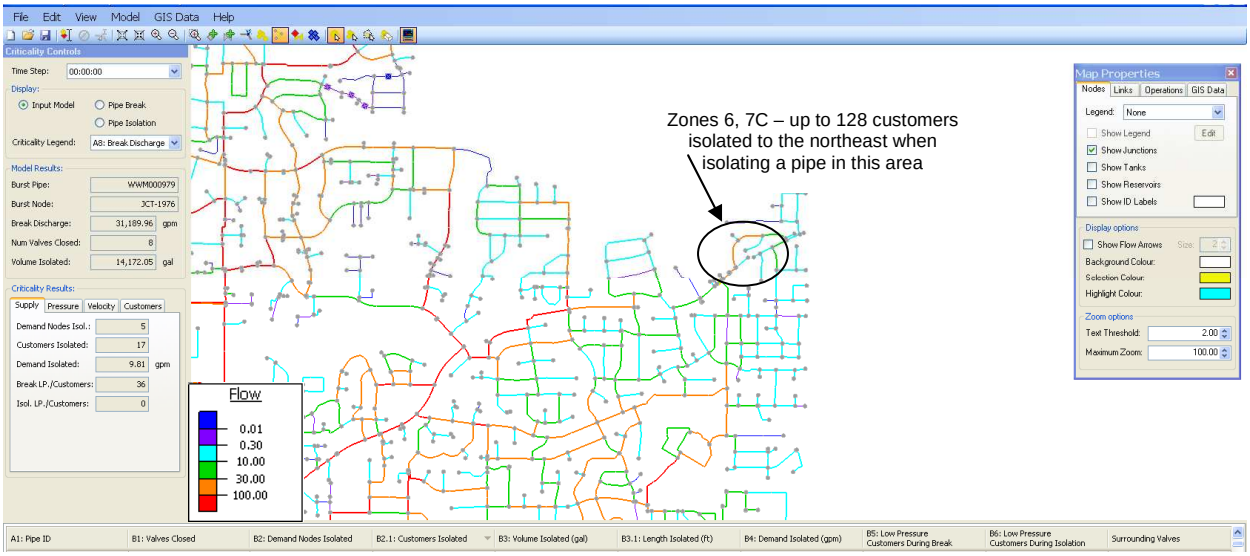

Figure 5.13 – Zones 6, 7C – Butler Market Road near eastern edge of system – customer isolation

Table 5.4 – critical pipes in 8 sections of the system based on number of customers isolated when isolating a pipe for repair after a break

Critical Pipes	Approximate Address	Pressure Zone(s)	Number of Customers Isolated
WWM005213	Mt. Bachelor Drive –S- Westwood Res & Pump	Westwood	549
WWM003715	Mt. Bachelor Drive –S- Westwood Res & Pump	Westwood	549
P000023B	Mammoth Dr -S- Brookside Way	Westwood	542
P000023A	Mammoth Dr -S- Brookside Way	Westwood	542
WWM001975	Mammoth Dr -S- Brookside Way	Westwood	542
WWM006861	Mt. Bachelor Drive –S- Westwood Res & Pump	Westwood	542
WWM003124	Mammoth Dr -S- Brookside Way	Westwood	542
WWM003125	Mammoth Dr -S- Brookside Way	Westwood	542
WWM003667	SW Mt. Washington Drive -S- Shevlin Park Road	3	369
WWM003666	SW Mt. Washington Drive -N- Shevlin Park Road	3	369
P00000J3	SW Mt. Washington Drive -N- Shevlin Park Road	3	369
P00000J2	Shevlin Park Road –W- SW Mt. Washington Drive	3	361
P000020I	Shevlin Park Road –W- SW Mt. Washington Drive	3	361
WWM004383	Shevlin Park Road –W- SW Mt. Washington Drive	3	361
WWM004384	Shevlin Park Road –W- SW Mt. Washington Drive	3	361
WWM004874	Butler Market Road just -W- Purcell Boulevard	6, 7B	310
P00000EE	Butler Market Road just -E- Purcell Boulevard	6, 7B	310
P0000098	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	309
WWM002291	Purser Ave -W- Purcell Blvd	6, 7B	304
WWM002292	Purser Ave -W- Purcell Blvd	6, 7B	304
WWM003078	Purcell Blvd -N- Butler Market Road	6, 7B	304
WWM002909	Purcell Blvd -N- Butler Market Road	6, 7B	304
WWM006404	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	300
WWM003807	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	300
WWM003808	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	300
WWM005391	NW Reserve Camp Ct / Summerhill Dr	3, 4C	298
WWM003256	NW Reserve Camp Ct / Summerhill Dr	3, 4C	298
WWM004201	NW Reserve Camp Ct / Summerhill Dr	3, 4C	298
WWM004385	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270
WWM004204	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270
WWM004382	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270
WWM003562	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270
WWM000378	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270

WWM000380	Summerhill Drive –N- NW Reserve Camp Ct	3, 4C	270
P0000094	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	258
P0000097	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	258
WWM005237	SE Bronzewood Avenue -E- SE Castlewood	4 East (4B)	258
WWM005426	Mammoth Dr -S- Brookside Way	Westwood	241
WWM005427	Mammoth Dr -S- Brookside Way	Westwood	241
P00000K0	Mammoth Dr -S- Brookside Way	Westwood	241
P00000K1	Mammoth Dr -S- Brookside Way	Westwood	241
P0000233	Mammoth Dr -S- Brookside Way	Westwood	241
P0000234	Mammoth Dr -S- Brookside Way	Westwood	241
WWM003079	Purcell Blvd -N- Butler Market Road	6, 7B	226
WWM004841	Purcell Blvd -N- Butler Market Road	6, 7B	226
WWM002293	Purcell Blvd -N- Butler Market Road	6, 7B	226
P00000ED	Purcell Blvd -N- Butler Market Road	6, 7B	214
P00000EJ	Purcell Blvd -N- Butler Market Road	6, 7B	214
P000001C	Purcell Blvd -N- Butler Market Road	6, 7B	214
WWM000332	Purcell Blvd -N- Butler Market Road	6, 7B	214
WWM000335	Purcell Blvd -N- Butler Market Road	6, 7B	214
WWM000336	Purcell Blvd -N- Butler Market Road	6, 7B	214
WWM000337	Purcell Blvd -N- Butler Market Road	6, 7B	214
WWM003080	Purcell Blvd -N- Butler Market Road	6, 7B	214
P00000KC	Fairway Ridge Lane & Devil's Lake Dr	3	209
P000023Q	Fairway Ridge Lane & Devil's Lake Dr	3	209
WWM004317	Fairway Ridge Lane & Devil's Lake Dr	3	209
P000018B	Pilot Butte – between Res #2 and Norton Ave	4 East (4B)	192
WWM005251	Pilot Butte – between Res #2 and Norton Ave	4 East (4B)	192
WWM006129	Pilot Butte – between Res #2 and Norton Ave	4 East (4B)	192
WWM006130	Pilot Butte – between Res #2 and Norton Ave	4 East (4B)	192
WWM003665	Mt. Washington Dr -N- Shevlin Park Rd	3, 4D, 5A	190
P000020P	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM003109	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM003110	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM003112	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM004208	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM007409	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM007410	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM007412	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
WWM003513	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189
P000020Q	Market St / Nordic Ave – just down from PRV 46	3, 4D, 5A	189

P000018J	Norton Ave – NW – Pilot Butte pipe from Res #2	4 East	177
WWM001126	Norton Ave – NW – Pilot Butte pipe from Res #2	4 East	177
P000018G	Norton Ave – NW – Pilot Butte pipe from Res #2	4 East	169
P000018H	Norton Ave – NW – Pilot Butte pipe from Res #2	4 East	169
WWM007342	Mt. Bachelor Drive -E- Clearnight Drive	Westwood, 4I	138
WWM007341	Mt. Bachelor Drive -E- Clearnight Drive	Westwood, 4I	138
WWM006863	Mt. Bachelor Drive -E- Clearnight Drive	Westwood, 4I	138
WWM006865	Mt. Bachelor Drive -E- Clearnight Drive	Westwood, 4I	138
WWM000154	Mt. Bachelor Drive -E- Clearnight Drive	Westwood, 4I	138
WWM002906	Butler Market Road near eastern edge of system	6, 7C	128
WWM002907	Butler Market Road near eastern edge of system	6, 7C	128
WWM002908	Butler Market Road near eastern edge of system	6, 7C	128
WWM004857	Butler Market Road near eastern edge of system	6, 7C	128

5.5 B5 Number of low pressure customers during break / B7 Minimum pressure after break / and B10 Nodes below zero during break

As a reminder, in the criticality runs severe or "catastrophic" break conditions were simulated. This brings conservative results, but given the importance of maintaining supply to customers even under severe conditions it is prudent to be conservative in the criticality / vulnerability assessment.

Other metrics particularly important in the Bend system include 'number of low pressure customers during break' and the related metrics 'nodes below zero pressure during break' and 'minimum pressure after break'. The statistics for 'number of low pressure customers during break' are shown in Table 5.5. Just over 5% of the pipes in the system would cause low pressures to 500 or more customers. It is important to re-emphasize that the analysis simulated *severe* break conditions, so the results are conservative.

Table 5.5 – Statistics for number of low pressure customers during break

Number of low pressure customers	Total number of pipes, when broken, causing low pressures	Percentage of pipes this represents in system
Between 2501 and 3100	21	0.21%
Between 2001 and 2500	29	0.29%
Between 1501 and 2000	22	0.22%
Between 1001 and 1500	45	0.45%
Between 501 and 1000	498	4.99%
Between 101 and 500	1,715	17.18%
100 or less	7,650	76.65%

The low pressure constraint used in the analysis was 20 psi. The area that showed the most extreme low pressures under break conditions was a fairly large area of Zone 4 East (4B). Figure 5.14 is a 'snapshot' of the model results from a simulated break on a pipe on Reed Market Road at Brookswood Boulevard under calibration conditions. Pipes on Reed Market Road, SW Bond Street, Brookswood Boulevard, Silver Lake Boulevard, Miller Avenue, Aune Road, 2nd Street, 4th Street, Wilson Avenue, Chase Road and numerous others caused low pressures at as many as 3,080 customers.

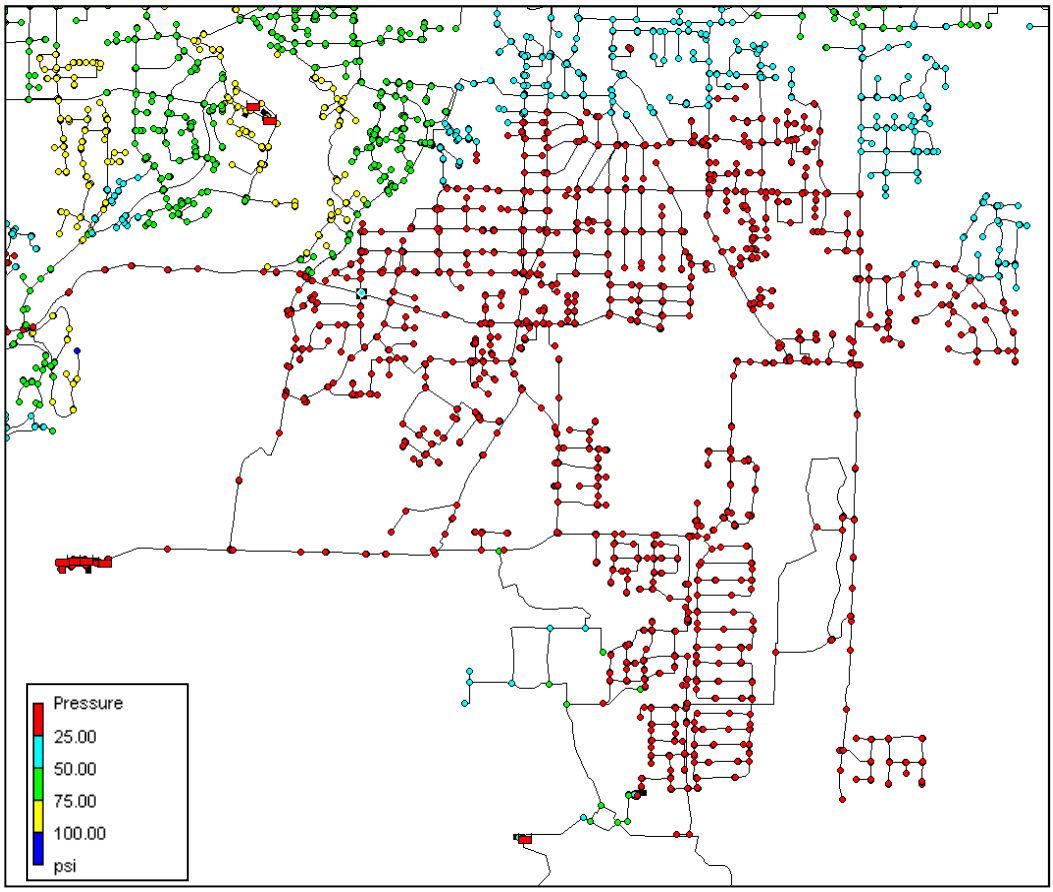

Figure 5.14 – Zone 4 East – low pressure nodes as a result of simulated break on Reed Market Road at Brookswood Boulevard

It is important to remember that the analysis was performed under steady state conditions, matching a specific hour on the calibration day. Naturally, some facilities would be on and some would be off at particular times during the day. The steady state scenario had the Rock Bluff Reservoir and Pilot Butte Reservoir #2 supplying Zone 4 East; the Scott Street Pump Station and the Bear Creek wells were not active in the simulation.

To try and overcome the effects of the break, two pumps in the Scott Street Pump Station and both Bear Creek Well Pumps were turned on in the model and a model simulation was performed. The figure below shows that pressures improved significantly at well over half of the problem nodes. But the figure still shows a pocket of nodes below Reed Market Road and Powers Road that remain below 20 psi even with the additional help from the Scott Street station and the Bear Creek Wells. (Note – the third Scott Street pump was turned on in a subsequent simulation and results showed only a very slight improvement in pressures in this area).

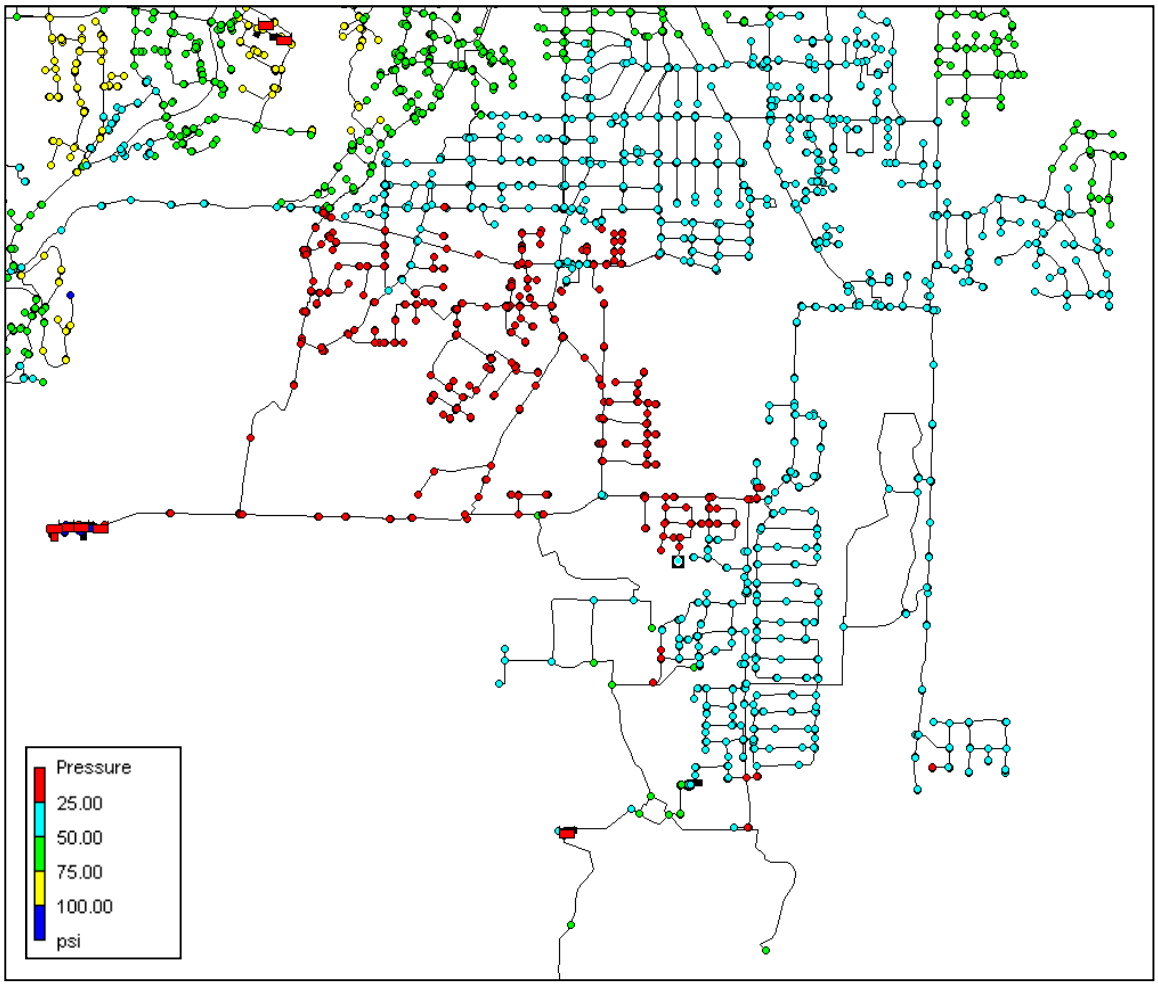

Figure 5.15 – Zone 4 East – some pressure improvement after turning on two Scott Street pumps and the two Bear Creek Well pumps

These pipe criticality and hydraulic model results therefore point to system vulnerability in the 4 East Pressure Zone in terms of low pressure should a major pipe break occur, regardless of which facilities are operating. Even with nearly all of the supply sources providing water to the zone, certain areas in the zone could suffer low pressures depending on the severity and location of the pipe break. The pipes on Reed Market Road and those pipes near to where the Reed Market Road 16-inch diameter main enters Zone 4 East create the greatest vulnerability in the event of a break, but as noted above, pipes along SW Bond Street, Brookswood Boulevard, Silver Lake Boulevard, Miller Avenue, Aune Road, 2nd Street, 4th Street, and Wilson Avenue – when broken – cause some areas of low pressure also.

The next most vulnerable area of the system in terms of resulting low pressure in the event of a pipe break is in the eastern pocket of Zone 5. The two figures and Table 5.6 below show that if a pipe were to be broken on NE Neff Road near the St. Charles Medical Center, up to 1,400 customers would suffer a drop in pressure below 20 psi. The table shows the pipes causing the most customers to have low pressure – essentially pipes along NE Neff between Cliff Drive and 27th Street as well as on NE Purcell Boulevard and NE Williamson Boulevard. The affected area extends north to the border with Zone 6 and includes the St. Charles Medical Center, and east to the border with Zone 6A.

This section of Zone 5 is fed by Pilot Butte Reservoirs 1 and 3, which were both supplying a large volume of water under this break scenario. There are no additional supply sources for Zone 5 in this area. This, coupled with the presence of the St. Charles Medical Center – one of the identified critical customers – makes this an area recommended for increased reliability measures in the future.

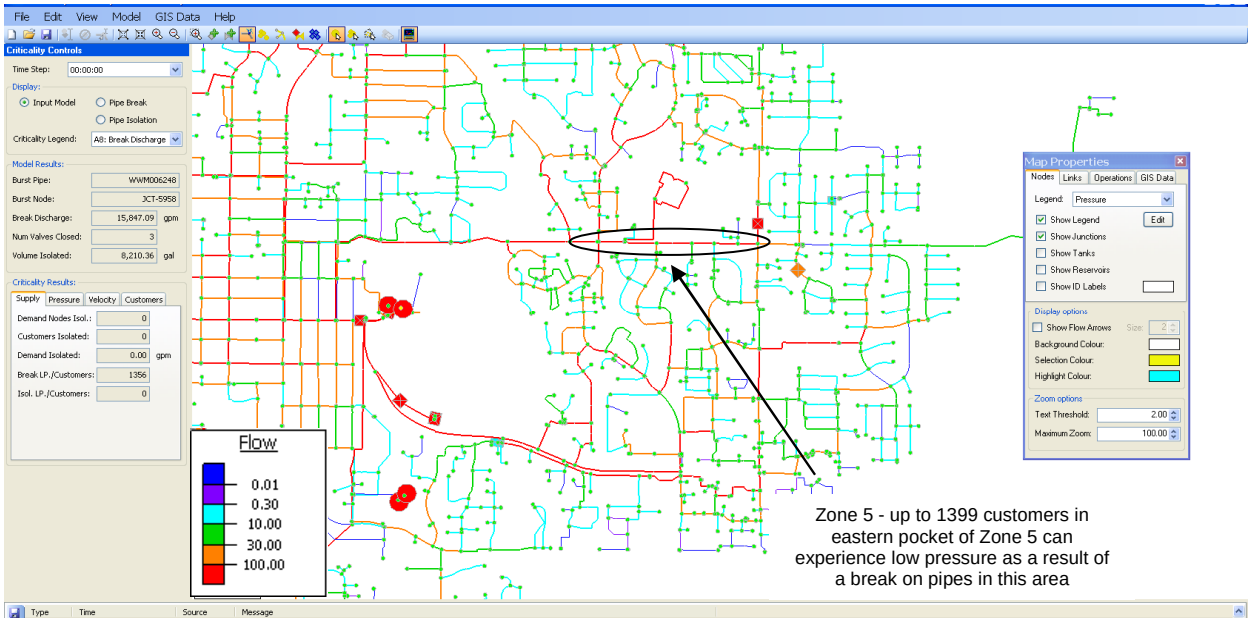

Figure 5.16 – Zone 5, east end – a pipe break in this area on/near NE Neff Road near St. Charles Medical Center could cause low pressures for up to 1399 customers

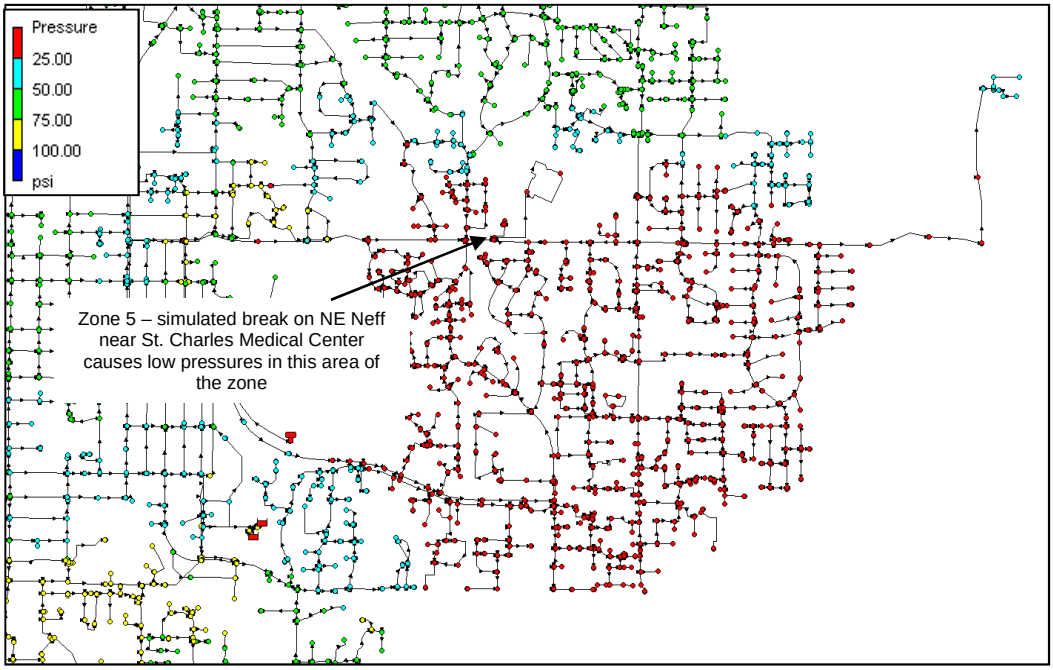

Figure 5.17 – Zone 5, east end – resulting low pressures from simulation of pipe break on NE Neff Road near St. Charles Medical Center

Table 5.6 – Zone 5, east end – critical pipes causing low pressure in the event of pipe break in the vicinity of NE Neff Road near St. Charles Medical Center

Critical Pipes	Approximate Address	Pressure Zone(s)	Number of Low Pressure Customers During Break
WWM006249	NE Neff Road -E- NE Purcell Boulevard	5	1399
WWM001466	NE Neff Road -E- NE Purcell Boulevard	5	1398
WWM005085	NE Neff Road -E- NE Purcell Boulevard	5	1377
WWM006248	NE Neff Road -E- NE Purcell Boulevard	5	1356
WWM002723	NE Williamson Boulevard -S- NE Neff Rd	5	1356
WWM001465	NE Neff Road at NE Purcell Boulevard	5	1278
P00000AU	NE Neff Road -E- NE Purcell Boulevard	5	1247
WWM005083	NE Neff Road -W- NE Purcell Boulevard	5	1228
WWM004035	NE Purcell –S- NE Neff	5	1228
WWM006253	NE Neff Road -E- NE Williamson Boulevard	5	1101
P00000AT	NE Neff Road -E- NE Medical Center Drive	5	972

The next most vulnerable area from the standpoint of low pressures from a pipe break is in Zone 3 along Mt. Washington Road from Skyliners Road south down to Chandler Avenue, where Zone 3 feeds Zone 4G, and including Bridge Creek Drive off Mt. Washington. The figures and Table 5.7 below show the approximate locations and the pipes causing vulnerability, as well as the nodes resulting in low pressure. As many as 1,015 customers suffer low pressure depending on the location of the pipe break. The Outback site is the primary supply for this area of the system, pointing to the vulnerability of this part of Zone 3 given a supply interruption along Mt. Washington Drive or on Skyliners Road near Mt. Washington.

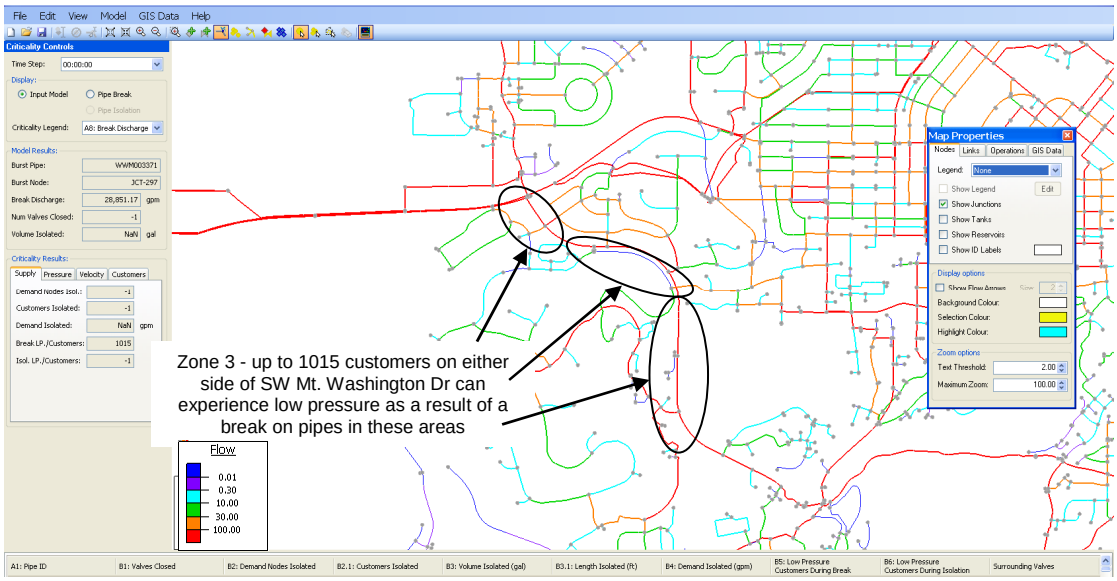

Figure 5.18 – Zone 3 – pipe breaks along Mt. Washington Drive south of Skyliners Road cause low pressures to the south and west

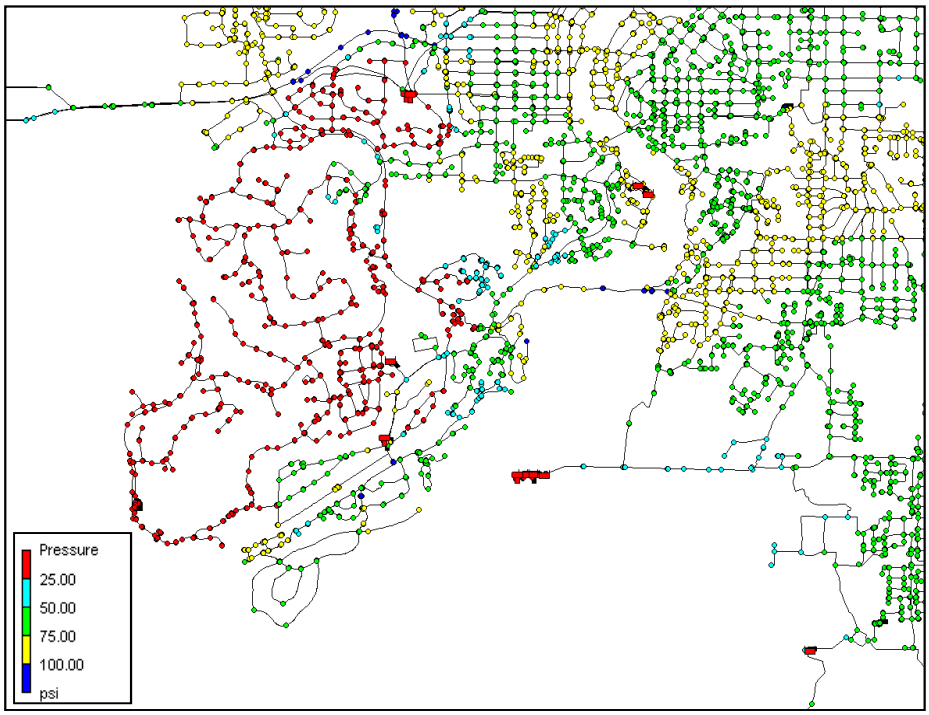

Figure 5.19 – Zone 3 – nodes suffering low pressure based on a pipe break on Mt. Washington Drive just south of Skyliners Road

Table 5.7 – Zone 3 – critical pipes causing low pressure in the event of pipe break along Mt. Washington Drive south of Skyliners Road

Critical Pipes	Approximate Address	Pressure Zone(s)	Number of Low Pressure Customers During Break
WWM003371	SW Mt. Washington Drive -S- Skyliners Road	3	1015
WWM004268	Hosmer Lake Drive – W- SW Mt. Washington	3	1015
WWM005372	SW Mt. Washington Drive -S- Skyliners Road	3	1015
P00000MT	SW Mt. Washington Drive -S- Skyliners Road	3	960
P00000MS	Near PRV 21 off SW Mt. Washington Drive	3	960
P00000MR	Near PRV 21 off SW Mt. Washington Drive	3	940
WWM003570	Near PRV 21 off SW Mt. Washington Drive	3	902
WWM003571	Skyliners Road -W- SW Mt. Washington Drive	3	902
WWM001960	SW Mt. Washington Drive -W- Flagline Dr	3	870
P00000MJ	SW Mt. Washington Drive -E- Flagline Dr	3	822
P00000MI	SW Mt. Washington Drive -E- Flagline Dr	3	821
WWM004261	SW Mt. Washington Drive -E- Flagline Dr	3	813
WWM004262	SW Mt. Washington Drive -E- Flagline Dr	3	813
P00000MN	SW Mt. Washington Drive -S- Simpson Ave	3	781
WWM005408	SW Mt. Washington Drive -S- Troon Ave	3	779
WWM004275	Near PRV 21 off SW Mt. Washington Drive	3	779
P00000LQ	SW Mt. Washington Drive -S- Simpson Ave	3	737
WWM002945	Near PRV 21 off SW Mt. Washington Drive	3	732
WWM004292	SW Mt. Washington Drive -S- Simpson Ave	3	722
P00000KX	SW Mt. Washington Drive -N- Bridge Creek Dr	3	719
P00000L0	SW Mt. Washington Drive -N- Bridge Creek Dr	3	719
P00000KY	SW Mt. Washington Drive -N- Bridge Creek Dr	3	719
P00000KZ	SW Mt. Washington Drive -N- Bridge Creek Dr	3	719
WWM004304	Bridge Creek Dr -W- SW Mt. Washington Dr	3	696
P00000L3	Bridge Creek Drive at Metolius Dr	3	696
P00000L4	Bridge Creek Drive at Metolius Dr	3	696
P00000L5	Bridge Creek Drive at Metolius Dr	3	696
P00000L7	Bridge Creek Drive at Metolius Dr	3	688
P000023U	Bridge Creek Drive at Metolius Dr	3	688

One additional vulnerable location with respect to low pressures from a pipeline break is in the lower part of Zone 4 East (4B), centered on the intersection of Fox Run Road, Brosterhous Road, and American Lane and pipes extending west, northeast, and south of that intersection. The figures below and Table 5.8 show the pipes which, when broken, cause pressures to drop below 20 psi, and the approximate area of nodes and associated customers affected. The worst pipe breaks and number of low pressure customers are listed in the table. Under current operations there are no additional supply sources to turn on in this area of the system, so the area is vulnerable to pipe breaks in these locations. However, planned changes to the Tillicum system will likely modify the way this part of the system operates; additional criticality assessment should be performed after the changes have been implemented.

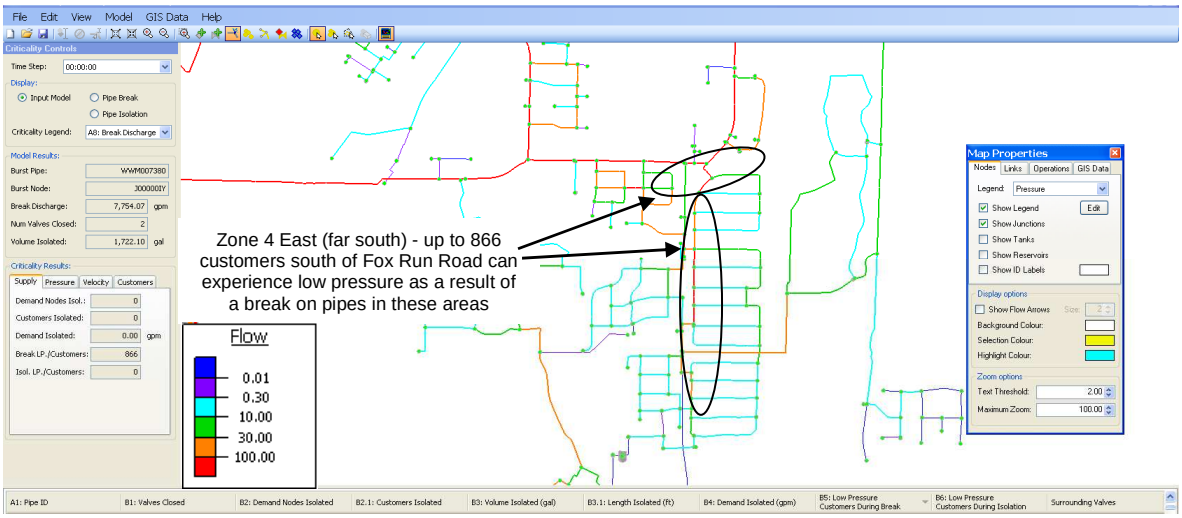

Figure 5.20 – Zone 4 East (far south) – pipes, when broken, causing potential low pressures south of Fox Run Road

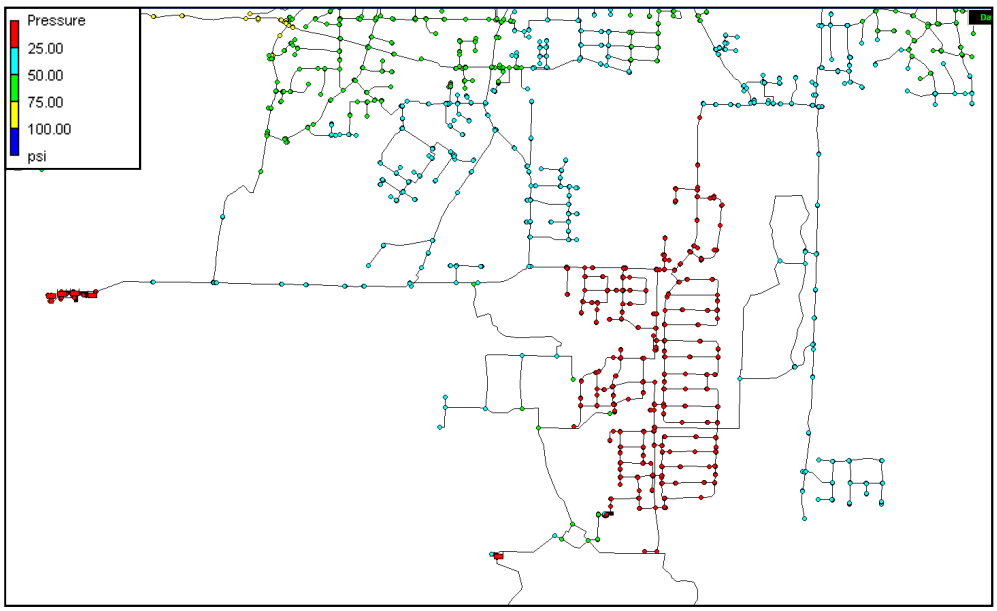

Figure 5.21 – Zone 4 East (far south) – nodes suffering low pressure based on a pipe break along Fox Run Road or Brosterhous Road

Table 5.8 – Zone 3 – critical pipes causing low pressure in the event of a pipe break along Brosterhous Road or south of Fox Run Road

Critical Pipes	Approximate Address	Pressure Zone(s)	Number of Low Pressure Customers During Break
WWM006896	Fox Run Road	4 East	875
WWM003642	Brosterhous Road -W- Fox Run Road	4 East	866
WWM007380	Fairfield Drive -S- Foxborough Lane	4 East	866
WWM002554	Fairfield Drive -S- Foxborough Lane	4 East	866
WWM002561	Fairfield Drive -N- Foxborough Lane	4 East	866
WWM002562	Fairfield Drive -N- Foxborough Lane	4 East	866
WWM002562	Foxborough Lane at Fairfield Drive	4 East	866
WWM003646	American Lane -N- Fox Run Road	4 East	866
P0000035	American Lane -N- Fox Run Road	4 East	866
WWM003645	American Lane -W- Fox Run Road	4 East	866
WWM003695	Fairfield Drive -S- Fox Run Road	4 East	866
WWM003694	Fairfield Drive -S- Fox Run Road	4 East	866

5.6 B6 Low Pressure Customers during Isolation / B11 Min Pressure after Isolation / and B14 Low Pressure Nodes after Isolation

These metrics focus on resulting pressures and the number of nodes/customers experiencing low pressure as a result of pipe isolation for repair. The most severe are described here. In some of these cases the total number of customers and total demand isolated is not substantial – some of these are potential areas for future growth that are currently in the model. However, it is important to note which pipes make these locations vulnerable in the event that growth does indeed occur. Table 5.9 shows the statistics for this criticality metric.

Table 5.9 – Statistics for number of low pressure customers during pipe isolation

Number of low pressure customers	Total number of pipes, when isolated for repair, causing low pressures	Percentage of pipes this represents in system
Between 501 and 720	11	0.11%
Between 201 and 500	4	0.04%
Between 101 and 200	4	0.04%
Between 51 and 100	27	0.27%
50 or less	9,934	99.5%

There are essentially three areas of concern, shown in the figures and Table 5.10 below:

1. Zone 3 pipes along SW Mt. Washington Drive as it runs between Zones 4K and 4A; Bridge Creek Drive just west of SW Mt. Washington Drive; and then to the southwest at Metolius Drive near Meeks Trail;
2. Zone 5 pipes at the intersection of Neff Road and 27th Street; and
3. Zone 4 East pipes at and just west of the intersection of NE Bear Creek Road and 15th Street.

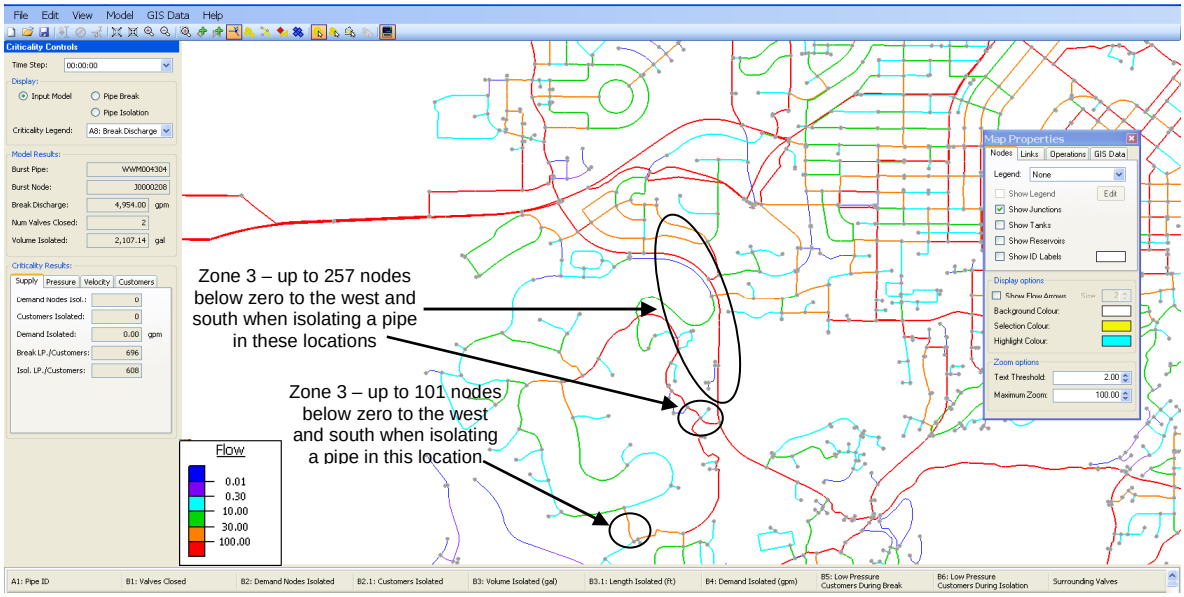

Figure 5.22 – Zone 3 – Portions of Mt. Washington Dr and Bridge Creek Dr – pipes causing low pressure customers and nodes after isolation

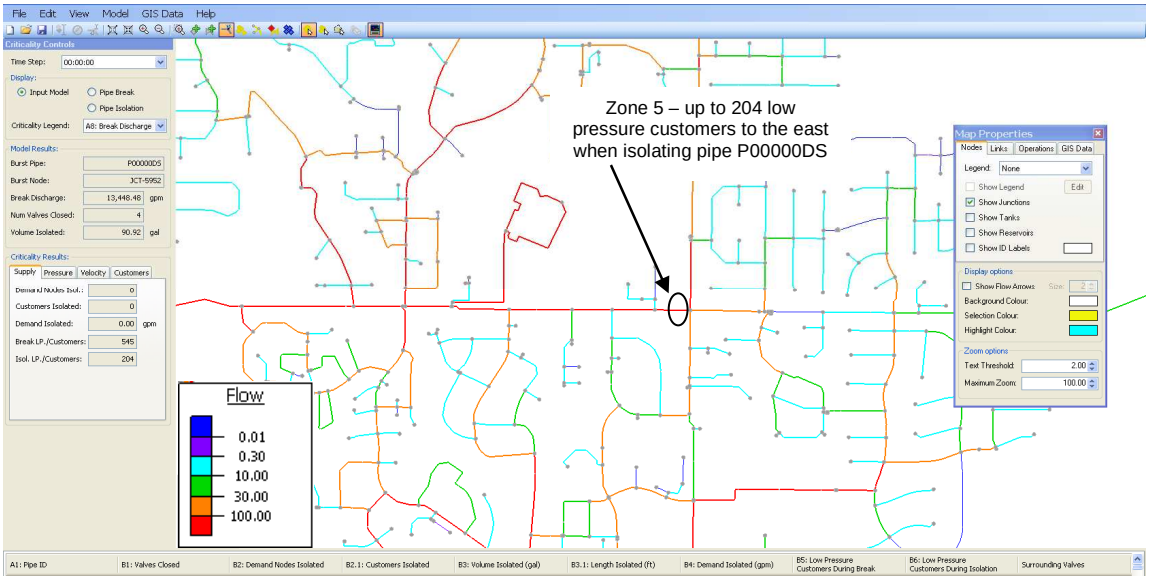

Figure 5.23 – Zone 5 – Neff Road at 27th Street – pipes causing low pressure customers and nodes after isolation

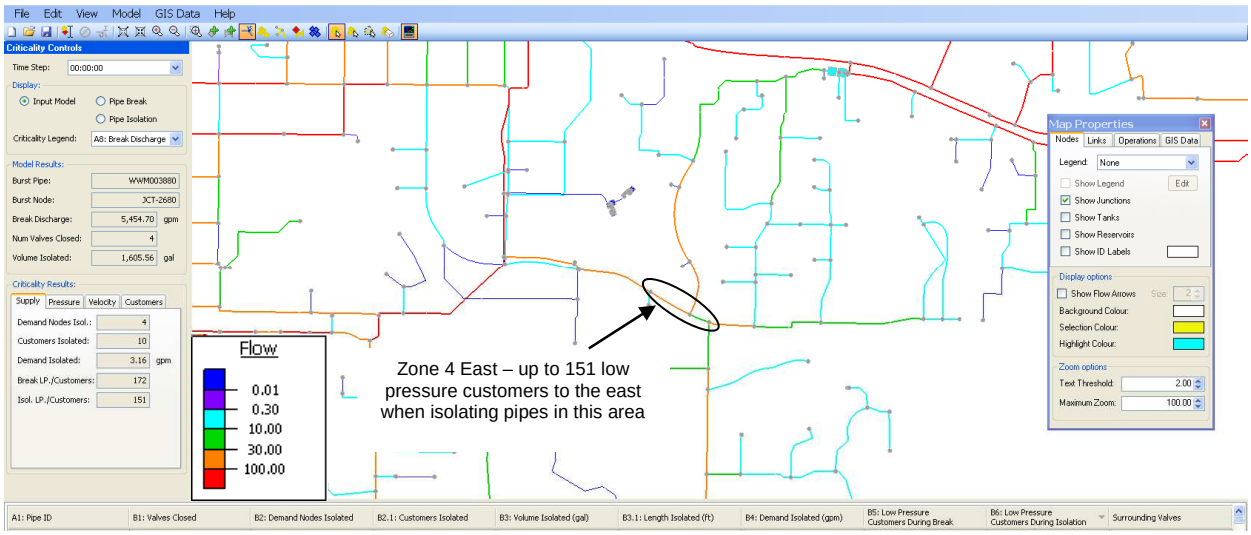

Figure 5.24 – Zone 4 East – NE Bear Creek Road -W- 15th Street pipes causing low pressure customers and nodes after isolation

Table 5.10 – Zone 3 – critical pipes causing low pressures to significant numbers of customers during isolation in Zones 3, 5 and 4 East

Critical Pipes	Approximate Address	Pressure Zone(s)	Number of Low Pressure Customers During Isolation
WWM004261	SW Mt. Washington Dr near Troon	3	714
P00000MN	SW Mt. Washington Dr -S- Simpson	3	714
P00000LQ	SW Mt. Washington Dr -S- Simpson	3	714
WWM004292	SW Mt. Washington Dr -S- Simpson	3	706
WWM004304	Bridge Creek Dr -W- SW Mt Washington	3	608
P00000L3	Bridge Creek at Metolius Dr	3	605
P00000L4	Bridge Creek at Metolius Dr	3	605
P00000L5	Bridge Creek at Metolius Dr	3	605
P000023U	Bridge Creek at Metolius Dr	3	605
P00000DS	Neff Rd at 27th Street	5	204
P0000465	NE Bear Creek Road at 15th Street	4 East	151
WWM003880	NE Bear Creek Road -W- 15th Street	4 East	151
P000016Q	NE Bear Creek Road -W- 15th Street	4 East	151
WWM003881	NE Bear Creek Road -W- 15th Street	4 East	151
P00000KT	SW Mt. Washington Dr -S- Bridge Creek	3	98
WWM003396	Metolius Dr –N- Meeks Trail	3	10

6 Prioritization

The final step of the pipe criticality analysis was to develop a method for ranking the most vulnerable areas, leading to which pipes should be paralleled or replaced in order to strengthen these locations in the network. Optimatics took the results of the analyses and looked at the number of valve closures for isolation, the severity of pipe breaks and isolation with respect to the isolation of the critical customers identified by Bend, isolation of the greatest number of customers, and resulting low pressures under simulated break and simulated isolation conditions.

As noted early in this memorandum, the maximum number of valves needed to isolate any break in the system is eight (8). This is a relatively low maximum number, and the area of the system where either 7 or 8 valves need to be closed to isolate a break – downtown on Nashville Avenue and Louisiana Avenue – does not show up in the criticality results as a vulnerable area with respect to customer isolation or low pressure. Therefore, 'number of valves to close' is not a major concern in the Bend system and therefore was not used as a measure in prioritizing the most critical pipes.

Those metrics that were used to build the prioritization table are:

- Pipes causing vulnerability near the two critical customers – St. Charles Medical Center and Deschutes Brewery
- Number of demand nodes isolated / number of customers isolated following isolation of broken pipe (B2)
- Number of low pressure customers during break (B5)
- Low pressure customers during isolation (B6)
- Minimum / low pressures after break or isolation (B7, B11, B14)

The analyses identified numerous pipe numbers that cause vulnerability in the system in the event of break or isolation. The prioritization process does not specifically call out each single pipe, but instead identifies the location in the system and the major streets and intersections.

6.1 Identifying the most critical pipes

Given the results from the criticality analyses an assessment was made to identify and prioritize the critical pipes which cause the greatest vulnerability with respect to isolating critical customers, isolating large numbers of customers, and causing low pressure. Seven locations are considered first priority, listed in Table 6.1 and then described in the sub-sections following. An additional six areas beyond these seven, highlighted earlier in this memorandum, are briefly summarized again for reference after the first priority area descriptions.

Table 6.1 – Metrics used to prioritize the top 7 critical areas

Priority Number	Location	Cause vulnerability near St. Charles Medical Center	Cause vulnerability near Deschutes Brewery	Cause vulnerability due to low pressures during break	Cause vulnerability due to many customers isolated during break or isolation
1	**Zone 5 - NE Neff Road and NE Purcell Boulevard / St. Charles Medical Center**	✓		✓	✓
2	**Zone 5 - Deschutes Brewery area off SW Simpson Ave and SW Colorado Ave**		✓	✓	
3	**Zone 4 East (4B) – pipes on Reed Market Road and other streets**			✓	
4	**Zone 3 – pipes on and off Mt. Washington Drive south of Skyliners Road**			✓	✓
5	**Westwood Zone (3C) – Mt. Bachelor Drive / Mammoth Drive area**			✓	✓
6	**Zone 4 East (4B) – Brosterhous Road / American Lane / Fox Run Road**			✓	
7	**Zone 3 – Intersection of Mt. Washington Drive and Shevlin Park Road**				✓

Priority Area 1 – Zone 5 - NE Neff Road and NE Purcell Boulevard / St. Charles Medical Center

The two most critical customers identified by Bend in the City network are the St. Charles Medical Center, located north of NE Neff Road between NE Purcell Boulevard and NE 27th Street (model node JCT-6609) and the Deschutes Brewery, located near Colorado and Simpson (model node JCT-1455). It is crucial that water supply is maintained to both of these customers at all times. In the analysis OptiCritical ™ identified the most critical pipes surrounding each customer, as noted early in Section 5, which are those pipes which, if broken or isolated, would cause pressure to drop below 20 psi to the critical customer or that would completely isolate the customer. In the case of the Medical Center, additional criticality metrics – specifically the low pressure metrics – showed that pipes along NE Neff Road, NE Purcell Boulevard, and other nearby streets, in the event of pipe break, caused nearly 1,400 customers in that area of the system to suffer low pressure. This includes the Medical Center. Based on these results, this location is deemed most vulnerable. Figure 6.1 shows the most critical pipes affecting the Medical Center as well as the additional pipes to the east on and off NE Neff Road which will cause supply and low pressure vulnerability in the event of break or isolation. The model shows only one feeder main to the Medical Center, extending north from NE Neff Road. Constructing at least one new pipe to connect to the Medical

Center complex from a different main in the network will reduce the vulnerability of the Medical Center. One or more parallel mains should be considered along NE Neff Road and NE Purcell Boulevard to strengthen reliability in this section of the network.

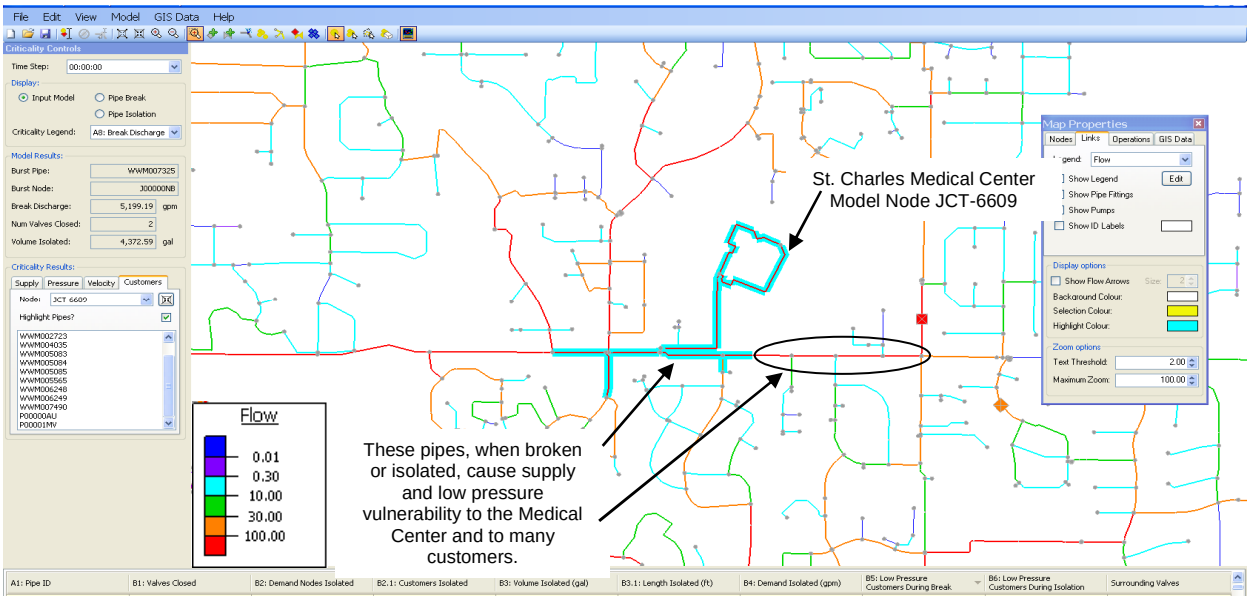

Figure 6.1 – Priority Area 1 – highlighted pipes on NE Neff and NE Purcell, when broken or isolated, cause supply and low pressure vulnerability to the St. Charles Medical Center and to numerous customers to the south and north

Priority Area 2 – Zone 5 – Deschutes Brewery area off SW Simpson Ave and SW Colorado Ave

Though the criticality program did not indicate that pipes in this area, should they break or be isolated for repair, would isolate a large number of customers or cause low pressures, this location is considered a high priority area given the presence of critical customer Deschutes Brewery. Figure 6.2 shows the pipes which, if broken or isolated for repair, could have an adverse effect on supply and service pressure to the Brewery. Fortunately there are several pipe routes to the area should a break or isolation take place on a nearby main, and many of these pipes - on SW Colorado, SW Simpson, and SW Shevlin Hixon – are 16-inch diameter and able to carry significant flow. The figure and model do, however, show that there is only one 10-inch diameter feed to this customer from an 8-inch diameter pipe on SW Simpson Avenue. At least one additional feed into the Brewery from a different main will help to improve reliability in the event of a supply interruption.

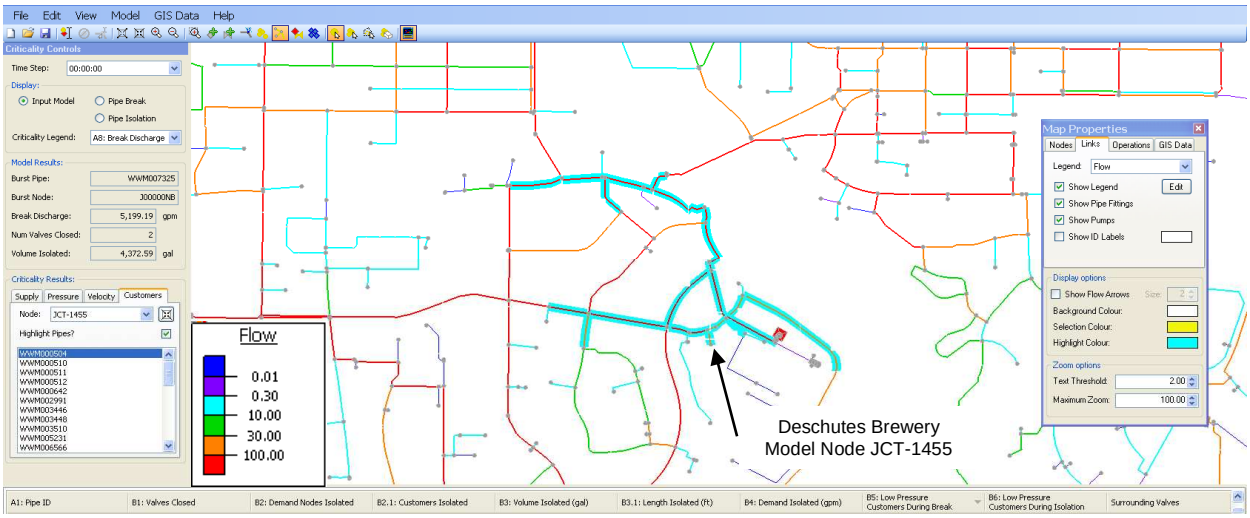

Figure 6.2 – Priority Area 2 – highlighted pipes on SW Simpson, SW Colorado, and SW Shevlin Hixon, when broken or isolated, cause supply and low pressure vulnerability to the Deschutes Brewery location

Priority Area 3 – Zone 4 East (4B) – pipes on Reed Market Road and other streets

Criticality results showed that this pressure zone is vulnerable to low service pressure under break conditions to pipes on Reed Market Road / SE Arthur Avenue and numerous other streets to the east of where Reed Market enters Zone 4 East. Up to nearly 3,100 customers in Zone 4 East could be adversely affected during a pipe break situation (again, keeping in mind that severe break conditions were simulated). Figure 6.3 indicates the areas of the most critical pipes.

The criticality analysis and subsequent modeling analyses indicated that, depending on the severity and location of the pipe break in the zone, some areas could suffer lower than desirable pressure even with most of the supply sources contributing flow to the zone. The worst case in terms of number of customers with low pressure occurs with potential breaks on the 16-inch diameter main on Reed Market Road / SE Arthur Avenue. Breaks on Brookswood Boulevard, Silver Lake Boulevard, SW Chamberlain Street, Miller Avenue, Aune Road, 2nd Street, 4th Street, and Wilson Avenue could also cause low pressure in certain areas.

One or more additional supply feeds to Zone 4 East would reduce vulnerability to pipe break and/or isolation in the zone.

Priority Area 4 – Zone 3 – pipes on and off Mt. Washington Drive south of Skyliners Road

The criticality results indicated that anywhere from 690 to 1,015 customers could suffer low pressure in the event of a pipe break on Mt. Washington Drive south of Skyliners Road down to Mountaineer Way. Figure 6.4 shows the critical pipe locations. The affected customers are primarily in that section of Zone 3 which is just west of Mt. Washington Drive and south of Zone 4K. The system maps and model show that there is only one feed into this area of the network – the 12-inch diameter Bridge Creek Drive take-off from Mt. Washington Drive – which explains the isolation vulnerability. At least one additional feed into this part of Zone 3 should be implemented to provide redundant supply and reduce the vulnerability.

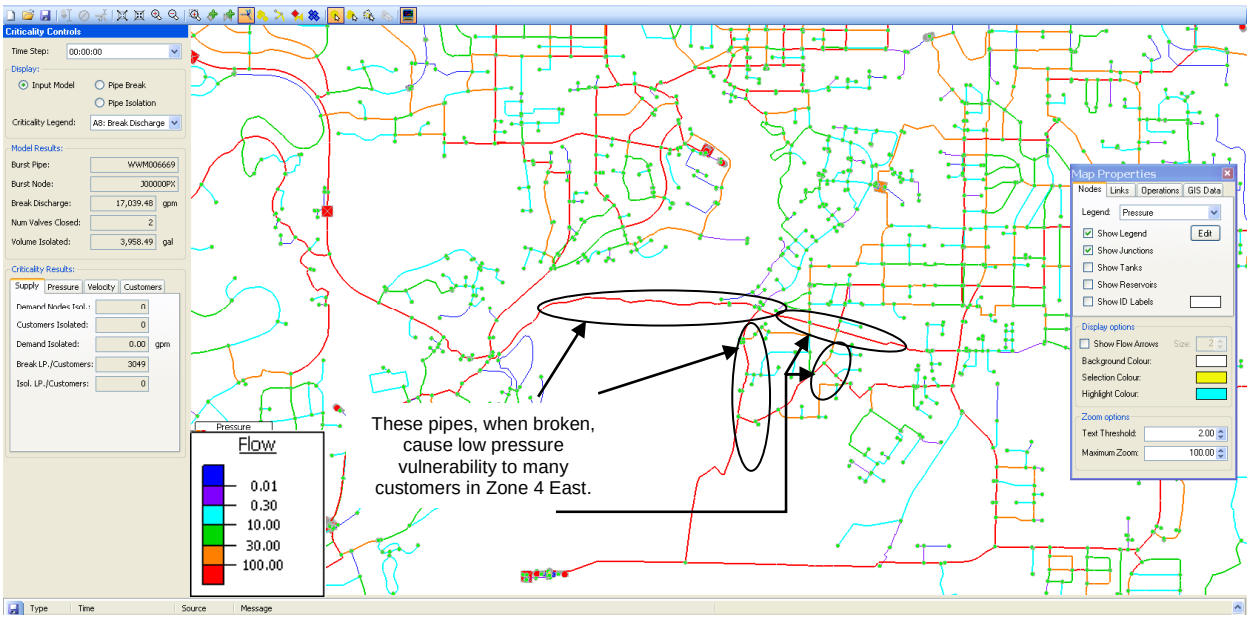

Figure 6.3 – Priority Area 3 – Zone 4 East – area served by Reed Market Road main and additional mains on nearby streets, when broken or isolated, cause supply and low pressure vulnerability

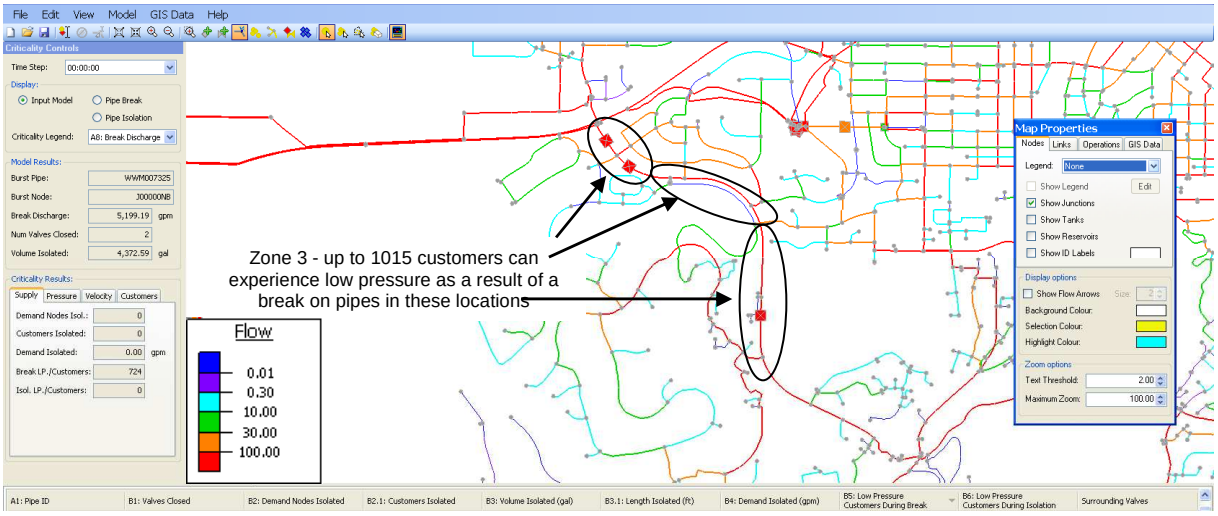

Figure 6.4 – Priority Area 4 – Zone 3 – pipe breaks along Mt. Washington Drive south of Skyliners Road, when broken or isolated, cause low pressures and/or isolation of just over 1,000 customers

Priority Area 5 – Westwood Zone (3C) – Mt. Bachelor Drive / Mammoth Drive area

The pipe criticality simulations showed that a pipe break or isolation on any of 8-10 pipes south of the Westwood Pump Station – essentially pipes on Mt. Bachelor Drive or Mammoth Drive (see Figure 6.5 below) – isolates the whole lower end of the Westwood Zone as well as Zone 4I. Based on the customer count this could mean up to nearly 550 customers isolated.

One or more additional feeds into the lower part of the Westwood Zone from the north are recommended for implementation. This would provide backup supply in the event of a break or isolation on the Mt. Bachelor Drive and Mammoth Drive mains.

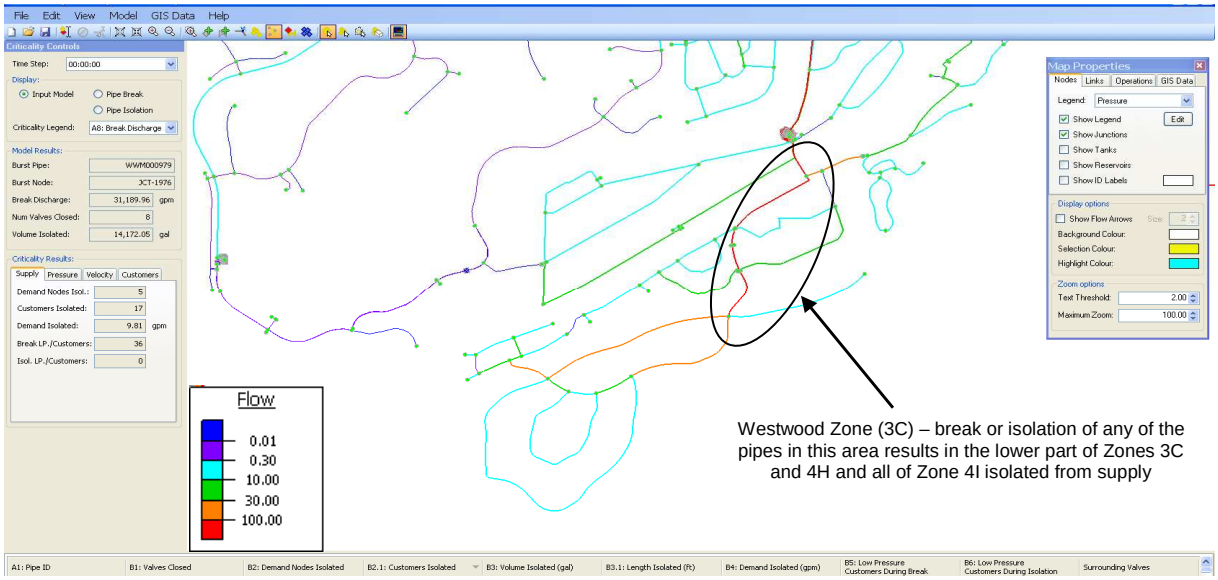

Figure 6.5 – Priority Area 5 – Westwood Zone (3C) – pipes south of Westwood Pump Station on Mt. Bachelor Drive or Mammoth Drive, when broken or isolated, cause isolation of more than 500 customers

Priority Area 6 – Zone 4 East (4B) – Brosterhous Road / American Lane / Fox Run Road

The next most critical area of the system based on resulting low pressures in the event of a pipe break is the lower portion of Zone 4 East (4B), centered around the intersection of Brosterhous Road, American Lane, Sipchen Road, and Fox Run Road. The criticality results showed that a break along Brosterhous Road, American Lane, Fox Run Road, Fairfield Drive, or Foxborough Lane could cause up to 875 customers (primarily to the south of the intersection, but some just north) to suffer low pressure.

Figure 6.6 shows the area of concern. Strengthening redundancy in this section of Zone 4 East is recommended. The planned modifications to the Tillicum area may provide the necessary strength; further review is warranted during design of the new improvements and operating measures.

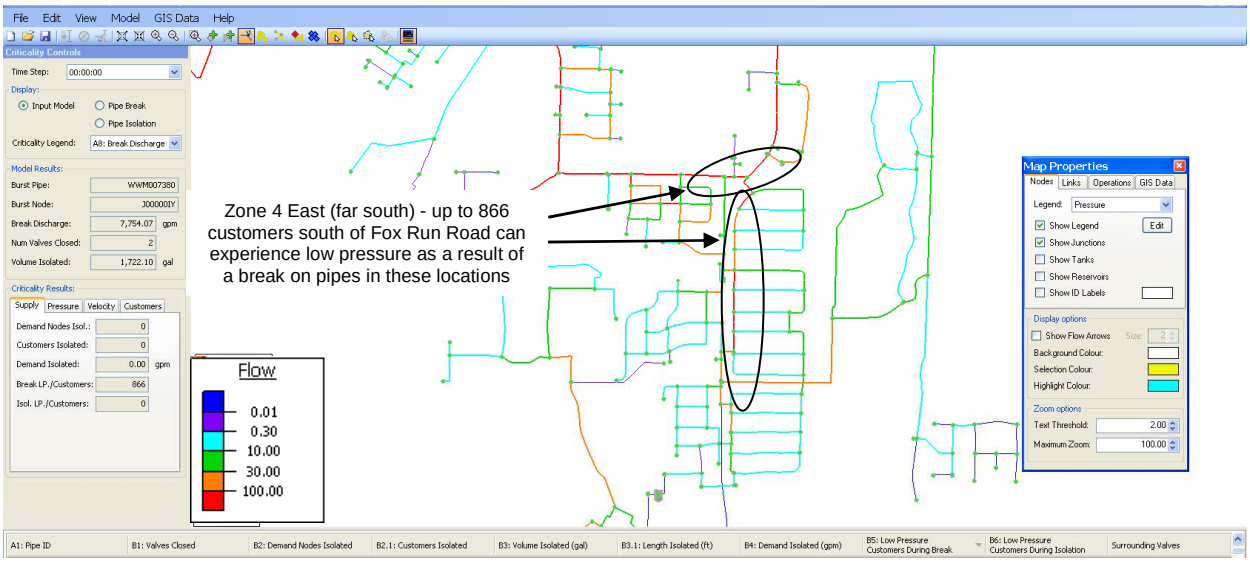

Figure 6.6 – Priority Area 6 – Zone 4 East (4B - south) – pipe breaks along Brosterhous Road, American Lane, Fox Run Road, and Fairfield Drive cause low pressures and/or isolation of up to 875 customers

Priority Area 7 – Zone 3 – Intersection of Mt. Washington Drive and Shevlin Park Road

Certain pipes on Mt. Washington Drive and on/off Shevlin Park Road (see Figure 6.7), when isolated for repair, could isolate up to 369 customers. These customers are located in Zone 3 near the intersection of these two major roads and just to the southeast, and in all of Zone 4C, since there is only the feed from pressure reducing station 59 supplying this smaller zone from Zone 3. Just north of the intersection, if a pipe on Mt. Mt. Washington Drive up to and including the pipe on NW Nordic Avenue were to be isolated for repair, all customers in smaller zones 4D and 5A would be isolated, representing nearly 200 additional customers.

It is recommended that the City consider the strategic addition of new mains in this location to add redundancy and reduce reliance on one supply point into the zone and subzone areas noted above.

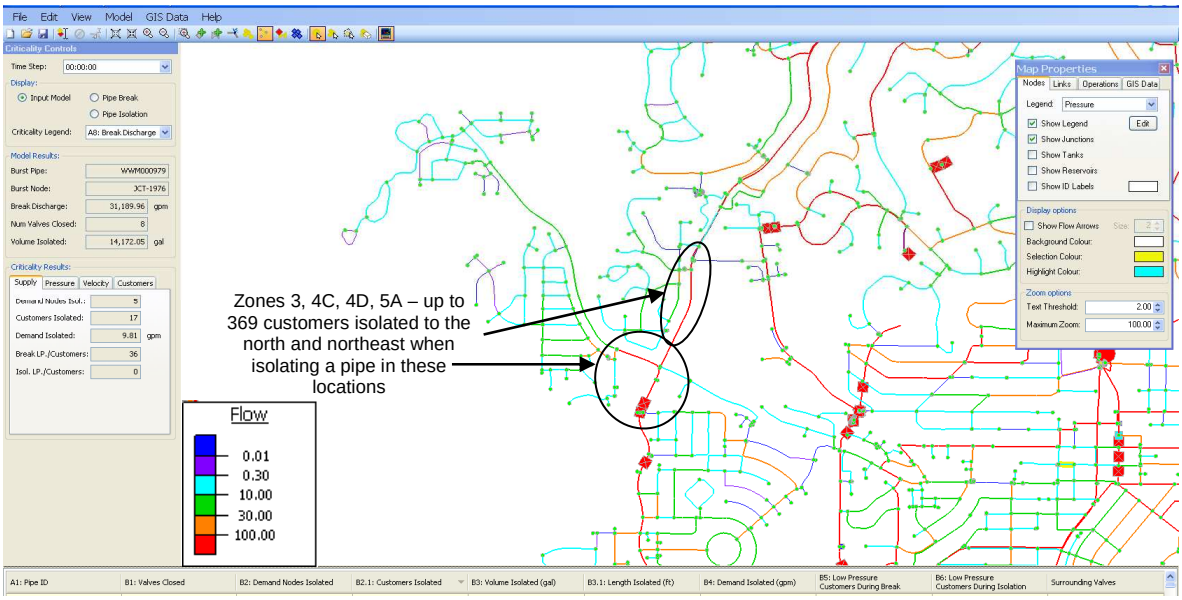

Figure 6.7 – Priority Area 7 – Zone 3, 4C, 4D, 5A – pipe breaks along Mt. Washington Drive, Shevlin Park Road, and NW Nordic Avenue cause isolation of up to 369 customers

6.2 Additional Areas of Priority

In Section 5 of this memorandum there are several additional areas that can be deemed critical based on the number of customers isolated during an isolation of a pipe for repair. These are the locations listed below; between 130 and 310 customers could be isolated:

1. Pipes in Zone 6 and 7B at the intersection of Butler Market Road and Purcell Boulevard, and north along Purcell
2. Zone 4 East (4B) pipes along Bronzewood Avenue off SE 15th Street
3. Pipes in the far southeast end of Zone 3 near the intersection of Fairway Ridge Lane and Devil's Lake Drive
4. Zone 4 East (4B) pipes supplying the zone from Pilot Butte Reservoir #2 to the north and west
5. Zone 6 and 7C pipes along Butler Market Road near the eastern edge of the system
6. Zone 4 East pipes at and just west of the intersection of NE Bear Creek Road and 15th Street

The City can determine the priority of addressing these locations as it develops its capital improvement plans over the next 10 years. Optimatics will cross reference these results with solutions from the optimization runs to aid in the prioritization of improvements for the capital improvement plan. Also, if road improvement work is planned for any of these areas then the City can choose to implement new pipe improvements at the same time, saving money on installation.

6.3 Comparison of identified areas of priority with pipe data in other City databases

In Section 6 – entitled *Recommended Water System Improvements* – of the 2007 Water System Master Plan (MP) Update Final Report it states that the hydraulic analysis performed for the study "found that distribution system water line improvements are needed to improve fire flow capacities within the distribution system and also provide improved hydraulic transmission capacity and accommodate system expansion needs." A map showing recommended improvements and a pipe listing are provided in Appendices A and B of that report. Optimatics took this information and compared it to the areas of priority revealed in the criticality analysis to see if and where there are locations/pipes that overlap.

Priority Area 1 – Zone 5 – NE Neff Road and NE Purcell Boulevard / St. Charles Medical Center

The area of highest priority from the criticality analysis is NE Neff Road and NE Purcell Boulevard, including the St. Charles Medical Center, in Pressure Zone 5. There are several new pipes recommended from the 2007 Master Plan Update that are near to this area, though not directly in the center of it, which should be studied further to determine their potential to improve reliability. These pipes are:

1. D-43 – 27th Street north of NE Neff Road – 16-inch diameter
2. D-208 – NE Purcell Boulevard – S- Lotus – 12-inch diameter
3. D-209 – Cliff Drive off NE Neff Road –W- NE Purcell Boulevard – 12-inch diameter

Priority Area 2 – Zone 5 – Deschutes Brewery area off SW Simpson Ave and SW Colorado Ave

One recommended pipe improvement from the 2007 MP Update would add strength to the network near the Deschutes Brewery. It is D-277, a new 12-inch diameter main on Simpson Avenue to Colorado Avenue / Shevlin-Hixon.

Priority Area 3 – Zone 4 East (4B) – pipes on Reed Market Road and other streets

There are a number of new pipe, storage, and supply recommendations for Zone 4 East (4B) in the 2007 MP Update which would provide additional back-up supply and strength to the network where the criticality analysis revealed vulnerability. The City should do further analysis to determine the priority of these improvements, which are listed here. Some of these may already be in design/construction:

<u>Pipes</u>

1. D-24 – Reed Market Road – west of Brosterhous – 16-inch diameter
2. D-5 – Hayes Avenue / Brosterhous Road – 24-inch diameter
3. D-107 – Parrell Road – 18-inch diameter
4. D-108 – Reed Lane – 16-inch diameter
5. D-112 – Reed Lane – 12-inch diameter
6. T-1 , T-2, T-3 – Powers Road from Rock Bluff facility to Brosterhous Road – 24-inch diameter
7. D-244 – North Pilot Butte Drive – 12-inch diameter
8. D-248 – Hollinshead Court / Hollinshead Historic Park – 8-inch diameter
9. D-239 – 11th Street / Pilot Butte Res/Wells – 12-inch diameter
10. D-224 – Neff Road / Park Ridge – 10-inch diameter

<u>Storage</u>

1. 3.0-MG Rock Bluff II Reservoir
2. 3.5-MG Pilot Butte VI Reservoir
3. 3.0-MG Rock Bluff III Reservoir

Wells

1. Pilot Butte Wells – 6.0 MGD
2. Rock Bluff Wells – 3.0 MGD
3. Bear Creek Wells – 2.0 MGD

Priority Area 4 – Zone 3 – pipes on and off Mt. Washington Drive south of Skyliners Road

There are no substantial improvement recommendations from the 2007 MP Update which coincide with these locations. There is one 8-inch diameter pipe (D-106) and PRV recommendation on Yates Avenue off Mt. Washington Drive which would provide an additional feed for Pressure Zone 4G beyond its one existing feed on Chandler Avenue. This is a prudent recommendation.

Priority Area 5 – Westwood Zone (3C) – Mt. Bachelor Drive / Mammoth Drive area

There are no recommended improvements in the 2007 MP Update which tie the upper and lower sections of the Westwood Zone together across Century Drive. Such a connection would facilitate supply from Tetherow (through PRV Station 73) to the southern parts of Westwood. The 2007 Update does recommend a new 8-inch diameter pipe on Century (D-123).

Priority Area 6 – Zone 4 East (4B) – Brosterhous Road / American Lane / Fox Run Road

Several new pipes are recommended in the 2007 Update for this section of the network:

1. D-9 – Kobe to Conifer Avenue (Ponderosa Pines) – 10-inch diameter
2. D-11 – Brosterhous Road – 12-inch diameter
3. D-111 – Klahani Drive (Tillicum Village) – 8-inch diameter
4. D-116 – Klahani Drive to Mowitch (Tillicum Village) – 8-inch diameter

Priority Area 7 – Zone 3 – Intersection of Mt. Washington Drive and Shevlin Park Road

No improvement recommendations are listed in the 2007 MP Update for this location.

6.4 2007 MP Update Recommendations within the Additional Areas of Priority

The 2007 MP Update shows recommended improvements in or near several of the six additional areas of priority identified in the criticality analysis.

1. Pipes in Zone 6 and 7B at the intersection of Butler Market Road and Purcell Boulevard, and north along Purcell – no improvement recommendations are listed in the 2007 MP Update for this location.

2. Zone 4 East (4B) pipes along Bronzewood Avenue off SE 15th Street.
    a. D-1 – Reed Market Road and 15th Street (Orion) – 12-inch diameter
    b. D-47 – Breitenbush Lane off Lostin Circle – 10-inch diameter
    c. D-21 – 15th Street to Wildcat Drive – 12-inch diameter
    d. D-23 – Bronzewood Court – 12-inch diameter
    e. D-40 – Castlewood Drive – 10-inch diameter
    f. D-28 – Blackridge Place – 8-inch diameter

3. Pipes in the far southeast end of Zone 3 near the intersection of Fairway Ridge Lane and Devil's Lake Drive - no improvement recommendations are listed in the 2007 MP Update for this location.

4. Zone 4 East (4B) pipes supplying the zone from Pilot Butte Reservoir #2 to the north and west. Recommended new pipes for this location are also listed under Priority Area 3 above. They are:
    a. D-244 – North Pilot Butte Drive – 12-inch diameter
    b. D-248 – Hollinshead Court / Hollinshead Historic Park – 8-inch diameter
    c. D-239 – 11th Street / Pilot Butte Res/Wells – 12-inch diameter
    d. D-224 – Neff Road / Park Ridge – 10-inch diameter

5. Zone 6 and 7C pipes along Butler Market Road near the eastern edge of the system. There is one recommended pipe just east of this location which could help with back-up supply should there be a pipe break on Butler Market Road just ahead of the existing PRV feeding Zone 7C. It is listed as D-279, a 16-inch diameter pipe connecting Purcell Boulevard to Butler Market Road.

6. Zone 4 East pipes at and just west of the intersection of NE Bear Creek Road and 15th Street. There are several pipes listed in the 2007 MP Update which would strengthen this intersection and the surrounding network:
    a. D-55 – NE Bear Creek Road – 16-inch diameter
    b. D-206 – NE Bear Creek Road – 12-inch diameter
    c. D-54 – 15th Street to Bear Creek Road – 16-inch diameter

6.5 Pipe Material Correlation with Vulnerable Areas

Figure 2.1 in Section 2 shows the pipe material data in the GIS. Optimatics performed a visual correlation of pipe material with the vulnerable areas of the system identified by the pipe criticality analysis.

The City has stated that they are intent on replacing the galvanized iron main which exists in the system. The criticality results did not indicate that there are galvanized iron mains that are important feeder mains to the vulnerable areas.

There is a fairly large amount of cast iron main in the older, central portion of the water system. Some cast iron can hold up quite well over time, especially if the water quality in a system is favorable. However, the quality of pipe installation and construction techniques can vary, and these can have an impact on the integrity and performance of the mains. Bend expressed that some cast iron installed before 1950 suffers from poor installation practices and has experienced problems. Fortunately, though the central part of the system is oldest the network in that area has good connectivity and looping. The criticality analyses did not show particular locations of vulnerability here. However, there are a few locations in the system identified by the criticality results which do have cast iron pipe. These are described below. Should any on the list correspond with problematic cast iron pipe in the City's records then these should become candidates for replacement.

Zone 5 near St. Charles Medical Center

1. NE Neff Road between NE Williamson Boulevard and NE Medical Center Drive – existing 16-inch diameter pipe
2. NE Medical Center Drive from NE Neff Road to Watt Way – existing 8-inch diameter pipe

Zone 4 East (4B) – Pilot Butte Facility area

1. North Pilot Butte (the 2007 MP update recommends a new 12-inch diameter pipe here, D-244)
2. 11th Street / Pilot Butte Res/ Wells (the 2007 MP update recommends a new 12-inch diameter pipe here, D-239)

Zone 5 / Zone 4 East (4B) – Scott Street Pump Station – suction side

There is a long stretch of existing 12-inch diameter main on Colorado Avenue leading to the Scott Street pump station that the GIS shows as cast iron. The pump station plays an important role in helping to move surface water to the east in the winter. If the existing main has experienced any breaks or significant leakage then it should be considered for replacement.

Zone 4 East (4B) – south

The existing 8-inch diameter north-south pipe on Brosterhous Road south of Brosterhous/Miller is shown as cast iron and was identified in Priority Area 6 as a main that could cause low pressures and isolation if broken.

Zone 4 East (4B) – Bear Creek well area

The existing 8-inch diameter pipes on NE Bear Creek Road and SE 115th Street are show as cast iron and identified as potentially causing low pressure vulnerability during pipe isolation for one of the 'Additional Areas of Priority.'

7 Conclusions

The pipe criticality results for the Bend system provide valuable insight into where the system is most vulnerable with respect to the effects of pipe breaks and pipe isolation. The City can add this information to the body of knowledge it uses to prioritize where to spend its capital improvement dollars to strengthen the system.

Optimatics will reference the criticality results against results from the master plan optimization to aid in prioritizing improvements for the 10-year capital improvement plan.

The steady-state model for the 2009 calibration day was connected to the OptiCritical ™ program and used in the analyses. A steady-state representation of the system is essentially a "snapshot" in time; this means that there was a defined demand distributed to the model nodes, and that certain facilities were on and others were off reflecting what actually occurred on that day. In a few cases, after looking at the criticality results, Optimatics used the model to assess the impacts of turning on additional facilities beyond those active during the calibration day to see the resulting effects. Severe break conditions were used to compare the relative consequence of each pipe failing and to provide conservative results. This yielded information on where the system is vulnerable during break and/or isolation, with respect to interrupting supply to critical customers and to large numbers of customers, as well as to low service pressure.

An area in the southern end of Zone 4 East was identified as a vulnerable area in the criticality analysis. This area is near Tillicum, which is slated for modifications in how the area will be served. The City should take into account the criticality results as it designs improvements to the Tillicum area and ensure those locations in Zone 4 East which are identified as vulnerable locations will be strengthened.

The electronic mapping information for the acquired South Bend area did not show sufficient shutoff valving for proper criticality analysis. It is known that the area has shallow buried pipe and other challenges. The City has been replacing some pipe with ductile iron pipe to alleviate maintenance and strengthen fire flow availability. Other capital and operational changes to this service area are in the works. During this planning period when numerous options are being considered, the City should take stock of where the South Bend service area is vulnerable with respect to single feeds and related supply issues, and implement measures to reduce this vulnerability.