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optimizing water systems

Water System Master Plan Update Optimization Study

City of Bend, Oregon, Project No. WA09FA

Final Report

February 2011

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Executive Summary

The purpose of this report is to present the recommendations resulting from the Water Master Plan Update Optimization Study undertaken by Optimatics. The report outlines relevant data, constraints, assumptions and methodology employed in the development of the recommended Final Build-out Solution and Capital Improvement Plan (CIP). This study and report builds on the previous 2007 Water Master Plan Update developed by Murray, Smith & Associates, Inc. (MSA).

Authorization

Optimatics and sub-consultant MSA received authorization to undertake the Water Master Plan Update Optimization Study (City Project No. WA09FA) in March 2009.

Compliance

This report and the Water Master Plan Update Optimization Study are not intended to be a complete Master Plan as defined under Chapter 333, Division 61, of the Oregon Administrative Rules (OAR). Items the report does not cover in significant detail are:

- Status of water rights
- Current status of drinking water quality, compliance with regulatory water quality standards and future plans for water treatment
- Financing program for constructing improvements (e.g. user rates, system development charges, finance programs)

This report does cover level of service goals, present and future deficiencies, assessment of fire flow capacity in the system and the results of a comprehensive analysis using an optimized decision support process to evaluate alternatives that address system deficiencies now and in the future. The results of this study are a recommended set of system improvements to meet the needs of the system for at least 20 years. In addition, an associated implementation plan for the next 10 years is provided. The recommendations cover supply, storage, distribution facilities, and system operation.

Planning Period

The improvements recommended in this study cover the period from today until build-out. The CIP presented in Section 3 addresses the next 10 years of development to the year 2020.

Study Area and Existing System

The City of Bend, located in Central Oregon, serves approximately 75,000 residents. The City is fortunate to be located near water sources with excellent quality – groundwater from the substantial Deschutes Aquifer and surface water collected from the Cascade Mountains. Surface water supply is collected 13 miles from the City limits and delivered to the system via the Outback facility. Groundwater is extracted at nine well locations spread across the City. Facilities include 25 groundwater wells, 15 finished water storage reservoirs, 6 booster pump stations and approximately 420 miles of transmission and distribution mains. The Bend system is operationally complex; there are 80 control valve stations serving 7 primary pressure zones and numerous sub-zones.

Optimized Decision Support Process

For this Water Master Plan Update Optimization Study, the City employed an optimized decision support process to assist in the development of an unbiased, low-cost improvement plan based on the best available data. An optimized decision support process involves all of the traditional planning steps including data collection, development of unit costs, hydraulic model update and calibration, and model analysis to evaluate different alternative solutions that will allow the system to meet demands in the future. Using optimization to assist the planning process allows for many more alternatives to be evaluated compared to trial-and-error modeling. This provides a number of benefits including a higher level of transparency in the recommended improvements, a better understanding of the impacts of different decisions and greater confidence that the plan represents the lowest-cost option considering both capital costs and life-time operating costs.

Project Scope

This comprehensive study involved a number of work steps:

Task 1 – Calibrate City of Bend Dynamic Water Model. The model update and calibration process was undertaken by Murray, Smith & Associates, Inc. (MSA) and is documented in their report titled *Water Model Development Documentation for Water System Optimization* (January 2011 – Appendix A)

Task 2 – Consequence of Failure Analysis. The consequence of failure analysis involved evaluation of the impact of pipe break events and isolation of breaks system-wide, with the aim of assisting the City to identify the areas of the system which are the most vulnerable (see Appendix B).

Task 3 – Development of the Optimization Model. This included development of the Design Data Summary (DDS) Report (Appendix C) and formulation of the optimization model to consider capital and operating decisions to meet current and future needs.

Task 4 – Optimization Study. The Optimization Study consisted of two parts – the first was an analysis of current system summer and winter operations (see Appendix D), and the second was the development of an optimized plan meeting build-out demand conditions.

Task 5 – Staged Implementation Plan. Evaluation of both the recommended existing fire flow improvements and the Build-out Master Plan improvements resulted in the development of a sequence of implementation that will ensure the system continues to provide adequate level of service and reliability in the near-term.

This report focuses on the outcomes of future plan development in Task 4 and the CIP developed in Task 5. Documentation related to Tasks 1 through 3, and the Operations Optimization is contained in the report appendices as noted.

Planning assumptions and criteria

The recommendations in this study were developed using specific design criteria that defined satisfactory system operation. These included minimum allowable pressure under both normal operation and fire flow conditions and maximum allowable velocity. A significant effort was made to develop a set of guidelines for the City to use with regards to emergency storage. The City chose to adopt the Washington Design Guidelines as the basis for defining storage requirements specific to the City of Bend to be used in this study.

A major assumption influencing the recommended Final Build-out Solution was the capacity of the surface water source. At the commencement of this study the City was investigating the potential of expanding the source to a maximum capacity of 23 MGD/36 cfs. It was agreed that the optimization analysis should determine how best to integrate this additional supply. However, later in the study it was revealed that the capacity of the surface water source would likely be much less; only 13.5 MGD/21 cfs. This information came to light after the Final Build-out Solution was finalized. The impact of a reduced surface water supply capacity (13.5 MGD/21 cfs) was evaluated as part of the development of the 10-year implementation plan.

Water demands

The projected water demands used in this study were developed by MSA. The average day, maximum day and peak hour demands for the existing, 10-year and build-out scenarios are summarized in Table E.1. MSA also analyzed historical data to develop diurnal patterns for extended period simulation and an appropriate peak hour demand factor to be used in this study.

The build-out demand values were developed based on medium residential development density within the proposed future urban growth boundary (UGB). The 10-year demand projection represents an approximately linear interpolation between current demand and projected build-out demand. The distribution of the 10-year demand was applied assuming that half of the growth in water demand to reach build-out demand at medium density within the current system facilities area (i.e. the existing UGB) will be realized.

Table E.1 – Projected future water demand summary

Year	Water Demand (MGD)		
	Average Day Demand (ADD)	Maximum Day Demand (MDD)	Peak Hour Demand (PHD)
2008 (1)	12.8	29.2	48.0
10-year projection (2)	21.7	48.8 (4)	87.9 (5)
Build-out Development (3)	37.1	83.5 (4)	150.3 (5)

Notes to Table E.1:

(1) Existing ADD, MDD & PHD based on 2008 water production records.

(2) 10-year ADD developed assuming half of the growth to meet build-out demand at medium density development would be realized within the existing UGB, plus half of growth to meet Tetherow build-out demand and Juniper Ridge at 294 acres.

(3) Build-out ADD assumes medium density development across the proposed UGB, plus Tetherow at 889 residential units and Juniper Ridge at 515 acres.

(4) MDD equals ADD x 2.25 (based on historical data, see Table 3.2 in the DDS report).

(5) PHD based on comparison of recorded peak hour and maximum day production values from 2008 and 2009. PHD:MDD factor agreed at 1.8.

Existing and future deficiencies

As part of this study, modeling analyses were undertaken to identify existing deficiencies in the Bend system. The consequence of failure analysis provided an indication of areas which are vulnerable to pipe break and isolation events. A system-wide fire flow analysis was conducted under existing and future demand conditions to determine where there are restrictions in the distribution system and the appropriate size for replacement pipes. When considering the future demand projections, a broad suite of improvement options were identified in discussions with City staff that would enable transmission of flow to growth areas in the system.

Recommended improvements

The recommended improvements were developed using a 'build to target' approach. This involves sizing capital improvements to meet projected build-out demands and then selecting the date of implementation for the recommended improvements to enable to system to meet the desired level of performance in the interim years. The Final Build-out Solution consists of new supply, pipe, pump and storage facilities and is designed to meet the required design criteria under future maximum day demands.

The estimated cost of the improvements is presented in Table E.2. As mentioned above, the Final Build-out Solution was developed under the assumption that the surface water source would contribute 23 MGD/36 cfs. At the time of writing this report, the anticipated maximum flow from the surface water source at build-out is much less; only 13.5 MGD/21 cfs. For consistency, Table 2.18 shows the estimated cost of the surface water source at 13.5 MGD. The additional supply that was assumed to come from this source (9.5 MGD) has been included as a second line item and is assumed to be met from wells.

Table E.2 – Total Capital Costs – Final Build-out Solution

Cost Item	Cost
"Surface Water Supply"	
13.5 MGD, membrane treatment, no hydro[1]	$57,750,000
Additional supply to meet 23 MGD (9.5 MGD)[2]	$12,825,000
New Groundwater Wells (35.7 MGD)	$45,490,000
New Storage (14.5 MG)	$24,130,000
New Pipe Improvements for Growth	$43,625,000
Pipe Improvements for Fire Flow	$11,458,000
Pump Station Expansion	$1,744,000
New Valves	$600,000
TOTAL	**$197,622,000**

1) As per HDR Memo *Surface Water / Groundwater Cost Comparison, DRAFT*, September 2010. Costs for all other items are based on 2009 Unit Costs developed by MSA (October 2009). Estimated 2010 dollars for Surface Water Supply and 2009 dollars for remaining cost items are assumed equivalent and called 2009 dollars.

2) Assume met from additional wells at Outback, $1.35 million per MGD

The final step in this study was the phasing of improvements in the Final Build-out Solution over the next 10-years. Table E.3 summarizes the improvements that are recommended to meet increasing demands over the next 10 years. The improvements are broken down into pipe, well and storage improvements. No booster pump station upgrades are needed within the next 10 years. In addition to the improvements selected by the optimization, three emergency valves are recommended for implementation in the 10-year timeframe. Note that Table E.3 does not address improvements in the South Bend area as these were not evaluated as part of the optimization analysis (refer to Section 3.2.1 for more details). Table E.3 also does not include the cost of existing fire flow improvements, addressed below.

Figure E.1 shows a timeline of projected maximum day demand and recommended supply capacity increases for the next 10 years.

Table E.3 – Master Plan Improvements – Phasing for 10-year period
(Full details of these improvements can be found in Appendix G)

Year	MDD (MGD)	ADD (MGD)	Pipes	Cost	Tanks	Capacity	Cost	Wells	Capacity	Cost	Total Cost
Now	29	12.8	Juniper Ridge 16-inch connection on 18th *	$1,292,000							$1,292,000
2011	31	13.8	Tetherow improvements – B (Skyline Ranch 18-inch main) *, T (reconfiguration of the customers on the suction side of Tetherow PS). Open Zone 4J/4A boundary	$1,434,000							$1,434,000
2012	33	14.7	Extend larger diameter pipe out of Pilot Butte on Lafayette to 11th, piping associated with new Awbrey well	$241,000				Awbrey	1.5 MGD	$1,944,000	$2,185,000
2013	35	15.6	New parallel pipe near College PS in Level 3, new Level 5 pipe connection on Roanoke; site and discharge piping for new Level 5 Well east of Pilot Butte	$1,169,000				New Level 5 A (In vicinity of Shirley Ct)	2 MGD	$2,721,600	$3,890,600
2014	37	16.4	Parallel piping from Rock Bluff to Brookswood	$1,535,000							$1,535,000
2015	39	17.3	Continue parallel piping from Rock Bluff to Brosterhous; open Zone 4B/4I boundary at Reed Market	$2,940,000				Shilo	2 MGD	$2,721,600	$5,661,600
2016	41	18.2	Parallel mains on Brosterhous and Reed Market, replace piping along Wilson in Zone 4B	$1,742,000				New Level 6 (Butler Market/ Brinson Blvd)	1 MGD	$1,360,800	$3,102,800
2017	43	19.1	Extend larger diameter piping out of Pilot Butte on Lafayette from 11th to 8th	$402,000				New Level 5 A	2 MGD	$2,721,600	$3,123,600
2018	45	20.0	Parallel piping in Level 6 – Boyd Acres and Brinson Blvd; piping for Level 6 Well at Butler Market Well; New Pilot Butte tank connection	$1,364,000	Pilot Butte 4	3 MG	$5,807,000	New Level 6	2 MGD	$2,721,600	$9,892,600
2019	47	20.9	Replace existing pipe along 8th from Lafayette to Seward	$1,000,000				New Level 5 A	1 MGD	$1,360,800	$2,360,800
2020	49	21.8	Parallel main on Glassow and new main on Summit in Level 2; Replacement of piping on Norton and Olney in Level 5	$1,366,000				New Level 6	2 MGD	$2,721,600	$4,087,600
TOTAL				$14,485,000			$5,807,000			$18,273,600	$38,565,600
								Including 3 new valves		$225,000	**$38,790,600**

Note: All costs are based on 2009 unit costs developed by MSA (October 2009)

* Although it is understood that these improvements (Skyline Ranch Rd – Tetherow and 18th - Juniper Ridge) will be covered by the developer(s), full costs are presented here.

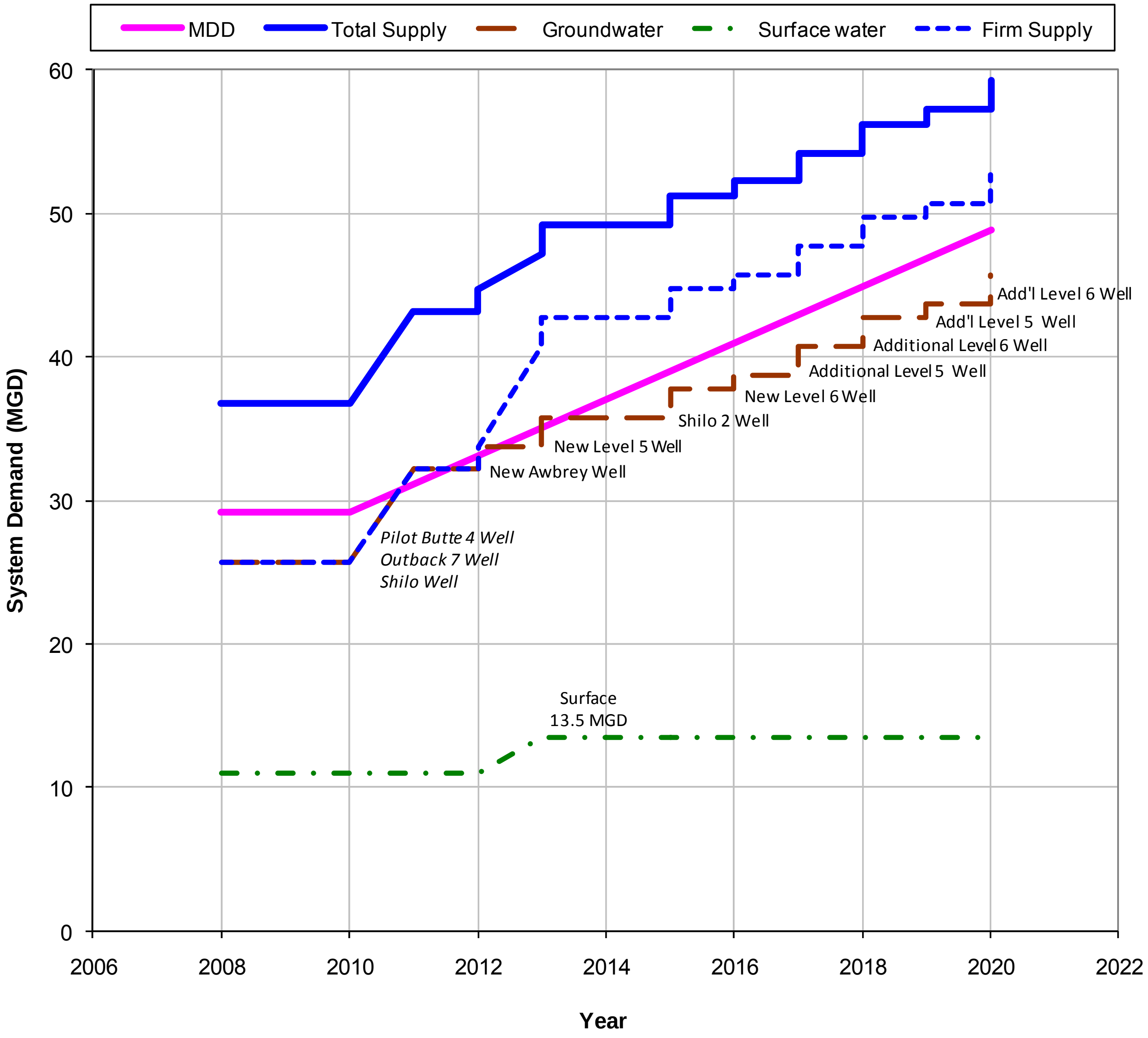

Figure E.1 – Projected MDD and supply capacity increases to year 2020

The fire flow improvements were treated separately. The cost of fire flow improvements to address existing deficiencies is $9.5 million (refer Appendix H). To assist in prioritizing the improvements, an ‘available’ fire flow analysis was performed to determine how much flow can be taken from the system at any point without drawing system pressures below 20 psi. The fire flow improvements were prioritized based on the following drivers:

- Only improvements addressing deficient hydrants in the existing system were included
- Initial sorting was based on the extent of flow deficiencies relative to zoned fire flow requirements. Further prioritization will be performed by the City of Bend.
- Information about the associated benefit, such as the number of customer parcels impacted by the improvement has been included in the analysis

Conclusions and Recommendations

It is recommended that the City adopt the recommendations in this study for the CIP and develop a financing plan for their implementation. The City should be aware that the improvements have been developed using a number of key assumptions. Changes to these assumptions may significantly affect the recommendations. In particular, the following assumptions influenced the recommended plan:

- **The rate and location of development and demand growth** – it was assumed that early growth would be located in the southeast, tied to the completion of the Southeast Interceptor
- **Surface water source capacity and timing of delivery system improvements** – as discussed in the report, there were changes to the surface water supply assumptions during this study. At this time it is uncertain what the capacity of the surface water supply will be in the future. The 10-year plan assumes a capacity of 13.5 MGD while the Final Build-out Solution was based on an ultimate capacity of 23 MGD. Any additional supply that is not realized will need to be made up by new wells. The location of these new wells may impact the associated transmission improvements. The costs presented here assume all additional groundwater would be located at Outback; no additional transmission costs are included for these wells.
- **Location of groundwater wells; issues of contamination and 2-year time of travel** – the issue of groundwater contamination was discussed at project meetings during this study but it was decided that new well locations should not be discounted based on this potential future restriction. If the restriction does come into force it will likely affect both existing and proposed new well locations and will have a significant impact on the system that extends beyond the issues of growth and supply addressed in this study.

Regardless of whether there are significant changes to the above assumptions, the City should review and update this plan within the next five to seven years.

The benefits of this study have been far reaching. At the outset, the City acknowledged that previous planning efforts had relied on data of variable quality. In addition, there had been little input from City Operations staff into the planning process. This study allowed the City to capitalize on its accomplishments in improved system data quality to develop a capital infrastructure plan that the City can be confident in. Also, Operations staff were involved throughout the study and provided valuable input and feedback. In addition to developing a set of improvements that meet future demands at least cost, the study provided insight into how to best operate the existing system to minimize energy costs and identified where the system is most vulnerable to pipe break events. The optimized decision support process allowed the City to investigate a wide range of options and test alternative scenarios related to well and storage locations, zone boundary modifications, how to address existing deficiencies and where it makes most sense to place new infrastructure based on the assumed timing and location of demand growth.

1 Introduction and Background

In March 2009, Optimatics and Murray, Smith & Associates, Inc. (MSA) were engaged by the City of Bend (the City) to undertake a comprehensive review and optimization of the City's Water Master Plan. MSA recently completed the Water System Master Plan (WSMP) Update in March 2007. The current study, referred to as the WSMP Update Optimization Study, involved reconstruction and calibration of the hydraulic model, assessment of pipe criticality, optimization of current operations for winter (representing non-irrigation season) and summer (representing irrigation season); and optimization of future infrastructure requirements.

1.1 System Background

The City of Bend is located east of the Cascade Mountains in Central Oregon. The climate is high desert with typically mild winters and warm dry summers. The City's population is approximately 81,000 and the City is responsible for delivery of potable supply to over 22,000 service connections, representing approximately 62,000 people served (2008 values, as per Bend Draft Water Management and Conservation Plan, 2011). Two other water providers serve potable water to customers in areas adjacent to the City's system – Roats Water System and Avion Water Company (see Figure 1.1).

The City is fortunate to be located near to water sources with excellent quality – groundwater from the substantial Deschutes Aquifer and surface water collected from the Cascade Mountains. Very little treatment of these supplies is required before delivery to customers.

Surface water supply is collected from an intake at Bridge Creek, 13 miles from the City limits. Bridge Creek flows are supplemented via an existing diversion of a natural spring that flows into the middle fork of Tumalo Creek. Transmission mains deliver this raw water supply from the intake at Bridge Creek to the Outback site where disinfection is carried out prior to distribution.

Bend currently operates 9 groundwater facilities throughout its service area, consisting of 25 wells which pump Deschutes Aquifer water to the system. Emergency interties also exist with the neighboring Avion and Roats water systems. The distribution system consists of approximately 420 miles of water main, 15 storage reservoirs and 6 booster pump stations. A large number of pressure reducing valves (PRVs) exist to limit maximum pressures in the system.

Elevations generally decrease from the foothills in the west towards the east and northeast. The Deschutes River crosses the city centrally from south to north. There are several prominent buttes in the service area. The distribution system is divided into a number of pressure levels based on elevation and the aim of maintaining service pressures between 40 pounds per square inch (psi) to 80 psi.

The highest level, Level 1, is located on Awbrey Butte. Supply from the Outback Reservoirs enters the system at Level 3 and is delivered to the Overturf Reservoirs and Awbrey Reservoir. Booster pumps lift to Levels 1 and 2. Levels 3, 4 and 5 are supplied via a combination of gravity surface water supply and groundwater pumping and Levels 6 and 7 are supplied from higher levels via PRVs. Level 4 is split into an east and a west section along the Deschutes River. There are a number of other small pressure zones near Awbrey Butte and Overturf, and along the eastern edge of the system.

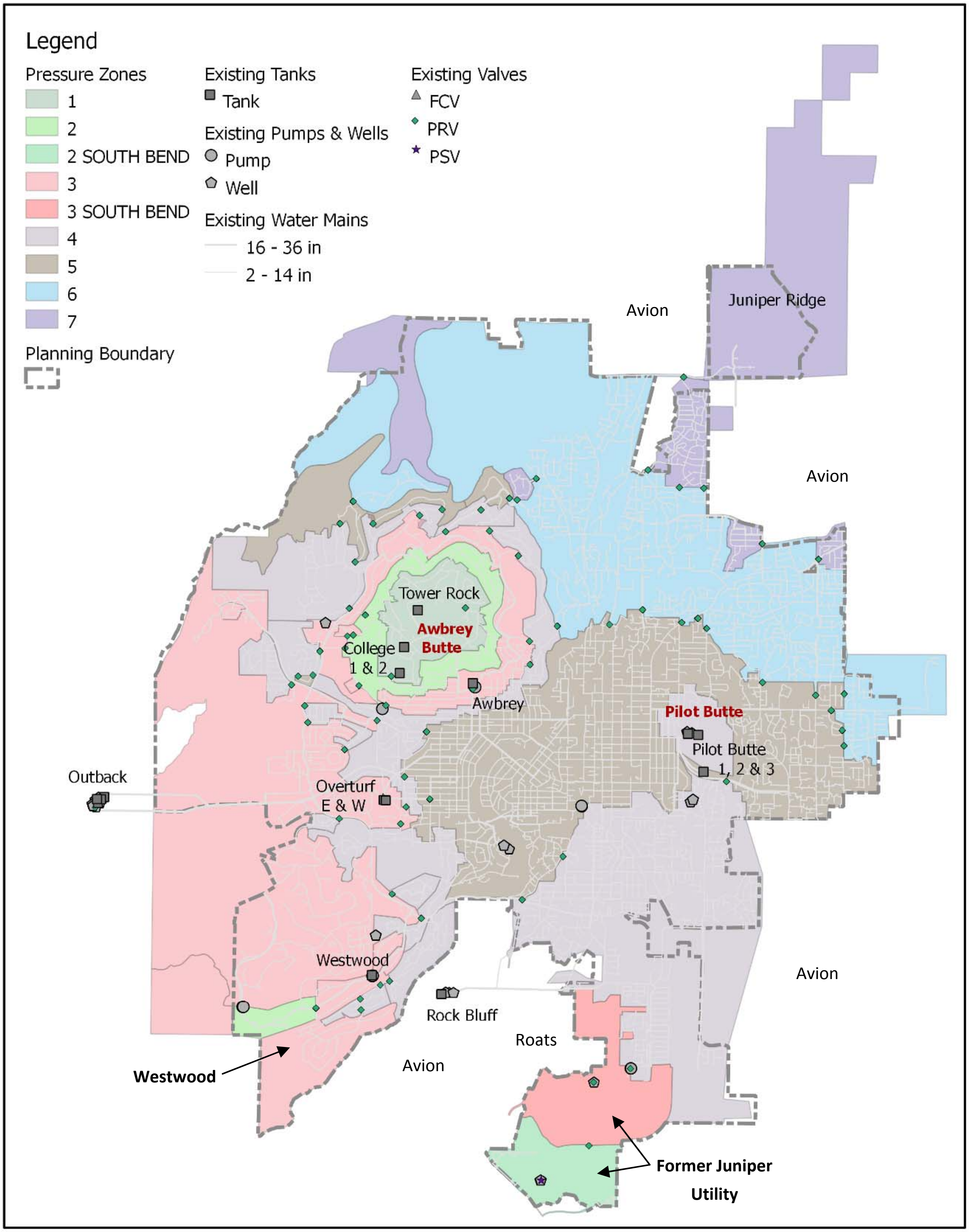

Figure 1.1 – Bend service area showing pressure levels and major supply and storage facilities

Over the last several years Bend has acquired two services areas: the Westwood Service area in the southwest corner of the system and the former Juniper Utility service area located in the southeast corner. The Juniper system, now typically referred to as South Bend, consists of two pressure levels which have similar hydraulic grades to Levels 2 and 3 in the main system. These southern areas are known as Zones 2B and 3D. Two groundwater facilities are located in this area – Hole Ten and Shilo. The new Murphy Pump Station facility connects South Bend to the main system.

The Westwood system (Zone 3C) is supplied from a groundwater well, ground storage and booster pump facility. The storage and booster pump facilities were intended to be temporary; this study has evaluated options for reconfiguring the operation of this zone. A recently commissioned booster station called Tetherow, designed to supply new development in the Tetherow area (Zone 2A), has the ability to supply Westwood if needed via a PRV station at the western end of Westwood.

Compared to many other systems supplying an equivalent number of customers, operation of the Bend Water System is complex, due primarily to the multiple sources of supply, large number of pressure zones and the associated PRVs.

1.2 Optimized Decision Support

For this Water Master Plan Update Optimization Study, the City has employed an optimized decision support process to assist in the development of low-cost, transparent infrastructure recommendations based on the best available data and supported by sound engineering analysis and judgement. The previous Master Plan Update completed in 2007 was a step forward for the City in that it improved on previous efforts; however, the City acknowledged that certain data were lacking and a number of inputs from the City were not coordinated with operations. The City recognized a need for improved data and analysis to provide water system operations recommendations and to ultimately develop a 10 year Capital Improvement Program (CIP) based on sound engineering analysis and planning.

At the time the previous master plan was completed the City was anticipating rapid growth. In the wake of the global financial crisis development effectively stopped, reducing System Development Charge (SDC) funds which support infrastructure development. The City required a better decision-making tool that would allow sound decisions to be made based on engineering analyses and provide confidence to decision makers by answering the myriad of ‘what-if’ scenario questions. To achieve this end, the City needed to gain a greater understanding of the existing system and how the system performance changes under dynamic conditions.

An optimized decision support process involves all of the traditional master plan steps including data collection, development of unit costs, hydraulic model update and calibration, and model analysis to evaluate different alternative solutions that will allow the system to meet demands in the future. Using optimization to assist the planning process allows for many more alternatives to be evaluated compared to trial-and-error modeling. This provides a number of benefits including a higher level of transparency in the recommended improvements, a better understanding of the impacts of different decisions or events and greater confidence that the plan represents the lowest cost option considering both capital and life-time operating costs.

For this project the optimization technique employed was an evolutionary algorithm based on the theory of natural selection and the survival of the fittest. The genetic algorithm (GA) is able to sort through millions of combinations of improvements, taking into account both cost and hydraulic performance to produce low-cost, hydraulically viable solutions meeting any number of design constraints. Once the optimization has been formulated for a particular problem it is possible to run a myriad of scenarios testing different ‘what-if’ scenarios, providing decision makers with confidence in the selected solutions.

The decision support process for this optimization study included numerous points of contact with City staff via meetings and workshops as well as regular teleconference calls. Optimatics solicited staff feedback on the trends of various potential solutions as well as preferences for certain aspects of the solutions. The Project Team of Optimatics and MSA also brought their many years of experience and expertise to bear on each aspect of the study, drawing from strategies and problem-solving approaches which have been successful in their work on other water systems.

1.3 Purpose and Scope

The City’s aim with the WSMP Update Optimization Study was to improve upon the 2007 WSMP Update through a model update, pipe criticality analysis, operations optimization and future capital improvements optimization. The intended outcomes of this work included more efficient system operations, improved levels of service and an optimized master plan based on best available data that minimizes capital and associated operating costs of future infrastructure improvements designed to meet future build-out demands. The capital improvement projects to be implemented in the first 10 years of the plan were to be prioritized to meet the City’s near-term needs and be compatible with available funding.

This comprehensive study involved the following work steps

Task 6 – Calibrate City of Bend Dynamic Water Model
Task 7 – Consequence of Failure Analysis
Task 8 – Development of the Optimization Model
Task 9 – Optimization Study
Task 10 – Staged Implementation Plan

Task 1 – Calibrate City of Bend Dynamic Water Model

The model update and calibration process was undertaken by Murray, Smith & Associates, Inc. (MSA). MSA’s report titled *Water Model Development Documentation for Water System Optimization* (January 2011, **Appendix A**) includes details of the model development from the City’s GIS database and the calibration effort including spatial distribution of existing demands, steady-state and extended period simulation (EPS) analyses. The model update process ensured a one-to-one relationship with the GIS database, bringing value to the City not only for the tasks of this project but for all future uses of the model. Calibration of the Summer EPS Model was completed in September 2009. The calibration of the Winter EPS model was revised in January 2010 after new data was collected in December 2009.

As part of an amendment to the project, MSA also developed revised demand projections for build-out and year 2020. The new demand projections were necessary given the changes to the hydraulic model since the 2007 Master Plan Update was completed. Details of the demand projection are included in the MSA report. A summary of information in MSA’s report that is pertinent to this study is provided in Sections 2.1 and 2.2. The full report is provided in **Appendix A**.

Task 2 – Consequence of Failure Analysis

The Consequence of Failure Analysis (Task 2) was performed during 2009 using an early version of the updated model developed by MSA. This model was a calibrated steady-state model. The consequence of failure analysis involved evaluation of the impact of pipe break events and isolation of breaks system-wide, with the aim of assisting the City to identify the areas of the system which are the most vulnerable.

In order to complete this analysis the model needed to include all the system shut-off valves; these are not usually included in a hydraulic model. The effort to ensure the model had a 1-1 relationship to the City's GIS data made the process of importing the shut-off valves straightforward.

The results of the consequence of failure analysis included the identification of vulnerable areas of the system and prioritization of each area based on factors such as impact to critical customers, number of customers affected and the extent of the hydraulic consequences such as resulting low pressures in the event of break or isolation. The results of these analyses were presented in a project update meeting on December 9, 2009. The final memorandum (March 2010) describing the outcomes of the analysis is provided in **Appendix B**.

Task 3 – Development of the Optimization Model

Task 3 included the development of the Design Data Summary (DDS) Report and agreement on the data, constraints and options to be considered in the optimization analysis. A number of revisions were made to this document as the study progressed and new information came to light. The final version of the DDS Report (March 2010) is provided in **Appendix C**; however, critical information is also included in the body of this report.

Task 4 – Optimization Study

The Optimization Study consisted of two parts – the first was an analysis of current system operations for winter (non-irrigation season from October 15 – April 15) and summer (irrigation season from April 15 to October 15). The second analysis was the development of an optimized master plan meeting build-out demand conditions. The master plan optimization analysis built upon the formulation and results of the operations optimization analysis.

Due to the extreme differences in demand between the two seasons, the initial Operations Optimization considered both summer and winter operating conditions. The aim of the Operations Optimization was to determine operational settings for wells, pumps, and valves that would minimize overall energy costs while maintaining current levels of service. A secondary aim was to improve water quality in storage reservoirs through increased turnover, particularly in the winter. The results of these analyses were initially presented and discussed with the City on December 9, 2009. A final set of optimization runs incorporating feedback from the City was completed and the results presented at a project workshop on March 17, 2010. The final memorandum outlining the outcomes of the Operations Optimization for summer and winter operations (September 2010) is provided in **Appendix D**.

This Final Report describes the formulation and summarizes the results and key trends of the second analysis, the final Build-out Optimization runs. The aim of the Build-out Optimization was to determine optimal capital improvement solutions, together with operational recommendations, which will enable the water system to effectively meet the projected demand, storage, and supply requirements at build-out. Within this aim, the optimized solutions were designed to maximize use of available surface water supply, adhere to

Bend's water rights for surface water and for groundwater, provide sufficient storage in the system to meet future operational needs, and required storage for standby, emergency and fire flow needs.

As an addendum to the original scope of work, a comprehensive fire flow deficiencies analysis was completed for both existing and build-out demand conditions. This analysis led to the development of a prioritized list of main replacement recommendations in addition to the master plan improvements.

Task 5 – Staged Implementation Plan

A key outcome for the City was a staged implementation plan for the next 10 years. Optimatics has evaluated both the recommended fire flow improvements and the Build-out Master Plan improvements to develop a sequence of implementation that will ensure the system continues to provide adequate level of service and reliability in the near-term. The 10-year Capital Improvement Plan (CIP) is outlined in Section 3.

A number of recent studies undertaken by the City have informed this Optimization study and are included in **Appendix F** of this report, specifically:

MSA, *City of Bend Water System – Tetherow Development: Alternatives Analysis*, January 2011

MSA, *Former Juniper Utility – Proposed Water System Improvements*, January 2011

MSA, *Updated Capital Improvement Project (CIP) Cost Estimates*, June 2010

MSA, *Water System Planning for the Juniper Ridge Development, Bend, Oregon*, September 2009 (included in **Appendix A**)

1.4 Acknowledgements

Optimatics would like to thank City staff for their input and guidance throughout this master planning study. In particular we would like to thank:

Tom Hickmann, P.E.; City Engineer, Assistant Public Works Director

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Spencer Sanvitale; CAD/GIS Supervisor

Ken Vaughan; Modeling staff

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2 Analysis of Requirements to Meet Build-out Demands

This section outlines the data, constraints, analysis and results of the Build-out Optimization runs. The analysis of the system under build-out demand conditions started in January 2010. Preliminary solutions were presented to the City at a project update meeting in March, and interim results were presented in a conference call in June. During these months there was significant communication among the City, Optimatics, and MSA, with major decisions ultimately made in collaboration with the City about the storage constraints, design peaking factor, and diurnal demand curves. Adjustments and refinements were made to the optimization formulation in accordance with the decisions, and a final set of runs were completed in August, 2010.

2.1 Hydraulic Model

The hydraulic model used in the development of the Build-out Master Plan is based on the calibrated summer extended period simulation (EPS) model developed by MSA, dated September 25, 2009. Full details of the model development and calibration are provided in MSA's report *Water Model Development Documentation for Water System Optimization* (January 2011 – **Appendix A**).

For the existing model, demands were distributed throughout the network based on the location of customer meters. Water meter address data was mapped and associated with the nearest model node serving the customers within each zone. Three demand distributions were ultimately developed; winter, summer and average day. Both the summer and winter demand distributions were analyzed in the Operations Optimization (refer **Appendix D**). This was necessary as demands vary widely over the year and consequently different operating strategies are required. The winter and summer distributions are based on customer billing records from representative months, while the average day distribution is an overall yearly average. In order to create a model for the master planning effort it was necessary to develop a set of demands and appropriate diurnal patterns representing maximum day and peak hour demands. This is discussed in the following section.

The model was developed with a one-to-one relationship to the GIS ensuring consistent identifiers for elements in both databases. To the extent possible this relationship has been maintained in the development of the build-out solutions. For example, if a new pipe splits an existing pipe, the existing pipe ID has been recorded in both sections of the split pipe to ensure it can be cross referenced to the GIS data.

As part of the calibration process MSA took care to ensure all PRV settings at zone boundaries were correctly recorded. The hydraulic model includes relevant operating rules for pumps and valves controlled via SCADA. For the future scenario new controls were added to well and booster pump facilities which the City anticipates will be controlled by SCADA in the future. The exact settings for these controls were evaluated in the optimization.

In order to use the model with Optimatics' optimization program, Optimizer, it was necessary to export the InfoWater model to EPANET format. This was completed using an export facility in InfoWater. The conversion was verified by comparing the hydraulic results from InfoWater and EPANET to ensure an accurate match.

2.2 Demand Forecast – Build-out and 10-year Scenarios

The MSA Water Model Development Documentation outlines development of projected water demands for both the build-out and 10-year (year 2020) demand scenarios.

The future demand forecast and spatial distribution of demands was revised a number of times since the first pass was presented by MSA in November 2009. Water demand projections were developed with consideration for both historical rates of water demand growth and the availability of developable and re-developable land within the existing UGB. Refinements were made to the assumed per capital consumption for residential customers, the per-acre usage rates for non-residential areas, and the spatial distribution of development growth in the early years of development.

The following data are relevant to the demand projections:

Residential demand: 172 gallons per capita day (includes a 10% factor for non-revenue water – the difference between revenue water and system production i.e. water for operational uses, meter inaccuracies, leakage etc.)

Non-residential demand: Assumed 64% of total demand associated with residential demand, 34% non-residential (as per 2008 billing record data). Total amount of non-residential demand calculated from the projected residential demand (Non-residential demand = 0.36/0.64 x Residential demand) and converted into a number of gallons per acre per day (gpapd) based on the projected area of developed non-residential parcels. This equates to 4,000 gpapd at build-out.

Tetherow: Build-out equates to 889 residential units

Juniper Ridge: Water use projections for the Juniper Ridge Development were consistent with those used in the MSA study *Water System Planning for the Juniper Ridge Development, Bend, Oregon* (September 2009) and equate to 4,500 gpapd.

The build-out demand values were developed based on medium residential development density within the proposed planning boundary. The planning boundary was developed in discussions between MSA and City planning and GIS staff. The extents of the existing UGB and the build-out planning boundary are presented in the MSA *Water Model Development Documentation* January 2011 (**Appendix A**), Figure 1.25. Figure 2.1 below presents the existing UGB (red), proposed UGB (blue) and the planning boundary (black) used in the development of the build-out demands. The areas where the planning boundary extends beyond the existing UGB are west and north of Awbrey Butte, and Tetherow. Areas of the existing UGB served by Avion and Roats Water Systems are not included in the City's planning boundary. The expected year at which build-out will be reached was discussed at a number of project meetings. Initially it was proposed that build-out be assumed to occur by the year 2030. However in discussions with City staff it was agreed that, based on the amount of demand in the build-out projection, it is unlikely that this will be realized in 20 years. It was agreed that a fixed year would not be assigned to the build-out projection but that build-out would be defined as the time when system demand reaches the demand associated with medium residential development within the proposed planning boundary.

The 10-year demand projection represents an approximately linear interpolation between current demand and projected build-out demand. The distribution of the 10-year demand was applied assuming that half of the growth in water demand to reach build-out demand at medium density within the current system facilities area (i.e. the existing UGB) will be realized.

The future demands were developed on a parcel basis, necessitating a method to populate the model with the demand information. Within the existing service area, the center point of each parcel was used to join parcel demand to the nearest model node serving the relevant pressure zone. As a result, the distribution of future demand differs slightly from the existing demand distribution, where demand was calculated at customer meters and then connected to the nearest model node.

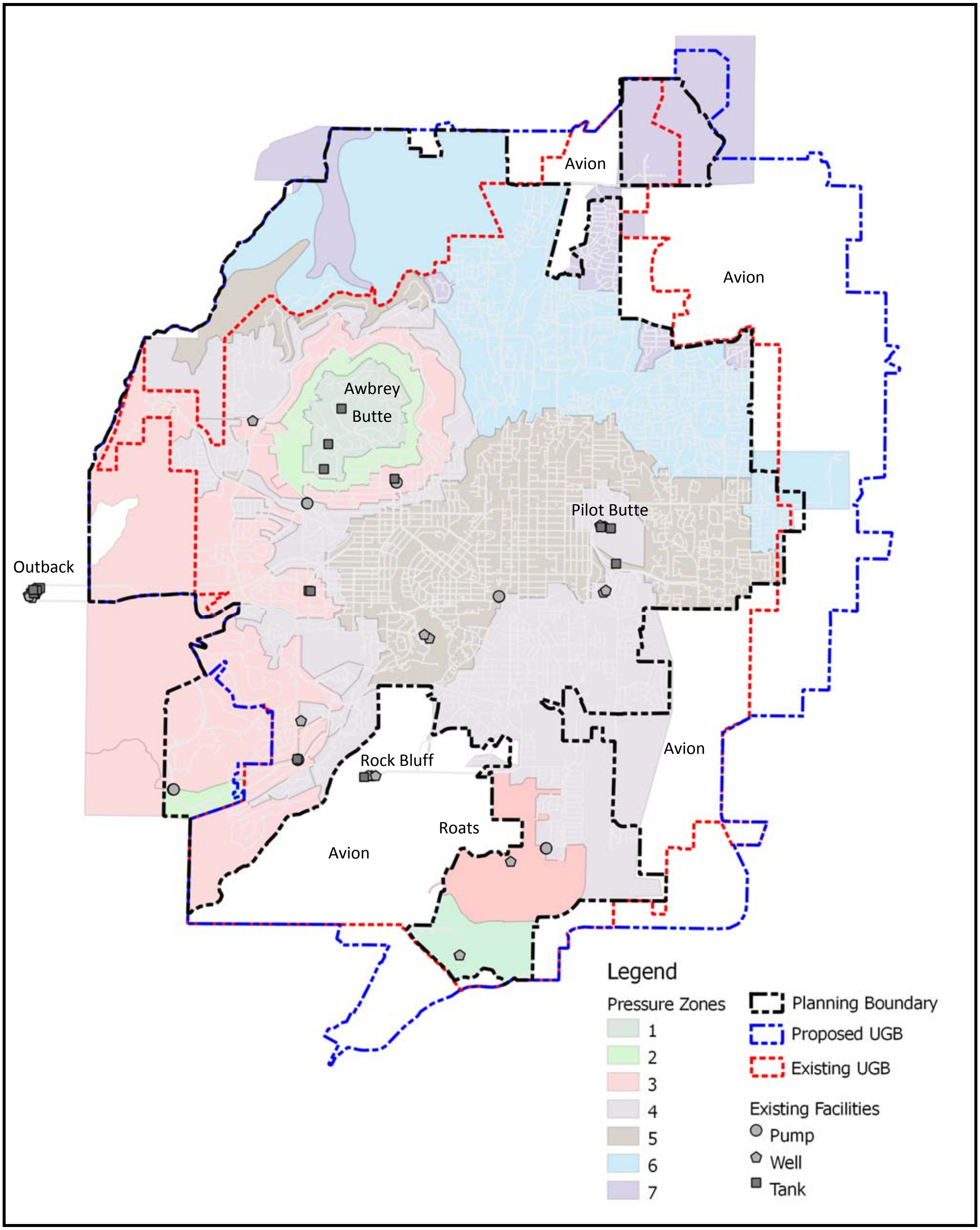


Figure 2.1 – Existing and Proposed UGBs and the Planning Boundary used in this study

The Tetherow and Juniper Ridge developments were treated separately. It was assumed that half of the growth associated with full development of Tetherow would be realized in the 10-year planning horizon. For the Juniper Ridge area it was assumed that Phase 1 (293 acres) would be realized in the 10-year timeframe and Phase 2 (an additional 222 acres) by build-out.

The resulting demand growth is concentrated in the east for the near-term 10 year analysis; 70% of the new demand is associated with Zone 4B, Level 5 and Level 6. The City anticipates near-term growth will occur along the Southeast Interceptor corridor. Development of the area north and west of Awbrey Butte (within the proposed UGB but outside the existing facilities boundary) will require significant new infrastructure, both for potable supply and wastewater collection. This is not seen as likely in the near term and is expected to be driven by developers.

The State of Oregon Department of Land Conservation and Development (DLCD) has advised Bend that their existing Master Plans for both the water and sewer networks must be amended to only cover development within the existing UGB. As described above, this study provided an opportunity for the City to revise their demand projections. The 10-year demand case only addresses development within the existing UGB (with a few noted exceptions: Tetherow and Buckingham Elementary School included, areas served by Avion and Roats not included). The build-out case – projected to occur beyond the 20-year master planning period, does consider development outside the existing UGB, however the differentiation between the 10-year and build-out improvements provides an indication of which improvements are solely related to development outside the UGB.

Design demand factors

Historical production records were reviewed to determine the typical ratio of maximum day demand (MDD) to average day demand (ADD) as well as the ratio of peak hour demand (PHD) to maximum day demand. At the commencement of the study, interrogation of the City's production records for the years 2006 to 2008 revealed a MDD:ADD demand ratio of 2.25. In the 2007 plan, a textbook value of 1.5 was used as the PHD:MDD peaking factor. For this study, records for 2008 and 2009 were reviewed to determine an appropriate PHD:MDD ratio (earlier City water demand data did not have the required resolution for this analysis). It was agreed with Bend staff that a peaking factor of 1.8 should be used with the projected demand scenarios for this study (slightly higher/more conservative than the observed PHD:MDD ratio in 2008 of 1.7). As this value is based on only two years of records it should be reviewed and revised as more data become available.

Table 2.1 shows the system-wide demand values for average day (ADD), maximum day (MDD) and peak hour demands (PHD) for the existing, 10-year and build-out scenarios. Figure 2.2 presents this information in graphical form. The demand values for build-out are higher than those considered in the 2007 Master Plan, shown in the last line of Table 2.1. Reasons for the increase in build-out demand include differences in the underlying assumptions of development density and the area served. In addition, the 2007 Master Plan used a textbook value for the PHD:MDD ratio. As mentioned above, recent City demand data showed the ratio to be much higher.

Table 2.1 – Projected future water demand summary

Year	Water Demand (MGD)		
	Average Day Demand (ADD)	Maximum Day Demand (MDD)	Peak Hour Demand (PHD)
2008 (1)	12.8	29.2	48.0
10-year projection (2)	21.7	48.8 (4)	87.9 (5)
Build-out Development (3)	37.1	83.5 (4)	150.3 (5)
Build-out Development in 2007 Master Plan	30.7	71.5	107.3 (5)

Notes to Table E.1:

(1) Existing ADD, MDD & PHD based on 2008 water production records.

(2) 10-year ADD developed assuming half of the growth to meet build-out demand at medium density development would be realized within the existing UGB, plus half of growth to meet Tetherow build-out demand and Juniper Ridge at 294 acres.

(3) Build-out ADD assumes medium density development across the proposed UGB, plus Tetherow at 889 residential units and Juniper Ridge at 515 acres. 2007 planning area was the existing UGB plus Tetherow and Juniper Ridge.

(4) MDD equals ADD x 2.25 (based on historical data, see Table 3.2 from the DDS report).

(5) PHD based on comparison of recorded peak hour and maximum day production values from 2008 and 2009. PHD:MDD factor agreed at 1.8. 2007 Master Plan value assumed textbook value of 1.5 x MDD

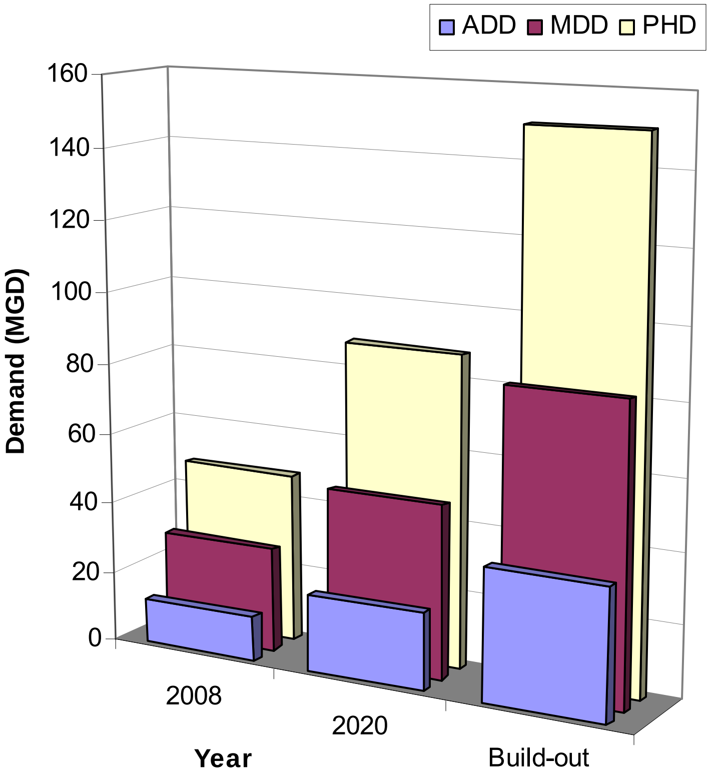


Figure 2.2 – Projected future water demand by year

Design demand curves

For the optimization analyses, diurnal curves were developed that allow simulation of MDD and PHD within a 24-hour evaluation to ensure appropriate sizing of facilities. Two idealized diurnal curves have been developed for use in existing and future simulations when identifying deficiencies and improvements. These curves reflect the shape of the curves identified during July 2009 (summer calibration) but result in a system-wide MDD to PHD factor of 1.8. A separate diurnal curve has been maintained for Zones 1 and 2 because the customer base is primarily residential and therefore usage is expected to vary more dramatically over a 24-hour MDD period due to summer irrigation demands. The recommended design diurnal curves are shown in Figure 2.3.

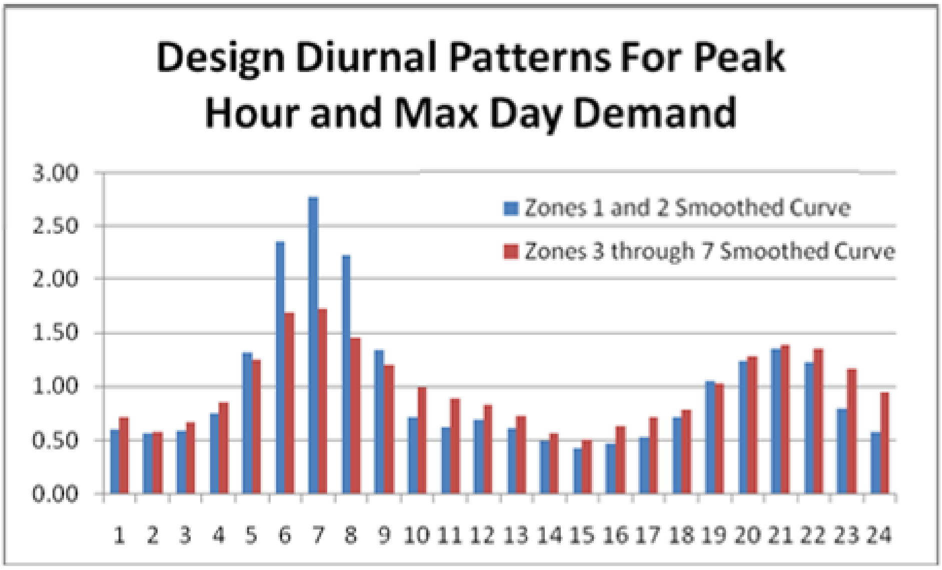


Figure 2.3 – Proposed design diurnal curves to simulate maximum day and peak hour demand (from MSA Report, August 2010)

2.3 Supply Assumptions

2.3.1 Current Sources and Water Rights

The City of Bend uses two sources of supply to meet customer demands – surface water collected in the Cascade Mountains and groundwater drawn from the Deschutes Aquifer.

Existing surface water rights total 23.3 MGD during the irrigation season (April 15 to October 15). However, during this time period one of Bend's surface water permits (S-49823) is very junior in priority date and not a reliable irrigation season source. Moreover, the remaining irrigation season surface water rights have annual volume limitations and are subject to curtailment by the Deschutes Basin Watermaster based on streamflow in Tumalo Creek and demand for water by Tumalo Irrigation District. With these variables (priority date, water right priority date, streamflow, and demand by downstream water users) the amount of water available during irrigation season could range from 23.3 MGD down to 7.2 MGD. During the non-irrigation season the City's surface water rights total 13.6 MGD.

Table 3.5 of the DDS Report (**Appendix C**) summarizes the existing surface water rights and Table 3.6 of the DDS Report summarizes the existing water rights for groundwater sources. The City's groundwater rights total 44.1 MGD. Table 2.2 below lists the existing groundwater facilities and capacities.

With the current surface water system infrastructure, the City is able to divert and deliver approximately 11.8 MGD into its distribution system. Based on historical data (2006 to 2008), during summer operation the Outback surface water facility typically runs at about 8-9 MGD and wells contribute 15 MGD to 20 MGD.

2.3.2 Future Source Options

Bend currently has rights to 21 cfs/13.6 MGD during the winter, but competing senior water rights and available streamflow may reduce availability during the irrigation season. Based on discussions at the April 2010 project update meeting, the Build-out Optimization was formulated under the assumption that 36 cfs/23 MGD will be available from the surface water source. One advantage of this approach to the Master Plan is that it ensures transmission piping is not undersized. This scenario was analyzed so as not to preclude future generations from the opportunity of developing more completely the City's existing water rights. The cost of this scenario is unknown at this time but could be compared to the cost of having groundwater meet the additional future demand needs, which would include securing and mitigating groundwater rights together with the capital and operations/maintenance costs of new wells in the system.

Since the Build-out Solution was finalized there have been changes to the City's understanding regarding the potential future capacity of the surface water source. It is now anticipated that the maximum flow rate that could be expected is 27 cfs/18 MGD, but is more likely to be 21 cfs/13.5 MGD. This information was incorporated into the analysis of the 10-year demand case to see how it impacts the needed size of piping to support transmission of supply from Outback. Once future plans for the surface water supply are more concrete, the recommendations for piping improvements from the Outback site should be re-evaluated to ensure they are appropriate.

As the system grows the City should ensure that a firm supply capacity equal to the anticipated maximum day demand is maintained. Firm capacity is calculated by summing the capacity of all continuously available sources, excluding the largest source. Based on the projected future water demand (Table 2.1) the supply system will need to be expanded to produce an average day demand of approximately 37.1 MGD and a maximum day demand of approximately 83.5 MGD under build-out conditions.

Existing (expected as of April 2011) supply capacity is 32.2 MGD from wells (excluding Rock Bluff 2) and 11.6 MGD from the surface water source. The surface water source is not a continuously available source as it can be rendered unavailable if an event such as a fire in the watershed causes the water to be excessively turbid. Current plans to upgrade the treatment facilities at Outback to include membrane treatment will increase the reliability of the surface source, potentially allowing at least a portion of the surface water capacity to be relied upon to meet firm supply capacity needs. In determining the necessary future supply capacity it has been assumed that, in the future, the surface water facility will be able to reliably provide 7.2 MGD (based on historical summer flow rates).

Further analysis of reliable well supply in the Bend system is provided in **Appendix E**.

Table 2.2 – Summary of Groundwater Well Capacity (expected April 2011)

Groundwater Production Facility	**Zone Supplied**	**Rated Capacity (MGD)**
COPPERSTONE_W	3	1.4
OUTBACK_W1	3	1
OUTBACK_W2	3	1.1
OUTBACK_W3	3	1.7
OUTBACK_W4	3	1.7
OUTBACK_W5	3	1.8
OUTBACK_W6	3	1.8
OUTBACK_W7	3	1.8
OUTBACK_W8	3	*Future*
WESTWOOD_W	4A	1
BEAR_CREEK_W1	4B	1.5
BEAR_CREEK_W2	4B	1.6
ROCK_BLUFF_W1	4B	1.2
ROCK_BLUFF_W2	4B	1.1
ROCK_BLUFF_W3	4B	1.2
PILOT_BUTTE_W1	5	1.2
PILOT_BUTTE_W2	*5*	*Decommissioned*
PILOT_BUTTE_W3	5	1.3
PILOT_BUTTE_W4	5 (4B emerg)	1.6
RIVER_W1	5	2.7
RIVER_W2	5	3
SHILOH_W1	3D	*Decommissioned*
SHILOH_W2	3D	*Decommissioned*
SHILOH_W3	3D/4B	2
HOLE_10_W1	2B	0.8
HOLE_10_W2	2B	0.8
Total Groundwater Capacity		33.3
Total In-service Capacity, 2010 (without Rock Bluff 2)		**32.2**

2.4 Fire Flow Requirements

Section 4.1.1 of the DDS describes the fire flow requirements for the Bend system. A residual pressure of 20 pounds per square inch (psi) must be maintained under fire flow conditions. Table 2.3 lists the fire flow requirements for the different land use types in the City, ranging from 1,500 gallons per minute (gpm) for residential structures up to 3,500 gpm for the Central Business District (CBD). MSA provided details of the land use categories that apply to each node in the hydraulic model, and these were used to determine the appropriate fire flow requirement. Figure 2.4 shows the model nodes color coded by fire flow rate.

Optimatics used the fire flow requirement data in a comprehensive fire flow analysis to determine where the system cannot meet the fire flow requirements under maximum day conditions. This analysis was performed under both existing and build-out demand conditions. Any fire flow that resulted in pressure below 20 psi was assessed and pipe replacements and/or new pipe connections were recommended to bring the system up to the 20 psi standard. Sections 2.8.14 and 4 contain more details about these recommended improvements.

Table 2.3 – Recommended fire flow rates

Land Use Code	Number of nodes	Definition	Fire Flow (gpm)
AOD	2	Airport Operations District	2,500
ARID	13	Aviation Related Industrial District	2,500
ASD	38	Aviation Support District	2,500
ASDRA	2	Aviation Support District Reserve Area	2,500
CB	41	Central Business District (CBD)	3,500
CC	57	Convenience Commercial District	2,500
CG	393	General Commercial District	2,500
CL	421	Commercial Limited	2,500
CN	3	Commercial Neighborhood	2,500
EFUTRB	13	Exclusive Farm Use Tumalo/Redmond/Bend	1,500
IG	130	General Industrial District	2,500
IL	678	Light Industrial District	2,500
IP	8	Industrial Park?	2,500
ME	67	Mixed Employment	2,500
MR	191	Mixed-use Riverfront (redevelopment of mill site properties)	2,500
PF	37	Public Facilities (Schools, Public Buildings, etc.)	2,500
PO	2	Professional Office	2,500
PO/RM/RS	4	Mixed Use Office/Residential	2,500
RH	206	High Density Residential	1,500
RL	40	Low Density Residential	1,500
RM	785	Medium Density Residential	1,500
RR10	48	Medium-10 Density Residential (RM-10)	1,500
RS	3,029	Standard Density Residential	1,500
SM	4	Surface Mining District	2,500
SR2-1/2	31	Suburban Low Density Residential (SR 2 ½)	1,500
UAR10	121	Area Reserve District	1,500
Total	**6,364**		

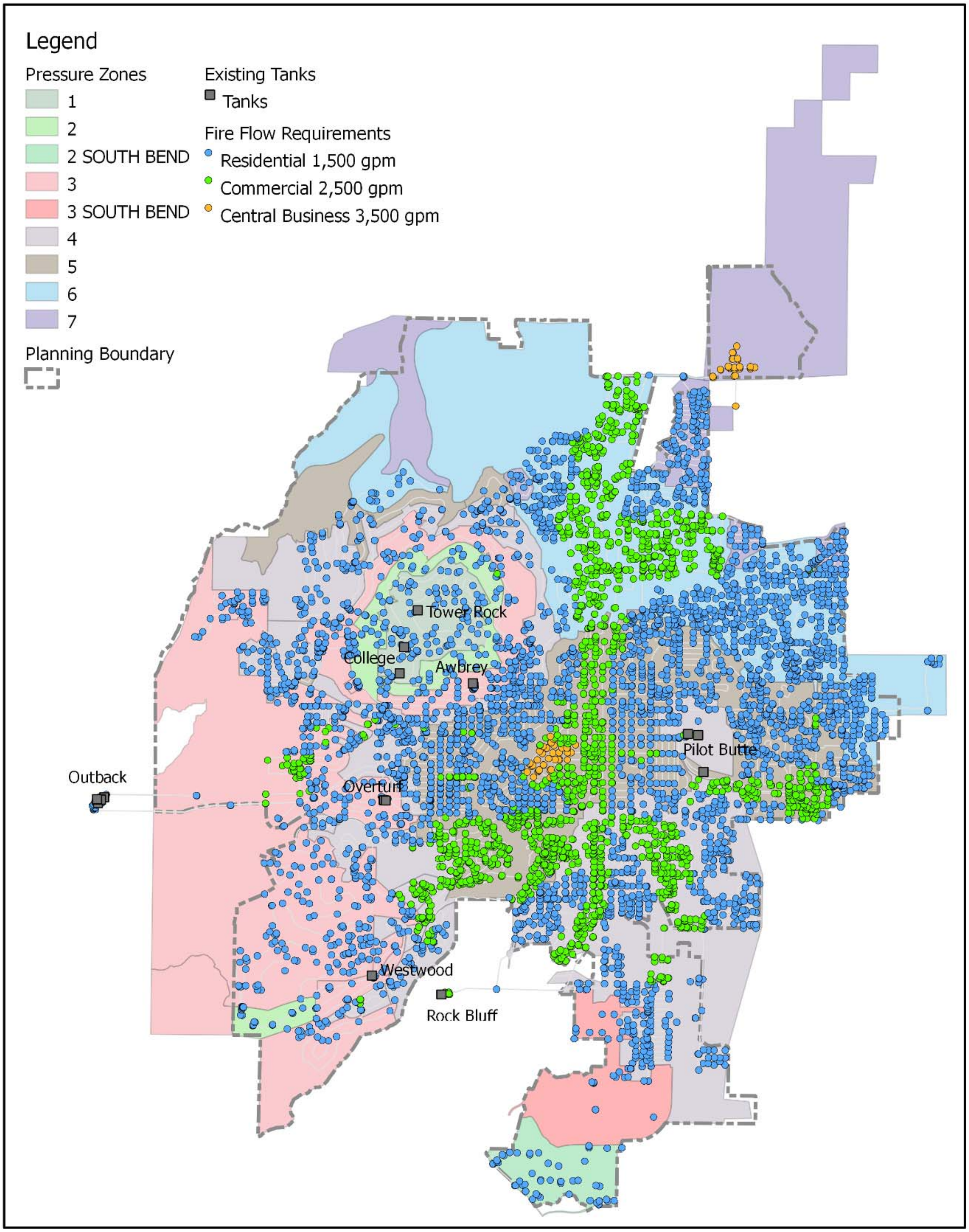


Figure 2.4 – Fire flow rates associated with each model node

2.5 Design Constraints

2.5.1 Pressure

All nodes in the model with customer demands are subject to the pressure criteria described in the DDS report. The minimum allowable pressure criterion is 40 psi. There are a number of locations where this minimum pressure is not met in the existing system under current peak hour conditions. Those locations that experience pressure below 40 psi under existing peak hour demand conditions are shown on Figure 2.5 and listed in Table 2.4.

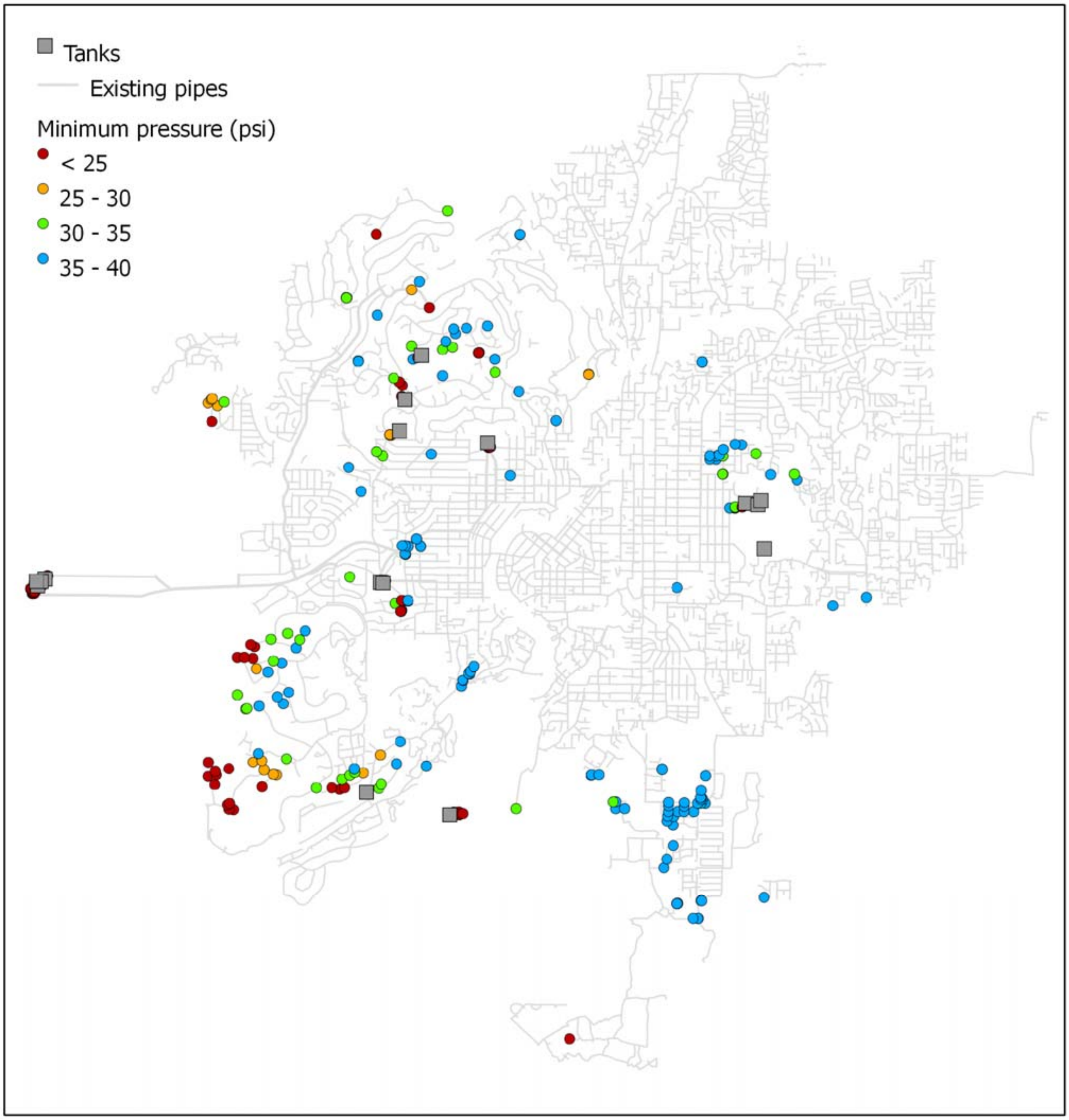


Figure 2.5 – Locations with pressure below 40 psi under existing peak hour demand conditions

Table 2.4 – Demand nodes with pressures below 40 psi under existing peak hour conditions

Node ID	Demand GPM	Elevation ft	Peak Hour Pressure psi	Zone and Location	
JCT-72	0.60	3870.04	3.12	Level 3	Tetherow suction
JCT-117	0.09	3870.04	4.43	Level 3	Tetherow suction
JCT-239	23.82	3869.86	19.01	Level 3	Tetherow suction
JCT-105	5.31	3869.80	20.71	Level 3	Tetherow suction
JCT-253	26.20	3869.88	21.39	Level 3	Tetherow suction
JCT-109	18.86	3869.80	22.43	Level 3	Tetherow suction
JCT-246	42.76	3869.88	22.48	Level 3	Tetherow suction
JCT-236	21.44	3869.88	22.48	Level 3	Tetherow suction
JCT-938	8.04	3610.71	23.76	Zone 6B	High elevation
JCT-3187	3.07	3973.80	27.64	Level 3	Awbrey Butte - west
JCT-124	30.39	3869.81	28.52	Level 3	Tetherow suction
JCT-896	8.52	3716.19	29.06	Zone 5B	Near PRV
JCT-223	95.60	3869.71	29.34	Level 3	Tetherow suction
JCT-714	1.98	3871.42	30.08	Zone 4C	Off Shevlin Park Rd/
JCT-1629	36.62	3948.05	30.33	Level 3	Overturf
JCT-3086	3.04	4102.68	30.63	Level 2	Awbrey Butte - east
JCT-114	15.78	3869.80	31.77	Level 3	Tetherow suction
JCT-256	66.27	3869.92	32.03	Level 3	Tetherow suction
JCT-112	44.43	3881.57	32.72	Level 3	Westwood
JCT-106	15.18	3881.57	32.74	Level 3	Westwood
JCT-119	25.74	3869.80	33.04	Level 3	Tetherow suction
JCT-3361	13.12	3609.78	33.70	Zone 6B	High elevation
JCT-125	12.69	3869.81	33.72	Level 3	Tetherow suction
JCT-234	46.67	3869.88	33.75	Level 3	Tetherow suction
JCT-591	6.66	3956.03	33.81	Level 3	Awbrey Butte - south
JCT-3112	27.32	4238.05	33.82	Level 1	Tower Rock
JCT-377	10.45	3957.95	33.84	Level 3	Overturf
JCT-4206	3.74	3746.09	33.84	Level 5	Pilot Butte
JCT-585	25.46	3956.01	34.68	Level 3	Awbrey Butte - south
JCT-3111	26.35	4238.05	34.69	Level 1	Tower Rock
JCT-259	45.2	3870.16	34.73	Level 3	Tetherow suction
JCT-255	22.85	3870.19	34.75	Level 3	Tetherow suction
JCT-4157	5.76	3750.42	34.85	Level 5	Pilot Butte
JCT-4228	12.92	3731.81	34.94	Level 5	Pilot Butte
JCT-260	28.36	3870.18	35.61	Level 3	Tetherow suction
JCT-245	31.6	3870.22	35.63	Level 3	Tetherow suction
JCT-221	54.24	3869.83	35.70	Level 3	Tetherow suction
JCT-3116	33.55	4240.70	35.83	Level 1	Tower Rock
JCT-1960	9.35	3778.73	35.85	Level 5	West - high elevation
JCT-1963	6.73	3778.77	35.86	Level 5	West - high elevation
JCT-1962	5.50	3778.77	35.87	Level 5	West - high elevation

Node ID	Demand GPM	Elevation ft	Peak Hour Pressure psi	Zone and Location	
JCT-3041	13.72	3961.65	36.25	Level 3	Near Awbrey
JCT-3307	2.10	3749.82	36.32	Zone 5D	High elevation
JCT-4199	10.25	3745.78	36.33	Level 5	Pilot Butte
JCT-228	32.57	3869.93	36.37	Level 3	Tetherow suction
JCT-2359	15.15	3957.28	36.45	Level 3	Near Awbrey
JCT-3078	18.05	4240.14	36.46	Level 1	Tower Rock
JCT-4220	4.03	3746.08	36.52	Level 5	Pilot Butte
JCT-1037	51.55	3881.57	36.93	Level 3	Westwood
JCT-2956	2.74	3764.68	37.02	Level 5	Pilot Butte
JCT-128	15.93	3869.81	37.18	Level 3	Tetherow suction
JCT-4207	0.46	3746.20	37.35	Level 5	Pilot Butte
JCT-4132	7.88	3750.26	37.36	Level 5	Pilot Butte
JCT-3131	19.09	4237.98	37.59	Level 1	Tower Rock
JCT-875	52.18	3974.34	37.70	Level 3	Awbrey Butte - west
JCT-3444	18.51	3841.55	37.93	Zone 4B	Rock Bluff
JCT-202	23.16	3869.83	38.06	Level 3	Tetherow suction
JCT-2287	2.80	3775.95	38.11	Level 5	Awbrey - west
JCT-3441	0.06	3852.04	38.15	Zone 4B	Rock Bluff - Murphy Suction
JCT-2571	9.30	3838.41	38.31	Zone 4B	Rock Bluff
JCT-2570	2.07	3838.41	38.31	Zone 4B	Rock Bluff
JCT-3425	1.03	3842.55	38.37	Zone 4B	Rock Bluff
JCT-1995	15.81	3778.70	38.43	Level 5	West - high elevation
JCT-1994	6.22	3778.70	38.43	Level 5	West - high elevation
JCT-3438	11.39	3841.58	38.45	Zone 4B	Rock Bluff
JCT-3098	56.4	4240.84	38.49	Level 1	Tower Rock
JCT-3436	23.33	3841.50	38.78	Zone 4B	Rock Bluff
JCT-3455	5.80	3841.55	38.80	Zone 4B	Rock Bluff
JCT-2742	7.49	3763.57	38.81	Level 5	South - Scott St suction
JCT-4268	10.06	3737.85	38.88	Level 5	Pilot Butte
JCT-195	28.59	3869.83	38.92	Level 3	Tetherow suction
JCT-3121	19.37	4238.09	39.04	Level 1	Tower Rock
JCT-1268	6.42	3778.14	39.06	Level 5	Southwest - high elevation
JCT-1296	2.54	3778.14	39.06	Level 5	Southwest - high elevation
JCT-4200	6.29	3746.17	39.07	Level 5	Pilot Butte
JCT-3195	18.54	3972.28	39.11	Level 3	Awbrey Butte - north
JCT-3437	16.56	3842.42	39.18	Zone 4B	Rock Bluff
JCT-2634	13.58	3838.45	39.19	Zone 4B	Rock Bluff
JCT-2622	6.03	3838.45	39.19	Zone 4B	Rock Bluff
JCT-3439	8.12	3842.60	39.26	Zone 4B	Rock Bluff - Murphy Suction
JCT-1925	2.43	3778.82	39.37	Level 5	West - high elevation
JCT-3445	10.45	3842.92	39.39	Zone 4B	Rock Bluff - Murphy Suction
JCT-574	14.18	3855.23	39.53	Zone 4A	Awbrey Butte
JCT-3469	0.89	3839.51	39.65	Zone 4B	Rock Bluff

Node ID	Demand GPM	Elevation ft	Peak Hour Pressure psi	Zone and Location	
JCT-3457	1.44	3843.53	39.66	Zone 4B	Rock Bluff - Murphy Suction
JCT-1034	7.92	3871.58	39.68	Zone 4I	
JCT-3143	39.38	4237.80	39.78	Level 1	Tower Rock
JCT-206	32.26	3869.84	39.79	Level 3	Tetherow suction
JCT-4266	12.31	3737.85	39.80	Level 5	Pilot Butte
JCT-3452	5.17	3839.86	39.80	Zone 4B	Rock Bluff - Murphy Suction
JCT-3141	36.59	4237.90	39.82	Level 1	Tower Rock
JCT-4241	2.93	3746.08	39.90	Level 5	Pilot Butte

In a many locations it would not be possible to maintain a pressure of 40 psi due to the relative elevation difference between the source or tank and the customer node. In these instances an exception was applied in the optimization analysis. Levels 1 and 2 on Awbrey Butte were subject to a reduced minimum allowable pressure of 30 psi. A number of other isolated nodes were excluded from the standard minimum pressure criterion and instead the optimization was simply required to maintain pressure above the existing peak hour pressure. Figure 2.6 highlights where modified pressure constraints were applied in the optimization.

Two significant areas - the suction side of Tetherow PS in Level 3 and to the east of Rock Bluff in Zone 4B - are highlighted as low pressure areas in the existing system model, however the optimization was required to lift pressures in these areas to 40 psi where possible.

2.5.2 Velocity

There are very few locations in the existing system where velocity exceeds 7 feet per second (fps). The aim of the optimization was to maintain this. New pipes were also required to maintain velocities below 7 fps. In order to ensure appropriate sizing of new infrastructure a penalty was applied if this criterion was not met in new pipes.

2.5.3 Tank Levels

As part of the Operations Optimization analyses completed in April 2010 (*Summer and Winter Operations Optimization Results* – **Appendix D**), the City identified aims for improved tank operation. Specifically, Bend operators want to be better able to maintain the level in the Pilot Butte Reservoirs under high demand conditions, and also improve tank turnover during winter conditions.

For the Build-out Optimization, the aim was to ensure tanks did not lose volume over a 24-hour period (i.e. they should return to their starting level), and also that necessary standby and fire flow storage was maintained. A comprehensive review of storage standards in Oregon, Idaho and Washington was completed to help the City develop a set of appropriate guidelines to determine storage volume needs in the water system.

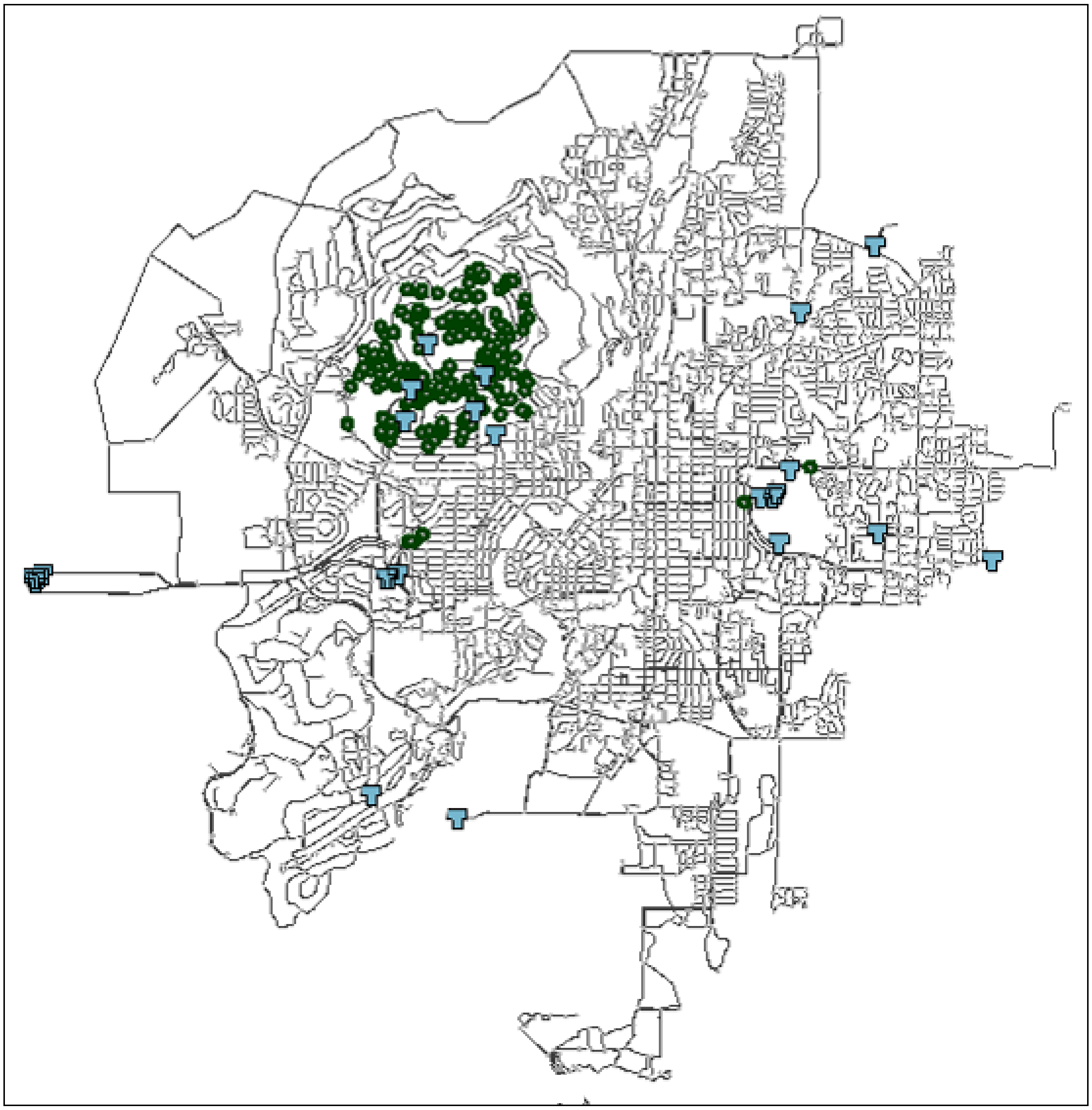


Figure 2.6 – Locations subjected to modified minimum allowable pressure criteria

2.5.4 Storage Requirements

A separate memorandum (*Review of storage standards and recommended storage guidelines for the City of Bend*, June 2010, contained in **Appendix E**) reviewed and summarized the applicable storage standards in neighboring states (Washington, Idaho and Oregon) and regions (Ten States Standards) and recommended guidelines to be adopted by the City for planning activities. After reviewing and discussing this information, Bend chose to adopt the Washington Design Manual guidelines. These guidelines are the most quantitative of those reviewed and provide a prescribed approach to estimating storage requirements.

Based on the analysis and calculations presented in the storage memorandum and discussions with Bend staff, the guidelines summarized in Table 2.5 are recommended for adoption in future planning activities.

Table 2.5 – Recommended storage component definitions for future planning activities

Upper Dead	Estimate the combined operating, equalization and upper dead storage volumes as 35% x MDD. Planning Engineers must verify the necessary volume through hydraulic modeling. Modeling must verify that Standby and Fire storage volumes can be maintained under MDD conditions.
Operating	
Equalization	
Standby	Ensure provisions for a standby volume of 2 x ADD. Wells may be relied on to offset the above-ground storage volume if the following conditions are met: - Only the capacity of wells that are located together with at least one or more reliable wells may be counted, with reliable capacity determined by the concept of firm capacity (largest well out of service) - Wells can be started automatically via SCADA - Wells have back-up power.
Fire	To be determined as per 2007 Master Plan, unless revised requirements are put in force (check with Fire Department): 2 hrs x 1,500 gpm = 0.18 MG Residential 2 hrs x 3,000 gpm* = 0.54 MG Commercial 2 hrs x 5,000 gpm* = 1.5 MG CBD **Higher rates for commercial/CBD zones account for chance of more than one fire occurring simultaneously* Given the significant potential to offset Standby storage with well supply, it is recommended that Bend not consider 'nesting' of standby and fire storage volumes.
Lower Dead	Assess based on a static pressure of 25 psi at all service connections.

A more in depth discussion of these categories can be found in the Storage Constraint Review Memorandum, **Appendix E**.

In making the decision to follow the Washington guidelines, the City considered the following important issues:

- Well reliability: historically the City has experienced problems with a number of wells, particularly on Pilot Butte. In the future it is expected that mechanical equipment will be more reliable; however, it would be undesirable to rely on 100% of the well capacity.
- Availability of back-up power under emergency conditions: relying on wells to meet standby storage needs places increased reliance on back-up power and mechanical infrastructure, and also on fuel supplies to power emergency generators. The City has advised that is entitled to preferential use of diesel supplies in the event of an emergency.
- The reliability of the aquifer: trends show that aquifer levels have declined from previous levels; however, the decline has not been significant. Bend will need to continue to monitor the aquifer levels and may need to revise how much this source is relied upon if levels drop in the future.

As the system grows, the City should monitor maximum day demands and ensure that a firm supply capacity (i.e. the sum of the capacity of all sources minus the capacity of the largest source) equal to MDD is maintained. It is recommended that all new wells be linked to SCADA, and able to be operated on back-up power.

Necessary above-ground storage to meet future operational and equalization needs should be evaluated with the help of a hydraulic model to ensure this component of storage is accounted for appropriately. Due to the need to maintain normal operating pressures above 40 psi throughout the system, there will always be some volume of above-ground storage available to meet standby needs.

Input from Operations staff indicated that the preference would be to maintain as much standby storage above ground as possible; water held above ground does not rely upon the availability of mechanical equipment and power to be delivered to the system. However from a practical standpoint, it would be difficult to find enough space to have all standby storage above ground, not to mention very expensive. An additional important consideration is water quality; it is inadvisable to install excessive amounts of storage due to potential lack of turnover and the associated potential for water quality degradation.

Given the distributed nature of supply in the Bend system, it is appropriate to capitalize on groundwater well assets to offset standby storage needs, within reason. The Washington guidelines provide a more defined way to determine the potential offset. Based on the Washington guidelines calculation, the current system maintains approximately 28% of the necessary emergency storage above-ground (see Table 2.6). The future recommendations for storage included here are comparable to this ratio.

The City should regularly review the Washington guidelines and reevaluate the ground water offset for standby storage as necessary. If changes are made to the Washington Design standards that form the basis of the recommended guidelines used here, or if data show that the aquifer is impacted in such a way that it becomes a less reliable source the percentage of groundwater used to offset stand by storage may need to be revised.

2.5.4.1 Comparison to 2007 Storage Recommendations

The Storage Constraint Review Memorandum (**Appendix E**) included a comparison of the recommended guidelines to the criteria applied in the 2007 Master Plan. There are some differences in the way that the contribution of groundwater is presented in each case. In the 2007 Master Plan, the contribution of groundwater was stated as a proportion of total storage needs (equalization, operating, standby and fire). This is slightly misleading, as groundwater should only be used to offset the standby component of storage. Operating storage should be maintained above ground. It is clearer to define the groundwater contribution as a percentage of the standby component only.

In the 2007 Master Plan, the assumed groundwater contribution at build-out was 55% of total storage, or 50 MG. This equates to 80% of the calculated standby requirement (as per the 2007 Master Plan) of 63 MG. As shown in Section 2.8.12, the Final Build-out Solution provides approximately 25% of standby storage above ground with the remainder (75% or 18.6 MG) being met from reliable groundwater wells.

Table 2.6 – Storage Volume Requirements, Available Storage and Offsets from Wells – Existing System (all volumes in MG)

	A	C	D	B	E	F	H	G	I	J
Pressure Zone	**Existing Storage**	**Dead Storage**	**Fire Suppression**	**Standby Requirement**	**Operating Volume**	**Standby Available**	**Well Offset[3]**	**Contribution to/from other zones**	**Total Standby Capacity**	**Standby Capacity ÷ Requirement**
		Level below which 20 psi cannot be Maintained	Based on land use in supported zones	2 x ADD for zones supported by each storage	Calculated from hydraulic model	=A-C-D-E	2 days x reliable well capacity		=F+H+G	= I/B
Level 1[1]	1.0	0.15	0.18	0.76	0.17	0.50	n/a	0.26 From Level 3	0.76	100%
Level 2[1]	1.5	n/a	0.54	0.81	0.46	0.46	n/a	0.35 From Level 3	0.81	100%
Level 3[2], Tetherow, and Awbrey sub-zones	3.7	n/a	1.50	3.70	1.28	0.90	14.0 Outback	-11.20 To various	3.70	100%
Zone 4A, Westwood	3.3	0.17	0.54	2.04	0.94	1.64	0.0	0.4 From Level 3	2.04	100%
Zone 4B, South Bend	2.5	n/a	1.50	4.20	0.56	0.46	4.0 Hole Ten, Rock Bluff	0.00	4.46	106%
Level 5, 6 & 7	11.6	0.18	3.00	14.17	5.32	3.14	0.0	10.19 From Level 3, Zone 4B	13.33	94%
Totals	**23.6**	**0.49**	**7.26**	**25.68**	**8.73**	**7.10** (28% of standby requirement)	**18.0**	**0.00**	**25.10**	**98%[4]**

Note: This table is a simplified version of Table 9 in the Storage Constraint Review Memorandum (**Appendix E**). Please refer to the full table for more detail.

1) In the existing system, Levels 1 and 2 rely on pumping from Awbrey to make up their requirements. This booster pump station has back-up power and capacity to meet MDD + fire.

2) Outback 1 and 2 have not been counted towards Level 3 storage because they are required for chlorine contact.

3) Well offset only includes redundant wells on SCADA and with back-up power (locations as noted)

4) The slight storage deficit will be addressed either when the new surface water treatment comes online (freeing up Outback Reservoirs 1 & 2) or by adding SCADA and back-up power to existing wells (e.g. River Wells)

2.5.4.2 Build-out System – Storage requirements

Table 2.7 presents the estimated storage volumes that would be necessary under build-out conditions in each major pressure level, based on the various guidelines discussed above. The final column shows whether wells could be used to offset the requirements. The offset amount is double the firm standby well capacity, assuming wells can operate for two days to meet the 2 x ADD standby requirement. The optimization was configured to ensure minimum fire storage volumes were maintained across all storages, that tanks did not lose volume over a 24-hour period, and that minimum service pressures were maintained system-wide. These operating constraints ensure appropriate tank operating volumes and levels are maintained.

Table 2.7 – Estimated Storage Volume Requirements at Build-out and Potential Offset from Wells

Pressure Zone	A Dead Storage	B Fire Suppression (MG)	C Standby Requirement (MG)	D Estimated Operating & Equalization (MG)	E Total Storage (MG) =A+B+C+D	Potential Offset
Level 1 [1]	15%	0.18	1.2	0.5	1.8	All above ground
Level 2 [1]	n/a	0.54	1.5	0.6	2.6	All above ground
Level 3 [2], Tetherow, Westwood and Awbrey sub-zones	n/a	1.5	19.0	7.5	28.0	Above-ground storage and well offsets to standby
Zone 4A	34% of Westwood	0.54	3.2	1.3	5.0	Above-ground storage and well offsets to standby
Zone 4B and South Bend	n/a	1.5	12.2	4.8	18.6	Above-ground storage and well offsets to standby
Level 5, 6 & 7	n/a	3.0	37.1	14.6	54.7	Above-ground storage and well offsets to standby [2]
Totals		**7.3**[3]	**74.2**	**29.2**	**110.7**	

Notes to Table 2.7

1) It has been assumed that wells will not be used to offset standby storage requirements in Levels 1 and 2, due to their elevation and isolation. New storage is proposed at the Tower Rock and College 1 sites to meet the storage needs in these levels.

2) Additional capacity may come from the following sources: planned wells at Pilot Butte, new wells located in Zones 5 and 6, potential acquisition of Pine Nursery well, new wells at Awbrey, or additional capacity in higher zones.

3) The volume required for fire suppression does not change based on increasing demands. It is related to the number of pressure levels rather than demand.

2.6 Optimization Formulation

The optimization formulation process involves model analysis and configuration of the optimization software to link to the hydraulic model. Its purpose is to create a range of decision options aimed at achieving the optimization goals while maintaining or improving system hydraulic performance. The following sections outline the various decision options and hydraulic constraints considered in the Build-out Optimization.

2.6.1 Options

The process of identifying options to include in the optimization formulation involved review of previous master plan recommendations; assessment of the hydraulic model and analysis of system performance compared to specific design criteria; and discussion and brainstorming with City staff. The following sections outline pipe, storage, pump and well supply options developed and tested as part of the optimization formulation process.

2.6.1.1 Pipe options

The previous master plan identified a wide range of pipe improvement options to provide for transmission, distribution and fire flow needs. These were reviewed by Bend staff to determine which improvements remained valid options for consideration in the optimization – i.e. those that had not yet been constructed. It should be noted that the previous master plan was completed using a previous version of the hydraulic model; it was therefore necessary to reanalyze the system using the recently calibrated hydraulic model to confirm the location and extent of existing deficiencies.

In addition to those options from the 2007 Master Plan deemed suitable for inclusion in the optimization, Optimatics undertook a deficiencies analysis using the hydraulic model to develop new pipe options to evaluate in the optimization. With the projected build-out demands distributed to the hydraulic model nodes, Optimatics analyzed the model results to identify locations where there are bottlenecks or restrictions that hinder supply of surface water from Outback to the system; where other stressed mains and low pressures are occurring due to the projected increase in demand; and where new pipe should be located to meet new demand on the outskirts of the system.

Fire Flow Analysis

In addition to the general deficiencies analysis described above, a comprehensive fire flow analysis was performed at each of the nodes in the existing and build-out models to identify local deficiencies, primarily in smaller distribution mains. As noted in Section 2.4 above, each model node has been designated with a specific fire flow requirement based on land use. Optimatics performed a comprehensive fire flow analysis with this information under maximum day demand conditions, and then analyzed results on a zone-by-zone basis. Where the network fell below 20 psi, pipe upgrades (primarily replacement of existing pipe; in some cases a new connection was added) were added at specific locations at the minimum diameter to bring the pressures into compliance.

Many of the identified improvements from the fire flow analyses were fixed in the build-out model, as opposed to being considered as decision options, since they are purely driven by fire flow needs and do not impact transmission and distribution of supply. A handful of the fire flow improvements, primarily in Zone 4B and Level 5, were included in the optimization at a minimum size with the option to increase the size if it was shown to benefit the system in meeting future supply goals. Rather than fixing the diameters of these pipe options, the optimization was allowed to size them as appropriate – with minimum diameter equal to the diameter needed to meet fire flow requirements – in its search for optimal solutions.

The results of the fire flow analysis are presented in Sections 2.8.14 and 4.

Additional Pipe Options to Strengthen System and to Meet Growth

The Consequence of Failure and Operations Optimization analyses completed prior to the Build-out Optimization analyses provided insight into areas of the system which need to be strengthened and potential improvements that could be implemented to improve transmission and simplify system operations. Under future build-out demand conditions most areas of the system are projected to have an increase in demand compared to present maximum day conditions. There are also new demand centers located along the outskirts of the system (primarily in the northwest, in addition to Juniper Ridge in the northeast). Running the model under these conditions showed areas where new transmission and distribution mains will be needed to service new developments and move water effectively through the system.

The DDS Report (**Appendix C**) provides information on the pipe diameter ranges, assumed Hazen-Williams roughness coefficients (C-factors), and pipe unit costs used in the optimization analyses.

Figure 2.7 highlights the new pipe options formulated into the Build-out maximum day optimization. The different colors reflect the range of diameter sizes that the optimization was able to select for each option. These were based on engineering judgment and helped to streamline the overall optimization analysis.

2.6.1.2 Storage options

Throughout the course of this study there has been significant discussion related to future storage requirements. The previous master plan recommended that the City rely on groundwater to meet a portion of standby storage needs in the future. In this study the City desired to work with a more rigorous set of storage criteria based on a more stringent set of engineering guidelines. At first the approach was to assume that 100% of the standby storage needs would be provided through above-ground storage. The idea was that although the resulting cost of storage would be high, the approach would reveal the best locations in the system for placing additional above-ground storage. The total amount of this storage could then be scaled back as necessary based on certain factors – such as available dollars and the character and extent of future growth – and supplemented with groundwater in the event of emergency.

Based on this approach, Optimatics completed a survey of the entire service area to determine where storage could be placed. Various strategies were used to determine which levels and zones are in need of new storage, which have available sites, and which sites would benefit multiple zones in an emergency (given the presence of PRVs throughout the system and thus the ability to supply lower zones from higher zones). The review included both existing sites and new sites, and the option of pumped ground storage was considered (a ground level storage coupled with a booster pump station to lift supply to system pressure). Figure 2.8 shows the tank location options that were developed and subsequently evaluated in the optimization. The Storage Constraint Review Memorandum in **Appendix E** contains details of all the sites reviewed to determine the maximum storage volume potential in the system.

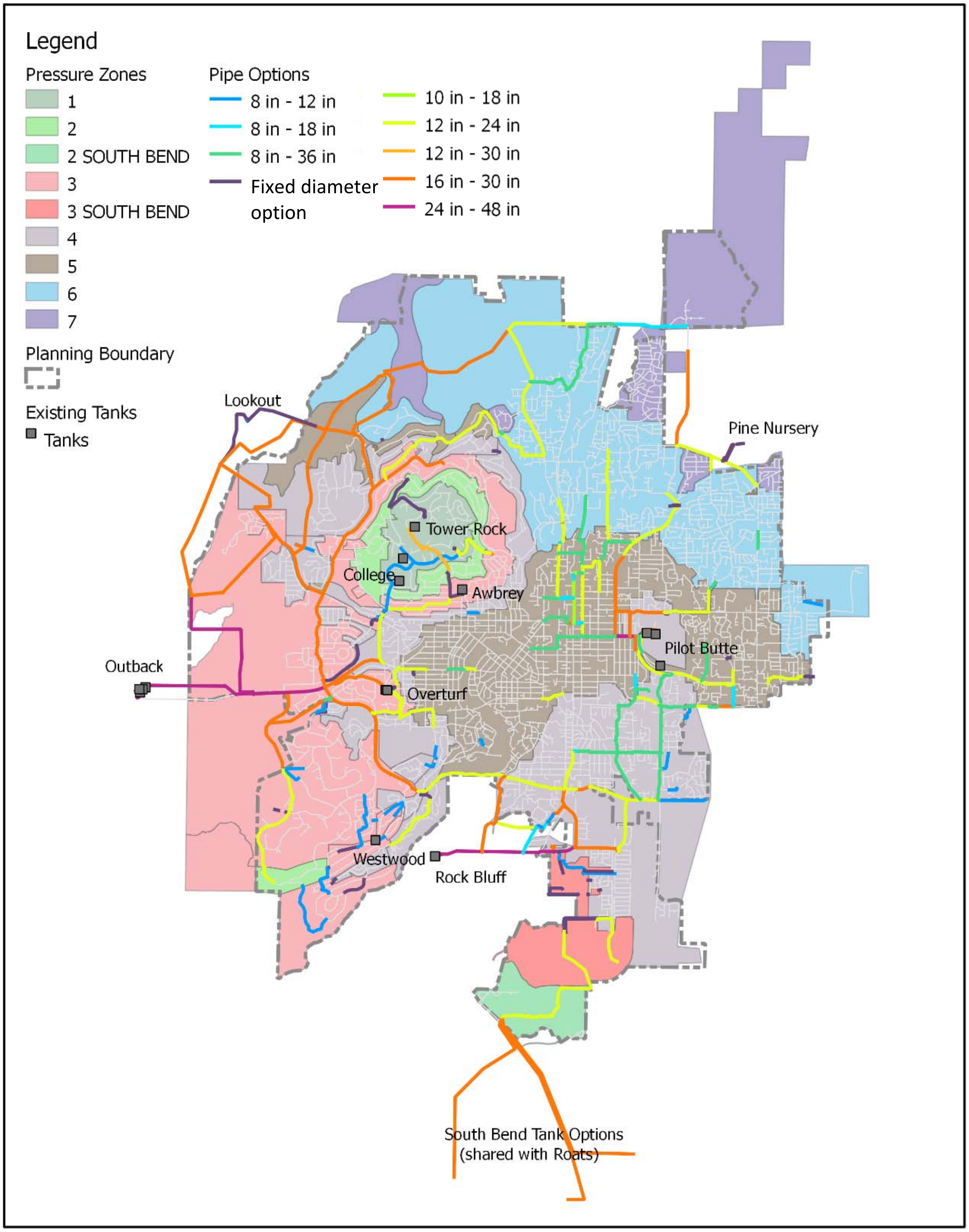


Figure 2.7 – New pipe options in Build-out optimization analysis

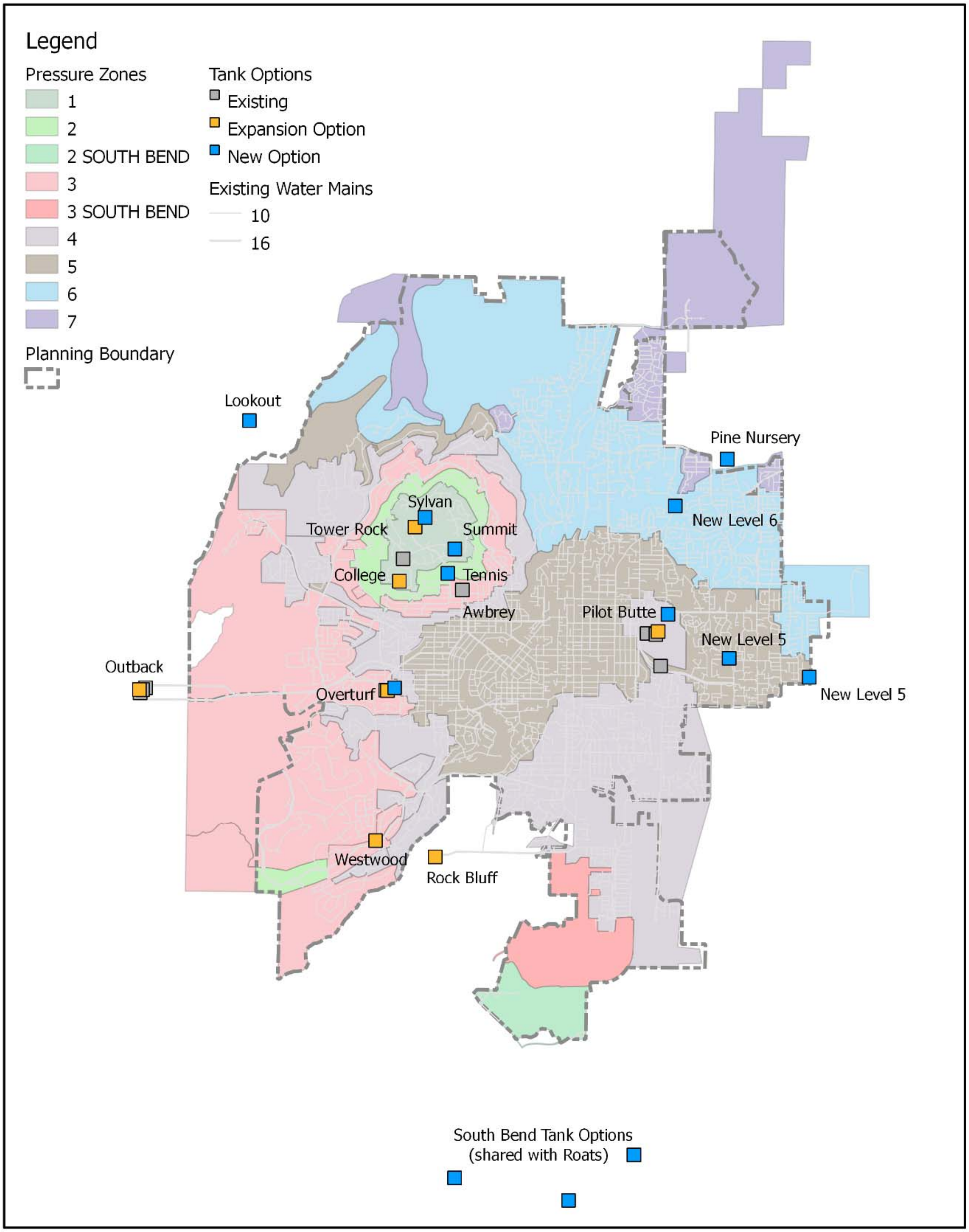


Figure 2.8 – Tank location options considered in the optimization

As discussed in Section 2.5.4, the City requested a review of storage criteria applied in Oregon and neighboring states and subsequently decided to adopt the Washington Design Manual guidelines for emergency storage. As a result, the Final Build-out Solution includes a modest increase in above-ground storage and benefits from the decision to rely on redundant and reliable groundwater wells to offset stand-by storage, therefore significantly reducing the cost of above ground storage. However, for the record, all the potential storage sites identified as part of the system storage review are discussed below.

Level 1 and 2

The 1.0-MG Tower Rock Reservoir serves Level 1, but given the existing PRV stations between Levels 1 and 2 and other smaller stations that reduce water from Level 2 to subzones of Level 3, additional storage in Level 1 could be made available to supply these lower zones in an emergency. City staff visited the Tower Rock site and confirmed that there is room to build additional storage there.

In addition to evaluating the expansion of existing storage amount at the Tower Rock site, two locations were indentified for new storage located in Level 1 that would support Levels 2 and 3 – Summit Park and Sylvan Park. Both parks have two side-by-side tennis courts which could conceivably have in-ground storage added beneath them. The storage would be rectangular in the shape of the court and be made of concrete. To determine the maximum available storage at each site if the tank were 30 feet deep, calculations were performed using dimensions of 100 feet by 60 feet per court. With two courts side by side, the total storage available is approximately 2.5 MG.

Level 3

An analysis of existing above-ground storage revealed a deficit in Level 3. This zone is an important zone for supplying lower zones. In general, existing elevations in the Level 3 network are not conducive to new storage. The best option is to build additional storage at the Outback site. This was formulated into the optimization as expansion of Outback Reservoir 3.

One potential new storage option, which would be filled from the Level 3 gradient via PRV and then serve downstream demands, is located off Lookout Drive to the northwest of the existing edge of the system. A volume of 2.5 MG was assumed for this tank option. The location is outside the UGB however, and was later removed from the potential storage options being considered.

Level 4

The existing overflow level in the Overturf Tanks, which serve Level 4A, is 3,871 feet. This is 9 feet below the 3,880-foot overflow level of Pilot Butte Reservoir 2, which serves Zone 4B. The idea of building a new tank at the Overturf site with a higher overflow elevation to match Pilot Butte 2 was considered in preliminary optimization runs. It was not favored however as restrictions in the Zone 4A mean that significant piping improvements would be needed to allow storage at Overturf to support demands in Zone 4B.

After review of the interim optimization run results, the idea of adding a buried tank at the Overturf site at Level 5 hydraulic grade was put forward. The tank would be filled from Zone 4B and new piping would connect it to Level 5 either to the north at Galveston or to the south at Century Drive.

An option to expand the existing storage at Rock Bluff, which serves Level 4B directly but whose volume would be available to supply Level 5 and lower zones in the event of emergency, was included in the optimization formulation. The City has existing plans for an additional 6 MG of storage at this site.

Levels 5, 6 and 7

Two new tank options were considered at the Pilot Butte site. The first was drawn from MSA's Final Technical Memorandum of the *Water System Planning for the Juniper Ridge Development* study. Given the total development assumption of 515 acres, a new storage tank was preliminarily designed to be 5.7 MG. It was sited just south of Neff Road at a Middle School land parcel. The design calls for the new tank to be filled from Level 5 via the existing 16-inch diameter main on Neff Road. There would be a dedicated supply line that leaves the tank and follows Neff Road east to Purcell Boulevard, then north along Purcell and connecting to the Level 6 piping at Curt Circle. This new tank and piping configuration was formulated into the optimization.

The second tank option at Pilot Butte is located on the northern face of the butte at Level 5 hydraulic grade. This site was proposed because there is an existing scar on the butte, so construction of a tank would encounter less public opposition. A new pipe would connect this tank to the newly installed 24-inch diameter main from Pilot Butte 1.

In addition to these elevated tank options, Optimatics and the City reviewed a number of vacant sites in Level 5 east of Pilot Butte and in Level 6 and identified four potential pumped ground storage locations. It was agreed that these storage options would be considered in conjunction with new groundwater wells. The well would fill the tank and a booster pump station would lift the supply to system pressure. This configuration would avoid inefficient filling of storage from the system and re-pumping to system pressure as well as address the need for new supply to the lower pressure levels.

South Bend

The final new storage option was sited south of the South Bend network on Deschutes National Forest land. MSA performed a review of the area south of the network and identified three potential sites. The middle of these three sites, located just west of the intersection of China Hat Road and Arnold Ice Cave Road, was chosen as the tank location to evaluate in the optimization. The tank would be filled by the Murphy Pump Station, and the storage would likely be shared with Roats Water System.

2.6.1.3 Well options

To meet the additional forecasted demand at build-out, new well supply will be needed in the system. During the Project Update meetings Bend staff identified locations in the system where new wells could be constructed as well as those existing well sites which could be expanded. The well options formulated into the optimization are described in the following subsections and highlighted on Figure 2.9.

Expansion of Outback Wells

The city has plans to implement additional wells at the Outback facility area. The water would move through the same process as existing well water at the site and then be fed by gravity into the system. Parallel pipe options from the Outback site into the system were included in the optimization formulation to be able to transmit the additional supply should these options be selected.

New Tetherow Well

A new well option was evaluated Level 3 north of the Tetherow pump station, near the intersection of Skyline Ranch Road and Seaton Loop.

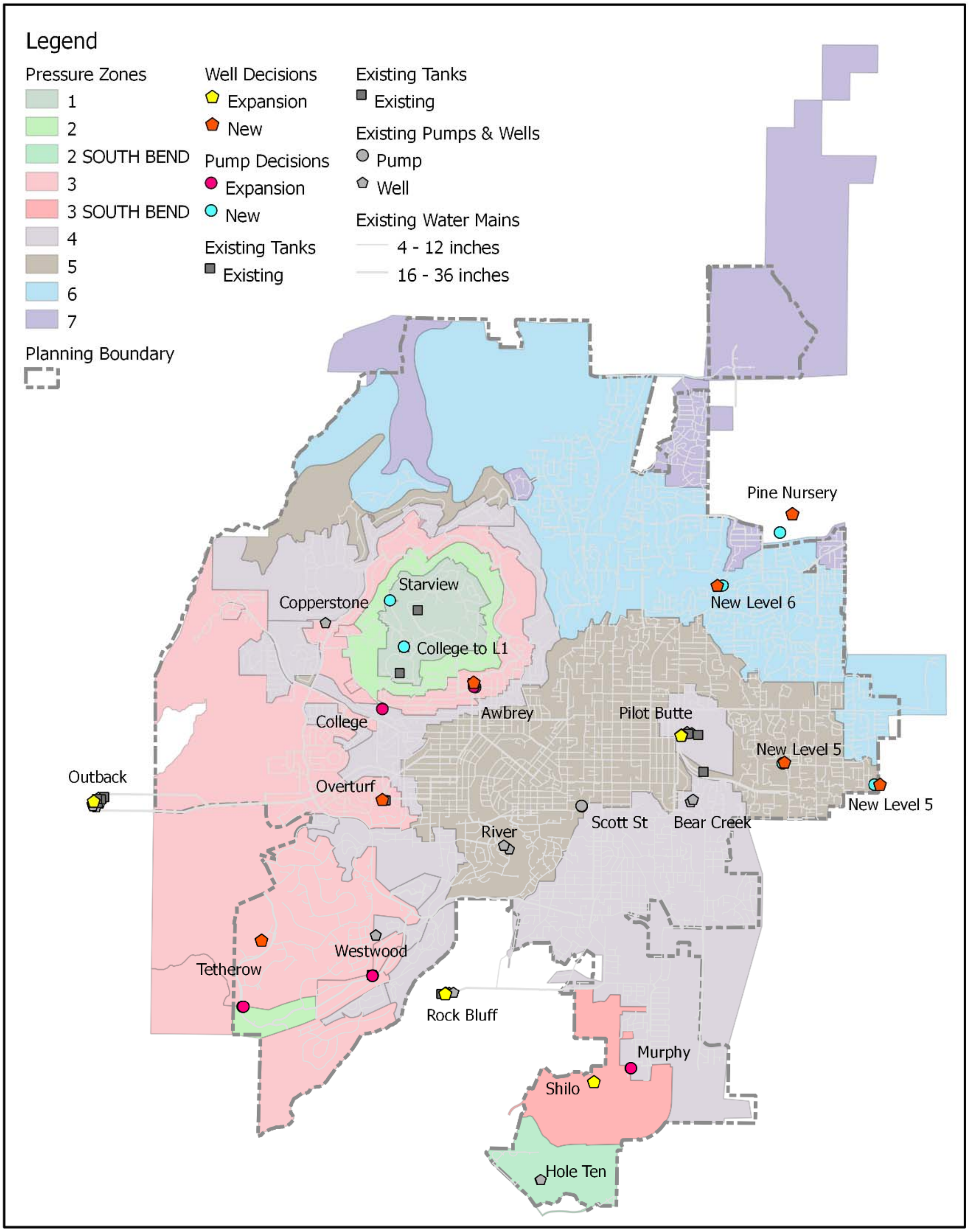


Figure 2.9 – Pump and Well options considered in the optimization

New Overturf Well

A new well option was added at the Overturf facility to provide additional supply to Level 4A.

Expansion of Rock Bluff Wells

An additional new well option was added at the Rock Bluff facility, which would expand the amount of well supply delivered to the system from this site to Level 4B. New parallel pipe options from the Rock Bluff facility into the system were also added to the optimization.

Expansion of Bear Creek Wells

Expansion of the Bear Creek Wells was considered in the interim runs; however the City reports that these wells have exhibited transmissivity issues, so the option was later removed from the optimization formulation.

Expansion of Shilo Wells

The City has recently re-commissioned the Shilo facility and installed a new 12-inch diameter pipe connection that allows this well to supply Zone 4B. The option to expand the well capacity at this site was evaluated in the optimization formulation.

New Awbrey Well

A new well option was added at the Awbrey facility to provide additional supply to Level 5. The City is uncertain whether there will be challenges to drilling a well at this site but wished to include the option in the optimization analysis.

Expansion of Pilot Butte Wells

The City has recently constructed a new well, Well 4, and has plans for three additional wells at this site (5, 6 and 7). The newly-constructed Pilot Butte Well 4 was added to the model and considered an ‘existing’ supply source. The additional wells were considered as options in the optimization. New parallel pipe options from the facility into the system were included in the optimization.

New Pine Nursery Well

A new well option was added at the Pine Nursery facility in the northeast on the assumption that the City could take over this facility from Bend Parks and Recreation District. There is a very small pump in place at the site, but the well has been tested to a higher capacity. Flow tests showed that the site can pump 1,800 gpm without dropping the level in the underlying aquifer. Bend would install a larger pump if it were to take over this facility; the optimization included the option to add more wells at this site.

New Well sites in Level 5 and 6

As part of the review of potential storage locations, two sites east of Pilot Butte in Level 5 and one site along Butler Market Road in Level 6 were identified as feasible locations for combined well and storage facilities. The option of only installing a well at each site was also evaluated.

Feedback from operations staff indicated that new wells in the east of the system would be a welcome addition to the system, not considering groundwater 2 year time of travel and groundwater contamination issues which had not been clearly discussed or evaluated at the time of this study. As demands increase it also makes sense to increase supply on this side of the system to limit the amount of supply that needs to be transferred from west to east and the associated costs for improving transmission capacity.

2.6.1.4 Pump station options

Level 2 to Level 1

Assessment of Bend's booster pumping operation in Levels 1 and 2 did not reveal significant opportunities for improvement with existing infrastructure. There is little 'pumping and dumping' through PRVs, so the operation is reasonably efficient. However, supplying Level 1 from Awbrey represents a high pumping head situation as water is lifted from Level 5 to Level 1. At the Project Update meetings in August 2009, the idea of adding a small booster station from Level 2 to Level 1 was discussed.

Two new pump station options were developed and added to the model in the operations runs. These options have been carried over as options to test in the Build-out optimization. The first option is in the vicinity of NW Starview Drive and NW Fitzgerald Court. Vertical Projects, LLC brought forth the idea of adding a small pump station here, where there is an existing pit, which could provide a redundant supply source for Level 1 (drawing from Level 2). A station was added to the model with a single 15-horsepower (hp) pump. Under current hydraulic conditions the operating point of this potential pump is 425 gpm at 140 feet of lift.

A second pump station option was added to the model at College 2 Reservoir. A short section of main is required to tie this station into Level 1 piping along Coe Court. This new station would also draw suction from Level 2 and supply Level 1, but it would be buffered by the reservoir storage.

The use of either new pump station option may reduce the existing pumping energy required to lift water to Level 1, allowing Awbrey to serve as a back-up under certain seasonal or other demand conditions. Another consideration when evaluating this option is the additional draw on the College Pump Station that would be required if Level 1 is supplied from Level 2.

College booster station expansion

To accommodate the potential for filling new or existing storage on Awbrey Butte via Level 2, an option to expand the capacity of the existing College Booster Station was added to the optimization. Flow rate choices were provided for the optimization to choose from in the evaluation of whether to select this station expansion, and if so, at what size. A new parallel pipe option was also added to the discharge side of the station to enable transmission of the additional flow if the expansion option is chosen.

Awbrey booster station expansion (drawing from Level 3 to Level 1)

The Awbrey booster station was formulated with an option to expand its existing pump capacity in order to supply new and existing storage in Level 1. New pipe options were added and configured to convey the additional flow to the existing Tower Rock tank. To save pump energy costs, the new pump option would draw from the existing 18-inch diameter Level 3 main on the inlet side of Awbrey Reservoir, rather than from the Reservoir (Level 5 grade line).

Westwood

The Westwood Pump Station facility was intended as a temporary facility; it is problematic and likely inefficient so Bend desired to investigate alternative ways to supply the Westwood Zone and neighboring zones. Ideas for alternative ways to supply customers in this area are discussed in Section 2.6.1.5.

Tetherow

The Tetherow Pump Station has sufficient capacity to meet existing needs; in fact it is oversized. In the future, however, new development in the Tetherow area may call for additional fire flow capacity to be provided. A fire flow rate of 3,500 gpm has been proposed which is currently the flow limit of this station. In order to maintain firm supply capacity (assuming largest pump out of service), it will be necessary to increase the capacity of some pumps in this station if the development proceeds.

South Bend

The hydraulic model was set up in accordance with the information contained in the *Former Juniper Utility – Proposed Water System Improvements* memoranda developed by MSA (included in **Appendix F**). Under these recommendations the Tillicum area is rezoned into Level 4B and the Murphy Pump Station becomes the primary source of supply for Zones 2B and 3D. As mentioned above, the Shilo Well was reconstructed to pump to Zone 4B through a new 12-inch diameter connection. The City is currently constructing new piping from the Murphy pump station to Zone 3D which will later be extended into Zone 2B. Currently the Hole Ten wells continue to supply Zone 2B (South Bend). Once the piping is in place the Murphy station will pump to Zone 2B, and the Hole Ten wells will operate only as an emergency supply facility.

Murphy

Similar to the Tetherow Pump Station, the Murphy pump station currently has adequate capacity to meet peak hour and fire flow demands. However, as demands increase in the future it will be necessary to increase the capacity of some pumps in order to ensure the station can still provide a firm capacity equal to maximum day plus fire flow.

2.6.1.5 Potential modification of Zone Boundaries

In line with Bend’s desire to simplify the system and streamline pressure zones, Optimatics evaluated modifications to some zone boundaries. When assessing the feasibility of joining smaller pressure zones into larger neighboring zones, the aim is to ensure that service pressures are still above the minimum requirement and not more than 10 psi below current pressures. In some areas, combining zones into a higher pressure level would require installation of individual PRVs to customer connections which has an associated cost (assumed to be $1000/connection). The modifications considered in the optimization included changing PRV settings in combination with opening boundary pipes/valves, and/or adding new pipe to complete the merging of zones. Table 2.8 lists the options formulated into the optimization to improve system operations along selected zone boundaries.

Table 2.8 – Potential candidates for zone boundary modification

Option	Location	Purpose
Zone 4K into Level 3	Open connections on Flagline Court and Green Lakes Loop. Open PRV.	Increase circulation, suction pressure at Tetherow. Requires individual customer PRVs
Zone 4J into Zone 4A	Open boundary at NW Crossing Drive and Shevlin Park Road	Increase circulation
Zone 4I into Zone 4A	Open connections on SW Reed Market and Mt. Bachelor Drive	Reduce pumping volume at Westwood/Tetherow
Zone 4I into Zone 4B	Open connection at Route 372/Reed Market Rd	Reduce pumping volume at Westwood/Tetherow
Zone 4G into Zone 4A	New connection on Cascade Lakes Highway	Remove demand off Mt Washington Drive/Level 3 piping
Zone 4F into Zone 4A	New connection at NW Summerfield Road	Increase circulation
Internal connection,	Century Drive to Mammoth Drive	Improve supply redundancy for customers south of Century Drive along Sunshine Way and Mammoth Drive
Westwood into Level 3	New connections at Pine Hollow, Cobb Street or Bachelor View Road. Open existing connections northeast of Westwood PS. Supply highest elevation customers via Tetherow	Reduce reliance on Westwood PS, reduce energy needs, increase circulation

2.6.1.6 New Pressure Reducing and Flow Control Valves

Several new control valves were added to the hydraulic model at the boundaries of pressure zones where potential new pipe options were placed. These are described below and shown on Figure 2.10.

Level 1 into Level 3

As noted in the storage options section above, a new storage option at the Sylvan Park location was evaluated. The optimization was formulated with a new pipe option extending from this tank to Farewell Drive, west to Starview Drive, then north to Perspective Drive. Just before the intersection with the existing 24-inch diameter main on Perspective Drive, a new pressure reducing station was proposed as an option to reduce pressure from the Level 1 hydraulic gradient to Level 3.

Level 2 into Level 3

The storage options also included a new storage at Summit Park on the southeast side of Awbrey Butte. The tank would be supplied from Level 2 from new pipes along Summit Drive. On the discharge side of the new storage, new pipe would extend to Summit Drive, north and east on Summit to Wyeth Court, south and east along Wyeth Court to Powell Butte Loop and ending at the intersection of Powell Butte Loop and Awbrey Road. A new pressure reducing station just west of Awbrey Road would reduce pressure from Level 2 to Level 3.

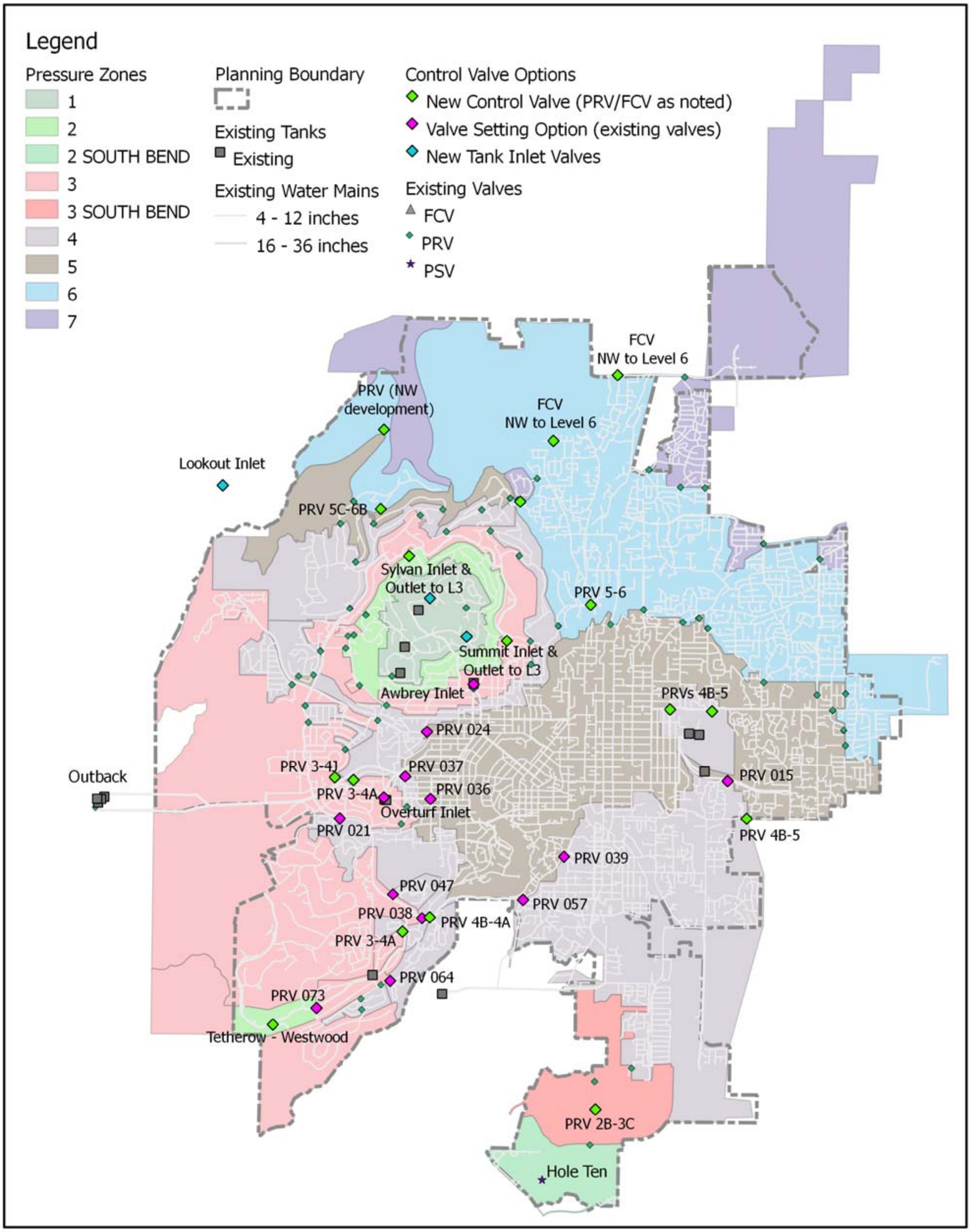


Figure 2.10 – New and existing valve decision options considered in the optimization

New valve option labels indicate from- and to- zones; existing valve labels indicate GIS IDs

Level 3 into Zone 4J

A new development is planned north of Skyliners and east of Mt Washington Drive that would be part of Zone 4J. A PRV connection from Level 3 was included in the model along with the new piping. Although the pipes were not sized in the optimization due to lack of information about the future demands in this area, the setting of the valve was evaluated.

Level 3 into Level 6

New pipe options were included in the optimization formulation to supply Level 3 on the north side of Awbrey Butte. One of these options was to extend Level 3 piping north and east beyond Pressure Reducing Station 67, following Glenbrook, to the interface with Level 6 at the river. A new pressure control station to reduce pressure in the supply from Level 3 to Level 6 was proposed to be located near NW Lower Village Road just south of the existing Pressure Reducing Station (GIS ID 79).

Level 5 into Level 6

There are new pipe options to strengthen the fire flow capacity of the network along the northern portion of Zone 5, as well as to convey additional supply from Level 5 into Level 6. A new pipe option and new pressure reducing station are proposed just between Level 5 and Level 6 along Highway 97 just after the split of Highway 97 and Highway 26, with the station reducing the pressure into Level 6.

Northwest Development connections

System projections for Build-out predict that new growth will take place primarily to the northwest and northeast of the existing service area. Development in the northwest will require significant new piping to convey the anticipated flow. Two new flow control valves were included in the model at the end the proposed piping connecting into Level 6. The aim was to determine whether there was benefit in using the new piping to assist with transmitting supply to the lower pressure levels. The optimization was formulated to evaluate the size of the pipes and settings on the valve connections to Level 6. The location of the first valve option is just north of the intersection of O B Riley Road and Glen Vista Road, and the second is on Cooley Road west of Hunnell Road.

2.6.1.7 Pressure Reducing and Flow Control Valve Setting Adjustments

The settings of a number of control valves were evaluated in the optimization. Table 2.9 shows the flow control and pressure reducing valves, current settings for flow / pressure for winter and summer conditions, and the range of setting options that the optimization was configured to evaluate to determine the most favorable settings.

The first two valves in Table 2.9 are the flow control valves (FCVs) that fill Overturf and Awbrey. Analysis of the existing system summer EPS model results showed that flow from Outback to these reservoirs fluctuates significantly, which often affects the available head in the transmission line. Controlling the rate of flow over a 24-hour period would provide a more constant driving head for the system and increased ability to incorporate surface water supply.

A key aim in the Operations Optimization was to improve the recovery of the Pilot Butte Reservoirs in Zone 5. The Build-out Optimization formulation also aimed to ensure all reservoirs maintain volume over the maximum day. Adjustments to the settings of valves on the boundary of Level 4 and Level 5 (Valve numbers/GIS IDs WAPRV024A, WAPRV036A, WAPRV037A, WAPRV015A, WAPRV015B, WAPRV039A and WAPRV057A) were evaluated to determine if modifications to the settings will improve the reservoir levels. In addition, the setting of the Athletic Club PRV (GIS ID WAPRV038A) was evaluated. The remainder of the PRV setting options in Table 2.9 relate to the potential zone boundary modifications discussed previously in Section 2.6.1.5.

Table 2.9 – Control valves with settings evaluated in the optimization

Valve ID	From Level / To Level
Overturf FCV	Level 3 to Level 4
Awbrey FCV	Level 3 to Level 5
WAPRV024A	Level 4A (West) to Level 5 - Newport & Juniper
WAPRV036A	Level 4A (West) to Level 5 - Cumberland and 15th
WAPRV037A	Level 4A (West) to Level 5 - 17th St. & Galveston
WAPRV038A	Level 3 to Level 4B (East) - Mt. Washington & Athletic Club
WAPRV015A	Level 4B (East) to Level 5 - Hwy 20 @ 1734
WAPRV015B	Level 4B (East) to Level 5 - Hwy 20 @ 1735
WAPRV039A	Level 4B (East) to Level 5 - Wilson & Bond
WAPRV057A	Level 4B (East) to Level 5 - Bond & Reed Market
WAPRV047A	Level 3 to Zone 4G - Chandler & Mt. Washington
WAPRV064A	Zone 3C (Westwood) to Zone 4I - Wild Rapids & Wild Rapids
WAPRV021A	Level 3 to Zone 4K - Green Lakes Loop
WAPRV073A	Zone 2A (Tetherow) to Zone 3C (Westwood) - Tetherow & Campbell

2.6.1.8 Booster Pump and Well Pump Controls

The changes to existing controls evaluated with the optimization include modifying initial status (on/off) of pump facilities as well as trigger levels for wells and booster stations based on storage levels. There are a number of decisions in the optimization which involved adding automatic controls to pumps which are currently manually operated. This has been done based on information from Bend indicating that SCADA could be added to control these pumps if it is shown to be beneficial in meeting Bend's operational goals. The targeted pumps were:

- Pilot Butte Well 3 (water lube)
- River Well 1
- River Well 2

Some existing wells are not suitable for control based on tank levels or system pressure; however the optimization was configured to evaluate whether or not these particular wells should be maintained and operated to meet future maximum day demands. The wells in question are Copperstone Well (submersible, runs to waste for 10-15 minutes on start up) and Pilot Butte Well 1 (oil lube, must be run to waste for 24 hours before use).

In addition to adding controls for the above wells, Optimatics evaluated changes to existing well controls at selected facilities. The logic behind introducing different control setting options for existing well relates to changing the priority of supply from different facilities. For example, the Scott Street Pump Station and Bear Creek Wells are both controlled by the level in Pilot Butte 2. For the optimization, Optimatics configured control options in the model that could make Scott Street the primary facility and Bear Creek the secondary supply facility.

Table 2.10 lists the current summer and winter controls for each pump and well facility evaluated in the optimization. The pumps and wells are grouped based on the tank which controls their operation. The range of settings (tank levels) that were tested with the optimization are listed in the final column. For new wells, the optimization was configured to select operation status (on or off) and the maximum flow rate at each site.

Table 2.10 – Control setting decisions

ID	Current tank level setting (ft)		Tank level setting options (ft)
	Winter	Summer	
TOWER ROCK RESERVOIR			
Awbrey Booster Pump 1 - On	27.5	28.9	24.5 - 27.5
Awbrey Booster Pump 1 - Off	29.5	29.5	26.5 - 29.5
Awbrey Booster Pump 2 - On	26	26	23 - 26
Awbrey Booster Pump 2 - Off	27.5	27.5	24.5 - 27.5
New Awbrey Pump Option - On	n/a	n/a	25 - 27
New Awbrey Pump Option - Off	n/a	n/a	27.1 - 29
AWBREY RESERVOIR			
Valve Inlet - Open	17	17	14 - 16
Valve Inlet - Closed	18	17.9	17 - 19
River Well 1 - On	n/a	n/a	14 - 16
River Well 1 - Off	n/a	n/a	16 - 18
River Well 2 - On	n/a	n/a	13 - 15
River Well 2 - Off	n/a	n/a	16 - 18
OVERTURF RESERVOIR			
Valve Inlet - Open	21.8	23	21.8 - 23.8
Valve Inlet - Closed	23	24.6	24 - 26
PILOT BUTTE RESERVOIR 1			
Pilot Butte Well 3 - On	n/a	n/a	22 - 24
Pilot Butte Well 3 - Off	n/a	n/a	26 - 29

Table 2.10 – Control setting decisions cont.

ID	Current tank level setting (ft)		Tank level setting options (ft)
	Winter	Summer	
PILOT BUTTE RESERVOIR 2			
Bear Creek Well 1 - On	35	35	33 - 35
Bear Creek Well 1 - Off	37	37	35 - 37
Bear Creek Well 2 - On	34	34	32 - 34
Bear Creek Well 2 - Off	36	36	34 - 36
Scott St Pump 1 - On	29	29	29 - 34
Scott St Pump 1 - Off	33	33	33 - 36
Scott St Pump 2 - On	31	31	31 - 35
Scott St Pump 2 - Off	35	35	35 - 37
Scott St Pump 3 - On	27	27	27 - 30
Scott St Pump 3 - Off	32	32	32 - 35
ROCK BLUFF RESERVOIR 1			
Rock Bluff Well 1 - On	34.9	34.9	32.9 - 34.9
Rock Bluff Well 1 - Off	37.2	37.2	35.2 - 37.2
Rock Bluff Well 3 - On	36	36	34 - 36
Rock Bluff Well 3 - Off	38.2	38.2	36.2 - 38.2

2.6.2 Method to estimate power costs in the optimization

As part of the Operations Optimization, an analysis was completed of historical well production and associated power costs. The analysis of data from year 2008 revealed an annual power cost for groundwater pumping of $603,000. For the same period the volume of groundwater pumped was approximately 2,600 million gallons (MG), resulting in a power cost per million gallons of $230/MG.

Optimatics has estimated that energy costs (that is, only those costs associated with kWh consumption) account for approximately 50% of total annual power costs. In the optimization the energy cost value for each facility has thus been doubled to approximate the overall power costs. In summary the following calculations have been used in the optimization:

The equation used to calculate pump power (kW) is: $P = C \times Q \times H / \eta$

Where: $C = 0.0001886$, Q = flow (gpm), H = head (ft), η = efficiency

The energy, E (kWh), used by a pump over time is: *E = P x t (hours of pumping)*

The cost of this energy requirement will then be: *Cost = E x Cost per kWh*

To determine system-wide power costs, the following approximation has been used:

Estimated annual power costs = Σ for all facilities [Daily energy cost per pump / Annual energy ratio] x Days in a year x Factor to represent total power costs

Where: *Annual energy ratio* = 2.25 for maximum day

Factor to represent total power costs = 2

Power costs have been projected over a 20-year design period and the net present value (NPV) calculated using a discount rate of 6%. This allowed the optimization to consider the trade-off between capital improvements and power costs over a longer time frame than a single year.

NOTE: Since the NPV and power cost values are a rough order of magnitude approximation only, the costs presented in the following sections simply represent annual energy costs for the scenarios evaluated.

2.7 Build-out Optimization Results

The layout of the Final Build-out Solution including pipe improvements (not including fire flow piping improvements, refer Section 2.8.14), new storage, new wells, new pumps and new valves is shown in Figure 2.11. The following sections provide additional information about the solution and discussion of observations made from the optimization run results and trends.

2.7.1 Recommend Improvements and Estimated Costs

Pipes

A full list of recommended piping improvements needed to satisfy projected build-out maximum day demand and integrate supply from surface and groundwater sources is provided in **Appendix G**. The estimated cost of these improvements is $43.6 million. This does not include costs associated with pipe improvements that are understood to be either recently constructed, under construction or planned for construction near term. This applies to:

- 24-inch diameter pipe from the Pilot Butte Reservoirs in Level 5 to the intersection of Lafayette and 12th street (replaces existing 12-inch pipe)
- A 12-inch diameter pipe from the Shilo Well facility to the suction side of Murphy Pump Station/ Zone 4B
- 12- and 16-inch diameter transmission main piping in the former Juniper Utility area from Murphy Pump Station to Mountain High (the optimization results confirmed MSA's recommendations for this area – as per *Former Juniper Utility – Proposed Water System Improvements*, January 2011, **Appendix F**)
- Piping connections to allow the Tillicum area to be supplied from Zone 4B (again as per MSA recommendations)

Upon review of the proposed recommendations, the City advised that the preference is to replace rather than parallel existing pipe alignments which require additional capacity. However, in some instances, parallel mains are recommended due to the importance of the existing line. The following major lines are recommended to have parallel mains installed:

- *Projects L3-2, L3-4 and L3-5, Outback site and along Skyliners to Skyline Ranch Road* – the piping out of Outback is key to maintaining supply to the city; shutting one of the lines down in order to replace it would have a bit impact on the system
- *Projects Z4B-1 and Z4B-2, Powers Road, Rock Bluff to Brosterhous (16-inch existing)* – the recommended size for a parallel main is 42-inches which would be near equivalent to constructing a new line. The existing 16-inch line is the only connection from Rock Bluff to Zone 4B and shutting it down would have a significant impact on the system. In fact, the City may wish to consider installing two new mains rather than a single 42-inch main next to the existing main for added redundancy.
- *Projects Z4B-3 and Z4B-7, Brosterhous/97 from Powers to Reed Market (12-inch existing)* – the City indicated that a dual line system would be beneficial along this route due to it being a high traffic volume area which includes a crossing of 3rd Street and a canal.

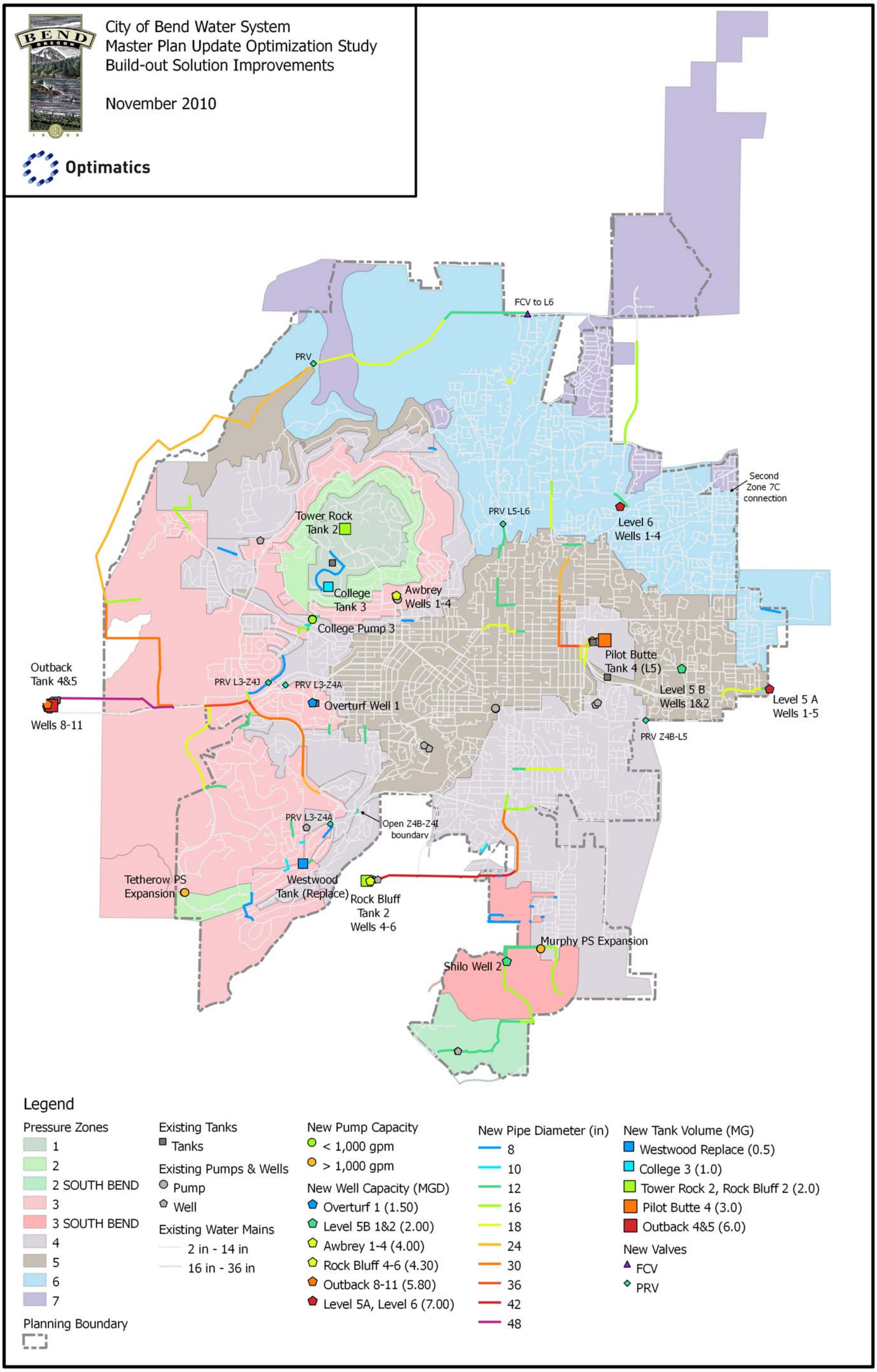


Figure 2.11 – Final Build-out Solution Layout

Note: A large scale version of this map is available in hardcopy at the end of this report, and in the electronic **Appendix I**

- *Project L6-3, Boyd Acres from Ross Rd to Brinson Blvd (16-inch existing)* – a relatively major line in an industrial area with plenty of right of way.
- *Project L6-2, Brinson from Butler Market to 18th* – this route includes two canal crossings, making a dual line system beneficial.

There are also some areas where a parallel pipe is unavoidable as the new pipe is in a different pressure zone to the existing pipe. The following locations fall into this category:

- *Project L2-1*, Glassow and Summit Drive between College 1 Reservoir and Coe Ct (creates a loop in Level 2)
- *Project L3-3*, Piping past College PS, from the suction side of College to downstream of PRV 002 (provides another way to fill Awbrey)
- *Project L3-2*, Shevlin Dr, at round-a-bout with Crossing Dr (similar to above, Level 3 connection, past Zone 4J/A piping)
- *Project L3-1*, Champanelle Way from Niagara to Green Lakes Loop (bypasses 4K)
- *Project L5-18*, Century Drive, Knoll to Simpson (creates a tie between Level 5 piping, past Zone 4B piping)

Storage

Five new storage tanks have been recommended in the Final Build-out Solution at the Pilot Butte, Outback, Rock Bluff, Tower Rock and College 1 tank sites. In addition it is recommended that the Westwood Tank be replaced, maintaining storage at this site. Table 2.11 lists the storage volumes at these sites and the associated costs.

The additional storage in Levels 1 and 2 is strictly not required for the purposes of meeting emergency storage needs. There is sufficient reliable supply capacity in Level 3 to meet the needs of that zone and offset the emergency storage requirements in Levels 1 and 2, via the Awbrey Pump Station. The Awbrey Pump Station has back up power and is sized to meet maximum day plus fire flow. However, given the isolation of Levels 1 and 2 due to their elevation and single reliable supply point, Optimatics recommends that the City consider meeting the emergency storage needs for these zones above ground. The recommended new storage volumes shown in Table 2.11 allow the two zones to be supplied by gravity for a period of time (up to two days of average day demand) under emergency conditions.

The Westwood tank was not selected to be overhauled, instead the optimization selected to decommission the tank (a lower cost option, the option to leave the tank in its existing condition was not considered). In order to maintain satisfactory pressure near the Westwood Tank site a new valve connection was recommended between Level 3 and Zone 4A at West Ridge Avenue, and the Westwood Well was selected to operate all day. However, these alternatives do not represent a reliable solution for Zone 4A, in particular for customers in the south of the zone, so Optimatics recommends that the City maintain a tank at this site.

Table 2.11 – Recommended new storage – Final Build-out Solution

Location	Storage construction:	New Volume (MG)	Cost
Outback 4 & 5	Above-ground Concrete	6.0	$7,020,000
College 3	Above-ground Concrete	1.0	$2,366,000
Tower Rock 2	Above-ground Concrete	2.0	$3,755,000
Rock Bluff 2	Above-ground Concrete	2.0	$3,755,000
Pilot Butte 4 (Level 5)	Buried Concrete	3.0	$5,807,000
Westwood (replace)	Above-ground Concrete	0.5	$1,427,000
Total Cost		**14.5**	**$24,130,000**

Wells

A total of 36 MG of new well capacity is recommended in the Final Build-out Solution. Table 2.12 lists the locations and capacities of new wells at existing and new sites. As noted in Section 2.3.2, the optimization assumed that the surface water source would contribute 23 MGD in the build-out scenario. If this does not eventuate, new wells in addition to those listed will be required to meet firm supply capacity needs.

Table 2.12 – Recommended new wells – Final Build-out Solution

Location	Max Day Contribution (MG)	Maximum Flow Rate (gpm)	Pump Capacity (MGD)	Pump Head (ft)	Cost [2]
Expanded Outback Wells (#8-11)	5.8	4,000	5.8	~500	$7,776,000
New Overturf Well	1.4	1,000	1.4	~500	$1,944,000
Expanded Shilo Well (#2)[1]	1.3	1,400	2.0	~500	$2,721,600
Expanded Rock Bluff Wells (#4-6)	4.0	6,000	4.0	~400	$5,443,200
New Awbrey Wells (#1-4)	4.3	3,000	4.3	~500	$5,832,000
New East Level 5A Wells (#1-5)[3] In vicinity of Shirley Ct	7.1	4,900	7.1	~800	$9,525,600
New East Level 5B Wells (#1-2)[3] In vicinity of Paula Dr/Purcell Blvd	2.0	1,400	2.0	~800	$2,721,600
New Level 6 Wells (#1-4)[3] Butler Market Rd/Brinson Blvd	7.1	4,900	7.1	~800	$9,525,600
Total Well Cost	**34.3**		**35.7**		**$45,489,600**

1) Assumes Shilo Well 3 online, this is additional capacity
2) Includes cost of standby generator for each new well
3) These locations do not take into account issues related to potential groundwater contamination and 2 year time of travel

Of note, the optimization did not select to add any new wells at Pilot Butte (Well 4 was assumed to be online). Increasing the supply from this site necessitated additional pipe upgrades to deliver the supply to Level 5 and north to Level 6. Instead, the optimization favored developing new wells east of Pilot Butte, effectively distributing the supply and reducing the need for additional piping.

In the Consequence of Failure Analysis the area east of Pilot Butte in Level 5 was shown to be vulnerable in the event of a pipe break along Neff Road. New wells in this area will help address this issue by providing supply locally.

In Level 6, two new well sites were evaluated, one being the existing well site at Pine Nursery. The optimization favored the alternative site near the intersection of Butler Market Road and Brinson Blvd, as this location did not require significant additional piping to connect the supply into the existing system. By comparison, the well at Pine Nursery would require a significant length of main to be installed to connect the supply to Level 6 piping.

Expansion of the River Well site was not considered as an option in the optimization. However, it is noted that these pumps are running forward on their curves in the Build-out Maximum Day scenario. Optimatics recommends that the City monitor the operation of these wells and when they are due for replacement evaluate the pump head requirements for the replacement pumps.

Pumps

Two pump stations are recommended to be expanded in the Final Build-out Solution; Tetherow and Murphy. These stations supply isolated areas of the system and therefore it is important to ensure there is sufficient redundancy at each. Table 2.13 lists the recommended capacity increases at each station and the estimated associated costs.

Table 2.13 – Recommended new pumps – Final Build-out Solution

Description	Existing Capacity	Maximum flow rate for new pumps	Cost
Tetherow Pump Station Replacing pumps 4, 5 & 6 *MD + fire flow = 4,000 gpm*	1 x 150 gpm 5 x 700 gpm	3 x 1,250 gpm (replace 3 700s)	$784,800
Murphy Pump Station Replacing pumps 3, 4 & 5 *MD + fire flow = 2,500 gpm*	5 x 300 gpm	3 x 1,000 gpm (replace 3 300s)	$959,400
Total Pump Station Cost			**$1,744,200**

Note: Cost based on maximum flow rate using cost rate curve developed by MSA. Cost for pump replacement or additional pumps in an existing station assumed 60% of cost for new pumps.

For the Tetherow and Murphy Pump Stations, upgrades will be needed in the future to ensure firm capacity of maximum day plus fire flow is maintained (largest pump out of service). This can be achieved by switching out some of the existing pumps for higher capacity pumps. Based on the projected demand and fire flow requirements, three 1,250 gpm pumps will be needed in place of three 700 gpm pumps at Tetherow, and three 1,000 gpm pumps in place of three 300 gpm pumps at Murphy.

The College Pump Station is stated to have two pumps with capacities of 1,050 gpm and 900 gpm respectively. MSA confirms that the SCADA indicates this station can produce 1,950 gpm, and this has been field verified by Bend Operations staff. However, the pump curves in the model do not match this flow; the second pump capacity is only 400 gpm (see Figure 2.12). When the model is next updated, the pump curves should be revised to match field data.

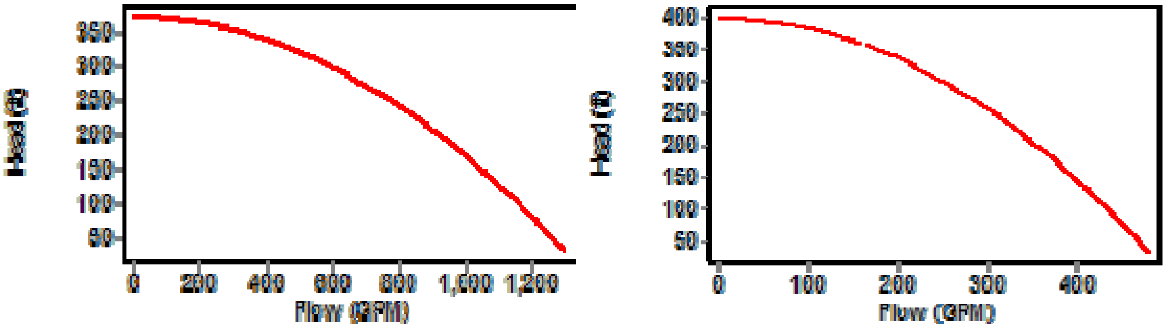


Figure 2.12 – College pump curves in the hydraulic model, Pump 1 right, Pump 2 left

All three pumps in the Scott Street Pump Station run in the build-out maximum day scenario. This pump station is not the sole source of supply to Zone 4B and thus is not as critical compared to Murphy Pump Station, for example. When the pumps at Scott Street reach the end of their useful life Optimatics recommends the City evaluate the typical operating points of these pumps to determine whether it makes sense to replace them with higher capacity pumps.

Valves

A number of new valves are recommended as part of the Final Build-out Solution; some to allow for additional supply to an area and others provide increased redundancy. Table 2.14 lists the new valves and associated costs. Although not required for hydraulic reasons (pressure, fire flow), based on the outcomes of the Consequence of Failure Analysis a new connection to Zone 7C Is recommended to provide a second supply to this area.

Table 2.14 – Recommended new valves – Final Build-out Solution

Description	Type	Status	Cost
New valve associated with new piping on Skyliners, Level 3 to Zone 4J/4A	PRV	Active	$75,000
PRV in new NW Development (reduce pressure for lower elevation areas north of butte)	PRV	Active	$75,000
New Level 5 to 6 connection at Division and Mt Washington	PRV	Active	$75,000
Connection from new NW development to Level 6	FCV	Active	$75,000
Level 3-4A connection near Westwood (helps fill the tank and provides emergency supply)	PRV	Active	$75,000
Second connection Zone 4B to Level 5 at Bear Creek Rd (assists fire flow)	PRV	Emergency	$75,000
New valve to assist with fire flow, Level 3 to Zone 4A north of Overturf	PRV	Emergency	$75,000
Second connection to Zone 7C	PRV	Emergency	$75,000
Total New Valve Cost			$600,000

In addition to the selection of new valves, the optimization evaluated the setting of a number of existing valves. In particular the optimization evaluated the settings for flow into Overturf and Awbrey Reservoirs, and the setting of the Athletic Club PRV. Further details of these operational decisions are discussed below.

2.8 Observations and Discussion

2.8.1 Westwood

The Final Build-out Solution recommends that the Westwood Pump Station be decommissioned and the Westwood Zone reconfigured such that higher elevation customers are supplied from Tetherow, and the remainder of the zone is absorbed into Level 3. There are a number of factors that contribute to this recommendation, as discussed below.

Operations advised that the Westwood pump station was implemented as a temporary facility and is in poor condition. The preference is to take it out of service if there is a way to work without it. Operations has successfully supplied all of Westwood (and 4H and 4I) from the Tetherow PS via the existing PRV (GIS ID WAPRV073) in the past. This operation is not recommend as a long-term solution as it does not capitalize on the fact that the lower elevation customers could be fed by gravity from Level 3, thereby reducing pumping costs.

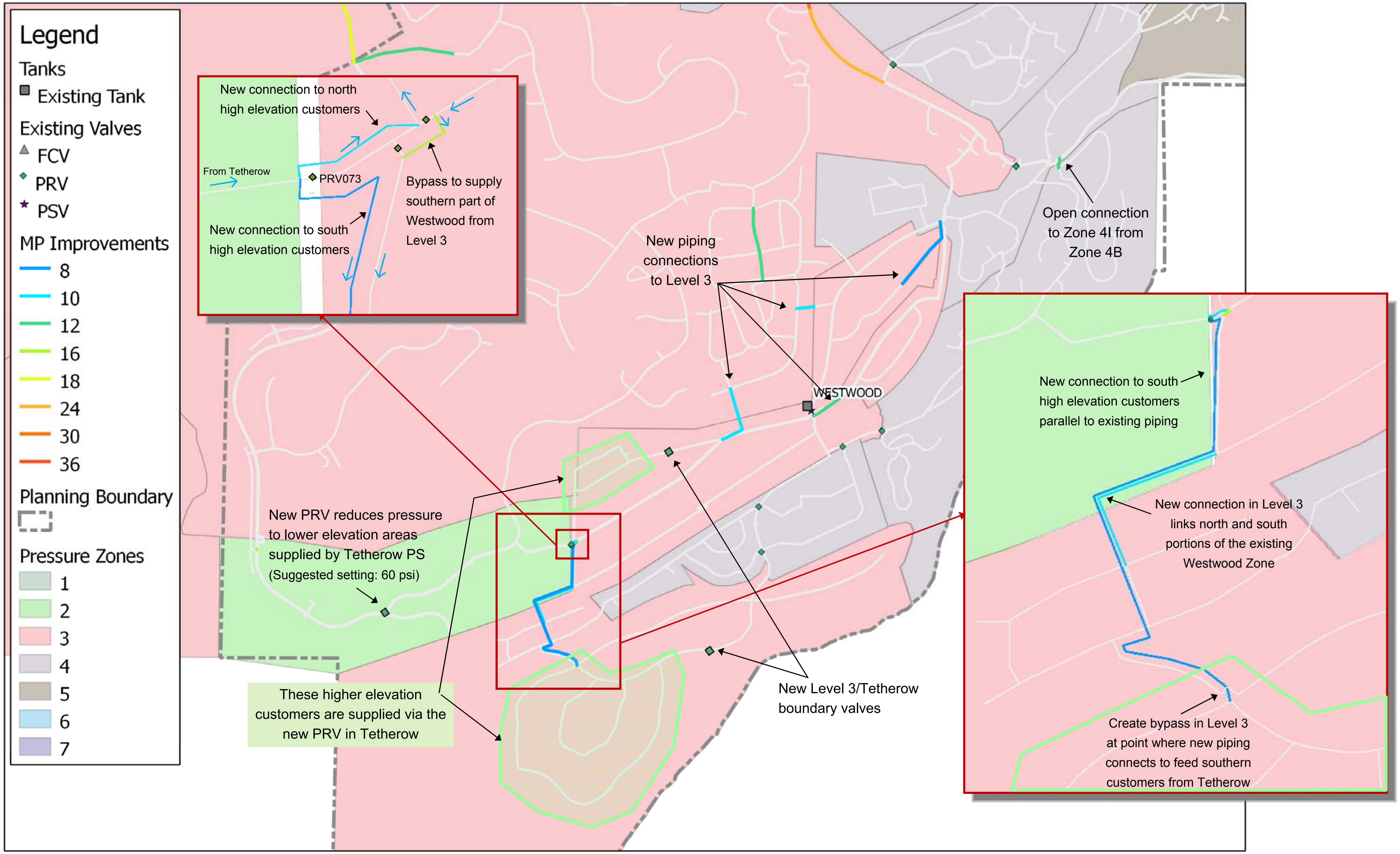
The hydraulic model demonstrates that it will be difficult to maintain the level in the Westwood Reservoir in the future if the pump station stays in service. Under build-out maximum day conditions, it is not possible to maintain the level in the Westwood Tank if the pump station is running, unless significant improvements were made in Zone 4A. There are restrictions to filling the reservoir because of the single 12-inch diameter connection between Overturf and Westwood, and the limit of Westwood Well. Total demand in the Westwood/Zone 4H/Zone 4I area is 1.9 MGD for Max Day Build-out; this is more than double the existing maximum day demand of 0.75 MGD. The optimization favored taking the Westwood PS offline for the following reasons:

- Reduces cost of pumping
- Eliminates the need for improvements in Zone 4A and expansion of Westwood PS/Reservoir

In the near term, some customers in Zone 4I can be supplied from Zone 4B by opening up a connection to the main on Reed Market Road (GIS ID WV0012721). This was recommended as part of the operations optimization to reduce demand off the Westwood pump station. This is also recommended in the Final Build-out Solution. The PRV that supplies Zone 4I (Station 64) remains active; approximately 50% of the demand is supplied from Zone 4B and the remainder is met through the PRV via Zone 4H.

The proposed long term solution involves shifting lower elevation Westwood Zone customers to be supplied from Level 3 and higher elevation customers to be supplied from Tetherow. A number of small new connections are needed between Westwood and Level 3 and within Westwood itself to maintain looping and reliable supply. These are shown in Figure 2.13.

It is acknowledged that Westwood customers would see lower pressures if they are supplied from Level 3, on the order of 10 psi lower. This would not be acceptable for high elevation customers in the southwest (River Bluff Trail) and north (Cartmill Drive) of the Westwood Zone. The proposed solution has these two areas supplied from the Tetherow PS via a PRV and new piping. For the lower elevation customers, given they currently see pressures above 65 psi at peak hour (most are higher, around 80-90 psi), a lower pressure would be adequate and well above the 40 psi requirement.



New connection to north high elevation customers

Bypass to supply southern part of Westwood from Level 3

New connection to south high elevation customers

New piping connections to Level 3

Open connection to Zone 4I from Zone 4B

New PRV reduces pressure to lower elevation areas supplied by Tetherow PS (Suggested setting: 60 psi)

These higher elevation customers are supplied via the new PRV in Tetherow

New Level 3/Tetherow boundary valves

New connection to south high elevation customers parallel to existing piping

New connection in Level 3 links north and south portions of the existing Westwood Zone

Create bypass in Level 3 at point where new piping connects to feed southern customers from Tetherow

Figure 2.13 – Recommended boundary changes and piping improvements for the Westwood Zone

Redundancy and fire flow

The recommended solution for Westwood involves creating a boundary between Tetherow and Level 3 in Westwood. It is recommended that valves are installed that will facilitate flow from Level 3 to the Tetherow Zone, and vice-versa, in the event of an emergency.

It should be noted that the proposed solution places greater reliance on the Tetherow Pump Station and the piping which feeds the pump station. Without the Westwood pump station it will be impossible to supply the club house in Tetherow in the event that the Tetherow Pump station was out of service. Given that the pump station has a large number of pumps, there would have to be a significant incident to prevent any flow through this station. In reviewing the proposed recommendations, Operations indicated that the Tetherow pump station is believed to be reliable as it is new; obviously it will be important to maintain back-up power facilities to this station. Improvements recommended in Level 3 on the suction side of the pump station will also increase redundancy.

Operations also reported that there have been challenges in the past meeting fire flow requirements in the south-east of the Westwood zone. If the higher elevation customers are supplied from Tetherow as proposed, this will eliminate the observed pressure problems. If the City desires the flexibility of meeting fire flow at these locations from Level 3 some additional improvements would be required. Analysis of the model with a fire flow of 1,500 gpm at the highest elevation node in Westwood indicated a restriction in the piping near these customers – approximately 2,000 ft of 8 inch pipe along Mammoth Drive and River Bluff Trail. Replacing this pipe with a 12-inch diameter pipe would result in adequate pressures under fire flow conditions, assuming supply via Level 3. This improvement is not included in the Final Build-out Solution as it is not deemed necessary, so long as the other improvements are implemented.

2.8.2 Tetherow

The City currently experiences problems with the Tetherow Pump Station; in particular it is difficult to maintain adequate suction pressure to the pump station during periods of high demand. In June 2010 MSA completed a preliminary review of alternative solutions to address the suction-side deficiencies under existing demand conditions. Their results indicated a number of alternative solutions that satisfied peak hour and fire flow demand conditions both in Level 3 and in the Tetherow zone. The optimization analysis reviewed these solutions under build-out conditions. MSA issued a memorandum summarizing the recommendations for this area - *City of Bend Water System – Tetherow Development: Alternatives Analysis*, January 2011 - which is included in **Appendix F**.

The section of Level 3 that supplies the suction side of the Tetherow Pump Station is currently supplied by a single 12-inch diameter connection to the piping along Mt. Washington Drive at Brokentop Drive. In addition to the observed pressure problems under high demand conditions, the Consequence of Failure Analysis completed as part of the Optimization Study highlighted this area as particularly vulnerable in the event of a pipe break near the connection point. The improvements considered for this area are aimed at both increasing service pressure and improving redundancy.

The improvements have been designed to meet residential fire flow rates in Level 3 on the suction side of the pump station, as well as the following fire flow rates at the highest elevation point in the Tetherow zone:

- 1,750 gpm under existing demand conditions
- 3,500 gpm under future build-out demand conditions

MSA's analysis identified the following improvement options, which were subsequently evaluated in the optimization. The locations of these improvements are shown on Figure 2.14.

A – Either open valves to allow flow from Level 3 through Zone 4K and provide individual PRVs to approximately ten customers in Zone 4K, or alternatively install a 12-inch diameter, 1,000-foot connection bypassing Zone 4K.

B – Construct a new line from the existing 16-inch diameter line on Skyline Ranch Road connecting to the 36-inch diameter line on Skyliners Road

G limited – Improve 12-inch diameter, 4,200-foot section on Mt Washington Drive to at least 16-inch diameter or larger

G extended – Extend improvement along Mt. Washington Drive from Skyliners Road to Brokentop Drive

D – Construct a new 12-inch diameter, 1,200 foot pipeline connection between the 16-inch diameter main on Skyline Ranch Road to the 12-inch diameter line on Brokentop Drive

T – Change the boundary of the Tetherow Zone, extending it to the intersection of Skene Trail and Skyline Ranch Road, primarily by closing /opening valves on existing pipelines plus one new connection.

The optimization analysis indicated that all of the above improvements are needed under build-out conditions. The recommended sizing and timing is listed in Table 2.15.

Table 2.15 – Recommended improvements for the Tetherow area including Level 3 based on Build-out Optimization analysis results

Improvement ID	Description	Recommended Size Build-out conditions	Estimated Cost	Recommended Timing
A	Bypass of Zone 4K from Hosmer Lake Dr to Green Lakes Loop.	12-inch	$204,000	2020
B	Connection from Skyliners to Skyline Ranch Rd	18-inch	$1,431,000	2011
D	Connection from Skyline Ranch Rd to Brokentop Dr	12-inch	$218,000	Build-out
G	Extended option – replace piping in Mt Washington from Skyliners Rd to Brokentop Dr	36-inch 30-inch	$334,000 $2,135,000	Build-out
T	Shift customers along Bonneville Loop to Tetherow Zone with a new connection and closing a valve at Skene Tr	8-inch	$1,400	2011

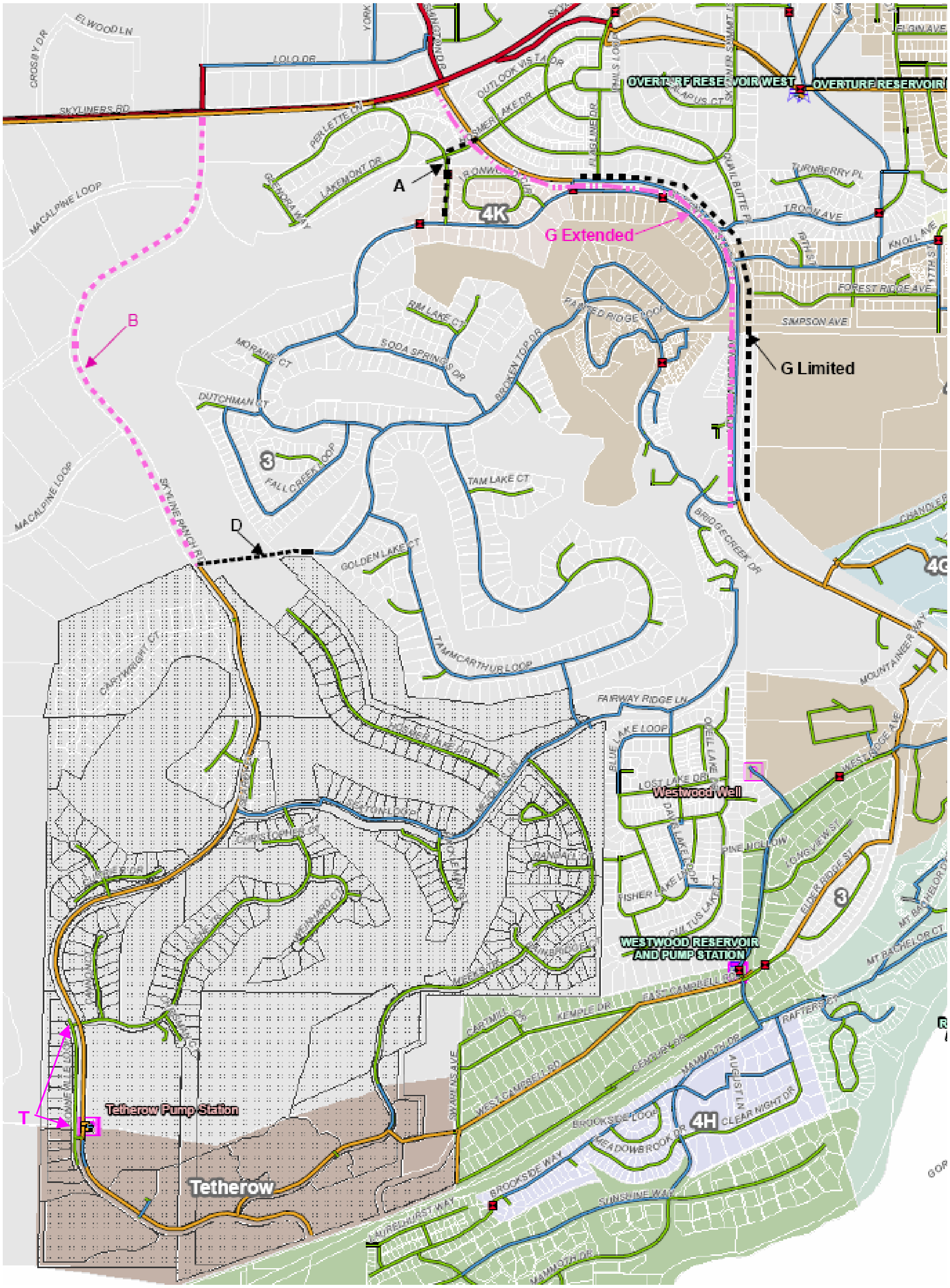


Figure 2.14 – Improvement Options for Tetherow area – per MSA Memo June 2010

2.8.3 Juniper Ridge Improvements

The optimization evaluated the option of a new tank in the vicinity of Pilot Butte at Level 6 hydraulic grade, as proposed by MSA in their evaluation of improvements needed to support the Juniper Ridge development (refer to MSA memo *Water System Planning for the Juniper Ridge Development, Bend, Oregon*, September 2009, **Appendix A**). In addition, the optimization evaluated the option of a tank at Level 5 hydraulic grade. This option was discussed at a number of project meetings and it was agreed it could be feasible if located on the north face of the butte and there would be less public opposition.

Given these two options, the optimization favored a tank located at the Level 5 hydraulic grade; it did not select to implement the Level 6 tank option. The Level 6 tank option was likely less favorable as it does not support Level 5 and would also require a significant length of new pipe to connect the outlet of the tank to Level 6.

The recommended volume of the Level 5 Pilot Butte Tank in the Final Build-out Solution is 3 MG; less than the proposed volume of 5.7 MG at Build-out for the Level 6 Juniper Ridge Tank. The 5.7 MG volume was calculated based on the needs of the Juniper Ridge development in isolation from the rest of the Bend system. The storage volumes proposed in the Final Build-out Solution reflect the needs of the entire system and take into account the ability to move supply from higher zones to lower zones to meet equalization, standby and fire suppression needs.

2.8.4 South Bend

Significant improvements are planned for the South Bend area (former Juniper Utility). MSA reviewed the area as part of a separate study and recommended new transmission and distribution piping improvements that will enable the City to provide satisfactory service under future maximum day demand and fire flow conditions. Although the distribution improvements were not reviewed as part of the optimization study, the transmission improvements were included in the optimization to verify the recommended sizes. The optimization also evaluated the operation of Murphy Pump Station, the Shilo Wells and the potential benefit of including a tank south of the region.

The model was set up as per the recommendations in MSA's Memorandum *Former Juniper Utility – Proposed Water System Improvements* (**Appendix F**). The changes to the existing system included:

- Tillicum rezoned into Zone 4B
- Shilo Wells pumping to Level 4 via new piping (12-inch diameter)
- New piping from Murphy Pump Station to the Shilo Wells and south to Mountain High.
  Phase 1: 16-inch diameter main south from Shilo to the Mountain High Loop.
  Phase 2: 12-inch diameter main from Mountain High Loop to Mountain High.
- Murphy Pump Station operating to supply Level 2 (Mountain High) with Level 3 being fed via existing PRV 69 and a new PRV at the northern end of Timber Ridge. Hole Ten wells emergency only

The proposed transmission piping sizes along Country Club Drive and Mountain High Loop in the Final Build-out Solution are consistent with those proposed by MSA (as noted above).

Storage tank

The option to build a storage tank sound of the Bend system that would be shared with Roats Water System was evaluated in the optimization. There are merits to this option including increased reliability for the South Bend area and reduced potential for pressure fluctuations due to operating a constant pressure pumped system. However, the feasible sites for storage are a significant distance from the existing piping and connecting a tank to the system would be costly. As a result, this option was never selected in the optimization solutions. In discussions with Bend staff it was agreed that the costs outweighed the benefits of this option.

2.8.5 Pilot Butte Wells

The City has existing plans for additional wells at the Pilot Butte site. The option to expand the well pumping capacity, up to the maximum allowed at this site, was considered in the optimization. No additional wells (after Well 4) were recommended as part of the Final Build-out Solution. Interim solutions that included new wells at this site required additional piping capacity (above what is currently proposed) to utilize the extra supply. As discussed in the following section, alternative well sites were evaluated east of Pilot Butte, and in Level 6. These sites were selected in preference to expanding capacity at Pilot Butte.

2.8.6 Storage and well supply at Rock Bluff

Interim solutions presented for the build-out scenario did not include any new storage at the Rock Bluff facility. However, a significant increase in the well capacity at this site was observed in the interim solutions (up to 8 MGD additional capacity). Given Operations' preference for maintaining storage above ground, and the fact that the City currently has plans for storage at this site, the hydraulic model was analyzed to determine an alternative solution at this site involving increased storage and a lower groundwater pumping rate. It was determined that a similar hydraulic performance could be achieved for a similar cost if the groundwater wells pumped at a lower rate for a longer period of time, and the total storage volume was increased by 2 MG. Given that the cost of these two options is very similar (within $1 million); the Final Build-out Solution includes the recommendation to build additional storage at Rock Bluff, together with new wells with a capacity of 4 MGD.

2.8.7 New Wells located in the east

Feedback from operations staff indicated that wells in the east would be a welcome addition to the system. The previous Master Plan also included a recommendation to build supply capacity in the east of the system. Note that this study did not consider the potential impact of groundwater contamination and 2-year time of travel.

Four potential new sites were evaluated, as discussed in Section 2.6.1.3 – two in Level 5 east of Pilot Butte, the Pine Nursery location (Level 6) and a site in Level six near the intersection of Butler Market Road and Brinson Boulevard. New well sites were assigned an additional cost ($1m) in the optimization formulation to account for the need to acquire land and set up a new facility. Despite this cost, the optimization favored implementing well capacity at these sites.

The City was interested to know what the impact would be if new well sites in Level 5 and 6 were not allowed as choices in the optimization. The optimization tested the sensitivity of the solutions to these options. The results indicated that without new wells in the east, additional piping on the order of $10 million would be necessary to transmit the supply from alternative sites. Since the total amount of supply that is needed remains the same regardless of where it is located, other costs related to new well and storage capacity were very similar.

Another observation from the sensitivity runs was that placing new wells on the east side of the system also reduced the tendency of the optimization solutions to rely on proposed new piping in the northwest to assist in transmitting supply to the northeast. This is illustrated in Figure 2.15. The addition of new piping capacity in the northwest is completely dependent on the timing and scope of new development.

City Engineering and Operations staff confirmed that, if the total number of wells is the same, having more well sites would not significantly increase operations and maintenance efforts. Since all new wells will be on SCADA they will not require manual starting. Given the above observations, the Final Build-out Solution includes the recommendation to install new wells in the east of the system.

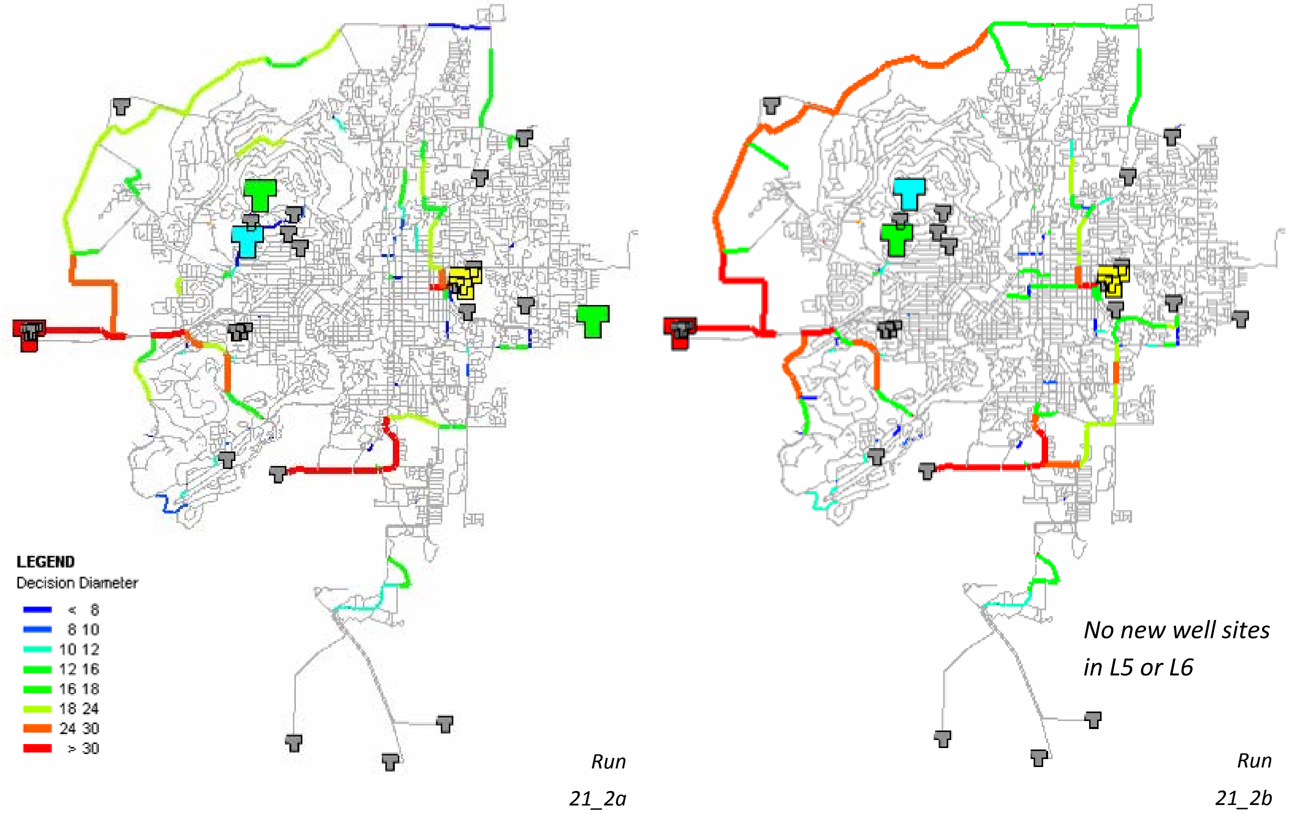


Figure 2.15 – Results of two scenario runs, one with the option to place wells in the east of the system (left), and one without (right)

2.8.8 Development Northwest of Awbrey Butte

The build-out demand projection assumes there will be new development west and north of Awbrey Butte. As shown on Figure 2.11, the proposed piping to serve these developments in the Final Build-out Solution follows a path outside of UGB; the routes follow existing roadways, however they are intended as placeholders only. If or when development occurs in this area it is anticipated that additional corridors will become available for new transmission pipes.

The assumption that growth will occur in the area northwest of Awbrey Butte affects the recommendations for the location of new supply and transmission infrastructure. Located close to the Outback facility, these new development areas are supplied solely from Outback, resulting in the need for new supply capacity and parallel mains. The optimization results also indicated that, assuming the northwest development does go ahead, there would be benefit in extending the transmission improvements all the way to tie into Level 6 near the Juniper Ridge development.

As part of the staging process to develop the 10-year CIP, Optimatics evaluated the need for additional transmission capacity under lower demand conditions. The results indicated that without the new development and if capacity at Outback remains close to the current capacity, there is no need to parallel the lines from Outback. If new capacity is added at Outback but the new northwest developments are not in place, the size of the parallel main can be significantly smaller than the current recommended size in the Final Build-out Solution. Given this information, the City should review the needed improvements in this area of the system in the future when more is known about the likely extent and location of new development.

2.8.9 Operational decisions

One key observation from the optimization results is that there was a trend towards minimizing the amount of supply transferred from Outback to the Overturf and Awbrey Reservoirs. New wells have been recommended at both the Overturf and Awbrey sites to help maintain the reservoir levels as demands increase. Flow into the tanks via the existing inlet valves is controlled in the Final Build-out Solution to minimize filling during peak demand periods. Awbrey does not receive inflow from Outback during the morning peak demand period. When Awbrey Reservoir is filling the flow rate is approximately 4,000 gpm. Conversely, Overturf Reservoir does fill during the morning, but at a reduced rate (less than 1,000 gpm).

The additional supply capacity at Outback is primarily diverted north to the new northwest development, and south via Mt Washington Drive to Zone 4B through the Athletic Club PRV. The setting of the Athletic Club PRV is recommended to increase as demand increases in Zone 4B. The proposed setting in the Final Build-out Solution is 80 psi. Operations expressed concern that raising the setting of the PRV would affect Rock Bluff and Pilot Butte 2 Reservoirs. This would be true under existing conditions; under the build-out scenario there is significantly more demand in Zone 4B and the model does not indicate that raising the setting will impact the operation of Rock Bluff or Pilot Butte 2.

The trigger level settings for pumps and wells that are based on reservoir levels were evaluated in the optimization. Due to the scenario being a build-out maximum day demand case, all existing wells were selected to operate to meet the high level of demand; there was little change to the trigger level settings for those pumps that are already controlled based on tank levels. It was assumed that the Pilot Butte Wells would be placed on SCADA and trigger level controls were developed for these pumps based on the level in Pilot Butte Reservoir 1 (lead pump on at 28 ft, off at 31 ft, lag pump on at 24 ft, off at 29 ft). As per the

Operations Optimization recommendations, the River Wells were configured to operate based on the level in the Awbrey Reservoir.

The Operations Optimization results indicated a benefit in running the Scott Street pump station in preference to the Bear Creek Wells. The head requirement of the booster pumps is much less than the wells, so the associated energy costs are less. In the build-out maximum day scenario it is necessary to run the Bear Creek wells in order to meet the supply requirements of the system. Under lower demand conditions it is still recommended that the Scott Street pumps run as the lead facility to fill Pilot Butte 2 Reservoir.

The new wells in Level 6 will likely need to be controlled based on system pressure in that zone. The new wells in Level 5 could be controlled based on the level in the Pilot Butte reservoirs, or they could be controlled based on system pressure in the area east of Pilot Butte. Operation of new wells located at existing storage facilities would be controlled based on the levels in the tank.

2.8.10 Flow from Outback

Figure 2.16 compares flow from the Outback facility in the 2008 Summer EPS Scenario and the Final Build-out Solution. In addition to the assumption that the surface water source will provide 23 MGD by build-out, 6 MGD of new well capacity is recommended at Outback to help meet the demands of new development. If, as seems most likely at the time of writing, the capacity of the surface water source is only 13.5 MGD, an additional 9.5 MGD of well capacity would need to be substituted at Outback to maintain the same flow from this facility in the Final Build-out Solution (bringing total new well supply at this site to 15.5 MGD). As mentioned in Section 2.8.8, a large proportion of the flow from Outback in the build-out scenario supplies new development northwest of Awbrey Butte (14 MGD under Build-out MDD).

It is not known whether the Outback site could support such a significant increase in well capacity, however, it was not possible to address this in the current study. The City should investigate the groundwater withdrawal limits at Outback. If the maximum potential well supply is significantly less, the Final Build-out Solution will need to be revised.

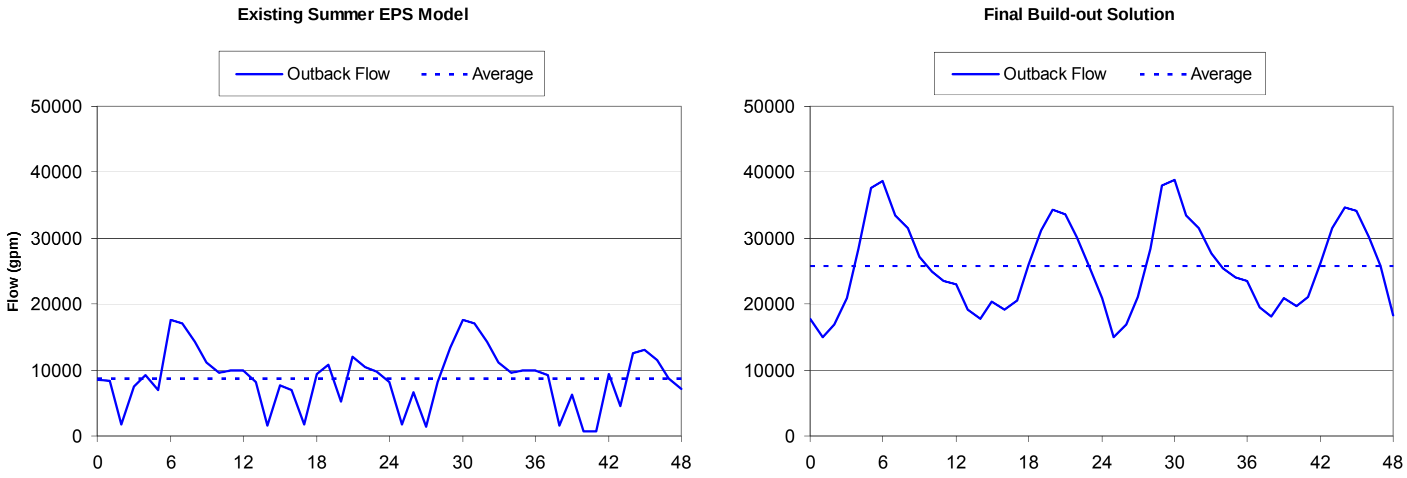
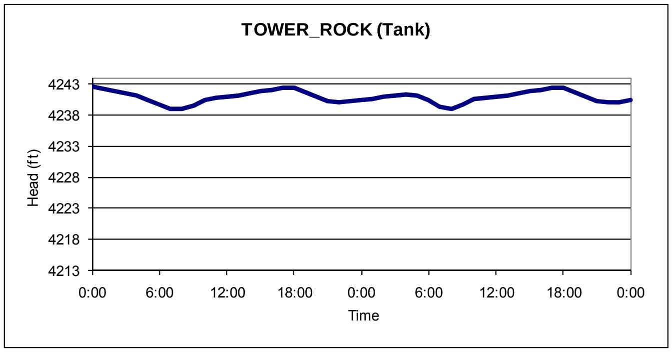
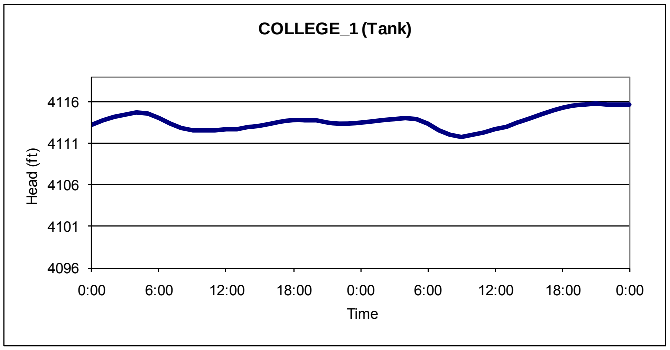


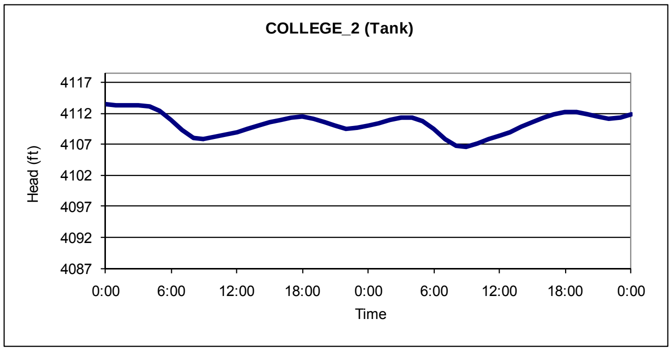
Figure 2.16 – Flow from Outback - Summer EPS scenario left, Final Build-out Solution right

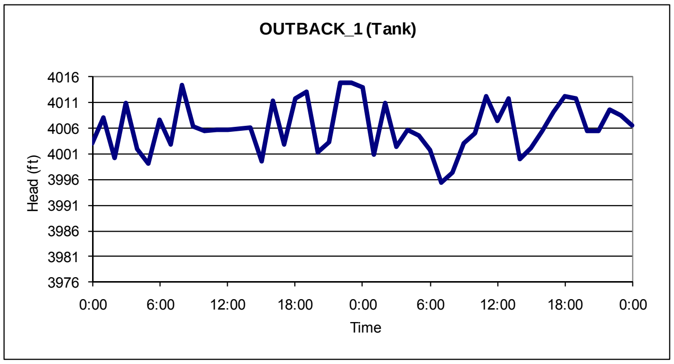
2.8.11 Reservoir levels

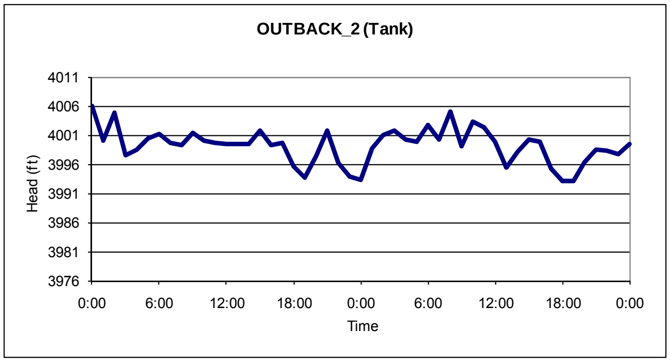
Optimization was constrained to ensure that storage tanks did not lose volume over a 24-hour period, that is, they should return to their start level by the end of the day. The following charts demonstrate how each tank level fluctuates over the course of two consecutive build-out maximum day demand scenarios.

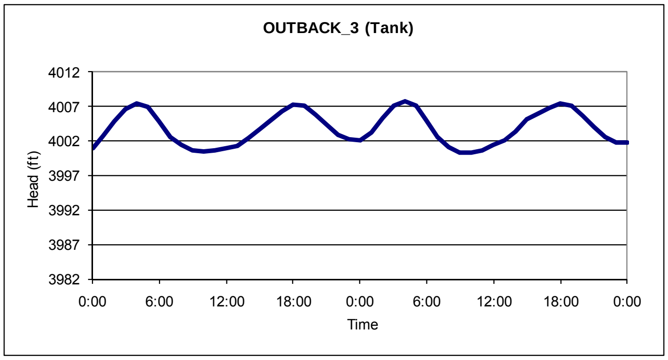

TOWER_ROCK (Tank)

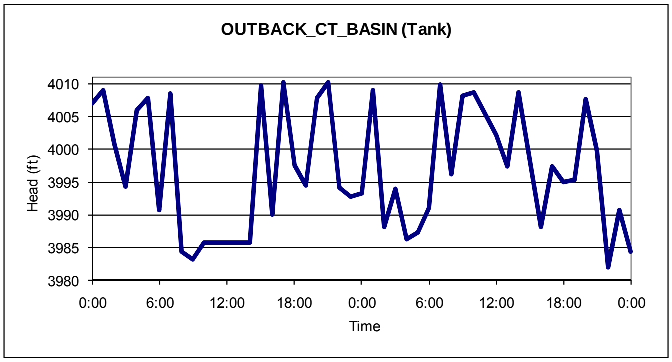

COLLEGE_1 (Tank)

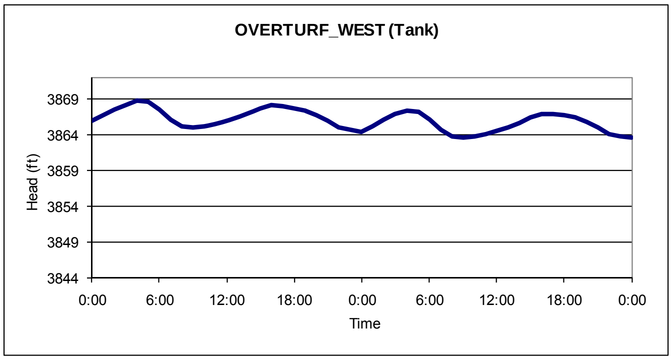

COLLEGE_2 (Tank)


OUTBACK_1 (Tank)


OUTBACK_2 (Tank)


OUTBACK_3 (Tank)


OUTBACK_CT_BASIN (Tank)


OVERTURF_WEST (Tank)

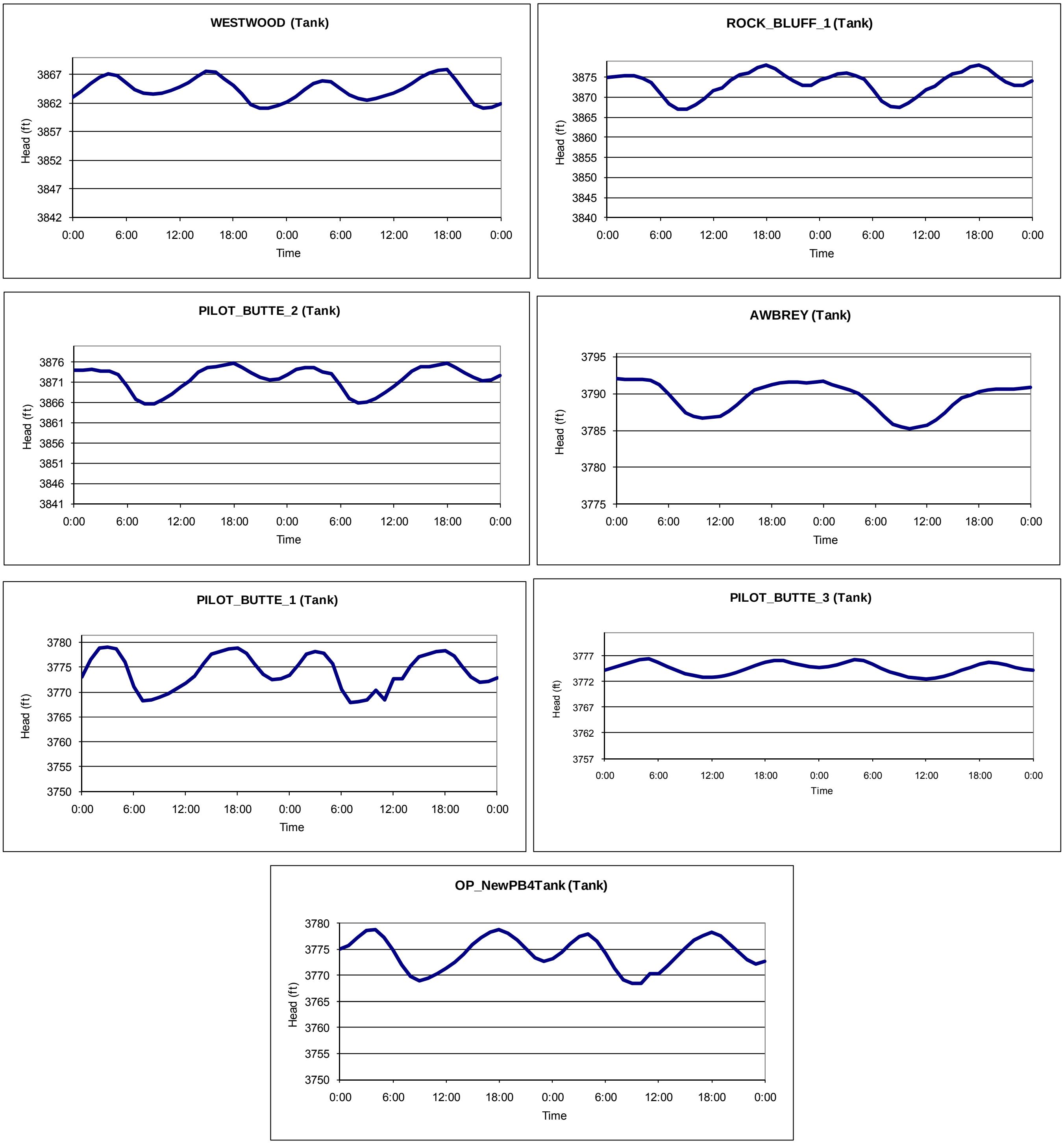


Figure 2.17 – Water levels in each tank in the Final Build-out Solution

2.8.12 Emergency Storage

As discussed in Section 2.5.4, the City decided to adopt the Washington Design Manual guidelines for determination of emergency storage in this study. The optimization was formulated to ensure that fire storage volume for each zone was maintained in above-ground storage. The resulting solutions were checked to ensure they include enough above-ground storage and reliable groundwater supply to meet standby storage requirements.

Table 2.16 contains a list of current and proposed future groundwater wells and their capacities at build-out and compares this to projected maximum day demand. The table then determines whether or not wells can be relied upon to meet emergency supply needs based on whether they are connected to SCADA and have back-up power. The table is grouped based on major supply areas: Levels 1, 2 and 3 (including all the pressure zones around Awbrey Butte); Zone 4A; Zone 4B; Levels 5, 6 and 7; and South Bend (Zones 2B and 3D). The capacity of redundant wells in the system is then compared to the emergency storage requirement of two times average day demand. The table demonstrates that there is ample reliable groundwater capacity to offset standby storage needs at build-out.

Table 2.17 lists the existing and proposed future storage volumes at each storage site. For each tank, the minimum water level observed during the maximum day simulation in the model is used to determine the amount of emergency storage in each tank. This is then compared to the required fire and standby storage volumes for the zones which are supported by each tank, or group of tanks. Finally, where there is a deficit, the table applies reliable groundwater supply to offset the storage requirement. Based on this analysis, approximately 25% of the overall standby storage requirements at build-out are provided by above ground storage in the Final Build-out Solution. This is consistent with the amount of standby storage maintained above ground in the existing system (refer Section 2.5.4)

2.8.13 System flows

Figure 2.18 shows the system schematic and flows from wells and through valves and pumps between zones in the Final Build-out Solution. The flows are based on operation during a Build-out Maximum Day.

Table 2.16 – Comparison of well capacity recommended in the Final Build-out Solution and demand by pressure level under projected build-out conditions

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
						=sum(F) Red => G<H				=F x I x J	discount non-redundant	=sum(L)	=M x 2 Red => N<O	
Production Facility	**Zone Supplied**	**Pump Size (hp) / Capacity (MGD)**	**Pump Type OR New Well Count**	**Approx. Static Water Level (feet)**	**Capacity (MGD)**	**Total Capacity MGD**	**Build-out MDD MGD**	**Future Back-up Power**	**Future SCADA Capability**	**Capacity Back-up + SCADA**	**Firm**	**Firm Capacity MGD**	**Supply Volume over 2 days**	**Standby 2xADD MGD**
Surface Water Source	**3**				**23.0**					**7.2**	**7.2**			
COPPERSTONE_W	3	250	Line Shaft Turbine	510	1.4			0	0	0.0	0.0			
OUTBACK_W1	3	150	Submersible	482	1.0			1	0	0.0	0.0			
OUTBACK_W2	3	150	Submersible	482	1.1			1	0	0.0	0.0			
OUTBACK_W3	3	250	Line Shaft Turbine	478	1.7			1	1	1.7	1.7			
OUTBACK_W4	3	250	Line Shaft Turbine	482	1.7			1	1	1.7	1.7			
OUTBACK_W5	3	250	Line Shaft Turbine	486	1.8			1	1	1.8	0.0			
OUTBACK_W6	3	250	Line Shaft Turbine	480	1.8			1	1	1.8	1.8			
OUTBACK_W7	3	250	Line Shaft Turbine	480	1.8			1	1	1.8	1.8			
OUTBACK_W8	*3*	*1.8 MGD*	*1*	*480*	*1.8*			*1*	*1*	1.8	0.0			
New Level 3 (Outback)	*3*	*1.3 MGD*	*3*	*480*	*3.9*	41.0	24.4	*0.67*	*1*	*2.6*	*2.6*	16.8	33.6	21.7
WESTWOOD_W	4A	150	Submersible	283	1.0			0	1	0.0	0.0			
New Level 4 (Overturf)	*4A*	*1.4 MGD*	*1*	*n/a*	*1.4*	2.4	3.6	*0.00*	*1*	*0.0*	*0.0*	0.0	0.0	3.2
BEAR_CREEK_W1	4B	350	Line Shaft Turbine	629	1.5			0	1	0.0	0.0			
BEAR_CREEK_W2	4B	350	Line Shaft Turbine	652	1.6			0	1	0.0	0.0			
ROCK_BLUFF_W1	4B	150	Line Shaft Turbine	393	1.2			1	1	1.2	1.2			
ROCK_BLUFF_W2	4B	150	Submersible	395	1.1			0	0	0.0	0.0			
ROCK_BLUFF_W3	4B	150	Line Shaft Turbine	395	1.2			1	1	1.2	0.0			
SHILOH_W3	4B	250	Line Shaft Turbine	355	2.0			1	1	2.0	0.0			
New Level 4 (Shilo)	*4B*	*1.0 MGD*	*2*	*355*	*2.0*			*0.50*	*1*	*1.0*	*1.0*			
New Level 4 (Rock Bluff)	*4B*	*1.3 MGD*	*3*	*395*	*3.9*	14.5	12.2	*0.67*	*1*	*2.6*	*2.6*	4.8	9.6	10.8
PILOT_BUTTE_W1	5	250	Line Shaft Turbine	743	1.2			0	0	0.0	0.0			
PILOT_BUTTE_W3	5	250	Submersible	786	1.3			0	1	0.0	0.0			
PILOT_BUTTE_W4	5 (4B emerg)	300	Line Shaft Turbine	702	1.6			1	1	1.6	0.0			
New Zone 5 (Awbrey)	*5*	*1.1 MGD*	*4*	*n/a*	*4.4*			*0.75*	*1*	*3.3*	*3.3*			
New Zone 5A (Pumped ground facilities)	*5*	*1.4 MGD*	*5*	*n/a*	*7.0*			*0.80*	*1*	*5.6*	*5.6*			
New Zone 5B (Pumped ground facilities)	*5*	*1.0 MGD*	*2*	*n/a*	*2.0*			*0.50*	*1*	*1.0*	*1.0*			
RIVER_W1	5	500	Line Shaft Turbine	360	2.7			1	1	2.7	2.7			
RIVER_W2	5	400	Line Shaft Turbine	242	3.0			1	1	3.0	0.0			
New Zone 6 (Pumped ground facilities)	*6*	*1.8 MGD*	*4*	*n/a*	*7.2*	30.4	41.7	*0.75*	*1*	*5.4*	*5.4*	18.0	36.0	37.1
HOLE_10_W1	2B	150	Submersible	410	0.8			1	1	0.8	0.8			
HOLE_10_W2	2B	150	Submersible	412	0.8	1.6	1.6	1	1	0.8	0.0	0.8	1.6	1.4
Existing Groundwater Supply Capacity (MGD) (excluding Rock Bluff 2)					**32.2**									
Total Future Groundwater Supply Capacity (MGD)					**66.9**	**66.9**				**45.4**	**33.2**	**33.2**	**66.4**	**74.2**
Total Supply Capacity (Ground and Surface) (MGD)					**89.9**	**89.9**	**83.5**			**52.6**	**40.4**	**40.4**	**80.8**	

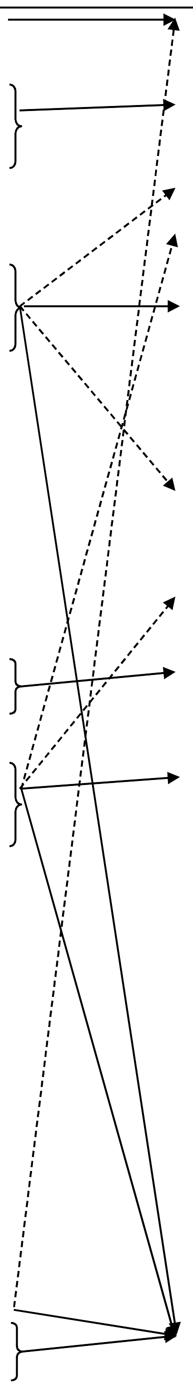
Key to Table 2.16 :

New Well	Proposed details
Assumed future SCADA/Back-up power status	
Not counted, not redundant	

Notes to Table 2.16

1) Red text in Columns G and N indicates that the available capacity in a particular level is less than the required capacity. In all of these cases, however, supply is available from a higher zone to meet the deficit
2) Outback Wells 1 & 2 portable generator has capacity to run one well at a time
3) Two of Outback Wells 3, 4 & 5 can run on one generator
4) Outback Well 6 generator should operate three wells eventually
5) Generator at Rock Bluff is able to run two of the three wells at once
6) Rock Bluff 2 is always off
7) Shilo Wells are currently out of service. Shilo 3 was scheduled to have portable generator plug-in facilities following upgrade in Spring 2010
8) Pilot Butte 2 has been decommissioned
9) Generator confirmed at Pilot Butte 4, no generator at Pilot Butte 3

Table 2.17 – Assessment of available above-ground emergency storage compared to requirements



	A	B	C	D	E	F	G				H	I	J	K	L
Storage	**Storage Volume (MG)**	**Dead storage (static 25 psi)**	**Minimum level on MD**	**% Emerg Avail**	**Emergency Volume (MG)**	**Fire suppression (MG)**	**Standby Avail (MG)**	**- - ▸ Pumping ──▸ Direct/PRV**	**Zone**		**Standby Requirement 2xADD**	**Combined Standby**	***Offset from Wells w back-up power (2 days x MGD)***	**Allocation to/from other zones**	**Capacity div by Requirements**
		From model	From model	=C-B	=D*A		=E-F					=sum of H	*From Well Summary*		=(G+J+K)/I
TOWER_ROCK	1.0	15%	84%	69%	0.68	0.18	1.90		1		1.16	1.16		-0.50	120%
TOWER_ROCK_2	2.0	15%	84%	69%	1.39									To Level 2	
COLLEGE_1	0.5	0%	72%	72%	0.36				2		1.21	1.50		0.50	108%
COLLEGE_2	1.0	6%	63%	57%	0.58	0.54	1.13							From Level 1	
COLLEGE_3	1.0	0%	72%	72%	0.72										
									2A	Teth PS, 3	0.31	*in 3*			
													Hole Ten		
									2B	South Bend	0.54	*in 4B*	1.60		
Note: Assuming Outback 1 & 2 can contribute to standby given treatment upgrades															
OUTBACK_1	2.3	0%	60%	60%	1.37								*Outback, Copperstone*		
OUTBACK_2	3.0	0%	48%	48%	1.45				3		10.55	19.04	19.20	-5.00	116%
OUTBACK_3	3.7	0%	68%	68%	2.49	1.50	7.88							To 4A, 4B & 5	
OUTBACK_4/5	6.0	0%	68%	68%	4.07										
OUTBACK_CT_BASIN	1.5	100%	n/a, required for CT						3A		0.19	*in 2*			
									3B		0.10	*in 2*			
									3C	WestW PS, 4A	0.99	*in 3*			
									7	N Awbrey Butte	0.99	*in 3*			
													Shilo		
									3D	South Bend	0.88	*in 2B*	0.00		
WESTWOOD	0.5	34%	68%	34%	0.16								*Westwood, New wells*		
OVERTURF_EAST	1.5	26%	74%	48%	0.69	0.54	1.01		4A		3.17	3.17	0.00	2.50	111%
OVERTURF_WEST	1.5	26%	74%	48%	0.69									From 3	
													Bear Creek, Rock Bluff, Shilo (rezoned)		
ROCK_BLUFF_1	1.5	0%	69%	69%	1.07				4B		10.82	12.24	9.60	2.50	114%
ROCK_BLUFF_2	2.3	0%	69%	69%	1.62	1.50	1.82							From 3	
PILOT_BUTTE_2	1.0	0%	64%	64%	0.63										
									4C		0.30	*in 3*			
									4D		0.29	*in 3*			
									4E		1.63	*in 3*			
									4F		0.16	*in 3*			
									4G		0.24	*in 3*			
									4H	Off Westwood	0.19	*in 3*			
									4I	Off Westwood	0.54	*in 3*	*4A?*		
									4J		0.23	*in 3*			
									4K		0.06	*in 3*			
AWBREY	5.1	0%	58%	58%	2.97								*River, Pilot Butte, New Zone 5 wells*		
PILOT_BUTTE_1	1.5	12%	58%	46%	0.68				5		16.25	37.09	25.20	10.80	111%
PILOT_BUTTE_3	5.0	0%	64%	64%	3.20	3.00	5.18							From L6 wells	
OP_NewPB4Tank	3.0	0%	44%	44%	1.34										
									5A		0.02	*in 3*			
									5B		1.27	*in 3*			
									5C	With 4E	0.04	*in 3*			
									5D		0.09	*in 3*			
													New Zone 6 wells		
									6		15.79	*in 5*	10.80	-10.80	
														To Level 5	
									6A		0.77	*in 5*			
									6B		1.15	*in 3*			
Note: Green text indicates new storage volumes									6C	Juniper Ridge	3.25	*in 5*			
									7A	With 5B	0.61	*in 5*			
									7B		0.22	*in 5*			
									7C		0.17	*in 5*			
									7D		0.03	*in 5*			
Totals	**45.0**	**3.13**			**26.2**	**7.26**	**18.90**				**74.20**	**74.20**	**66.40**	**0.00**	**115%**
			Percentage of standby requirements being met above ground				25%						89%		

Notes:

Dashed and solid lines indicate how supply from reservoirs can be transferred to lower or higher zones (solid indicates gravity supply through PRVs, dashed lines indicate pumping)

Colors in Column I indicate which zones have been grouped together.

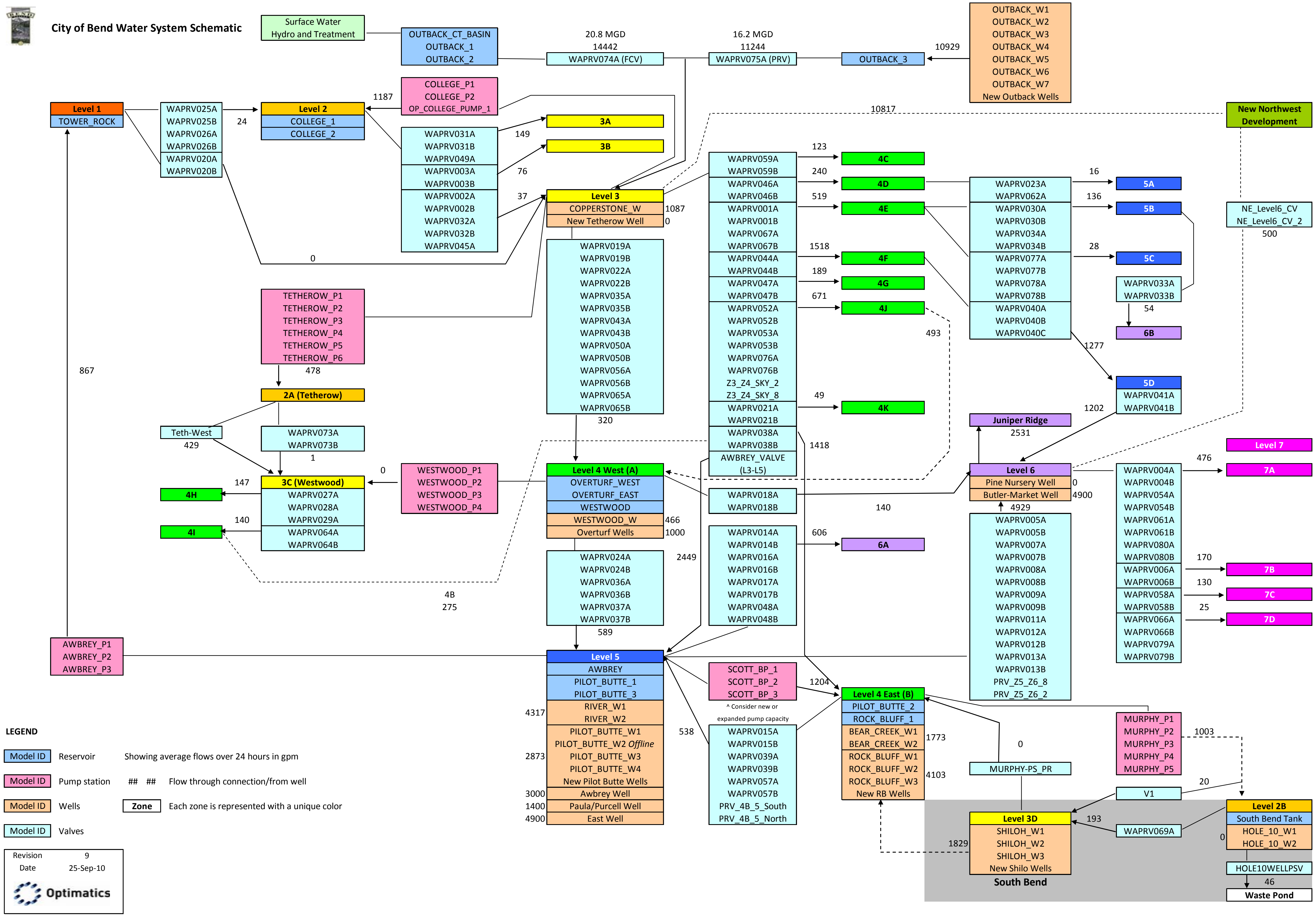


Figure 2.18 – Major flows in the Bend System – Final Build-out Solution

2.8.14 Fire Flow Improvements

The determination of fire flow improvement needs was carried out in an analysis separate from the optimization. The improvements were fixed in the model prior to evaluating the build-out scenario, except in instances where upsizing a replacement pipe would potentially provide benefit to the system in meeting maximum day or peak hour demands (this was relevant primary in Level 5).

Each zone was analyzed to determine which pipes needed to be replaced and at what size to ensure the fire flow could be provided at a residual pressure of 20 psi at every node. The improvements addressed all pipe deficiencies, regardless of whether the pipe served a hydrant or not. This analysis resulted in the identification of approximately 30 miles of fire flow improvements. All 2-inch diameter lines were assessed to determine what replacement size would meet fire flow requirements. Later a review of hydrant locations confirmed that no 2-inch diameter pipe has a hydrant connected to it, so these improvements are provided in a separate list and not included in the cost summary.

To assist in prioritizing the improvements, Optimatics also performed an ‘available’ fire flow analysis – looking at how much flow can be taken from the system at any point without drawing system pressures below 20 psi. Figure 2.19 shows the available flow at 20 psi calculated for each pipe in the system under existing maximum day demand conditions. The analysis did not take into account any losses or restrictions that may exist at hydrant laterals or hydrants themselves, but provides an indication of the system’s capacity to convey flow which in turn makes it possible to see which improvements are most critical. This is in line with the approach used by commercial modeling packages such as InfoWater.

Prior to running the available flow analysis, Optimatics used a tool to snap hydrants to pipes in the model with reference to the hydrant coordinates and stub line information from the GIS. In this way the available flow analysis reported on both the flow available to the downstream end of each pipe and also to each hydrant in the system.

In order to come up with a final list of fire flow improvements, the results of the available flow analysis were used to determine which hydrants could not meet the required flow. Using this information, it was possible to determine which pipe improvements are needed to address hydrant deficiencies, and which are only required if new hydrants are installed on deficient lines. The total cost for replacement of mains addressing hydrant deficiencies under Build-out demand conditions is $11,458,000. A subset of these improvements is needed to address existing deficiencies. More detail of the existing system fire flow improvements is provided in Section 4.

A listing of the recommended pipe improvements addressing fire flow requirements is provided in **Appendix H**. Each improvement has been assigned a project reference, and related projects are grouped together under a single project reference. The listing in **Appendix H** includes and clearly identifies improvements that address existing deficiencies, as well as recommended replacement sizes addressing anticipated future deficiencies, undersized mains which do not currently have hydrants and 2-inch diameter mains.

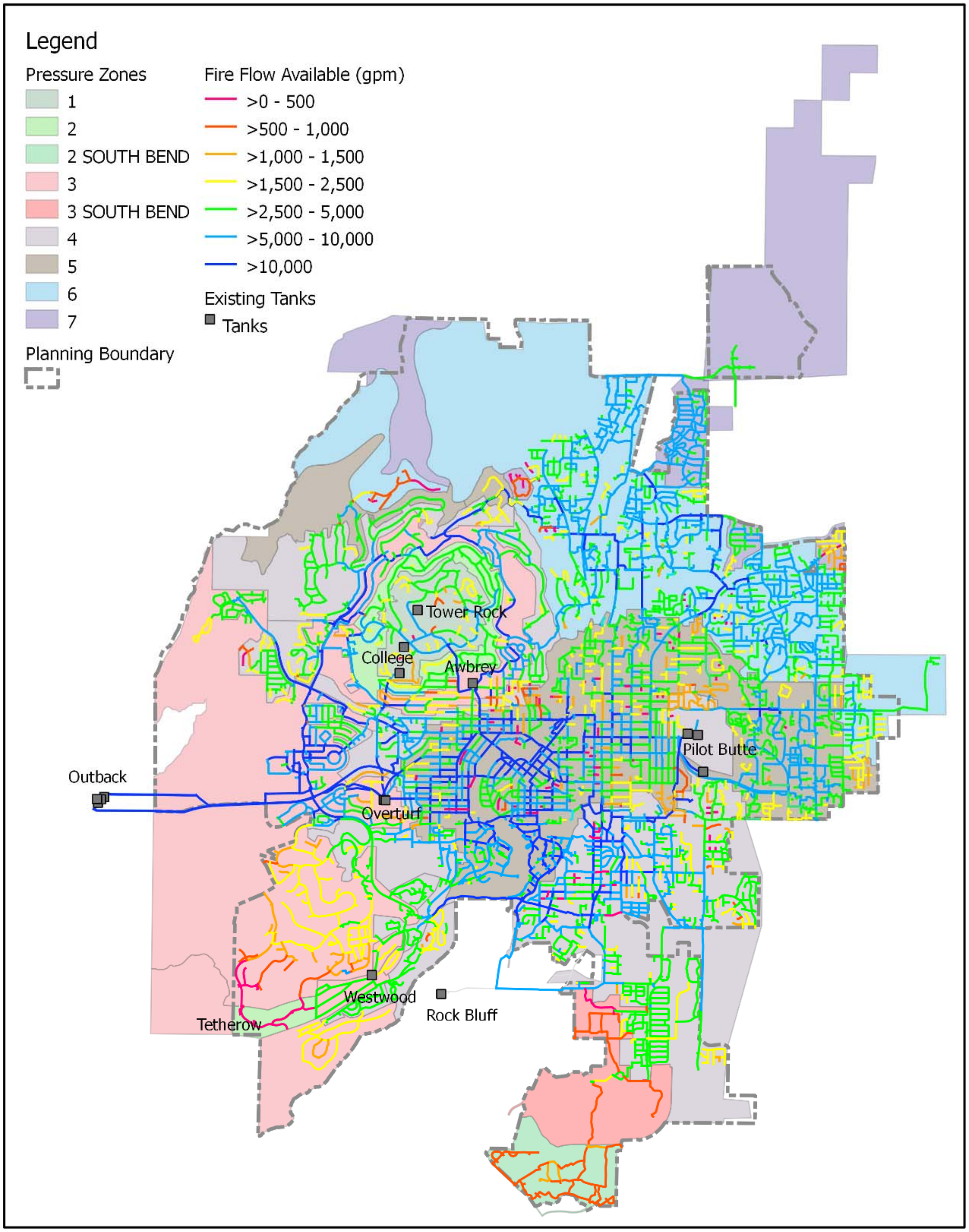


Figure 2.19 – Available flow at 20 psi residual pressure in the Bend System (existing maximum day demand conditions)

Note: a large version of this map is available in electronic **Appendix I**

Figure 2.20 shows the size of pipe replacements needed to address deficiencies under build-out demand conditions. Refer to Section 4 for details regarding the prioritization of these improvements. Figure 2.21 highlights deficient pipes that are not included in the prioritized list of pipe replacements because they are not related to deficient hydrants (2-inch mains, dead-end lines without a hydrant, or situations where the hydrant on the line is close to a larger main line and thus receives adequate flow). The cost of improving these pipes would likely be borne by a developer.

Fire flow improvements in the South Bend area were not explicitly addressed in the Master Plan Update Optimization Study. MSA completed a study of this area which recommended replacement of the existing poorly installed piping network with a new 8-inch diameter grid and appropriately spaced fire hydrants in conjunction with new transmission main which is currently under construction. These improvements will ensure the system can meet fire flow requirements to build-out.

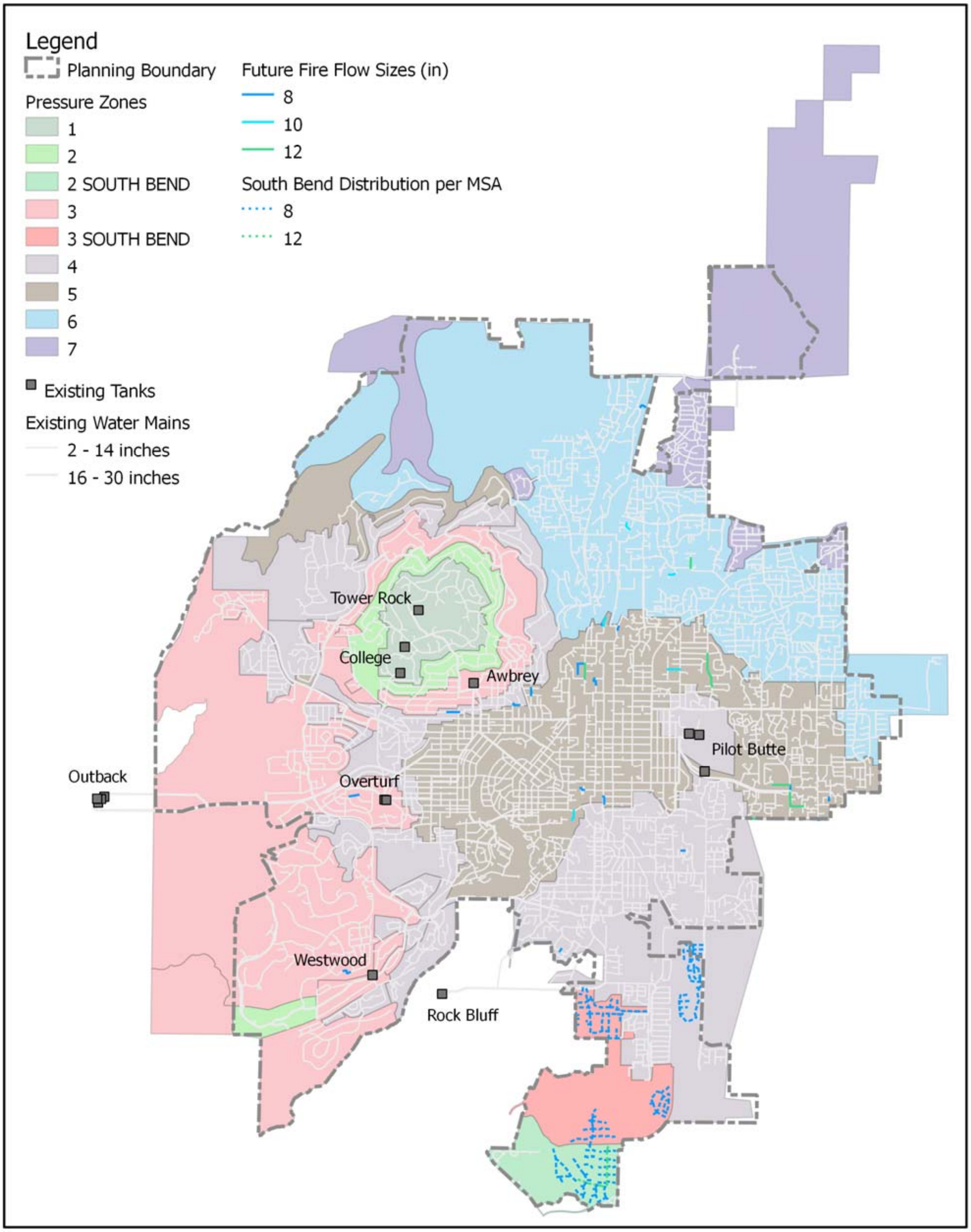


Figure 2.20 – Recommended minimum diameters for new pipes needed for system to meet fire flow conditions on future maximum day

Note: A large scale version of this map is available in the electronic **Appendix I**

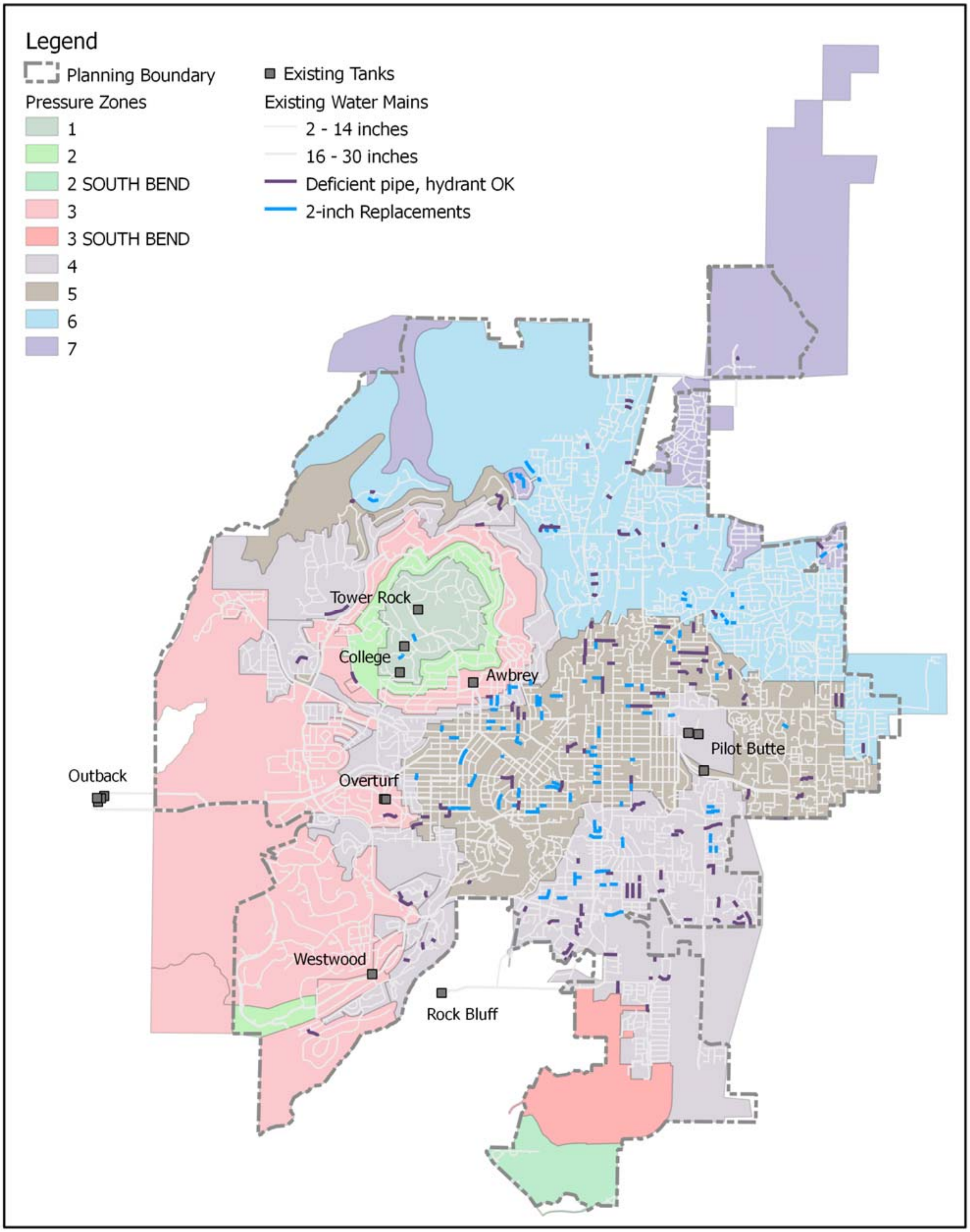


Figure 2.21 – Pipes which were identified as being deficient in meeting fire flow, but do not supply a hydrant, or the associated hydrant is not deficient (e.g. near larger main line)

Note: A large scale version of this map is available in the electronic **Appendix I**

2.8.15 Total Capital Costs

Table 2.18 lists the total estimated capital costs associated with the Final Build-out Solution. As mentioned above the Final Build-out Solution was developed under the assumption that the surface water source would contribute 23 MGD/36 cfs. At the time of writing this report, the anticipated maximum flow from the surface water source at build-out is much less; only 13.5 MGD/21 cfs. For consistency, Table 2.18 shows the estimated cost of the surface water source at 13.5 MGD (as per HDR's memorandum *Surface Water / Groundwater Cost Comparison, DRAFT*, September 2008). The additional supply that was assumed to come from this source (9.5 MGD) has been included as a second line item and is assumed to be met from wells at the Outback site. The cost of this supply has been calculated using a unit cost of $1.35m/MGD capacity.

As discussed above, it is not known whether the Outback site could support such a significant increase in well capacity, however, it was not possible to address this in the current study. The City should investigate the groundwater withdrawal limits at Outback. If the maximum potential well supply is significantly less than 26 MGD (existing 11 MGD plus 15.5 MGD new), the Final Build-out Solution will need to be revised.

Table 2.18 – Total Capital Costs – Final Build-out Solution

Cost Item	Cost
"Surface Water Supply"	
13.5 MGD, membrane treatment, no hydro[1]	$57,750,000
Additional supply to meet 23 MGD (9.5 MGD)[2]	$12,825,000
New Groundwater Wells (35.7 MGD)	$45,490,000
New Storage (14.5 MG)	$24,130,000
New Pipe Improvements for Growth	$43,625,000
Pipe Improvements for Fire Flow	$11,458,000
Pump Station Expansion	$1,744,000
New Valves	$600,000
TOTAL	**$197,622,000**

1) As per HDR Memo *Surface Water / Groundwater Cost Comparison, DRAFT*, September 2010. Costs for all other items are based on 2009 Unit Costs developed by MSA (October 2009). Estimated 2010 dollars for Surface Water Supply and 2009 dollars for remaining cost items are assumed equivalent and called 2009 dollars.

2) Assume met from additional wells at Outback, $1.35 million per MGD

3 Capital Improvements Plan – 10-year

3.1 Background

The final phase of the Water System Master Plan Update Optimization Study involved determining which improvements identified in the Final Build-out Solution will be necessary to maintain system performance over the next 10 years and prioritization of these improvements. As discussed in Section 2.2, an intermediate demand projection representing anticipated growth in the next 10 years was developed by MSA as part of this study. Throughout this study there has been discussion about the confidence the City has in the projected rate of development. Given the recent economic conditions it is likely that the “10-year” demand level may not be reached in the proposed timeframe. However it is prudent to be conservative with demand projections. To assist the City in planning their capital improvements, the recommendations in this section are not only tied to a year but also to a level of system demand. In this way the City can monitor how demands increase each year and time the implementation of capital upgrades appropriately.

3.1.1 10-year Demand projection

As described in Section 2.2, the 10-year demand projection represents an approximately linear interpolation between current demand and projected build-out demand. The distribution of the 10-year demand was applied assuming that half of the growth in water demand to reach build-out demand at medium density within the current system facilities area (i.e. the existing UGB) will be realized. The Tetherow and Juniper Ridge developments were treated separately. It was assumed that half of the growth associated with full development of Tetherow would be realized in the 10-year planning horizon. For the Juniper Ridge area it was assumed that Phase 1 (293 acres) would be realized in the 10-year timeframe.

The resulting projected demand growth is concentrated in the east; 70% of the new demand is associated with Zone 4B, Level 5 and Level 6. The City anticipates near-term growth will occur along the Southeast Interceptor corridor. Development of the area north and west of Awbrey Butte will require significant new infrastructure, both for potable supply and wastewater collection. This is not seen as likely in the near term and is expected to be driven by developers. Growth to the north and west of Awbrey Butte was assumed to occur after the first ten years.

3.1.2 General factors influencing the phasing of capital improvements

The City anticipates that properties along the Southeast Interceptor Corridor (i.e. Zone 4B) will be the first to develop in the near term. Currently the interceptor is planned to be in service by 2015.

As well as the anticipated location of near-term growth, a number of other factors have been taken into consideration in the development of the 10-year CIP. Some areas of the system have known deficiencies and have been given special focus. These areas are the Tetherow and Juniper Ridge developments and the South Bend area. Improvements that are related to Tetherow and Juniper Ridge have been flagged in the ‘Needs/Relationship’ column in the improvements listing (**Appendix G**).

The South Bend area was studied by MSA. The recommended improvements for this area are outlined in the memorandum *Former Juniper Utility – Proposed Water System Improvements*, January 2011 (**Appendix A**). The optimization analysis evaluated and verified the transmission piping improvements as recommended by MSA. These improvements are summarized in a separate listing in **Appendix G**.

A feature that will affect supply and storage requirements in the next five years is the timing of the surface water project. The assumption that there will be a significant increase in supply capacity at Outback, together with the potential for growth north of Awbrey Butte in the future, influenced the recommended size and location of a number of improvements in the Final Build-out Solution. One of the aims in developing the 10-year CIP was to gain an understanding of which improvements are necessary if the surface water source is not expanded or if the development northwest of Awbrey Butte does not occur. As discussed in Section 2.8.8, much of the new supply assumed to be in place at Outback by build-out would service new demands in the northwest. Until development occurs in this location, the City wants to know which improvements can be delayed or potentially downsized. To help answer this question, two different 10-year scenarios were evaluated in the optimization as discussed below.

3.1.3 Scenarios evaluated in the optimization analysis

To assist the development of the 10-year CIP, demand scenarios that could be evaluated in the hydraulic model were set up to be analyzed with the optimization program. To meet the needs of the intermediate demand scenario, the optimization was configured to select only from those improvements that were recommended in the Final Build-out Solution. In this way, a subset of the improvements needed to allow the system to operate under build-out conditions was identified to support the 10-year demands. This approach follows the concept of ‘build to target’ which aims to ensure that improvements made in the near-term will be appropriately sized to meet build-out conditions.

As discussed above, it was not until the time the 10-year CIP was being developed that it was known the surface water supply would unlikely be expanded to deliver 23 MGD. The maximum supply level could be 27 cfs/18 MGD but is more likely to be 21 cfs/13.5 MGD. The two 10-year demand case optimization runs were used to evaluate which improvements are needed with lower flows from Outback:

10-year demands (MDD 48.8 MGD) – Surface water providing 13.5 MGD

10-year demands (MDD 48.8 MGD) – Surface water providing 18 MGD.

A third analysis scenario with existing system demands (MDD 29.2 MGD) and surface water providing 11 MGD was used as point of comparison to the 10-year scenarios to identify near term improvement needs.

When assessing the scenario with the surface water at 18 MGD case, the optimization was allowed to resize the parallel mains out of Outback to see what diameter would be appropriate for a lower flow condition compared to what was evaluated at build-out.

3.2 Results

The existing MDD analysis highlighted which improvements will provide benefit in the near term. Comparing the two 10-year analyses revealed how the supply capacity at Outback impacts needed transmission improvements. For the purposes of the 10-year CIP recommendations presented here, it was assumed that the second phase of the surface water project will not be realized in the next 10-years. The improvements listing (**Appendix G**) contains notes on which improvements are required when supply capacity is added to the Outback site.

With the surface water capacity at 13.5 MGD under the 10-year demand scenario the optimization did not recommend implementation of new wells at Outback (beyond Well 7 which was assumed to be in place) and none of the parallel main options along Skyliners were selected. Instead, new wells are recommended in the eastern and central areas of the system; east of Pilot Butte, at Awbrey Reservoir, at Shilo and in Level 6.

In the scenario with surface water at 18 MGD, the optimization chose to implement the first section of parallel main from Outback at 18-inch diameter. This is significantly smaller than the proposed 48-inch diameter parallel main recommended in the build-out scenario which allows for integration of the increased supply at Outback and serves the development northwest of Awbrey Butte.

3.2.1 Cost Estimate and Layout Diagrams

Table 3.1 summarizes the improvements that are recommended to meet increasing demands over the next 10 years. This summary does not include improvements in the South Bend area (see below) as these were not evaluated in the optimization study. The improvements are broken down into pipe, well and storage improvements. No booster pump station upgrades are needed within the next 10-years. Three new valves should be implemented in the 10-year timeframe to improve redundancy in key areas of the system. These are the second connection from Zone 4B to Level 5 at Bear Creek Rd, the new valve to assist with fire flow between Level 3 to Zone 4A north of Overturf and the second connection to Zone 7C as shown in Table 2.14.

The timing of piping improvements is linked to the timing and location of new wells and storage. More detail on the piping improvements is provided in **Appendix G** and the relationship between the pipe, well and storage improvements are noted in the “Need/Relationship” column. Supporting files showing how costs for new pipes, storage and well capacity increases have been calculated are included in **Appendix I** (electronic).

A 16-inch connection is required along 18th Street to service fire flow demands in Juniper Ridge. It is understood that this will be implemented by the developer; however, the improvement remains in the list of piping improvements (flagged in the “Need/Relationship” column in **Appendix G**).

3.2.1.1 Improvements for the South Bend/Former Juniper Utility area

Improvements in the South Bend area are presented separately in Table 3.2. The optimization analyses verified the recommended transmission main sizes, but did not attempt to evaluate the distribution recommendations. Table 3.2 summarizes all the improvements identified by MSA for this area of the system (refer memorandum *Former Juniper Utility – Proposed Water System Improvements* in **Appendix F**). The main difference in the two estimates is due to slight differences in calculated pipe lengths in the two evaluations.

Improvements in the South Bend area are flagged as ‘planned’ or ‘in ground’ as follows:

- Connecting Tillicum into 4B – the City has advised that these connections are in the ground, however the optimization results indicated that an additional pipe connection at Dayspring Drive and Splendor Drive would benefit the system.
- Connection from Shilo to Zone 4B – the City advises this pipe is constructed. This improvement was not included in MSA’s recommendations for South Bend (it was part of a separate set of recommendations), however it has been grouped together with the South Bend improvements here.
- New transmission piping in South Bend – the City has advised that piping from Murphy Pump Station to the Shilo Wells is in place. Piping from the Shilo Wells to the Timber Ridge PRV location is also constructed. Piping from northern side of Timber Ridge through to Mountain High is expected to be in place by 2012/2013.

There remains approximately $2.9 million worth of transmission and facility improvements, and $9.9 million of distribution improvements to be implemented in this area.

Table 3.1 – Master Plan Improvements – Phasing for 10-year period (refer Appendix G for more detail)

Year	MDD (MGD)	ADD (MGD)	Pipes	Cost	Tanks	Capacity	Cost	Wells	Capacity	Cost	Total Cost
Now	29	12.8	Juniper Ridge 16-inch connection on 18th *;	$1,292,000							$1,292,000
2011	31	13.8	Tetherow improvements – B (Skyline Ranch 18-inch main) *, T (reconfiguration of the customers on the suction side of Tetherow PS). Open Zone 4J/4A boundary	$1,434,000							$1,434,000
2012	33	14.7	Extend larger diameter pipe out of Pilot Butte on Lafayette to 11th, piping associated with new Awbrey well	$241,000				Awbrey	1.5 MGD	$1,944,000	$2,185,000
2013	35	15.6	New parallel pipe near College PS in Level 3, new Level 5 pipe connection on Roanoke; site and discharge piping for new Level 5 Well east of Pilot Butte	$1,169,000				New Level 5 A (In vicinity of Shirley Ct)	2 MGD	$2,721,600	$3,890,600
2014	37	16.4	Parallel piping from Rock Bluff to Brookswood	$1,535,000							$1,535,000
2015	39	17.3	Continue parallel piping from Rock Bluff to Brosterhous; open Zone 4B/4I boundary at Reed Market	$2,940,000				Shilo	2 MGD	$2,721,600	$5,661,600
2016	41	18.2	Parallel mains on Brosterhous and Reed Market, replace piping along Wilson in Zone 4B	$1,742,000				New Level 6 (Butler Market/ Brinson Blvd)	1 MGD	$1,360,800	$3,102,800
2017	43	19.1	Extend larger diameter piping out of Pilot Butte on Lafayette from 11th to 8th	$402,000				New Level 5 A	2 MGD	$2,721,600	$3,123,600
2018	45	20.0	Parallel piping in Level 6 – Boyd Acres and Brinson Blvd; piping for Level 6 Well at Butler Market Well; New Pilot Butte tank connection	$1,364,000	Pilot Butte 4	3 MG	$5,807,000	New Level 6	2 MGD	$2,721,600	$9,892,600
2019	47	20.9	Replace existing pipe along 8th from Lafayette to Seward	$1,000,000				New Level 5 A	1 MGD	$1,360,800	$2,360,800
2020	49	21.8	Parallel main on Glassow and new main on Summit in Level 2; Replacement of piping on Norton and Olney in Level 5	$1,366,000				New Level 6	2 MGD	$2,721,600	$4,087,600
TOTAL				$14,485,000			$5,807,000			$18,273,600	$38,565,600
								Including 3 new valves		$225,000	**$38,790,600**

Note: All costs are based on 2009 unit costs developed by MSA (October 2009)

* Although it is understood that these improvements (Skyline Ranch Rd – Tetherow and 18th - Juniper Ridge) will be covered by the developer(s), full costs are presented here.

Table 3.2 – South Bend Improvements Summary (refer Appendices F and G for more detail)

Model ID	Project ID	Location/Description	Length (ft)	Diameter (in)	Estimated Cost	Refined Timing	MSA Estimate *		
Tillicum – into 4B								***Length***	***Cost***
P12	Till-1	Tillicum connection - Mowitch & Chase	77	8	$10,735	In ground	P12	40	$10,000
P13	Till-2	Tillicum connection - Klahani & Brosterhous	62	8	$8,665	In ground	P13	100	$13,000
P14	Till-3	Tillicum connection - Killowan	145	8	$20,231	In ground	P14	190	$26,000
P15	Till-4	Tillicum connection - Rae & Jackson	23	8	$3,262	In ground	P15	30	$10,000
OP187	Till-8	Tillicum connection to Splendor	82	8	$11,500	2010	n/a		$0
P16	Till-5	Tillicum - Benham parallel	379	8	$52,990	Fire flow	P16	320	$45,000
P17	Till-6	Tillicum - Rae parallel	1,627	8	$227,772	Fire flow	P17	1,550	$217,000
P18	Till-7	Tillicum - Illahee parallel	673	8	$94,153	Fire flow	P18	690	$96,000
South Bend									$0
P1	Constructed	Murphy PS to Shilo	2,507	12	$476,311	In ground	P1	2,580	$489,000
OP173	Constructed	Shilo Well piping (P9 as per MSA)	10	12	$0	In ground	P9	50	$10,000
OP13	Constructed	Shilo to Level 4	3,256	12	$618,638	In ground	n/a		$0
P2	Constructed	Shilo to new Valve nth of Timber Ridge	1,433	16	$343,963	In ground	P2	1,430	$342,000
P3	SB-1	Country Club	3,204	16	$768,955	2012/13	P3	2,950	$708,000
P4	SB-2	Mountain High Loop	860	12	$163,448	2012/13	P4	860	$163,000
P5	SB-3	Mountain High Loop	740	12	$140,539	2012/13	P5	1,800	$342,000
P5A	SB-3	Mountain High Loop	1,045	12	$198,548	2012/13			$0
P7	SB-4	Mountain High Drive	841	12	$159,762	2012/13	P7	1,830	$348,000
P7A	SB-4	Mountain High Drive	548	12	$104,143	2012/13			$0
P7B	SB-4	Mountain High Drive	523	12	$99,463	2012/13			$0
P8	SB-4	Mountain High Drive	1,023	12	$194,353	2012/13	P8	1,020	$193,000
P10	SB-5	South Bend - Murphy to Brosterhous	1,527	16	$366,398	In ground	P10	1,590	$381,000
P11	SB-5	South Bend - Brosterhous to Pines Mobile	1,994	16	$478,531	2011/12	P11	1,790	$430,000
Pumps & Surge tank (PS1-2 VFD pumps at Murphy and PS2-Surge Tank)							PS1, PS2		$100,000
Valves (V1-North of Timber Ridge and V2-PRV at Brosterhous for Pines Mobile)							V1, V2		$150,000
Hydrants (H1 - 47 new hydrants at 400 ft spacing)							H1		$367,000
Total for Category 1 per MSA 11/20/09					**$4,542,359**				**$4,440,000**
Category 2 per MSA 11/20/09 (Distribution for Tillicum, Nottingham, Timber Ridge, Mountain High & Pines Mobile, including hydrants)									**$9,859,000**

*Per *Former Juniper Utility – Proposed Water System Improvements* January 2011 (contained in **Appendix F**)

3.2.2 Supply and demand; timing of new wells

Figure 3.1 shows a timeline of projected maximum day demand and recommended supply capacity increases for the next 10 years. There are three drivers that control groundwater supply needs:

> **Normal operation** – ensure system operation is satisfactory (tanks operating over a normal range and system pressure at required levels) with all sources online under maximum day demands. This is confirmed for the future scenario through hydraulic modeling and was a key aim of the optimization.
>
> **Standby storage with groundwater offset** – ensure that the sum of above-ground standby storage (volume below minimum operating level not including dead storage) and reliable groundwater well capacity meets or exceeds the standby storage requirements as per Washington guidelines. This has been confirmed through spreadsheet calculations.
>
> **Firm supply to meet MDD** – Firm supply capacity is defined as the sum of the capacity of all sources, not including the largest source. Firm supply should be greater than or equal to maximum day demand.

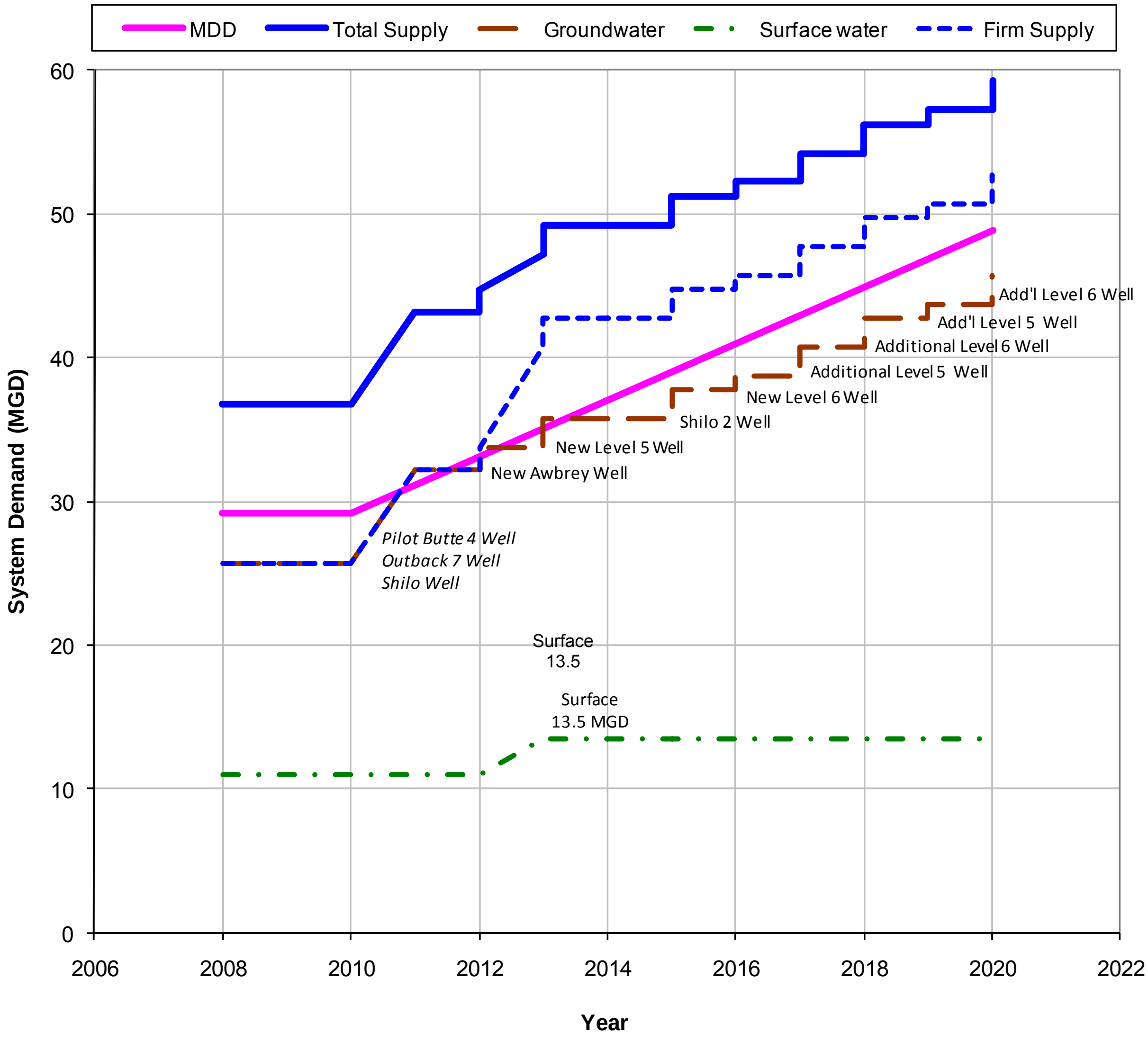


Figure 3.1 – Projected MDD and supply capacity increases to year 2020

The chart in Figure 3.1 shows total supply and firm supply. In the Bend system, the largest source is the surface water source. At the current time, this source can be taken out of service if there is an event in the watershed that increases turbidity. However, in the future, the City advised the limiting factor on the surface water source will be stream flow, as the proposed membrane treatment system will be able to operate during high turbidity events. It has been agreed that, for the purposes of determining firm supply capacity in this study, up to 7.2 MGD of surface water can be included in the calculations. The inclusion of some surface water in the firm supply calculations is shown by the dashed navy line on Figure 3.1.

The groundwater supply line (brown) must be in line with the projected MDD line until the surface water improvements are completed. The first increase in groundwater capacity comes from bringing Pilot Butte 4, Outback 7 and Shilo wells online. These wells will address the current firm supply deficit. In the following years it is recommended that new wells be implemented in Level 5, one near Awbrey Reservoir and one east of Pilot Butte.

The challenge in creating the staged CIP comes in not knowing whether and by how much demands will change prior to the surface water project being completed. To be conservative, Optimatics recommends the City include new wells in the plan as per Figure 3.1 and that the City carefully monitor demands to determine if it may be possible to delay the Awbrey and east Level 5 wells until after the surface water source improvements are completed. Although the improvements to the surface water source will assist in meeting firm supply needs, it will be necessary to implement more wells prior to the end of the 10-year CIP in order to meet the operating needs of the system, and to supplement standby storage needs as demands increase.

3.2.3 Observations and layout maps

Figure 3.2 below shows the entire system with the timing of all improvements recommended in the Final Build-out Solution highlighted. Figures 3.3 through 3.8 provide closer views of the improvements in the following areas: Southwest (Outback, Tetherow and Westwood); Southeast (South Bend), Zone 4B (Rock Bluff); Level 5 East; Level 5 West and Level 6; Awbrey Butte.

3.2.4 Emergency Storage

As discussed in Section 2.5.4, the City chose to adopt the Washington Design Guidelines as the basis for defining storage requirements specific to the City of Bend to be used in this study. The optimization was formulated to ensure that fire storage volume for each zone was maintained in above-ground storage. The resulting solutions were checked to ensure they include enough above-ground storage and reliable groundwater supply to meet standby storage requirements.

Table 3.3 contains a list of current and proposed groundwater well capacity in the 10-year Plan and compares this to projected maximum day demand in the 10-year demand scenario. The table indicates whether or not wells can be relied upon to meet standby supply needs based on whether they are connected to SCADA and have back-up power. The table is grouped based on major supply areas: Levels 1, 2 and 3 (including all the pressure zones around Awbrey Butte); Zone 4A; Zone 4B; Levels 5, 6 and 7; and South Bend (Zones 2B and 3D). The capacity of redundant wells in the system is then compared to the standby storage requirement of two times average day demand. The table demonstrates that there is a significant amount of reliable groundwater capacity that can be used to offset standby storage needs in the 10-year Plan.

Table 2.17 in Section 2.8.12 presented the standby storage needs in each zone and how they are met (by above-ground storage and groundwater well offsets) in the Final Build-out Solution. In a similar manner, Table 3.4 lists the existing and proposed future storage volumes at each storage site in the 10-year plan (the only new storage proposed in this timeframe is Pilot Butte 4). For each tank, the minimum water level observed during the maximum day simulation in the hydraulic model has been used to determine the amount of emergency storage in each tank. This is then compared to the required fire and standby storage volumes for the zones which are supported by each tank, or group of tanks. Finally, where there is a deficit, the table applies reliable groundwater supply to offset the storage requirement.

Based on the analysis summarized in Table 3.4, approximately 25% of the overall standby storage requirements for the 10-year demand scenario are provided by above-ground storage in the 10-year Plan. This is consistent with the amount of standby storage maintained above ground in the existing system (refer Section 2.5.4). Note that in the 2007 Master Plan, the assumed groundwater contribution at build-out was 55% of total storage, or 50 MG. This equates to 80% of the calculated standby requirement (as per the 2007 Master Plan) of 63 MG, meaning that only 20% of standby storage was met by above-ground storage.

Note that the upgrades to the surface water treatment system free up some of the existing Outback tanks to be counted towards standby storage. In the existing conditions analysis all three storages plus the CT Tank were discounted as they are required to meet the necessary chlorine contact time.

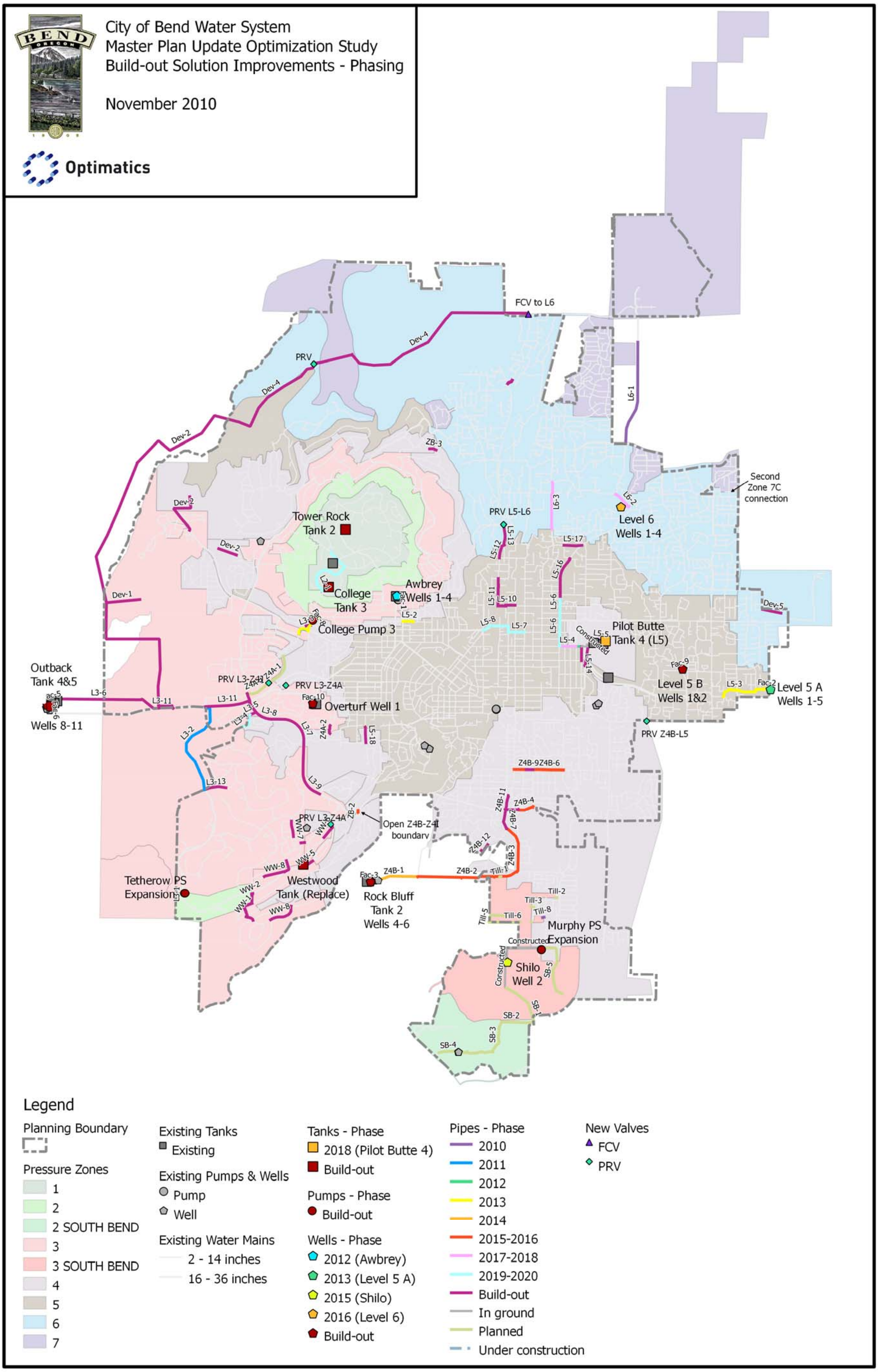
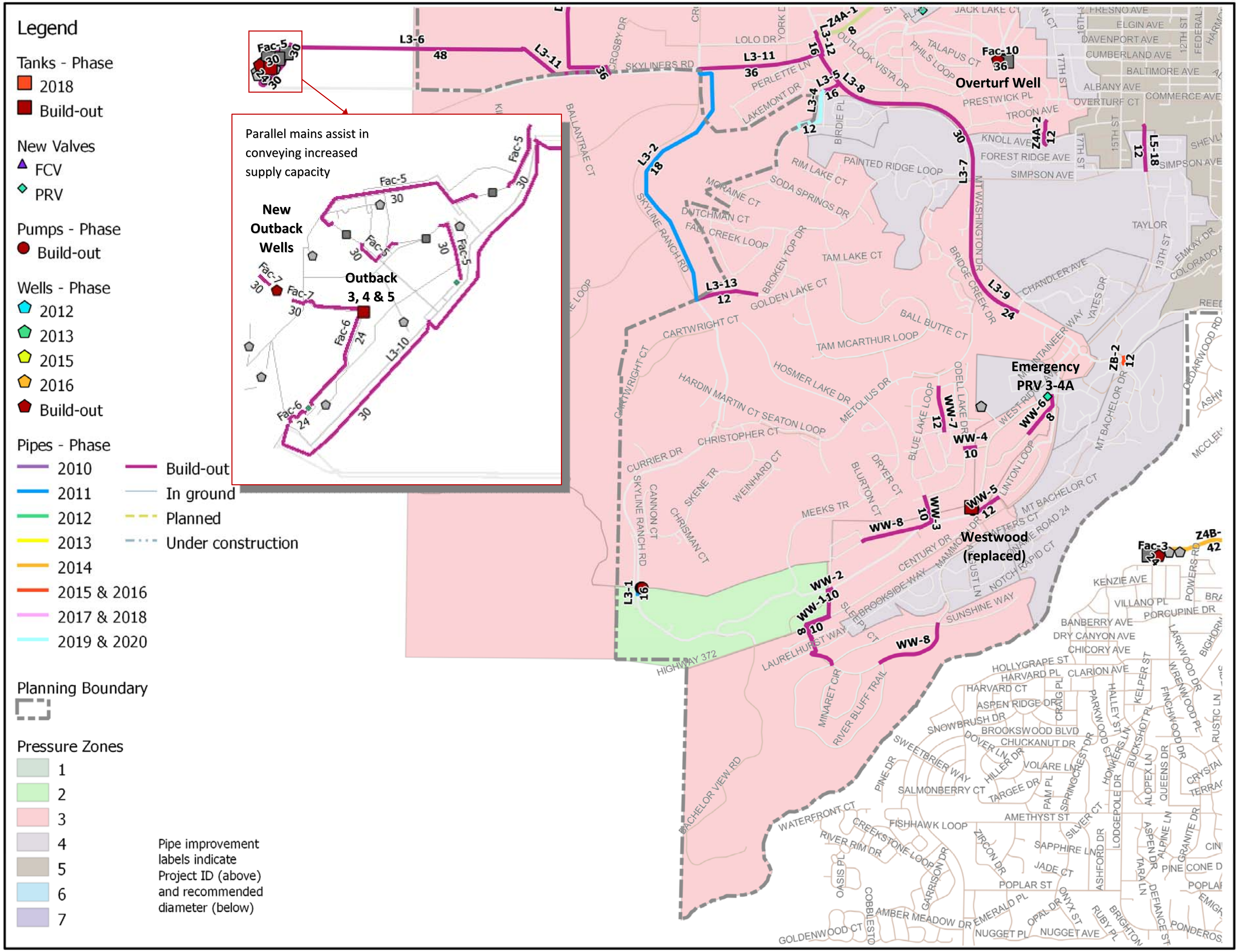


Figure 3.2 – Recommended phasing of Master Plan Improvements

Note: A large scale version of this map is available in hardcopy at the end of this report, and in the electronic **Appendix I**



Parallel mains assist in conveying increased supply capacity

Pipe improvement labels indicate Project ID (above) and recommended diameter (below)

Figure 3.3 – Phasing of Improvements – Southwest area: Outback, Tetherow, Westwood

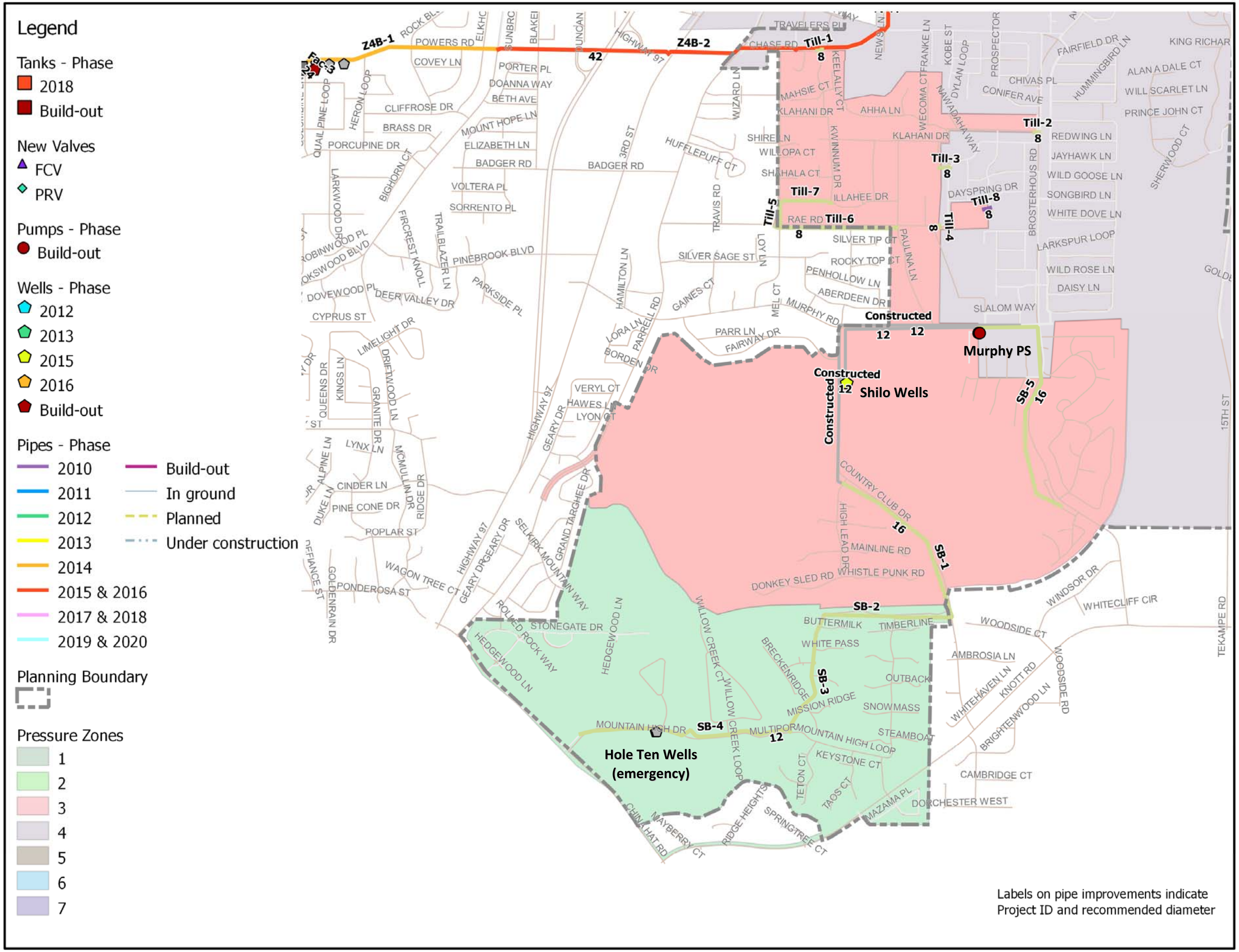
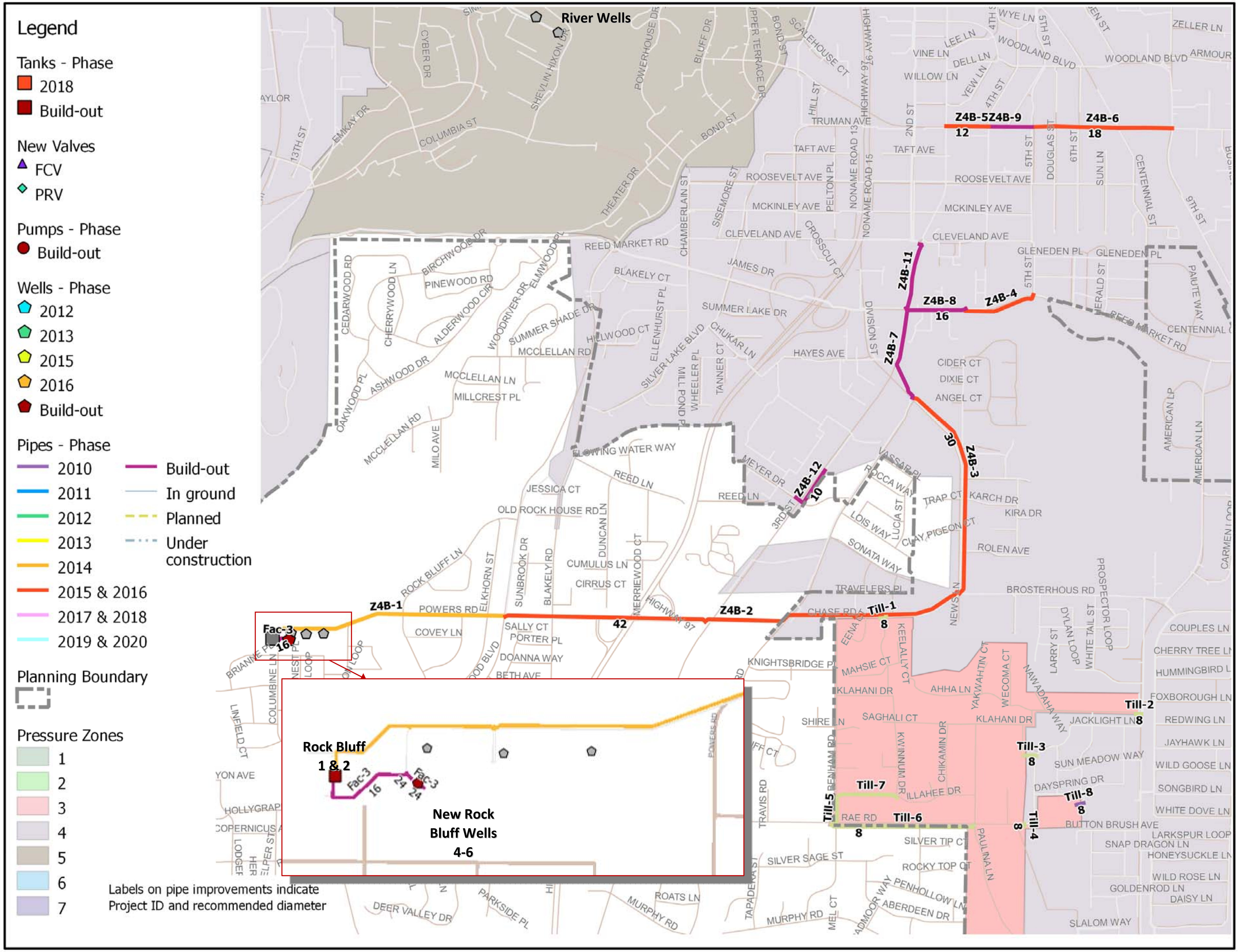


Figure 3.4 – Phasing of Improvements – Southeast area: South Bend



Labels on pipe improvements indicate Project ID and recommended diameter

Figure 3.5 – Phasing of Improvements – Zone 4B, Rock Bluff

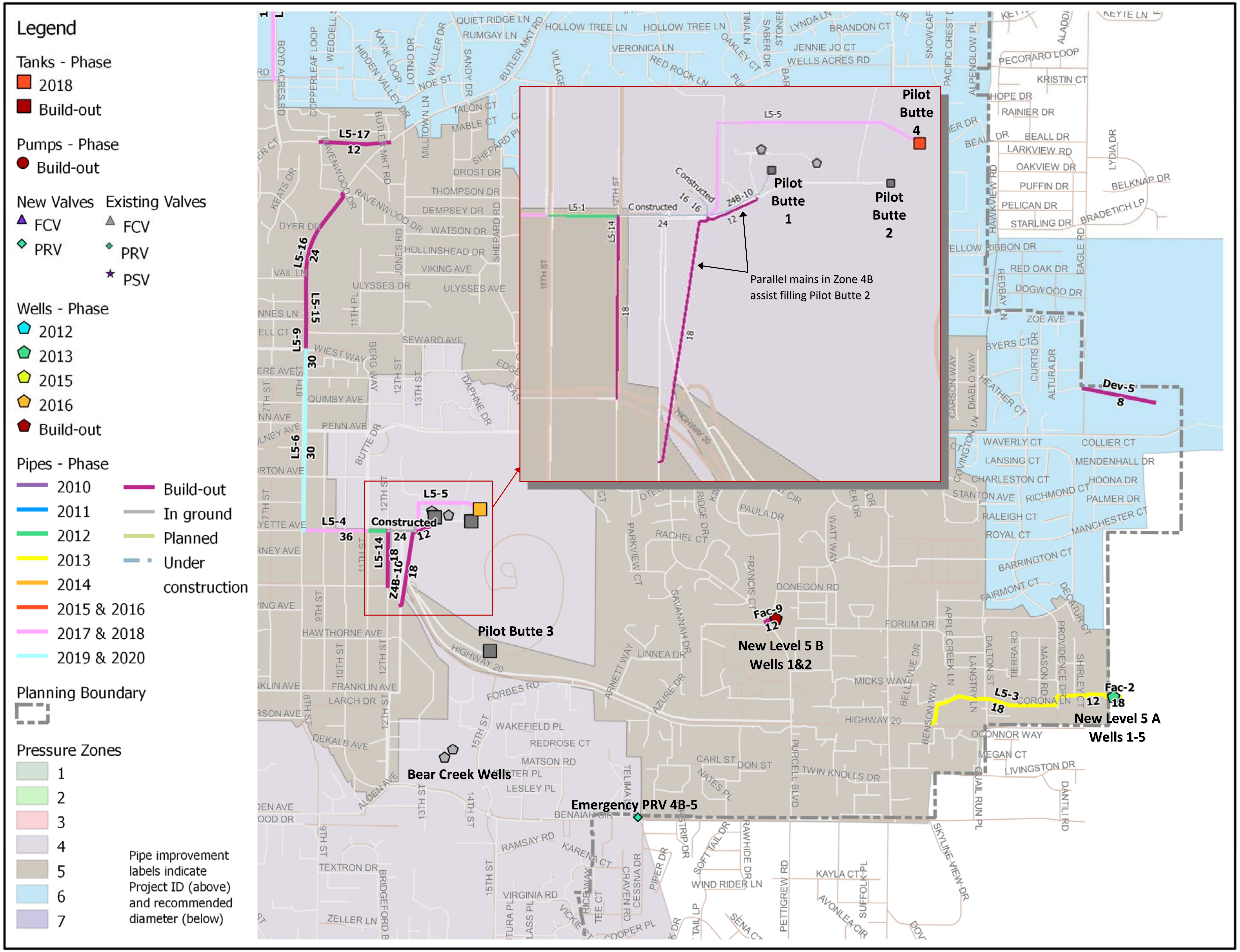


Figure 3.6 – Phasing of Improvements – Level 5 East

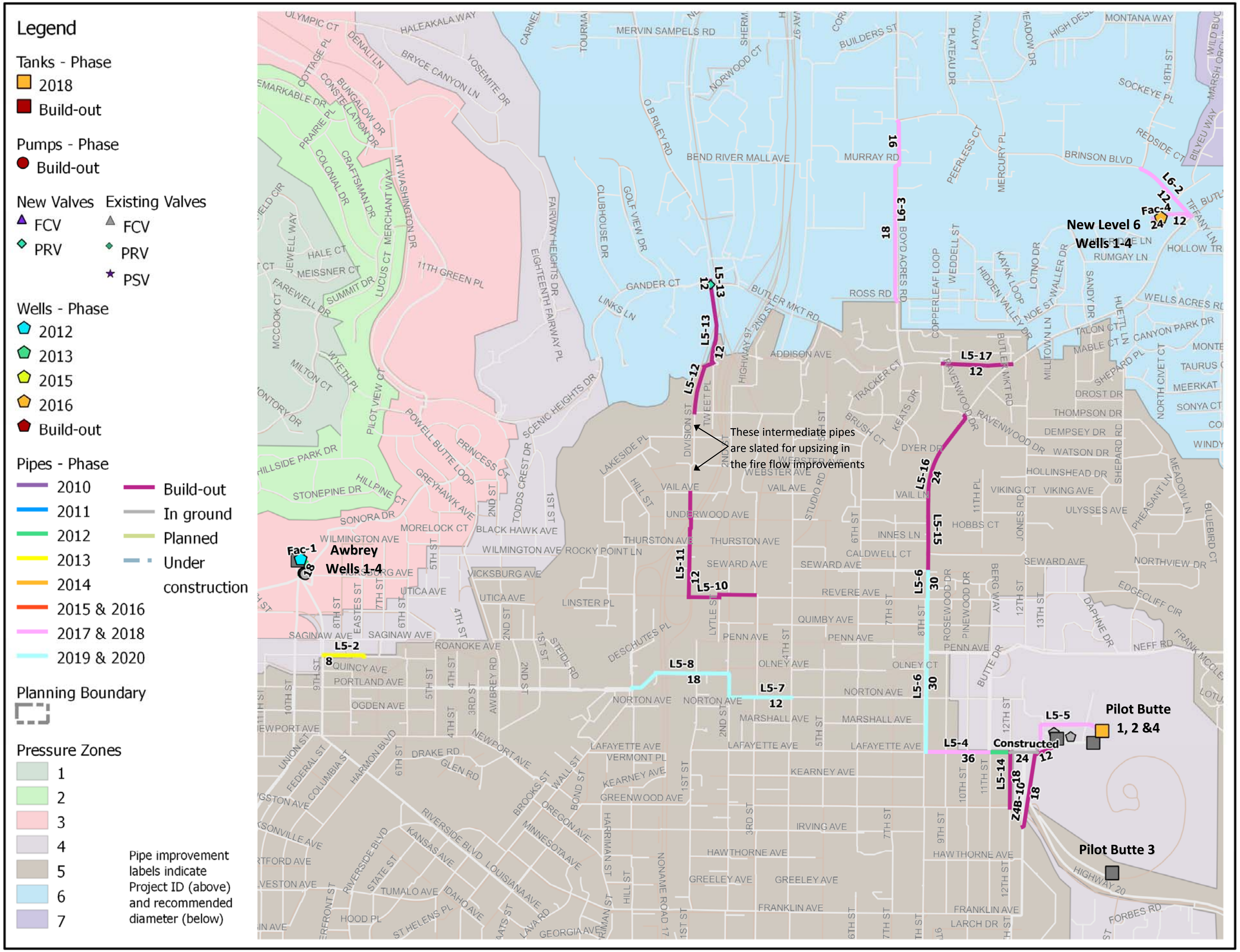


Figure 3.7 – Phasing of Improvements – Level 5 West and Level 6

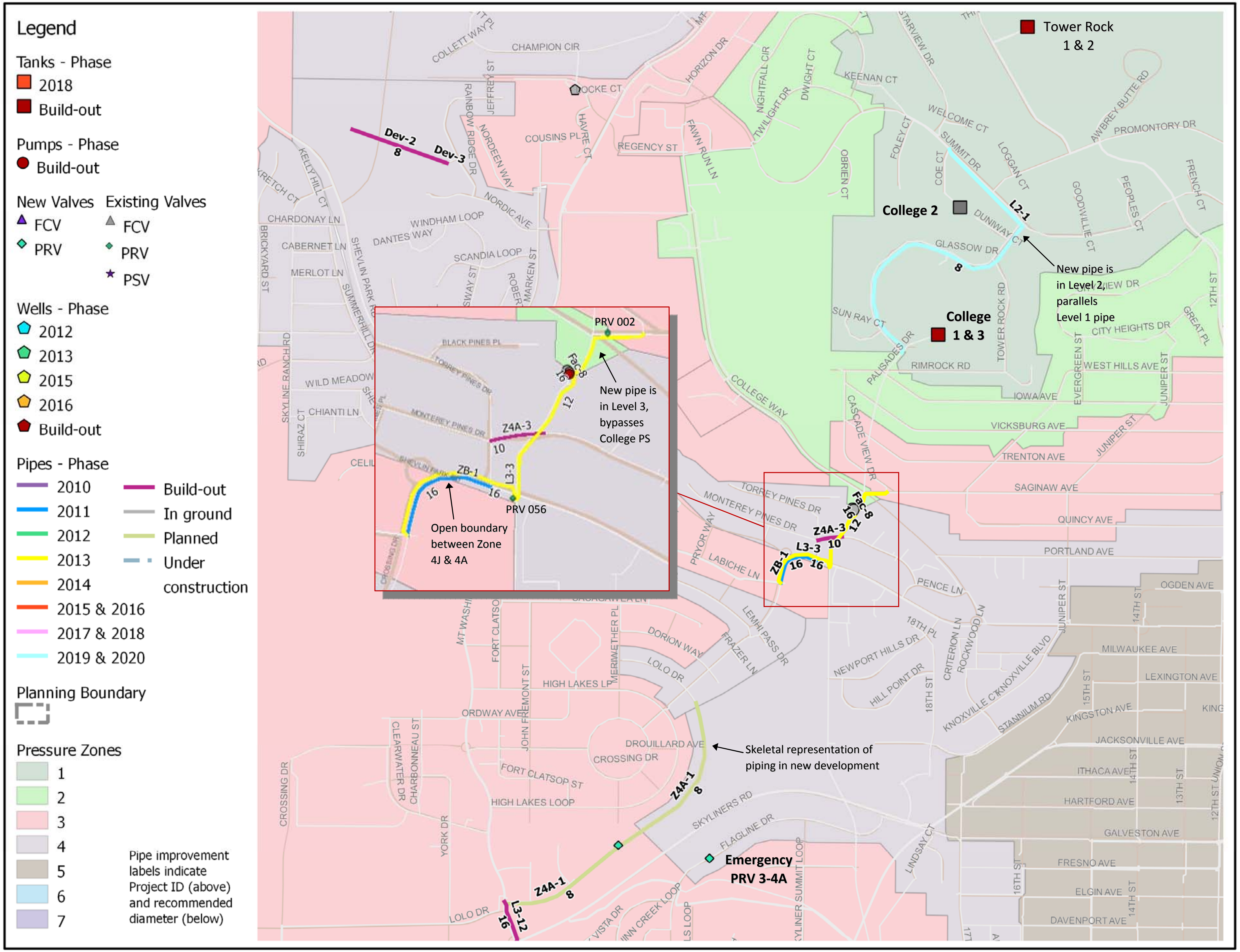


Figure 3.8 – Phasing of Improvements – Awbrey Butte

Table 3.3 – Comparison of well capacity recommended in the 10-year Solution and demand by pressure level under projected 10-year conditions

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
						=sum(F) Red -> G<H				=F xJ xJ	discount non-redundant	=sum(L)	=Mx2 Red -> N<O	
Production Facility	**Zone Supplied**	**Pump Size (hp) / Capacity (MGD)**	**Pump Type OR New Well Count**	**Approx. Static Water Level (feet)**	**Capacity (MGD)**	**Total Capacity MGD**	**Build-out MDD MGD**	**Future Back-up Power**	**Future SCADA Capability**	**Capacity Back-up + SCADA**	**Firm**	**Firm Capacity MGD**	**Supply Volume over 2 days**	**Standby 2xADD MGD**
Surface Water Source	**3**				**13.5**					**7.2**	**7.2**			
COPPERSTONE_W	3	250	Line Shaft Turbine	510	1.4			0	0	0.0	0.0			
OUTBACK_W1	3	150	Submersible	482	1.0			1	0	0.0	0.0			
OUTBACK_W2	3	150	Submersible	482	1.1			1	0	0.0	0.0			
OUTBACK_W3	3	250	Line Shaft Turbine	478	1.7			1	1	1.7	1.7			
OUTBACK_W4	3	250	Line Shaft Turbine	482	1.7			1	1	1.7	1.7			
OUTBACK_W5	3	250	Line Shaft Turbine	486	1.8			1	1	1.8	0.0			
OUTBACK_W6	3	250	Line Shaft Turbine	480	1.8			1	1	1.8	1.8			
OUTBACK_W7	3	250	Line Shaft Turbine	480	1.8			1	1	1.8	1.8			
OUTBACK_W8	*3*	*1.8 MGD*	*0*	*480*	*0.0*			*1*	*1*	0.0	0.0			
New Level 3 (Outback)	*3*	*1.4 MGD*	*0*	*480*	*0.0*	25.8	10.8	*0.00*	*1*	*0.0*	*0.0*	14.2	28.4	9.6
WESTWOOD_W	4A	150	Submersible	283	1.0			0	1	0.0	0.0			
New Level 4 (Overturf)	*4A*	*1.4 MGD*	*0*		*0.0*	1.0	2.6	*0.00*	*1*	*0.0*	*0.0*	0.0	0.0	2.3
BEAR_CREEK_W1	4B	350	Line Shaft Turbine	629	1.5			0	1	0.0	0.0			
BEAR_CREEK_W2	4B	350	Line Shaft Turbine	652	1.6			0	1	0.0	0.0			
ROCK_BLUFF_W1	4B	150	Line Shaft Turbine	393	1.2			1	1	1.2	1.2			
ROCK_BLUFF_W2	4B	150	Submersible	395	1.1			0	0	0.0	0.0			
ROCK_BLUFF_W3	4B	150	Line Shaft Turbine	395	1.2			1	1	1.2	0.0			
SHILOH_W3	4B	250	Line Shaft Turbine	355	2.0			1	1	2.0	0.0			
New Level 4 (Shilo)	*4B*	*1.0 MGD*	*2*	*355*	*2.0*			*0.50*	*1*	*1.0*	*1.0*			
New Level 4 (Rock Bluff)	*4B*	*1.7 MGD*	*0*	*395*	*0.0*	10.6	8.3	*0.00*	*1*	*0.0*	*0.0*	2.2	4.4	7.4
PILOT_BUTTE_W1	5	250	Line Shaft Turbine	743	1.2			0	0	0.0	0.0			
PILOT_BUTTE_W3	5	250	Submersible	786	1.3			0	1	0.0	0.0			
PILOT_BUTTE_W4	5 (4B emerg)	300	Line Shaft Turbine	702	1.6			1	1	1.6	0.0			
New Zone 5 (Awbrey)	*5*	*1.1 MGD*	*1*	*n/a*	*1.1*			*0.00*	*1*	*0.0*	*0.0*			
New Zone 5A (Pumped ground faci	*5*	*1.4 MGD*	*4*	*n/a*	*5.6*			*0.75*	*1*	*4.2*	*4.2*			
New Zone 5B (Pumped ground facil	*5*	*1.0 MGD*	*0*	*n/a*	*0.0*			*0.00*	*1*	*0.0*	*0.0*			
RIVER_W1	5	500	Line Shaft Turbine	360	2.7			1	1	2.7	2.7			
RIVER_W2	5	400	Line Shaft Turbine	242	3.0			1	1	3.0	0.0			
New Zone 6 (Pumped ground facilit	*6*	*1.8 MGD*	*3*	*n/a*	*5.4*	21.9	26.1	*0.67*	*1*	*3.6*	*3.6*	10.5	21.0	23.2
HOLE_10_W1	2B	150	Submersible	410	0.8			1	1	0.8	0.8			
HOLE_10_W2	2B	150	Submersible	412	0.8	1.6	1.0	1	1	0.8	0.0	0.8	1.6	0.9
Existing Groundwater Supply Capacity (MGD) (excluding Rock Bluff 2)					**32.2**									
Total Future Groundwater Supply Capacity (MGD)					**47.4**	**47.4**				**30.9**	**20.5**	**20.5**	**41.0**	**43.3**
Total Supply Capacity (Ground and Surface) (MGD)					**60.9**	**60.9**	**48.7**			**38.1**	**27.7**	**27.7**	**55.4**	

Key to Table 3.3:

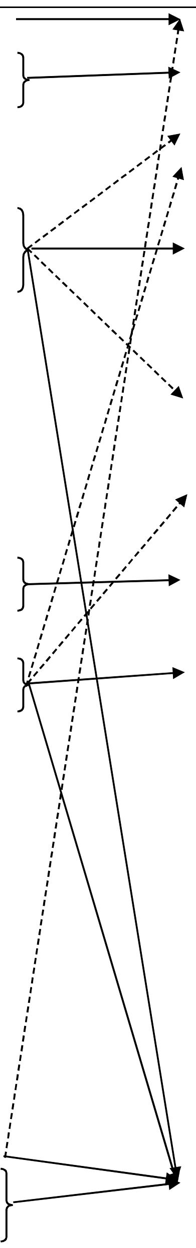
New Well	Proposed details
Assumed future SCADA/Back-up power status	
Not counted, not redundant	

Notes to Table 3.3:

1) Red text in Columns G and N indicates that the available capacity in a particular level is less than the required capacity. In all of these cases, however, supply is available from a higher zone to meet the deficit
2) Outback Wells 1 & 2 portable generator has capacity to run one well at a time
3) Two of Outback Wells 3, 4 & 5 can run on one generator
4) Outback Well 6 generator should operate three wells eventually
5) Generator at Rock Bluff is able to run two of the three wells at once
6) Rock Bluff 2 is always off
7) Shilo Wells are currently out of service. Shilo 3 was scheduled to have portable generator plug-in facilities following upgrade in Spring 2010
8) Pilot Butte 2 has been decommissioned
9) Generator confirmed at Pilot Butte 4, no generator at Pilot Butte 3

Table 3.4 – Assessment of available above-ground emergency storage compared to standby & fire requirements – 10-year demand scenario

	A	B	C	D	E	F	G				H	I	J	K	L
Storage	**Storage Volume (MG)**	**Dead storage**	**Minimum level on MD**	**% Emerg Avail**	**Emergency Volume (MG)**	**Fire suppression (MG)**	**Standby Avail (MG)**	**- - ► Pumping ──► Direct/PRV**	**Zone**		**Standby Requirement 2xADD**	**Combined Standby**	***Offset from Wells w back-up power (2 days x MGD)***	**Allocation to/from other zones**	**Capacity div by Requirements**
		From Model	From Model	=C-B	=D*A		=E-F					=sum of H	*From Well Summary*		=(G+J+K)/I
TOWER_ROCK	1.0	15%	84%	69%	0.68	0.18	0.50		1		0.96	0.96		0.50 From Level 3	105%
COLLEGE_1	0.5	0%	75%	75%	0.38	0.54	0.42		2		0.95	1.15		0.80 From Level 3	106%
COLLEGE_2	1.0	6%	63%	57%	0.58										
									2A	Teth PS, 3	0.15	*in 3*			
									2B	South Bend	0.34	*in 4B*	*Hole Ten* 1.60		
OUTBACK_1	2.3	0%	58%	58%	1.33										
OUTBACK_2	3.0	0%	55%	55%	1.66	1.50	3.92		3		4.52	7.51	*Outback, Copperstone* 14.00	-10.00 To 1, 2, 4A, 4B & 5	105%
OUTBACK_3	3.7	0%	66%	66%	2.42										
OUTBACK_CT_BASIN	1.5	100%	n/a, required for CT						3A		0.11	*in 2*			
									3B		0.10	*in 2*			
									3C	WestW PS, 4A	0.71	*in 3*			
									7	North Awbrey Bu	0.00	*in 3*			
									3D	South Bend	0.51	*in 2B*	*Shilo* 0.00		
WESTWOOD	0.5	34%	68%	34%	0.16										
OVERTURF_EAST	1.5	26%	79%	53%	0.76	0.54	1.05		4A		2.28	2.28	*Westwood, New wells* 0.00	1.50 From 3	112%
OVERTURF_WEST	1.5	26%	72%	46%	0.67										
ROCK_BLUFF_1	1.5	0%	79%	79%	1.22	1.50	0.37		4B		7.37	8.22	*Bear Creek, Rock Bluff, Shilo (rezoned)* 4.40	7.20 From 3	146%
PILOT_BUTTE_2	1.0	0%	67%	67%	0.66										
									4C		0.27	*in 3*			
									4D		0.18	*in 3*			
									4E		0.44	*in 3*			
									4F		0.13	*in 3*			
									4G		0.15	*in 3*			
									4H	Off Westwood	0.16	*in 3*			
									4I	Off Westwood	0.32	*in 3*	*4A?*		
									4J		0.18	*in 3*			
									4K		0.05	*in 3*			
AWBREY	5.1	0%	54%	54%	2.76										
PILOT_BUTTE_1	1.5	12%	56%	44%	0.64	3.00	4.73		5		12.40	23.20	*River, Pilot Butte, New Zone 5 wells* 13.80	7.20 From Level 6	111%
PILOT_BUTTE_3	5.0	0%	62%	62%	3.11										
OP_NewPB4Tank	3.0	0%	41%	41%	1.23										
									5A		0.02	*in 3*			
									5B		0.07	*in 3*			
									5C	With 4E	0.02	*in 3*			
									5D		0.07	*in 3*			
									6		7.52	*in 5*	*New Zone 6 wells* 7.20	-7.20	
									6A		0.49	*in 5*			
									6B		0.07	*in 3*			
									6C	Juniper Ridge	1.85	*in 5*			
									7A	With 5B	0.55	*in 5*			
									7B		0.22	*in 5*			
									7C		0.14	*in 5*			
									7D		0.02	*in 5*			
Totals	**33.6**	**2.83**			**18.3**	**7.26**	**11.00**				**43.32**	**43.32**	**41.00**	**0.00**	**137%**
							25%						95%		



Notes:

Dashed and solid lines indicate how supply from reservoirs can be transferred to lower or higher zones (solid indicates gravity supply through PRVs, dashed lines indicate pumping)

Colors in Column I indicate which zones have been grouped together.

4 Fire Flow Improvements addressing Existing Deficiencies

As discussed in Section 2.8.14, the determination of fire flow improvement needs was carried out in an analysis separate from the optimization. Each zone was analyzed to determine which pipes will need to be replaced and at what size to ensure that fire flow can be provided at a residual pressure of 20 psi at every node. This analysis was performed under both existing and future build-out demand conditions. To assist in prioritizing the improvements, an ‘available’ fire flow analysis was also performed to determine how much flow can be taken from the system at any point without drawing system pressures below 20 psi.

Key aims for the City in prioritizing the fire flow improvements were:

- Ensuring only improvements addressing deficient hydrants in the existing system were included in the list
- Developing a list of improvements that were sorted based on deficiency in terms of available flow compared to required fire flow in gallons per minute (gpm). The City will complete the final prioritization based on local factors such as number of customers impacted.
- Including information about the associated benefit, such as the number of customer parcels impacted by the improvement.

To develop the ordered list of fire flow improvements, the results of the available flow analysis were used to determine which hydrants could not meet their required flow. Using this information, it was possible to determine which pipe improvements are needed to address existing hydrant deficiencies, and which are only required if new hydrants are installed on deficient lines. A listing of the recommended pipe improvements addressing fire flow requirements is provided in **Appendix H**. The listing includes data related to:

- The location of the improvement (street address)
- GIS ID of hydrant connected to each pipe being recommended for replacement
- GIS ID of hydrant that was the key driver for each pipe improvement (the “critical hydrant”), and the associated fire flow requirement at that hydrant
- Whether or not the pipe recommended for replacement is a dead-end line
- The lowest pressure in the system calculated for each fire flow case without the improvements in place and the node at which that pressure was observed

The fire flow improvements have been listed in order of the severity of fire flow deficiency at existing hydrants. Related projects have been grouped together based on the critical hydrant they address. The fire flow available to a given hydrant based on the existing system analysis is compared to the requirement (based on zoning) and a deficiency has been calculated. All the projects have been sorted based on the calculated deficiencies.

The estimated cost of the recommended improvements addressing existing fire flow deficiencies is $9,485,000. At a review meeting in October 2010, City operations staff reviewed the top priority improvements identified in **Appendix H**. Final prioritization of the fire flow improvements was outside the scope of this project and will be completed by City staff.

As well as the improvements listing, **Appendix H** contains figures showing the location of the top 100 fire flow improvements (order based on existing deficiency) highlighting street names and land use zones.

Appendix H also includes information related to improvements that would be needed if new hydrants were to be installed on existing lines that are too small to support fire flow, such as 2-inch diameter mains. These improvements are grouped as follows:

1) Pipe improvements that address deficient lines but where the critical hydrant was not deficient (e.g. instances where the hydrant is near a larger main line and so can meet the requirement, but where the analysis demonstrated it was not possible to provide fire flow to the end of the line)
2) Pipe improvements that address pipes which cannot meet fire flow but do not currently serve hydrants
3) 2-inch main replacements

A review of all 2-inch mains determined that none serve hydrants (apart from 3 instances where the hydrant is close to the main line and it was subsequently confirmed each has a 6-inch stub from the main to the hydrant).

Appendix A – MSA Modeling Report

Appendix B – Consequence of Failure Analysis Report

Appendix C – Design Data Summary Report

Appendix D – Operations Optimization Report

Appendix E – Storage Constraint Review Memorandum

Appendix F – MSA Memoranda

Updated Capital Improvement Project (CIP) Cost Estimates

Former Juniper Utility – Proposed Water System Improvements

Tetherow Development: Alternatives Analysis

Appendix G – Master Plan Improvements – detail

Appendix H – Fire Flow Pipe Improvements

Appendix I (electronic)

- Hydraulic Models of Final Build-out Solution
- Electronic copies of full report and appendices