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Water System Master Plan Update Optimization Study

City of Bend, Oregon, Project No. WA09FA

Design Data Summary Report
FINAL

September 2010

Table of Contents

1 Purpose, Background and Scope 1

1.1 System Description 1

1.2 Previous Studies 3

1.3 Project Scope 4

2 Project Methodology and Deliverables 5

2.1 Calibration of the City of Bend Dynamic Water Model 5

2.2 Consequence of Failure Analysis 6

2.3 Development of the Optimization Model 7

2.4 Optimization Study 7

2.5 Staged Implementation Plan 8

2.6 Deliverables 8

3 System Design Variables and Costs 9

3.1 Hydraulic Model 9

3.2 Demand Cases 11

3.3 Pipe Criticality Data 22

3.4 Source Options 24

3.5 Pipe Options 32

3.6 Storage Options 35

3.7 Pump Station Options 40

3.8 Valves and Zone Boundaries 43

3.9 Optimized Model Controls 44

3.10 Operating Cost Calculations 45

4 Design Criteria 49

4.1 Supply Pressure 49

4.2 Flow Velocity 51

4.3 Storage 51

5 References 58

Appendix A – Pipe Criticality Measures 59

Appendix B – Hydraulic Profile 63

Appendix C – System Operating Rules and Pump Data 64

List of Tables

Table 3.1 – 2008 ADD and MDD by pressure zone 11
Table 3.2 – Bend system demand factors (relative to Average Day) 14
Table 3.3 – Current and projected future water demand summary 16
Table 3.4 – Water demand summary by Pressure Level 19
Table 3.5 – Bend Surface Water Rights Summary 25
Table 3.6 – Bend Groundwater Rights Summary 26
Table 3.7 – Groundwater production facility summary 27
Table 3.8 – Existing system – Pipe diameter statistics 32
Table 3.9 – Existing system – Pipe material statistics 32
Table 3.10 – New pipes – Sizes and Unit costs (construction) 33
Table 3.11 – Existing storage reservoir summary (sorted by Pressure Level) 35
Table 3.12 – Recommended new reservoirs, 2007 Master Plan Update 36
Table 3.13 – Existing booster pump station summary 40
Table 3.14 – Pumping facilities and applicable schedules 47
Table 3.15 – Summary of Pacific Power Rate Schedules (all rates in dollars) 48
Table 4.1 – Recommended fire flow rates 50
Table 4.2 – Existing storage summary (sorted by pressure level) 53
Table 4.3 – Summary of recommended fire storage volume 54
Table 4.4 – Assessment of current demands vs available storage 55
Table 4.5 – Future storage requirements 57

Table of Figures

Figure 1.1 – Bend Service area showing the location of neighboring Avion and Roats service areas................2

Figure 3.1 – Bend Service area showing pressure levels and major facilities..10

Figure 3.2 – Historical production records – 2006 to 2008 – Monthly totals...12

Figure 3.3 – Historical production records – 2006 to 2008 – Monthly totals for well and surface supply...........13

Figure 3.4 – Historical production records for years 2006 to 2008 – Daily production 14

Figure 3.5 – Water Demand Flow Chart (per *Water Model Development Documentation*, MSA, August 2010) 17

Figure 3.6 – Potential change in annual system demand as a result of conservation......................................20

Figure 3.7 – Pipe Material Data in Bend GIS 23

Figure 3.8 – Favorable locations for new groundwater facilities 29

Figure 3.9 – Potential transmission main corridors (circled numbers represent anticipated sequence of implementation for interceptors)...34

Figure 3.10 – Potential locations for new storage to support the South Bend area..38

Figure 3.11 – Estimated Reservoir Unit Cost Curves – Concrete vs Welded Steel (MSA, 2009) 39

Figure 3.12 – Estimated Pump Station Unit Cost Curve (MSA, 2009)..42

Figure 4.1 – Storage components 51

1 Purpose, Background and Scope

Optimatics and Murray Smith & Associates (MSA) have been engaged by the City of Bend (the City) to undertake a comprehensive review and optimization of the City's Master Plan. In March 2007, MSA completed the Water System Master Plan (WSMP) Update. The current study, referred to as the WSMP Update Optimization Study, involves model calibration, assessment of pipe criticality and optimization of current operations and future infrastructure requirements.

This Design Data Summary (DDS) report summarizes the methodology, assumptions and design data to be used in the WSMP Update Optimization Study. The purpose of the DDS report is to seek confirmation from Bend on the methodology, assumptions, data and deliverables to be used or provided in this project. Such confirmation is important to ensure that the optimization model formulation and runs are based on accurate and complete information.

1.1 System Description

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. 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 a diversion at Bridge Creek, 13 miles from the City limits, and supplemented by a diversion of natural spring flows from the Tumalo Creek basin. Transmission mains deliver this raw water supply 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. The service area has a number of prominent buttes. The distribution system is divided into a number of pressure levels based on elevation and the aim of maintaining service pressures between 40 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 (Overturf Reservoirs) and Level 5 (Awbrey Reservoir). Booster pumps lift supply 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 east and west sections along the Deschutes River.

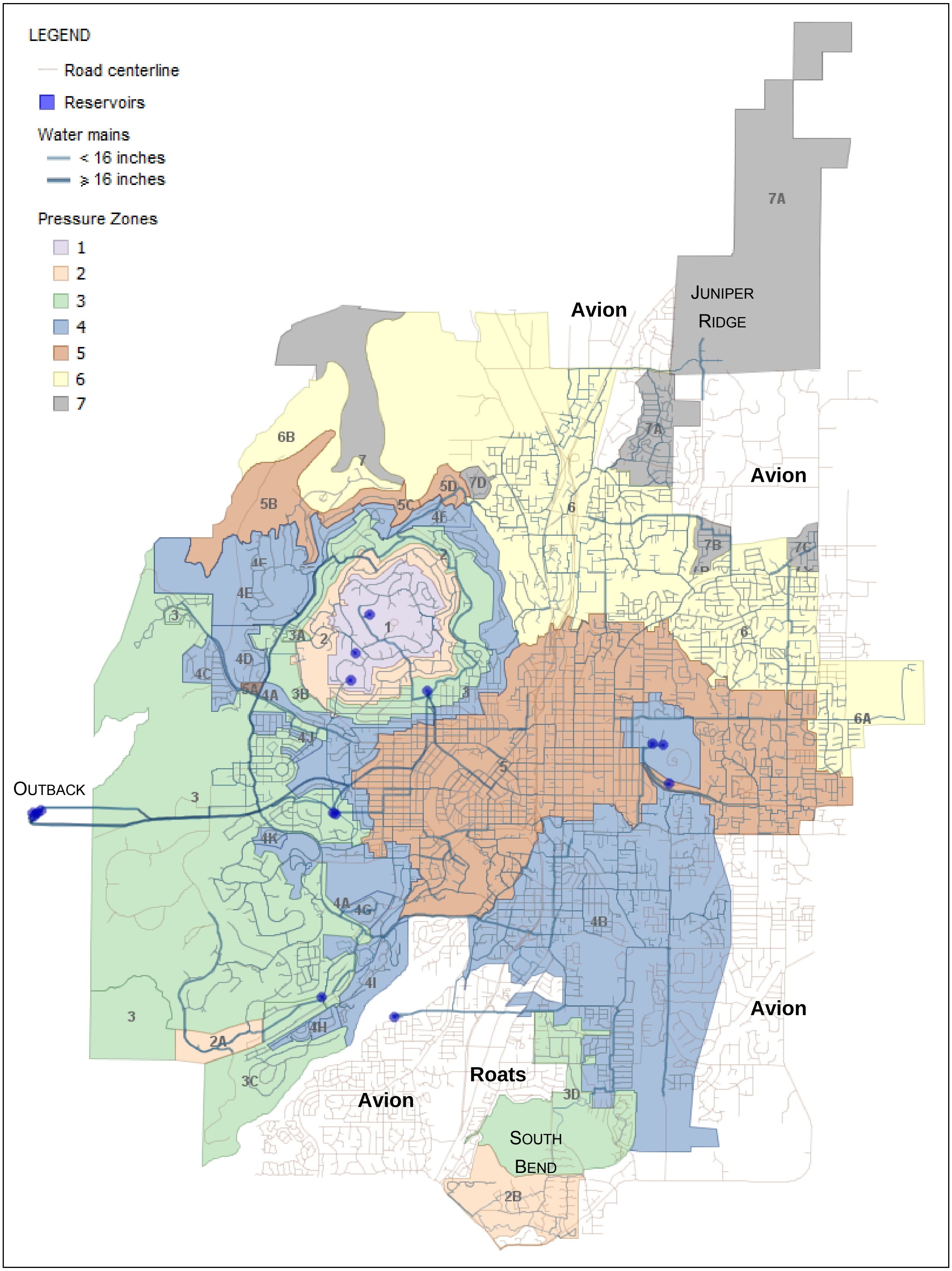


Figure 1.1 – Bend Service area showing the location of neighboring Avion and Roats service areas

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 the former Utility 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), and has the ability to supply Westwood if needed via a PRV station at the western end of Westwood.

Though growth has slowed considerably in the current economic climate of the last two to three years, prior growth in the Bend region had been substantial. For purposes of future planning the City wishes to maintain previous projections reflecting steady growth. To meet this future growth, additional supplies will be required. Options for the future system are discussed in Section 3.

1.2 Previous Studies

The City has undertaken a number of studies in the last six years, listed below, which informed this Optimization study. A list of references for this document is provided in Section 5.

MSA, *Water Model Development Documentation for Water System Optimization*, Draft, December 2009 and later updated – outlines specific details of the model construction and calibration as well as future demand projections.

MSA, *City of Bend Water System – Tetherow Development: Existing Alternatives Analysis*, June 2010 – analysis to determine improvements to meet existing fire flow requirements

MSA, *Updated Capital Improvement Project (CIP) Cost Estimates*, June 2010 – cost estimates for use in the optimization analyses.

MSA, *Former Juniper Utility – Proposed water System Improvements*, November 2009 – final proposed improvements for the South Bend area

MSA, *Water System Planning for the Juniper Ridge Development, Bend, Oregon*, September 2009 – recommendations for supply, transmission and storage supporting the Juniper Ridge development

MSA, *Alternatives Analysis for Improving the City's Water System in the Southerly Portion of the City (South Bend), Including the former Juniper Utility Area*, December 2008 – Describes six options and recommends a short-term and long-term plan for South Bend area to improve system redundancy, supply security and fire flow capacity.

CH2M HILL, *Bend Water System Master Plan CIP Prioritization Final Documentation Memorandum*, February 2009 – contains details of the prioritization process used to develop a 10-year capital improvement plan considering eight criteria with different importance weightings.

MSA, *Water System Master Plan Update*, March 2007 – Comprehensive 25-year master plan for the City.

City of Bend, *Water Management and Conservation Plan Final Report*, December 2004 – due for update. Contains details of future demand projections, conservation measures and future supply options.

1.3 Project Scope

The 2007 Water System Master Plan (WSMP) Update provided recommended improvements to meet year 2030 demands based on a traditional simulation analysis. The City's aim with the present WSMP Update Optimization Study is to improve upon the 2007 Plan through a model update, pipe criticality analysis, operations optimization and future capital improvements optimization. The intended outcomes of this work are more efficient system operations, improved levels of service and an optimized master plan that minimizes capital costs of future infrastructure improvements designed to meet year 2030 demand needs and the associated operating costs. The capital improvement projects to be implemented in the first 10 years of the plan will be prioritized to meet the City's near-term needs and be compatible with available funding.

This comprehensive study involves the following work steps:

Task 1 – Calibrate City of Bend Dynamic Water Model

Task 2 – Consequence of Failure Analysis

Task 3 – Development of the Optimization Model

Task 4 – Optimization Study

Task 5 – Staged Implementation Plan

These study steps are described in further detail in Section 2.

2 Project Methodology and Deliverables

The City of Bend has created a comprehensive scope of work for the Water Master Plan Update (WSMP) Optimization Study. The project steps and associated deliverables are described in the following sections.

2.1 Calibration of the City of Bend Dynamic Water Model

It is critical that the model be accurately calibrated before the optimization analyses take place. Prior to commencement of this study the City undertook a comprehensive review of all valves in the Bend system. This revealed a number of anomalies which have been recorded and corrected. In addition, system operators have been working to improve the pressure zone structures by adjusting the settings of a number of PRVs in the system. Both of these significant efforts by City staff make the calibration of the hydraulic model particularly important, bringing the model into line with what is currently true in the system. Bend is aware that additional improvements could be made to the pressure settings and zone boundaries and these will be assessed as part of the optimization study.

At the WSMP Kick-off Meeting held in April 2009, it was identified that the existing hydraulic model does not correspond exactly to the GIS data. This situation would ultimately cause difficulties in the future and would have significant impacts on any work that involves incorporating GIS data – for example, valves and hydrants – into the hydraulic model for pipe criticality or pipe flushing analyses. As a modification and addendum to the original scope, Bend approved additional work under the model calibration task to rebuild the model from the GIS data source. This process involved the following steps:

- Convert pipe shapefile to InfoWater model
- Add facilities to the model including pump stations, wells, reservoirs and PRVs
- Assign elevations to all non-facility model nodes
- Set and verify pressure zone boundaries utilizing valve status information
- Add pump and well controls to updated model
- Add diurnal curve information to updated model

The ultimate goal is to have a one-to-one relationship between the pipes and nodes in the GIS and those in the model. Having the GIS and model in sync with each other will support the model's ongoing maintenance and will ensure that there is accuracy among the important planning tools being used by the City.

The calibration was undertaken using the model built from the GIS data. MSA developed a field testing plan for City staff to collect hydrant pressures and flows to be used in the steady-state calibration. SCADA data will be used to define the boundary conditions (tank levels, pump and well flows) for use in the extended period simulation (EPS) calibration.

Prior to commencing the calibration, the following checks were made:

- Ensure that all new and existing raw water piping has been added to the model
- Ensure that all new and existing facilities (i.e. Outback Wells), including changes in operation, have been added to the model
- Perform an updated demand allocation based on 2008 customer billing records
- Verify the validity of the winter and summer diurnal curves used in the model

Calibration is focused on two efforts: steady state conditions (a 'snapshot' in time – valuable for numerous design applications and fire flow simulations) and EPS (akin to a 'motion picture' which simulates dynamic system performance over a given timeframe – valuable for operations simulations and changes, experimenting with the setting of pump trigger levels, observation of tank water level behavior under different demand conditions).

The steady-state calibration will focus on comparing pressures and flows, collected at system hydrants, with model pressures and flows. Adjustments to the model pipe diameters, pipe connectivity, friction factors and valve settings may be required to obtain adequate agreement between the field and model. Some field checking may be necessary where model results and field results disagree - closed or partially closed valves may be present nearby. EPS calibration will primarily involve the comparison of actual tank level and pump and well flows over time with what the model predicts at those facilities. Where differences exist, modifications to the model controls or diurnal patterns may be required. Again, some field checking by Bend staff may be necessary in specific locations where the model and field results are not in substantial agreement.

The deliverable from this step will be an updated, calibrated, GIS-based InfoWater hydraulic model including all existing elements as well as proposed future improvement alternatives used for the genetic algorithm optimization.

2.2 Consequence of Failure Analysis

Once the steady-state model has been updated and calibrated, Optimatics will utilize its OptiCritical™ software to perform a consequence of failure analysis. This analysis identifies those pipes that, should they fail, will have a great impact in terms of critical customers and/or number of customers being out of water, difficulties in isolating the break, resulting low pressures, etc. The City is in a good position to take full advantage of OptiCritical's capabilities due to the recent valve maintenance work that has been completed, as well as the model update effort that ensures agreement with the GIS databases.

A demonstration of the software was provided at the Kick-off Meeting in April, 2009. Optimatics then conducted a conference call with Bend staff to review the result parameters offered by the OptiCritical program, and identified those parameters which are of greatest importance to the City. The City also identified some critical customers and confirmed their preferences regarding main prioritization. The most critical pipes will be reviewed with the City to determine if they should be included as pipes requiring rehabilitation or replacement in the optimization analysis for future demand conditions. It could turn out that the pipe criticality results are not directly applicable to the optimization; even so, they will be valuable stand-alone results which the City can use in its planning strategies to strengthen reliability in specific areas of the system.

The deliverable for this analysis will be a technical memorandum describing the background, setup, and results of the OptiCritical analysis. Included will be a prioritization list which identifies the most critical pipes in the system, under break or isolation conditions, based on the most important metrics to Bend.

2.3 Development of the Optimization Model

The optimization study will be broken into two parts. First, current demands for both a typical summer day and typical winter day will be considered in separate optimization analyses which will aim to improve current system operations. Next, projected 2030 maximum day demands will be used as the basis for developing a Build-out master plan optimization.

The optimization formulations will incorporate allowable operating strategies, infrastructure improvement options including mains requiring replacement, unit capital and operating costs, and constraints defined by the City's design and performance criteria. This DDS report is a critical first step in the formulation process, and is the deliverable for this task. The *Data & Formulation Review Workshop*, held during the first week of August, 2009, enabled the City and the project team to perform further review of the required data prior to commencement of the optimization runs.

2.4 Optimization Study

As mentioned above, the optimization study has two parts – an operations optimization using current demands for summer and for winter and a Build-out master plan optimization. The Operations Optimization will develop an operations strategy to minimize operating costs. This optimization will create and evaluate a wide range of modified operating decisions in terms of the supply quantities from different sources, pump set points, regulating valve settings, and other elements. The Operations Optimization will be conducted for a typical summer and typical winter day. The calibrated model will be set up to represent these conditions based on historical production and SCADA operations data.

Following formulation and preliminary runs, the optimization process will include interim and final run phases. Results of the Interim Operations Optimization runs will be summarized in a technical memorandum and discussed with City operations and planning staff. Any recommended modifications will be checked by City operators to ensure they are feasible and within the realm of what can be achieved with the current system configuration. Additional improvements may be recommended for future implementation. A final set of optimization runs will be undertaken to finalize the recommendations.

It is anticipated that improvements identified in the Operations Optimization will be incorporated into the hydraulic model to be used for the 20-year Master Plan (MP) Optimization. The 20-year MP Optimization will identify near-optimal infrastructure improvements to meet projected Build-out demands at least cost while satisfying the design criteria. The maximum day demand case will be used in order to properly size facilities.

The Build-out MP Optimization will minimize project life-cycle costs to achieve the best balance between capital improvement costs and lifetime operating costs. The optimization will be formulated based on in-depth discussions with City staff to identify the entire range of capital improvements to be considered. These options are discussed in Section 3.

As with the Operations Optimization, interim and final optimization runs will be carried out for the Build-out MP Optimization. The City will review interim results, submitted by Optimatics in the Interim Layout Summary Memorandum, and provide feedback on the near-optimal interim solutions presented so that final runs and refinement can be completed to develop the recommended optimized Build-out MP Solution.

The Optimatics-MSA team will work closely with City staff to refine the preferred optimized Build-out plan and finalize the infrastructure improvement projects. Optimatics will prepare a final technical memorandum documenting the optimization process, selection criteria used, and outcomes of the Operations and Build-out MP Optimization analyses.

2.5 Staged Implementation Plan

The final step in this study will be to analyze the optimized improvements and prepare a staged implementation plan for the next 10 years based on growth projections provided by the City. Prior to developing the detailed Capital Improvement Plan (CIP), improvements to be included in the 10-year CIP will be identified in a separate optimization run formulated for the 10-year demand case.

The detailed CIP will reflect the timing of the projects based on hydraulic need and the City's capacity to implement the improvements. City input regarding the likelihood and location of near-term developments will help to inform this process. The existing conditions, 10-year, and Build-out hydraulic models will be used to assess hydraulic need. Additional drivers such as available budget and the condition of existing facilities, as well as the outcomes of the pipe criticality analysis, will be used to determine the appropriate timing of infrastructure improvements up to the 10-year situation.

2.6 Deliverables

As mentioned in the previous sections, in addition to this DDS Report the following deliverables will be generated during the study:

- Calibrated, GIS-based, InfoWater hydraulic model
- Memoranda summarizing results of
    - Criticality Analysis
    - Operations Optimization
    - Build-out Master Plan Optimization

The final deliverable will be a comprehensive Final Report summarizing the technical memoranda and presenting the results of the staging process and implementation plan.

3 System Design Variables and Costs

This section contains details of the data and costs required in the optimization analyses. It also discusses the data needs for the pipe criticality analysis that will precede the optimization analyses. Included in the discussion are the hydraulic model statistics and operation, the demand cases that will be considered in developing the master plan, and the potential options to be evaluated in developing an optimized plan to meet future demands.

Water system planning aims to ensure that supply and distribution systems will be capable of providing estimated future maximum day demands. As the City of Bend grows there will be a need for additional sources of supply and increased capacity within the distribution system to ensure satisfactory levels of service to customers. Specific areas of need for the Bend system are addressed below.

MSA developed unit costs to be used in this study and these are presented in the following subsections. Cost estimates are based upon recent and historical experience with construction costs for similar work in the region and assume improvements will be accomplished by private contractors. Cost estimates represent opinions of probable costs only, acknowledging that final costs of individual projects will vary depending on actual labor and material costs, site conditions, market conditions for construction, regulatory factors, final project scope, project schedule, and other factors.

3.1 Hydraulic Model

The calibrated extended period simulation model received from MSA in September 2009 included 23 reservoirs (fixed head sources, mostly representing groundwater wells), 15 tanks, 44 pumps (21 well and 23 booster), 136 control valves and approximately 7600 pipes representing 420 miles of water mains.

MSA has produced a comprehensive report, titled *Water Model Development Documentation for Water System Optimization,* Draft, December 2009. The document outlines the details of the model creation from GIS, the steady-state calibration based on fire flow tests, and the extended period simulation (EPS) calibration against SCADA information. It contains a comprehensive listing of all facilities included in the hydraulic model as well as the details of the existing and future demand distributions.

Figure 3.1 shows the Bend service area indicating the location of pressure levels and major facilities such as storage reservoirs, groundwater wells, and pressure reducing stations. As part of the model build and calibration effort, MSA developed a hydraulic profile which is included in Appendix B.

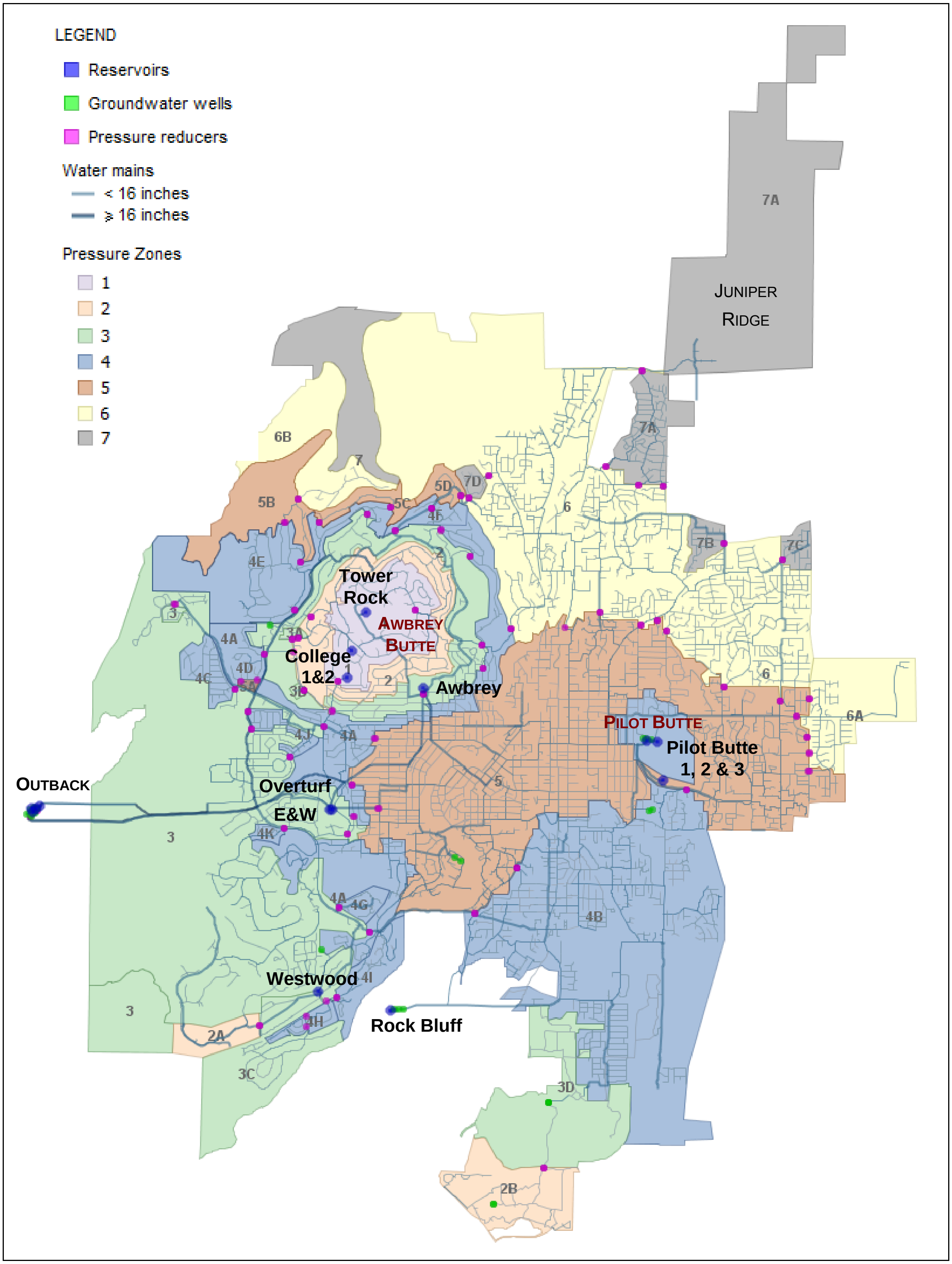


Figure 3.1 – Bend Service area showing pressure levels and major facilities

3.2 Demand Cases

For the water system optimization study, several demand scenarios are required to be analyzed including two existing condition scenarios (summer and winter), a 10-year growth horizon (year 2020), and a Build-out growth horizon (year 2030 or later, depending on future growth rate). These demand scenarios will be used to prioritize and optimize improvements.

3.2.1 Existing system demands and demand use factors

The existing conditions demand scenarios were developed by MSA from current water production records – annual production for average demands, and specific summer and winter period demands have been developed. The spatial demand allocation is based on available meter records (2008 billing data) and linking metered data to the City's parcel GIS. Table 3.1 shows the calculated year 2008 average day demands (ADD), maximum day demands (MDD), and number of service connections in each pressure zone.

Table 3.1 – 2008 ADD and MDD by pressure zone

Zone	Demand ADD (gpm)	Demand MDD (gpm)	Service connection count
1	264	745	394
2	236	648	485
Tetherow (2A)	0	0	1
2B	50	102	338
3	820	2,193	2,083
3A	9	20	21
3B	34	80	6
Westwood (3C)	148	403	367
3D	50	81	277
4A	481	1,148	1,105
4B	1,359	2,897	3,572
4C	83	222	270
4D	58	152	168
4E	144	375	292
4F	34	94	62
4G	17	39	14
4H	48	127	163
4I	36	79	138
4J	48	120	193
4K	12	29	53
5	2,972	6,085	6,403
5A	7	20	21
5B	15	42	26
5C	2	5	2
5D	19	49	30
6	1,485	3,336	3,476

Zone	Demand ADD (gpm)	Demand MDD (gpm)	Service connection count
6A	169	409	506
6B	24	67	39
7A	173	420	546
7B	76	187	214
7C	37	89	127
7D	6	12	37
Grand Total	**8,916**	**20,278**	**21,429**

Demand factors for different seasonal conditions have been calculated based on historical production records for the years 2006 through 2008. Three charts below present the demand data in graphical form. Figure 3.2 compares total monthly production for each of these three years. It can be seen that there is a reasonably consistent pattern of demand over each year, and that demand has been increasing slightly each year.

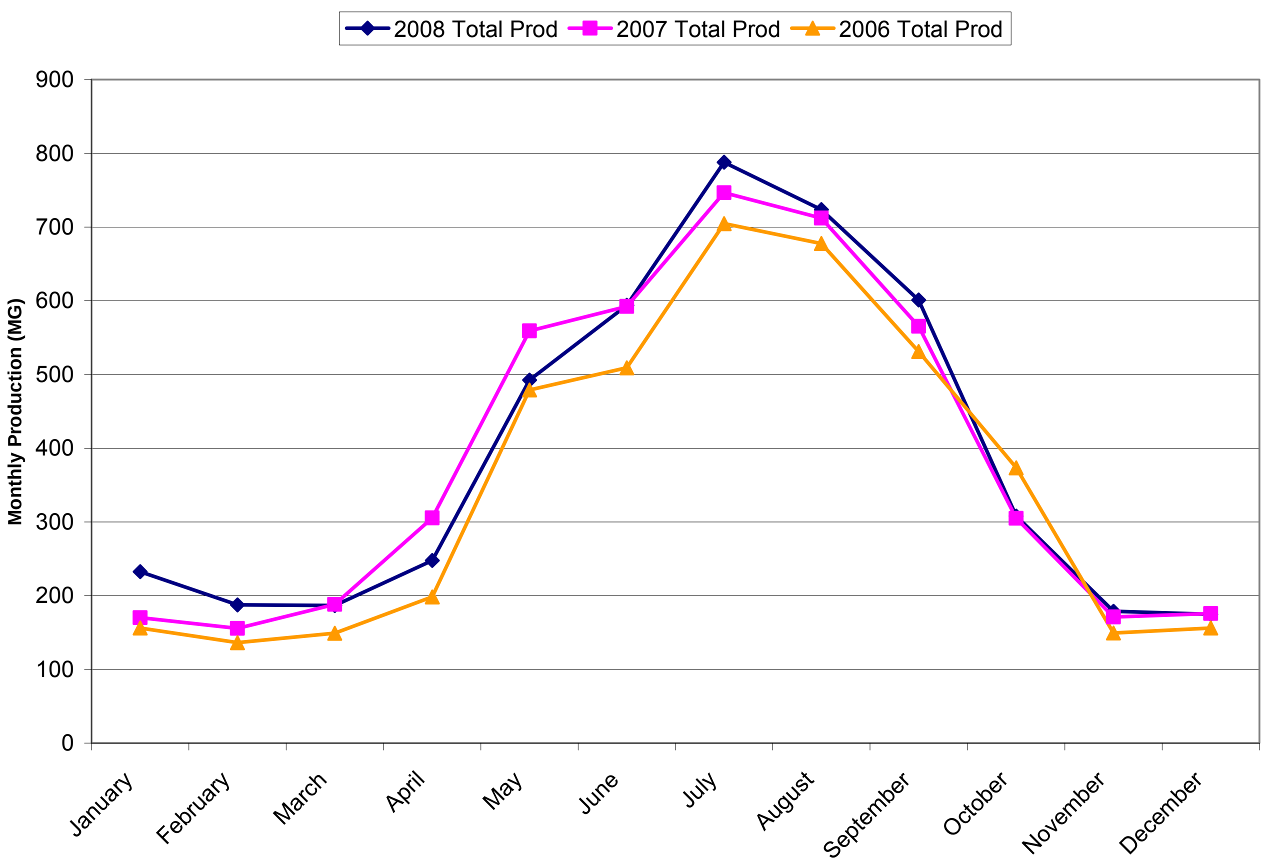


Figure 3.2 – Historical production records – 2006 to 2008 – Monthly totals

Figure 3.3 shows the breakdown of groundwater and surface water supply over the 2006 to 2008 period. Again there is a consistent pattern of volumes provided from each source in each year, with surface supply remaining relatively constant throughout the year, and groundwater supply peaking to meet the high summer demands.

Bend has mentioned that, during the months approaching summer, it is difficult to maintain surface water supply when the ground water wells (especially the River Wells) are turned on. This can be seen in Figure 3.3 between the months of April and May, where the surface water supply decreases as the groundwater supply increases. As total demands increase further in the summer months it is then possible to incorporate more surface water supply.

Despite the months of April and May being problematic from the point of view of maximizing surface water supply, the optimization will still consider typical summer and winter conditions. The aim of the optimization is to reduce peak (summer) operating costs and improve winter time operations to maximize surface water use and improve water age. Methods developed to maximize surface water use in the system under these two conditions will likely also apply to the “shoulder” periods of April-May and October-November.

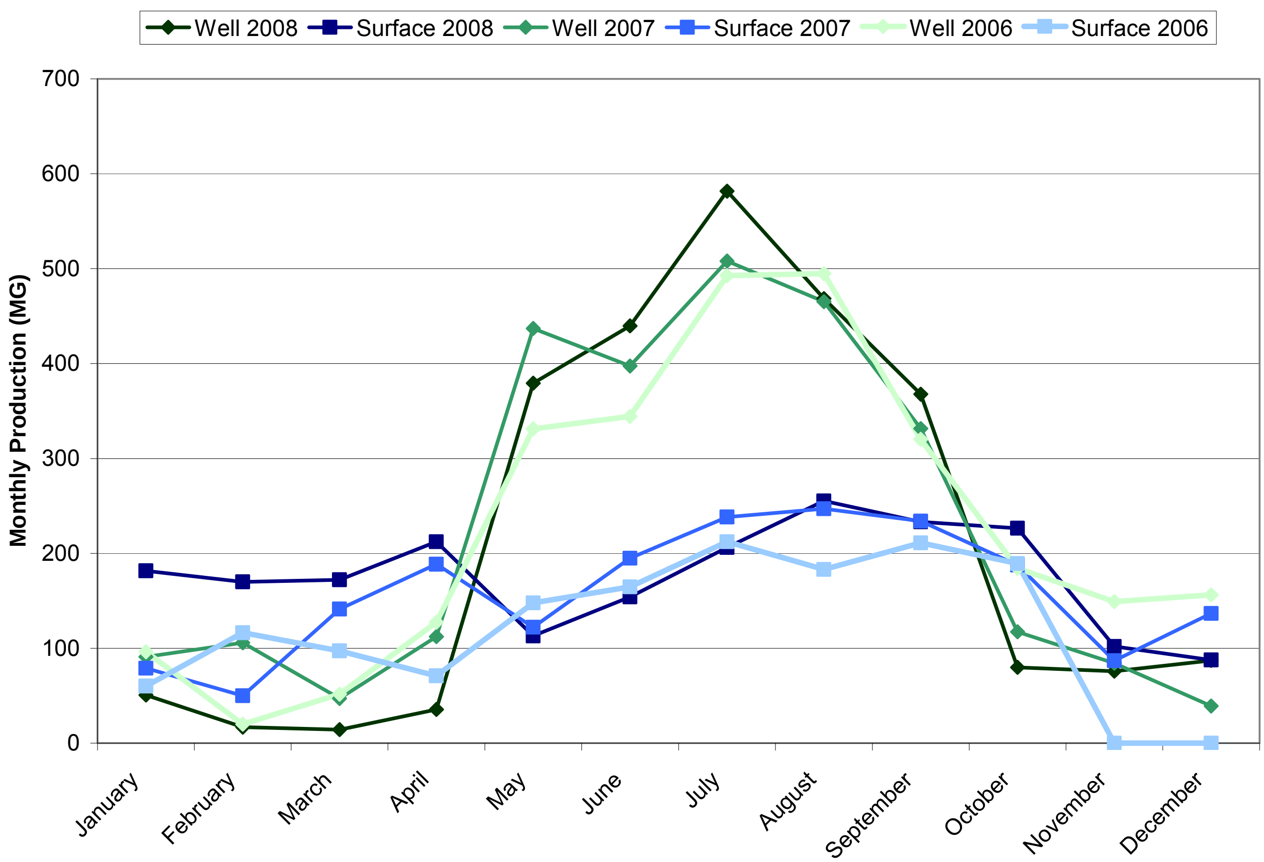


Figure 3.3 – Historical production records – 2006 to 2008 – Monthly totals for well and surface supply

Figure 3.4 was developed using daily production records for the years 2006 to 2008. Based on the data shown in the figure, Optimatics calculated demand factors for minimum and maximum day demands compared to average annual demands. In addition, an assessment was made to determine appropriate factors that apply to the typical summer and typical winter day scenarios. Data points used for the determination of demand factors are highlighted on the chart. The demand factors that apply to the Bend system are provided in Table 3.2.

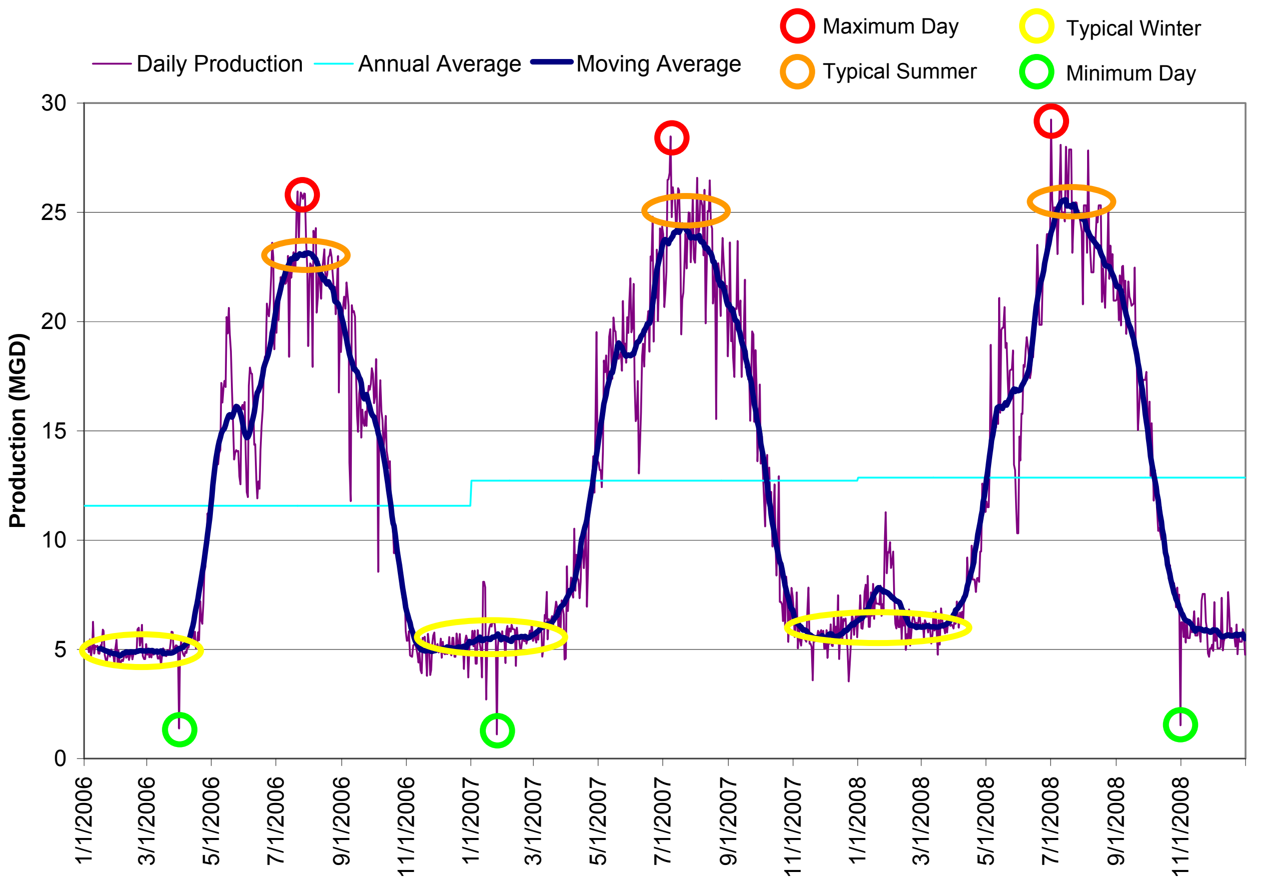


Figure 3.4 – Historical production records for years 2006 to 2008 – Daily production

Table 3.2 – Bend system demand factors (relative to Average Day)

Scenario	Factor
Minimum Day(1)	0.10
Typical Winter Day(1) (2)	0.40
Average Day	1.00
Typical Summer Day(1) (2)	1.85
Maximum Day(1)	2.25
Peak Hour(3)	4.05

(1) Calculated based on historical data from 2006 to 2008

(2) These factors have been adjusted based on the 2009 winter (January) and summer (July) periods used by MSA to develop the calibrated EPS model. Historical records show the typical summer to average day ratio may be closer to 2.

(3) A peak hour to maximum day demand factor of 1.8 has been calculated from hourly production data collected in 2008 and 2009. The 2007 Master Plan used MD:PH ratio of 1.5

3.2.2 Future demands

*September 2010. **Note:** The demand projections and spatial distribution have change from those presented here due to a revision of the demands in the Juniper Ridge development to match previous analysis assumptions for this area, a revision to the 10-year spatial distribution and corrected calculation of the peak hour to maximum day peaking factor based on recent production records and SCADA data.*

The City of Bend is located within an Urban Growth Boundary (UGB) which includes the service areas of the City, Roats Water System and Avion Water Company. Bend's water service area represents a subset of the UGB; MSA has worked together with Bend staff to determine the appropriate ultimate service area to use as the basis for future demand projections (refer to Figure 1.25 of *Water Model Development Documentation for Water System Optimization*, August 2010).

As a result of the current economic climate it is likely that demand for water will occur at a slower rate than was assumed in the 2007 Master Plan Update. Yet, to be conservative, Bend has advised that demand projections should not be reduced based on the recent slowdown in economic growth.

As outlined in the Future Demand section of the *Water Model Development Documentation for Water System Optimization* MSA completed a comprehensive analysis of available data pertaining to historical demand and population information, current and future land use, and near-term developer plans to generate water demand projections for the year 2020 and for the Build-out situation.

Two specific data sets – the *Buildable Lands Inventory (BLI)* database and the *Parcel Inventory & Alternative 4A UGB Proposal Data for the Area Outside the Existing UGB (Framework Plan)* provide future land use zoning for parcels within the City, as well as low (min), mean, and high (max) dwelling unit per acre density estimates. In the 2007 Master Plan Update, expected demand growth was distributed within the existing UGB through infill of under-developed areas up to the maximum number of potential dwelling units for the relevant zoning designation. The same philosophy has been applied in the most recent demand projection where MSA has used the low, medium and high dwelling unit per acre density values to develop future demand estimates.

At the project update meeting in December 2009, the total system demand estimates were reviewed and comparisons were made to the previous master plan assumptions and other demand projection methodologies, i.e., using past growth rates to predict future demand. From these discussions it was agreed that the following assumptions would be used to develop demands to use for the optimization study:

1. Use the "Low" density value for the 10-year projection = 21.0 MGD ADD
    - Bend confirmed that this figure is appropriate given current economic climate, slowed growth, etc.
2. Use the "Medium" density 20-year value for the Build-out projection = 37.1 MGD
    - This is slightly higher than the estimated 31.5 MGD saturation development value used in the 2007 Master Plan. Bend acknowledged that the system is never likely to reach theoretical Build-out (represented by the High development projection). Also, from a supply perspective, 37.1 MGD ADD will mean ~83.5 MGD for Maximum Day demands.

Table 3.3 shows current, 10-year and Build-out demand estimates for the Bend system. Figure 3.5 provides a representation of how the demands have been built up from information relating to residential and non-residential developable areas in the system.

Table 3.3 – Current and 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	21.0 (2)	47.3 (4)	113.4 (5)
Build-out Development (6)	37.1 (3)	83.5 (4)	200.3 (5)

Notes to Table 3.3:

(1) Existing demand based on 2008 water production records.

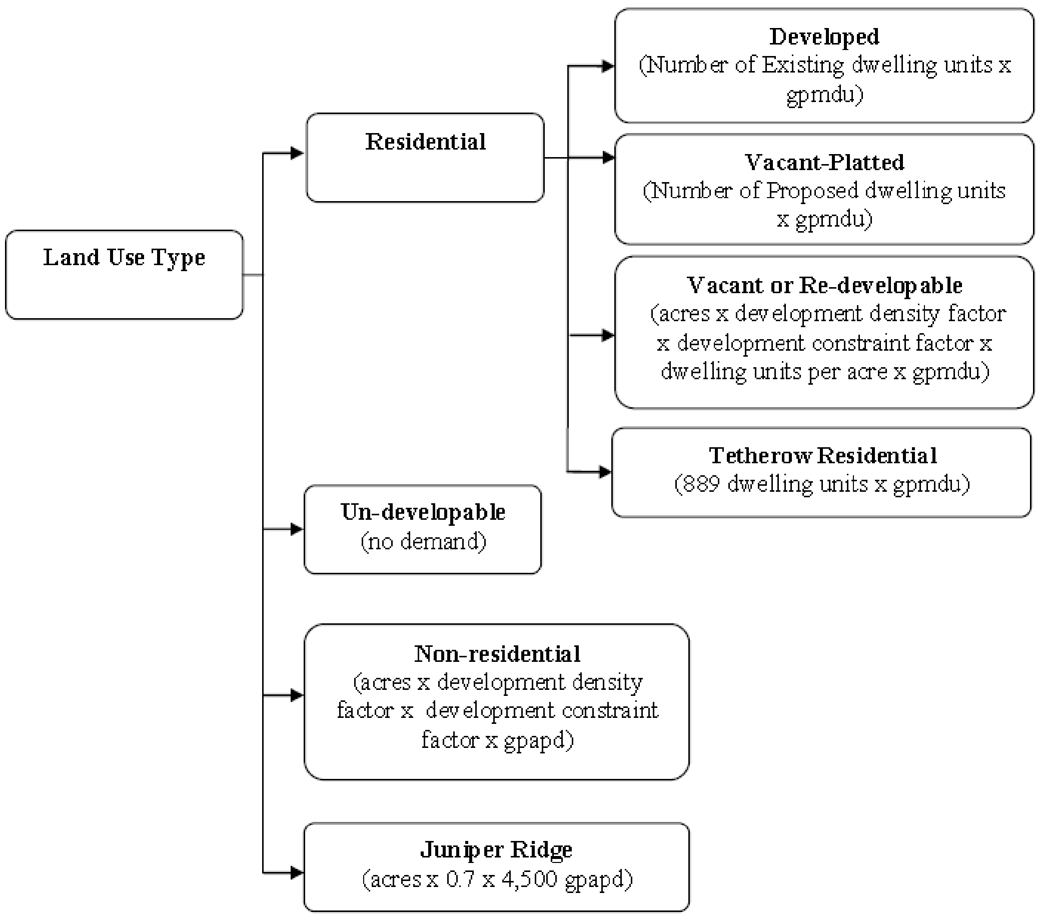
(2) 10-year ADD developed based on 172 gpcpd residential demand and 3,200 gpapd non-residential demand.

(3) Build-out ADD developed based on 172 gpcpd residential demand and 4,000 gpapd non-residential demand.

(4) MDD equals the ADD x 2.25 (based on historical data, see Table 3.2). Note: the 2007 MP used AD:MD of 2.3.

(5) PHD factors based on summer diurnal patterns developed by MSA are 2.87 in residential areas and 1.84 in mixed use areas, with a system wide peaking factor of 2.4. Note: the 2007 MP used PH:MD of 1.5 (textbook value).

(6) Includes Juniper Ridge at 515 acres by 2030 (4,500 gpapd), and Tetherow at 889 residential units



Definitions:

gpmdu: gallons per minute per dwelling unit = 2.4 people per dwelling unit times 172 gallons per capita per day

gpapd: gallons per acre per day

development density factor: 0.85 for residential and 0.7 for non-residential

development constraint factor: Constrained = 0.5, Unconstrained = 1.0

Figure 3.5 – Water Demand Flow Chart
(per *Water Model Development Documentation*, MSA, August 2010)

The following assumptions have been made in the development of the demand projections:

- Any portions of the existing City limits or UGB within the Roats or Avion service area were not included.
- 515 acres of Juniper Ridge are included in the projections. Water use projections for the Juniper Ridge Development are consistent with those used in the Water System Planning for the Juniper Ridge Development, Bend, Oregon (MSA, September 2009) and equal to 4,500 gallons per acre per day (gpapd).
- Residential Demand
    - ♦ Projections were made using "low" (10-year) and "medium" (Build-out) development densities for **all developable or re-developable parcels** based on the "buildable lands database", with the assumption of the land being **85%** developable. Areas listed as 'development-constrained' (meaning at least 50% of the area could not be developed) were assumed to be 50% developed. For residential parcels this approach was used to specify the total number of future units.
    - ♦ Residential per capita water usage was estimated from the 2008 billing records and peaked by **10.0%** for non-revenue water to project future residential water usage. This is 156 gallons per capita per day (gpcpd) x 1.1 = 172 gpcpd and compares with 158 gpcpd calculated in the 2004 WMCP, based on 2003 data.
    - ♦ All of Tetherow is included in the projections with a 20-year residential unit count of 889, which is consistent with the 2007 WMP.
- Non-residential demand
    - ♦ All non-residential land use types (with the exception of Road Right of Way, Water and Wetland), were projected assuming that the ratio of current residential to non-residential demand (64%) will remain consistent into the future. This approach results in a calculated value of 3,200 gpapd for the 10-year projection and 4,000 gpapd for the Build-out projection, with 70% of the land being developed. If the parcel was development-constrained, an additional 50% factor was applied. This is less conservative than the 4,500 gpapd used in Juniper Ridge.
    - ♦ Buckingham Elementary School is included even though it is outside the UGB, but no other customers in that area are included.

Although not specifically an issue of growth, Bend has advised that a separately piped, non-potable irrigation system currently operates to supply irrigation demands in South Bend. Customers are presently charged a flat rate for water use. After 2018 this service will cease and all irrigation demands in South Bend will be supplied from the potable system. This will therefore cause an increase in demand in this part of Bend's service area. Since irrigation demand will be billed in the same way as domestic supply it has been assumed that usage patterns in this area of the system will reflect those elsewhere in the system.

The total system demand estimates, based on population growth, have been calculated and this demand has then been broken down into future flows by Pressure Level. In the hydraulic model, the center point of each parcel was used to join parcel demand to the nearest node serving the same zone. Table 3.4 shows existing and future projected demand projections by level.

Table 3.4 – Water demand summary by Pressure Level

Pressure Level	Demand Category	Existing Demands (MGD)		10-year projection (MGD)		Build-out Development (MGD)	
		Average Day Demand (ADD)	Maximum Day Demand (MDD)	Average Day Demand (ADD)	Maximum Day Demand (MDD)	Average Day Demand (ADD)	Maximum Day Demand (MDD)
1	Residential	0.38	0.87	0.38	0.86	0.58	1.31
2	Residential	0.34	0.77	0.38	0.86	0.61	1.36
Teth	Residential	0.00	0.00	0.06	0.13	0.16	0.35
2B	Residential	0.07	0.16	0.13	0.30	0.27	0.61
3	Residential	1.18	2.69	2.54	5.72	5.28	11.87
3A	Residential	0.01	0.03	0.05	0.11	0.10	0.22
3B	Residential	0.05	0.11	0.05	0.11	0.05	0.11
WestW	Residential	0.21	0.49	0.26	0.58	0.49	1.11
3D	Residential	0.07	0.16	0.20	0.45	0.44	0.99
4A	Residential	0.69	1.56	1.00	2.25	1.58	3.57
4B	Residential	1.96	4.45	3.04	6.85	5.41	12.17
4C	Residential	0.12	0.27	0.13	0.29	0.15	0.33
4D	Residential	0.08	0.19	0.10	0.22	0.14	0.33
4E	Residential	0.21	0.47	0.38	0.86	0.82	1.83
4F	Residential	0.05	0.11	0.05	0.11	0.08	0.18
4G	Mixed	0.02	0.06	0.06	0.14	0.12	0.27
4H	Residential	0.07	0.16	0.07	0.16	0.09	0.21
4I	Residential	0.05	0.12	0.15	0.35	0.27	0.60
4J	Residential	0.07	0.16	0.09	0.20	0.11	0.26
4K	Residential	0.02	0.04	0.02	0.05	0.03	0.07
5	Mixed	4.29	9.75	5.53	12.44	8.13	18.28
5A	Residential	0.01	0.02	0.01	0.02	0.01	0.02
5B	Residential	0.02	0.05	0.20	0.44	0.63	1.42
5C	Residential	0.00	0.01	0.01	0.02	0.02	0.04
5D	Residential	0.03	0.06	0.03	0.06	0.05	0.11
6	Mixed	2.14	4.86	4.02	9.05	7.90	17.76
6A	Residential	0.24	0.55	0.30	0.67	0.39	0.87
6B	Residential	0.03	0.08	0.24	0.54	0.57	1.29
Juniper R		n/a	n/a	0.93	2.09	1.63	3.66
7A	Residential	0.25	0.57	0.26	0.59	0.31	0.69
7B	Residential	0.11	0.25	0.11	0.25	0.11	0.25
7C	Residential	0.05	0.12	0.06	0.14	0.08	0.19
7D	Residential	0.01	0.02	0.18	0.41	0.51	1.15
TOTALS		**12.80**	**29.20**	**21.02**	**47.30**	**37.10**	**83.48**

3.2.3 Impacts of conservation efforts

At the project update meeting held in December 2009 there was discussion related to the potential impact of conservation on future system demands. Bend staff noted that they have seen the impact of conservation in the past but as public awareness and enforcement dropped off, demand increased again. There are many drivers that would result in conservation in the future, including:

- Increases in price of water or a move to water budget pricing or seasonal rates
- Increases in development density/reduction in lot size
- Changes to plumbing codes, green building design standards and related standards
- Enhancements to irrigation technologies
- Behavior changes due to education/public awareness initiatives/enforcement/future incentive programs

Further discussion highlighted that, despite the drivers noted above, there may not be any appreciable impact to the expected maximum day demand. Figure 3.6 shows the potential impact that conservation would have on annual demand, where the overall volume of water use may drop but the weather-driven maximum day usage would stay about the same (the peak of these curves):

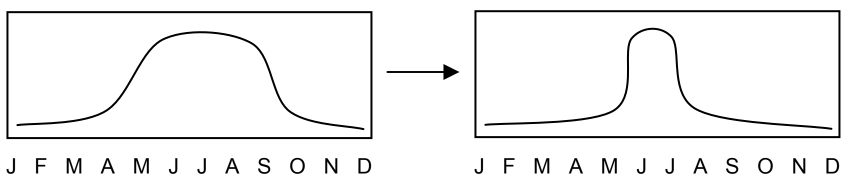


Figure 3.6 – Potential change in annual system demand as a result of conservation

There are a number of relevant observations that can be made from Figure 3.6:

- Annual average consumption will be reduced
- Maximum day demand levels may only occur, say, 5 times a year
- The need would still exist to design system capacity to meet maximum day demand
- Reduced annual consumption will provide operators more flexibility – Bend can save up Tier 2 water rights to cover the less frequent maximum day events (there are volumetric limits on Tier 2 rights but not a maximum flow rate restriction)

In addition to efforts to reduce annual per capita consumption there is the possibility of reducing peak hour flows. This could be achieved through efforts to modify irrigation practices. Currently, system-wide peak hour (PH) to maximum day (MD) ratio is 2.4 (being a combination of a residential PH:MD of 2.9 and mixed use areas PH:MD of 1.8). However, whether this would have a significant impact on the necessary system infrastructure is debatable when considering the following:

- fire flow requirements are likely to govern sizing of distribution mains and pumping capacities (so shaving the peak may have little impact)
- maximum day demand will govern sizing of transmission and supply (so, again, shaving the peak has little impact)
- peak hour demands may affect operational storage requirements

3.2.4 Potential future developments outside the UGB

As mentioned above, it is anticipated that future developments may occur outside the current UGB. The Bend long-range planning group is currently reviewing and updating the UGB. However, for purposes of consistency, the WSMP Update Optimization will utilize the same UGB considered in the 2007 Master Plan Update and include the new Tetherow development and the imminent Juniper Ridge development.

The Optimization Study will result in the development of a 'baseline' plan which, in the future, can be compared to a number of alternative growth scenarios. Evaluation of alternative development scenarios does not fall within the current project scope but would include consideration of potential developments at the edge of and/or outside the current UGB to determine the impact on necessary improvements within the existing system. Comparison of the baseline solution and these alternative scenarios would inform Bend about the implications of new developments and the extent of system improvements they could reasonably expect developers to be responsible for.

A record of potential development areas outside the current UGB discussed at the April 2009 Kick-off Meeting is provided for reference:

- North – the area north of Awbrey Butte, on either side of the Deschutes River, was identified as a potential growth area based on current developer sentiment. This area would likely be part of Pressure Level 6.
- West – the area north of the transmission mains from Outback to Overturf and west of Pressure Level 4 was identified as another potential growth area. Any new development would likely be part of Pressure Level 3.

3.3 Pipe Criticality Data

The desired outcome from the criticality analysis is a listing of the most critical pipes in the system in terms of the risks associated with failure of each pipe. Risk is a combination of both the consequence of failure and the likelihood of failure:

Risk = Consequence of Failure x Likelihood of Failure

Optimatics' software OptiCritical will be used to assess the consequence of failure of all pipes in the Bend system. The minimum required information for the consequence of failure analysis is the calibrated steady state model and the details of shutoff valves (location and operability). The analysis generates a database containing a large number of results metrics related to the impact of pipe breaks and isolation of breaks on system pressures, number of service connections and customer demands, and flow velocities. Further details of these parameters are included in Appendix A. The criticality analysis assessed the relative consequence of failure for each pipe in the network based on a number of different metrics of most concern to Bend.

Data related to likelihood of failure can be incorporated, if available, to facilitate prioritization of mains for replacement according to risk. The following additional items were identified in the Kick-off Meeting as factors that may affect likelihood of failure of pipes in the Bend system:

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

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

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

Bend's current GIS includes material information for many pipes, shown on Figure 3.7. In the CIP prioritization process (CH2M HILL, February, 2009) both pipe material and year of installation were considered as factors relating to likelihood of failure. The City stated that significant effort was required to obtain comprehensive pipe age data. As pipe material and age are roughly related, it has been agreed that pipe material only will be considered as a likelihood of failure metric in the prioritization process.

Bend has identified two major customers for which supply is critical – the St. Charles Hospital and associated medical facilities (at Neff and 27th) and the Deschutes Brewery (at Colorado and Simpson). The Brewery is a significant customer due to its sophisticated equipment which relies on water pressure being maintained. These two customers will be investigated in detail to determine which mains are critical to their supply.

As noted earlier, the criticality results will be studied to determine if there are any pipes that should be included as replacement options in the 2030 future optimization analyses. If no pipes turn out to be replacement options for the future analyses, the City will still have a valuable set of stand-alone criticality data that can be used in making decisions to strengthen selected sections of the network.

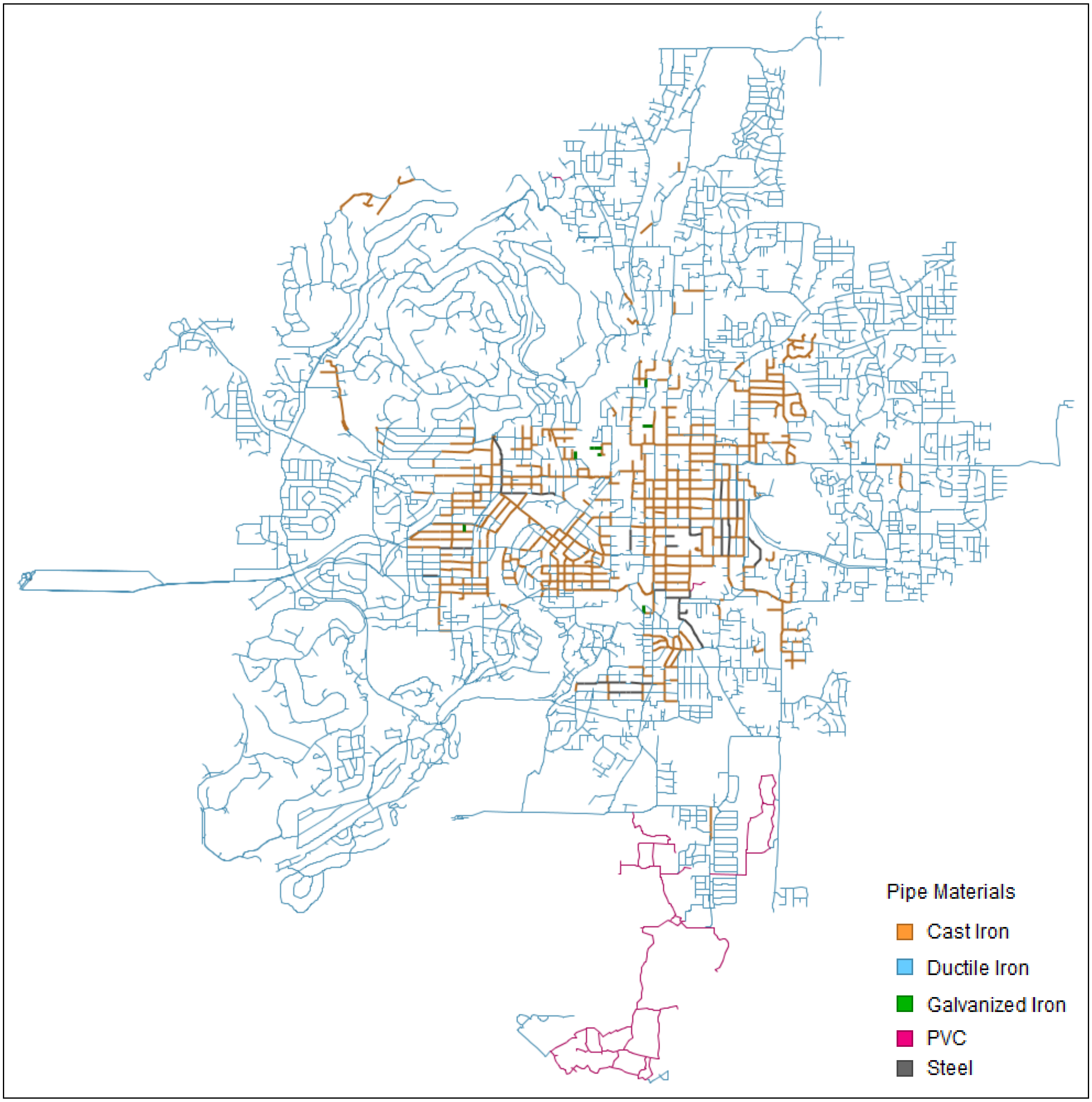


Figure 3.7 – Pipe Material Data in Bend GIS

3.4 Source Options

3.4.1 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, demand by downstream water users) the available amount of water 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 summarizes the existing surface water rights and Table 3.6 summarizes the existing water rights for groundwater sources. The City's groundwater rights total 44.1 MGD.

Table 3.7 lists the existing groundwater facilities and capacities, updated by City staff in September 2009.

With the current surface water system infrastructure, the City is able to divert and put into its distribution system approximately 11.8 MGD. 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.

3.4.2 Future Source Options and Costs

Bend has recently completed a study evaluating the feasibility of installing a hydro-generation facility on the raw water lines to the Outback site. The evaluation was based on conservative (i.e. low) surface flow values. Bend has advised that, for consistency, the Optimization Study supply assumptions should match the flow values used in the hydro planning effort. This also takes into account uncertainty with respect to securing the additional water rights required to guarantee higher flow rates.

Bend currently has rights to 21 cfs/13.6 MGD during the winter, but senior water rights and available streamflow may reduce availability during the irrigation season. The hydro study considered that during a maximum day (June/July) scenario, up to 18 cfs/11.6 MGD could be available, but more likely the value would be less due to available stream flow and competing water rights.

Based on discussions at the April 2010 project update meeting, the Build-out optimization runs will assume 36 cfs/23 MGD is available and must be utilized. This will ensure transmission piping is not undersized. This scenario assumes that the City would come to an agreement with other water right holders on the stream (including Tumalo Irrigation District) that would allow a more reliable use of 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.

Table 3.5 – Bend Surface Water Rights Summary

<table>
<tr><th>Source Type</th><th>Source</th><th>Application, Permit, or Certificate</th><th>Priority Date</th><th>Authorized Rate (cfs)</th><th>Total Rate (cfs)
(mgd)</th><th>Status</th><th>Comments</th></tr>
<tr><td rowspan="10">Surface Water</td><td>Bridge Creek</td><td>S-49823</td><td>12/12/1983</td><td>15</td><td>15.00
(9.69)</td><td>Permit</td><td>Available for use year-round. Junior right, not reliable during irrigation season</td></tr>
<tr><td rowspan="8">Tumalo Creek</td><td>85526</td><td>Senior to all other rights on Tumalo Creek</td><td>6</td><td rowspan="8">21.113
(13.64)</td><td>Certificated</td><td>Available for use year-round</td></tr>
<tr><td rowspan="3">S-31411</td><td>9/30/1900</td><td>4.5</td><td rowspan="3">Certificated</td><td rowspan="7">Only available during irrigation season Subject to volume limits and curtailment during irrigation season due to low flows in Tumalo Creek.</td></tr>
<tr><td>8/5/1900</td><td>2</td></tr>
<tr><td>6/1/1907</td><td>0.02</td></tr>
<tr><td rowspan="3">S-31665</td><td>9/30/1900</td><td>1.314</td><td rowspan="3">Certificated</td></tr>
<tr><td>4/28/1905</td><td>0.186</td></tr>
<tr><td>6/1/1907</td><td>1.103</td></tr>
<tr><td>Transfer B-112</td><td>10/29/1913</td><td>5.99</td><td>Certificated</td></tr>
<tr><td colspan="4">Total Permitted Surface Water Rate</td><td colspan="3">36.113 cfs (23.33 mgd)</td></tr>
</table>

Table 3.6 – Bend Groundwater Rights Summary

Source Type	Facility Name	Application, Permit, or Certificate	Priority Date	Authorized Rate (cfs)	Total Rate (cfs) (mgd)	Status	Comments
Groundwater	Lava Island Wells I-VIII Bear Creek Well II Outback Wells III - VI Pilot Butte IV Shilo III Hole Ten I & II	Permit G-4435	11/8/1968	7.75	7.75 (5.01)	Permit	
	Outback Wells I-IV Airport Well II Bear Creek Well I	Certificate 85414	9/10/1990	10	10 (6.46)	Certificated	
	River Wells I & II	Certificate 85415	10/31/1971	2.7	16.04 (10.36)	Certificated	
	River Wells I & II	Certificate 68702		0.9		Certificated	
	River Wells I & II Pilot Butte Wells I & II Copper Stone (Awbrey Glen) Well	Certificate 85412		7.57		Certificated	
	River Wells I & II Pilot Butte Wells I & II Bear Creek Wells I & II	Certificate 85413		4.87		Certificated	
	Westwood Well	Permit G-8565 Certificate 85411 for 1.51 cfs	12/22/1978	2.45	2.45 (1.58)	Permit and Partial Certificate	
	Rock Bluff Wells I – III Pilot Butte Well III	Permit G-11379 Certificate 85559 for 4.16 cfs	6/30/1989	8	8 (5.17)	Permit and Partial Certificate	Extension of time pending
	Bear Creek Wells III-V	Permit G-16177	8/22/1992	12	12 (7.75)	Permit	Use is subject to mitigation
	Pilot Butte Wells III-V	Permit G-16178	8/22/1992	12	12 (7.75)	Permit	Use is subject to mitigation
				Total Permitted Groundwater Rate	*68.24 cfs (44.08 mgd)*		

Table 3.7 – Groundwater production facility summary

Groundwater Production Facility	Pump Size (hp)	Pump Type	Approx. Static Water Level (feet)	Capacity (MGD)	Back-up Generator Facilities Y = yes/N= no
Awbrey Glenn (Copperstone)	250	Line Shaft Turbine	510	1.4	N
Bear Creek Well I	350	Line Shaft Turbine	629	1.5	N
Bear Creek Well II	350	Line Shaft Turbine	652	1.6	N
Outback I	150	Submersible	482	1.0	Y (5)
Outback II	150	Submersible	482	1.1	N (5)
Outback III	250	Line Shaft Turbine	478	1.7	Y (5)
Outback IV	250	Line Shaft Turbine	482	1.7	Y (5)
Outback V	250	Line Shaft Turbine	486	1.8	N (5)
Outback VI (1)	250	Line Shaft Turbine	480	1.8	Y (5)
Outback VII (1)	250	Line Shaft Turbine	480	1.8	Y (5)
Pilot Butte I (2)	250	Line Shaft Turbine	743	1.2	N
Pilot Butte II (2)	*250*	*Line Shaft Turbine*	*734*	*0.0*	N
Pilot Butte III (2)	250	Submersible	786	1.3	N
Pilot Butte IV (2)	300	Line Shaft Turbine	702	1.6	Y
River Well I	500	Line Shaft Turbine	360	2.7	N
River Well II	400	Line Shaft Turbine	242	3.0	N
Rock Bluff I	150	Line Shaft Turbine	393	1.2	Y (3)
Rock Bluff II (3)	150	Submersible	395	1.1	N (3)
Rock Bluff III	150	Line Shaft Turbine	395	1.2	Y (3)
Westwood	150	Submersible	283	1.0	N
Shilo I (4)	*25*	*Submersible*	*335*	*0.0*	*N*
Shilo II (4)	*25*	*Submersible*	*335*	*0.0*	*N*
Shilo III (4)	*250*	*Line Shaft Turbine*	*355*	2.0	*Y*
Hole Ten North	150	Submersible	410	0.8	Y
Hole Ten South	150	Submersible	412	0.8	Y
Total Groundwater Supply Capacity (MGD)				**33.3**	
Total In Service Groundwater Supply Capacity (MGD) (see notes below)				**26.8**	

Note: Data in this table is based on information in the 2007 Master Plan Report and has been updated to reflect current conditions

(1) Outback Well VI was constructed recently and is now operational. Well VII is currently under construction and will be on line by the end of summer 2009.

(2) The Pilot Butte wells have been problematic in the past. At the time of writing, Pilot Butte I was temporarily out of service. Pilot Butte II has been removed from service (capacity was 1.1 MGD) and Pilot Butte III was recently put back in service. Pilot Butte IV is slated to come on line within the year and will supply Level 5, with the ability to pump to Level 4 in emergency conditions. Plan for wells V, VI, VII with same capacity as IV.

(3) Rock Bluff Well II is always off. The generator at Rock Bluff is able to run two of the three wells at once

(4) All Shilo wells are currently out of service. Shilo I well to be abandoned, Shilo II well to be backup monitoring well with no pump, just capped, Shilo III will have portable generator plug in facilities following upgrade this spring. Output with delivery to Level 4 is approximately 2 MGD.

(5) Outback Wells I and II have portable generator capacity for one well at a time; there is a generator for Wells III, IV, and V but only two of these wells can be run at a time; the Well VI generator should ultimately be able to operate three wells there, which would include Well VI and Well VII.

Based on the water demand estimates presented in Section 3.2.2 above, 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. Current supply capacity is 33.3 MGD from wells and 11.6 MGD from the surface water source; a firm capacity of 33.3 MGD. With the upgrades to the surface water system there will be up to 23 MGD available from that source, although this may not affect the system's firm supply capacity (calculated by excluding the largest source). Up to an additional 50.2 MGD of supply will be needed above the existing firm capacity to meet future maximum day demands if none of the surface water supply is relied upon to provide firm capacity. The optimization is not considering firm capacity and the location of back-up wells; it will help determine how best to utilize the 23 MGD of surface water and existing wells together with 27.2 MGD of new groundwater to meet future maximum day demands.

Options for new water sources include:

- Expansion of existing groundwater facilities
- New groundwater facilities
- The potential use of the well at Pine Nursery Park which could supplement supply to the north (Juniper Ridge) – this would require negotiations with Bend Parks and Recreation District
- Acquiring additional surface water rights and improving the surface water supply system
- Interties with neighboring providers

Groundwater

Once the new raw water pipeline is in place (eliminating the present delivery restrictions), the City's use of surface water may still be limited by streamflow and demands by Tumalo Irrigation District. It remains to be determined how Bend will meet peak day demands given the limitations of the shared surface water resource at various times of the year, as well as the impact this will have on how much additional future groundwater production capacity will be required.

The Water Management and Conservation Plan Report (2004) considered the option of moving towards 100% groundwater supply, but based on the most recent surface water study it was decided that this is not preferable from the standpoint of reliability, energy costs, water quality and the addition of hydroelectric generation. In addition, maintaining surface water provides Bend with two diverse sources of supply.

The 2007 Master Plan Update recommended that additional groundwater wells be developed to meet the additional supply requirement. A total of 29.6 MGD of additional well capacity was recommended, bringing total well capacity to approximately 50 MGD. The following locations were identified for capacity increases in the 2007 MP Update:

- Awbrey
- Bear Creek
- Outback
- Overturf
- Pilot Butte
- Rock Bluff
- Shilo
- Hole Ten

At the April 2009 Project Kick-off Meeting, a number of potential locations for new groundwater facilities were identified. Both the recommended groundwater expansions from the 2007 MP Update and the potential new sites are highlighted on Figure 3.8.

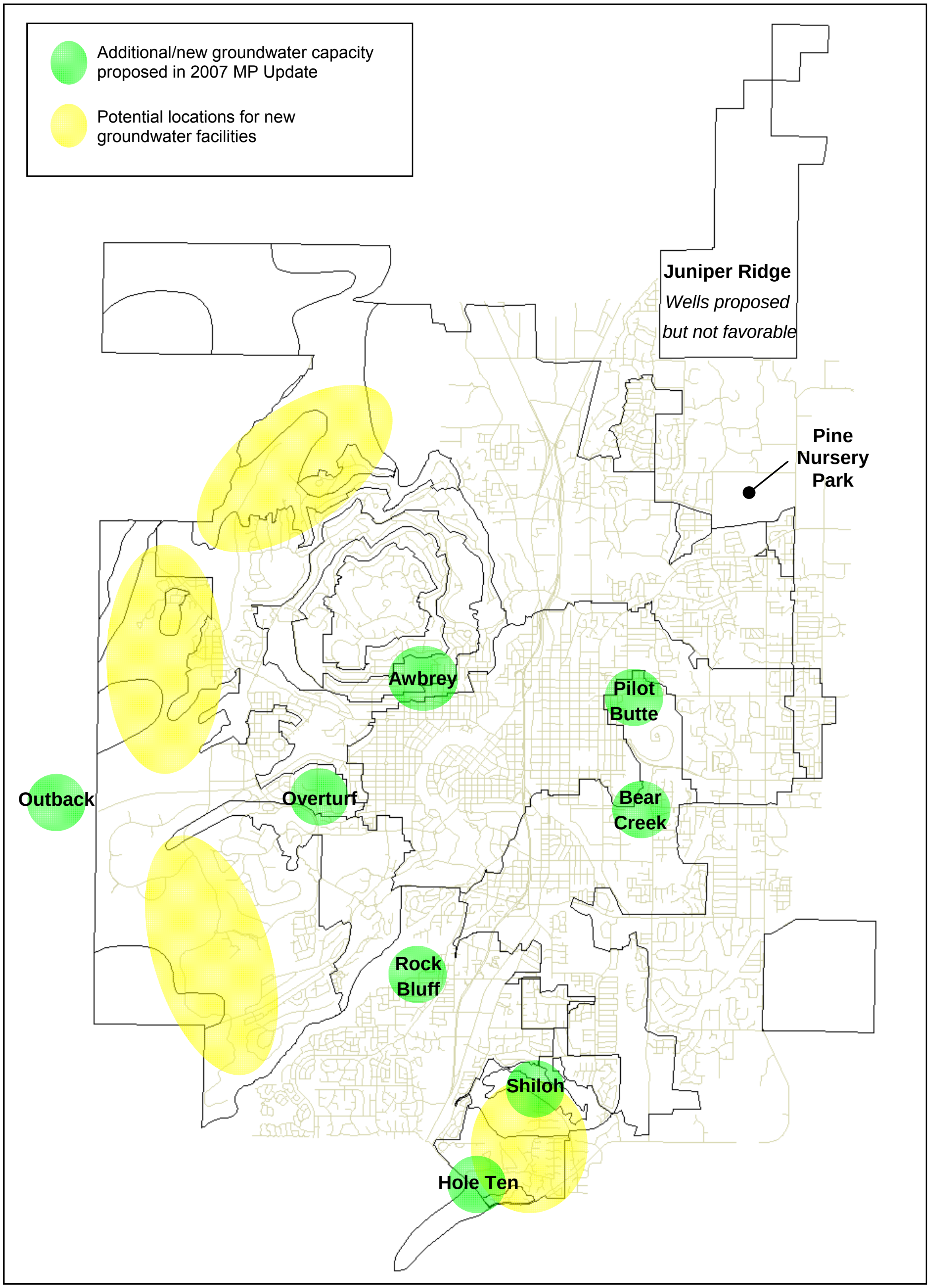


Figure 3.8 – Favorable locations for new groundwater facilities

As shown in Figure 3.8, the 2007 MP Update proposed new wells in Juniper Ridge to help meet future demands in this area. Bend has advised that developing groundwater capacity here is not favorable. The regional aquifer gradient matches ground elevation gradient sloping downwards to the northeast. To avoid potential complications associated with interactions between storm water injection wells and the Deschutes Aquifer, and being mindful of Underground Injection Control (UIC) rules, it is preferable to develop groundwater capacity in the west and south rather than north and east.

As part of the new plans for the South Bend area, it is understood that a new Shilo well will be constructed with a capacity of 2 MGD. Details of plans for this area are to be confirmed.

At the Project update meeting held in August 2009, several additional near-term options were discussed:

1. There are plans in place for new wells at Pilot Butte 5, 6, and 7. A new Outback Well 8 is being considered.
2. Pine Nursery Well in the northeast section of the system is an existing well owned by the Park District but it is not being used to its maximum. Bend would like to purchase the well from the Park District and make it fully operable again. Given its location the well could help meet the demand from the anticipated growth area in the northeast.
    - Information received from Bend Park & Recreation states that the well was drilled to 1057 feet and the static level is 702 feet. The well was test pumped at 1,800 gallons per minute for 24 hours with no effect on the static water level. Bend Park & Recreation has removed a large well pump and replaced it with a small submersible pump for supplemental uses, and to keep the well active. There is also a small well house for the electrical service and maintenance.
    - The well is covered by Certificate 57067 which allows for use of 0.96 cfs for supplemental irrigation of 77.1 acres and 1.78 cfs for frost protection on Nursery lands.
    - If Bend is successful in securing an agreement to use this existing well, existing groundwater rights exist to use at that well site and a permit amendment could be filed.

Costs for new wells

The cost for new wells is estimated at $1,350,000 per MGD of capacity (MSA 2009). This cost is based on the assumption of a 16-inch diameter steel casing and a depth of 750 feet below ground surface.

An additional consideration when selecting potential sites for new wells is that the depth of the aquifer varies throughout the city. Wells in the west do not need to be as deep as those on the eastern side of Bend and thus will be less costly to implement. However, as surface water enters the system from the west, care will need to be taken to ensure that any new wells in the west do not have an adverse effect on maximizing the surface water supply during high demand conditions.

The current well depths in the system are between 400 and 1,100 feet. It is believed that adding 40% additional cost to the capital costs to cover contingency, engineering, and administration should provide sufficient flexibility to cover the cost of additional depth beyond 750 feet.

Surface Water

Bend is currently working on a surface water study, looking at ways to improve the overall reliability of the raw water transmission system. Currently two 12-inch diameter lines transfer supply from the diversion at Bridge Creek to the Outback site. The pipes are vulnerable since they are shallow-buried, thin-walled steel pipes. In addition, new treatment rules will force Bend to provide further treatment to its surface water in the future.

Given this investment, and the lower operational costs associated with the surface water source, a major aim of the optimization study will be to determine ways to maximize use of available surface water throughout the year. Bend is currently working to protect its existing surface water rights for future use. As described previously, the City's surface water rights authorize up to 23.3 MGD during the irrigation season, but actual availability is dependent on streamflow and water demand by other appropriators on Tumalo Creek. Any plans to meet current peak day demand must take into account the maximum surface water available on any given day, added to the ability to produce maximum groundwater with existing and planned groundwater wells and associated groundwater rights.

Interties with neighboring providers

Bend is considering options to tie in with neighboring Roats and Avion systems. The Roats system operates at a higher hydraulic grade than the surrounding Bend system. A connection could be made via a PRV which would aid supply to the South Bend area. There is also the option to tie with Avion in Level 5 which may help avoid capital improvements.

Based on previous agreements, Bend estimates Roats/Avion purchase costs to be $0.65-0.70 per 100 cubic feet (ccf) (748 gallons). Any intertie transfer also needs to address chlorination as Roats and Avion currently do not chlorinate their supply.

3.5 Pipe Options

3.5.1 Existing Pipes

Table 3.8 lists the total length of main by diameter in the Bend system. Table 3.9 lists the total length of each pipe material. Existing pipes in the Bend system are primarily ductile iron. The next most common material is cast iron. The most common pipe diameter size is 8-inch, followed by 12-inch and 6-inch.

Table 3.8 – Existing system – Pipe diameter statistics

Pipe Diameter (inches)	Total Length (ft)	Total Length (miles)
2	30,742	5.8
4	24,067	4.6
6	358,226	67.8
8	990,187	187.5
10	168,825	32.0
12	417,591	79.1
14	9,860	1.9
16	180,062	34.1
18	13,222	2.5
24	15,723	3.0
30	12,297	2.3
36	14,131	2.7
Total	**2,234,932**	**423.3**

Table 3.9 – Existing system – Pipe material statistics

Pipe Material	Pipe Length (miles)
Cast Iron	49.7
Ductile Iron	358.2
Galvanized Iron	0.4
PVC	10.5
Steel	4.4
Total	**423.3**

3.5.2 New and Replacement Pipe Options and Costs

The 2007 Master Plan Update recommended $37.4 million of distribution piping improvements and $7.7 million of transmission piping improvements (2006 dollar estimate) to meet year 2030 requirements. Major transmission improvements identified in the 2007 Master Plan Update include:

- Transmission improvements between Outback and Washington Drive parallel to and along Skyliners Road
- Additional pipe from Rock Bluff to help with feeding South Bend via Murphy pump station
- New pipe to support supply to the new Juniper Ridge development

A large number of the identified distribution improvements were designed to meet fire flow capacity requirements. Fire flow will not be considered explicitly in the optimization. Optimatics proposes assessing fire flow in the hydraulic model and identifying a minimum replacement size for mains identified as under-capacity for 2030 conditions. In locations where further upsizing could provide benefits to transmission or distribution system capacity, these pipes will be considered as options for sizing (above minimum size) in the optimization.

At the Kick-off Meeting, potential transmission routes as well as routes that would be unfavorable for significant open cut construction were identified. These corridors are shown on Figure 3.9. The aim is to avoid the city center, and preference should be given to the proposed collection system interceptor routes. Once the future model is available, Optimatics will run a deficiency analysis and determine specific pipe options.

In addition to these transmission corridors, some specific improvements were identified:

- Replace plastic pipe (2-inch diameter mains in particular) in South Bend with 8-inch diameter DI pipe
- Replace all galvanized pipe (see Figure 3.7).

Unit costs for new pipes

Table 3.10 shows the costs that will be assumed for new pipes in the optimization. New pipes will be a minimum of 8-inch diameter to ensure fire flow capacity is maintained. The unit costs do not include property or easement acquisition cost, but do include rock excavation costs and a 40% cost addition for contingency, engineering, and administration.

Table 3.10 – New pipes – Sizes and Unit costs (construction)

Pipe Diameter (inches)	Roughness C Factor	Unit Cost ($/ft)
8	130	140
10	130	160
12	130	190
16	130	240
18	130	265
24	130	350
30	130	410
36	130	475

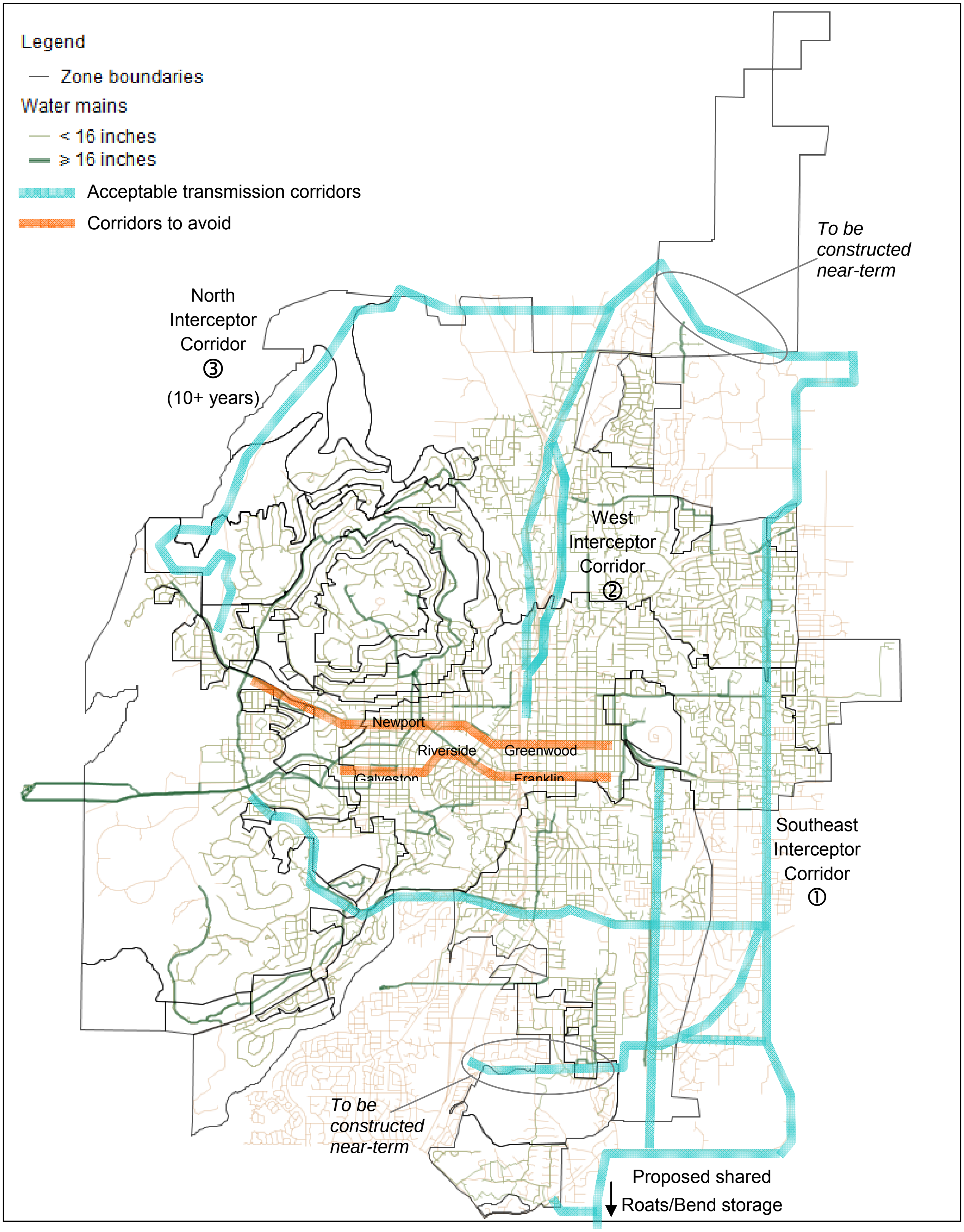


Figure 3.9 – Potential transmission main corridors
(circled numbers represent anticipated sequence of implementation for interceptors)

3.6 Storage Options

Storage volume requirements and the constraints that will be applied in the optimization are discussed in detail in Section 4.3. The following sections provide details of existing storage and options for location of additional storage in the system.

3.6.1 Existing Storage

A number of storage reservoirs are located throughout the City. Table 3.11 presents the storage details in terms of capacity and elevation, supply source and area served.

Table 3.11 – Existing storage reservoir summary (sorted by Pressure Level)

Reservoir Name	Reservoir Type	Capacity (mg)	Overflow Elevation (feet)	Floor Elevation (feet)	Source	Pressure Level Served
Tower	Welded Steel	1.00	4,224	4,213	Surface Water	1
College I	Welded Steel	0.50	4,123	4,100	Surface Water	2
College II	Welded Steel	1.00	4,118	4,087	Surface Water	2
CT Basin	Bolted Steel	1.50	4,024	3,980	Surface Water	3
Outback I	Bolted Steel	2.00	4,011	3,976	Surface Water	3
Outback II	Welded Steel	3.00	4,011	3,976	Surface Water	3
Outback III	Welded Steel	3.63	4,011	3,982	Outback Wells	3
Overturf I	Riveted Steel	1.50	3,871	3,843	Outback Reservoir I	4 West (4A)
Overturf II	Riveted Steel	1.50	3,871	3,843	Outback Reservoir I	4 West (4A)
Pilot Butte II	Welded Steel	1.00	3,880	3,840	Rock Bluff and Bear Creek	4 East (4B)
Rock Bluff	Welded Steel	1.50	3,879	3,841	Rock Bluff Wells	4 East (4B)
Awbrey	Concrete	5.00	3,795	3,775	Surface Water	5
Pilot Butte I	Welded Steel	1.50	3,782	3,750	Pilot Butte Wells	5
Pilot Butte III	Concrete	5.00	3,782	3,758	Pilot Butte Wells	5
Westwood	Welded Steel	0.50	3,872	3,842	Westwood Well	Westwood
Total Storage Capacity		**30.13**				

One operational difficulty in the system is in Pressure Level 4. As mentioned above, Level 4 operates as two separate zones - 4 West (4A) and 4 East (4B). The Overturf Reservoirs provide supply to 4A while Pilot Butte II and Rock Bluff support 4B. The overflow elevations of these reservoirs differ by just under 10 feet, with the Overturf Reservoirs at 3,871 feet and Pilot Butte II/Rock Bluff at approximately 3,880 feet. This interferes with the integration of surface water supply since 4A is operating at a lower level than 4B, restricting supply from west to east. The Scott Street Pump station is used in the winter to facilitate surface water transfer to 4B (Rock Bluff). During summer operation, groundwater wells are used to fill the 4B reservoirs.

In Level 5 there is a difference in the overflow levels of Awbrey and Pilot Butte I and III, but the eastern Pilot Butte Reservoirs are lower in this case so it does not hinder supply from west to east. During low demand periods, however, the difference in the levels of these storages makes it hard for Bend operators to keep the Pilot Butte Reservoirs fresh as their water levels will often sit below the Level 5 hydraulic grade line.

Although the two College tanks supply the same pressure level, they are not located on the same site, have different overflow levels, and do not float together.

3.6.2 New Storage Options and Costs

The recommended new storage reservoirs in the 2007 Master Plan Update are presented in Table 3.12. The table shows the priority of each recommendation as well as the location, pressure level served, recommended volume and estimated costs.

Table 3.12 – Recommended new reservoirs, 2007 Master Plan Update

Priority	Location	Pressure Level Served	Volume (MG)	Estimated Cost (2006 dollars)
1	Rock Bluff II	4 East (4B)	3.0	$3,750,000
2	Pilot Butte IV	6 & 7 (via 5)	2.3	$2,900,000
3	Pilot Butte V	6 & 7 (via 5)	3.0	$3,750,000
4	Juniper Ridge(1)	Juniper Ridge	2.0	$2,600,000
5	Pilot Butte VI	4B, 5, 6 & 7	3.5	$4,350,000
6	Rock Bluff III(2)	4B	3.0	$3,750,000
Total			**16.8**	**$21,100,000**

(1) Bend is now considering remote storage at Pilot Butte to support Juniper Ridge

(2) Alternatively could construct additional storage at Pilot Butte

These potential storage improvements were discussed briefly at the April 2009 Kick-off Meeting and again in the update meeting in December 2009. Bend advised that detailed design of the additional storage at Rock Bluff has been completed but construction has been put on hold. For Juniper Ridge, Bend is now considering installing additional storage on Pilot Butte rather than locating storage within the development (see below for more details). This should provide the required hydraulic grade to serve higher elevations in the Juniper Ridge development and should also avoid anticipated public opposition to new ground or elevated storage closer to the development.

Any new storage at Awbrey and Pilot Butte would need to be in-ground tanks, which are every expensive. Overturf and Rock Bluff are sites which would not require in-ground tanks; there is also plenty of space available at these locations.

The option of raising the overflow level of Overturf Reservoirs (and thus the hydraulic grade of Zone 4A) was discussed at the Project update meeting in August 2009. It was agreed that if additional storage is planned at this site it could be built at a higher elevation, replacing the existing storage. Bend has land available on the site that would facilitate this. If no additional storage is recommended then the overflow elevation would remain as it is currently.

Additional Level 4 storage could be located at the Westwood site although there is not a large amount of space. Bend would like to review overall plans for this site including the pump station and existing reservoir. The optimization analyses will consider options to change operations at this site and potentially expand storage if this provides benefit to the system.

The existing Awbrey Tank site has been identified as a difficult location for additional storage. There is already storage of 5 MG. A potential site for additional storage is the Tower Rock location. A 1-MG tank currently exists at this location and Bend advises that there is ample room for additional storage. There may be public opposition to new storage at this site; however, it can still be considered as an option in the optimization analyses. In addition, there are options for locating storage elsewhere on Awbrey Butte; specifically, parks and school fields represent opportunities for underground storage tank location.

The City is currently investigating the option of installing a new 5.7-MG storage at the Middle School Track, (near Pilot Butte, south of Neff Road) that could serve Zone 6 by gravity and support the new Juniper Ridge development. The storage would likely be implemented in two phases with the first at 3.9 MG and the second at 1.8 MG. The estimated cost for the total construction, including associated necessary transmission main, is estimated at $13.5 million.

Some areas of the Bend system currently operate as constant pressure pumped systems. Specifically, the Westwood and South Bend areas do not have elevated storage. Ideally the City would prefer to move away from this operation and the optimization will consider options to achieve this. There is potential for new storage to be located east of Tetherow on Forest Service land. However, the Forest Service will not grant an easement but would sell a long strip of land to Bend, making this an expensive option. The optimization can consider the option of new storage at this site with an additional factor to account for land costs.

The MSA Memo "*Alternatives Analysis for Improving the City's Water System in the Southerly Portion of the City (South Bend), Including the Former Juniper Utility Area*" (December 2008) identified a number of locations for storage to support South Bend (see Figure 3.10). The tanks would be at a hydraulic grade suitable for gravity supply to Zone 2B. Supply to Zone 3D could be via a PRV. Supply to support this storage could include the existing Shilo and Hole Ten Wells, or a new groundwater facility at the tank site. The optimization analyses will consider these options and provide a recommended future plan for operation in this area.

The City is in discussions with Roats Water System about the potential to share the costs of storage and transmission mains from this site. One challenge is the fact that Roats does not chlorinate its supply, complicating matters if a joint facility were to be pursued.

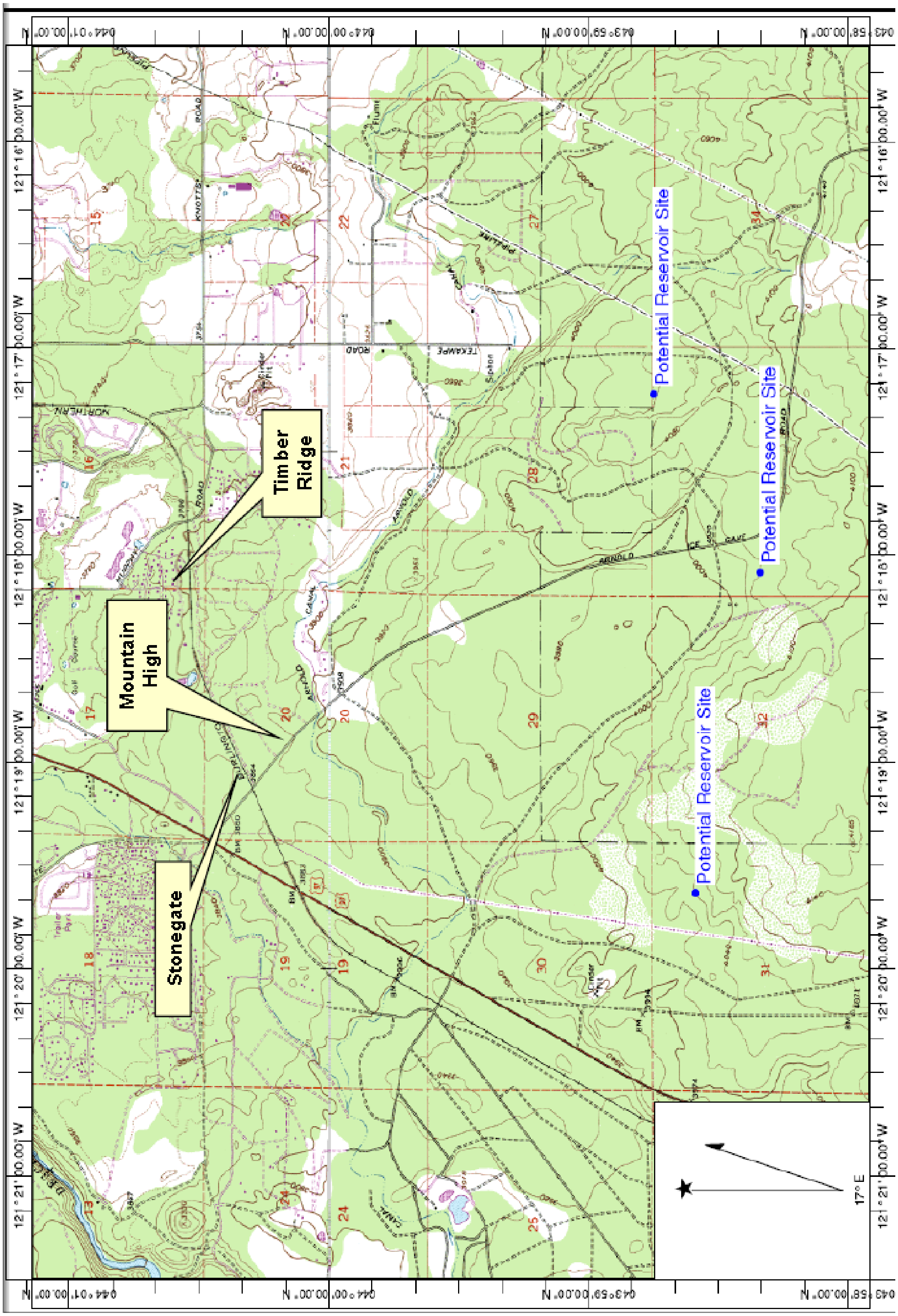


Figure 3.10 – Potential locations for new storage to support the South Bend area

Costs for new storage

The costs in Table 3.12 (2007 Master Plan) indicate a unit cost of approximately $1.2 - 1.3 million per million gallon (MG). MSA's September 2009 Memo (updated June 2010) provides a trend line for two types of storages – partially buried concrete and above ground steel tanks. Figure 3.11 repeats the graph in the MSA memorandum for reference. For above ground concrete reservoirs, the line for buried concrete reservoirs should be shifted down so it intersects $1.6 per gallon at 3 MG on the x-axis. Reservoir project cost estimates are based on the following assumptions:

- No rock excavation included, however significant cut and fill is included in the site work estimate, assuming construction on a hillside or butte.
- No property acquisition costs included as it is assumed that reservoirs will be constructed on City-owned property or property acquired at little or no cost to the project.
- Construction by private contractors.
- An ENR construction cost index of 8652 for Seattle, Washington (August 2009).
- 40% added cost to cover contingency, engineering, and administration

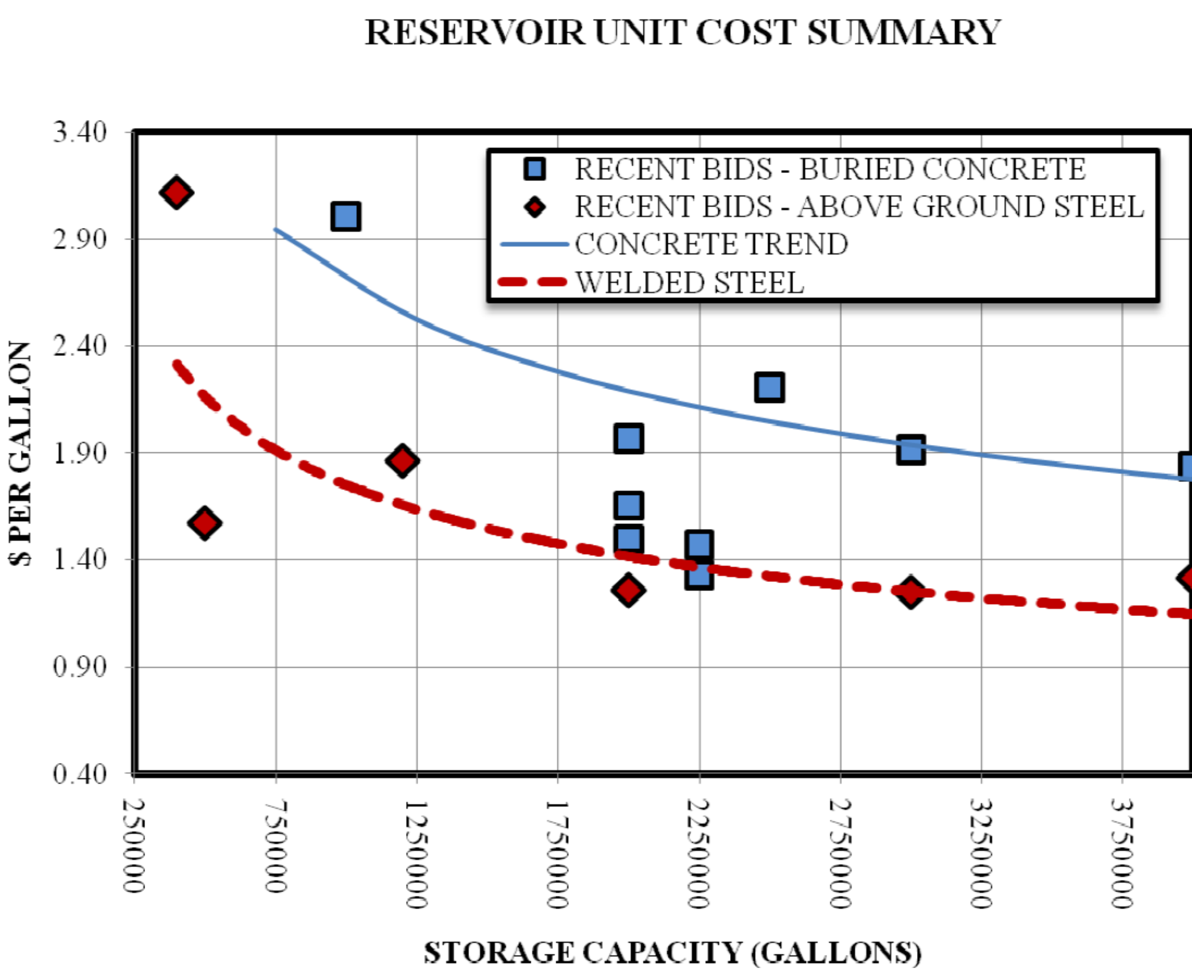


Figure 3.11 – Estimated Reservoir Unit Cost Curves – Concrete vs Welded Steel (MSA, 2009)

3.7 Pump Station Options

3.7.1 Existing Booster Pump Stations

The current system includes 6 pump stations to boost supply to higher elevation levels. The capacity and function of each pump station is listed in Table 3.13. The presence or absence of back-up generator facilities is also indicated.

Table 3.13 – Existing booster pump station summary

Pump Station	Unit	Capacity(1) (gpm)	Levels Serviced	Back-up Generator Facilities (Y/N)
Awbrey	1	950	Boosts water from Level 5 to Level 1	Y
	2	1,340		
	3	1,200		
College	1	1,050	Boosts water from Level 3 to Level 2	N
	2	900		
Westwood (2)	1	390	Boosts water from Westwood Reservoir to Westwood service area	Y
	2(3)	550		
	3	900		
	4	550		
Murphy(4)	1	300	Boosts water from Level 4B to Level 3D (In the future new piping will facilitate pumping 4B to 2B)	Y
	2	300		
	3	300		
	4	300		
	5	300		
Scott(5)	1	530	Boosts water from Level 5 to Level 4B	N
	2	530		
	3	530		
Tetherow	1	150	Boosts water from Level 3 to Tetherow	Y
	2	700		
	3	700		
	4	700		
	5	700		
	6	700		

(1) Flow rates indicate typical flow rates based on available SCADA data and model results if available to the nearest 50 gallons (per MSA analysis), otherwise they are based on pump curves which may or may not be accurate

(2) Two pumps are for pressure, one backs up the first. The third pump is for fire flow. The fourth pump is on a timer and runs for irrigation on a preset schedule.

(3) Flow includes some recirculation through the Westwood Reservoir and pump station

(4) 2007 MP Stated capacity of Murphy pumps was 450 gpm each.

(5) 2007 MP Stated capacity of Scott Street pumps was 1,250 gpm each.

3.7.2 New or Modified Booster Pump Stations and Costs

For areas where storage facilities support gravity supply to an area served by a pump station, it is recommended that a firm pumping capacity be equal to the area's maximum day demand. In the case of a pressure pumping system, firm capacity should be equal to the area's peak instantaneous demand plus fire flow. If the pressure pumped system is reasonably large, firm capacity equal to maximum day demand plus fire flow may be sufficient. For constant pressure pumping systems, emergency backup power generation facilities are very important.

Hydraulic modeling allows engineers to determine what the pumping requirements are for a particular design scenario. It should be noted that recommendations about pump capacity generated through the optimization process will simply provide an indication of the necessary firm pumping capacity, rather than full details regarding pump station design and standby pumps.

At the Kick-off Meeting, issues were raised about existing pump stations that should be addressed in the current Master Plan Update Optimization Study. These include:

- Scott Pump Station – at the moment it is used to push supply east to Pilot Butte under winter demand conditions. The City could consider using these pumps during summer to fill Pilot Butte and Rock Bluff Reservoirs in place of using wells to fill these storages. This may help with surface water integration.
- Current issues with the operation of pumps in the South Bend area – specifically interaction between the Murphy PS and Shilo/Hole Ten wells. Pressure is used to control pump operation in this area. If Bend proceeds with the option of building storage south of this location then controls could be based on storage levels, which would simplify operations.
- Surge issues at the Murphy PS are exacerbated by flexible, poorly installed pipes. A new 16-inch diameter ductile iron pipeline has been proposed to rectify this issue.
- Hole Ten Wells have new variable frequency drive (VFD) pumps that provide continuous pressure. There is a pond which collects excess water when demands are very low to stop the system from over-pressurizing. The Shilo wells are not currently being used as they conflict with the operation of the Murphy Pump Station. The wells have substantial capacity and could provide enough flow to fill reservoirs in Level 4 (Rock Bluff).
- Bend is experiencing problems operating the Westwood and Tetherow Pump Stations. The optimization will look for ways to improve operation in this area of the system, including options for storage, zone boundary configuration and pump station operation.

There is an opportunity to reduce pumping head to Level 1 (currently supplied from the Awbrey Pump Station in Level 5) and provide some redundancy by installing a booster station in Level 2. Two potential locations have been identified by Vertical Projects, one at College II Reservoir, and the other at the intersection of Starview & Fitzgerald. The latter location has a small pit that could be used for a small pump station with two 15-hp pumps.

MSA's Unit Costs memo provides cost estimates for pump stations of varying capacity. Figure 3.12 repeats this information for reference. Pump station project cost estimates are based on the following assumptions:

- No rock excavation included.
- No property acquisition costs included as it is assumed that pump stations will be constructed on City-owned property or property acquired at little or no cost to the project.
- Construction by private contractors.
- An ENR construction cost index of 8652 for Seattle, Washington (August 2009).
- 40% added cost to cover contingency, engineering, and administration

For pump capacities less than 25 HP, a cost of $30,000/HP will be assumed.

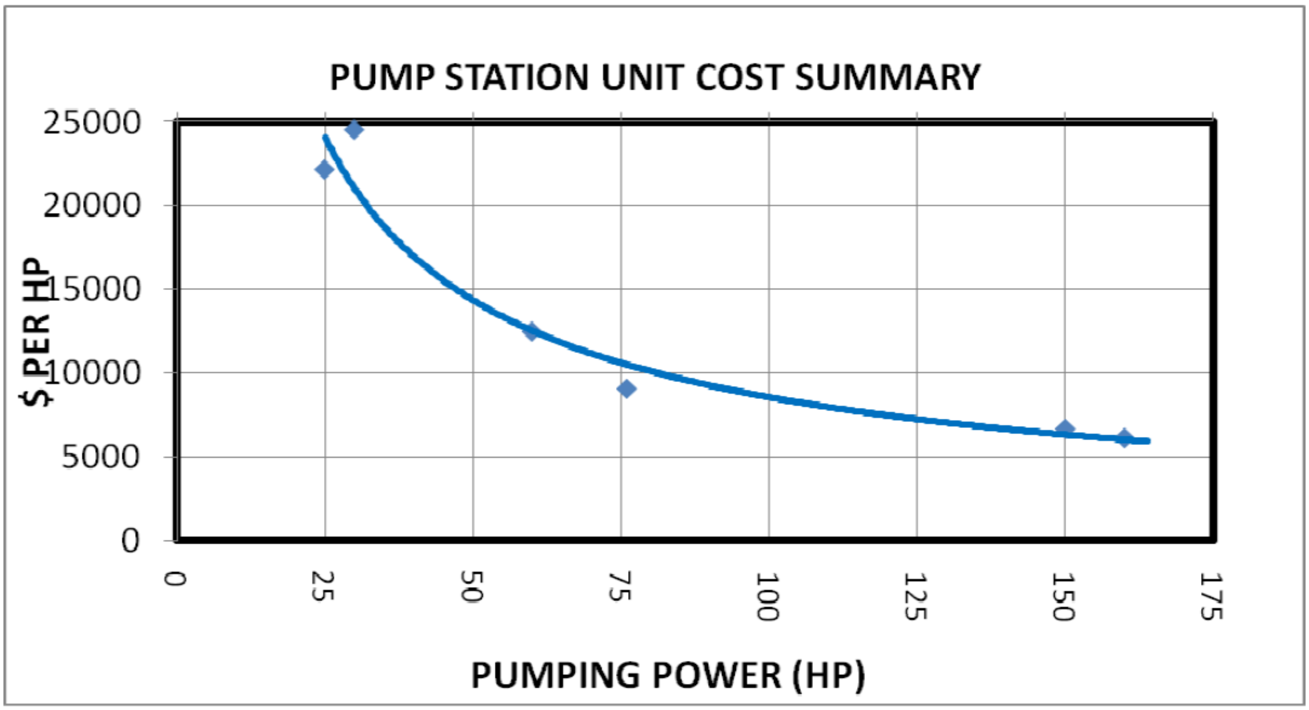


Figure 3.12 – Estimated Pump Station Unit Cost Curve (MSA, 2009)

3.8 Valves and Zone Boundaries

3.8.1 Existing Zone Boundaries

A brief discussion of the configuration of pressure levels was provided in Section 1.1. A hydraulic profile has been developed by MSA which shows all of the individual pressure zones, their HGL, storages and supply sources. This profile is provided in Appendix B. In addition to the major pressure levels there are many small pressure zones supplied by PRVs. In total there are 32 pressure zones in the Bend system.

3.8.2 Modifications to Level/Zone Boundaries

The operation of Levels 1 and 2 involves booster pump stations to lift supply to the appropriate hydraulic grade. There are also valve connections between these levels and lower levels. Optimatics will review the operation of this area to try to identify opportunities for increased efficiency.

The large number of PRVs that have been placed in the system also prevent circulation and create dead end lines in some locations. Bend would like to improve flow paths and avoid dead end lines where possible.

There are a large number of small subzones and these have been assessed to determine the feasibility of incorporating them into larger neighboring zones. Particularly in Level 4, there are a number of opportunities to combine subzones into 4A (e.g. 4G, 4I, 4J and 4K).

The Westwood pressure level (3C) operates at a hydraulic grade between that of Level 3 and Level 2. Adjacent Tetherow (2A) currently serves a single service connection, resulting in challenges in operating the Tetherow Pump Station. The pump station was designed to supply a substantial new development. A number of potential changes could be made in this area to improve operations such as modifying zone boundaries and changing the area supplied by the Tetherow Pump Station. These options and others will be considered in the optimization analyses.

The South Bend Memorandum (MSA, 2008) focused on former Juniper Utility and suggests short- and long-term improvements to address current problems. Bend is in the process of implementing the short-term recommendations. In the optimization analyses the long-term improvement options will be considered, along with any additional options for this area. The recommended long-term solution involves implementing a new reservoir south of Zone 2B at approximately 4,060 ft elevation and potentially adding new wells or modifying the Shilo wells to serve Zones 2B and 3D. Approximately 12,000 feet of transmission piping would be needed to connect the storage to the current system. Tying Zone 3D to 4B would provide additional redundancy. Alternative operational options include modifications to the Murphy Pump station, existing wells, storage and new pipelines.

The key benefit of the current long-term recommendation is that it would eliminate the need for constant pressure pumping in the South Bend area. Existing wells would be operated to supply their respective pressure levels, and new wells could be implemented at the proposed reservoir site south of the Mountain High area as demands increase. The proposed long-term solution would provide sufficient fire flow capacity to the former South Bend area, minimize system dependence on constant pressure pumping, reduce maintenance needs for the system, and improve domestic service within the former Juniper Utility area. In addition, it provides good flexibility in operating pressures for the area. Storage at the South Bend location could offset the need for storage at Rock Bluff.

3.8.3 New or modified valves

The optimization will be formulated to consider modifications to existing valve settings and the introduction of new valves where appropriate.

2007 Master Plan Update recommended a pressure sustaining valve (PSV) between Pressure Level 4B and 3SB at the intersection of Chase Road and Mowitch Drive. Bend is currently reviewing plans for this area; this option will be reviewed in light of proposed changes to the area and included if appropriate.

Specific options to modify existing valve settings include:

- Changing the flow control valve settings at Awbrey and Overturf with the aim of reducing peak flows through the transmission mains from Outback which should increase pressures in the transmission main and improve the ability to supply surface water further east.
- Changing PRV settings on the boundaries of Levels 4 (A and B) and 5 – the required settings are likely to be different under different demand cases. For example, during the winter the aim would be encourage drawdown and refill of the Pilot Butte Storages. In the summer the aim would be to maximize surface water transmission through the system. It is anticipated that a 5-7 psi range on the PRVs serving Level 5 will facilitate these aims.

Costs for new valves

The estimated cost of implementing new valves in the Bend system is $75,000 according the MSA Unit Cost Memorandum (September, 2009). Pressure reducing station project cost estimates are based on the following assumptions:

- No property acquisition costs included.
- Construction by private contractors.
- Station includes one 6-inch diameter pressure reducing valve and one 2-inch diameter pressure reducing valve.
- An ENR construction cost index of 8652 for Seattle, Washington (August 2009).

3.9 Optimized Model Controls

Bend currently faces a number of operational challenges including:

- Integration of surface water. Operators note that when the River Wells turn on they significantly impacts integration of surface water supply. The River Wells are high production wells (1,500 gpm) which supply Pressure Level 5, filling Awbrey Reservoir and impacting gravity supply from Outback to the lower pressure levels.
- Movement of water from west to east – piping restrictions and elevation differences between reservoirs in Level 4.
- The operation of the groundwater wells in summer is largely manual and this may affect the feasibility of recommendations for operational controls.

Appendix C contains information as provided by Bend Operators at the December 2009 meetings and outlines control settings for facilities under summer and winter conditions.

Although a SCADA system is in place it is currently used only in a limited way. Vertical Projects Consultants are currently reviewing the Bend system and have made a number of recommendations. Among them is a plan to implement key improvements which will enhance the existing SCADA and help Bend improve its data capture and monitoring goals. Other recommendations address the use of existing facilities. Some of the recommendations are:

- Tetherow – logic controllers are recommended to make better use of this station.
- The City should keep the Westwood station. It could either be upgraded or used as a back- up. A VFD exists there but needs to be repaired.
- Murphy Pump Station – recommendation is to install pump control valves and a hydropneumatic tank; remove the existing bladder tanks.

The optimization formulation will evaluate changes to existing controls and the introduction of set points for well and booster pumps based on storage levels throughout the system. The assumption is that SCADA upgrades would be made to allow some pumps to be operated automatically (candidates are pumps that are currently manually operated and do not need to be run to waste on start up). The aim will be to facilitate surface water integration through modifying the priority of which sources are used to fill storages, particularly on the east side of the system.

3.10 Operating Cost Calculations

In order to properly consider the full cost of infrastructure upgrades it is prudent to consider operating costs in the optimization. This allows life-cycle costs to be considered and minimized. This can include cost of water production at new and existing treatment plants and the cost of energy at existing, new and upgraded pump stations throughout the system.

In the Build-out MP Optimization where maximum day demands will be considered, a factor will be used to scale down costs to an average value before computing annual costs. This peaking factor is likely to be higher than the ratio between average and maximum day demands. Based on the current system operations it is understood that summertime energy costs will be significantly higher than winter costs. During the winter the system is supplied primarily from surface water by gravity. As demands increase in the summer months, additional well pumping is required to meet demands.

If data are available relating to water production and energy consumption, these can be compared to develop a reasonable factor to use in the calculation of annual operating costs. This assumption about the relationship between maximum day and average day operating costs will not be entirely accurate; however, it does provide an approximation of the operating costs and ensures that these are not ignored 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: $E = P \times t$ *(hours of pumping)*

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

Flow and head data, as well as hours of pumping, will be determined through hydraulic modeling. Additional data required to enable the above costs to be calculated are:

- Relevant efficiencies for individual pumps (assume 70 percent for pumps that have not been tested, 80 percent for new pumps)
- Energy costs
- Demand and other charges

Bend has provided example invoices from electricity provider Pacific Power & Light Company for all water facilities from July 2008. The invoices provide information on rate schedules and billing rates.

Three major schedules apply to Bend's water facilities: 23, 28 and 30. Schedule 23 (General Service – Small Nonresidential) is for low energy use facilities such as reservoirs and valves. Costs for these facilities are expected to be inconsequential and will not be considered in the optimization. Schedule 28 (General Service – Large Nonresidential 31 kW to 200 kW) is the most common schedule for pump stations, with Schedule 30 (General Service – Large Nonresidential 201 kW to 999 kW) applying to high consumption facilities such as the Outback, Pilot Butte and Rock Bluff wells. There are no time-of-use tariff rates.

Table 3.14 lists each well and pump station facility and the applicable rate schedule that applies. Table 3.15 contains a summary of the major charges under each schedule.

Optimatics proposes that the focus for the operations optimization (and when considering life cycle costs) be on minimizing energy costs. As mentioned above, there is no peak and off peak rates that apply to Bend, so there is no incentive to shift time of use to take advantage of lower rates. The primary aim then, which supports the goal of integrating the maximum amount of surface water, is to minimize total energy consumption.

It is difficult to realistically estimate monthly consumption or load size when only considering a 24- or 48-hour simulation period. As a result, it is necessary to make some assumptions when choosing the appropriate costs to apply. Supply energy charges and other charges are based on actual usage. In the optimization, total energy used per month will be calculated based on the energy use on the simulated day, using a determined ratio between that day and average annual energy consumption x 365/12.

Optimatics proposes to use the rates that apply up to the first 20,000 kWh of energy use under Schedules 28 and 30. When combined with the total other charges based on energy consumption, this leads to a cost of $0.05112/kWh for Schedule 28 facilities and $0.04986/kWh for Schedule 30 facilities.

Additional analysis of historical power cost information will be undertaken as part of the operations optimization task in this study.

Table 3.14 – Pumping facilities and applicable schedules

Facility	Item	Schedule
Wells		
Bear Creek Wells	1	28
	2	28
Pilot Butte Wells	1	30
	2	n/a
	3	30
Rock Bluff Wells	1	30
	2	30
	3	30
River Wells	1 (South)	28
	2 (North)	28
Copperstone Well		28
Westwood Well		28
Outback Wells	1	30
	2	30
	3	30
	4	30
	5	30
	6	28
	7	28
	8	28
Shilo Wells	1	28
	2	28
	3	28
Hole Tens Wells	North	28
	South	28
Pump stations		
Awbrey PS		28
Westwood PS		28
Scott Street PS		28
College PS		28
Murphy		28
Tetherow		28

Table 3.15 – Summary of Pacific Power Rate Schedules (all rates in dollars)

Description	Units	Schedule 23	Schedule 28	Schedule 30
Energy charges				
first 3,000(23)/20,000 kWh	Up to 3,000/20,000	0.04433	0.04114	0.04486
> 3,000(23)/20,000 kWh	Total monthly kWh minus 20,000/3,000	0.03274	0.04001	0.03881
Major delivery charges				
Basic Charge (based on kW load size [1])	Load Size kW [1]	Flat rate: 16.15 per mth Single Phase 24.10 per mth Three Phase	0.75 ≤ 50 kW 0.60 > 50 kW 0.35 > 100 kW 0.25 > 300 kW	0.00 ≤ 200 kW 1.10 > 200 kW 0.55 > 300 kW
Demand Charge (minimum 15 kW)	Maximum 15-minute instantaneous kW	≤ 15 kW 0.00 > 15 kW 3.77	3.46 [2]	3.87 [3]
Reactive Power Charge, based on maximum 15-minute reactive demand	kvar	0.65	0.65	0.65
Other charges				
Energy Conservation	Total monthly kWh	0.00084	0.00067	0.00061
Low Income Assistance	Total monthly kWh	0.00050	0.00050	0.00050
Delivery Charge Secondary	Total monthly kWh	0.02195	0.00682	0.00190
Oregon Tax Charge	Total monthly kWh	0.00199	0.00199	0.00199
Total 'other' charges	Total monthly kWh	0.02528	0.00998	0.00500

Notes

All rates quoted are for secondary voltage, as this appears to apply to all Bend Facilities

1) The Load Size is the average of the two greatest non-zero monthly demands during the 12-month period prior to and including the current billing month

2) This value (3.46) is taken from Bend billing data (sample invoices) from July 2008 and does not match the value showing in Schedule 28 as downloaded from www.pacificpower.net (2.21)

3) This value (3.87) is taken from Bend billing data (sample invoices) from July 2008 and does not match the value showing in Schedule 30 as downloaded from www.pacificpower.net (2.49)

4 Design Criteria

Design criteria that can be included in the optimization include limits relating to pressure, velocity, pipe headloss and operational constraints. The recommendations of the 2007 Master Plan Update were based on performance guidelines which were developed "*through a review of State requirements, American Water Works Association (AWWA) acceptable practice guidelines, operational practices of similar water providers, and discussions with City water system operations staff*". These guidelines were reviewed at the April Kick-off Meeting and the final criteria to be used in the optimization are summarized below.

4.1 Supply Pressure

The development of the existing pressure levels in the Bend system was based on the aim of maintaining pressures between 40 psi to 80 psi. The main driver for this arrangement was keeping within plumbing code and in the future Bend would like to try and simplify system operations by allowing larger pressure ranges in each level, requiring new developments to install PRVs in locations where high pressures are expected.

The minimum pressure criterion is 40 pounds per square inch (psi) and this should be maintained under peak hour conditions.

For existing areas, pressures will be maintained below the current maximum pressures (determine based on the hydraulic model analysis). For new developments the maximum pressure limit will be raised to 120 psi, with the assumption that developers will install the necessary PRVs to protect customers from high pressures.

At the April 2009 Kick-off Meeting, areas that are known to operate outside the recommended limits in terms of pressure were noted:

Low Pressure:

- Suction pressure at Tetherow PS may be less than 40 psi.
- Demand nodes on Awbrey Butte may experience low pressures. Pressures above 30 psi will be considered satisfactory; any improvement would be beneficial.

High Pressure:

- The South Bend area is currently extremely sensitive to high pressures. Until the pipes are replaced and the system is strengthened, pressures in this area should not be increased above 70 psi.
- In the extreme west of the system there are areas which currently experience pressures in the realm of 120 psi. Individual homes in this area should be fitted with PRVs.

Once the calibrated hydraulic model is received, Optimatics will assess current pressures and discuss any anomalies with Bend staff to determine if additional exceptions to the above criteria should be made.

4.1.1 Fire flow requirements

The City has adopted the State-mandated 20 psi residual pressure requirement under fire flow conditions (maximum day demands). Standard engineering practice is to assume that the largest fire for a given area can occur during maximum day demand conditions. In current hydraulic analyses reservoirs are assumed to be approximately half-full during fire flow events. The residential fire flow requirement is 1,500 gpm (International Building Code (IBC) for residential structures 3,000 square feet and larger) and the maximum commercial fire flow rate is considered to be 3,500 gpm (Commercial Highway). A full summary of fire flow rates for different land use types is provided in Table 4.1.

Table 4.1 – 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**		

4.2 Flow Velocity

Typical limits range between 5 to 7 feet per second (fps). Bend has advised that there is no specific limit. Sediment or scouring of pipes is not a significant concern for Bend given that water quality is so high. The main driver for sensible flow velocities will be energy requirements. This will be incorporated and monitored in the optimization by virtue of the operating cost calculations.

Optimatics will monitor and report on pipe velocities, particularly downstream of pump stations where transients can be an issue.

4.3 Storage

*September 2010 **Note:** The information in the section has been revised. Please refer to the following documents for the latest recommendations:*

Optimatics, Review of storage standards and recommended storage guidelines for the City of Bend, June 2010

Optimatics, Water System Master Plan Update Optimization Study, Final Report, February 2011

In a water distribution system, storage serves a number of purposes. Storages can help reduce peak flows in transmission mains by helping to meet peak demands, allow for more efficient operations through gravity supply, help maintain steady system pressures, and provide back-up supply in the event of an emergency. When assessing storage needs for a system, four components need to be considered. These components are described below and illustrated in the example in Figure 4.1:

Equalization storage – required to supply instantaneous demands that are in excess of the system's supply capacity.

Standby storage – to provide water during an emergency event such as a power failure or source outage.

Fire Storage – to provide water for fire suppression.

Dead – tank level/volume at which 20 psi can't be maintained (propose to assume 5% of total storage).

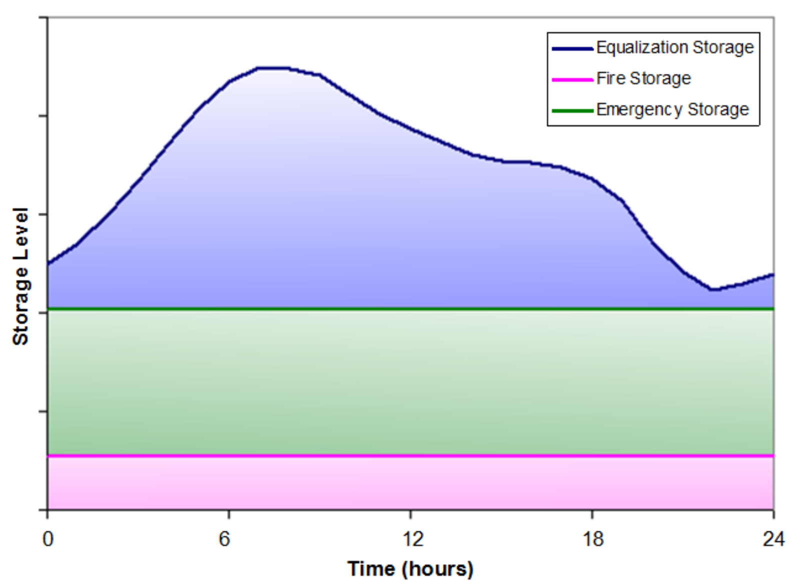


Figure 4.1 – Storage components

Equalization storage volume should be sufficient to meet normal system demands in excess of the maximum day demand, i.e., the difference between peak hour demand and maximum day demand. In the 2007 Master Plan Update, MSA recommended that "*operational storage volume in the amount of 25 percent of maximum day demand*" would be appropriate for the Bend system.

According to the Washington State Standards, equalization storage is calculated as:

Equalizing Storage (ES) = (PHD – Qs) x 150 minutes

Where *ES* = gallons (must be greater than zero)

PHD = peak hourly demand (gpm)

Qs = sum of capacity of all installed and active sources of supply (not including emergency sources)

In the optimization, this component of storage will be determined through analysis of the hydraulic model and is accounted for by ensuring that

(a) Minimum pressures are met under Maximum Day and Peak Hour demand conditions (minimum pressure constraint)

(b) Emergency and fire suppression storage volumes are maintained at all times (minimum storage volume constraint)

The optimization formulation will include constraints on minimum and maximum allowable storage levels, turnover requirements and comparison of start-of-day and end-of-day levels. These limits will be prepared as part of the formulation process and reviewed with Bend staff. A specific volume limit for operational needs will not be applied as a constraint.

Standby storage requirements must be determined for any system based on the type of emergency likely to be encountered, the reliability of supply sources, and the likely duration of an emergency event. In the Bend system, significant potential emergency scenarios include wildfire (which could lead to source contamination), or a power outage (which could affect groundwater supply).

The 2007 Master Plan Update determined that maintaining two days of average day demands (ADD) in storage would be prudent considering *"the region's risk of forest fires on one hand, and the City's recognized robust subsurface water source on the other".* This aligns with the Washington State Standard, which defines standby storage as:

Standby Storage $(SB_{TMS}) = (2 \text{ days}) \times ADD \times N - t_m \times (Q_S - Q_L)$

Where SB_{TMS} = standby storage for a system with multiple sources (gallons)

t_m = time that remaining sources are pumped on the day when the largest source is not available (minutes)

Q_S = sum of all installed and continuously available source of supply capacities, except emergency sources (gpm)

Q_L = largest capacity source available to system (gpm)

In the 2007 Master Plan Update, MSA recommended that, because of the ample and reliable groundwater aquifer, *"certain emergency storage volume requirements be provided by existing underground "storage" in the subsurface aquifer, rather than through costly constructed reservoir "tank" storage capacity."* This approach helps to reduce the costs associated with providing above-ground storage to meet the full emergency storage requirements. There would also be water quality benefits as high water age is unlikely to become a concern.

At the Kick-off Meeting in April 2009 this concept was reviewed and it was agreed that the same approach would be used in the optimization study. Back-up power must be available at groundwater facilities in order for the well capacity to be credited against the required emergency storage for a particular service area. The 2007 Master Plan Update recommended that emergency back-up power generation capabilities should be implemented at all groundwater well sites to help minimize risks relating to water supply during power failures. Table 3.5 shows which well facilities have back-up power and those that do not. Some of the sites have portable generators which can only provide power to one or two wells at a time. Presently, the estimated total capacity that can be operated with back-up power (including the soon to be commissioned Pilot Butte Well #4) is just over 14.7 MGD.

Discussions at the Kick-off Meeting also focused on recent well failures, and staff commented on the vulnerability of submersible well pumps currently in service. The extent to which subsurface storage is relied upon in the future to meet emergency storage needs should consider the reliability of this source of supply under emergency conditions.

The final element, fire suppression storage, is discussed in Sections 4.3.1 and 4.3.3.

Table 4.2 provides an assessment of current storage capacity in the Bend system sorted by pressure level.

Table 4.2 – Existing storage summary (sorted by pressure level)

Reservoir Name	Reservoir Type	Capacity (mg)	Pressure Level Served
Tower	Welded Steel	1.00	1
College I	Welded Steel	0.50	2
College II	Welded Steel	1.00	2
CT Basin	Bolted Steel	1.50	3
Outback I	Bolted Steel	2.00	3
Outback II	Welded Steel	3.00	3
Outback III	Welded Steel	3.63	3
Westwood	Welded Steel	0.50	4A, Westwood (pumped)
Overturf I	Riveted Steel	1.50	4A
Overturf II	Riveted Steel	1.50	4A
Pilot Butte II	Welded Steel	1.00	4B
Rock Bluff	Welded Steel	1.50	4B
Awbrey	Concrete	5.00	5
Pilot Butte I	Welded Steel	1.50	5
Pilot Butte III	Concrete	5.00	5
Total Storage Capacity		**30.13**	

Not all of the storage shown in Table 4.2 is available to meet emergency storage requirements. For example, the CT Basin is needed to provide adequate chlorine contact time and cannot be relied upon to meet standby storage needs.

4.3.1 Fire Storage Recommendations

The volume of storage that should be maintained for fire suppression is calculated based on the size and duration of fire events typically associated with the building type or land use of a specific location. Table 4.3 presents the assumed fire flow rates and durations used by MSA in the 2007 Master Plan Update to calculate fire storage requirements. The storage analysis assumed fire flow rates of 3,000 gpm and 5,000 gpm, in lieu of 2,500 gpm and 3,500 gpm for the respective commercial and industrial zoning designations (refer Section 4.1) to account for the potential for more than one fire occurring at a time. The resultant fire storage is 180,000 gallons for residential areas, 540,000 gallons for commercial/industrial areas, and 1,500,000 gallons for the commercial highway zone.

Table 4.3 – Summary of recommended fire storage volume

Zone	Zoning Description	Fire Flow Rate for Storage Calculation (gpm)	Duration (hours)	Recommended Fire Storage Volume (MG)
RS	Residential Urban Standard	1,500	2	0.18
RM	Residential Urban Medium	1,500	2	0.18
RH	Residential Urban High	1,500	2	0.18
CN	Commercial Neighborhood	3,000	3	0.54
CC	Commercial Convenience	3,000	3	0.54
CL	Commercial Limited	3,000	3	0.54
CG	Commercial General	3,000	3	0.54
CBD	Industrial Park	3,000	3	0.54
IP	Industrial Light	3,000	3	0.54
IG	Industrial General	3,000	3	0.54
CH	Commercial Highway	5,000	5	1.50

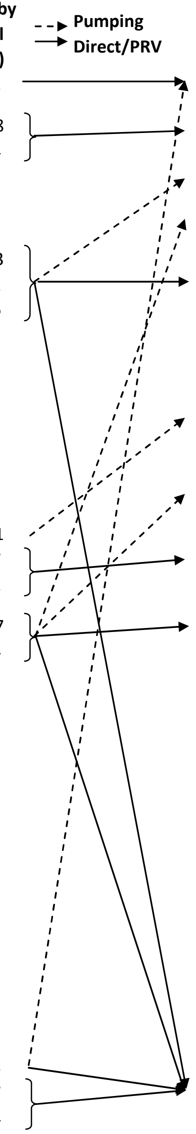
4.3.2 Standby Storage Requirements

Table 4.4 compares available storage to required standby storage, which is two times average day demand. The table also includes fire storage requirements by zone and then compares demands by zone to available storage and the capacity of wells with backup power. The information shows that approximately 30% of the City's current total storage needs are met through above-ground storage (note that the 2007 Master Plan Update showed 55%).

Table 4.4 shows a deficit in emergency storage in the northern zones (5, 6, and 7). The addition of Pilot Butte Well #4 with a back-up generator (not included in Table 4.4) overcomes this deficiency for the current system.

Table 4.4 – Assessment of current demands vs available storage

Storage	Storage Volume (MG)	Dead storage (assume 5%)	Minimum level on MD	% Avail	Emergency Vol Avail (MG)	Fire suppression (MG) TBC	Standby Avail (MG)
TOWER_ROCK	1.0	5%	84%	79%	0.79	0.18	0.61
COLLEGE_1	0.5	5%	77%	72%	0.36	0.54	-0.18
COLLEGE_2	1.0	5%	68%	63%	0.64		0.64
OUTBACK_1	2.3	60%	67%	7%	0.17		-1.33
OUTBACK_2	3.0	60%	77%	17%	0.51	1.50	0.51
OUTBACK_3	3.7	60%	70%	10%	0.36		0.36
OUTBACK_CT_BASIN	1.5	n/a, required for CT					
WESTWOOD	0.5	5%	54%	49%	0.23		-0.31
OVERTURF_EAST	1.4	5%	81%	76%	1.07	0.54	1.07
OVERTURF_WEST	1.4	5%	77%	72%	1.01		1.01
ROCK_BLUFF_1	1.5	5%	85%	80%	1.23	1.50	-0.27
PILOT_BUTTE_2	1.0	5%	70%	65%	0.64		0.64
AWBREY	5.1	5%	78%	73%	3.75		2.25
PILOT_BUTTE_1	1.5	5%	71%	66%	0.97	1.50	0.97
PILOT_BUTTE_3	5.0	5%	51%	46%	2.34		2.34
Totals	**30.5**				**14.08**	**5.76**	**8.32**



Zone	Standby Requirement 2xADD	Combined Requirement (MG)	Offset from Wells w back-up power (2 days x MGD)	Above Ground Capacity	Allocation to/from other zones	Capacity div by Requirements
1	0.76	0.76		0.61	0.15	100%
				Awbrey %	7%	
2	0.68	0.81		0.46	0.34	100%
				Awbrey %	15%	
2A	0.00	*in 3*				
			Hole Ten			
2B	0.14	0.29	3.20			1112%
			Outback, Copperstone			
3	2.36	3.70	8.00	-0.46	-3.84	100%
				To 4A & 5		
3A	0.02	*in 2*				
3B	0.10	*in 2*				
3C	0.43	0.67			0.67	100%
				Westwood %	100%	
				Overturf %	47%	
			Shilo			
3D	0.14	*in 2B*	0.00			
			Westwood			
4A	1.37	1.37	0.00	1.78	-0.40	100%
				Level 3 Well %	3%	
			Bear Creek, Rock Bluff			
4B	3.91	3.91	7.00	0.37	-3.46	100%
				All to 5		
4C	0.24	*in 3*				
4D	0.17	*in 3*				
4E	0.41	*in 3*				
4F	0.10	*in 3*				
4G	0.05	*in 3*				
4H	0.14	*in 3C*				
4I	0.10	*in 3C*				
4J	0.14	*in 3*				
4K	0.03	*in 3*				
			River, Pilot Butte			
5	8.57	14.17	3.20	5.56	6.54	108%
				Outback %	100%	
				Level 3 Well %	97%	
5A	0.02	*in 3*		RockB1/Pilot2	100%	
				Level 4B Well %	100%	
5B	0.04	*in 3*				
5C	0.00	*in 3*				
5D	0.06	*in 3*				
6	4.28	*in 5*				
6A	0.49	*in 5*				
6B	0.07	*in 3*				
7A	0.50	*in 5*				
7B	0.22	*in 5*				
7C	0.11	*in 5*				
7D	0.02	*in 5*				
Totals	**25.68**	**25.68**	**21.40**	**8.32**	**0.00**	**116%**
	% of standby storage requirement		83.3%	32.4%		

Notes for Table 4.4:

The first eight columns calculate available emergency storage and determine how much standby storage is available once fire suppression needs have been accounted for.

The volume of storage available to meet standby requirements is calculated based on the minimum tank level observed in the 2009 Summer EPS model and an assumed dead storage volume of 5%.

Column 9 shows how storage can be allocated to zones within the system, either by gravity (solid line) or via a booster pump station (dashed line).

Column 11 shows the total standby supply requirement, which is 2x ADD for each zone.

The remaining columns combine zones which have a common supply, takes into account wells with back-up power that may offset above-ground storage needs and determines whether there is sufficient supply to meet emergency requirements.

Assumptions:

1. Excess storage located in higher pressure levels can be allocated to support the needs of lower pressure levels. Hydraulic model testing would be required to verify that the distribution system can facilitate this.

2. Wells with back-up power can run for 24 hours at rated capacity to provide a daily volume equal to their rated capacity (in MG).

4.3.3 Total Future Storage Requirements

In order to keep storage costs down, the 2007 Master Plan Update recommended relying on 'aquifer storage' to meet roughly 55% of the emergency storage requirement by the end of the planning period. If it is assumed that 45% of the necessary standby storage will be provided by above-ground storage in the future (when total system demand is estimated to be 37.1 MGD), this translates to a requirement of 33.4 MG in above-ground standby storage, and a necessary reliable groundwater pumping capacity of 40.8 MGD.

Bend is concerned about relying on groundwater to meet a significant percentage of emergency storage requirements due to historical reliability of mechanical infrastructure of the wells. Given the quality and availability of the groundwater source it makes sense to rely on it to some extent. Relying solely on above-ground storage for emergency storage is a very expensive option and there may be other implications, such as impacts on water age and water quality.

For purposes of the optimization analysis, solutions will be required to size and locate storage so that 100% of emergency storage is provided above ground. This will provide Bend with the magnitude of potential cost should they opt for above-ground emergency storage only. This assumption will not affect decisions related to supply or transmission capacity and can be adjusted later based on available budget.

The total future storage requirement for the Bend system is presented in Table 4.5. This shows that approximately 100 MG of storage will be needed in the future; a 70 MG increase from the current system. The final column presents the minimum storage volume constraint that will be applied in the optimization. This is the sum of the fire storage and standby storage requirements. This constraint will set a minimum volume that must be maintained at all times under maximum day demand conditions. Operational storage needs above the required emergency and fire storage will be determined through hydraulic modeling and application of operational constraints in the optimization.

Table 4.5 – Future storage requirements

Zone	Future Demand (MGD, ADD)	Emergency Storage				Optimization Volume Constraint (MG)
		Estimated Operating (1)	Standby(2)	Fire(3)	Total	
1	0.58	0.33	1.16	0.18	1.67	1.34
2	0.61	0.34	1.21	0.54	2.09	1.75
2A (Tetherow)	0.16	0.09	0.31	*From 3*	0.40	0.31
2B (South Bend)	0.27	0.15	0.54	*From 4B*	0.70	0.54
3	5.28	2.97	10.55	0.54	14.06	11.09
3A	0.10	0.05	0.19	*From 2*	0.25	0.19
3B	0.05	0.03	0.10	*From 2*	0.13	0.10
3C (Westwood)	0.49	0.28	0.99	*From 3*	1.27	0.99
3D (South Bend)	0.44	0.25	0.88	*From 4B*	1.12	0.88
4A	1.58	0.89	3.17	0.54	4.60	3.71
4B	5.41	3.04	10.82	1.5	15.36	12.32
4C	0.15	0.08	0.30	*From 3*	0.38	0.30
4D	0.14	0.08	0.29	*From 3*	0.37	0.29
4E	0.82	0.46	1.63	*From 3*	2.09	1.63
4F	0.08	0.04	0.16	*From 3*	0.20	0.16
4G	0.12	0.07	0.24	*From 3*	0.31	0.24
4H	0.09	0.05	0.19	*From 3*	0.24	0.19
4I	0.27	0.15	0.54	*From 3*	0.69	0.54
4J	0.11	0.06	0.23	*From 3*	0.29	0.23
4K	0.03	0.02	0.06	*From 3*	0.08	0.06
5	8.13	4.57	16.25	1.5	22.32	17.75
5A	0.01	0.01	0.02	*From 3*	0.03	0.02
5B	0.63	0.36	1.27	*From 3*	1.62	1.27
5C	0.02	0.01	0.04	*From 3*	0.05	0.04
5D	0.05	0.03	0.09	*From 3*	0.12	0.09
6	7.90	4.44	15.79	1.5	21.73	17.29
6A	0.39	0.22	0.77	*From 5*	0.99	0.77
6B	0.57	0.32	1.15	*From 3*	1.47	1.15
6C (Juniper)	1.63	0.91	3.25	*From 5*	4.17	3.25
7A	0.31	0.17	0.61	*From 5*	0.78	0.61
7B	0.11	0.06	0.22	*From 5*	0.28	0.22
7C	0.08	0.05	0.17	*From 5*	0.21	0.17
7D	0.02	0.01	0.03	*From 5*	0.04	0.03
7 (new)	0.49	0.28	0.99	*From 3*	1.26	0.99
Total	**37.10**	**20.87**	**74.20**	**6.30**	**101.37**	**80.50**

Notes for Table 4.5:

(1) Operational storage is calculated as 0.25 X MDD for each level. This is provided as a guide only and will not be applied as an explicit constraint in the optimization.
(2) Standby storage is calculated as 2 X ADD for each zone.
(3) Fire storage is based on the largest fire anticipated for each level. As noted, some zones have been combined when calculating the requirements.
(4) Given the large area of Zones 5 and 6, both zones have a fire flow volume requirement even though both will be supported by Zone 5 storage.

5 References

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Appendix A – Pipe Criticality Measures

User Defined or Calculated Parameters

Category	Label	Explanation	Mode
A1	Pipe ID	Pipe ID in network model	User specified
A2	Diameter (in)	Pipe diameter	User specified
A3	Length (ft)	Length of pipe	User specified
A4	Material	Pipe material – Optional user-specified input. Useful for reference (with A5 and A6) only. Not used by software.	Optional
A5	Risk of Discoloration	Risk of specified pipe experiencing discoloration relative to risk for other pipes. This can be imported to be applied to every pipe.	User specified; Default = 1.0
A6	Risk of Burst	Risk of specified pipe bursting relative to risk of other pipes bursting. User may specify values equal to or greater than 0. This can be imported to be applied to every pipe.	User specified; Default = 1.0
A7	Critical Node (to be renamed “Burst Node”)	Node on pipe at which it is assumed that pipe breaks	User specified; Default is d/s node
A8	Break Discharge (gpm)	Rate of discharge from burst pipe at critical node. This is a function of break size (Specified as the emitter value by user in GUI) and pressure head at break location.	Calculated from input model
	Peak Flow (gpm)	Peak flow experienced in pipe in 24 hour simulation of imported model.	Calculated from input model
	Peak Velocity (ft/s)	Peak flow experienced in pipe in 24 hour simulation of imported model.	Calculated from input model

Results Parameters

Category	Label	Explanation
B1	Valves Closed	Number of valves that must be closed to isolate specified pipe.
B2	Nodes Isolated	Number of nodes that are isolated following isolation of burst pipe.
B3	Volume Isolated (gal)	The volume of water inside the pipes that are isolated.
B3.1	Length Isolated (ft)	Total length of pipes that are isolated.
B4	Demand Isolated (gpm)	The total demand at all nodes where pressure drops below minimum allowable service level.
B5	Unmet Connections During Break	Number of customers that do not receive supply while specified pipe is broken. Requires input model to have customers specified.
B6	Unmet Connections During Isolation	Number of customers that do not receive supply while specified pipe is isolated. Requires input model to have customers specified.
B7	Min Pressure During Break (psi)	The minimum network pressure when specified pipe is broken.
B8	Avg Pressure During Break (psi)	The average network pressure when specified pipe is broken.
B9	Std Dev of Pressure During Break (psi)	The standard deviation of pressure calculated for all nodes in the network when specified pipe is broken.
B10	Nodes Below Zero Pressure During Break	The number of nodes experiencing negative pressure when specified pipe is broken.

Category	Label	Explanation
B11	Min Pressure After Isolation (psi)	The minimum network pressure after specified pipe is isolated.
B12	Avg Pressure After Isolation (psi)	The average network pressure after specified pipe is isolated.
B13	Std Dev of Pressure After Isolation (psi)	The standard deviation of pressure calculated for all nodes in the network after specified pipe is isolated.
B14	Nodes Below Zero Pressure After Isolation	The number of nodes experiencing negative pressure after specified pipe is isolated.

Velocity and Discoloration

Definitions

Label	Explanation	Mode
Flushing Criteria	Either velocity or shear	User specified
Vc_f (ft/s)	The conditioning velocity calculated for each pipe in the forward direction. The peak velocity experienced by each pipe over the 24 hour simulation imported.	Calculated from input model
Vf_f (ft/s)	The second velocity threshold in the forwards direction for measuring how greatly the velocity has exceeded Vc.	Calculated from user inputs and model
Kv_f	Multiplier for calculating the forwards Vf from the forwards Vc.	User specified
Vc_b (ft/s)	The conditioning velocity calculated for each pipe in the backwards direction. The peak velocity experienced by each pipe over the 24 hour simulation imported.	Calculated from input model
Vf_b (ft/s)	The second velocity threshold in the backwards direction for measuring how greatly the velocity has exceeded Vc.	Calculated from user inputs and model
Kv_b	Multiplier for calculating the backwards Vf from the backwards Vc.	User specified

Results Parameters

Category	Label	Explanation
C1	∑ other pipes {Length} (This pipe burst; V > Vc in other pipes) (ft)	The total length of pipe in the network that experiences velocities greater than Vc when specified pipe bursts.
C2	∑ other pipes {Length * Risk of Discoloration} (This pipe burst; V > Vc in other pipes) (ft)	The length of pipe in the network for which Vc is exceeded when specified pipe breaks, weighted by the risk of discoloration at that pipe. Summed product of length and risk of discoloration.
C3	∑ other pipes {Length * Risk of Discoloration * Flow} (This pipe burst; V > Vc in other pipes) (ft.gpm)	The length of pipe in the network for which Vc is exceeded when specified pipe breaks, weighted by the risk of discoloration and the rate of flow through the pipe. Summed product of length, risk of discoloration and flow.
C4	∑ other pipes {Length} (This pipe burst; V > Vf in other pipes) (ft)	The total length of pipe in the network that experiences velocities greater than Vf when specified pipe bursts
C5	∑ other pipes {Length * Risk of Discoloration} (This pipe burst; V > Vf in other pipes) (ft)	The length of pipe in the network for which Vf is exceeded when specified pipe breaks, weighted by the risk of discoloration at that pipe. Summed product of length and risk of discoloration.
C6	∑ other pipes {Length * Risk of Discoloration * Flow} (This pipe burst; V > Vf in other pipes) (ft.gpm)	The length of pipe in the network for which Vf is exceeded when specified pipe breaks, weighted by the risk of discoloration and the rate of flow through the pipe. Summed product of length, risk of discoloration and flow.

Category	Label	Explanation
C7	Risk of Burst Causing V > Vc in other pipes (ft.gpm) (A5 * C3)	The relative expected value of discoloration that will occur within the network as a result of breaks at the specified pipe. A product of items A5 and C3. This assumes discoloration results from velocities exceeding Vc.
C8	Risk of Burst Causing V > Vf in other pipes (ft.gpm) (A5 * C6)	The relative expected value of discoloration that will occur within the network as a result of breaks at the specified pipe. A product of items A5 and C6. This assumes discoloration results from velocities exceeding Vf.

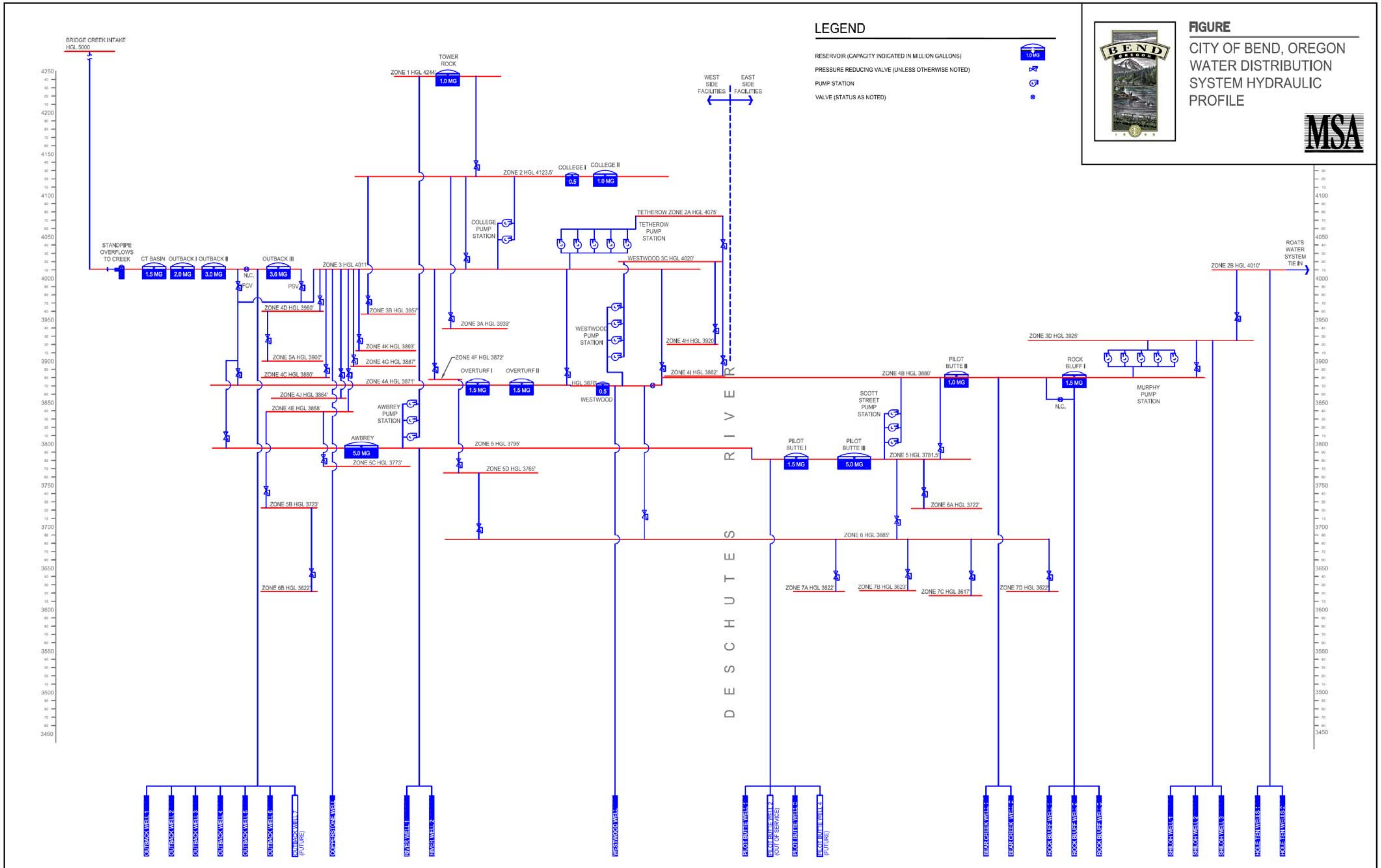
Category	Label	Explanation
D1	∑ other pipes {Length} (This pipe isolated; V > Vc in other pipes) (ft)	The total length of pipe in the network that experiences velocities greater than Vc when specified pipe is isolated.
D2	∑ other pipes {Length * Risk of Discoloration} (This pipe isolated; V > Vc in other pipes) (ft)	The length of pipe in the network for which Vc is exceeded when specified pipe is isolated, weighted by the risk of discoloration at that pipe. Summed product of length and risk of discoloration.
D3	∑ other pipes {Length * Risk of Discoloration * Flow} (This pipe isolated; V > Vc in other pipes) (ft.gpm)	The length of pipe in the network for which Vc is exceeded is exceeded when specified pipe is isolated, weighted by the risk of discoloration and the rate of flow through the pipe. Summed product of length, risk of discoloration and flow.
D4	∑ other pipes {Length} (This pipe isolated; V > Vf in other pipes) (ft)	The total length of pipe in the network that experiences velocities greater than Vf when specified pipe is isolated
D5	∑ other pipes {Length * Risk of Discoloration} (This pipe isolated; V > Vf in other pipes) (ft)	The length of pipe in the network for which Vf is exceeded when specified pipe is isolated, weighted by the risk of discoloration at that pipe. Summed product of length and risk of discoloration.
D6	∑ other pipes {Length * Risk of Discoloration * Flow} (This pipe isolated; V > Vf in other pipes) (ft.gpm)	The length of pipe in the network for which Vf is exceeded when specified pipe is isolated, weighted by the risk of discoloration and the rate of flow through the pipe. Summed product of length, risk of discoloration and flow.
D7	Risk of Isolation Causing V > Vc in other pipes (ft.gpm) (A5 * D3)	The relative expected value of discoloration that will occur within the network as a result of isolation occurrences at the specified pipe. A product of items A5 and D3. This assumes discoloration results from velocities exceeding Vc.
D8	Risk of Isolation Causing V > Vf in other pipes (ft.gpm) (A5 * D6)	The relative expected value of discoloration that will occur within the network as a result of isolation occurrences at the specified pipe. A product of items A5 and D6. This assumes discoloration results from velocities exceeding Vf.

Category	Label	Explanation
E1	∑ other pipes {Length} (Other pipe burst; V > Vc in this pipe) (ft)	The total length of pipe in the network which, if broken, cause velocities greater than Vc to occur in specified pipe.
E2	∑ other pipes {Length * Risk of Burst} (Other pipe burst; V > Vc in this pipe) (ft)	The length of pipe in the network which, if broken, cause velocities greater than Vc to occur in specified pipe, multiplied by the risk of break occurrence at those pipes. Summed product of length and risk of break.
E3	∑ other pipes {Length * Risk of Burst * Diameter} (Other pipe burst; V > Vc in this pipe) (ft.in)	The length of pipe in the network which, if broken, cause velocities greater than Vc to occur in specified pipe, multiplied by the risk of break occurrence and diameter at those pipes. Summed product of length, risk of break and pipe diameter.
E4	∑ other pipes {Length} (Other pipe burst; V > Vf in this pipe) (ft)	The total length of pipe in the network which, if broken, cause velocities greater than Vf to occur in specified pipe.
E5	∑ other pipes {Length * Risk of Burst} (Other pipe burst; V > Vf in this pipe) (ft)	The length of pipe in the network which, if broken, cause velocities greater than Vf to occur in specified pipe, multiplied by the risk of break occurrence at those pipes. Summed product of length and risk of break.

Category	Label	Explanation
E6	∑ other pipes {Length * Risk of Burst * Diameter} (Other pipe burst; V > Vf in this pipe) (ft.in)	The length of pipe in the network which, if broken, cause velocities greater than Vf to occur in specified pipe, multiplied by the risk of break occurrence and diameter at those pipes. Summed product of length, risk of break and pipe diameter.
E7	Risk of Other Pipe Burst Causing V > Vc in this pipe (ft.in) (A6 * E3)	A measure of the risk that a pipe break within the network will cause velocities to exceed Vc in specified pipe. A product of items A6 and E3.
E8	Risk of Other Pipe Burst Causing V > Vf in this pipe (ft.in) (A6 * E6)	A measure of the risk that a pipe break within the network will cause velocities to exceed Vf in specified pipe. A product of items A6 and E6.

Category	Label	Explanation
F1	∑ other pipes {Length} (Other pipe isolated; V > Vc in this pipe) (ft)	The total length of pipe in the network which, if isolated, will cause velocities greater than Vc to occur in specified pipe.
F2	∑ other pipes {Length * Risk of Burst} (Other pipe isolated; V > Vc in this pipe) (ft)	The length of pipe in the network which, if isolated, will cause velocities greater than Vc to occur in specified pipe, multiplied by the risk of isolation occurrence due to pipe break at those pipes. Summed product of length and risk.
F3	∑ other pipes {Length * Risk of Burst * Diameter} (Other pipe isolated; V > Vc in this pipe) (ft.in)	The length of pipe in the network which, if isolated, will cause velocities greater than Vc to occur in specified pipe, multiplied by the risk of isolation occurrence due to pipe break, and diameter at those pipes. Summed product of length, risk and pipe diameter.
F4	∑ other pipes {Length} (Other pipe isolated; V > Vf in this pipe) (ft)	The total length of pipe in the network which, if isolated, will cause velocities greater than Vf to occur in specified pipe.
F5	∑ other pipes {Length * Risk of Burst} (Other pipe isolated; V > Vf in this pipe) (ft)	The length of pipe in the network which, if isolated, will cause velocities greater than Vf to occur in specified pipe, multiplied by the risk of isolation due to break occurrence at those pipes. Summed product of length and risk.
F6	∑ other pipes {Length * Risk of Burst * Diameter} (Other pipe isolated; V > Vf in this pipe) (ft.in)	The length of pipe in the network which, if isolated, will cause velocities greater than Vf to occur in specified pipe, multiplied by the risk of isolation due to break occurrence and diameter at those pipes. Summed product of length, risk, and pipe diameter.
F7	Risk of Other Pipe Isolation Causing V > Vc in this pipe (ft.in) (A6 * F3)	A measure of the risk that isolation of another pipe within the network will cause velocities to exceed Vc in specified pipe. A product of items A6 and E3.
F8	Risk of Other Pipe Isolation Causing V > Vf in this pipe (ft.in) (A6 * F6)	A measure of the risk that isolation of another pipe within the network will cause velocities to exceed Vf in specified pipe. A product of items A6 and E6.

Appendix B – Hydraulic Profile



Appendix C – System Operating Rules and Pump Data

Facility	VFD	Zone From-To	Controlled on	Control ID	Summer On	Summer Off	Winter On	Winter Off	Manufacturer's Pump Curve	Shutoff Head (ft)	Design Head (ft)	Design Flow (gpm)	High Head (ft)	High Flow (gpm)	Curve Name	Notes
WELL AND BOOSTER PUMPS																
AWBREY_P1	No	5 to 1	Reservoir-Level	Tower-Rock	Below 27	Above 30	Below 27	Above 30	Unverified Design Point		500	840				
AWBREY_P2	No	5 to 1	Reservoir-Level	Tower-Rock	Below 25	Above 28	Below 25	Above 28	Awbrey Pump Curve	670	500	1200	375	1600		
AWBREY_P3	No	5 to 1	Manual						Awbrey Pump Curve	670	500	1200	375	1600		Manual only - runs off of generator only
BEAR_CREEK_W1	No	GW to 4	Reservoir-Level	Pilot Butte 2	Below 36	Above 38	Off		Bear Creek Well 1 Curve							
BEAR_CREEK_W2	No	GW to 4	Reservoir-Level	Pilot Butte 2	Below 35	Above 37	Off		Unverified Design Point		900	1050				
COLLEGE_P1	No	3 to 2	Reservoir-Level	College Res 1	Below 18	Above 22	Below 18	Above 22	Design Point (different to that noted on pump)		280	675				
COLLEGE_P2	No	3 to 2	Reservoir-Level	College Res 1	Below 16	Above 20	Below 16	Above 20	Design Point (different to that noted on pump)		300	250				
COPPERSTONE_W	No	GW to 3	Manual						Copperstone Well Curve						CURVE3	
HOLE_10_W1	Yes	GW to 2	Pressure @ discharge		60-62 psi		60-62 psi		Unverified Curve						XNG7	VFD soft start - always on
HOLE_10_W2	Yes	GW to 2	Pressure @ discharge		53 psi		53 psi									VFD
MURPHY_P1	Yes	4 to 3	Pressure @ discharge	Maintain 52 psi	53 psi		53 psi		Murphy Pump Station Curve						MURPHY	VFD
MURPHY_P2	Yes	4 to 3	Pressure @ discharge		43 psi		43 psi		Murphy Pump Station Curve						MURPHY	VFD
MURPHY_P3	Yes	4 to 3	Pressure @ discharge		33 psi		33 psi		Murphy Pump Station Curve						MURPHY	VFD
MURPHY_P4	Yes	4 to 3	Pressure @ discharge		23 psi		23 psi		Murphy Pump Station Curve						MURPHY	VFD
MURPHY_P5	Yes	4 to 3	Pressure @ discharge		Backup		Backup		Murphy Pump Station Curve						MURPHY	Backup
OUTBACK_W1	No	GW to 3	Manual						Unverified Design Point		600	680				Submersible pump - must be pumped to waste prior to use
OUTBACK_W2	No	GW to 3	Manual						Unverified Design Point		570	680				Submersible pump - must be pumped to waste prior to use
OUTBACK_W3	No	GW to 3	Reservoir-Level	Outback 3	Below 26	Above 28	Below 26	Above 28	Unverified Design Point based on SCADA		500	1200				
OUTBACK_W4	No	GW to 3	Reservoir-Level	Outback 3	Below 24	Above 27	Below 24	Above 27	Unverified Design Point based on SCADA		500	1200				
OUTBACK_W5	No	GW to 3	Reservoir-Level	Outback 3	Below 23	Above 26	Below 23	Above 26	Unverified Design Point based on SCADA		500	1050				
OUTBACK_W6	No	GW to 3	Reservoir-Level	Outback 3	Below 20	Above 24	Below 20	Above 24	Outback Well #6 Curve						OUTBACK_WELL_PUMPS	
OUTBACK_W7(1)	No	GW to 3	Reservoir-Level	Outback 3	*Future*				-							
PILOT_BUTTE_W1	No	GW to 5	Manual						PB#1 Curve						PB#1	
PILOT_BUTTE_W2		GW to 5	Out of Service						-							
PILOT_BUTTE_W3	No	GW to 5	Manual						Unverified Design Point based on SCADA		800	900				
PILOT_BUTTE_W4		GW to 5	Reservoir-Level	Pilot Butte 1	*Future*				-							
RIVER_W1	No	GW to 5	Manual						Unverified Curve						RIVERWELLNO1	
RIVER_W2	No	GW to 5	Manual						Unverified Curve						RIVERWELLNO2	
ROCK_BLUFF_W1	No	GW to 4	Reservoir-Level	Rock Bluff	Below 36	Above 38	Below 34	Above 36	Calibrated Curve						ROCKBLUFFWELL1-SCADA	
ROCK_BLUFF_W2	No	GW to 4	Manual						Unverified Curve						ROCKBLUFF	
ROCK_BLUFF_W3	No	GW to 4	Reservoir-Level	Rock Bluff	Below 35	Above 37	Below 33	Above 35	Rock Bluff Well 1 & 3 Curve						ROCKBLUFF_1&3	

Facility	VFD	Zone From-To	Controlled on	Control ID	Summer On	Summer Off	Winter On	Winter Off	Manufacturer's Pump Curve	Shutoff Head (ft)	Design Head (ft)	Design Flow (gpm)	High Head (ft)	High Flow (gpm)	Curve Name	Notes
SCOTT_BP_1	No	5 to 4	Reservoir-Level	Pilot Butte 2	Below 27	Above 30	Below 22	Above 26	Adjusted Curve (based on SCADA, not according to available MFR Curve)	110	90	1100	30	1600		
SCOTT_BP_2	No	5 to 4	Reservoir-Level	Pilot Butte 2	Below 25	Above 29	Below 21	Above 24	Adjusted Curve (based on SCADA, not according to available MFR Curve)	110	90	1100	30	1600		
SCOTT_BP_3	No	5 to 4	Reservoir-Level	Pilot Butte 2	Below 23	Above 28	Below 20	Above 22	Adjusted Curve (based on SCADA, not according to available MFR Curve)	110	90	1100	30	1600		
SHILOH_W1	No	GW to 3	Manual						-							
SHILOH_W2	No	GW to 3	Manual						-							
SHILOH_W3	No	GW to 3	Manual						Shilo Well 3 Curve	931	786	850	450	1375		
TETHEROW_P1	Yes	3 to Teth	Pressure @ discharge	Max 95 psi	85 psi		85 psi		Tetherow Pump 1 Curve	220	194	150	110	250		VFD set to maintain
TETHEROW_P2	Yes	3 to Teth	Pressure @ discharge		75 psi		75 psi		Tetherow Pumps 2-6 Curve	215	192	700	75	1400		VFD set to maintain
TETHEROW_P3	Yes	3 to Teth	Pressure @ discharge		65 psi		65 psi		Tetherow Pumps 2-6 Curve	215	192	700	75	1400		VFD set to maintain
TETHEROW_P4	Yes	3 to Teth	Pressure @ discharge		55 psi		55 psi		Tetherow Pumps 2-6 Curve	215	192	700	75	1400		VFD set to maintain
TETHEROW_P5	Yes	3 to Teth	Pressure @ discharge		45 psi		45 psi		Tetherow Pumps 2-6 Curve	215	192	700	75	1400		VFD set to maintain
TETHEROW_P6	Yes	3 to Teth	Pressure @ discharge						Tetherow Pumps 2-6 Curve	215	192	700	75	1400		Backup
WESTWOOD_P1	No	4 to West	Pressure @ discharge	Max 82 psi	Below 78	On	Below 78	On	Westwood Pump #1 Curve						XNG, Westwood PS#1	Always on - pressure relief into reservoir @ 78 psi
WESTWOOD_P2	No	4 to West	Pressure @ discharge		Below 73	Above 83	Below 73	Above 83	Westwood Pump #2 Curve						XNG1, Westwood PS#2	
WESTWOOD_P3	No	4 to West	Pressure @ discharge		Below 50	Above 60	Below 50	Above 60	Westwood Pump #3 Curve						XNG3, Westwood PS#3	Fire Pump
WESTWOOD_P4	No	4 to West	Time		4AM 4PM	10AM Midnight	Off		Westwood Pump #4 Curve						XNG5, Westwood PS#4	Irrigation pump
WESTWOOD_W	No	GW to 4	Reservoir-Level	Westwood	Below 20	Above 28	Below 18	Above 26	Unverified Design Point		386	460				
CONTROL VALVES																
Awbrey Reservoir		3 to 5	Reservoir Level		Below 17	Above 18	Below 15	Above 18								
			Flow control		6,500 gpm		3,000 gpm									
Overturf Reservoir		3 to 4A	Reservoir Level		Below 21	Above 23	Below 23	Above 24.5								
			Flow control		1,400 gpm		1,200 gpm									
Athletic Club PRV38		3 to 4B	4-inch		71 psi		71 psi									
			12-inch		63 psi		63 psi									
			Sustain		115 psi		92 psi									
Cumberland PRV36		4A to 5	6-inch		61 psi		57 psi									
			16-inch		Closed		51 psi									
Highway 20 PRV15		4B to 5	2-inch		49 psi		47 psi									
			8-inch		46 psi		43 psi									