Optimatics

optimizing water systems

Water System Master Plan Update Optimization Study

City of Bend, Oregon, Project No. WA09FA

Summer and Winter Operations Optimization Results

September 2010

Table of Contents

Table of Figures

List of Tables

Executive Summary

This memorandum presents the results of Operations Optimization runs undertaken as part of the Bend Water System Master Plan Update Optimization Study. The aim of the Operations Optimization was to assess potential changes to current system operations and potential minor capital improvements that will lead to reduced power costs and improved water quality.

The operation of the Bend system varies throughout the year. During the winter months supply is primarily from the surface water source whereas during summer it is necessary to turn on a number of groundwater wells to supplement the surface supply. The focus of the Summer Operations Optimization was to minimize pumping energy costs by maximizing surface water use where possible. For the Winter Operations Optimization, improving turnover in key reservoirs was a major aim.

The optimization analyses are based on evaluation of a computerized hydraulic model, developed and calibrated for the City of Bend (Bend) by Murray, Smith and Associates, Inc (MSA). As part of the calibration process, MSA assessed the model's performance under summer and winter extended period simulation (EPS) conditions. The models resulting from the EPS calibration effort have been used as the baseline cases for comparison in the optimization analyses under the assumption that they represent typical operating conditions for each season. The summer scenario represents a system demand of 23.45 million gallons per day (MGD) (16,300 gallons per minute (gpm)), while the winter demand scenario simulates a demand of 5.3 MGD (3,700 gpm).

Optimization Formulation

Optimatics formulated the optimization for summer and winter cases to consider a wide range of decision options aimed at achieving the objectives of reduced energy costs and improved reservoir turnover while maintaining hydraulic performance. Decisions included minor capital improvements such as short piping connections or booster pump stations, changes to existing control valve settings, and introduction or modification of well and booster pump controls.

Hydraulic design criteria were considered in the optimization through the definition of performance constraints. These constraints specify the required minimum pressure at customer connections and also how storage levels should vary throughout the day.

Finally, the hydraulic models have been used to estimate power costs associated with key water facilities under the various scenarios analyzed in the optimization. For this operations analysis the optimization was formulated to calculate energy costs only, rather than total operations and maintenance costs which would include power charges, maintenance and personnel costs.

Annual energy costs can be estimated if the typical relationship between energy usage in the analyzed scenario and annual energy usage is known. Bend provided detailed power cost information for the year 2008, as well as basic information for prior years. Analysis of this information led to the following observations:

- Annual power costs over the last few years for water facilities (wells, booster pumps, disinfection, surface water facilities) is on the order of $700,000
- Average daily power costs vary between $840 during the winter and $3,500 during the summer, with an annual average cost per day of $1,900

- In terms of the cost of water delivery to the system, comparison of annual system demand to power costs indicates a cost of $150/MG of total production (in 2008 there were 4,700 MG of water produced with an associated power cost of $700,000), or $270/MG of groundwater well production (2,600 MG in 2008)
- Typical variation of costs throughout any given year indicates the following ratios apply:
  - Summer: 1.83 x Annual Average
  - Winter: 0.44 x Annual Average
- Comparing estimates of annual energy costs based on pump power use simulated in the hydraulic model to actual power costs for corresponding facilities indicates an approximate ratio of energy costs to total power costs of 1:2

These ratios were used in the optimization to scale daily energy costs calculated in the winter and summer hydraulic simulations to an annual power cost value. These costs were then projected over a 20-year period and the net present value of calculated annual energy costs was developed using a discount rate of 6%, to allow the tradeoff between capital improvements and life-time power costs to be considered.

Optimization Results

The results of the optimization runs have demonstrated that there is opportunity to significantly reduce wintertime power costs and also make a good reduction in summertime power costs without major capital upgrades. In addition, the solutions have demonstrated operating strategies that could be used to maximize use of surface water in the existing system.

Three recommended strategies have been selected – two Summer Strategies (one short-term strategy without the River Wells in operation, and a long-term strategy with River Wells operating with on SCADA) and one Winter Strategy. Both Summer Strategies were shown to be 23% less costly than the Baseline Summer Scenario, while the Winter Solution is 67% less costly than the Baseline Winter Scenario.

Key recommendations from the Summer Strategies, in order of priority, include:

1. Control flow into Awbrey and Overturf Reservoirs and operate them over a wider range to reduce the peak flows from Outback, thus maintaining driving head and maximizing the flow of surface water through the Athletic Club PRV to the east side of the system
2. Raise the settings of selected control valves connecting Levels 4 and 5 to encourage gravity surface water transfer
3. Utilize Scott Street Pump Station in preference to Bear Creek Wells to meet Level 4B demands

Analysis of the hydraulic model indicates that these recommendations result in an increase in the amount of surface water supplied to the system and hence the reduction of groundwater pumping and the associated energy costs. The main difference between Summer Strategies #1 and #2 is the operation of the River Wells. In Strategy #2 without the River Wells in operation there is a need for additional groundwater supply, which is met from the Outback Wells. This is turn affects how key facilities are operated; it is necessary to increase flow to Awbrey Reservoir to maintain volume and it becomes more important to limit flow into the Overturf Reservoirs during peak periods. This operation is not recommended long-term as it puts stress on Level 3, evidenced by lower pressures in this zone in the hydraulic model.

The Winter Strategy recommendations focus on maximizing surface water use and also improving turnover in the east side storages. Similarly to the Summer Strategies it is recommended that flow into the Awbrey Reservoir be controlled during peak demand periods to allow as much surface flow as possible to pass through the Athletic Club PRV. If this is implemented the model indicates it is possible to maintain the volume in the east side storages without operating the Pilot Butte, Bear Creek or Rock Bluff Wells when system demands are low. Optimatics understands, however, that there are other reasons for running these wells during the winter, including keeping water fresh, as well as in emergency or maintenance situations. Thus, the Winter Strategy represents a desirable method of normal operation whenever it is feasible.

To achieve improved turnover in the Level 5 Pilot Butte Reservoirs, the Winter Strategy includes a recommendation to add control valves on the three northernmost connections across the Deschutes River between Awbrey Reservoir and Pilot Butte. Closing these connections forces the Pilot Butte Reservoirs to supply a larger area, helping to draw down the storages and induce turnover. The connections can be controlled to open based on the level in the Pilot Butte Storages when a sufficient drop in level has been achieved.

In addition to the operational recommendations above, the optimization evaluated potential changes to zone boundaries with the aim of potentially removing some subzones and simplifying system operations. Table 1 summarizes the recommended system improvements and modifications based on trends observed in the optimization runs. These improvements are recommended subject to review in the Build-out Master Plan Optimization.

Table 1 – List of recommended short-term system modifications

Option	Location	Purpose	Recommendation	Priority
Zone 4K into Level 3 (Figure 2.8)	Open connections on Flagline Court and Green Lakes Loop. Open PRV.	Increase circulation, suction pressure at Tetherow. Requires individual customer PRVs	Yes	1
Zone 4J into Zone 4A (Figure 2.7)	Open boundary at NW Crossing Drive and Shevlin Park Road	Increase circulation	Yes	2
Zone 4I into Zone 4B (Figure 2.5)	Open connection at Route 372/Reed Market Rd	Reduce pumping volume at Westwood/Tetherow	Yes, partial	3
Internal connection, Westwood (Figure 2.9)	Cascade Lakes Hwy to Mammoth Drive	Improve supply redundancy for southernmost customers	Yes	4
Westwood into Level 3 /Tetherow (Figure 2.9)	New connections at Pine Hollow, Cobb Street or Bachelor View Road. Open existing connections northeast of Westwood PS	Reduce reliance on Westwood PS, reduce energy needs, increase circulation	Yes – only after improvements to Level 3	5
Zone 5A, 5B, 5C PRVs	Awbrey Butte	Placing customers on individual PRVs will reduce maintenance, increase circulation	Yes – not high priority	6

The results of the Operations Optimization analyses presented in this report are intended to provide generalized recommendations based on the trends observed in the optimization solutions that operators can trial and adopt as appropriate, subject to their knowledge of the system and engineering judgment. The recommendations are based on the operation and results of the hydraulic model under specific demand scenarios and will not necessarily be appropriate for all operating scenarios. Many of the decisions formulated in the operations optimization runs will be carried forward to the Build-out Optimization formulation to evaluate their applicability under future demand conditions.

1 Introduction

This report presents the results of Operations Optimization runs undertaken as part of the Bend Water System Master Plan Update Optimization Study. The aim of the Operations Optimization was to assess potential changes to system operations and potential minor capital improvements that will lead to reduced power costs and improved water quality.

The operation of the Bend system varies significantly throughout the year. During the winter months supply is primarily from the surface water source in the west. A major wintertime challenge is achieving sufficient reservoir turnover, particularly on the east side of the system. To meet the higher demands of summer it is necessary to turn on a number of groundwater wells to supplement the surface supply. Bend operators face challenges in maximizing surface water supply (currently a significantly less expensive source than groundwater) due to transmission limitations in the system.

The focus of the Summer Operations Optimization was to minimize pumping energy costs by maximizing surface water use where possible. A number of options to achieve this goal have been considered and are described in more detail in the following sections. For the Winter Operations Optimization, improving turnover in key reservoirs was a major aim. Optimatics formulated the optimization for summer and winter cases to consider a wide range of decision options aimed at achieving these objectives.

2 Optimization Formulation

The optimization formulation process involves model analysis and configuration of the optimization software. Its purpose is to create a range of decision options aimed at achieving the optimization goals while maintaining or improving system hydraulic performance. A set of interim runs was completed and results presented in a meeting on December 9, 2009. Feedback from Bend staff about the decision options, formulation and presentation of the results were incorporated into the final runs and this report.

2.1 Options

2.1.1 Pipe options

Optimatics analyzed the hydraulic model to identify locations where there are bottlenecks or restrictions that hinder supply of surface water from Outback to the system. This analysis has led to the identification of both minor and major capital improvements that could enhance Bend's ability to maximize surface water supply.

Analysis of the transmission capacity from Outback to Overturf and Awbrey shows that there is reasonable capacity up until a point east of Overturf where only a single 18-inch diameter line supplies the Awbrey Reservoir. Paralleling this eastern section of main could significantly increase transmission capacity to Awbrey. The main that connects the Outback transmission mains to the Athletic Club PRV is also a potential bottleneck. The main starts at 16-inch diameter, reduces to 12-inch and then returns to 16-inch. Finding ways to parallel this main, either directly along Mt. Washington Drive, or indirectly along a different route through Level 3 should increase the ability to move water from west to east. Such improvements would also address low suction pressure concerns at the Tetherow Pump Station. However, these improvements represent major capital expenditure and Optimatics plans to evaluate them later in the master plan optimization under project Build-out demand conditions.

In addition to these major ideas, Optimatics searched for small piping connections that could improve connectivity and capacity within the system. One area of particular interest with respect to low pressure is Level 3 just north of the Tetherow Pump Station. On the peak hour of the simulated summer day some pressures dropped below 10 psi. Adding approximately 1,000 feet of new pipe between Flagline Court and Green Lakes Loop, bypassing the two closed valves on the northwest corner of Zone 4K, provides a connection from the Outback transmission mains to a 12-inch diameter line (see Figure 2.1). This should improve connectivity and increase the pressure in the affected areas to well above 30 psi.

Another location where a small section of pipe could increase transmission capacity is on the suction side of the College Pump Station. At the moment this station is supplied by a 12-inch diameter line. A potential 750-foot connection to Level 3 piping along Shevlin Park Road would open up a second (16-inch diameter) line to the pump station and increase suction capacity – see Figure 2.2. (Note – suction pressure is already high at 130 psi; this just adds a few more psi available to pump to Level 2). As described below, if the City decides to implement a new booster station to serve Level 1 from Level 2, the supply to this station will need to come from the existing College Pump Station. Therefore, strengthening the suction side of the College Station is likely to be necessary, particularly in the future.

A number of new pipe connections have been identified which would facilitate combining smaller zones into neighboring zones. These are discussed in Section 2.1.3.

2.1.2 Pump station options

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

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

A short section of main is required to tie this station into Level 1 piping along Coe Court. The new station would also draw suction from Level 2 and supply Level 1, but it would be buffered by the reservoir storage.

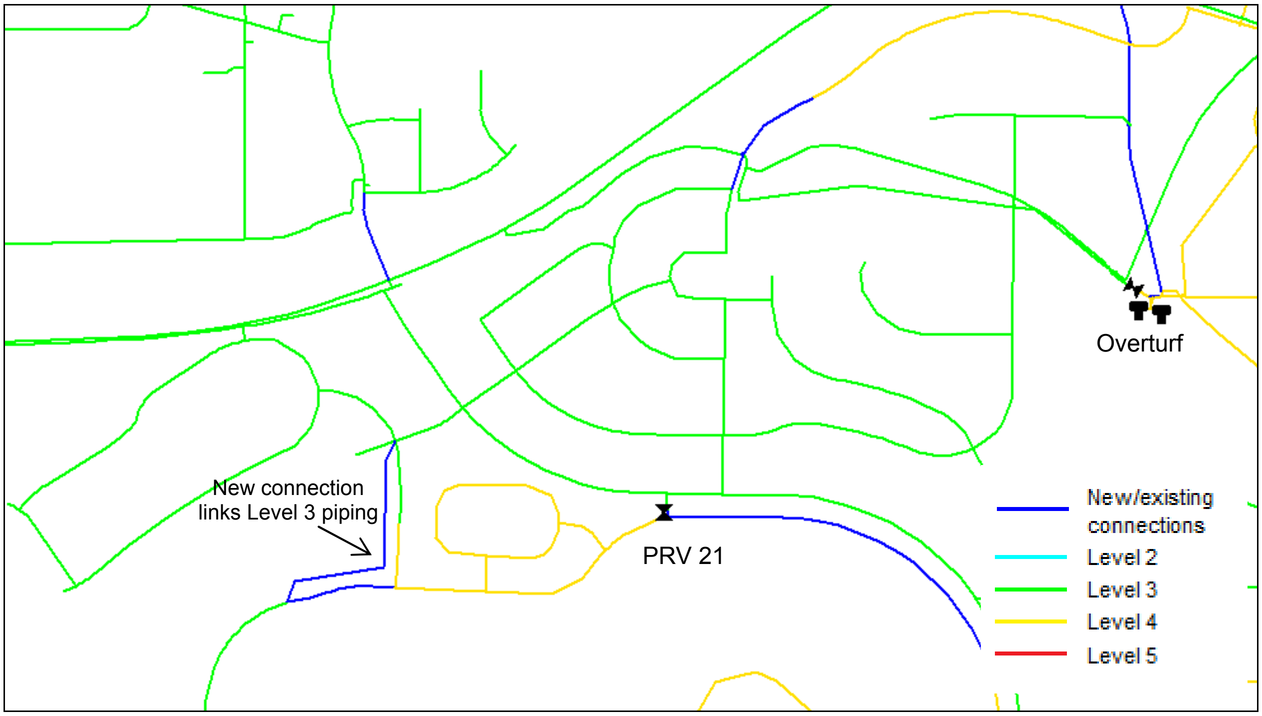


Figure 2.1 – Location of potential Level 3 connection at Flagline Court/Green Lakes Loop

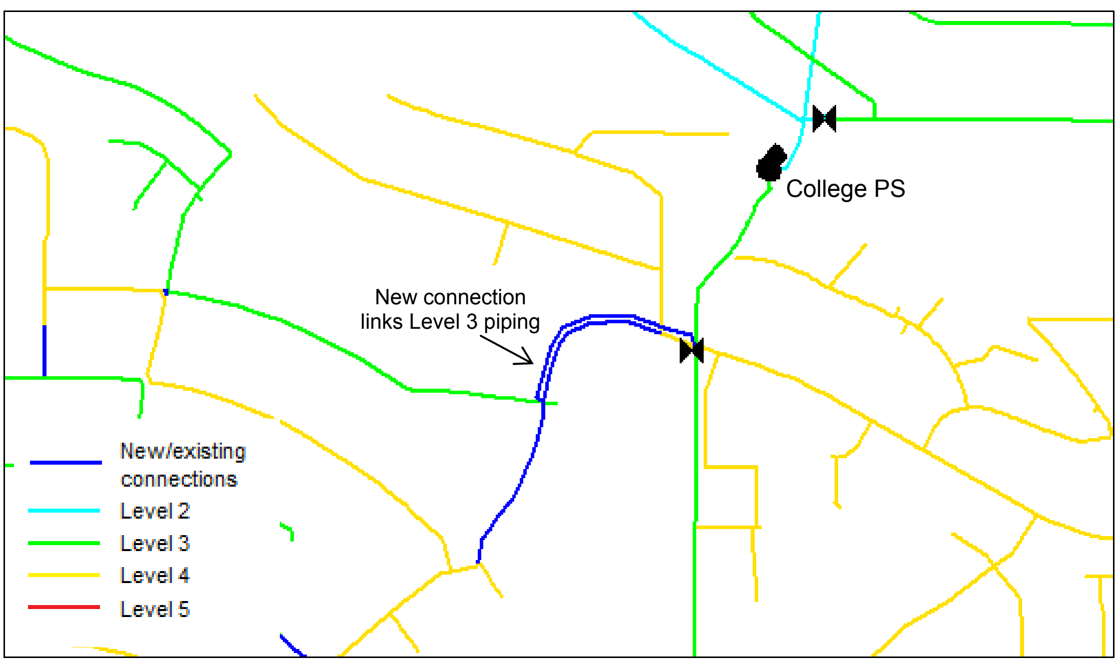


Figure 2.2 – Location of potential Level 3 connection near College PS

Figure 2.3 shows the locations of these pump station options. The use of either of these new pump stations may reduce the existing pumping energy required to lift water to Level 1, allowing the Awbrey station to serve as a back-up to Level 1 under certain seasonal or other demand conditions. Another consideration when evaluating this option is the additional draw on the College Pump Station that would be required if Level 1 is supplied from Level 2. Existing average day demand in both levels is about 0.4 MGD, so the demand on College PS could be increased two-fold if it is called upon to provide the Level 1 demand in addition to the demand of Level 2. Theoretically the station currently has capacity to support this additional demand, but conditions could change in the future.

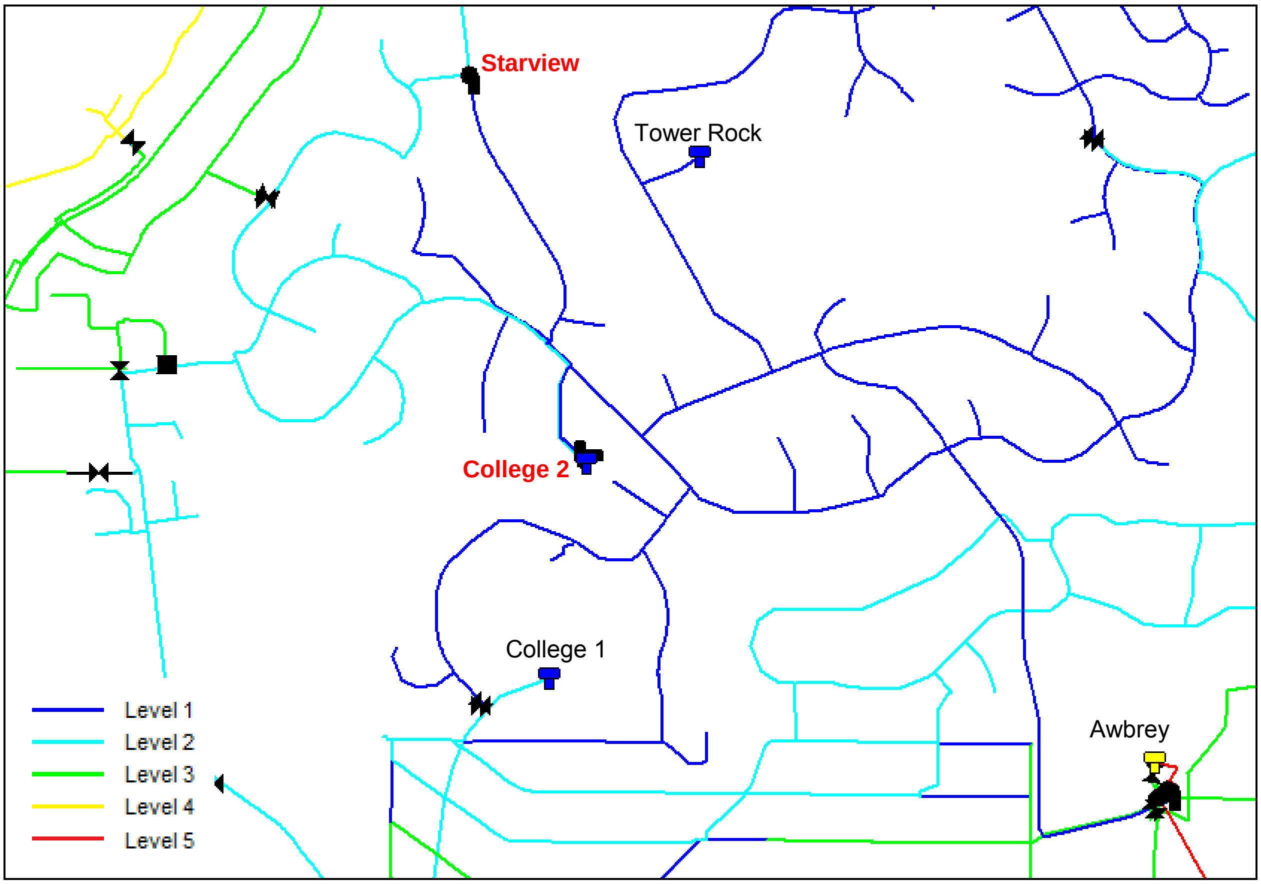


Figure 2.3 – Location of potential Level 2 to Level 1 Booster Pump Stations

The Westwood Pump Station facility is reportedly problematic and likely inefficient so Bend would like to investigate alternative ways to supply the Westwood Zone and neighboring zones. Alternative ideas for this area are discussed in Section 2.1.3.

The Operations Optimization runs did not consider any changes to the South Bend area operation (Murphy/Shilo/Hole Ten). Our understanding is that this area is being reviewed separately by Bend staff and that the results of the investigations will be incorporated into the future Build-out analyses.

2.1.3 Potential modification of Zone Boundaries

In line with Bend's desire to simplify the system and streamline pressure zones, Optimatics evaluated modifications to some zone boundaries. When assessing the feasibility of joining smaller pressure zones into larger neighboring zones, the aim is to ensure that service pressures are still above the minimum requirement and not significantly more than 10 psi below current pressures. If combining zones into a higher pressure level, the cost of adding individual PRVs to customer connections needs to be accounted for. The modifications being considered in the optimization include changing PRV settings in combination with opening boundary pipes/valves, and/or adding new pipe to complete the merging of zones. Note that each figure provided in this subsection is referenced to its location in the water system on the overall map shown in Appendix A.

Zone 4F into 4A

There are approximately 60 customers in Zone 4F. Although the zone cannot be supplied through a single connection to Zone 4A (due to lack of available transmission capacity), a potential location to link the two zones exists at the southern end of the zone. In order to maintain satisfactory pressures it would be necessary to keep PRV 44 active (see Figure 2.4).

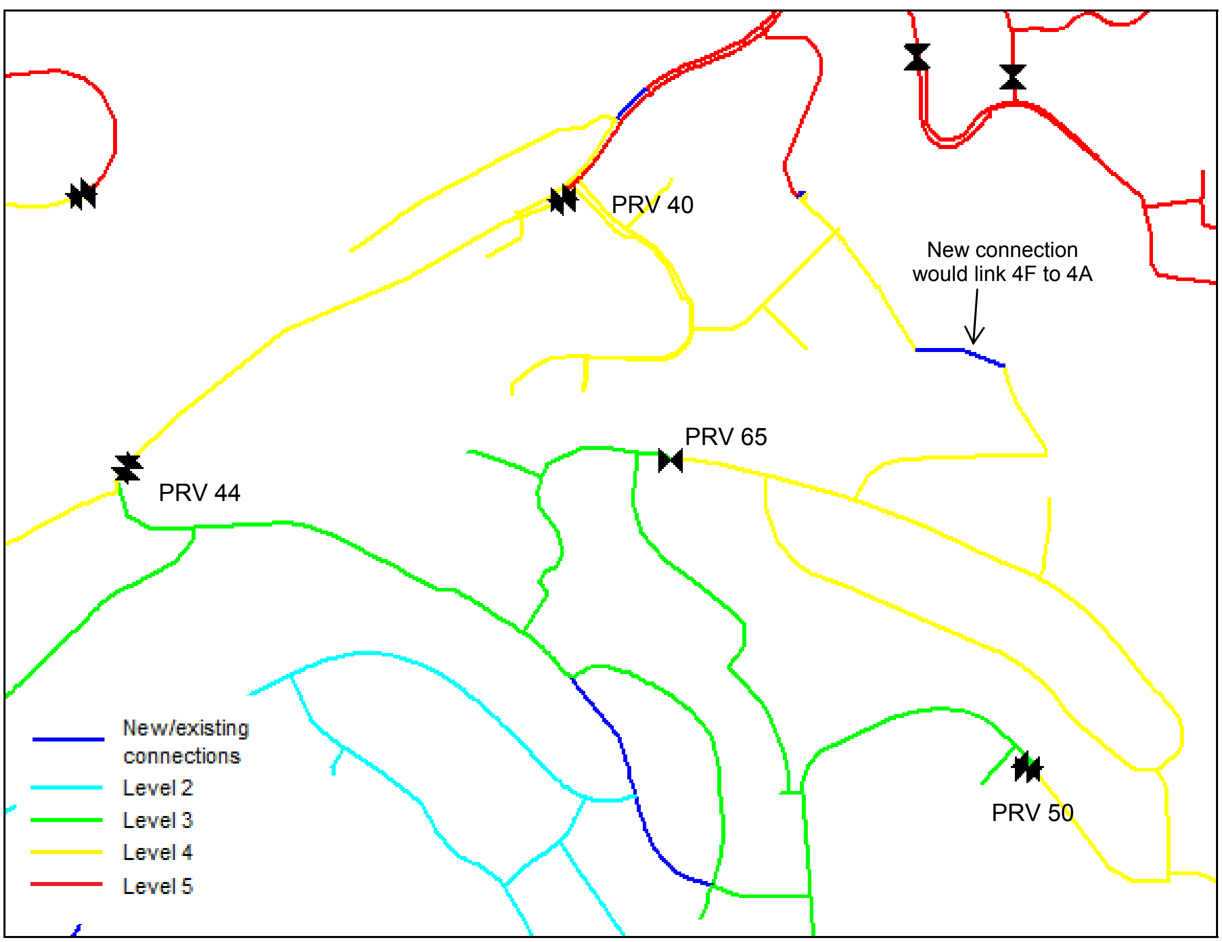


Figure 2.4 – Potential pipe connection between Zone 4F and Zone 4A

Zone 4G into 4A

There are approximately 15 customers in Zone 4G. The Zone is supplied via a PRV from Zone 3 along the transmission line that leads to the Athletic Club PRV. Reducing demand off this line will allow all flow to be directed east to Zone 4B, strengthening the ability of the system to move more surface water from west to east.

An alternative way to supply Zone 4G would be to implement a connection to Zone 4A along Cascade Lakes Highway / Chandler Avenue. Additional reinforcement could come from new pipe connections north of this location on Cascade Lakes Highway to tie in with an existing 12-inch diameter main.

Connecting 4G into 4A would likely result in pressures that are 10-15 psi lower than currently seen (approximately 60 psi at the highest elevation nodes in this zone) which may result in customer complaints.

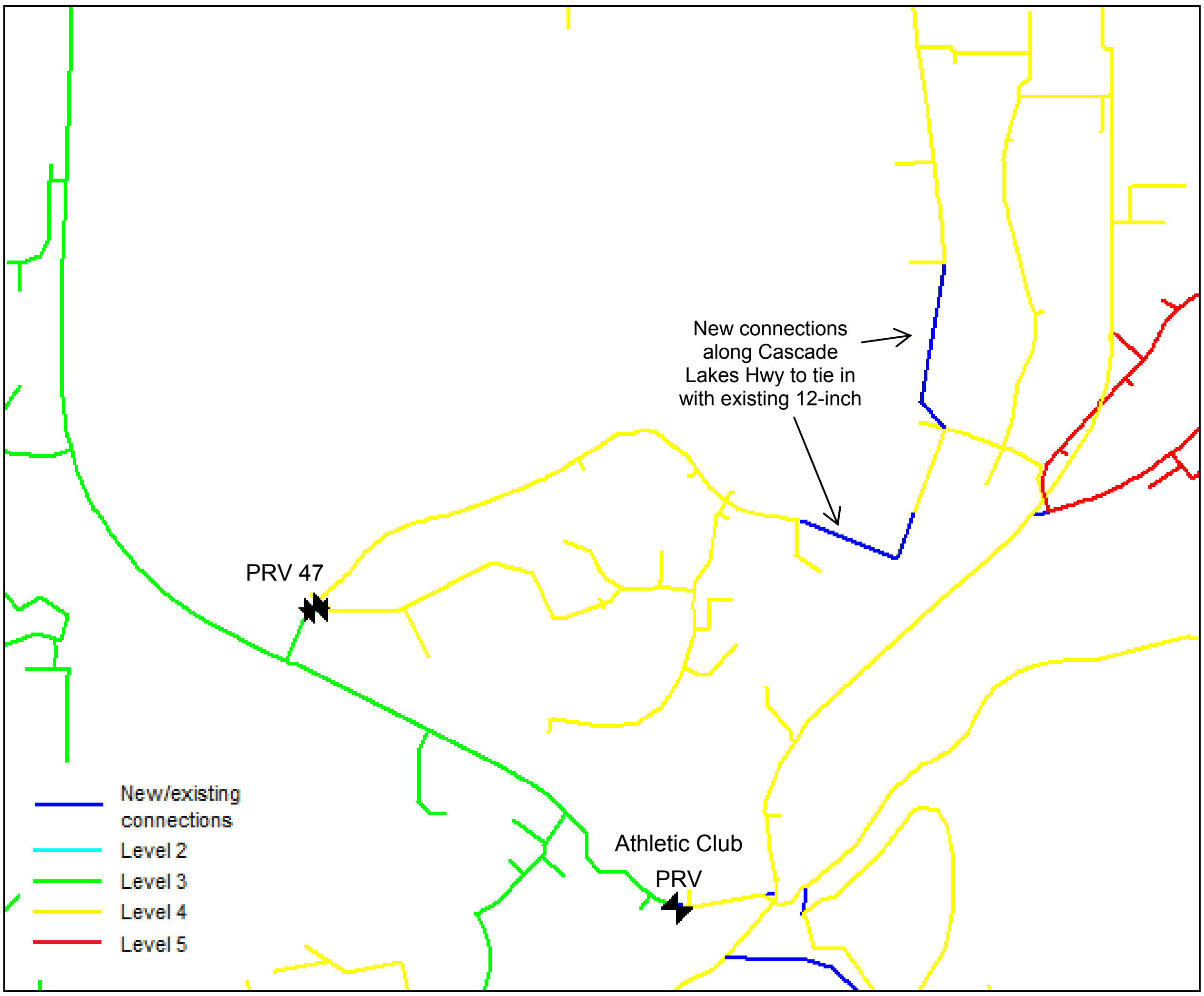


Figure 2.5 – Potential connections between Zone 4G and Zone 4A

Zone 4I into 4A or 4B

There are approximately 140 customers in Zone 4I, located south of Zone 4A and currently supplied via PRVs from Westwood which involves pumping and then subsequent loss of head through the valves. The hydraulic grade line (HGL) in Zone 4I is close to that of Zone 4A, although at that southern location the head in Zone 4A is significantly lower that the overflow of Overturf Reservoirs. The HGL in Zone 4I is even closer to that of Zone 4B. There is potential to open connections to 4I from either 4A or 4B to the east and to the south of the Athletic Club PRV.

Combining Zone 4I with Zone 4A may cause some nodes to experience pressures below 40 psi. Feedback from the December 2009 meeting suggested the idea of splitting Zone 4I such that the higher elevation nodes remain supplied via the PRV while lower elevation nodes would be supplied from either Zone 4A or 4B.

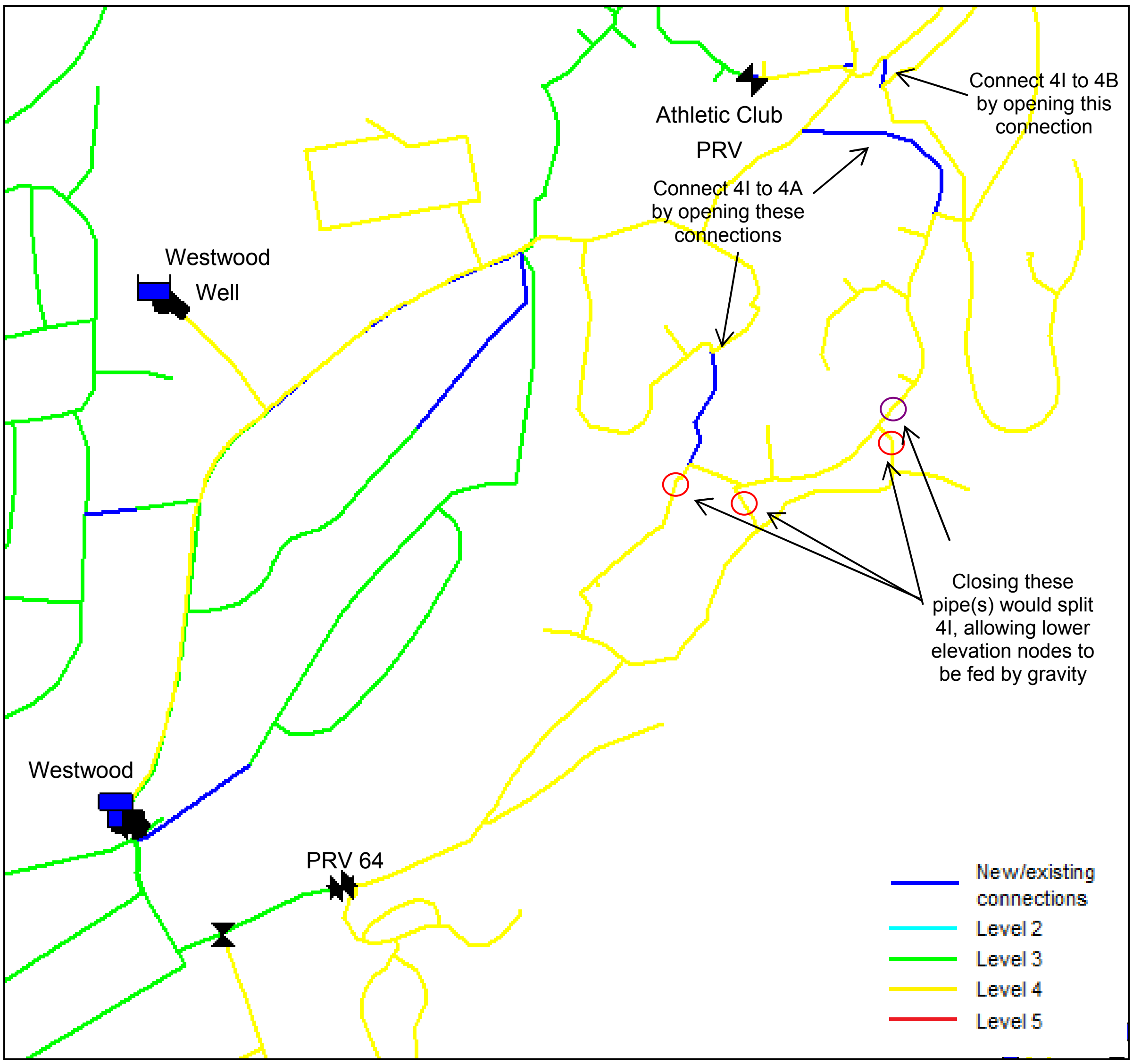


Figure 2.6 – Potential connections between Zone 4I and Zone 4A/4B

Zone 4J into 4A

There are approximately 200 customers in Zone 4J. The zone is located between Zone 3 and Zone 4A, with PRVs supplying the zone at constant pressure. Two pipes at the northeast corner of the zone could be opened to join this zone with Zone 4A. There would only be a slight change in resulting pressures for customers currently residing in 4J. Joining 4J with 4A would also open up this subzone to the larger zone, which would potentially improve water quality.

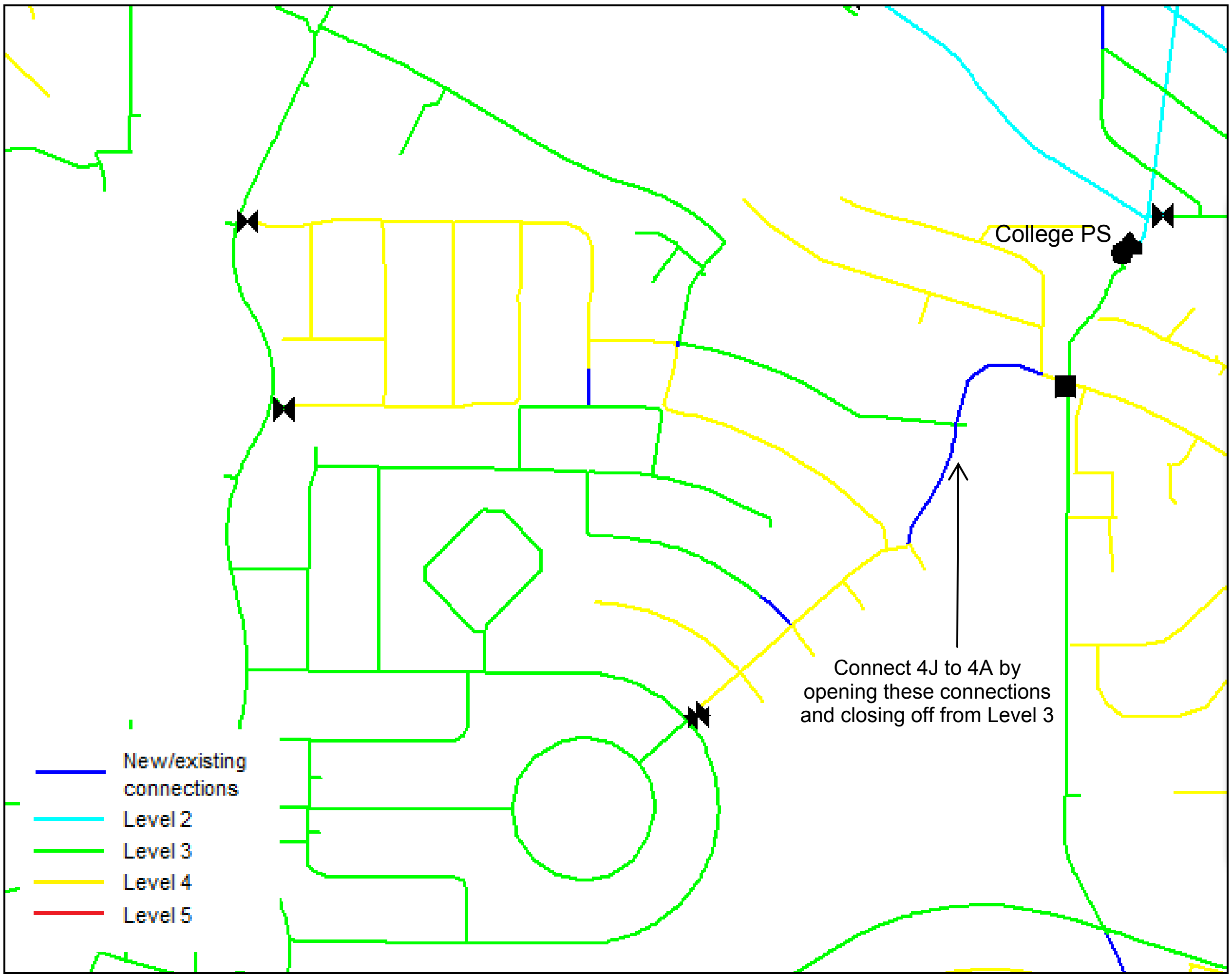


Figure 2.7 – Potential connections between Zone 4J and Zone 4A

Zone 4K into 4A

There are approximately 50 customers in Zone 4K. Opening up this zone to Zone 4A would reduce pressures by 10-12 psi (from 60 psi) but would increase circulation and improve water quality. This was discussed at the December meeting and Bend advised that they have tried the idea before and received low pressure complaints.

Including the zone in Level 3 would result in high pressures along Flagline Court. This could be managed by adding individual customer PRVs to the affected properties, and would provide an alternative second connection to support Tetherow suction pressure (refer Section 2.1.1). An additional option is to move the Zone 4A/4K boundary to the east and open up a second loop in Level 3. This involves closing pipe WWM005415 and opening the boundary valve at Broken Top Drive and Simpson Avenue. An additional 100 customers would require individual PRVs to facilitate this boundary adjustment.

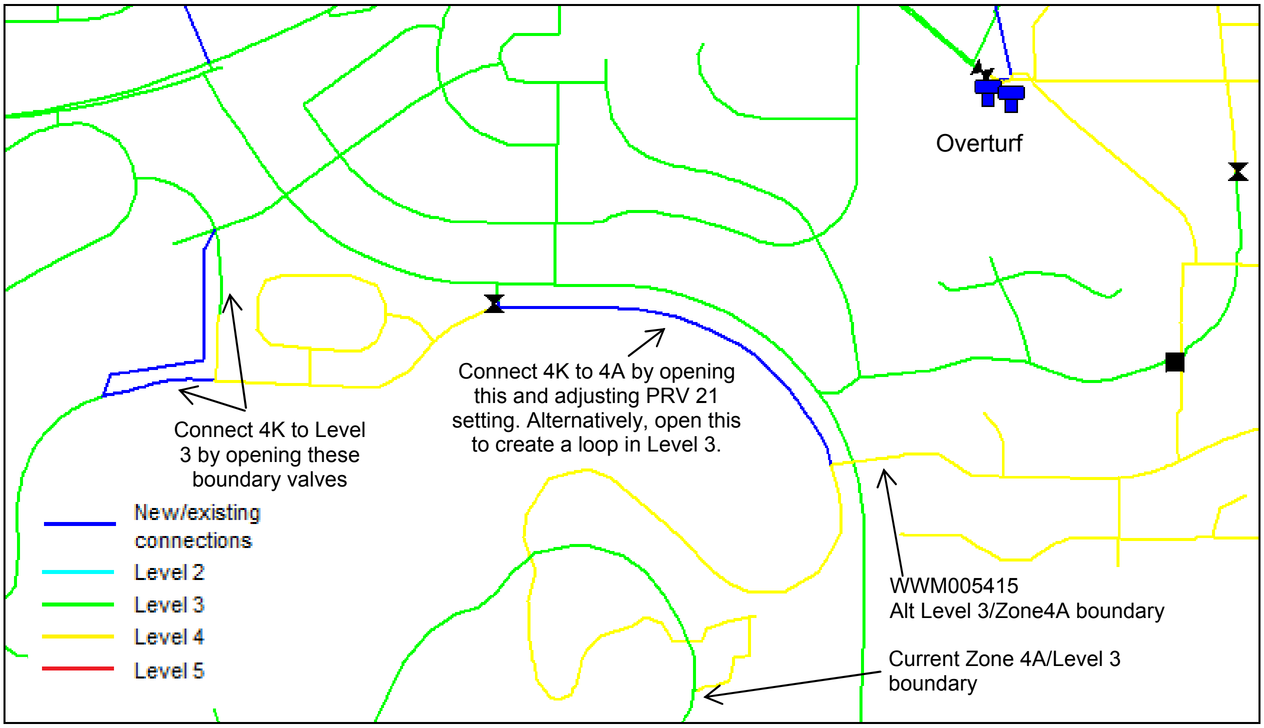


Figure 2.8 – Potential connection between Zone 4K and Zone 4A

Westwood into Level 3

There are approximately 370 customers in Zone 3C (Westwood). Currently these customers are supplied by the Westwood pump station, where discharge pressure is set to 78 psi. Elevations in the zone decrease to the south as the land slopes down towards the river. The Westwood facility is problematic for operators and Bend would like to investigate alternative ways to supply this area of the system.

Assuming that supply restrictions in Level 3 are eliminated (see Section 2.1.1 and 2.1.4), a number of opportunities exist to make connections between Level 3 (HGL 3990 on the boundary with Westwood) and Westwood (HGL 4020) – see Figure 2.9. Combining Westwood into Level 3 would mean lowering the operating grade about 30 feet (13 psi); however, it is anticipated that this would be acceptable as pressures are already at reasonable levels (60 psi at the highest point in the zone). A small number of higher elevation customers in the Westwood area could be moved into the Tetherow Zone to prevent low pressure complaints.

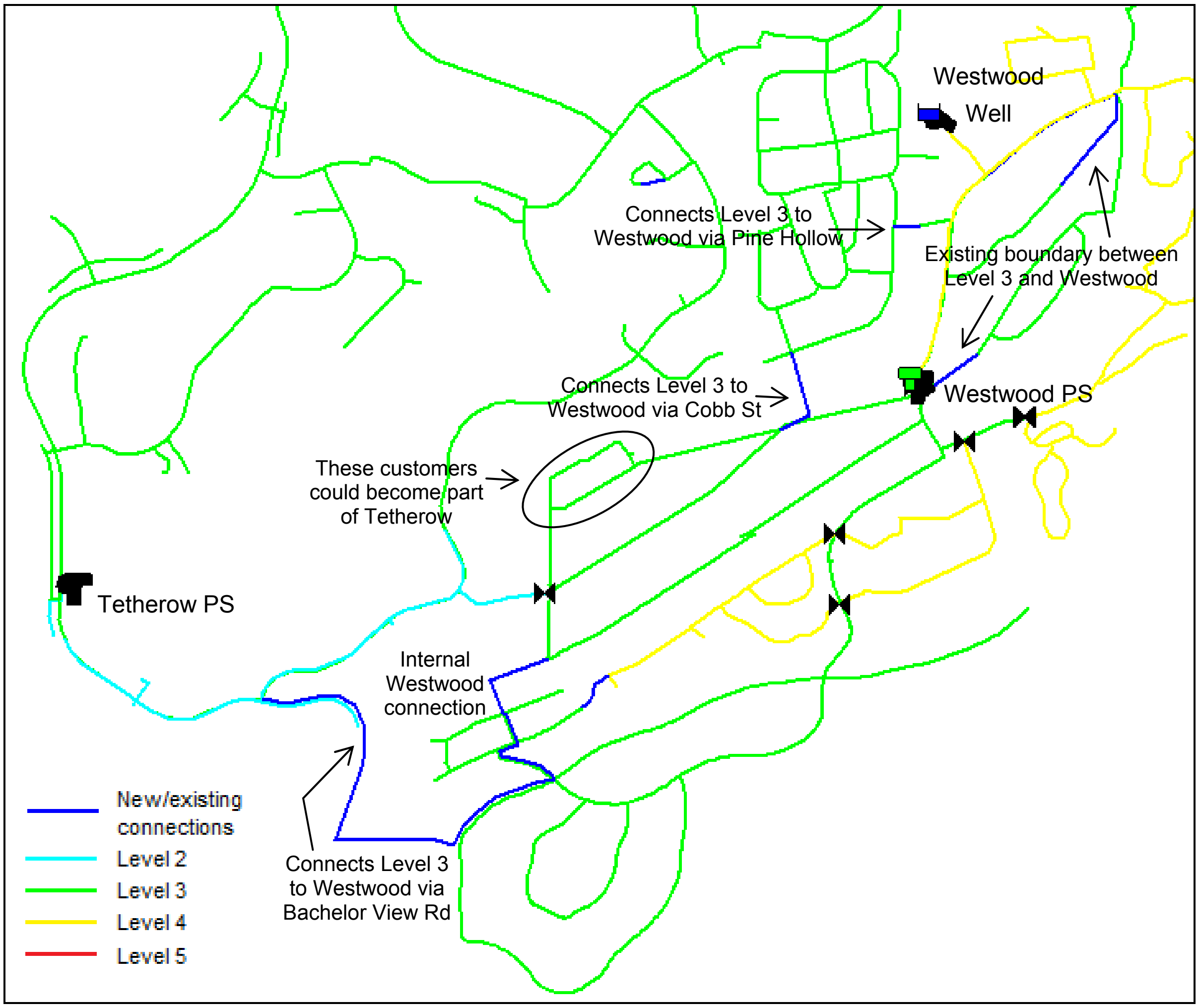


Figure 2.9 – Potential connections between Level 3 and Westwood (Zone 3C)

In addition to these zone boundary modifications, Optimatics has identified small zones with few customers that Bend may wish to consider as candidates for implementing customer PRVs. The benefit of installing individual customer PRVs would be a reduced reliance on existing PRVs in the system with associated reduction in maintenance costs.

Table 2.1 lists zones with fewer than 100 customers (including some mentioned above) that may represent potential candidates for individual customer PRVs, together with estimated costs using $1,000 per customer PRV. Some of these zones are expected to grow in the future and it may not be viable that all customers in the zone have individual PRVs.

Zones 5A, 5B and 5C (highlighted in bold text) appear to be ideal candidates for individual customer PRVs since the removal of the existing PRVs would open up loops in the zones they are supplied from which would improve redundancy and circulation. In addition, opening up these particular zones would each eliminate two PRVs, reducing maintenance requirements.

Table 2.1 – Potential Candidate Zones for Individual PRVs

Zone	Current Customer Count	Total estimated cost of individual PRVs ($)
5C	**2**	**2,000**
3B	6	6,000
4G	14	14,000
3A	21	21,000
5A	**21**	**21,000**
5B	**26**	**26,000**
5D	30	30,000
7D	37	37,000
6B	39	39,000
4K	53	53,000
4F	62	62,000

2.1.4 Valve Settings

The settings of a number of control valves are being evaluated in the optimization. Table 2.2 shows the flow and pressure control valves, current settings for flow / pressure for winter and summer conditions, and the range of setting options configured in the optimization to determine the most favorable settings.

The first two valves in Table 2.2 are the flow control valves (FCVs) that fill Overturf and Awbrey. Analysis of the model results shows that flow from Outback to these reservoirs fluctuates significantly, which often affects the available head in the transmission line (see Figure 2.10). If this rate of flow could be evened out there would be a more constant driving head for the system and increased ability to incorporate surface water supply.

In order to increase available driving head, particularly during peak hour demands, the optimization has been formulated to consider changes to the flow rates into these storages, including changing the rate of flow over a 24-hour period. At the December meeting, Bend Operators confirmed that such operation could be implemented using existing infrastructure. The idea is to reduce flow into the storages during times of high system demand, enabling the additional surface water supply to travel further east into the system. The proposed operational change would call for higher inflows overnight to ensure storage volume is maintained. This approach obviously causes the storages to fluctuate over a slightly larger range, but it should increase driving head and improve the potential to move more surface water supply to the east when demands are higher.

Table 2.2 – Control Valve Setting Options

Valve ID	From Level / To Level	Current Setting		Setting Options	
		Winter	Summer	Min	Max
Overturf FCV	Level 3 to Level 4	1200 (gpm)	1400 (gpm)	750	1500
Awbrey FCV	Level 3 to Level 5	3500 (gpm)	6200 (gpm)	3500	6500
WAPRV024A	Level 4A (West) to Level 5 Newport & Juniper	67 (psi) 3794 (HGL - ft)	62 (psi) 3782 (HGL - ft)	58 3773	67 3794
WAPRV036A	Level 4A (West) to Level 5 Cumberland and 15th	51 (psi) 3761 (HGL - ft)	57 (psi) 3775 (HGL - ft)	47 3752	61 3784
WAPRV037A	Level 4A (West) to Level 5 17th St. & Galveston	45 (psi) 3787 (HGL - ft)	44 (psi) 3785 (HGL - ft)	40 3776	49 3796
WAPRV038A	Level 3 to Level 4B (East) Mt. Washington & Athletic Club	72 (psi) 3878 (HGL - ft)	71 (psi) 3876 (HGL - ft)	71 3876	76 3887
WAPRV015A	Level 4B (East) to Level 5 Hwy 20 @ 1734	40 (psi) 3758 (HGL - ft)	47 (psi) 3774 (HGL - ft)	40 3758	51 3784
WAPRV015B	Level 4B (East) to Level 5 Hwy 20 @ 1735	38 (psi) 3754 (HGL - ft)	43 (psi) 3765 (HGL - ft)	34 3744	46 3772
WAPRV039A	Level 4B (East) to Level 5 Wilson & Bond	52 (psi) 3774 (HGL - ft)	52 (psi) 3774 (HGL - ft)	48 3764	56 3783
WAPRV057A	Level 4B (East) to Level 5 Bond & Reed Market	51 (psi) 3760 (HGL - ft)	58 (psi) 3776 (HGL - ft)	47 3750	62 3785
WAPRV047A	Level 3 to Zone 4G Chandler & Mt. Washington	72 (psi) 3892 (HGL - ft)	70 (psi) 3888 (HGL - ft)	50 3842	70 3888
WAPRV064A	Zone 3C (Westwood) to Zone 4I Wild Rapids & Wild Rapids	57 (psi) 3892 (HGL - ft)	53 (psi) 3882 (HGL - ft)	43 3859	53 3882
WAPRV021A	Level 3 to Zone 4K Green Lakes Loop	57 (psi) 3892 (HGL - ft)	58 (psi) 3894 (HGL - ft)	46 3866	58 3894
WAPRV073A	Zone 2A (Tetherow) to Zone 3C (Westwood) Tetherow & Campbell	65 (psi) 4015 (HGL - ft)	65 (psi) 4015 (HGL - ft)	55 3991	65 4015

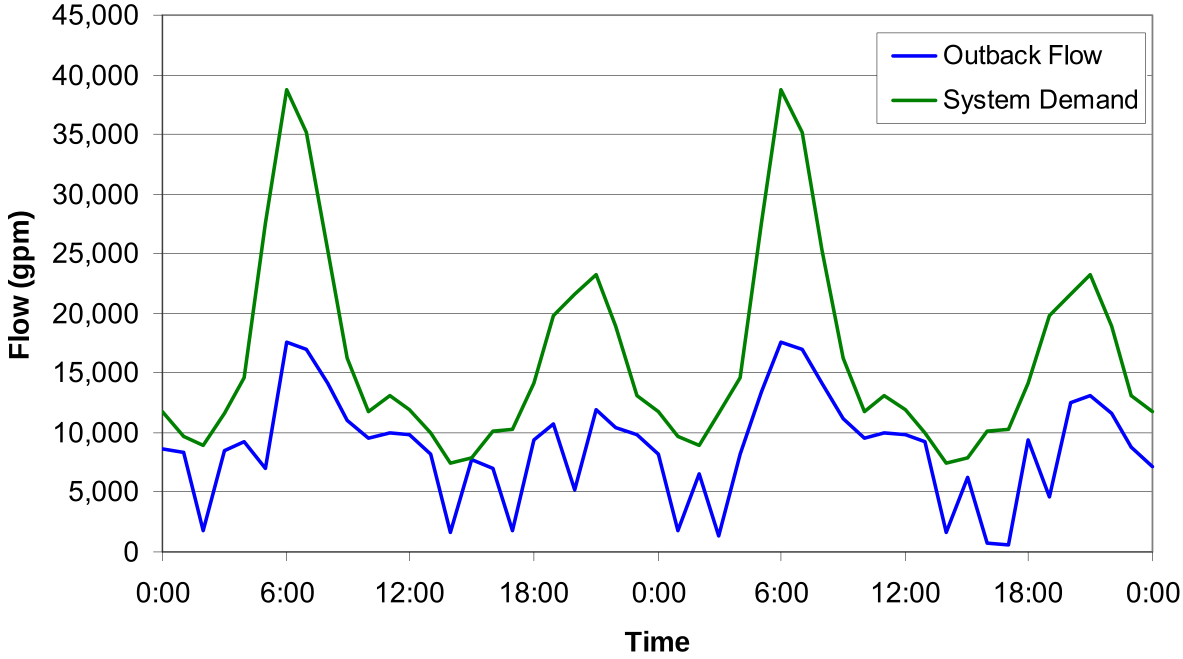


Figure 2.10 – Flow from Outback compared to system demand – Calibrated Summer Model

A key aim in the summer scenario is to improve the recovery of the Pilot Butte Reservoirs in Zone 5. Adjustments to the settings of valves on the boundary of Level 4 and Level 5 (the PRVs shown in Table 2.2 beneath the Awbrey and Overturf FCVs) have been considered to determine if modifications to the settings will improve the reservoir levels. In addition, the setting of the Athletic Club PRV was also evaluated. The remainder of the PRV setting options in Table 2.2 relate to the potential zone boundary modifications discussed previously in Section 2.1.3.

2.1.5 Controls

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

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

Some wells are not suitable for control based on tank levels or system pressure; however the optimization was configured to evaluate whether or not these particular wells should be utilized on a regular basis. The wells in question are Copperstone Well (submersible, runs to waste for 10-15 minutes on start up), Pilot Butte Well 1 (oil lube, must be run to waste for 24 hours before use) and Rock Bluff Well 2 (submersible, currently not normally in operation).

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

Table 2.3 lists the current controls for each facility in the summer and winter models and the range of different settings for these controls that are being tested with the optimization.

Table 2.3 – Control setting options for pumps and wells based on reservoir levels

ID	Current Setting (ft)		Setting Options (ft)
	Winter	Summer	
TOWER ROCK			
AWBREY_P1 On	27.5	28.9	24.5 - 27.5
AWBREY_P1 Off	29.5	29.5	26.5 - 29.5
AWBREY_P2 On	26	26	23 - 26
AWBREY_P2 Off	27.5	27.5	24.5 - 27.5
New Pump On (Starview/College)	n/a	n/a	25 - 27
New Pump Off (Starview/College)	n/a	n/a	27.1 - 29
AWBREY			
Reservoir Inlet Open	17	17	14 - 16
Reservoir Inlet Closed	18	17.9	17 - 19
RIVER_W1 On	n/a	n/a	14 - 16
RIVER_W1 Off	n/a	n/a	16 - 18
RIVER_W2 On	n/a	n/a	13 - 15
RIVER_W2 Off	n/a	n/a	16 - 18
OVERTURF			
Reservoir Inlet Open	21.8	23	21.8 - 23.8
Reservoir Inlet Closed	23	24.6	24 - 26
COPPERSTONE_W On	n/a	n/a	n/a
COPPERSTONE_W Off	n/a	n/a	n/a
PILOT BUTTE 1			
PILOT_BUTTE_W1 On	n/a	n/a	n/a
PILOT_BUTTE_W1 Off	n/a	n/a	n/a
PILOT_BUTTE_W3 On	n/a	n/a	22 - 24
PILOT_BUTTE_W3 Off	n/a	n/a	26 - 29

ID	Current Setting (ft)		Settings (ft)
	Winter	Summer	
PILOT BUTTE 2			
BEAR_CREEK_W1 On	35	35	33 - 35
BEAR_CREEK_W1 Off	37	37	35 - 37
BEAR_CREEK_W2 On	34	34	32 - 34
BEAR_CREEK_W2 Off	36	36	34 - 36
SCOTT_BP_2 On	31	31	31 - 35
SCOTT_BP_2 Off	35	35	35 - 37
SCOTT_BP_1 On	29	29	29 - 34
SCOTT_BP_1 Off	33	33	33 - 36
SCOTT_BP_3 On	27	27	27 - 30
SCOTT_BP_3 Off	32	32	32 - 35
ROCK BLUFF 1			
ROCK_BLUFF_W1 On	34.9	34.9	32.9 - 34.9
ROCK_BLUFF_W1 Off	37.2	37.2	35.2 - 37.2
ROCK_BLUFF_W2 On	n/a	n/a	n/a
ROCK_BLUFF_W2 Off	n/a	n/a	n/a
ROCK_BLUFF_W3 On	36	36	34 - 36
ROCK_BLUFF_W3 Off	38.2	38.2	36.2 - 38.2

2.2 Constraints

2.2.1 Pressure

All nodes in the model with customer demands are subject to the pressure criteria described in the Design Data Summary (DDS) report. The low pressure criterion is 40 psi. There are, however, a number of locations where this minimum pressure is not met in the calibrated summer model of existing conditions. Those locations that show pressure below 40 psi in the summer model are listed in Table 2.4. In the Operations Optimization these locations are simply required to meet or exceed the pressure in the existing model. Note that the Build-out Optimization will aim to improve hydraulic performance in these areas.

2.2.2 Velocity

Pipes showing velocities greater than 7 feet per second (fps) were tracked and observed but have not been penalized in the optimization solutions.

Table 2.4 – Demand nodes with minimum pressures below 40 psi in the Summer Model

ID	Minimum Pressure (psi)	Zone
JCT-3078	35.56	1
JCT-3098	37.45	1
JCT-3111	33.85	1
JCT-3112	32.98	1
JCT-3116	34.80	1
JCT-3121	38.20	1
JCT-3131	36.76	1
JCT-3138	39.90	1
JCT-3141	39.00	1
JCT-3143	38.96	1
JCT-3086	30.28	2
JCT-3099	39.81	2
JCT-1037	36.75	3
JCT-105	20.55	3
JCT-106	32.56	3
JCT-109	22.28	3
JCT-112	32.54	3
JCT-114	31.62	3
JCT-117	4.27	3
JCT-119	32.88	3
JCT-121	27.77	3
JCT-124	28.36	3
JCT-125	33.56	3
JCT-128	37.03	3
JCT-1629	30.33	3
JCT-195	38.77	3
JCT-202	37.90	3
JCT-206	39.64	3
JCT-221	35.54	3
JCT-223	29.18	3
JCT-228	36.21	3
JCT-234	33.59	3
JCT-2359	36.45	3
JCT-236	22.32	3
JCT-239	18.85	3
JCT-245	35.47	3
JCT-246	22.32	3
JCT-253	21.24	3
JCT-255	34.59	3
JCT-256	31.87	3
JCT-259	34.58	3
JCT-260	35.45	3
JCT-3041	36.25	3
JCT-3187	27.64	3
JCT-3195	39.11	3
JCT-377	33.84	3
JCT-585	34.68	3
JCT-591	33.81	3
JCT-72	2.96	3
JCT-875	37.70	3
JCT-1078	39.76	4A
JCT-574	39.53	4A
JCT-1024	39.67	4B
JCT-2570	37.74	4B
JCT-2571	37.74	4B
JCT-2622	38.62	4B
JCT-2634	38.62	4B
JCT-2652	39.49	4B
JCT-3420	39.55	4B
JCT-3425	37.84	4B
JCT-3429	39.55	4B
JCT-3436	38.24	4B
JCT-3437	38.65	4B
JCT-3438	37.92	4B
JCT-3439	38.73	4B
JCT-3441	37.71	4B
JCT-3444	37.40	4B
JCT-3445	38.87	4B
JCT-3449	39.77	4B
JCT-3452	39.24	4B
JCT-3455	38.26	4B
JCT-3457	39.14	4B
JCT-3469	39.09	4B
JCT-3488	39.96	4B
JCT-3509	39.92	4B
JCT-3510	39.94	4B
JCT-692	27.48	4C
JCT-714	30.08	4C

ID	Minimum Pressure (psi)	Zone
JCT-1034	39.68	4I
JCT-1268	38.30	5
JCT-1296	38.30	5
JCT-1324	39.95	5
JCT-1925	38.72	5
JCT-1952	39.46	5
JCT-1959	39.46	5
JCT-1960	35.19	5
JCT-1962	35.22	5
JCT-1963	35.22	5
JCT-1994	37.77	5
JCT-1995	37.77	5
JCT-2287	37.48	5
JCT-2742	38.71	5
JCT-2956	36.80	5
JCT-4132	37.29	5

ID	Minimum Pressure (psi)	Zone
JCT-4157	34.77	5
JCT-4199	36.26	5
JCT-4200	39.00	5
JCT-4206	33.77	5
JCT-4207	37.28	5
JCT-4208	39.94	5
JCT-4220	36.45	5
JCT-4228	34.88	5
JCT-4241	39.83	5
JCT-4266	39.74	5
JCT-4268	38.82	5
JCT-896	29.06	5B
JCT-3307	36.32	5D
JCT-3361	33.70	6B
JCT-938	23.76	6B

2.2.3 Tank levels

Charts showing the tank levels over a 48-hour simulation period in both of the Baseline scenarios have been included in Appendix B (summer) and Appendix C (winter). Tank level constraints are applied in the optimization to ensure that tank levels do not drop too low or overfill at any point during the simulation. A 'return level' constraint can also be applied to encourage the water level to be within a certain range at the end of the simulation.

Summer

The summer operations scenario shows that the current reservoir turnover is good, and the goal in the optimization was to ensure that each tank returns to its starting level at the end of each day. In the optimization formulation Optimatics set minimum and maximum water levels for each storage and constrained the level to return to within +/- 2 feet of the initial level at the end of the simulation.

Winter

The same minimum and maximum tank level constraints used in the summer formulation were applied to the winter formulation. In the winter scenario, the challenge is to induce drawdown in storages, particularly in Pilot Butte Reservoirs 1 & 3, to ensure turnover of volume and satisfactory water age.

In the optimization project update meetings held in August 2009, a goal of turning over 25% of the storage volume in the Pilot Butte Reservoirs every 3 to 4 days during the winter was suggested. This equates to a drop of 3-5 ft over the 48-hour period considered in the optimization. Thus, the optimization was formulated to try and achieve a drop of this magnitude in Pilot Butte Reservoirs 1 and 3. Other reservoirs in the system were simply required to return to within +/- 2 feet of the initial level at the end of the simulation.

3 Baseline Summer and Baseline Winter Scenarios

Before presenting the results of the optimization runs, it is necessary to understand the operating scenarios and associated costs in the base hydraulic models. For the summer scenario the base model is the calibrated EPS model developed by MSA based on data from July 2009. The winter model was set up by MSA using available information regarding the system configuration in January 2009. Both models contain detailed operational controls for pumps based on water levels in relevant storages.

3.1 Historical power cost records

Bend provided data from 2005 to 2008 relating to power bills from Pacific Power. The data for 2008 were very detailed, listing the individual amounts for each facility each month. For previous years, total monthly bills for each major account were provided. The monthly bills list all costs including pumping, reservoir and valve power costs and building power costs. These costs were analyzed to determine current trends in energy usage.

Table 3.1 shows the annual average daily production for the Bend system for the years 2006 through 2008, as well as the associated power costs for the system for those years. Total annual costs for all water facilities (including reservoir, valve and building power costs) were approximately $700,000 in 2008. Costs were slightly higher in 2007 ($740,000) and slightly lower in 2006 ($670,000). Average annual water production rates for these years show a similar relationship.

Table 3.1 – Annual daily production and annual power costs for Bend system

Year	Annual Average Daily Production (MGD) [1]	Annual Power Costs [2]
2006	11.55	$670,000
2007	13.84	$740,000
2008	12.84	$700,000

1) Based on production records – Bend has advised there is some uncertainty in these values

2) Represents the sum of charges under four accounts listed below. Includes all charges (energy and demand/load size).

420-7650-569.32-01	Water delivery pumping systems
420-7210-569.32-01	Watershed surface water
420-7220-569.32-01	Water wells
420-7240-569.32-01	Water production disinfection

Comparing annual system demands (12.8 MGD, or a total of 4,700 MG in 2008) to power costs ($700,000 in 2008) results in an average cost of $150/MG of total water production (surface plus groundwater). If power costs are compared to groundwater well production only (being 7.1 MGD, or 2,600 MG over the course of 2008), the average cost is $270/MG. This cost difference reinforces how maximizing surface water use will have a dramatic impact on annual power costs in the Bend system.

Table 3.2 shows the annual costs for each of the major water facilities in 2008 (January to December). This includes wells and booster pump stations but not all water facilities. The purpose of this summary is to provide a reference for comparison to the cost estimates developed from the hydraulic models.

Table 3.2 – Annual power costs for key Bend system facilities – 2008

Facilities	2008 Annual Cost Pacific Power [1]
Awbrey Pump Station	$29,400
Bear Creek Wells 1 & 2	$80,700
College PS #2	$5,700
Copperstone Well	$42,800
Hole 10 Wells	$67,100
Murphy Pump Station	$4,300
Outback 6,7,8	$27,700
Outback wells 1, 2	$40,500
Outback Wells 3,4,5	$91,200
Pilot Butte Wells 1,3	$74,900
North River Well	$29,200
South River Well	$74,700
Rock Bluff Well 1,2,3	$50,300
Scott Street Pump Station	$3,700
Shilo Wells	$16,300
Tillicum Village Pond	$11,700
Westwood Reservoir/Pumps	$13,800
Westwood Well	$7,600
Total	**$671,600**

1) Power costs include energy and demand charges for water facilities in the main system. Does not include costs associated with:

Surface water	Irrigation
Reservoirs	Airport system
Disinfection	

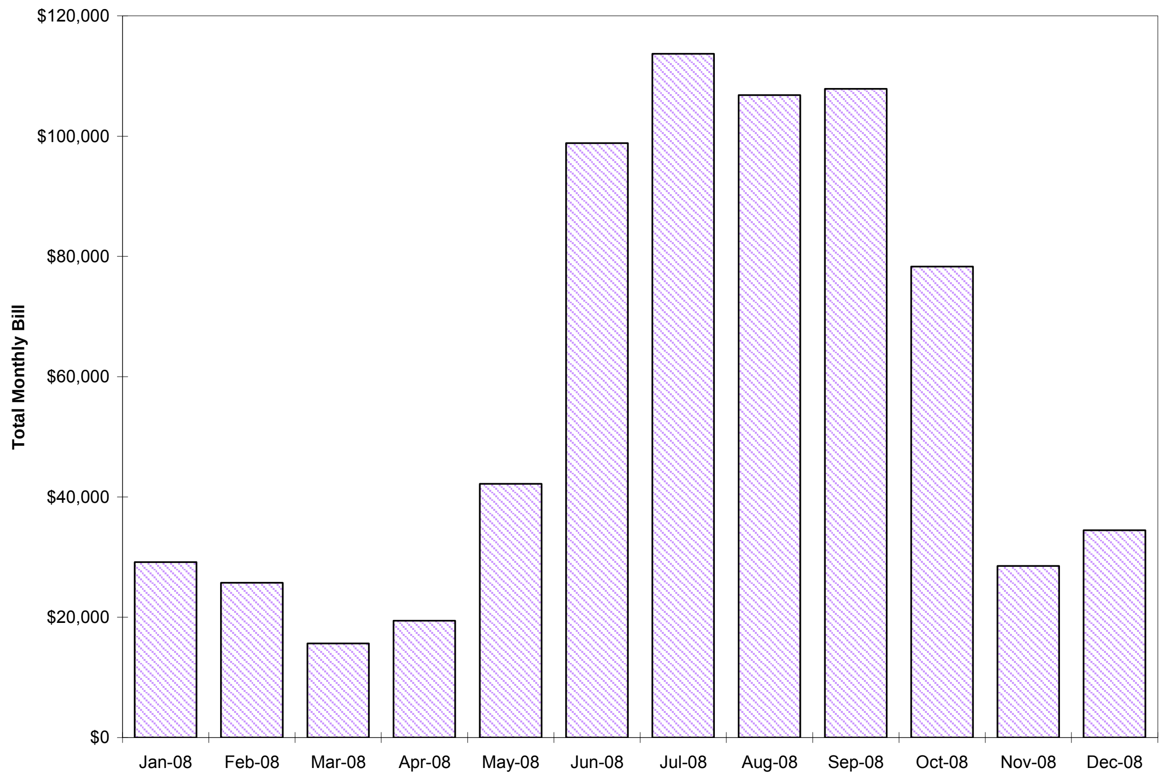


Figure 3.1 shows the breakdown by month of total costs from the 2008 records. The vast majority of these costs relate to well operation. Figure 3.2 show the contribution of facilities other than wells to the total power costs. The costs for booster pumps vary in a similar fashion to the well pumping which is related to system demand. Other costs, such as the costs of heating facility buildings, are higher in the winter.

Figure 3.3 takes the total cost information and breaks it down into daily, monthly, seasonal and annual costs. The costs shown above each month are the total monthly costs divided by the number of days in that month. The dashed lines show averages over different periods. The red dashed line is the average daily cost for the 4 highest (summer) months – $3,500/day. The blue dashed line is the average daily cost for the 6 lowest (winter) months – $840/day. The months of May and October have not been included in the summer or winter calculations as they are transitional months. The purple dashed line is the annual average daily cost ($1,900/day). As noted above, when compared to total water production, this is equivalent to a cost of $150/MG, or $270/MG of groundwater pumping.

Figure 3.4 compares the monthly well production values to the power costs for these facilities for 2008.

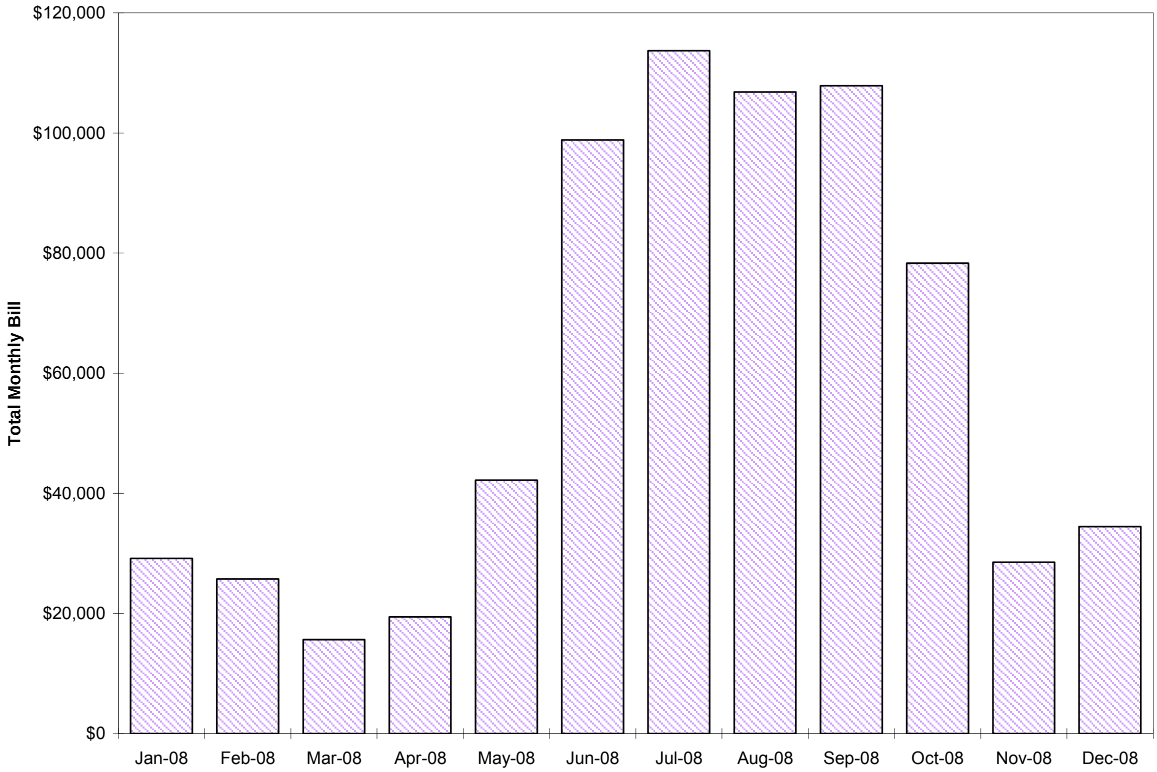


Figure 3.1 – Total monthly power costs for Bend facilities – 2008

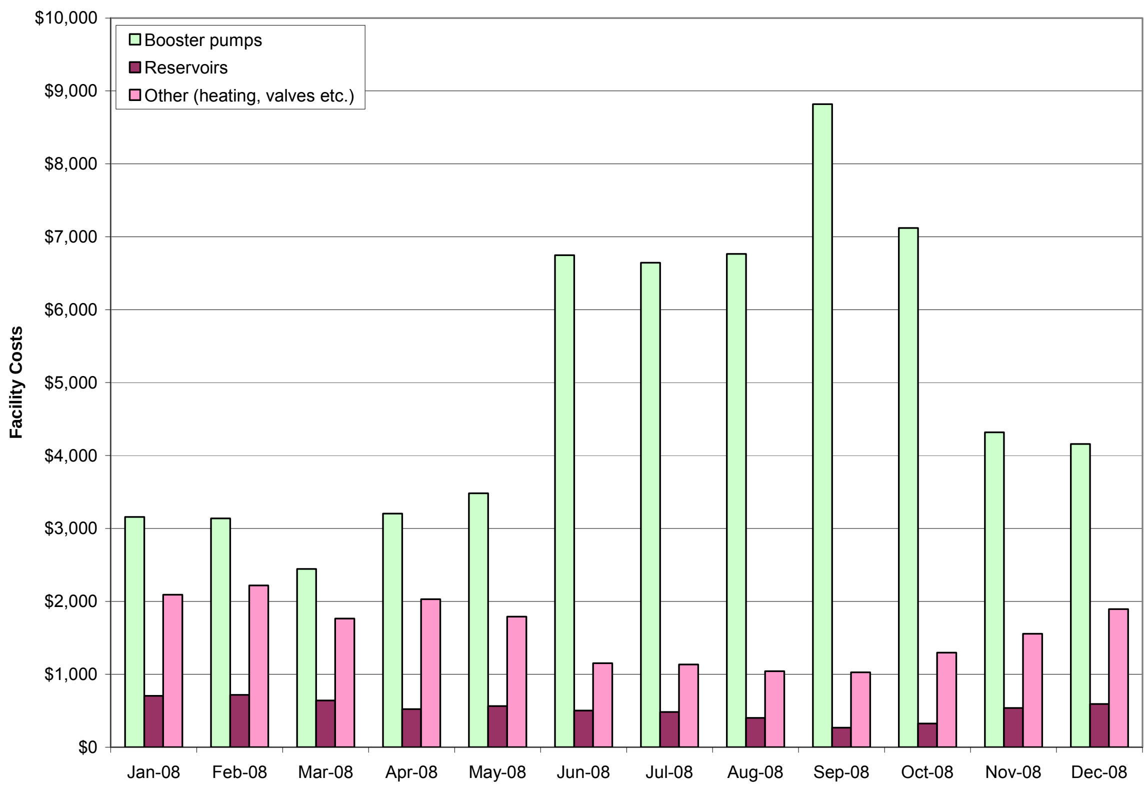


Figure 3.2 – Monthly power costs for booster pumps, reservoirs and other facilities – 2008

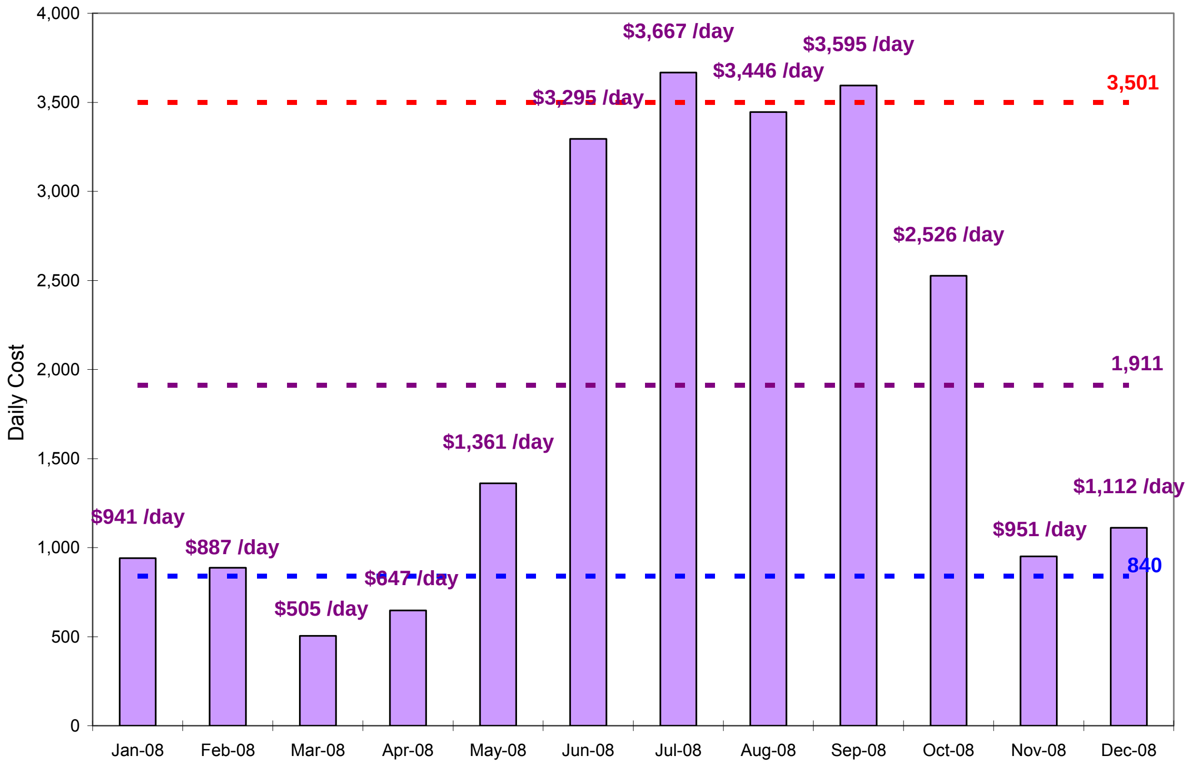


Figure 3.3 – System-wide power costs per day and winter, summer and annual averages – 2008

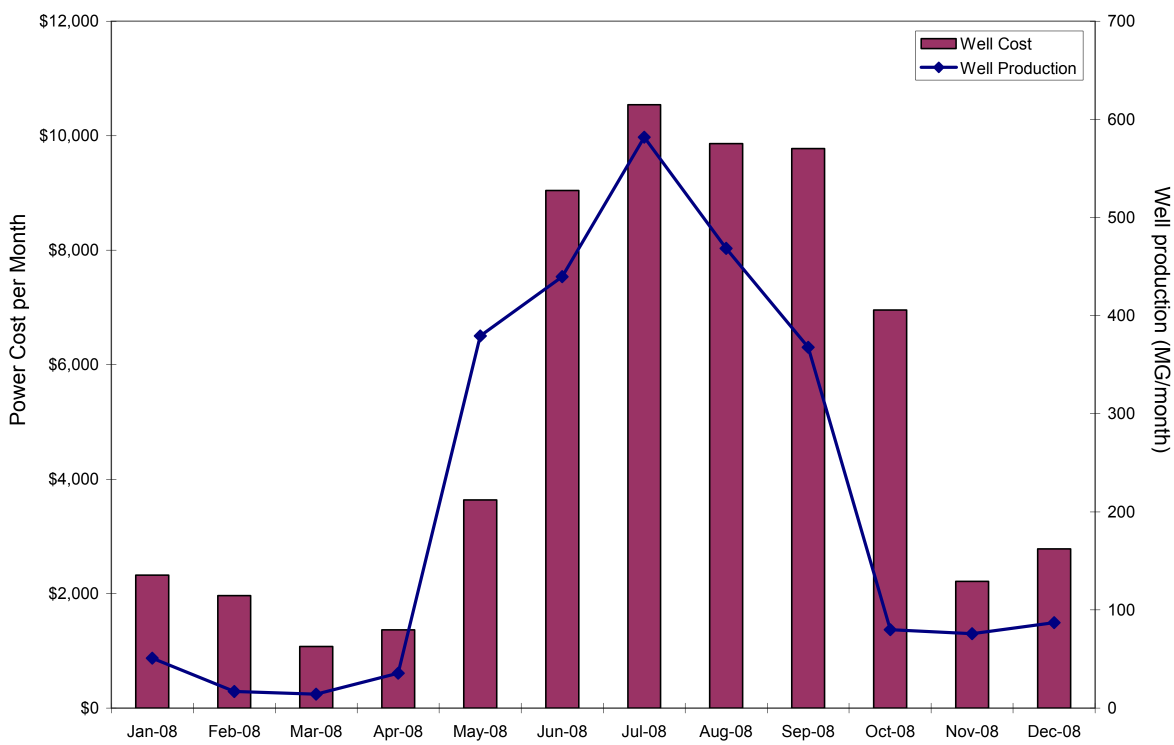


Figure 3.4 – Comparison of well production and associated power costs – 2008

3.2 Estimation of annual energy costs for summer and winter scenarios

Figure 3.3 allows us to estimate ratios that represent the relationship between energy costs from winter or summer demand situations and average annual costs.

Winter (Nov-May) power costs : Annual power costs = 840/1911 = 0.44
Summer (Jun-Sep) power costs : Annual power costs = 3501/1911 = 1.83

These ratios are very similar to the demand ratios calculated for these periods (Winter:ADD = 0.4; Summer:ADD = 1.85). When estimating the associated annual costs from the summer and winter scenarios, the ratios above were used to scale the costs to an average value.

3.3 Summer Baseline Scenario

Table 3.3 shows an estimation of the costs associated with the system operation as simulated in the calibrated summer EPS model. The system demand in this scenario is 23.45 MGD, or 16,300 gpm. The costs have been calculated based on the energy used by each pump, taking into account available information regarding pump efficiencies and tariff rate schedules for each pump.

Costs from the 48-hour simulation have been averaged to a 24-hour value. The daily cost of energy in this scenario is approximately $1,900. To scale this to an annual value, the summer energy factor of 1.83 was applied prior to multiplying by 365.

Table 3.3 – Baseline cost – summer energy costs

Facility	Daily Cost ($)	Annual Cost ($)[1]
AWBREY_P1	74.98	14,955
AWBREY_P2	10.55	2,104
AWBREY_P3	0.00	0
BEAR_CREEK_W1	206.02	41,091
BEAR_CREEK_W2	88.90	17,732
COLLEGE_P1	24.03	4,793
COLLEGE_P2	0.00	0
COPPERSTONE_W	215.65	43,012
HOLE_10_W1	129.04	25,738
HOLE_10_W2	0.00	0
MURPHY_P1	0.00	0
MURPHY_P2	0.00	0
MURPHY_P3	0.00	0
MURPHY_P4	0.00	0
MURPHY_P5	0.00	0
OUTBACK_W1	0.00	0
OUTBACK_W2	0.00	0
OUTBACK_W3	120.37	24,008
OUTBACK_W4	81.65	16,286
OUTBACK_W5	54.38	10,846
OUTBACK_W6	35.60	7,101
OUTBACK_W7	0.00	0
PILOT_BUTTE_W1	157.03	31,321
PILOT_BUTTE_W3	193.00	38,495
RIVER_W1	299.06	59,648
RIVER_W2	0.00	0
ROCK_BLUFF_W1	15.29	3,049
ROCK_BLUFF_W2	0.00	0
ROCK_BLUFF_W3	107.49	21,439
SCOTT_BP_1	3.66	731
SCOTT_BP_2	4.18	833
SCOTT_BP_3	2.60	519
SHILO3	0.00	0
TETHEROW_P1	0.00	0
TETHEROW_P2	0.00	0
TETHEROW_P3	0.00	0
TETHEROW_P4	0.00	0
TETHEROW_P5	0.00	0
TETHEROW_P6	0.00	0
WESTWOOD_COMB	25.77	5,141
WESTWOOD_W	45.72	9,120
Total	**1,894.98**	**377,961**

(1) Assuming that summer to annual energy ratio is 1.83. System demand is 23.45 MGD/6,300 gpm. Costs based on energy use from well and pump facilities only - $0.05/kWh

3.3.1 Hydraulic performance – summer

When comparing baseline scenarios to optimized solutions it is necessary to compare not only the cost but the hydraulic performance of the system in each solution. In addition to the locations with pressures below the 40-psi low pressure constraint noted in Table 2.4, the calibrated EPS model shows some model elements with pressure, storage level, or velocity conditions which fall outside the stated criteria (listed below). These elements were checked in the solutions from the optimization to ensure that the optimization results were no worse than the baseline model results.

- Pressures above 120 psi in some locations
- Pilot Butte 1 & 3 level dropping slightly over 48 hours
- Some pipes with velocity higher than 7 fps:
  - Mt. Washington Drive to Athletic Club – 9.5 fps in 12-inch section
  - Flow into Awbrey – 7.8 fps in 18-inch pipe
  - Zone 5 pipe from Pilot Butte 1 – 7.8 fps in 12-inch pipe
  - Piping near Bear Creek wells – up to 11 fps in section of 8-inch pipe

3.3.2 System Flows – summer

Figure 3.5 is a representation of the system under summer demand conditions, highlighting individual pressure zones and the transfer flows between them (average flow in gpm), either through pump stations or PRVs.

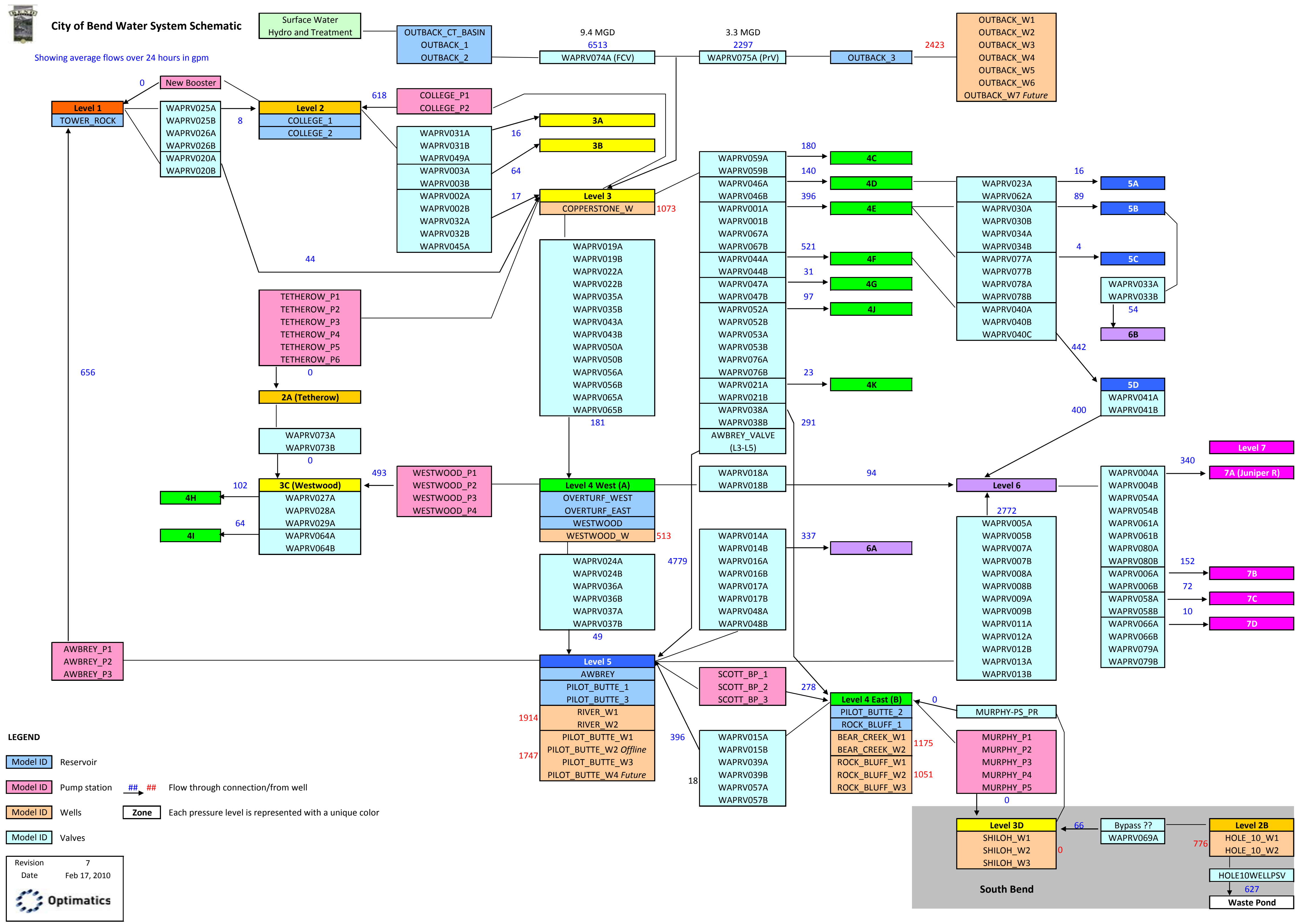


Figure 3.5 – Average flows in the Bend System – Calibrated EPS Summer Model

3.4 Winter Baseline Scenario

Table 3.4 shows an estimation of the costs associated with the system operation as simulated in the winter model. Demand in this model is 5.3 MGD or 3,700 gpm. Similar to the summer case, the costs from the 48-hour simulation have been scaled to represent an annual power cost. The daily cost of energy in this scenario is approximately $420. To scale this to an annual value, the winter energy factor of 0.44 was applied prior to multiplying by 365.

3.4.1 Hydraulic performance – winter

The hydraulic performance of the winter scenario is improved compared to the summer scenario in terms of minimum pressures and maximum velocities. However, there are a larger number of nodes experiencing pressures above 120 psi according to the model results. These nodes are located in Level 3. In addition, the following issues are noted:

- The Pilot Butte 1 & 3 Reservoirs sit full for most of the simulation which implies there is no turnover in these reservoirs.
- Outback 3 Reservoir also sits full. This storage is generally filled by the groundwater wells and only drains if the valve controlling flow from the surface water source cannot meet demand. It would be possible to route surface water through the tank in the winter to keep it fresh.

Compared to the summer scenario there is less pumping at the Awbrey, College and Westwood Pump Stations given the lower demands in the zones they supply. There is less pumping from groundwater wells, specifically Bear Creek and Outback, and no pumping from the Pilot Butte, River or Rock Bluff wells. In the model, the Scott Street Station does not operate (although SCADA showed it to be operating in the winter period).

Figure 3.6 shows a representation of the Bend system under winter demand conditions highlighting individual pressure zones and the average transfer flows (in gpm) between them, either through pump stations (in pink) or PRV connections (in blue).

Table 3.4 – Baseline cost – winter energy costs

Facility ID	Daily Cost ($)	Annual Cost ($)[1]
AWBREY_P1	2.59	2,145
AWBREY_P2	0.00	0
AWBREY_P3	0.00	0
BEAR_CREEK_W1	27.81	23,074
BEAR_CREEK_W2	0.00	0
COLLEGE_P1	1.60	1,325
COLLEGE_P2	0.00	0
COPPERSTONE_W	213.09	176,767
HOLE_10_W1	112.09	92,983
HOLE_10_W2	0.00	0
MURPHY_P1	0.00	0
MURPHY_P2	0.00	0
MURPHY_P3	0.00	0
MURPHY_P4	0.00	0
MURPHY_P5	0.00	0
OUTBACK_W1	0.00	0
OUTBACK_W2	13.50	11,203
OUTBACK_W3	8.77	7,272
OUTBACK_W4	0.00	0
OUTBACK_W5	0.00	0
OUTBACK_W6	0.00	0
OUTBACK_W7	0.00	0
PILOT_BUTTE_W1	0.00	0
PILOT_BUTTE_W3	0.00	0
RIVER_W1	0.00	0
RIVER_W2	0.00	0
ROCK_BLUFF_W1	0.00	0
ROCK_BLUFF_W2	0.00	0
ROCK_BLUFF_W3	40.26	33,400
SCOTT_BP_1	0.00	0
SCOTT_BP_2	0.00	0
SCOTT_BP_3	0.00	0
SHILO3	0.00	0
TETHEROW_P1	0.00	0
TETHEROW_P2	0.00	0
TETHEROW_P3	0.00	0
TETHEROW_P4	0.00	0
TETHEROW_P5	0.00	0
TETHEROW_P6	0.00	0
WESTWOOD_COMB	2.69	2,235
WESTWOOD_W	0.00	0
Total	**422.40**	**350,402**

(1) Assuming that winter to annual energy ratio is 0.44. System demand is 5.3 MGD/3,700 gpm. Costs based on energy use from well and pump facilities only - $0.05/kWh

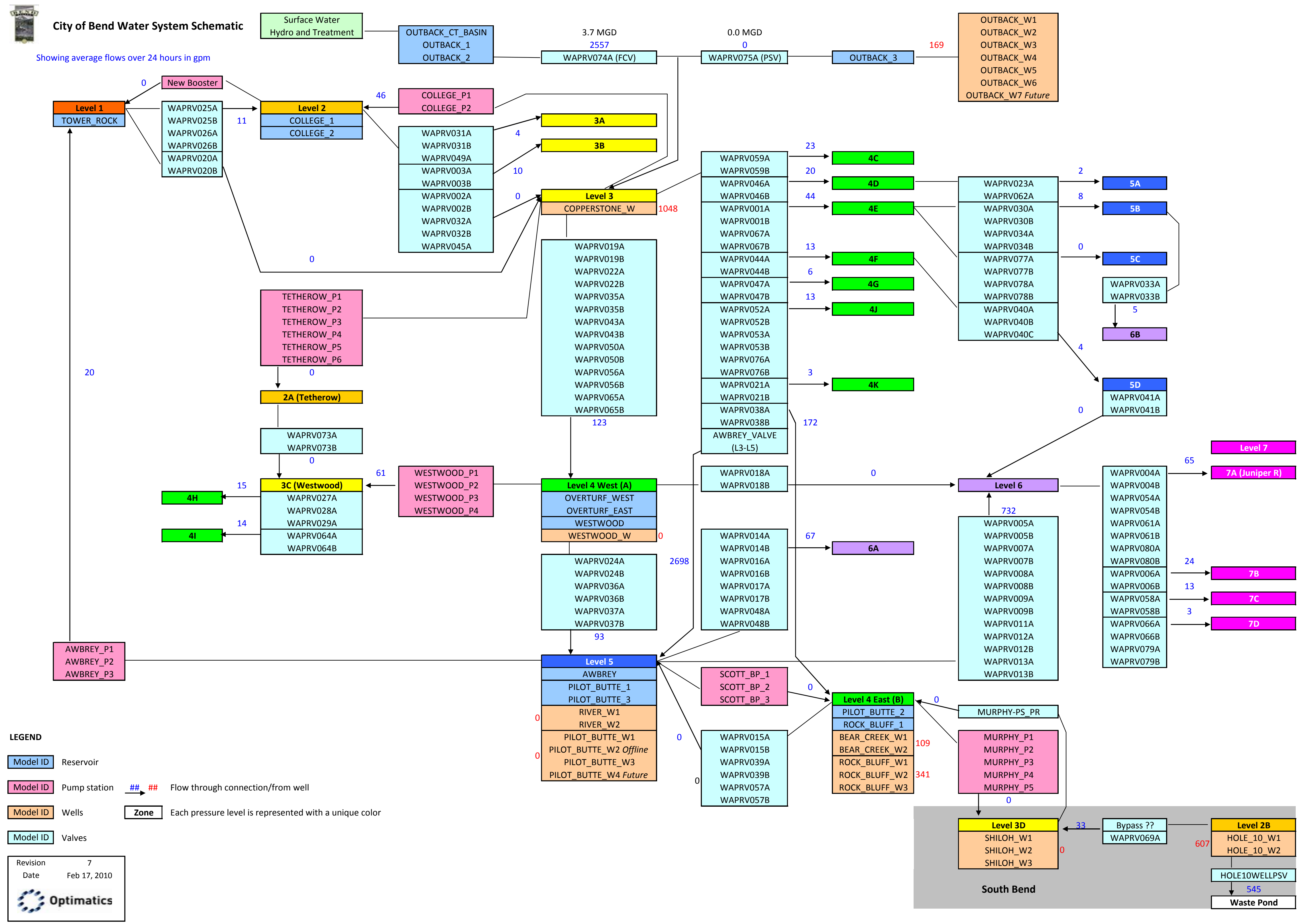


Figure 3.6 – Average flows in the Bend System – Current Winter EPS Model

3.5 Method to estimate power costs in the optimization

Comparing the total baseline energy costs in Table 3.3 (summer) and Table 3.4 (winter) to the annual cost from Table 3.2, it is apparent that energy costs account for approximately 50% of total annual power costs. In the optimization the energy cost value for each facility has thus been doubled to approximate the overall power costs.

In summary, the following calculations have been used in the optimization:

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

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

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

The cost of this energy requirement will then be: *Cost = E x Cost per kWh* ($0.05/kWh)

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

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

Where: *Annual energy ratio* = 1.83 for summer or 0.44 for winter

Factor to represent total power costs = 2

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

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

4 Optimization Results

4.1 Summer Demand Scenario

The summer optimization formulation was set up with options and constraints as described in Section 2. The optimization evaluates millions of different combinations of the decision options in the process of finding least-cost, hydraulically-feasible solutions. The main focus for the summer case was to reduce energy costs. Another aim in the summer scenario was to improve the recovery of the Pilot Butte Reservoir levels in Zone 5.

4.1.1 General trends

A large number of runs were completed for the summer scenario and the results have been reviewed to determine trends and common options selected in numerous optimized solutions. These are discussed below.

Zone consolidation

A number of the zone consolidation options were selected in the majority of the optimized summer solutions. Specifically the options to join Zone 4J into Zone 4A and Zone 4K into Level 3 were often selected. Combining Zone 4J into 4A increases flow into 4A and helps support the transfer of surface water to the east. Joining 4K into Level 3 requires individual customer PRVs to be implemented but opens up a second connection to the suction side of Tetherow Pump station, improving suction pressure.

The option to supply part of Zone 4I from Zone 4A or 4B was also selected frequently in the summer optimization runs, due to the fact that it reduces the demand off the Westwood Zone, minimizing the pumping requirement at Westwood PS.

Some solutions selected the option to include Zone 4G in Zone 4A although there was no significant hydraulic or cost incentive for this option.

The option to combine the Westwood Zone into Level 3 was chosen in some solutions, however, without some additional major upgrades this does not appear to be feasible due to the potential for low pressures to occur during peak hour demand periods. This area of the system is primarily residential with an associated high peak hour demand. With limited transmission capacity through Level 3 to the Westwood area, pressure fluctuations over the day are significant and pressures would drop below 40 psi during some hours. In the Build-out Optimization, Optimatics will look at strengthening this area to facilitate the elimination of the Westwood facility as the primary source of supply for the Westwood Zone.

Major transmission and supply decisions

All solutions selected the option of reducing flow into Awbrey Reservoir to some extent, particularly during periods of high system demand. This results in a wider operating range for this tank, in some cases up to 7 ft. In instances where the level in this storage dropped below 15 ft in the simulations, it was necessary to raise the PRV settings on the western side of Level 5 in order to maintain pressure at higher elevation nodes in this zone. Figure 4.1 shows the flow into Awbrey Reservoir in one of the optimized solutions and Figure 4.2 shows the resulting tank level over a 48-hour period.

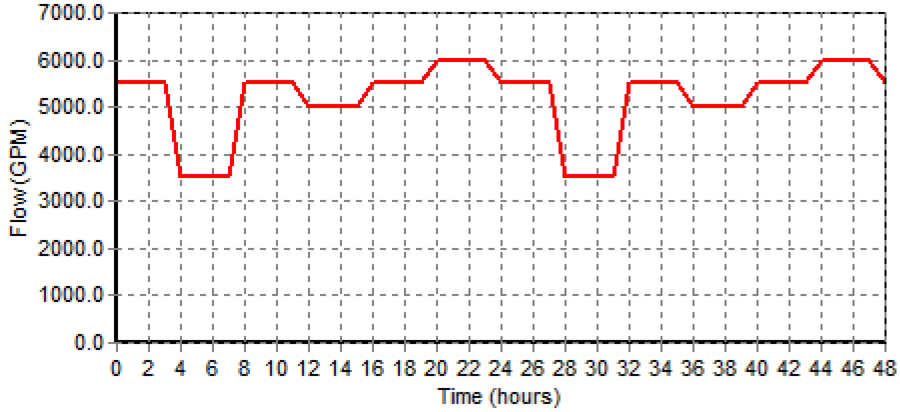


Figure 4.1 – Flow into Awbrey Reservoir reduced during the day and increased overnight – Optimized Summer Solution

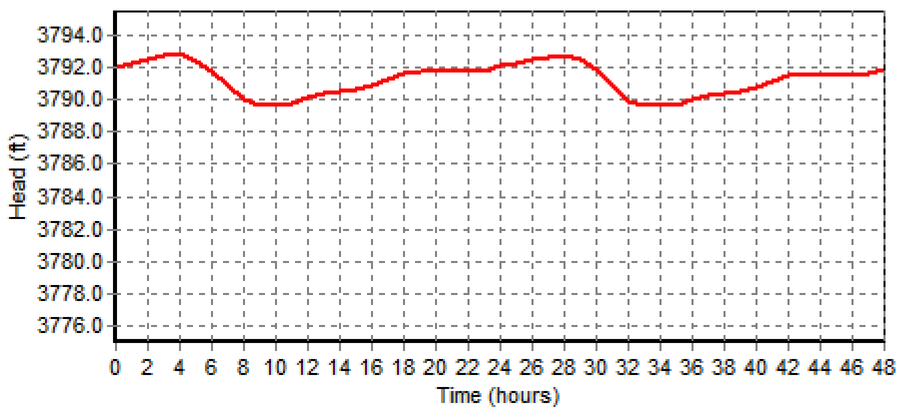


Figure 4.2 – Resulting water level in Awbrey Reservoir – Optimized Summer Solution

Reducing flow to Awbrey Reservoir during peak hour allows the Athletic Club PRV to be opened further and transmit more flow eastward to Zone 4B, making better use of surface water supply. This modification was seen in all optimized solutions. As a result of this increase in surface flow, there is less pumping needed at the Rock Bluff and Bear Creek Wells. In most cases there was increased use of the Scott Street pump station to lift water from Level 5 to Zone 4B. This pump station has a lower head requirement compared to the wells and therefore incurs lower energy cost.

When the Scott Street station is brought online there is an increase in flow through PRV Station 15 which supports the eastern portion of Level 5, east of Pilot Butte. Although in some respects this represents 'pumping and dumping' behavior, the area east of Pilot Butte has few connections to the rest of Level 5; there are only two connections north of Pilot Butte, one 16-inch diameter main along Neff Road, and an 8-inch diameter main between Pheasant Lane and Cliff Drive. As such, this area could be considered a separate zone and there is unlikely to be recirculation of flow from PRV 15 back to the Scott Street station.

Awbrey Butte

The options to implement a new Level 2 to Level 1 booster pump were rarely selected by the optimization. Under the summer demand scenario the small 15 HP option at Starview is not sufficient to maintain the Tower Rock Reservoir and thus the Awbrey Pump Station must operate so the savings in energy costs are minimal. There are also issues with the new pump adversely affecting pressure in Level 2, particularly near in the intersection of Farewell Drive and Summit Drive. (Note that Bend could possibly modify the zone boundaries and have these customers served from Level 1.)

The option of a pump station at College 2 Reservoir was never selected in early solutions. Hydraulic modeling of this option showed that the pump station has a detrimental effect on the level in the storage particularly if trying to supply all of Level 1 demand from Level 2. The controls for the existing College PS are based on the level in College 1 Reservoir and as a result the pumps do not respond to the dropping level in the College 2 Reservoir. Switching controls for one of the pumps to be based on the level in College 2 still did not allow the storage to recover.

Pilot Butte Reservoirs

As mentioned above, one aim of the summer optimization was to maintain the level in the Pilot Butte Reservoirs in Level 5. Figure 4.3 shows the levels in these storages in the calibrated EPS model and Figure 4.4 shows the level in one of the optimized summer solutions over a 96-hour period. There are slight differences in how the reservoir levels change over a 24-hour period, but the overall levels are similar. Over this time period it can be seen that there is no significant loss of volume in either scenario.

The hydraulic grade in the zone at this location is lower that on the western side of the zone, indicating some restrictions in the system. Observation of the hydraulic model indicates a restriction at the Pilot Butte 1 reservoir site. A 12-inch main experiences high headloss under peak demand conditions. This is the reason for the two storages operating at different levels (confirmed by SCADA). The Build-out Optimization will aim to address this system deficiency.

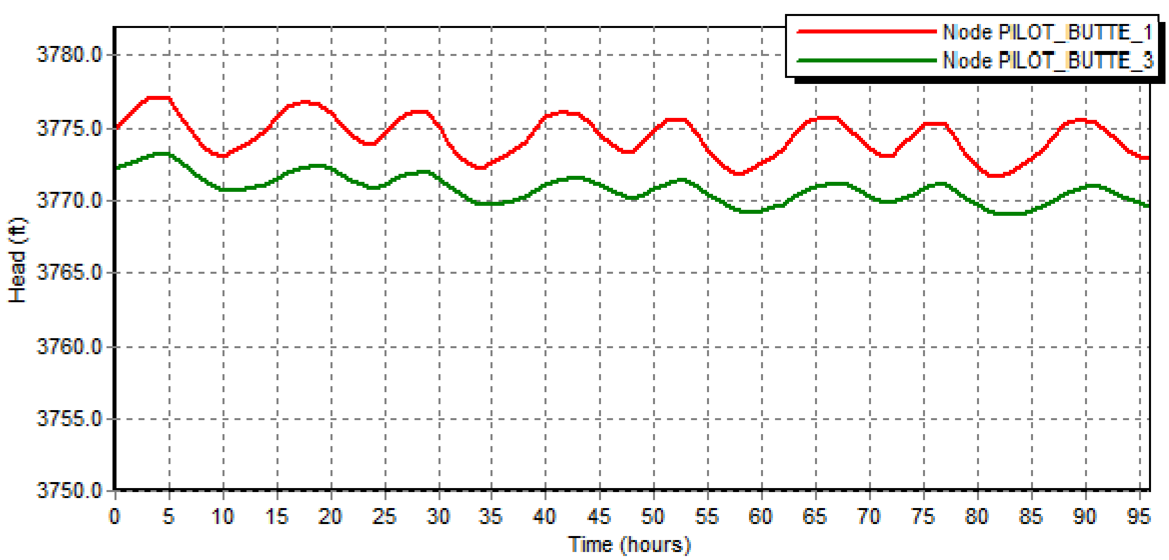


Figure 4.3 – Level in Pilot Butte Reservoirs – Calibrated EPS Model

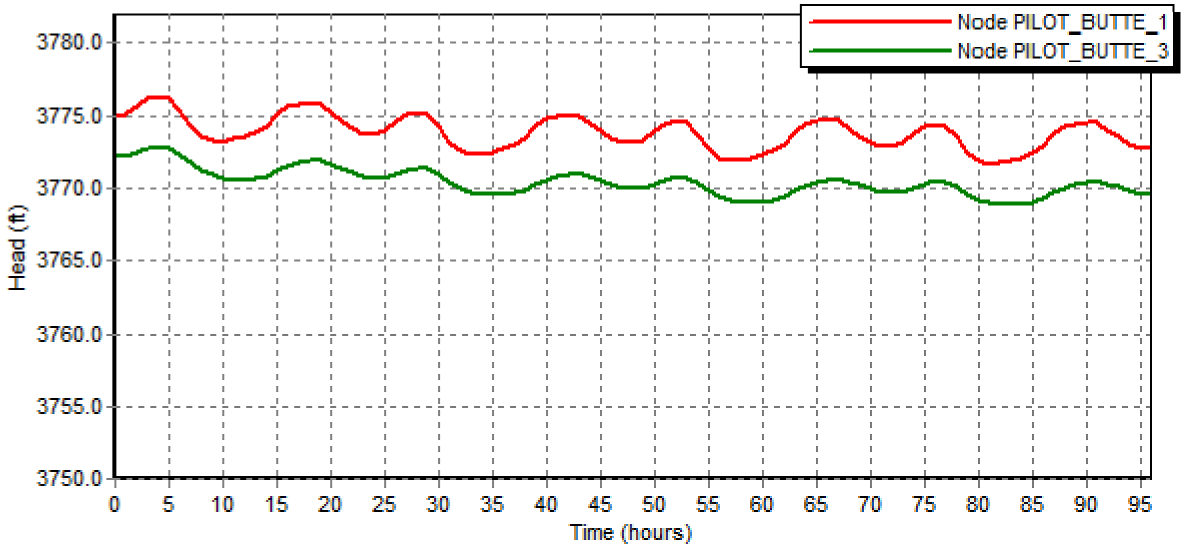


Figure 4.4 – Level in Pilot Butte Reservoirs – Optimized Summer Solution

River Wells

In all of the early solutions it was noted that the River Wells were operating. Given the discussions in the August meetings about these wells, Optimatics set up a new optimization formulation without the option to use these wells. The resulting solutions provided insight into the benefits that the wells provide to the system, but also show how the system can operate without them.

In the final optimization runs two alternative low cost solutions were found and are described below. The energy costs of each solution are very similar; however, one does not involve the River Wells and instead there is more groundwater supplied by the wells at Outback. Other wells supplying higher flows are the Pilot Butte Wells, Bear Creek Wells and Rock Bluff Wells.

There are a number of implications if the River Wells are not in operation. The primary repercussion is increased flow volume in the transmission mains from Outback which results in higher losses and slightly lower pressures in Level 3. The lower pressure in Level 3 causes some of the PRVs between Levels 1, 2, and Level 3 to open up (PRV 02 near College PS and PRV 20 near Awbrey), causing some inefficiency. It is possible the settings of these valves could be reduced to prevent flow, although this may cause even lower pressure in Level 3.

Compared to solutions with the River Wells operating, there is slightly higher flow through Athletic Club PRV to Zone 4B and also through PRV 15 to the eastern side of Pilot Butte (Zone 4B to Level 5). There is also more flow through the Zone 4A valves to Level 5.

4.2 Optimized Summer Solutions

To provide more detail on the final results, two specific solutions are described in this section. The first, Summer Strategy #1, has the River Wells operating, the second, Summer Strategy #2, does not.

4.2.1 Estimated energy costs

Table 4.1 lists the estimated energy costs calculated for the two final Summer Strategies. The cost differences described above with respect to whether or not the River Wells are operating are highlighted in the final column. It is recommended that Strategy #2, without the River Wells in operation, be viewed as a short-term strategy. This operation is not recommended long-term as it puts stress on Level 3, evidenced by lower pressures in this zone in the hydraulic model. Strategy #1, with River Wells operating with on SCADA, would represent a long-term strategy.

Table 4.1 – Estimated energy costs – Optimized Summer Strategies #1 & #2

ID	Strategy #1 – River Wells on SCADA – Long-term		Strategy #2 –River Wells not operating – Short-term		Annual Cost Difference (#1 - #2)
	Daily Cost ($)	Annual Cost ($)	Daily Cost ($)	Annual Cost ($)	
AWBREY_P1	78	15,483	75	14,964	-1,584
AWBREY_P2	0	0	11	2,103	
AWBREY_P3	0	0	0	0	
BEAR_CREEK_W1	78	15,561	95	18,897	-6,470
BEAR_CREEK_W2	73	14,610	89	17,744	
COLLEGE_P1	22	4,445	24	4,867	-423
COLLEGE_P2	0	0	0	0	
COPPERSTONE_W	0	0	0	0	0
HOLE_10_W1	129	25,738	129	25,738	0
HOLE_10_W2	0	0	0	0	
MURPHY_P1	0	0	0	0	0
MURPHY_P2	0	0	0	0	
MURPHY_P3	0	0	0	0	
MURPHY_P4	0	0	0	0	
MURPHY_P5	0	0	0	0	
OUTBACK_W1	0	0	0	0	-32,519
OUTBACK_W2	0	0	0	0	
OUTBACK_W3	140	27,948	140	27,952	
OUTBACK_W4	120	23,990	144	28,806	
OUTBACK_W5	52	10,375	120	23,868	
OUTBACK_W6	0	0	71	14,207	
OUTBACK_W7	0	0	0	0	
PILOT_BUTTE_W1	157	31,361	157	31,338	-4,795
PILOT_BUTTE_W3	169	33,620	193	38,438	
RIVER_W1	125	24,981	0	0	51,453
RIVER_W2	133	26,472	0	0	
ROCK_BLUFF_W1	12	2,368	14	2,713	-2,133
ROCK_BLUFF_W2	0	0	0	0	
ROCK_BLUFF_W3	85	16,985	94	18,774	

ID	Strategy #1 – River Wells on SCADA – Long-term		Strategy #2 –River Wells not operating – Short-term		Annual Cost Difference (#1 - #2)
	Daily Cost ($)	Annual Cost ($)	Daily Cost ($)	Annual Cost ($)	
SCOTT_BP_1	4	718	4	839	-2,113
SCOTT_BP_2	7	1,354	18	3,530	
SCOTT_BP_3	4	712	3	528	
SHILO3	0	0	0	0	0
TETHEROW_P1	0	0	0	0	0
TETHEROW_P2	0	0	0	0	
TETHEROW_P3	0	0	0	0	
TETHEROW_P4	0	0	0	0	
TETHEROW_P5	0	0	0	0	
TETHEROW_P6	0	0	0	0	
WESTWOOD_W	46	9,098	46	9,086	12
WESTWOOD_COMB	25	4,930	25	4,948	-18
Total	**1,458**	**290,749**	**1,451**	**289,339**	**1,410**
% Savings compared to Baseline Scenario ($1,895/$377,961)		**23%**		**23%**	

(1) Costs represent estimated annual energy costs for key water facilities only using $0.05/kWh. Not included are other power costs such as demand charges/load size charges. Also costs do not include costs associated with reservoirs, valve stations, buildings, disinfection, etc.

4.2.2 Energy cost savings

Both of the Summer Strategies result in energy cost savings compared to the Baseline Summer Scenario. There is a reduction in the estimated energy costs of approximately 23%. Major areas of savings include (1) not running the Copperstone Well, and (2) reduced pumping at Bear Creek Wells, Pilot Butte Wells and Rock Bluff Wells due to increased flow through the Athletic Club PRV and Scott Street Pump Station.

4.2.3 Location and cost of new infrastructure

In contrast to the solutions presented in the December 2009 meeting, there is very little capital infrastructure recommended as part of either Summer Strategy. Both of the solutions include the option to join Zone 4K into Level 3 which has an associated cost of approximately $50,000 to add PRVs to customer connections. This is approximately half the cost of a new pipe connection in Level 3 (Flagline Court/Green Lakes Loop). None of the solutions produced from the final optimization runs included the pump options from Level 2 to Level 1.

4.2.4 Reservoir levels

Tank levels over the 48-hour period for both Summer Strategies are provided in Appendix D. In both of the Summer Strategies there are some distinct changes in tank levels over the simulated 48-hour period compared to the Baseline Summer Scenario. Due to the modification of flow into Awbrey Reservoir there are changes to the levels in the Outback tanks and the Awbrey Reservoir. At the Outback tanks there is little change in the operating range shown in the Baseline Summer Scenario and Summer Strategies; however, the way the level changes over the day is different. At Awbrey, the operating range is increased, from 2 ft in the Baseline Scenario to 7 ft in Summer Strategy #1 (River Wells on SCADA) and 5 ft in Summer Strategy #2 (no River Wells).

4.2.5 Constraint violations

In both optimized Summer Strategies a small low pressure violation occurs at a customer connection near Pilot Butte Reservoir 1. Bend has advised that this area may be transferred to Zone 4B in the future since customer complaints have been received from this area in the past.

4.2.6 Flow from Outback

Options which modify well operation and flow into major storages improve the capacity to incorporate supply from the Outback facility. Increasing supply from this facility allows Bend to maximize the use of surface water in the system. Figure 4.5 and Figure 4.6 compare flow from the Outback facility in the Baseline Summer Scenario and the optimized Summer Strategies. It can clearly be seen how the optimized Strategies show a more even output of flow from Outback and through the Athletic Club PRV, with reduced peaks and overall higher average output from Outback than the Baseline scenario.

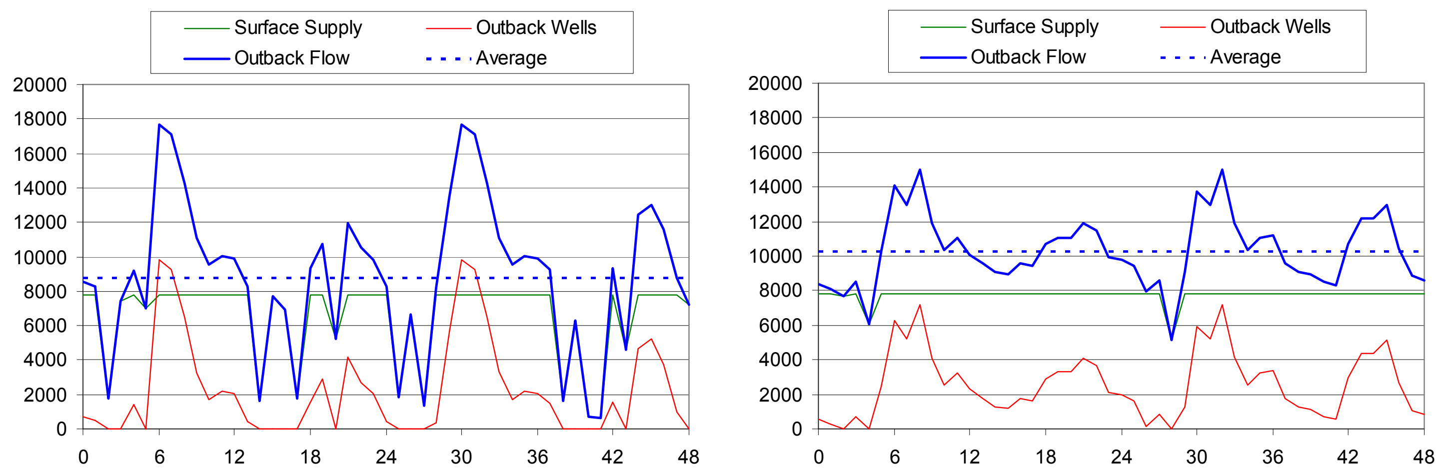


Figure 4.5 – Flow from Outback – Baseline on left, Optimized Summer Strategy #1 on right

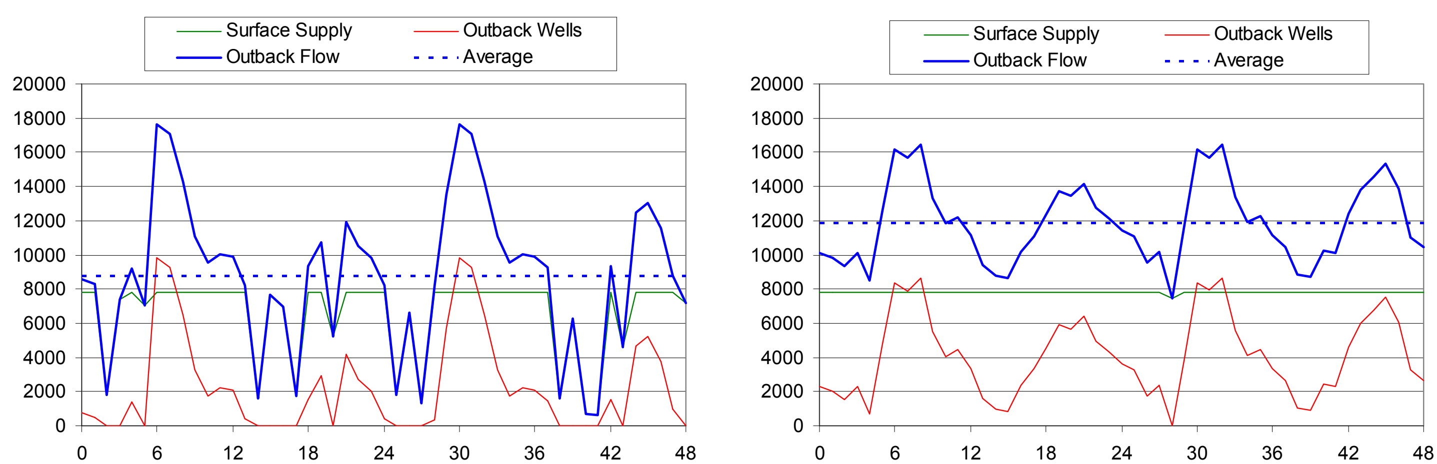


Figure 4.6 – Flow from Outback – Baseline on left, Optimized Summer Strategy #2 on right

The reason for the higher average output from the Outback facility in Summer Strategy #2 compared to Strategy #1 is the higher Outback Well output required to make up for the River Wells not being in operation.

4.2.7 System flows

Figure 4.7 and Figure 4.8 show the system schematic and major flows in both summer solutions. Flow values highlighted in yellow represent an increase compared to the Baseline Summer Scenario. Flow values highlighted in blue represent a decrease compared to the Baseline Summer Scenario.

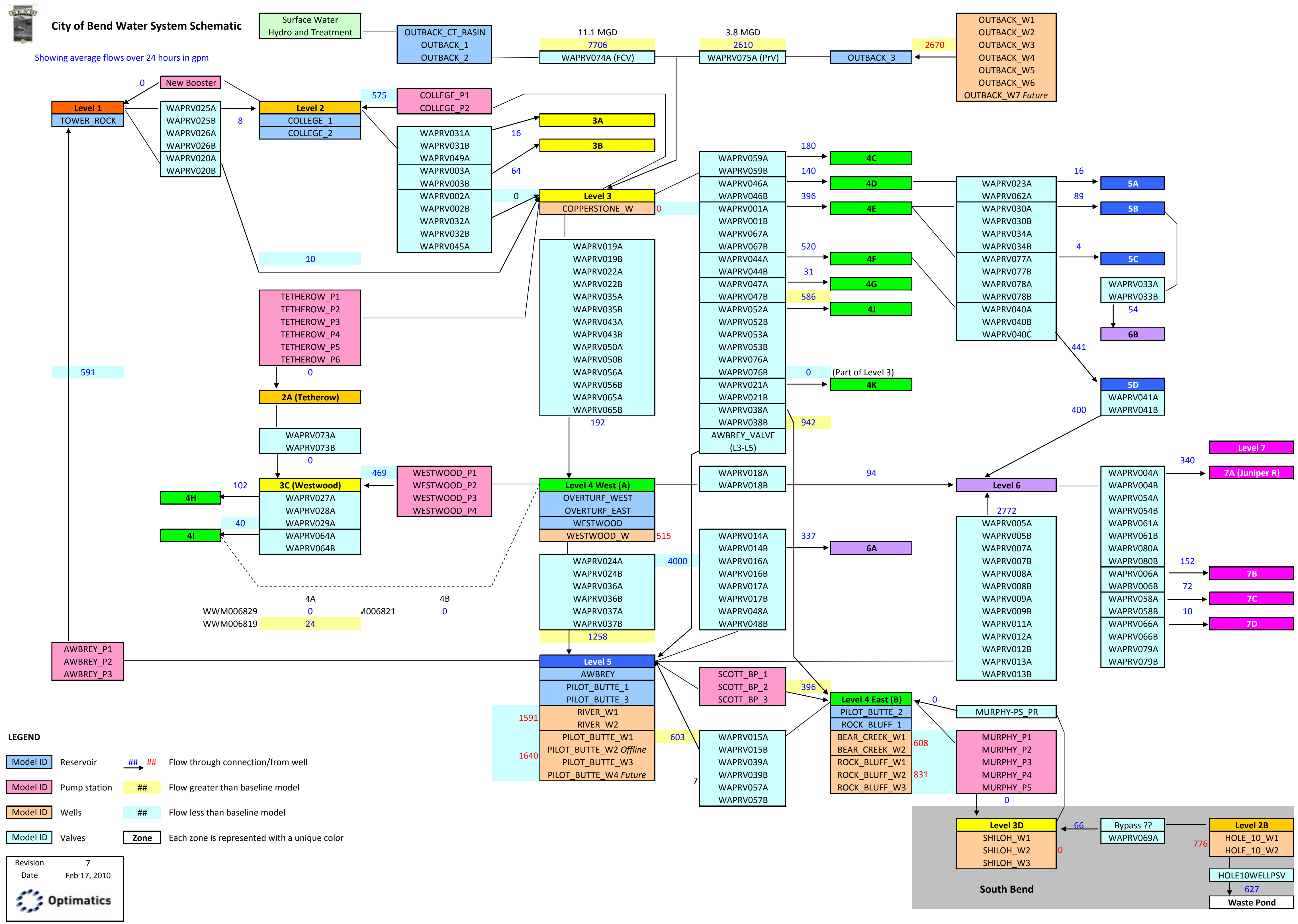


Figure 4.7 – Average flows (in gpm) in the Bend System – Optimized Summer Strategy #1 – River Wells Operating on SCADA – Long-term

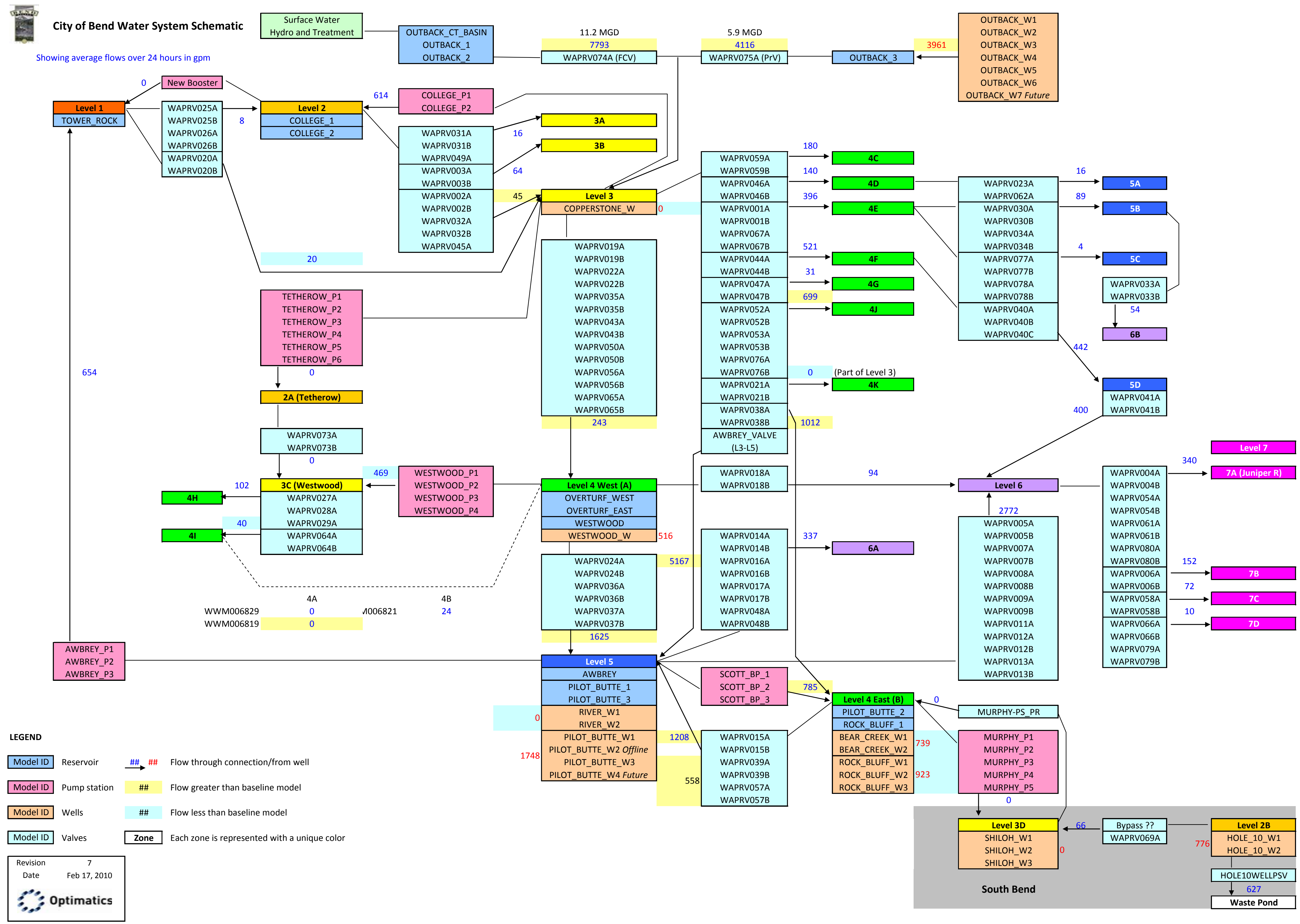


Figure 4.8 – Average flows (in gpm) in the Bend System – Optimized Summer Strategy #2 – River Wells not operating – Short-term

4.3 Winter Demand Scenario

The winter optimization formulation was set up in a similar way to the summer formulation, with some minor differences in the decision options and constraints as described in Section 2. A major aim was to determine ways in which to improve reservoir turnover at Pilot Butte. The optimization was also working to reduce energy costs.

4.3.1 General trends

Again, from the various runs undertaken for the winter scenario, a number of general observations can be made.

Zone boundary modifications

Similar to the Summer Demand Scenario, the option to connect Zone 4J into Zone 4A was selected in many of the Optimized Winter solutions. Unlike the summer scenario, the option of connecting Westwood into Level 3 is feasible under this lower demand condition. This option was selected quite often due to the reduced power costs associated with this configuration (Westwood is then supplied by gravity). In addition, the option to connect Zone 4I into Zone 4A or 4B was also commonly selected.

Transmission and supply options

In the winter optimization runs the Starview pump station option was selected in a number of solutions. Under the lower demand condition the entire Level 1 demand can be supplied from this pump station with little impact on Level 2. This avoids the need to use Awbrey Pump Station altogether under lower demand conditions and hence reduces overall energy costs. However the cost of the new pump station is approximately $450,000, so this did not form part of the final recommendations for improving operations in the short term.

The choice of the Starview location conflicts with the tendency of the optimization to select a pump station at College 2 Reservoir in the summer scenario. For the winter scenario the impact on Level 2 pressures is minimal, making the Starview option feasible. Since Starview does not require new piping it is a less expensive option for a new pump station compared to the College Reservoir location. If Bend were to implement a Level 2 to Level 1 pump station, however, the College 2 site would achieve the same reduction in energy costs at a small increase in capital cost with the added reliability of the reservoir as a buffer for Level 2.

Similar to the summer scenario, the Optimized Winter Solution selected options to reduce flow into Awbrey Reservoir during the day, allowing higher flows through the Athletic Club PRV to Zone 4B and a subsequent reduction in pumping from wells to maintain storage levels in the east. Overturf Reservoir level does not drop enough to open up the connection to the pipes from Outback; it simply floats on Zone 4A. Pilot Butte II and Rock Bluff Reservoirs operate in a similar manner since the wells in Zone 4B do not operate.

Figure 4.9 shows the flow into Awbrey Reservoir in one of the optimized solutions and Figure 4.10 shows the resulting tank level over a 48-hour period.

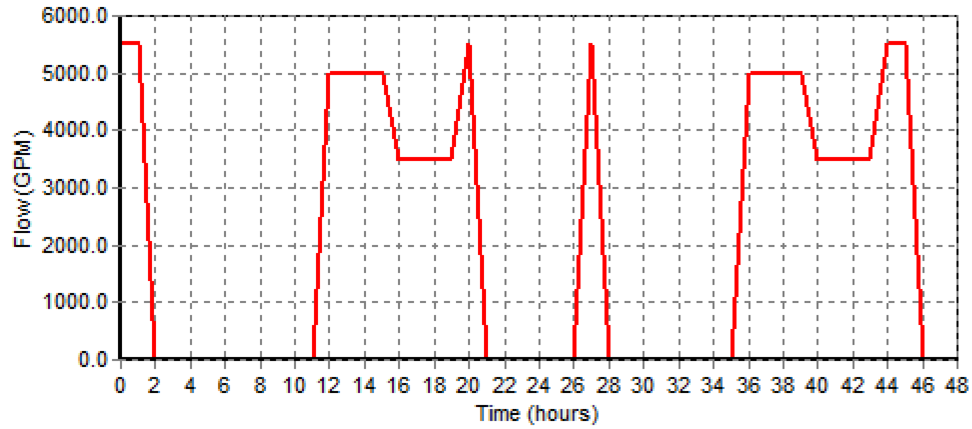


Figure 4.9 – Flow into Awbrey Reservoir reduced during the day and increased in the evening – Optimized Winter Solution

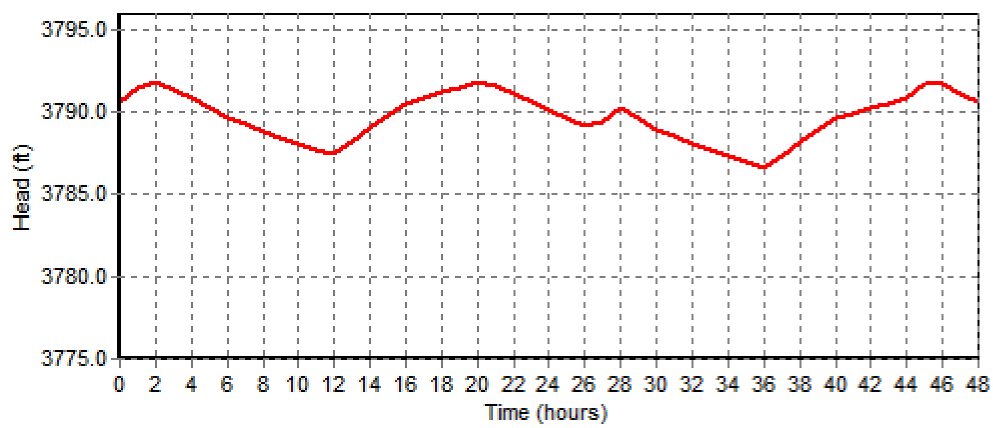


Figure 4.10 – Resulting level in Awbrey Reservoir – Optimized Winter Solution

Turnover at Pilot Butte Reservoirs 1 & 3

Initial optimized solutions struggled to get the desired turnover in Pilot Butte Reservoirs 1 & 3 despite use of the Scott Street Pump Station and no well pumping on the east side of the system. As a result, Optimatics introduced a number of new valve options within Level 5 to restrict flow from Awbrey and encourage greater use of Pilot Butte Reservoirs 1 & 3. A number of options were tested with the hydraulic model. The first was to throttle flow out of the Awbrey reservoir on site. The model results showed that simply throttling flow from the reservoir did not have a significant impact on Pilot Butte reservoir water levels. Closing the outlet completely for a period of time resulted in unacceptably low pressure on the west side of Level 5.

Next, the idea of implementing valves within the zone to encourage greater use of the Pilot Butte Reservoirs was investigated. There are five connections that cross the Deschutes River in Level 5 and these represent the most logical locations to reduce west-to-east transmission capacity in Level 5. Three major connections are located close to the Awbrey Reservoir – an 18-inch diameter main at Portland, a 16-inch diameter main at Newport and a 16-inch diameter main at Nashville/Louisiana. The other two connections are 12-inch and 16-inch diameter mains further south (Galveston and State Hwy 372) near the River Wells (see Figure 4.11).

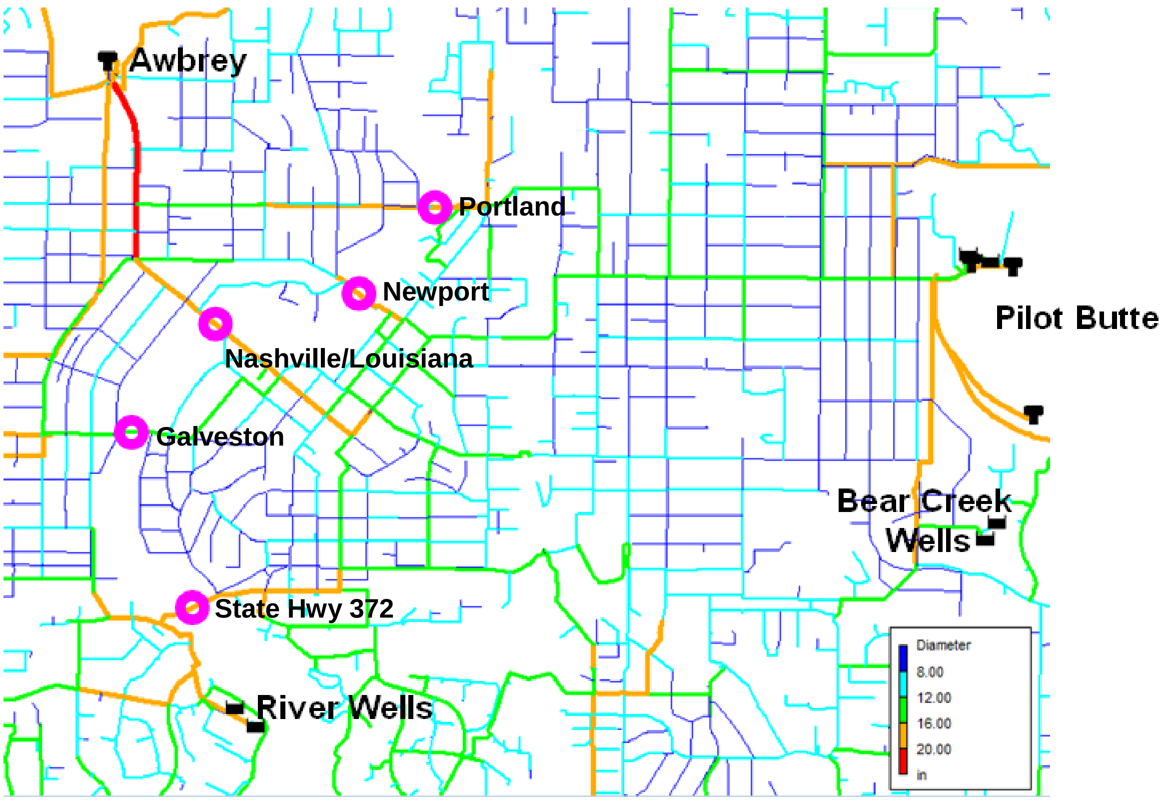


Figure 4.11 – Location of Deschutes River Crossings in Level 5

Optimatics looked at the impact of closing off the northern three connections and found that this resulted in much more dramatic changes in the levels of the Pilot Butte Reservoirs. Closing these connections forces much of the Level 5, 6 and 7 demands to be met from the Pilot Butte Reservoirs, significantly improving drawdown over the day. Given this result, the option to close these connections for all or part of a 24-hour period was added to the optimization formulation.

Final runs with these options in place resulted in different combinations and timing of the pipe connections to close. All of the solutions resulted in a 3- to 4-ft drop in the level of the Pilot Butte Reservoirs over a two-day period.

A side effect of restricting flow from Awbrey Reservoir to Level 5 is the reduced need for flow from Outback to Awbrey. This in turn leaves more supply available to pass through the Athletic Club PRV to supply Zone 4B, reducing the need to pump supply to the east of the system.

It should also be noted that, once the South Bend area is reconfigured it is understood that the Murphy Pump Station would be used to supply South Bend in the winter. As a result, there will likely be additional demand in the east of the system which may allow for improved turnover in the Pilot Butte Reservoirs.

4.4 Optimized Winter Solution

To provide more detail on the Optimized Winter Solutions, the results of the most promising solution are presented below.

4.4.1 Estimated energy costs

Table 4.2 lists estimated energy costs calculated for the Optimized Winter Solution. There is very little groundwater or booster pumping; the system is almost entirely supplied by surface water.

Table 4.2 – Estimated energy costs – Optimized Winter Solution

ID	Daily Cost ($)	Annual Cost ($)
AWBREY_P1	3	2,147
AWBREY_P2	0	0
AWBREY_P3	0	0
BEAR_CREEK_W1	0	0
BEAR_CREEK_W2	0	0
COLLEGE_P1	2	1,381
COLLEGE_P2	0	0
COPPERSTONE_W	0	0
HOLE_10_W1	111	91,675
HOLE_10_W2	0	0
MURPHY_P1	0	0
MURPHY_P2	0	0
MURPHY_P3	0	0
MURPHY_P4	0	0
MURPHY_P5	0	0
OUTBACK_W1	0	0
OUTBACK_W2	16	13,072
OUTBACK_W3	9	7,272
OUTBACK_W4	0	0
OUTBACK_W5	0	0
OUTBACK_W6	0	0
OUTBACK_W7	0	0
PILOT_BUTTE_W1	0	0
PILOT_BUTTE_W3	0	0
RIVER_W1	0	0
RIVER_W2	0	0
ROCK_BLUFF_W1	0	0
ROCK_BLUFF_W2	0	0
ROCK_BLUFF_W3	0	0
SCOTT_BP_1	0	0
SCOTT_BP_2	0	0
SCOTT_BP_3	0	0
SHILO3	0	0

ID	Daily Cost ($)	Annual Cost ($)
TETHEROW_P1	0	0
TETHEROW_P2	0	0
TETHEROW_P3	0	0
TETHEROW_P4	0	0
TETHEROW_P5	0	0
TETHEROW_P6	0	0
WESTWOOD_W	0	0
WESTWOOD_COMB	0	0
Total Cost	**139**	**115,546**
% Savings compared to Baseline Scenario ($422/$350,402)		**67%**

(1) Costs represent estimated annual energy costs for key water facilities only - $0.05/kWh. Does not include other power costs such as demand charges/load size charges. Does not include costs associated with reservoirs, valve stations, buildings, disinfection etc.

4.4.2 Energy cost savings

The energy costs in the Optimized Winter Solution are significantly lower than the Baseline Winter Scenario; a 67% reduction. Reasons for the reduced costs include:

- Increased surface supply allows the system to operate without the Copperstone Well, Rock Bluff Wells, and Bear Creek Wells, all of which are operating in the Baseline Winter Scenario. Scott Street Pump station is also not needed to support Pilot Butte 2 and Rock Bluff Reservoirs.
- Allowing Westwood to be supplied from Level 3 reduces pumping costs for this area. Changing the supply scheme to the Westwood zone reduces the operating range of the Westwood Reservoir. As a result the Westwood Well does not operate to fill the reservoir.

4.4.3 Flow from Outback

Figure 4.12 compares flow from the Outback facility in the Baseline Winter Scenario and the Optimized Winter Solution. The flow pattern for the optimized solution has greater peaks and valleys compared to the baseline solution, mostly due to the fact that the Awbrey Reservoir does not fill during the morning hours. Overall, there is a higher average output from Outback in the optimized solution.

4.4.4 Location and cost of new infrastructure

In terms of new infrastructure, there are three new pipe connections in the Optimized Winter Solution which facilitate supply of Westwood from Level 3 (see Figure 4.13). The estimated cost of these connections is $206,000. It should be noted, however, that options for modifying the supply to Westwood will be investigated further in the Build-out Optimization runs, which may impact the current recommendations in this area.

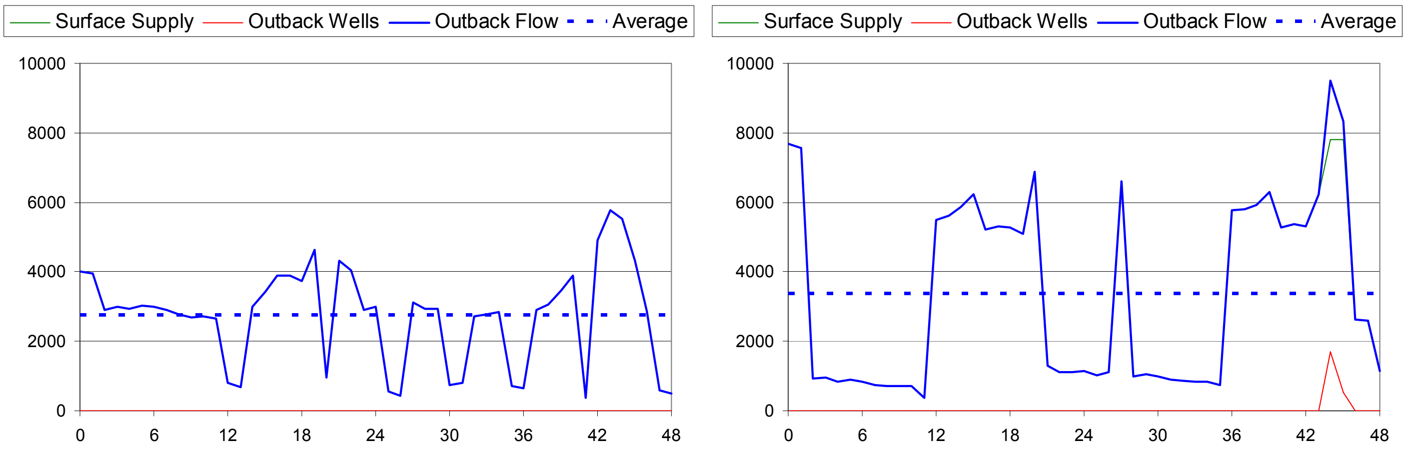


Figure 4.12 - Flow from Outback – Baseline scenario on left, Optimized Winter Solution on right

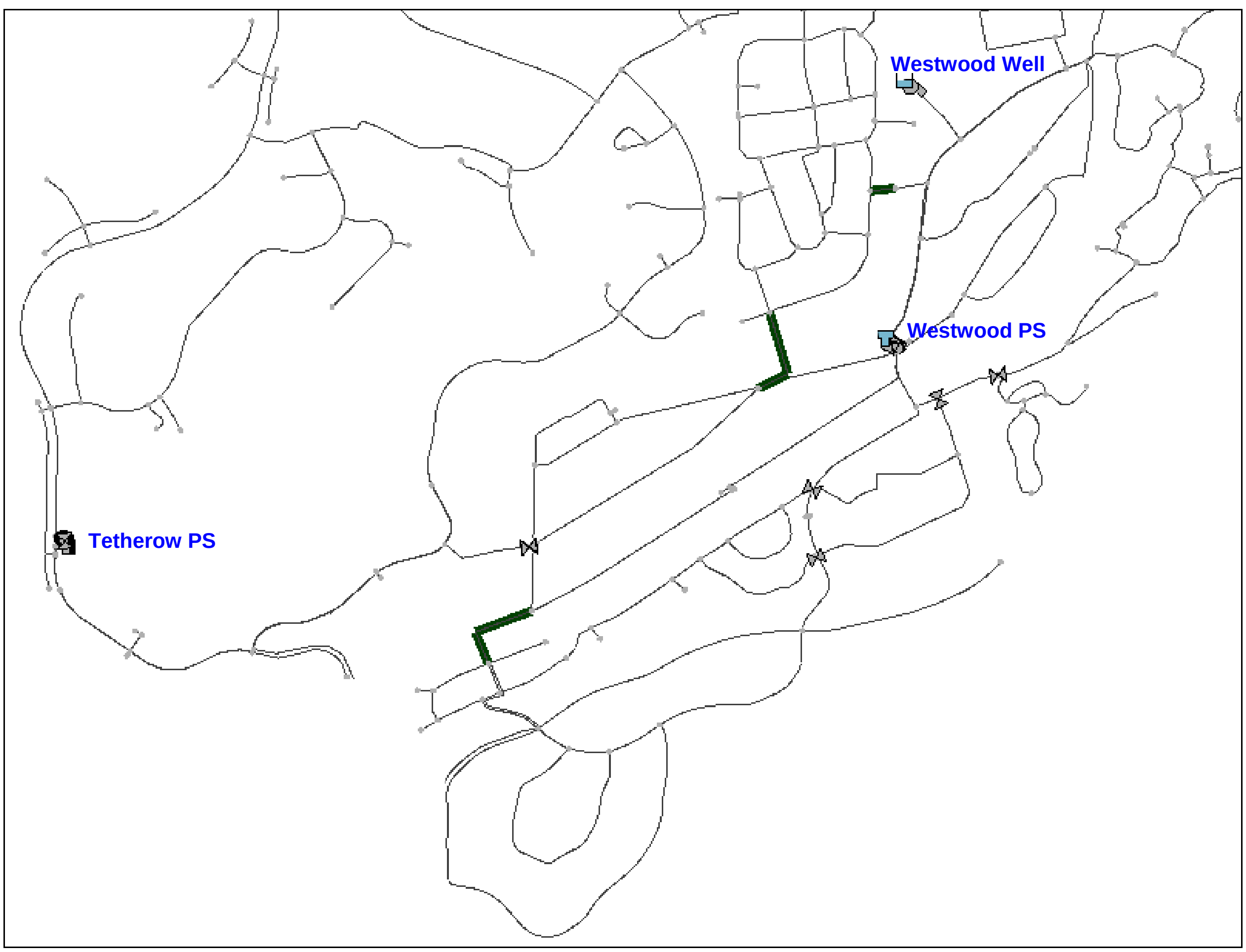


Figure 4.13 – New piping connections shown in bold allow Westwood to be supplied from Level 3 under winter demand conditions

4.4.5 Reservoir levels

Appendix E contains charts of tank levels over a 48-hour period. These can be compared to the Baseline Winter Scenario charts in Appendix C.

The turnover in the Pilot Butte Reservoirs 1 & 3 is a significant improvement from the Baseline Winter Scenario. The optimization considered which connections to close and the timing of closure. In the presented solution the two northernmost pipe connections across the Deschutes River are closed for most of the day and the third connection is closed all the time. This helps maintain a reasonable level in the Pilot Butte Storages to maintain system pressures while still inducing drawdown effectively. The flow through the five connections across the river is shown in Figure 4.14, and the levels in the Pilot Butte Reservoirs 1 & 3 under this scenario are shown in Figure 4.15.

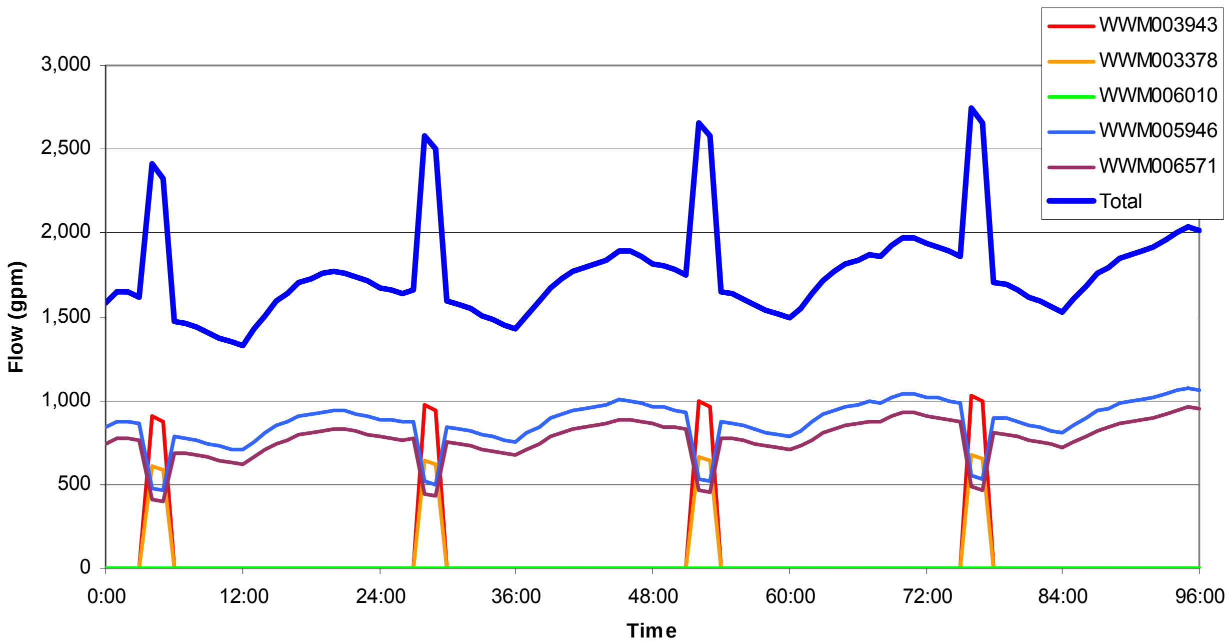


Figure 4.14 – Flow through connections at Deschutes River in Level 5 – Optimized Winter Solution (legend lists connections in order from north to south)

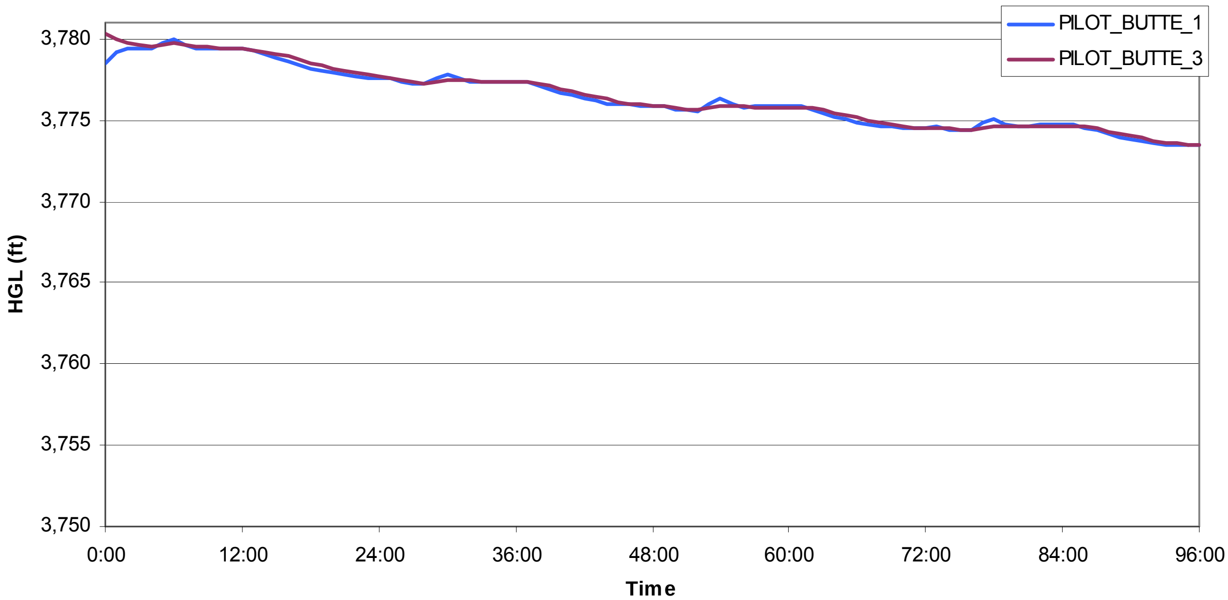


Figure 4.15 – Level in Pilot Butte Reservoirs – Optimized Winter Solution

4.4.6 Constraint violations

Similar to the Baseline Winter Scenario, the Optimized Winter Solution does not violate any of the minimum pressure or maximum velocity constraints. However, there are a number of high pressure nodes at several locations around the Overturf and Awbrey Reservoirs in Level 3. This is the same in the Baseline Winter Scenario.

4.4.7 System flows

Figure 4.16 shows the system schematic and average flows between zones in the Optimized Winter Solution. Flow values that are highlighted in yellow represent an increase compared to the Baseline Winter Scenario. Flow values highlighted in blue represent a decrease compared to the Baseline.

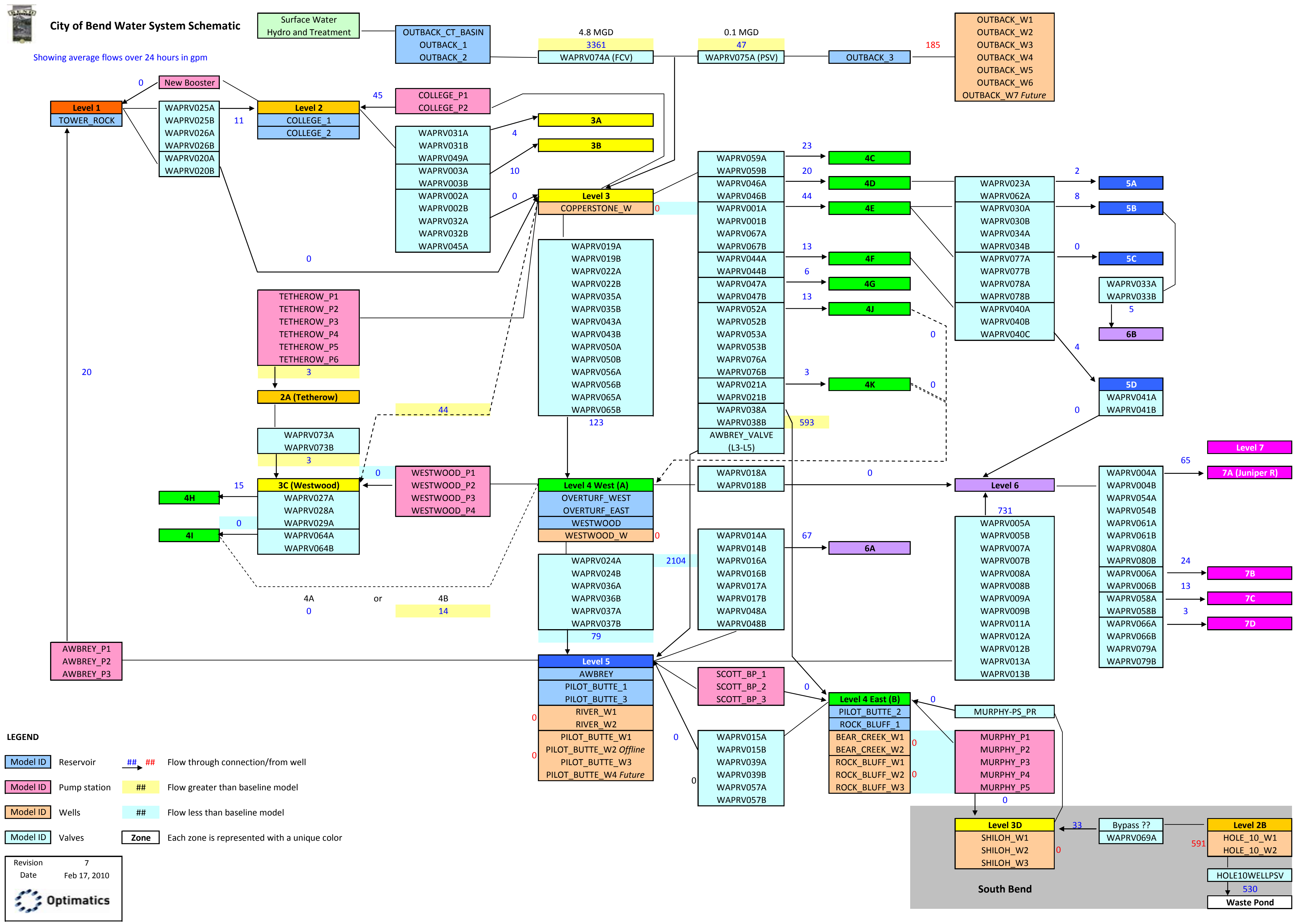


Figure 4.16 – Average flows (in gpm) in the Bend System – Optimized Winter Solution

5 Conclusions and Recommendations

The results of the optimization runs have demonstrated that there is opportunity to significantly reduce wintertime power costs and also make a good reduction in summertime power costs without major capital upgrades. In addition, the solutions have demonstrated methods that could be used to allow for maximized use of surface water in the existing system.

The following tables provide a summary of the recommended summer and winter strategies. These tables are aimed at providing generalized recommendations from the trends observed in the optimization solutions that operators can trial and adopt as appropriate, subject to their knowledge of the system and engineering judgment. The recommendations are based on the operation of the hydraulic model under a specific demand scenario and will not necessarily be appropriate for all operating scenarios.

Table 5.1 shows the various zone boundary changes and new infrastructure options evaluated in the optimization, provides a description of each change and indicates whether or not they are recommended, and the estimated costs.

Table 5.2 lists the valves that were evaluated in the optimization and the recommended settings for the Summer and Winter Strategies. In general the optimization results point towards increases in Level 4 to Level 5 PRV settings. Between the Summer Strategies there is more flow from Zone 4A to Level 5 and less from Zone 4B to Level 5 when the River Wells are operating.

Table 5.3 lists the controls for each well, pump and reservoir facility in the system, highlighting where changes have been recommended for both the Summer and Winter scenarios. Text in red indicates a change from the current summer settings; text in blue represents a modified setting for the winter scenario.

In terms of implementing the recommended control modifications, the following sequence is suggested, allowing for incremental testing and adoption of the key changes:

1. Incrementally implement changes to maximize surface water flow from west to east:
    a. Adjust valve settings at the Awbrey and Overturf Reservoirs and confirm that the recommended changes allow for recovery of storage volumes over a 24-hour period; monitor the effect on flows from Outback.
    b. Modify the PSV and PRV settings at the Athletic Club PRV and monitor for impacts (i.e., reduced pressure) in Level 3. Monitor flow through Athletic Club to confirm an increase can be achieved.
    c. Once items a & b have been implemented successfully, raise the settings of selected valves connecting Levels 4 and 5 to encourage gravity surface water transfer to Level 5.
2. Adjust Scott Street Pump Station and Bear Creek Well controls such that Scott Street is the lead year round (Note: this item can likely be implemented independent of the three items above and help to reduce groundwater pumping).

Many of the decisions formulated in the Operations Optimization runs will be carried forward to the Build-out Optimization formulation to evaluate their applicability under future demand conditions.

Table 5.1 – List of evaluated system improvements, and recommendations regarding implementation

Option	Location	Purpose	Recommendation	Priority	Approximate cost
Zone 4K into Level 3 (Figure 2.8)	Open connections on Flagline Court and Green Lakes Loop. Open PRV.	Increase circulation, suction pressure at Tetherow. Requires individual customer PRVs	Yes	1	$50,000
Zone 4J into Zone 4A (Figure 2.7)	Open boundary at NW Crossing Drive and Shevlin Park Road	Increase circulation	Yes	2	
Zone 4I into Zone 4A (Figure 2.6)	Open connections on SW Reed Market and Mt. Bachelor Drive	Reduce pumping volume at Westwood/Tetherow	No (results in low pressure)	-	
Zone 4I into Zone 4B (Figure 2.5)	Open connection at Route 372/Reed Market Rd	Reduce pumping volume at Westwood/Tetherow	Yes, partial for Summer	3	
Zone 4G into Zone 4A (Figure 2.5)	New connection on Cascade Lakes Highway	Remove demand off Mt Washington Drive/Level 3 piping	No	-	$240,000
Zone 4F into Zone 4A (Figure 2.4)	New connection at NW Summerfield Road	Increase circulation	No	-	$50,000
Internal connection, Westwood (Figure 2.9)	Cascade Lakes Hwy to Mammoth Drive	Improve supply redundancy for southernmost customers	Yes	4	$100,000
Westwood into Level 3 /Tetherow (Figure 2.9)	New connections at Pine Hollow, Cobb Street or Bachelor View Road. Open existing connections northeast of Westwood PS	Reduce reliance on Westwood PS, reduce energy needs, increase circulation	Yes - after Level 3 improvements in place	5	Pine Hollow $25,000 Cobb St $80,000
Parallel Pipe (Figure 2.1)	Flagline Court to Green Lakes Loop	Connect Level 3 suction side of Tetherow PS to the transmission lines on Skyliners	No	-	$200,000
Parallel Pipe (Figure 2.2)	Shevlin Park Road, Level 3	Connect 16-inch main to suction side of College St. Pump Station	No	-	$175,000
Level 2 to Level 1 PS (Figure 2.3)	College 2 Reservoir	Provide back up supply to Awbrey and a lower head pumping option to supply Level 1	No (affects supply to Level 2 customers)	-	$500,000
Level 2 to Level 1 PS (Figure 2.3)	NW Starview Drive and NW Fitzgerald Court	Provide back up supply to Awbrey and a lower head pumping option to supply Level 1	No (affects supply to Level 2 customers)	-	$450,000
Zone 5A, 5B, 5C PRVs	Awbrey Butte	Customers on individual PRVs, reduce maintenance, increase circulation	Yes – not high priority	6	$50,000

Table 5.2 – Current and modified summer and winter settings for valves in the Bend system

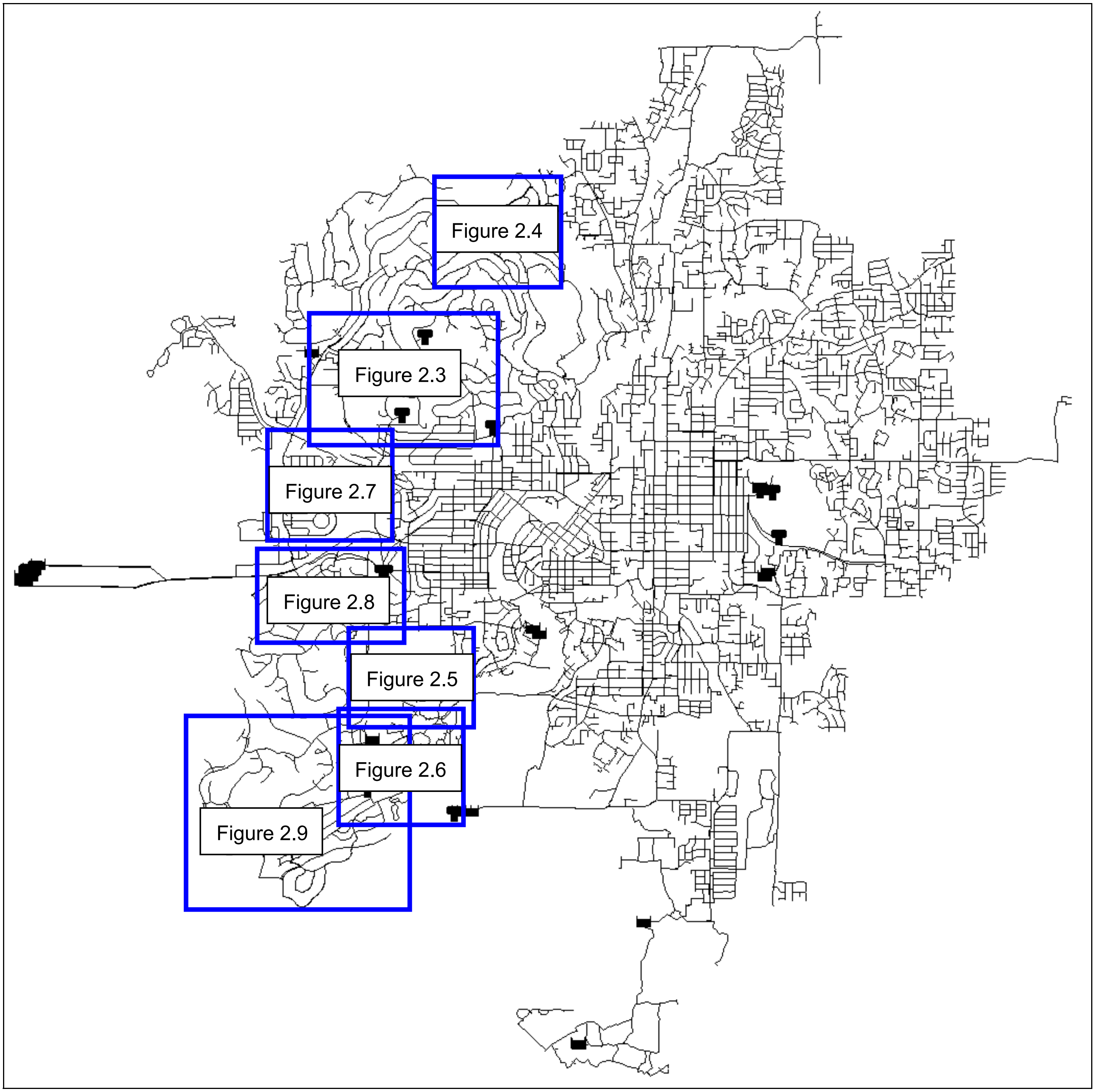
Valve ID	From Level / To Level	Current Setting		Setting Options		Proposed Setting		
						Summer		Winter
		Winter	Summer	Min	Max	Strategy #1	Strategy #2	
Overturf FCV	Level 3 to Level 4	1200 (gpm)	1400 (gpm)	750	1500	See Table 5.3		
Awbrey FCV	Level 3 to Level 5	3500 (gpm)	6200 (gpm)	3500	6500			
WAPRV024A	Level 4A (West) to Level 5 Newport & Juniper	67 (psi)	62 (psi)	58	67	66	66	62, no flow
WAPRV036A	Level 4A (West) to Level 5 Cumberland and 15th	51 (psi)	57 (psi)	47	61	61	61	No change, no flow
WAPRV037A	Level 4A (West) to Level 5 17th St. & Galveston	45 (psi)	44 (psi)	40	49	48	46	No change
WAPRV038A	Level 3 to Level 4B (East) Mt. Washington & Athletic Club	72 (psi)	71 (psi)	71	76	PRV 75 PSV 90	PRV 75 PSV 85	PRV 74 PSV 120
WAPRV015A	Level 4B (East) to Level 5 Hwy 20 @ 1734	40 (psi)	47 (psi)	40	51	47	51	No change, no flow
WAPRV015B	Level 4B (East) to Level 5 Hwy 20 @ 1735	38 (psi)	43 (psi)	34	46	44	44	No change, no flow
WAPRV039A	Level 4B (East) to Level 5 Wilson & Bond	52 (psi)	52 (psi)	48	56	54	54	No change, no flow
WAPRV057A	Level 4B (East) to Level 5 Bond & Reed Market	51 (psi)	58 (psi)	47	62	54	62	No change, no flow
WAPRV047A	Level 3 to Zone 4G Chandler & Mt. Washington	72 (psi)	70 (psi)	50	70	No change	No Change	No change
WAPRV064A	Zone 3C (Westwood) to Zone 4I Wild Rapids & Wild Rapids	57 (psi)	53 (psi)	43	53	No change	No Change	No change if 4I split, Reduce to 48 if 4I into 4B
WAPRV021A	Level 3 to Zone 4K Green Lakes Loop	57 (psi)	58 (psi)	46	58	No change	No Change	No change
WAPRV073A	Zone 2A (Tetherow) to Zone 3C (Westwood) Tetherow & Campbell	65 (psi)	65 (psi)	55	65	No change	No Change	No change, Active supplying part of Westwood

Table 5.3 – Current and modified controls recommended based on optimized summer and winter solutions (red and blue coloring indicates changes to existing settings)

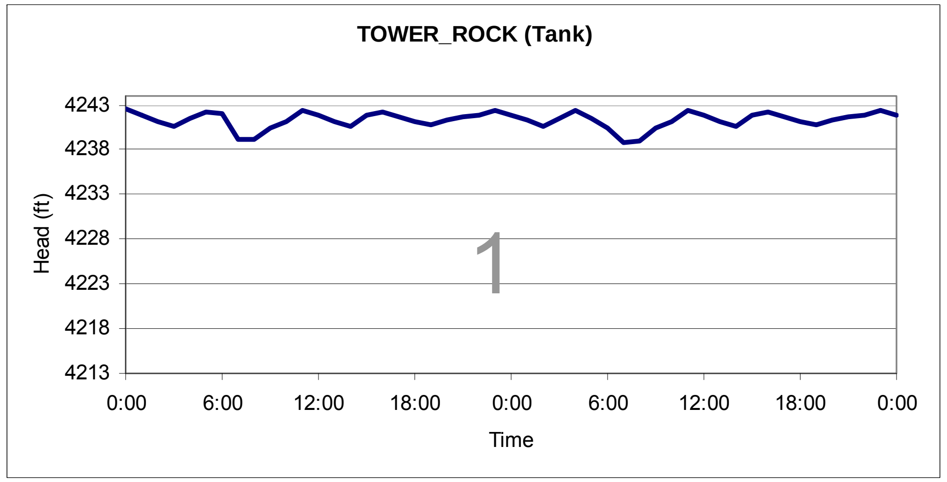
		Current Summer Strategy		*Optimized Summer Strategy #1*		*Optimized Summer Strategy #2*		*Current Winter Strategy*		*Optimized Winter Strategy*		
Facility	**Looks to:**	**On**	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**	**On**	**Off**	**Comments**
Awbrey PS												
Awbrey 1	Tower Rock Level	27	30	27.5	29.5	27.5	29.5	27	30	27	30	
Awbrey 2	Tower Rock Level	25	28	23	24.5	26	27.5	25	28	25	28	
College PS												
College 1	Tower Rock Level	18	22	17	22	17	22	18	22	18	22	
College 2	Tower Rock Level	16	20	16	20	16	20	16	20	16	20	
Copperstone	Outback 3 Level	Manual - On		Manual - Off		Manual - Off		Manual - On		Manual - Off		
Awbrey inlet				This strategy uses the River Wells to fill Awbrey, so there is less flow from Outback compared to the alternative strategy. Also less flow from 4B to 5		The River wells do not run, Outback wells make up the difference. As a result, need more constant flow from Outback to Awbrey.				FCV controls flow, altitude settings are suggestions only		
Altitude setting	Awbrey Level	17	18	16	19	14	19	15	18	14	17	
Awbrey FCV	Time	6,500 gpm		Midnight – 4 AM: 4,000 gpm 4 AM – 8 AM: Closed 8 AM – 12 PM: 5,500 gpm 12 PM – 4 PM: 6,500 gpm 4 PM – Midnight: 4,000 gpm		Midnight – 4 AM: 5,500 gpm 4 AM – 8 AM: 3,500 gpm 8 AM – 12 PM: 5,500 gpm 12 PM – 4 PM: 5,000 gpm 4 PM – 8 PM: 5,500 gpm 8 PM – Midnight: 6,000 gpm		3,000 gpm		Higher overnight (5,500 gpm), closed peak periods. Average 3,200 gpm		
	Equivalent PSV Setting			78 PSI overnight, 60 PSI 8AM - 4PM	Closed 4 AM-8AM	62.5 PSI	Closed based on levels			82.5 PSI	Closed 2 AM - Midday	
Overturf inlet				As there is less flow from Outback to Awbrey in this scenario, restricting flow into Overturf is not critical		Need to control flow to minimize during higher demand periods (4-8 AM).				FCV controls flow, altitude settings are suggestions only		
Altitude setting	Overturf Level	21	23	22	26	23	26	23	24.5	22	25	
Overturf FCV	Time	1,400 gpm		Midnight – 4 AM: 1,250 gpm 4 AM – 8 AM: 1,000 gpm 8 AM – 12 PM: 750 gpm 12 PM – 4 PM: Closed 4 PM – 8 PM: 1,500 gpm 8 PM – Midnight: 1,250 gpm		Midnight – 4 AM: 1,500 gpm 4 AM – 8 AM: Closed 8 AM – 12 PM: 1,500 gpm 12 PM – 4 PM: 1,000 gpm 4 PM – Midnight: 1,500 gpm		1,200 gpm		Higher overnight (1,500 gpm), lower daytime (750 gpm). Average 1,250 gpm		
	Equivalent PSV Setting			61 PSI	Closed based on levels	59 PSI	Closed based on levels			60 PSI	Filled on level controls	
Athletic Club PRV				PSV 90 psi (to allow higher flow at peak hour, see 115 psi most of day)	PRV 75 psi	PSV 85 psi (to allow higher flow at peak hour, see 110 psi most of day)	PRV 75 psi			PSV 120 psi	PRV 74 psi	
Outback				Settings for these wells were not considered in the optimization						Settings not considered in the optimization		
Outback 1	Manual	Manual - Off		Manual - Off		Manual - Off		Manual - Off		Manual - Off		
Outback 2	Manual	Manual - Off		Manual - Off		Manual - Off		Manual - On		Manual - On		
Outback 3	Outback 3 Level	26	28	26	28	26	28	26	28	26	28	
Outback 4	Outback 3 Level	24	27	24	27	24	27	24	27	24	27	
Outback 5	Outback 3 Level	23	26	23	26	23	26	23	26	23	26	
Outback 6	Outback 3 Level	20	24	20	24	20	24	20	24	20	24	
Westwood Well	Westwood Level	20	28	19	26	19	26	18	26	19	26	

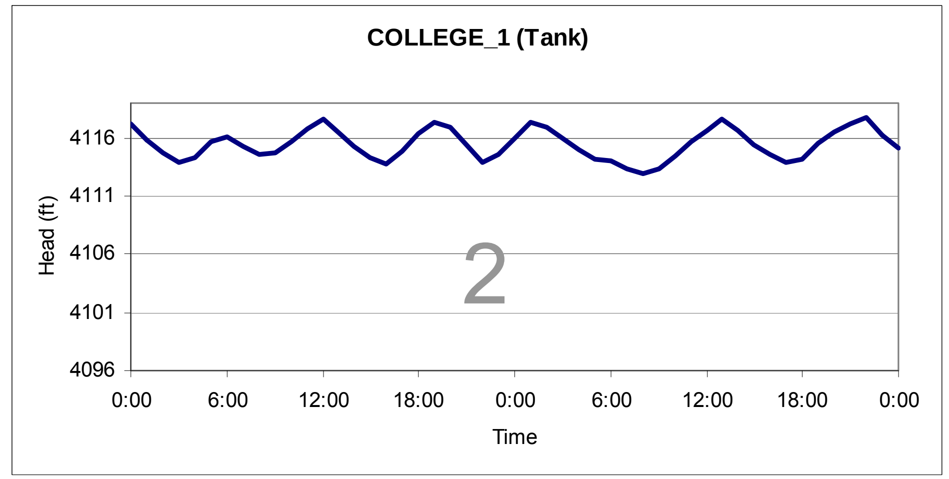
Facility	Looks to:	Current Summer Strategy On	Current Summer Strategy Off	Optimized Summer Strategy #1 On	Optimized Summer Strategy #1 Off	Optimized Summer Strategy #2 On	Optimized Summer Strategy #2 Off	Current Winter Strategy On	Current Winter Strategy Off	Optimized Winter Strategy On	Optimized Winter Strategy Off	Comments
Westwood PS		Maintain 78 psi		Maintain 78 psi		Maintain 78 psi		Maintain 78 psi		Closed		
Bear Creek				Lowered settings		Lowered settings						
Bear Creek 1	Pilot Butte 2 Level	36	38	33	35	33	35	Off		Off		
Bear Creek 2	Pilot Butte 2 Level	35	37	33	35	33	35	Off		Off		
Scott St PS				Raise to share load with Bear Creek, less pumping than Strategy #2		Raise to lead from Bear Creek				Does not operate, no change to settings		
Scott Street 1	Pilot Butte 2 Level	27	30	31	34	31	33	22	26	22	26	
Scott Street 2	Pilot Butte 2 Level	25	29	33	35	34	35	21	24	21	24	
Scott Street 3	Pilot Butte 2 Level	23	28	30	32	27	32	20	22	20	22	
Rock Bluff										Do not operate		Fine balance - opening up Athletic Club and not running Rock Bluff pumps affects ability to fill Overturf. May need to run Rock Bluff Wells if Overturf is not able to recover
Rock Bluff 1	Rock Bluff Level	35	37	34	36	35	37	33	35	33	35	
Rock Bluff 2	Manual	Manual - Off		Manual - Off		Manual - Off		Manual - Off		Manual - Off		
Rock Bluff 3	Rock Bluff Level	36	38	36	38	36	38	34	36	34	36	
River Wells						Do not operate						
River Well 1	Awbrey Level	Manual - On		15	17	14	16	Manual - Off		Manual - Off		
River Well 2	Awbrey Level	Manual - Off		14	16	10	16	Manual - Off		Manual - Off		
Pilot Butte Wells												
Pilot Butte 1	Manual	Manual - On		Manual - On		Manual - On		Manual - Off		Manual - Off		
Pilot Butte 3	Pilot Butte 1 Level	Manual - On		23	28	23	27	Manual - Off		Manual - Off		
Level 5 Valves on Deschutes												
Portland	Pilot Butte 3 (when refilling)	-		Open		Open		-		18	23	
	Time (when inducing drawdown)	-		n/a		n/a		-		Open 4 AM - 6 AM	Closed 6 AM - 4 AM	
Newport	Pilot Butte 3 (when refilling)	-		Open		Open		-		18	23	Could keep connections closed all the time and just use the level-based controls, depends how fast you want to drain
	Time (when inducing drawdown)	-		n/a		n/a		-		Open 4 AM - 6 AM	Closed 6 AM - 4 AM	
Nashville/	Pilot Butte 3 (when refilling)	-		Open		Open		-		18	23	
Louisiana	Time (when inducing drawdown)	-		n/a		n/a		-		Closed		

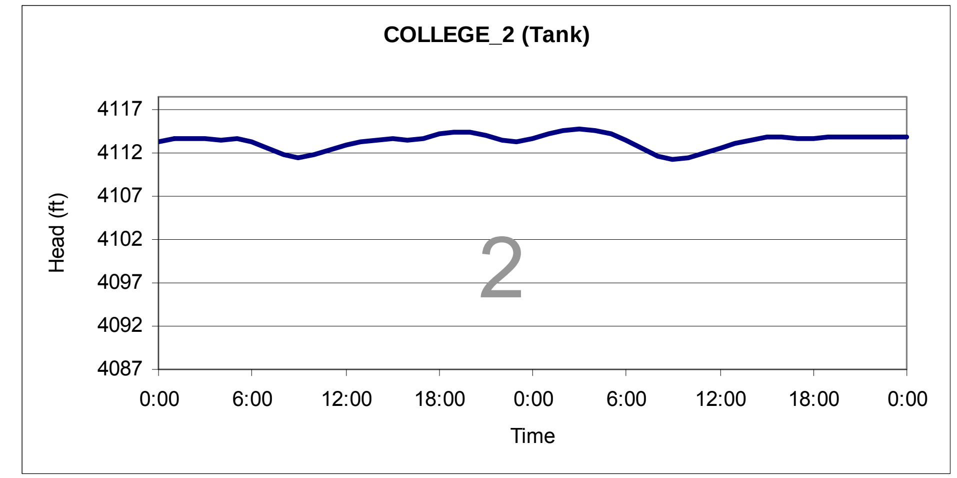
Appendix A – System map showing location of figures in Section 2

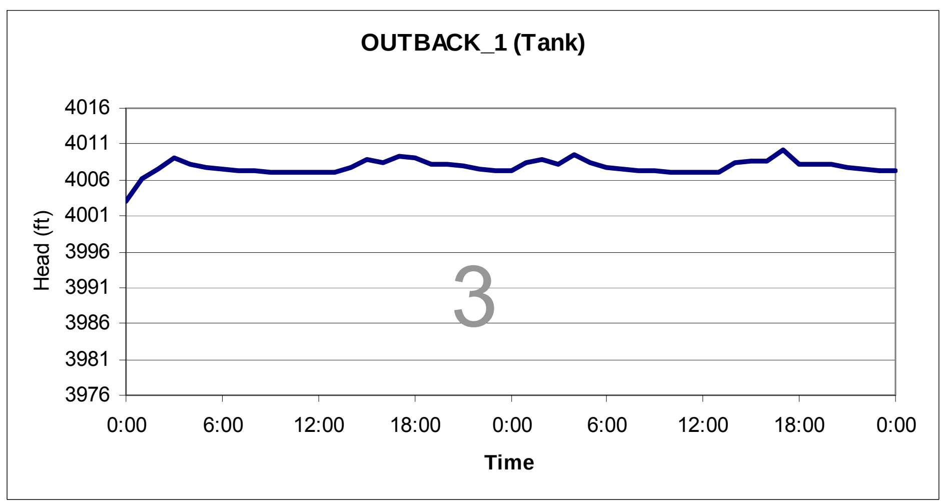


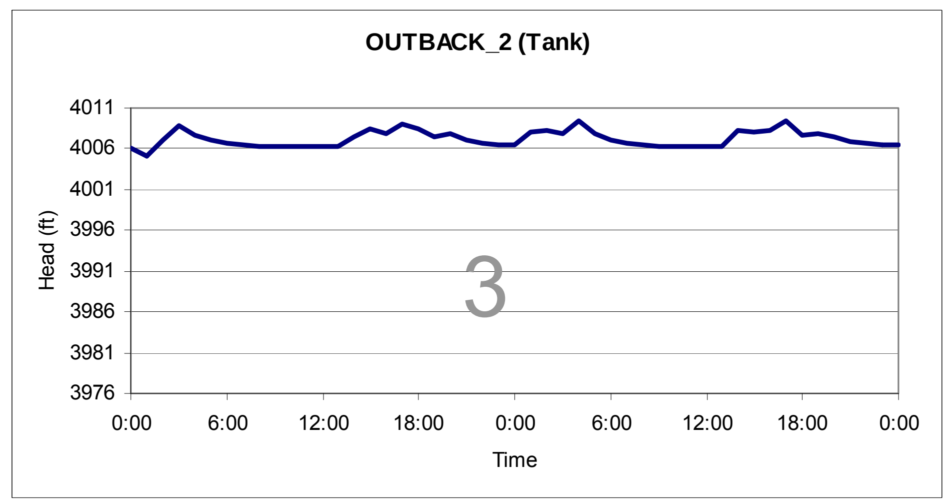
Appendix B – Storage Tank Levels – Calibrated (Baseline) Summer Model

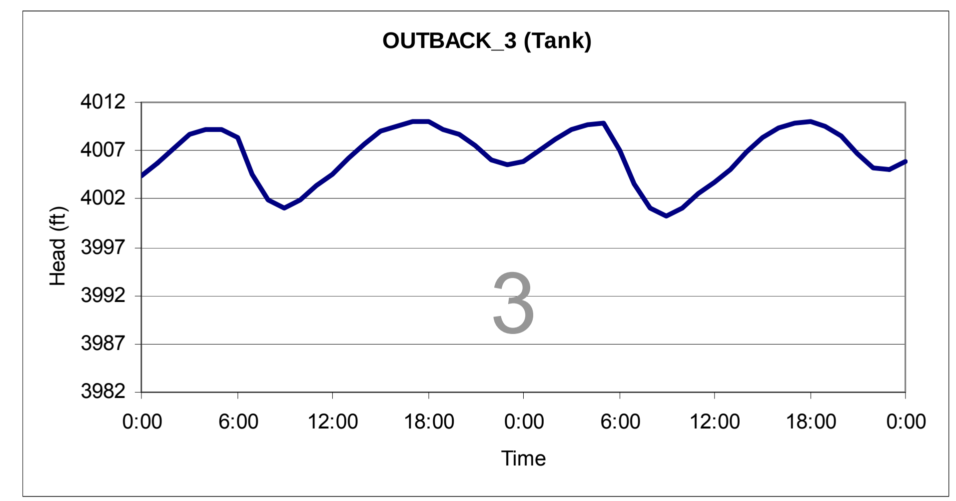


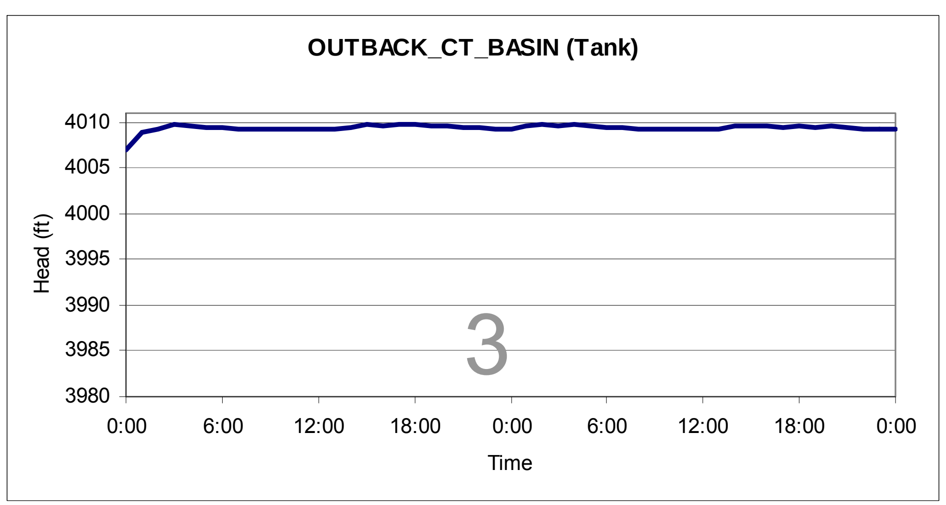


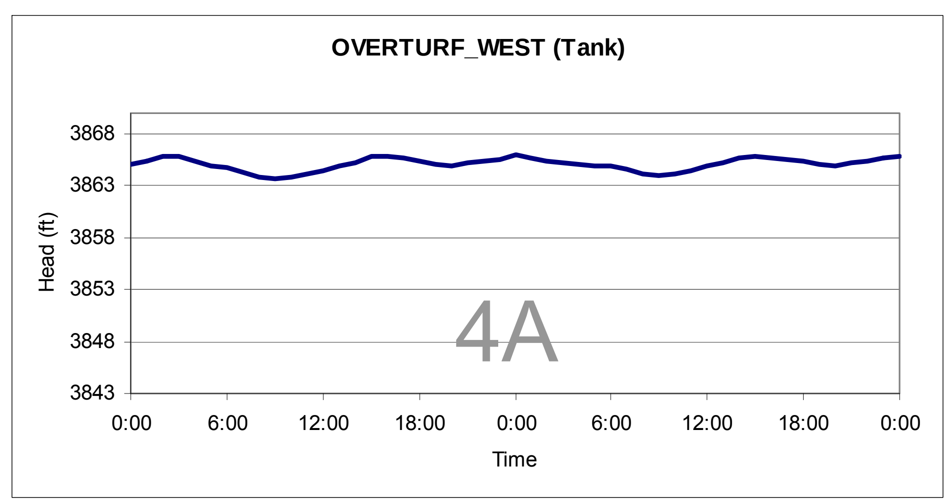


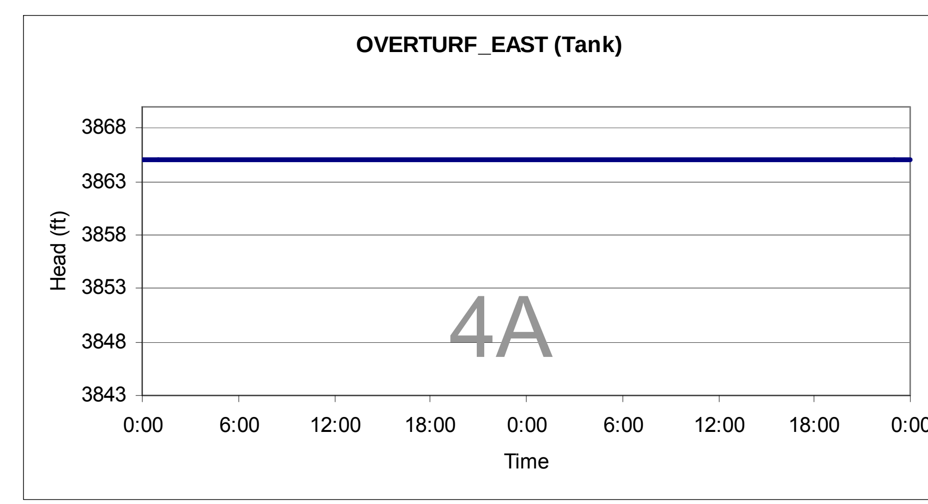


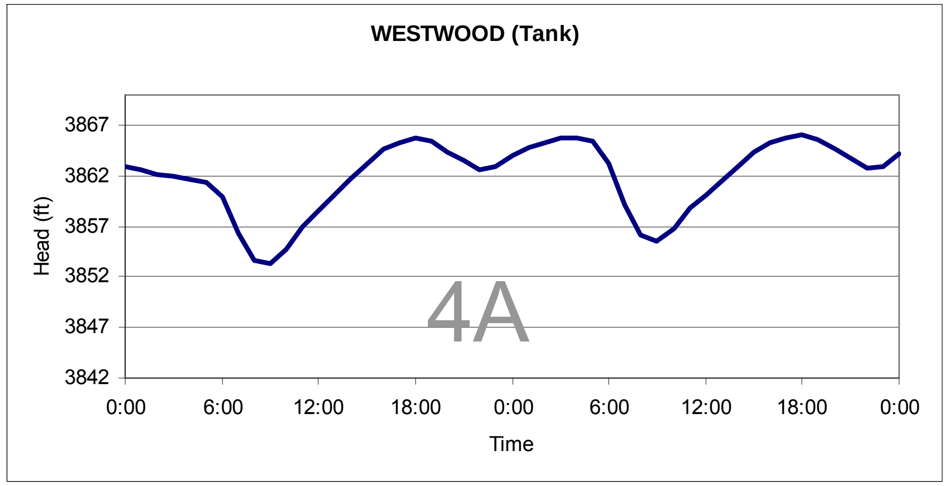








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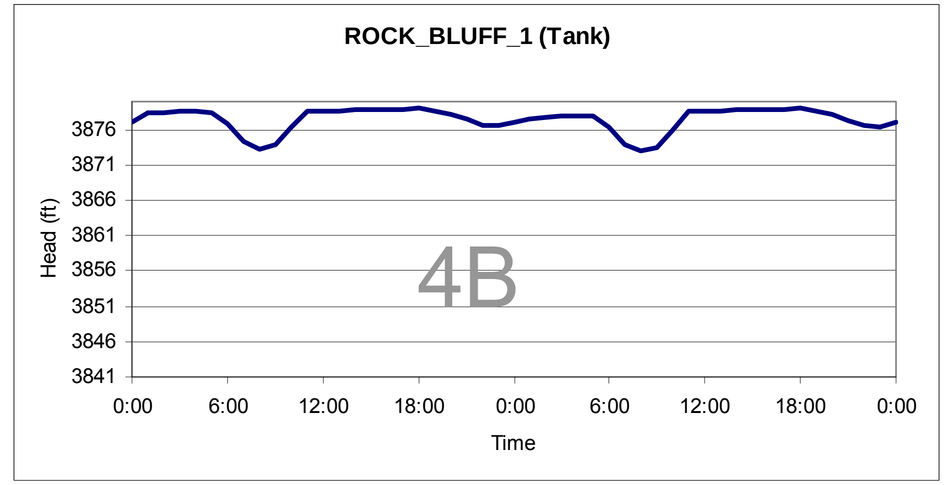
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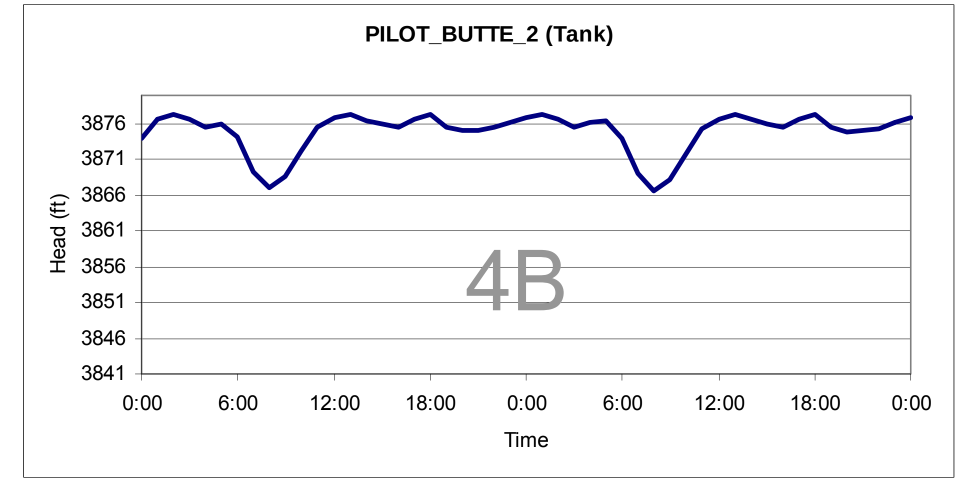
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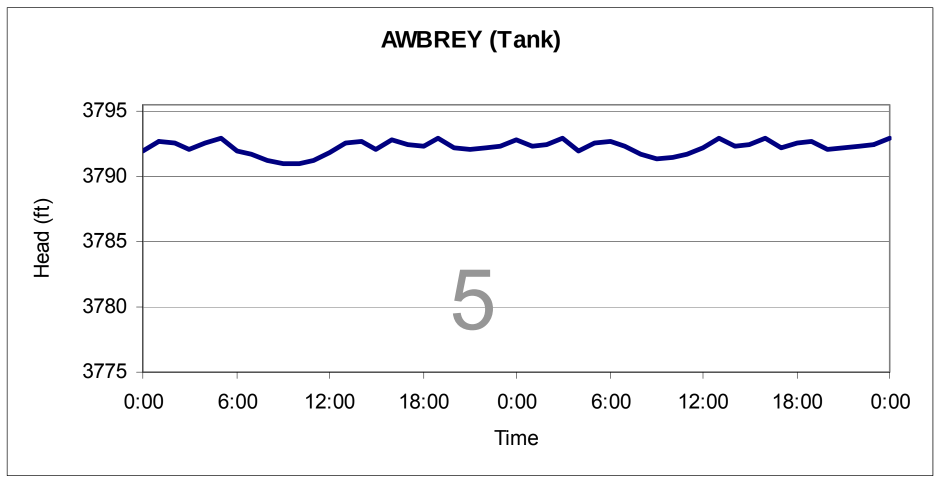
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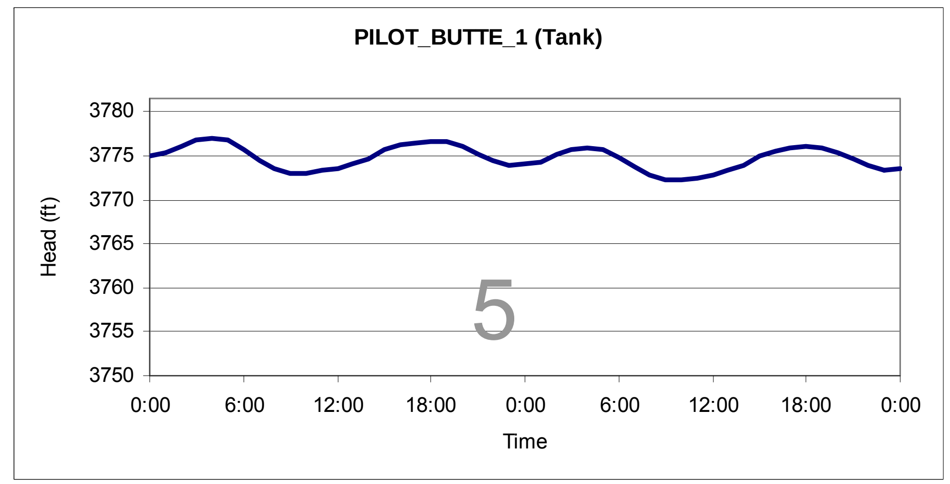
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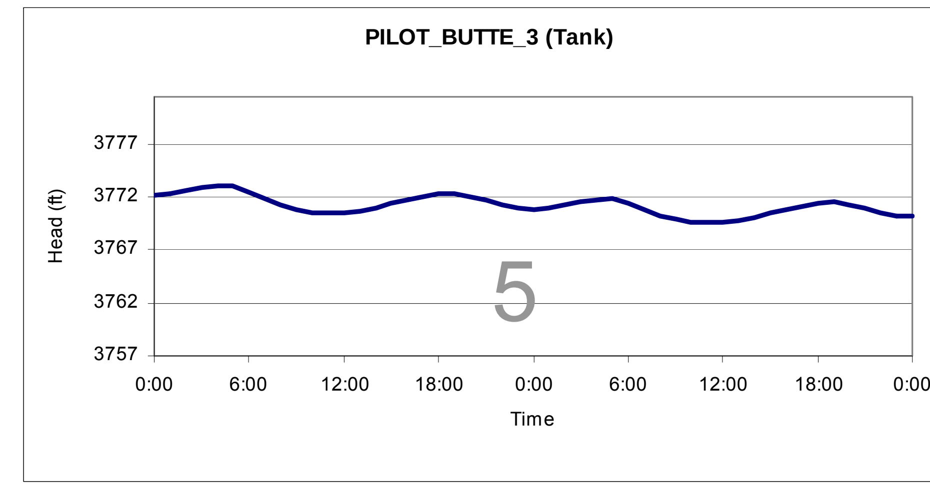
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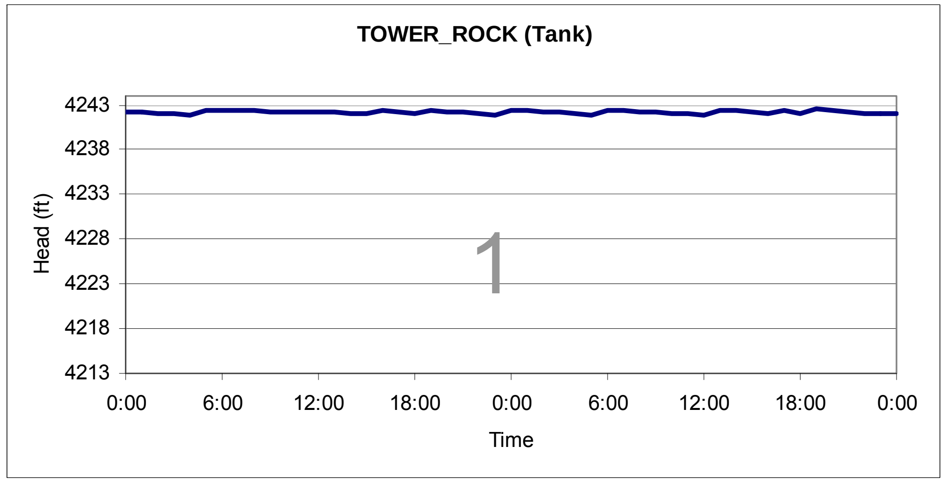
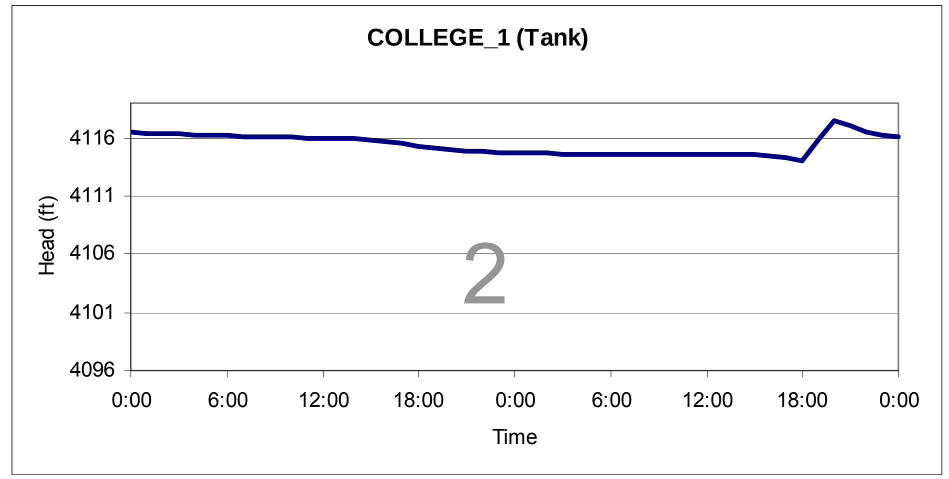
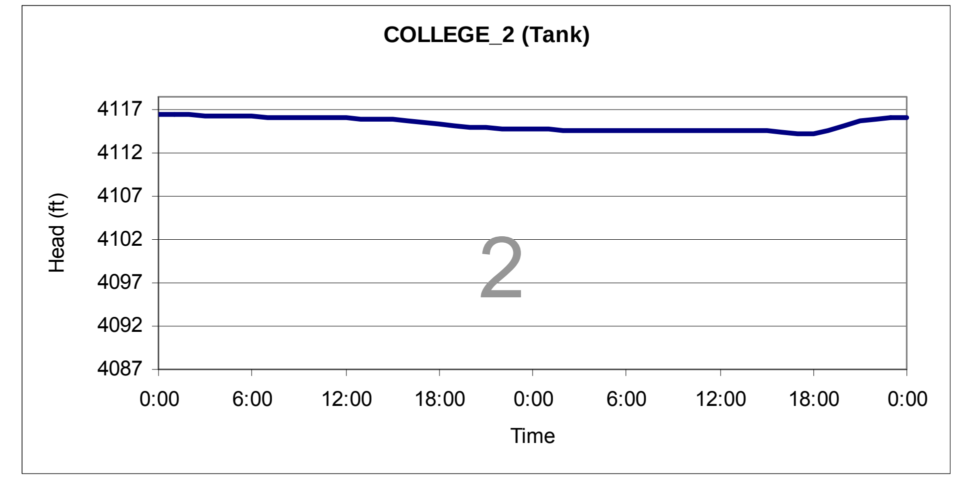
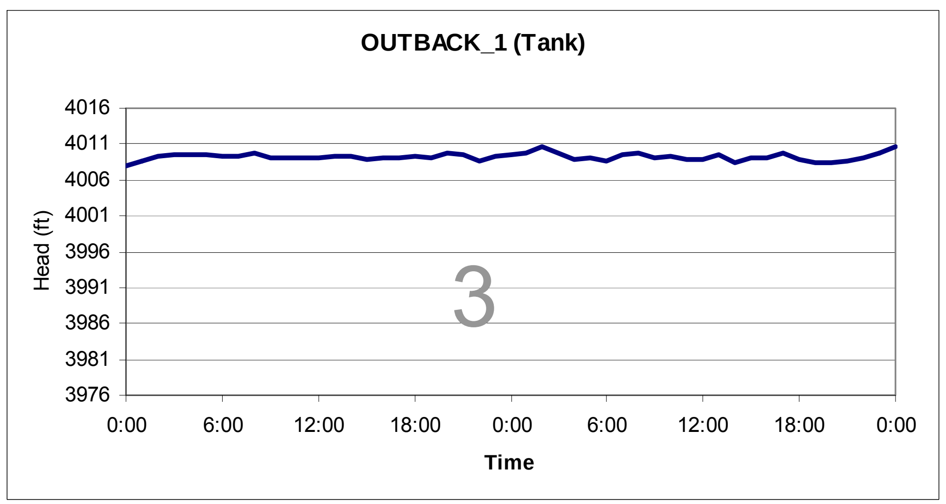
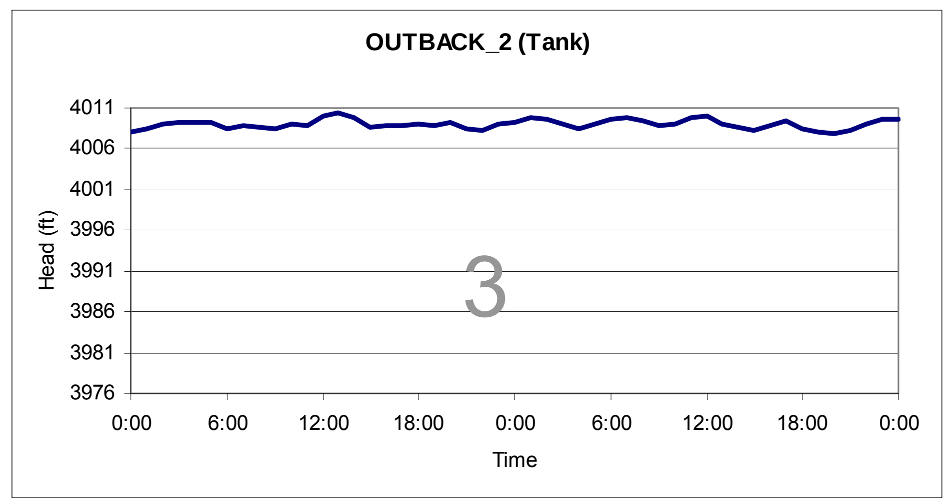
Appendix C – Storage Tank Levels – Baseline Winter Model

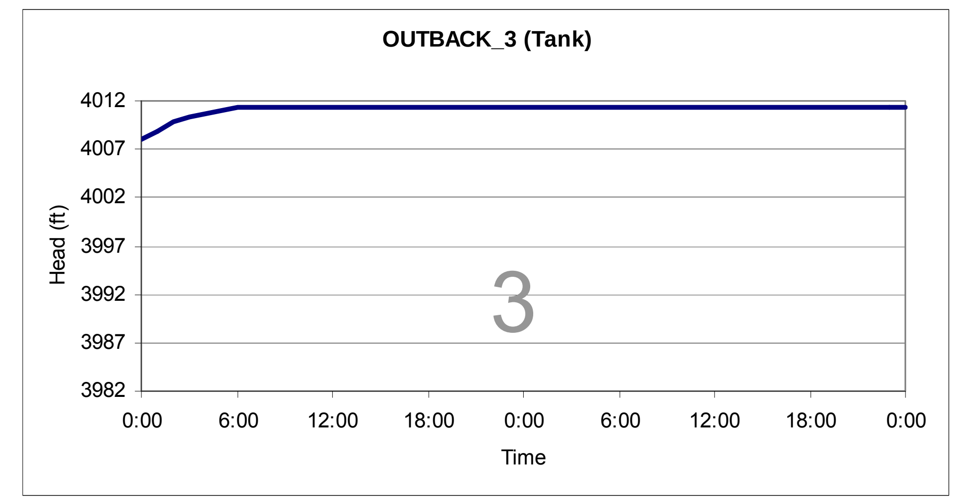


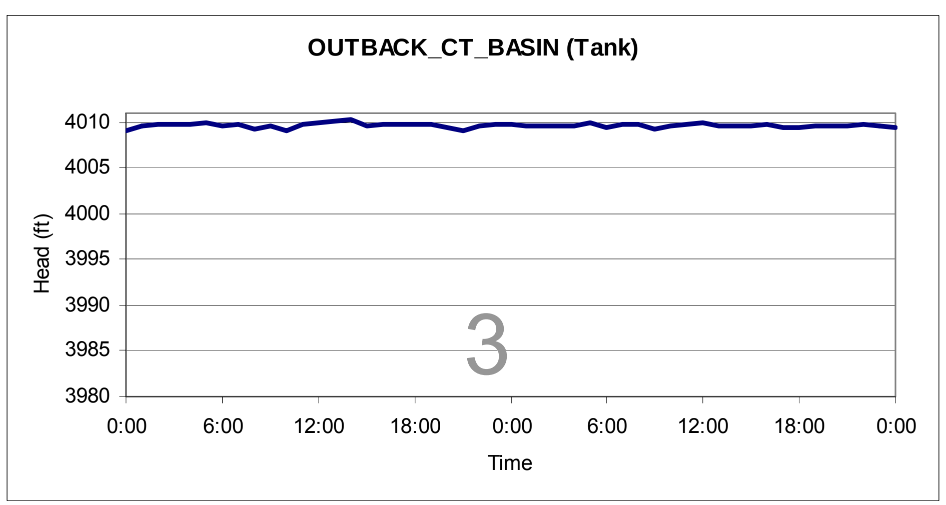


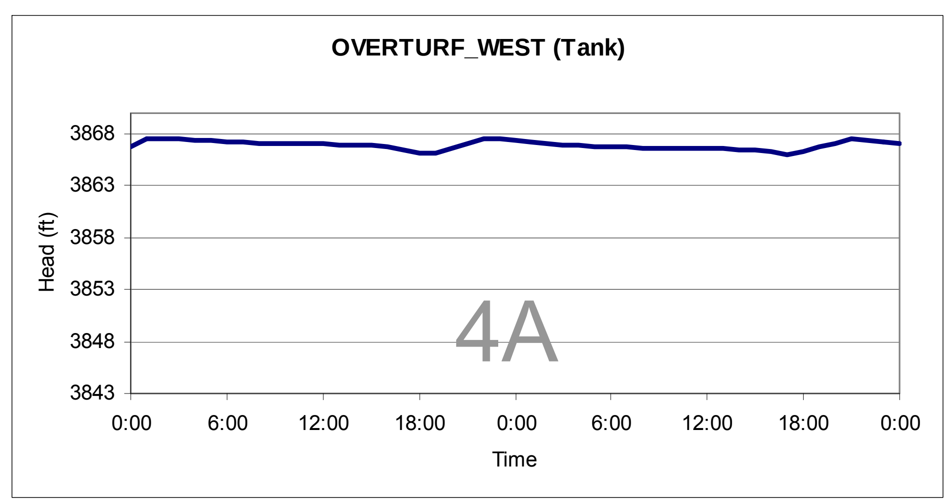


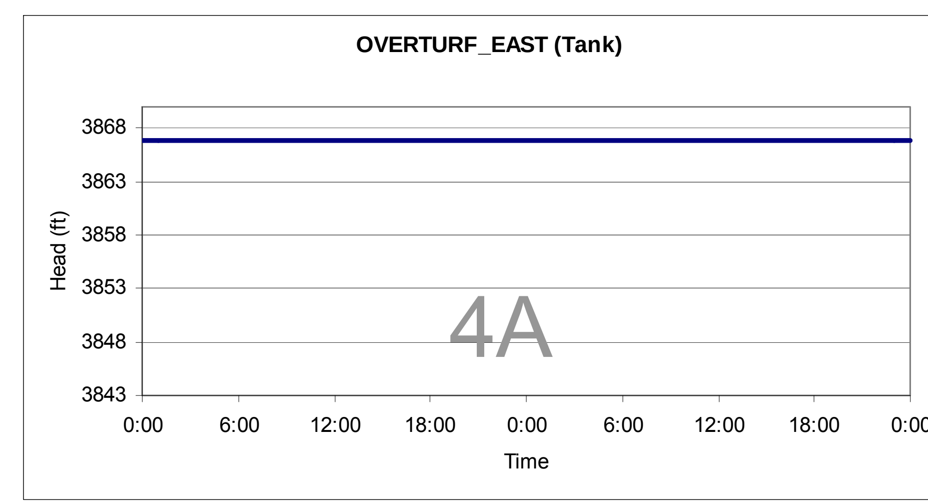


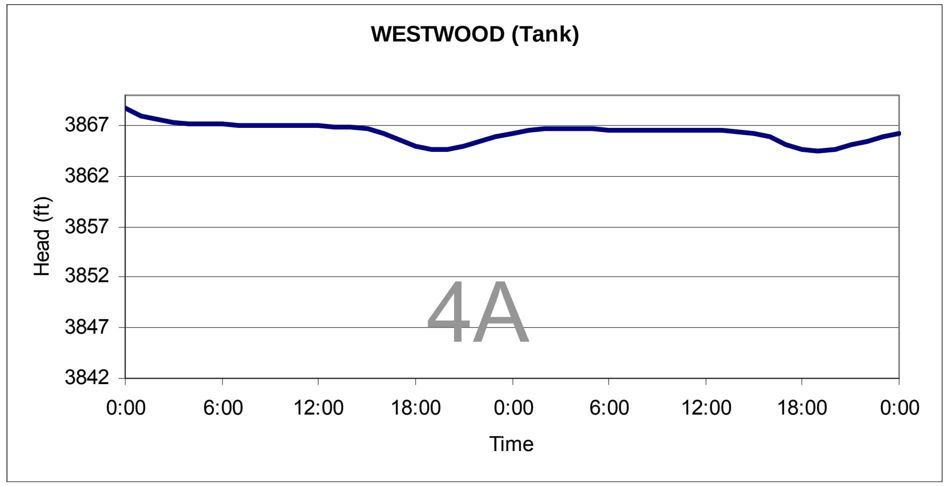








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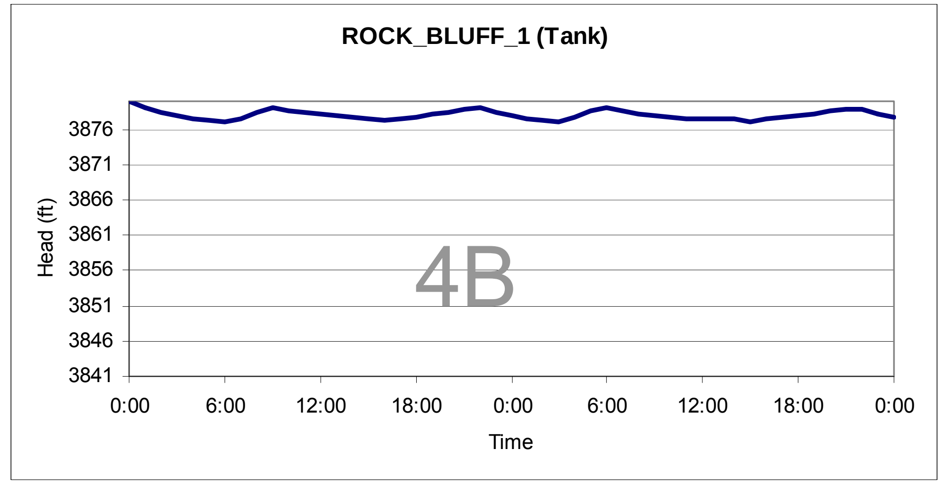
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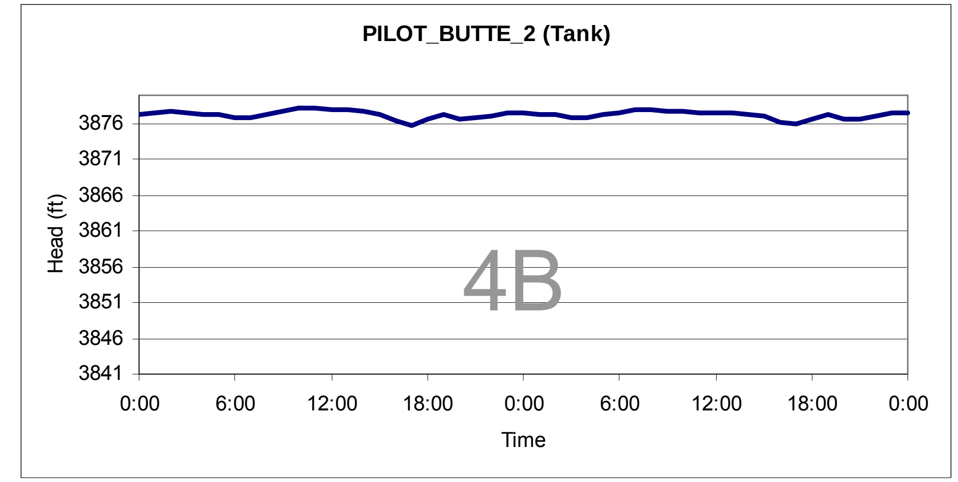
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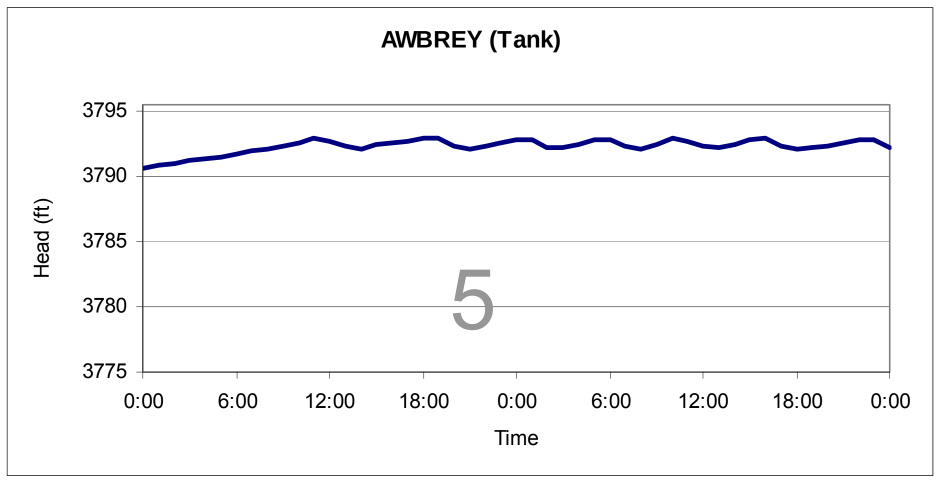
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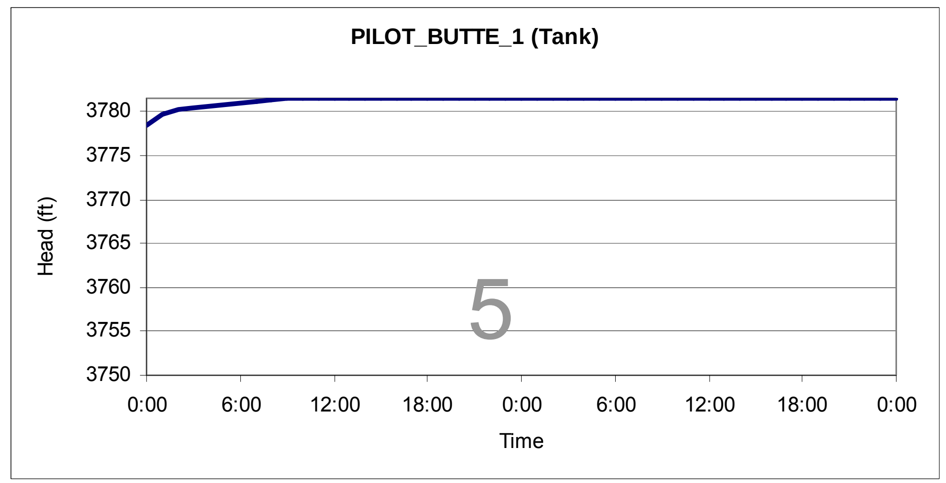
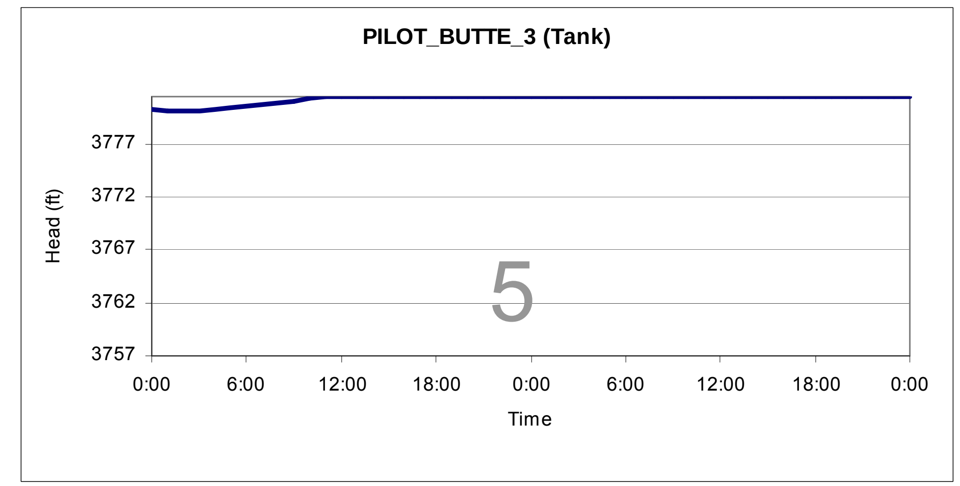
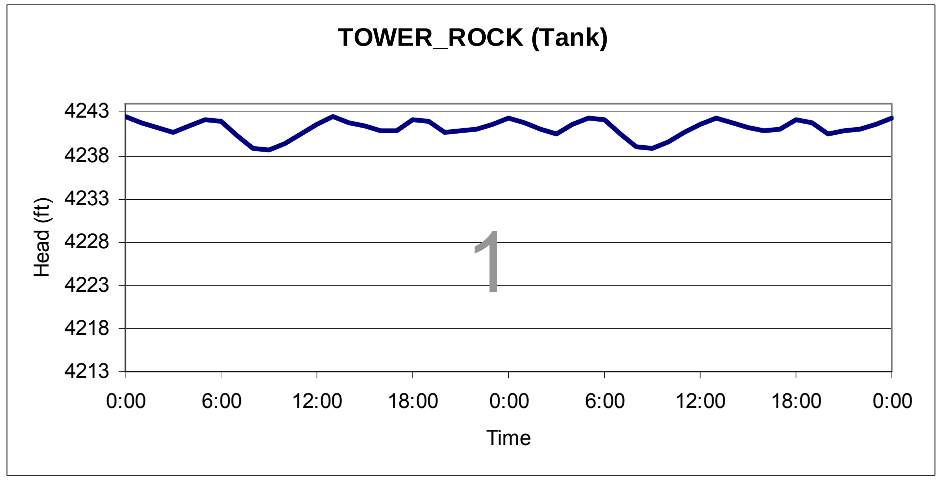
0:00 6:00 12:00 18:00 0:00 6:00 12:00 18:00 0:00
Time

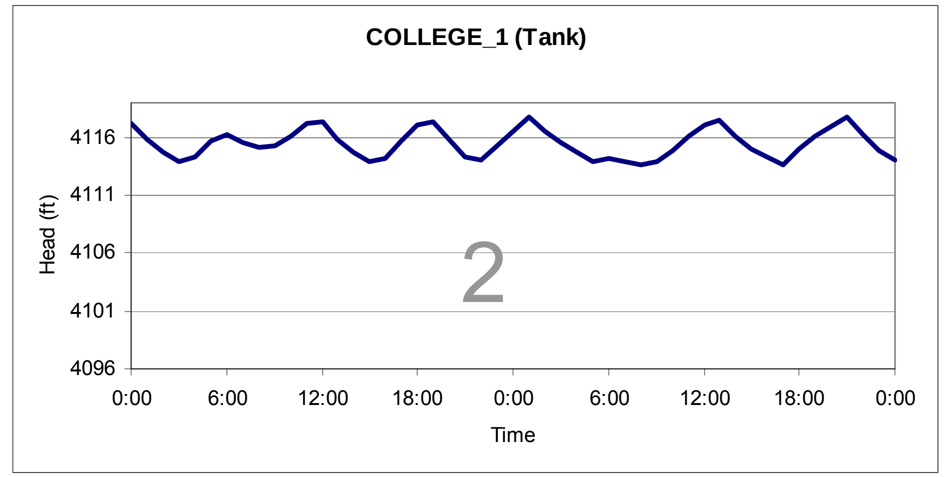

PILOT_BUTTE_1 (Tank)
Head (ft)
3780
3775
3770
3765
3760
3755
3750
5
0:00 6:00 12:00 18:00 0:00 6:00 12:00 18:00 0:00
Time

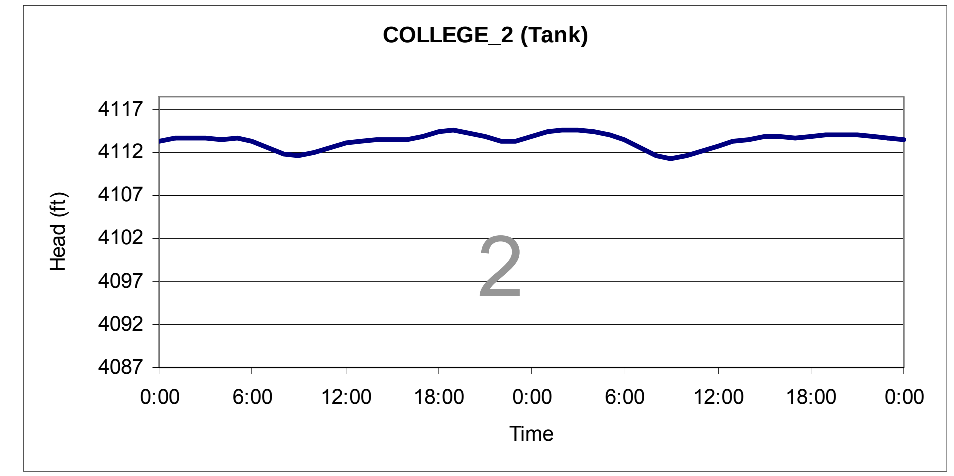

PILOT_BUTTE_3 (Tank)
Head (ft)
3777
3772
3767
3762
3757
5
0:00 6:00 12:00 18:00 0:00 6:00 12:00 18:00 0:00
Time

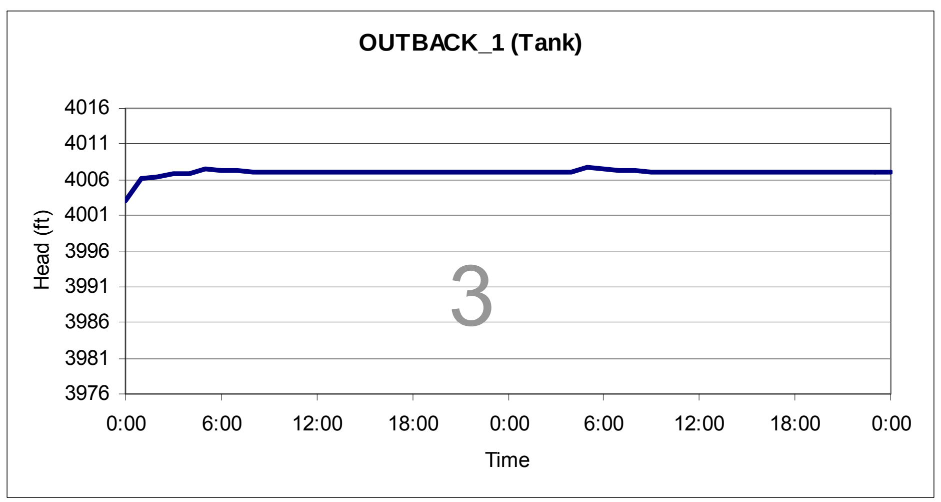
Appendix D – Optimized Solution – Summer – Tank Levels

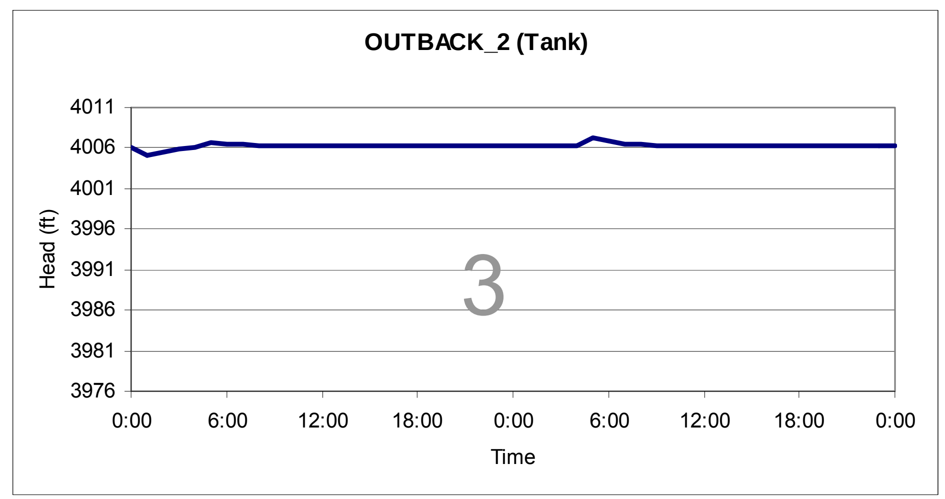
Summer Strategy #1 (with river wells)

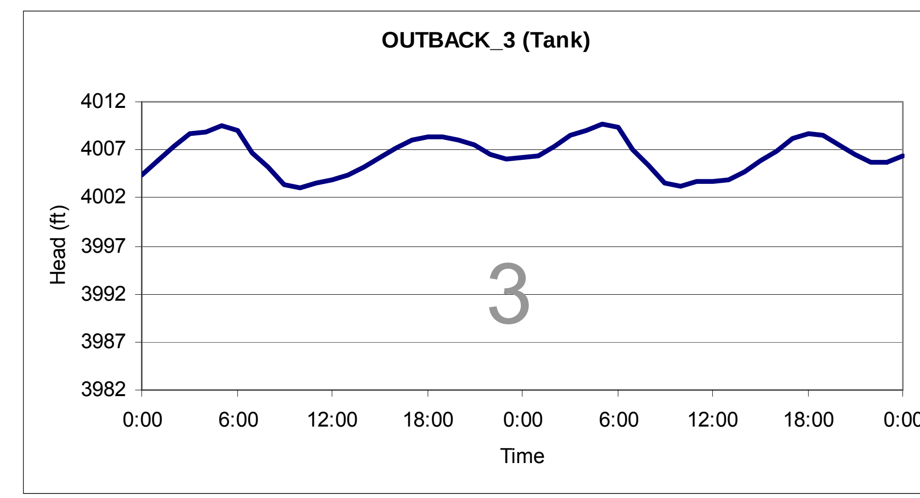


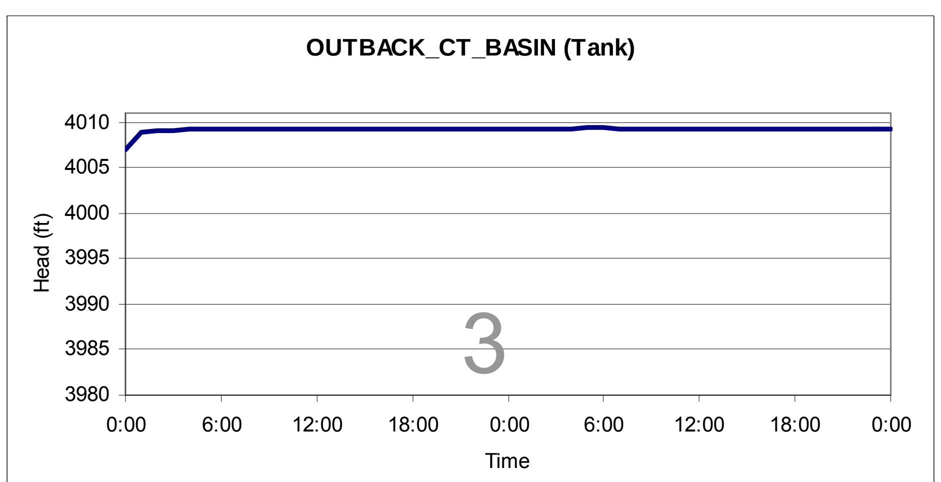


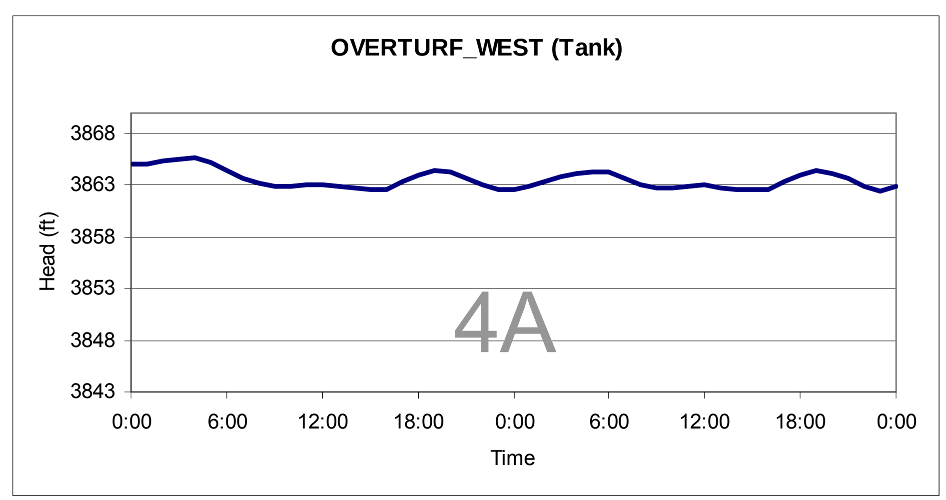


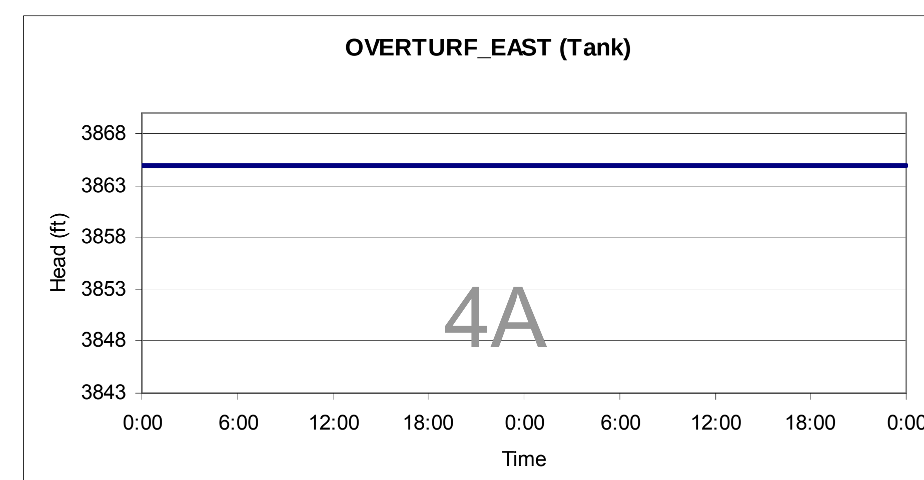




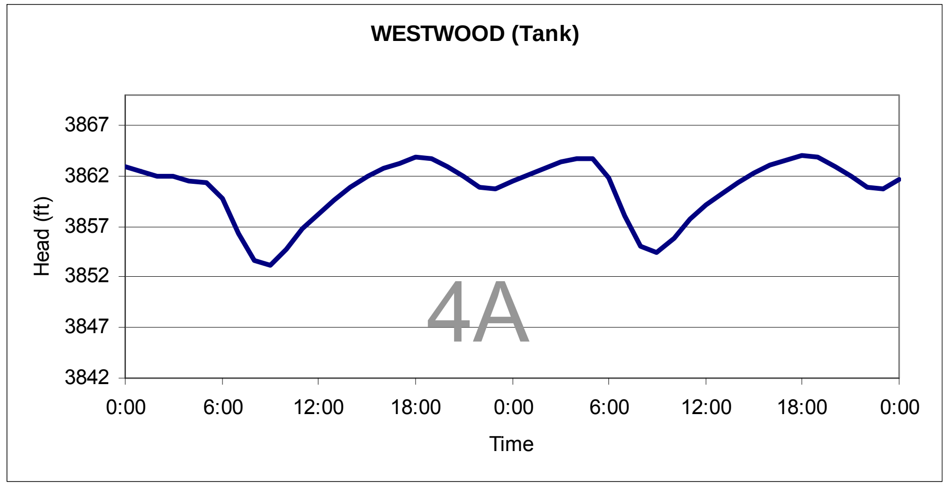


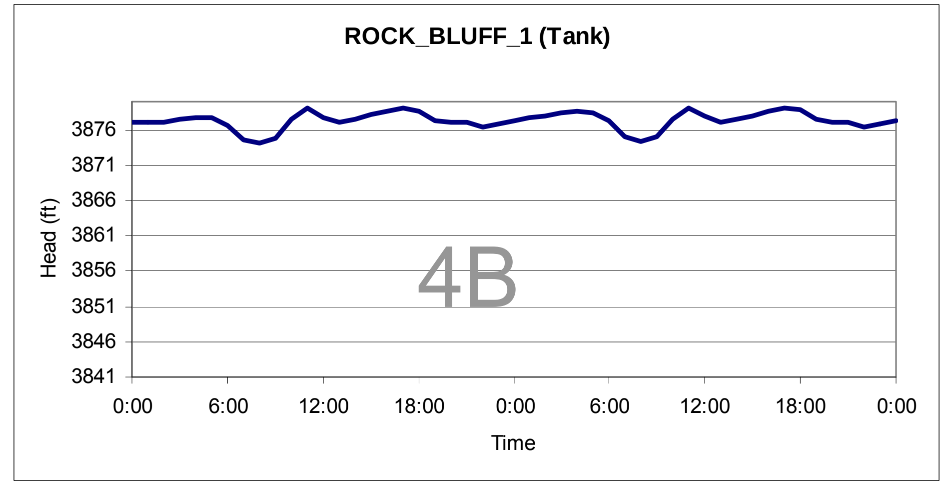


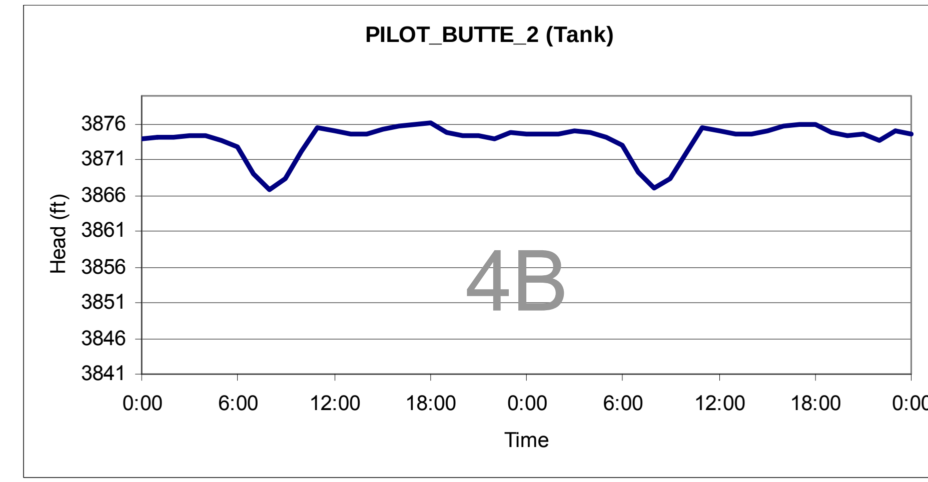


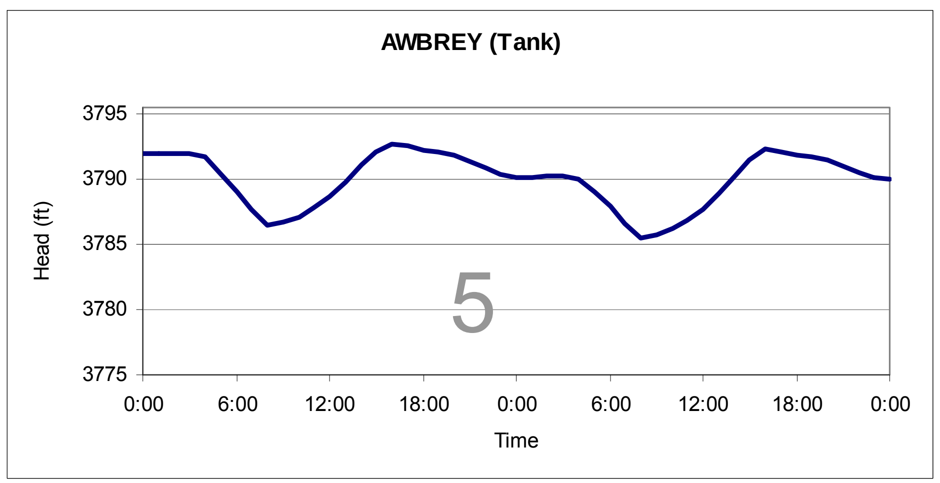


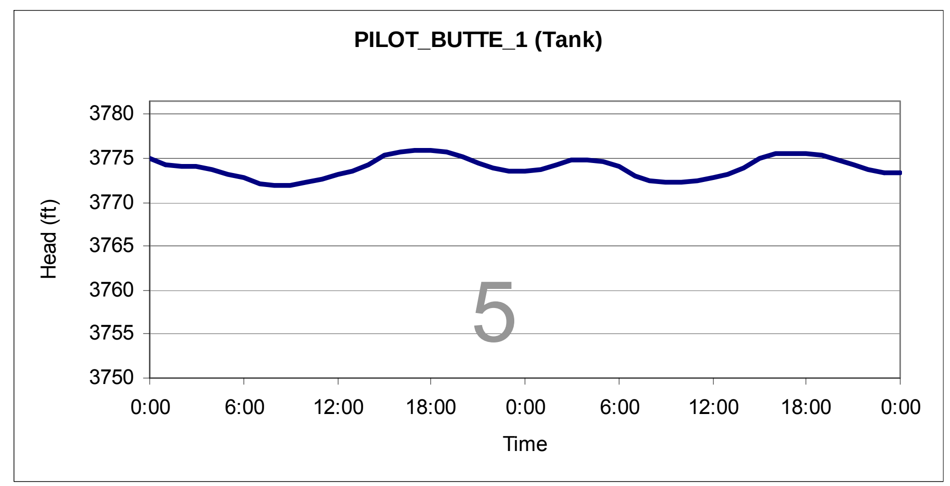
Summer Strategy #1 (with river wells)

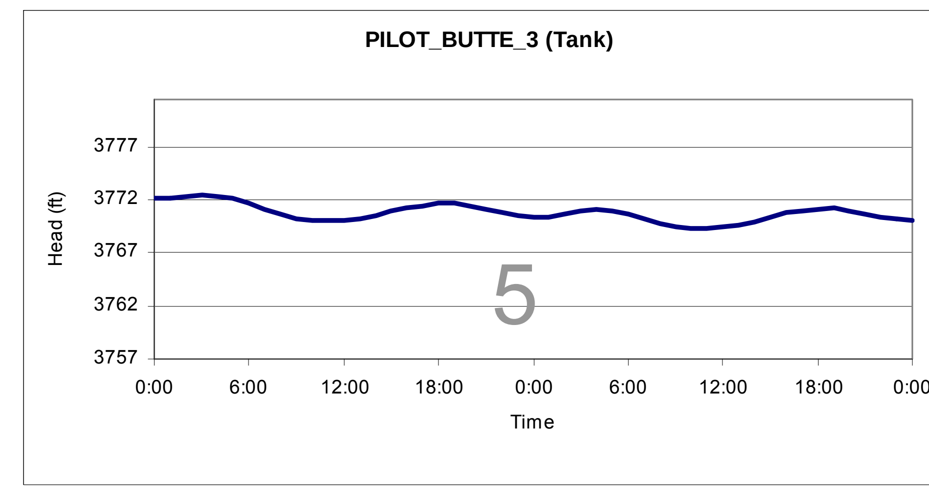




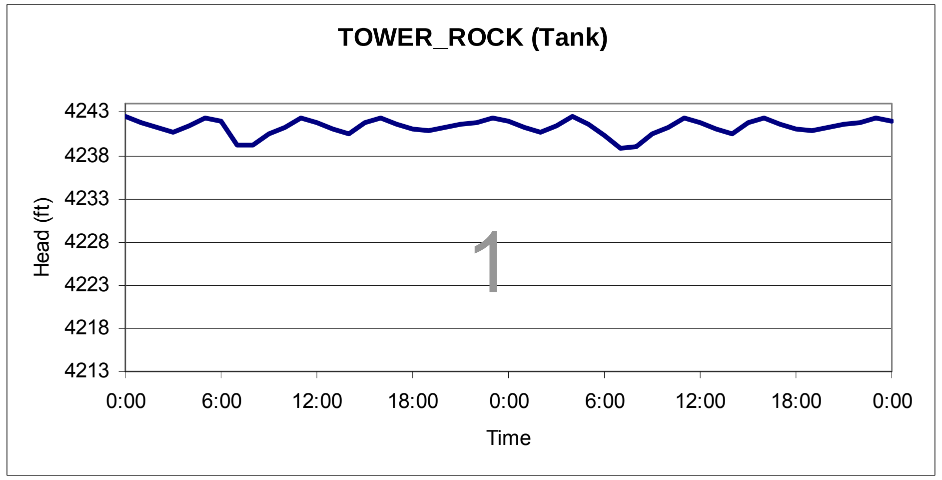


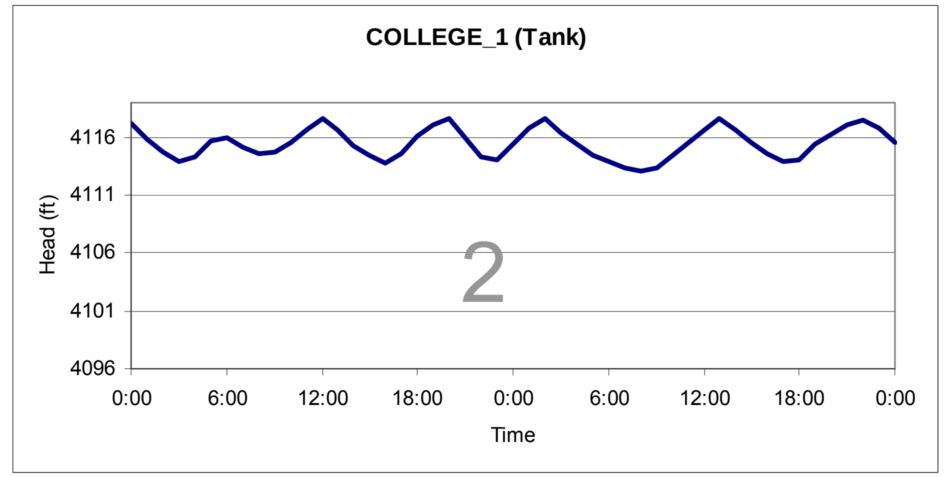


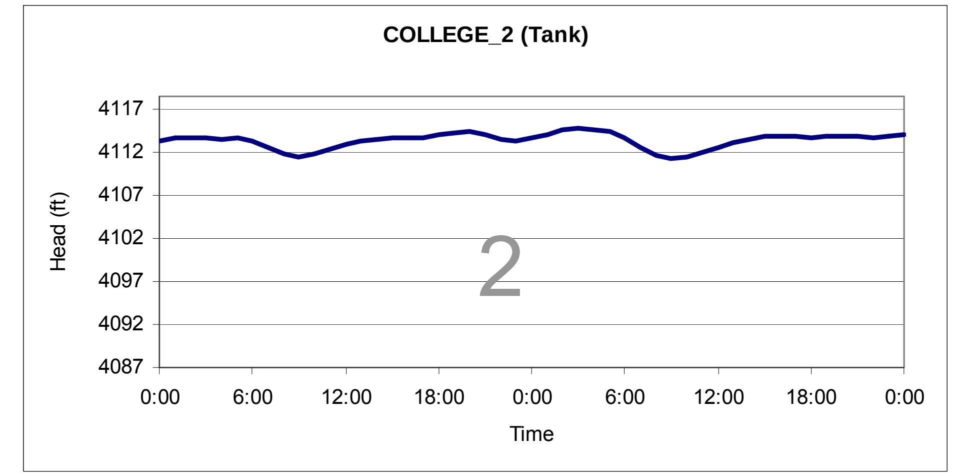


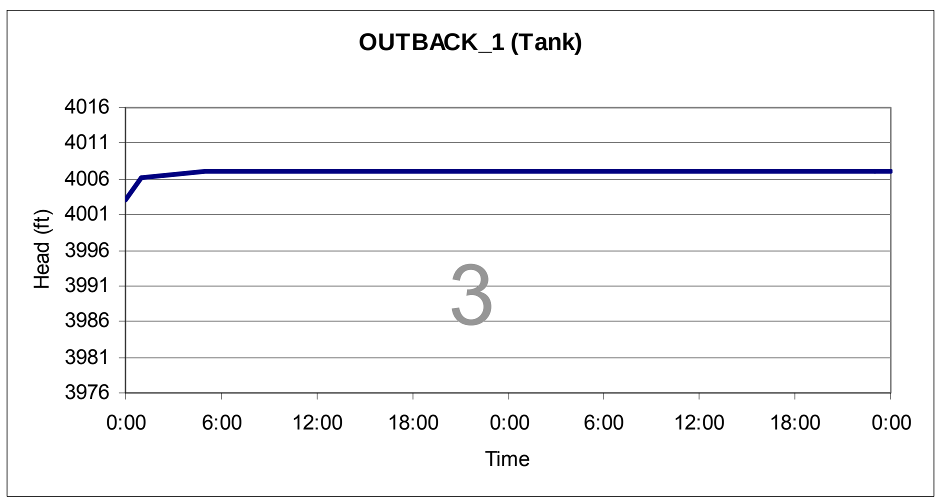


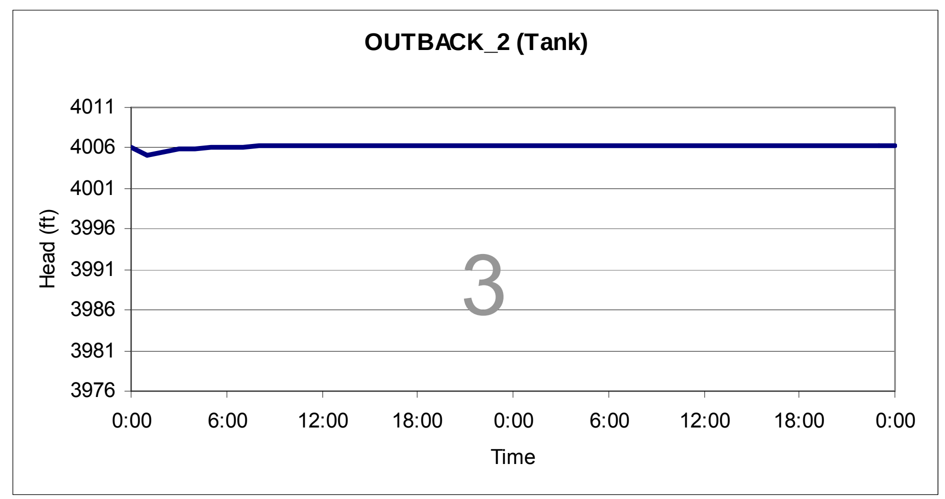
Summer Strategy #2 (without river wells)

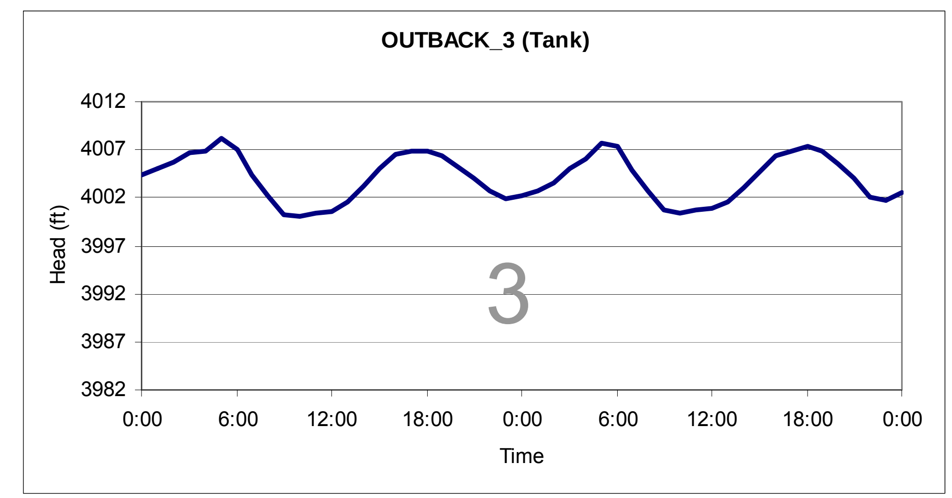


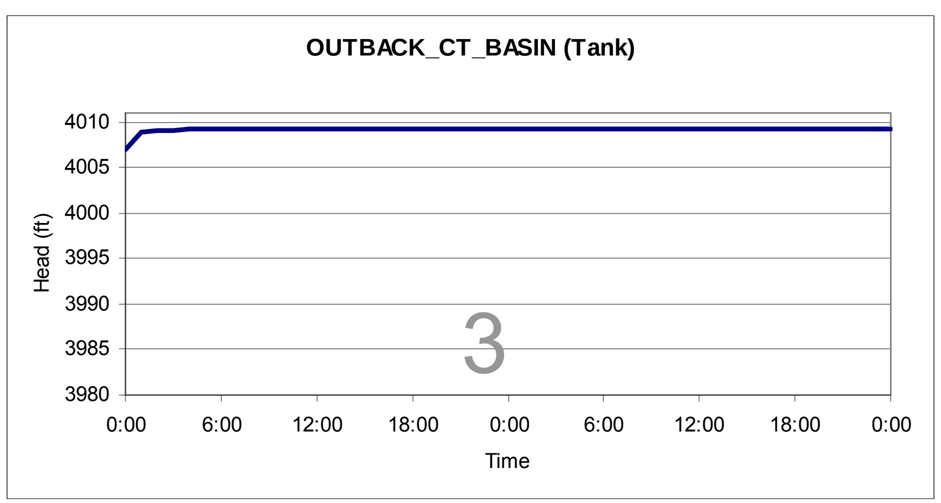


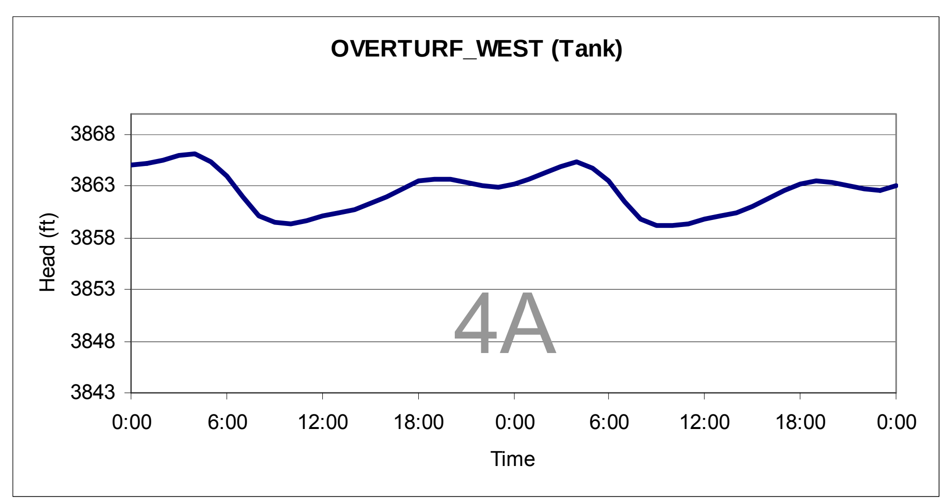


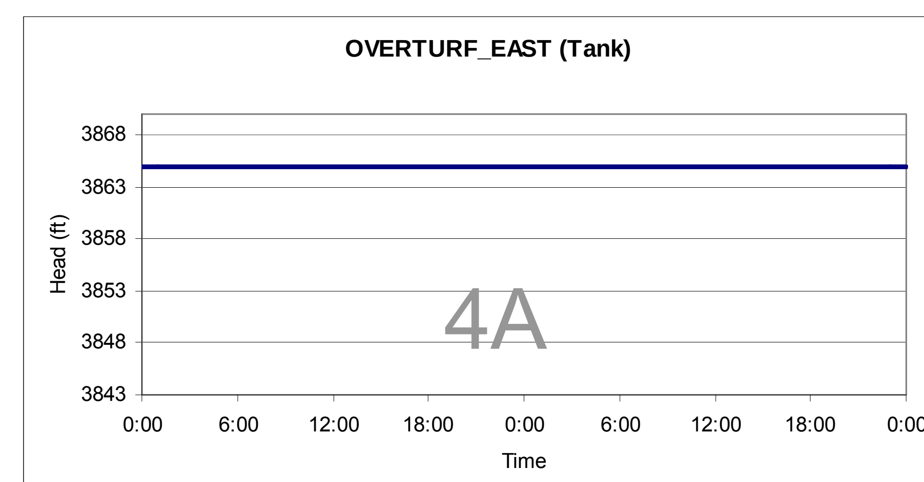




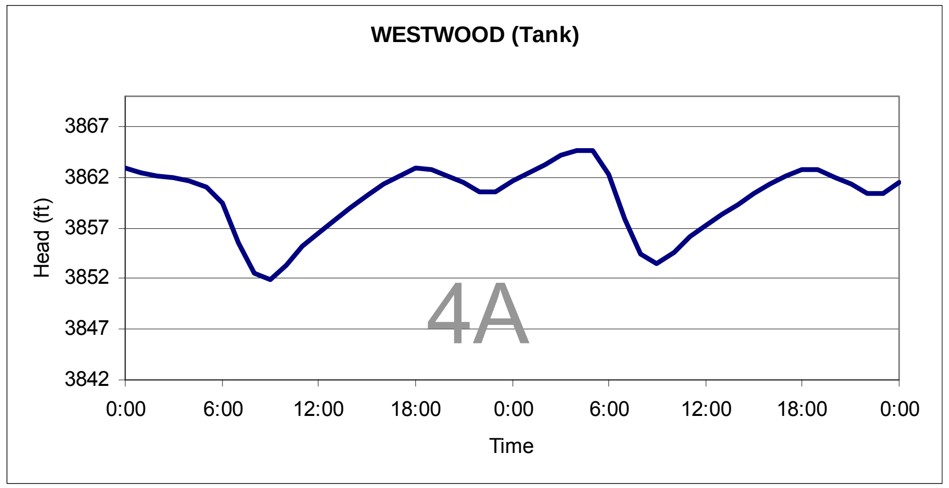


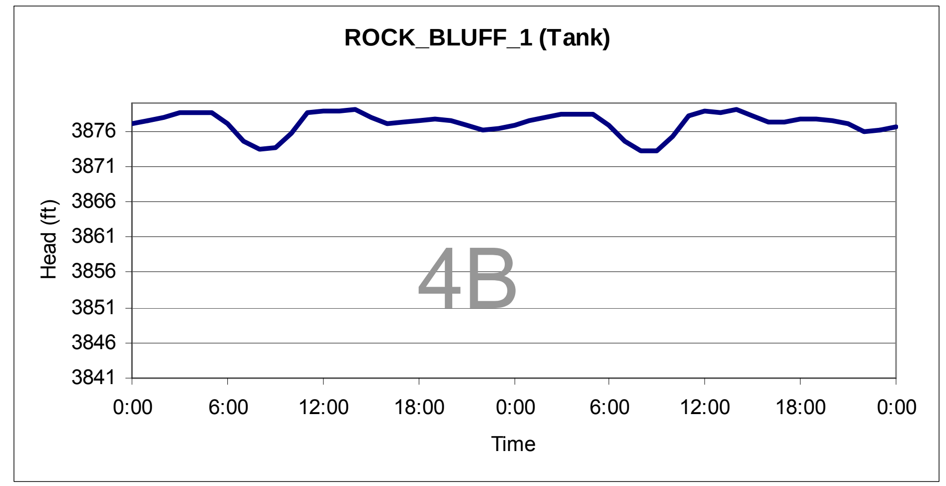


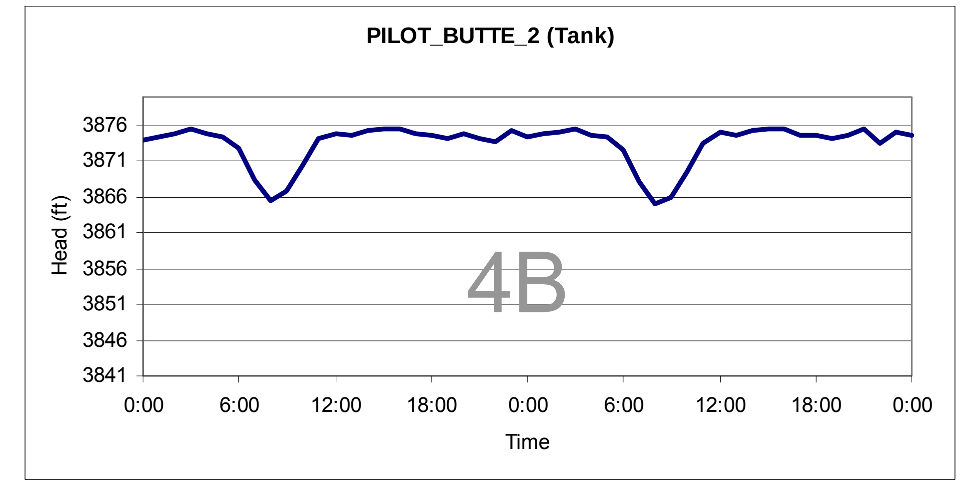


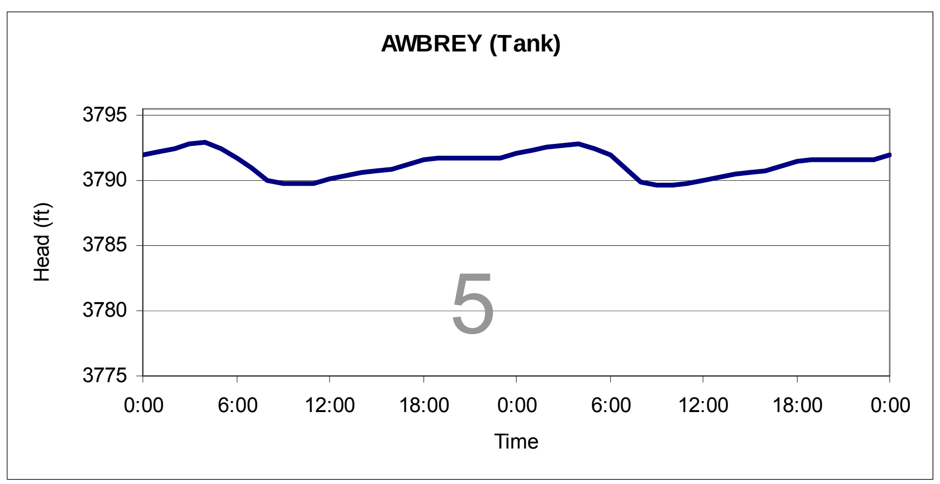


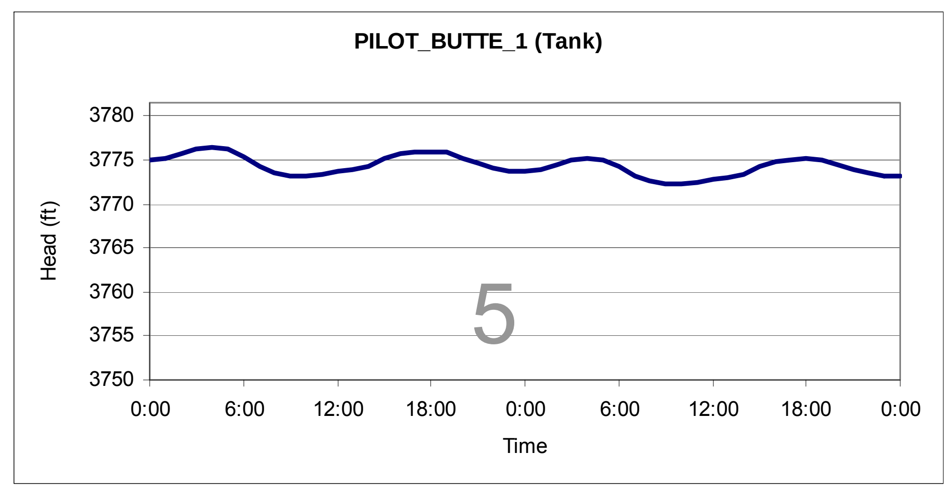
Summer Strategy #2 (without river wells)

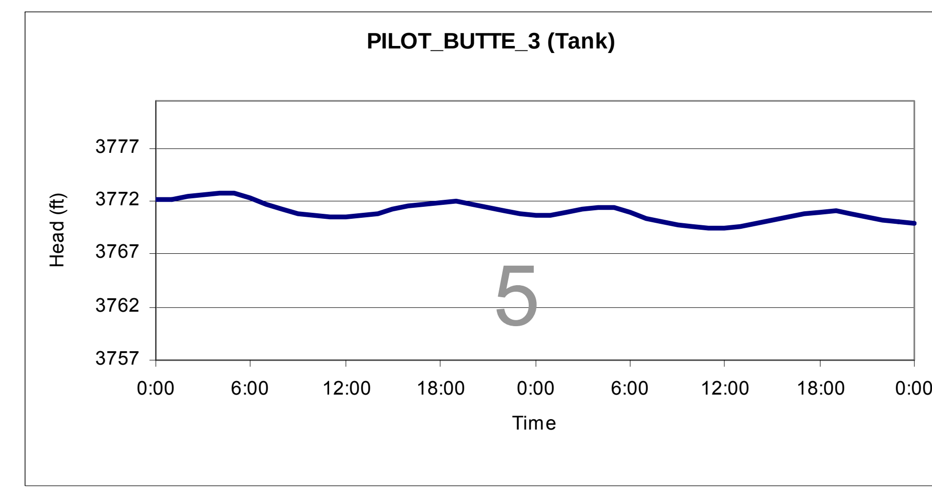




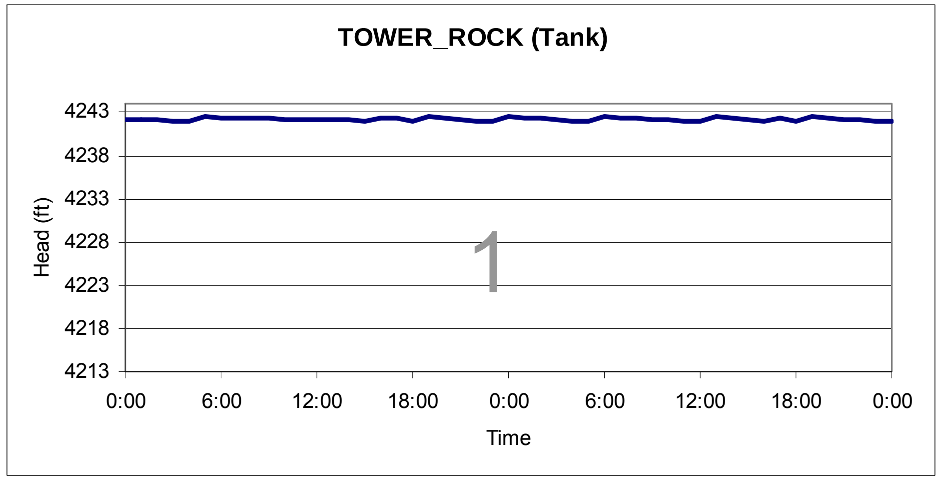


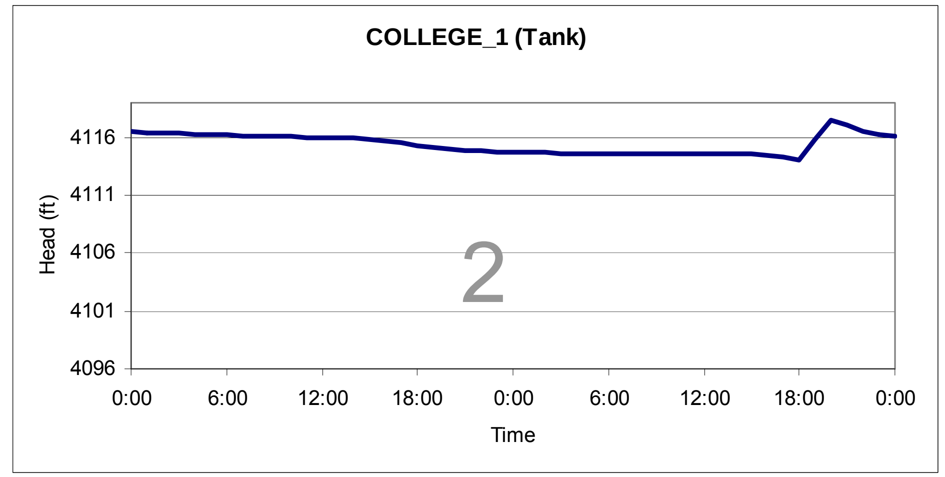


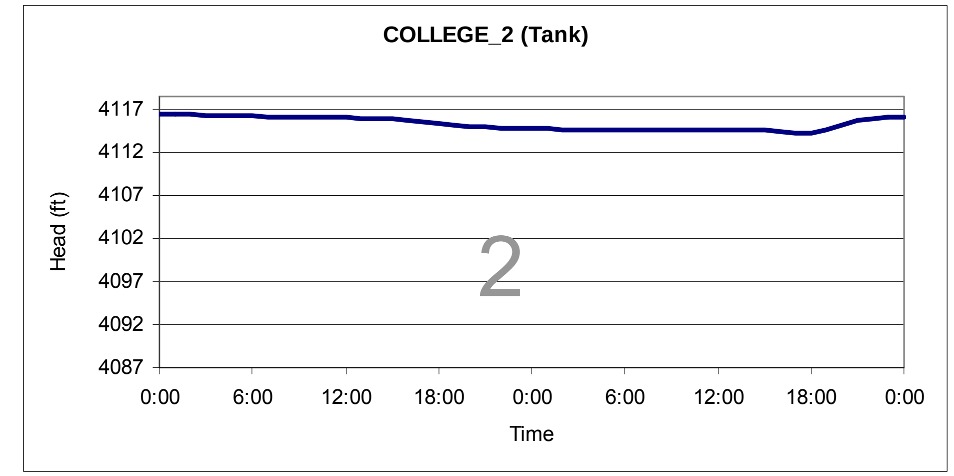


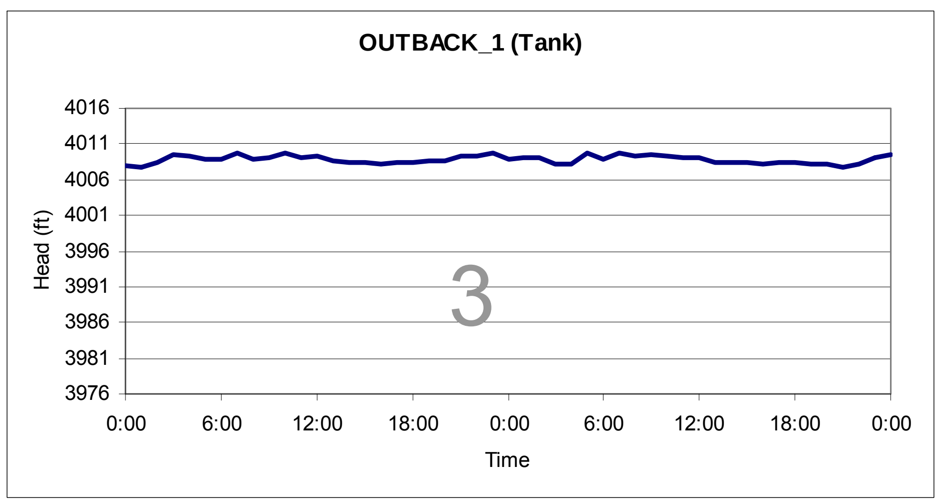


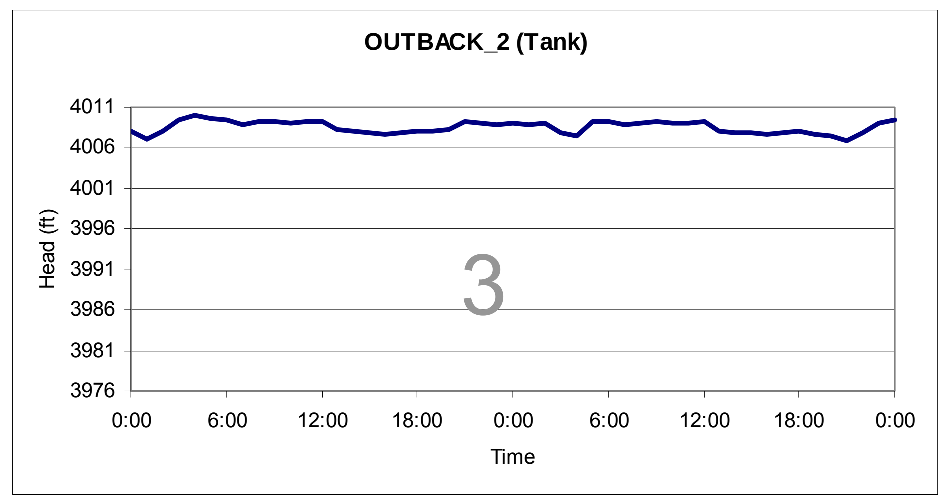
Appendix E – Optimized Solution – Winter – Tank Levels

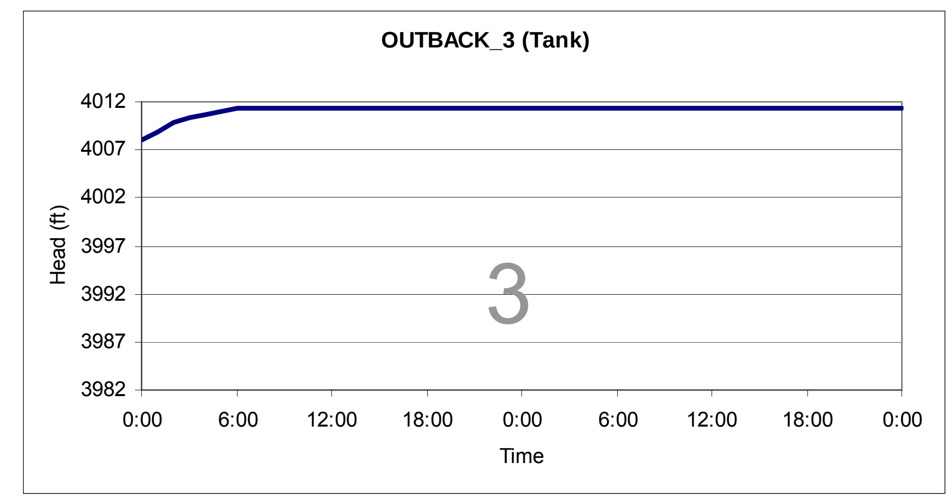


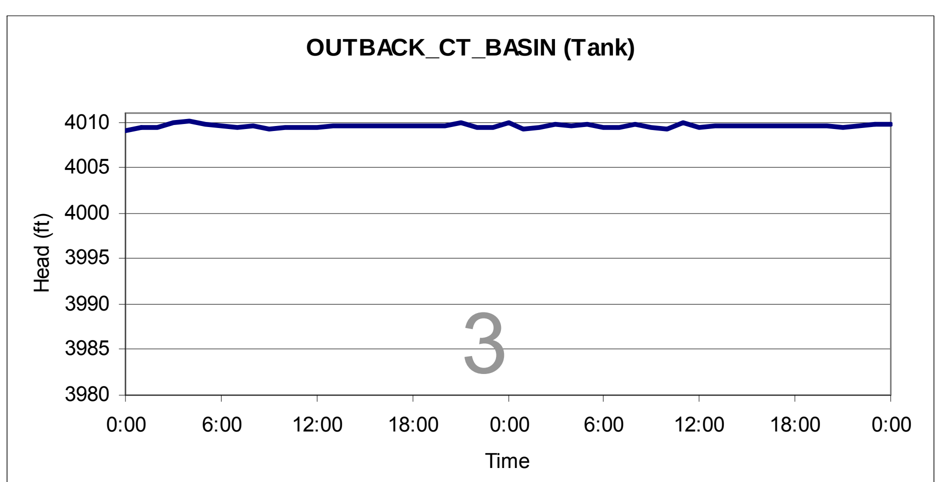


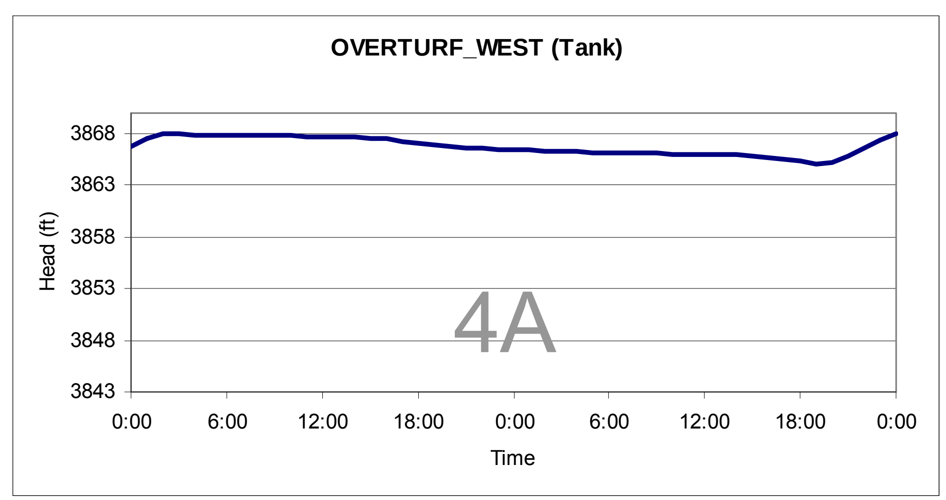


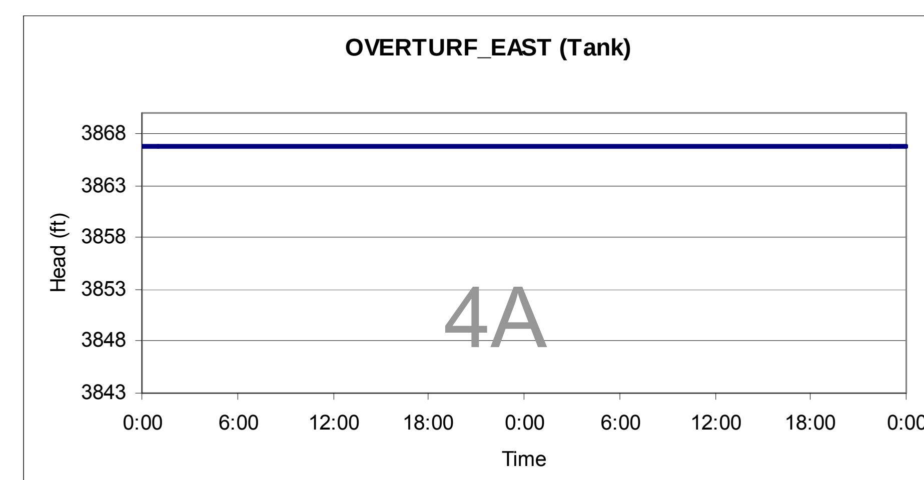












Optimized Winter Solution