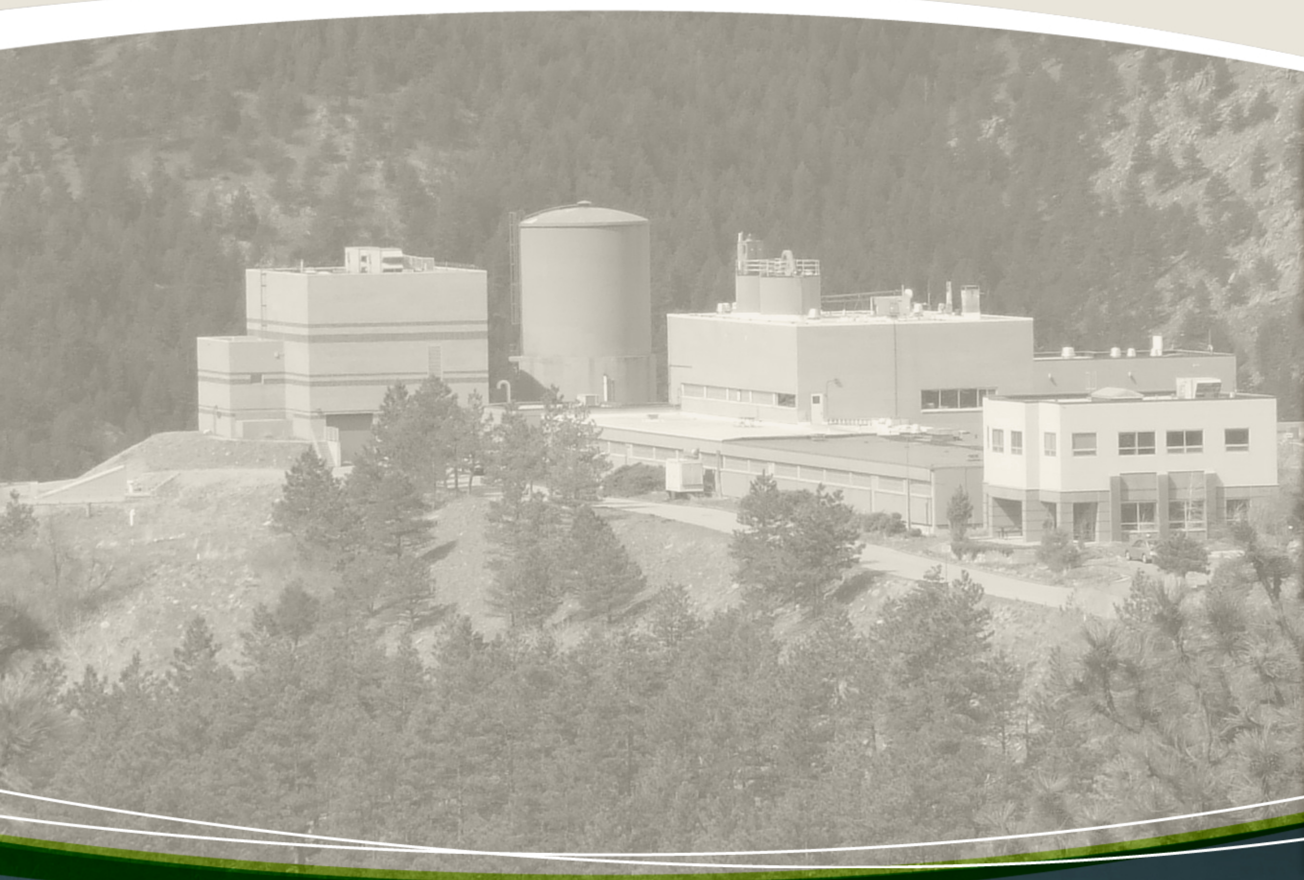
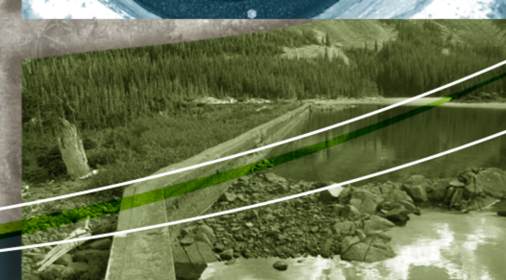
PREPARED FOR
CITY OF BOULDER

Treated Water Master Plan Update

OCTOBER 2011





WUMP VOLUME 5

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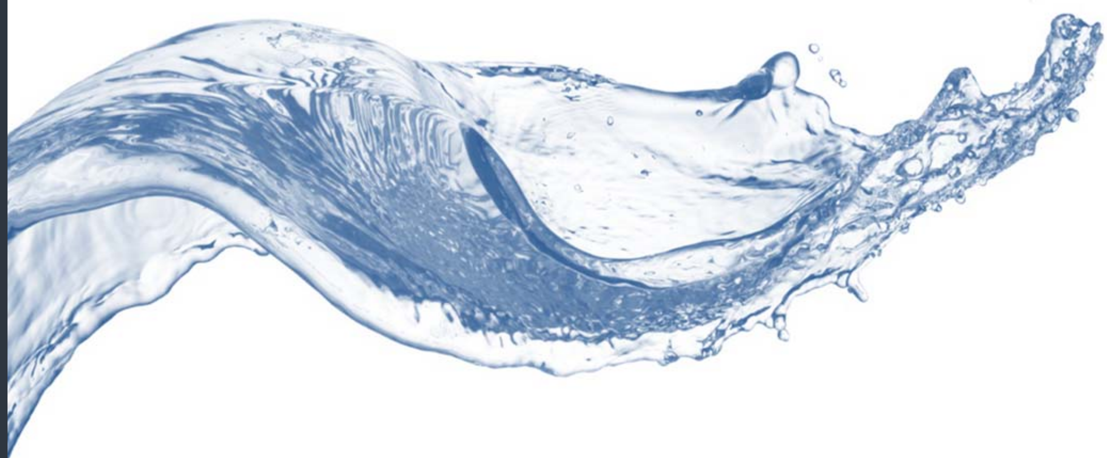
BUILDING A BETTER WORLD

VolumeFive

City of Boulder

Treated Water Master Plan Update



October 2011

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Acknowledgements

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1 Introduction

1.1 Purpose

The Treated Water Master Plan (TWMP) is intended to be a comprehensive summary of the City of Boulder's (City's) treated water system, including the Betasso Water Treatment Facility (BWTF), the Boulder Reservoir Water Treatment Plant (BRWTF), and the associated treated water storage and distribution facilities. The purpose of this TWMP is to describe and document the City's treated water system, provide an evaluation of the current conditions, and offer recommendations for improvements. This TWMP and its recommendations provide a framework for the management of the City's treated water systems in order to ensure reliable and safe treated water supply for the citizens of Boulder.

1.2 Information Sources

Many references were used in the preparation of this TWMP. Specific sources are identified throughout the document; however, some of the previous reports are summarized below:

- 2000-2010 City of Boulder Annual Reports
- 1999, City of Boulder Water Conservation Futures Study, 1999, Hydrosphere Resource Consultants, Inc.
- 2000 Treated Water Master Plan, Integra Engineering
- 2003 Boulder Reservoir Water Treatment Plant Predesign Report, MWH
- 2005 Betasso Water Treatment Facility – Facility Improvement Plan, Carollo
- 2007 Integrated Evaluation of the BRWTF Source Water Protection and Treatment Improvements Study (Integrated Study), Black & Veatch
- 2008 American Water Works Association (AWWA) Peer Review Report, QualServe™
- 2009 Water Quality Strategic Plan, City of Boulder (June 2009)
- 2010 Source Water Master Plan, MWH

In addition, this TWMP includes the information gained through several meetings with the City of Boulder staff, evaluations performed by MWH, and historical data provided by the City.

1.3 Report Organization

The TWMP consists of the following items and subsections:

- Section 1 Introduction
- Section 2 Description of the existing facilities and resources, including:
  - The raw water supply
  - Water treatment facilities
  - Treated water distribution system
  - System control
- Section 3 Summary of historical and new water quality regulations and goals
- Section 4 Review of historical treatment and distribution facilities reports and studies
- Section 5 Evaluation of water treatment plant and distribution system facilities
- Section 6 Asset management evaluation, including a summary of Betasso Water Treatment Facility and the Cherryvale/Iris pump stations, and an evaluation of the Boulder Reservoir Water Treatment Facility and the stranded facilities
- Section 7 Recommendations, conclusions, and recommended studies, including:
  - Previous study recommendations
  - Treatment facilities
  - Distribution system

1.4 List of Acronyms

The following list of Acronyms is provided for the benefit of the reader.

AL	Action Level
AWWA	American Water Works Association
BFC	Boulder Feeder Canal
BVCP	Boulder Valley Comprehensive Plan
BWTF	Betasso Water Treatment Facility
BRWTF	Boulder Reservoir Water Treatment Facility at 63rd Street
C-BT	Colorado-Big Thompson
CCL	Contaminant Candidate List
CCR	Consumer Confidence Reports
CDPHE	Colorado Department of Public Health and Environment
CIP	Capital Improvement Program
City	City of Boulder
CPE	Comprehensive Performance Evaluation
CT	Concentration X Time
CWSS	Community Water Supply Study
DAF	Dissolved Air Flotation
DBP	Disinfection Byproducts
D/DBPR	Disinfectants/Disinfection Byproducts Rule
EDCs	Endocrine Disrupting Compounds
EDSP	Endocrine Disruptor Screening Program
ESWTR	Enhanced Surface Water Treatment Rule

FBRR	Filter Backwash Recycling Rule
FTE	Full Time Equivalents
FY	Fiscal Year
GAC	Granular Activated Carbon
GAO	General Accounting Office
GIS	Geographical Information System
gph	gallons per hour
gpm	gallons per minute
GRW	Groundwater Rule
HAA_5	five Haloacetic acids
HDPE	High Density Polyethylene Pipe
HMWMD	Hazardous Materials and Waste Management Division
Hp	Horsepower
ICR	Information Collection Rule
IDSE	Initial Distribution System Evaluation
I&C	Instrumentation and Control
IESWTR	Interim Enhanced Surface Water Treatment Rule
IOCs	Inorganic Chemicals
kW	Kilowatts
LCR	Lead and Copper Rule
LRAA	Locational Running Annual Averages
MCLs	Maximum Contaminant Levels
MCLG	Maximum Contaminant Level Goal
MG	Million Gallons
MGD	Million Gallons per Day
mg/L	Milligrams per liter
MDD	Maximum Day Demand
MO	Motor Operated
MOA	Memorandum of Agreement
MRDLs	Maximum residual disinfectant levels
MRDLGs	Maximum residual disinfectant level goals
NCOD	National Contaminant Occurrence Database
NOM	Naturally occurring organic matter
NPDWRs	National Primary Drinking Water Regulations
NSDWRs	National Secondary Drinking Water Regulations
PAC	Powdered Activated Carbon
PLC	Programmable Logic Controller
PRVs	Pressure reducing valves
PSOCs	Potential sources of contamination
PWS	Public Water System
NTU	Nephelometric turbidity units
O&M	Operations and Maintenance
psi	Pounds per square inch
rpm	Revolutions per minute
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
SOCs	Synthetic organic chemicals
SOPs	System operating principles
SRF	State Revolving Fund
SWAA	Source Water Assessment Area
SWAP	Source Water Assessment and Protection Program
SWMP	Source Water Master Plan
SWPA	Source Water Protection Area
SWTR	Surface Water Treatment Rule
TCLP	Toxicity Characteristic Leaching Procedure
TCR	Total Coliform Rule

TCRDSAC	Total Coliform Rule/Distribution System Advisory Committee
TDH	Total dynamic head
TENORMs	Technologically Enhanced Natural Occurring Radioactive Materials
TOC	Total organic carbon
TTHM	Total trihalomethane
TWMP	Treated Water Master Plan
UCMR	Unregulated Contaminant Monitoring Regulation
UDF	Unidirectional Flushing Program
UFRV	Unit filter run volume
UMMS	Utilities Maintenance Management System
USEPA	United States Environmental Protection Agency
USPHA	United States Public Health Service
VOCs	Volatile organic compounds
WTF	Water Treatment Facility
WTP	Water Treatment Plant
WTRs	Water treatment residuals/sludge
WQCC	Water Quality Control Commission
WQCD	Water Quality Control Division
WQES	Water Quality and Environmental Services
WWTP	Wastewater Treatment Plant

2 Existing Facilities and Resources

Effective planning begins with an up to date description of the existing facilities that make up the treated water system. The City of Boulder's water system consists of raw water collection, storage, and conveyance facilities, hydropower facilities, two treatment plants, and treated water transmission, storage and distribution facilities. This section provides an overview of the system including:

- a brief summary of the source water system,
- a description of the BWTF,
- a description of the BRWTF, and
- a description of the treated water distribution system.

2.1 Raw Water Supply

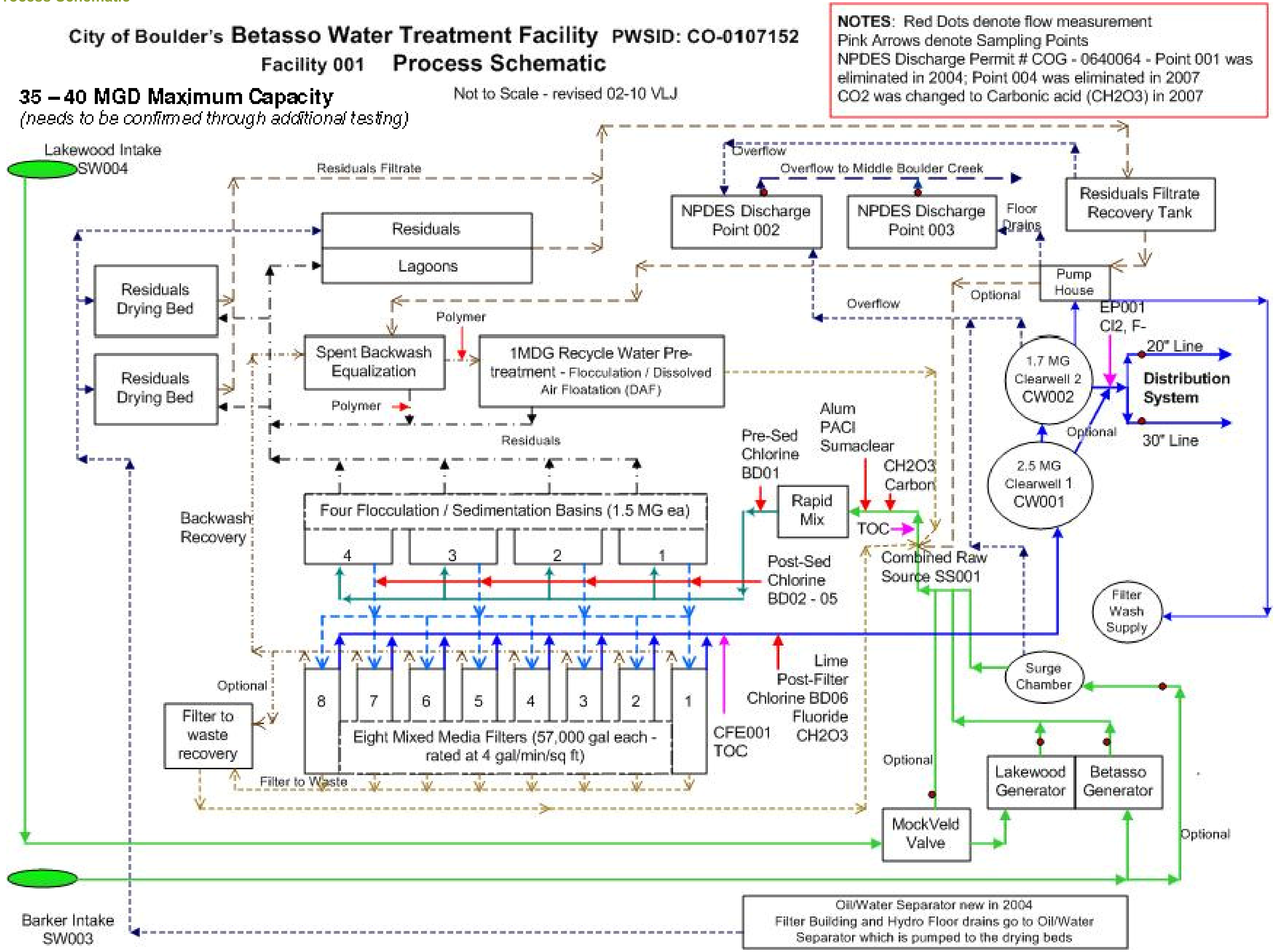
The City of Boulder derives its water supply from two surface water sources, the upper watershed of Boulder Creek and the upper Colorado River basin via the Colorado-Big Thompson (C-BT) Project transmountain diversion. The raw water supply system is described in detail in **Volume 4 – Source Water Master Plan (SWMP)**.

2.2 Water Treatment Facilities

2.2.1 Betasso Water Treatment Facility (BWTF)

The BWTF, located west of the city near Sugarloaf Mountain, was originally constructed in 1964. It was expanded to its present capacity in 1976. At about the time of the expansion, 50 MGD became widely accepted as the design capacity of the BWTF. Operational experience and an evaluation of historical data indicate that the actual capacity is somewhere between 35 and 40 MGD when considering operational goals of <0.1 NTU, 95% of the time. Further stress tests are needed to confirm the true capacity of BWTP. Over the years, numerous minor improvements have been made to the plant and a major upgrade to the chemical systems was completed in 1996. At present, another major upgrade is planned that will improve the solids handling systems and enhance filter performance. The existing plant is depicted schematically on **Figure 5-1**. Treatment consists of coagulation, flocculation, sedimentation, filtration, and disinfection. Polyaluminum chloride and alum are used as coagulants. Facilities to feed powdered activated carbon for taste and odor control are available, but not used. Except for the polymer, which is a component of the polyaluminum chloride compound, no polymer is used at present for coagulation/flocculation. The plant has four covered double-deck flocculation/settling basins, with horizontal paddle wheel flocculators and solids collection equipment on the lower level. Solids are discharged to sludge drying beds where they are dried prior to offsite disposal by land application. The filtrate and decant from the drying beds drains by gravity to the sludge filtrate equalization tank and is pumped to the spent backwash equalization (SBE) basin of the recycle pretreatment facility.

Figure 5-1: BWTF Process Schematic



There are eight constant-rate, mixed-media (anthracite, sand, and garnet) filter units. Filtered water is dosed with fluoride and disinfected by chlorination. Lime and carbon dioxide are added for corrosion control prior to discharge to dual clearwells. Surface washing capability is provided and the filter media is supported by Leopold underdrains. Filter backwash is discharged into the SBE basin. From the SBE basin, the filter backwash water is pumped to the dissolved air floatation (DAF) process where it is thickened. Subnatent is returned to the head of the plant and mixed with raw water for treatment. Thickened residuals are sent to the lagoons. Filter backwash can also be discharged to the filter to waste tank and then pumped back to the head of the plant.

The following paragraphs describe the BWTF process facilities in greater detail. An inventory of the major components of the BWTF is provided in **Table 5-1**.

Table 5-1: Betasso Water Treatment Facility Design Data

Item	Design Data	Notes
Design Flow	50 (million gallons per day) MGD	Although the design flow for the BWTF is 50 MGD, the actual capacity is likely to be 40 MGD or less, due to seasonal variations in water quality, flow splitting, pretreatment, and filter performance and process equipment conditions that limit the capacity.
Raw Water Supply		
Lakewood Pipeline	24-inches, 20 MGD (short term emergency conditions up to 30 MGD)	
Barker Pipeline	27.7 MGD (short term emergency conditions up to 40 MGD, longer term emergency conditions up to 30.1 MGD)	
Pressure Reduction		
Barker Pipeline	VAG PRV	Controlled through the Betasso hydro generation facility or the new VAG valve
Lakewood Pipeline	24-inch Mokveld PRV	Controlled through the Lakewood hydro generation facility or the Mockveld valve
Influent Flow Measurement		
Barker Vault		The Parshall flume is located in the lime room under the steel walk plates. There is an ultrasonic level indicator that is located on a stilling well in the lime room. This stilling well is connected by a 2" diameter line to the flat portion of the flume from the bottom. This 2" line and stilling well can be located from the filter gallery basement. The ultra-sonic level indicator on this stilling well measures the water level and the flow into the plant and then SCADA calculates flow from this level. There is a 2" hypochlorite line that runs perpendicular to the flow of the water downstream from the stilling well 2" line. This line is within the flow of water and could be compromising the accuracy of the ultra-sonic flow indication. This line is slated to be moved to above the maximum water level of the flume in the winter of 2010 for this reason.
Type	Differential pressure	
Lakewood Vault		
Type	Differential pressure	
Combined		
Type	Parshall flume	
Size	5 feet	
Level Measurement	Ultrasonic level sensor	

Item	Design Data	Notes
Rapid Mix		
Type	Pumped Diffusion	Installed in 2006.
Flow	800 gpm	
Pump Type	Horizontal Centrifugal	
Flocculation/Sedimentation		
Number of Basins	4	
Type	Rectangular over/under	
Dimensions		
Flocculation Zone	79.5' × 36.5' × 10'	
Sedimentation Zone	85' × 71' × 11' lower level plus 85' × 107' × 8' upper level	
Flocculators	Horizontal paddle, 6' diameter	
Stages	3	
Sludge Collector	Chain and flight	
Detention Time	Flocculation – 25 minutes Sedimentation – 2 hours	
Filtration		
Number	8	New media in 1995, recapped with anthracite 1998, recapped #4-8 with anthracite again in 2009. Loading rate value is with one unit offline. An old level sensor that utilizes compressed air to read the still-well level of the basins is located in the lime room. This level sensor is the master filter level control and provides feedback to the filters and tells them whether to increase or decrease flows to keep the basins and filters at the correct level. This instrument is on a still-well that is connected to the 36" filter flume header.
Type	Mixed – anthracite/sand	
Surface Area, each	1,056 ft^2	
Loading Rate @ 50 MGD	4.7 gpm/ft^2	
Filter level control	Compressed air level sensor	
Backwash		
Backwash Rate	5 to 15 gpm/ft^2	Low rates (5-7 gpm), high rates (13-17 gpm)
Wash Water Pumps		1-5 hp emergency backup pump
Number	2	
Capacity, each	972 gpm	
Wash Water Supply Tank		
Type	Welded steel	
Diameter	32.5 feet	
Water Depth	32 feet	
Capacity	200,000 gallons	
Spent Backwash Equalization (SBE) Basin		
Type	Concrete walls, asphalt-concrete floor	Clari-Vac® sludge removal
Dimensions	41 ft wide × 121 ft long × 18 ft high	
Water Depth	13 ft (height of overflow weir)	
Capacity	700,000 gallons	

Item	Design Data	Notes
Dissolved Air Floatation (DAF)		
DAF Thickener		Polymer can be added to aid in thickening SBE sludge.
Type	Nordic Water Products®	
Capacity	1 MGD	
Chemical Systems		
Alum	Liquid	
Storage Tanks	Two at 12,700 gallons each	
Feed Pumps	Two at 66.12 gph	
Average Dosage	10-12 mg/L	
Polyaluminum Chloride	Liquid	
Type	Sumaclear® 820B	
Storage Tanks	Four at 1165 gallons Four at 900 gallons	
Feed Pumps	Two at 69.66 gph	
Average Dosage	5-7 mg/L	
Powered Activated Carbon	Slurry	
Bulk Storage Tank	48,800 gal	
Feed pumps	One at 69.66 gph	
Dose	5-7 mg/L	
Lime		
Storage Hoppers	2	
Capacity, each	25 tons	
Feeders		
Number	1, 1	
Type	1 Volumetric screw, 1 Metered Pump	
Rate	3,800 lb/day	
Average Dose	25 mg/L	
Fluoride	Liquid Hydrofluorosilicic acid	
Storage Tank	One at 8,450 gallons	
Feed Pump		
Number	1	
Type	Pulsa	
Range	One at 12.73 gph	
Average Dose	0.9 mg/L	
Carbon Dioxide	Gas	
Type	Tomco® feed system	
Disinfection		
Type	Sodium hypochlorite 10% solution	
Storage	5 tanks at 4,000 gallons, each	
Average Dose		
Pre	1.5 mg/L	
Post	1.3 mg/L	

Item	Design Data	Notes
Clearwell		
Number	2	
Type	Welded steel	
Capacity		
Tank 1	2.5 MG	
Tank 2	1.7 MG	
Overflow Elevation	6,378	
Water Depth	34 feet	
Treated Water Transmission		
Flow Measurement	Venturi Tubes	
Sunshine Canyon Pipeline	30-inch, 50 MGD	
Boulder Canyon Pipeline	24-inch, 10 MGD	
Solids Handling		
South Lagoons		
Number	2	
Length	200 feet each; 400 feet total	
Width	50 feet	
Surface Area	10,000 ft^2 each; 20,000 ft^2 total	
Side Water Depth	5.1 feet	
Freeboard	1.5 feet	
Working Depth	3.6 feet	
Working Volume	269,500 gallons each; 539,000 gallons total	
North Lagoons		
Number	2	
Length	143 feet	
Width	48 feet	
Surface Area	7,000 ft^2 each; 14,000 ft^2 total	
Depth	4 feet	
Volume	208,000 gallons each; 416,000 gallons total	
Residuals Drying Bed		
Type	Concrete Pad	
Length	120 ft	
Width	75 ft	

2.2.1.1 Hydroelectric Generation

Four hydroelectric generation facilities are currently in service that generates power from the raw water feeding BWTF. **Table 5-2** provides a summary of these facilities.

Table 5-2: Summary of Raw Water Hydroelectric Generation Facilities

Hydro Name	Placed into Service	Capacity in kW	2009 Annual kWh	2006 Annual Revenue
Betasso Hydro	1987	6,400	16 Million	$922,969
Lakewood Hydro	2004			
Silverlake Hydro	1999	3,200	10.7 Million	$596,328
Boulder Hydro	2001	10,000	11.8 Million	$286,788
Total		**19,600**	**38.5 Million**	**$1,806,085**

2.2.1.2 Pressure Reduction

Pressure reduction on the Barker Pipeline is controlled through the hydroelectric facility or by a VAG-Armaturen pressure reducing valve (PRV). Pressure in the Lakewood Pipeline is reduced by a Mockveld PRV on site. A strainer is installed ahead of the PRV to keep larger material out of the PRV. The Mockveld PRV reduces the incoming pressure from about 300 pounds-per-square-inch (psi) to approximately 10 psi. A rupture disk designed to fail at 50 psi is installed in a branch line on the downstream side of the PRV. This safety system discharges to a natural drainage downhill from the PRV station. The Lakewood Pipeline also has a hydroelectric turbine/generator that is used for pressure reduction.

2.2.1.3 Raw Water Blending

Raw water from the Silver Lake/Lakewood Reservoir and Barker Reservoir sources is metered and blended together in a yard vault a short distance south of the plant. The vault also houses valves for controlling the total amount of flow and the relative proportions of water from each source.

2.2.1.4 Flocculation/Sedimentation

The plant has four flocculation/sedimentation basins. Two were constructed as part of the original plant in 1963 and the other two were added when the plant was expanded in 1975. Basins are two-level with flocculation and sedimentation on the lower level and sedimentation on the upper level. Water enters the basin at the west end of the lower level and passes through three stages of flocculation aided by horizontal paddle wheels. The flocculation zone has baffles hanging from the ceiling between flocculators and it appears that this arrangement allows the flow to pass through the flocculation zone by a direct path that does not promote optimal flocculation. After flocculation the water passes into sedimentation. On the lower level of the basin settled sludge is moved by a chain-and-flight collector to a trough at the east end of the basin where it is conveyed by an auger to a draw off pit where a manually actuated mud valve allows for periodic draw off to the sludge drying beds. Process flow rises along the east end of the basin to the upper level. Vertical baffles made from redwood boards staggered to provide baffled slots are provided to distribute flow at the upstream and downstream ends of the upper level. Basins 1 and 2 have the original mechanical variable speed controls to vary the flocculator drive speed. These are old and worn and are hard to adjust making it difficult to fine-tune the flocculator speed. Basins 3 and 4 have been retrofitted with electronic variable speed units, which are very easy to adjust to facilitate optimization of process operation.

2.2.1.5 Filtration

There are eight filters, four built with the original plant in 1964 and four built when the plant was expanded in 1976. Filters are mixed media with simple perforated tile underdrains manufactured by Leopold. The mixed filter media contains anthracite, quartz sand, and garnet. The filter media was replaced in 1995 and was recapped with anthracite in1998 due to media loss (this media loss was likely the result of buoyancy caused by entrained air that has now been fixed). The filters were again recapped in 2009.

Filters are operated on a constant rate basis with backwashing manually initiated on a run time basis. The old loss-of-head meters are in place, but ultrasonic level sensors are used instead. A flow meter and a rate of flow control valve are installed on each filter effluent line to control flow. Turbidity meters installed on each filter effluent provide one of the essential parameters used in operating the plant. Particle counters were installed in the mid-2000's on each filter and the combined filter effluent.

Backwashing is accomplished by gravity flow from the backwash reservoir. Finished water is pumped from the plant clearwells to the backwash reservoir to provide sufficient hydraulic head for the backwashing process. Backwash flow is controlled by a flow meter and rate control valve in the line from the backwash reservoir. A surface wash system is provided to enhance cleaning of media during backwashing. The filters at BWTF also have filter to waste capability.

2.2.1.6 Chemical Addition

Chemical systems include facilities for the addition of the following chemicals:

- **Alum**
  - Primary coagulant.
  - Stored and fed as liquid.
  - Fed in the influent line with a chemical application stinger
  - Fed alone at times or fed along with PACl, see below.

- **Chlorine**
  - Fed at a single location prior to sedimentation or at the effluent of each of the four flocculation/sedimentation basins, manual flow control.
  - Fed after filtration for disinfection and to maintain a residual out into the distribution system, PLC controlled flow pacing, and no residual trim.
  - Used a gas chlorine system until early 2000 when the process was converted to aqueous chlorine, (sodium hypochlorite, NaOCl, "bleach") primarily for public and employee safety.

- **Polyaluminum Chloride**
  - Prior to 1998 meeting the then current filtered water turbidity limit of 1 NTU 95 percent of the time was often difficult particularly during the spring runoff season when raw water alkalinity and pH are lower than normal and TOC concentrations become elevated. These conditions combine to reduce the effectiveness of alum coagulation. To address this problem, the existing alum storage tank and feed equipment was adapted to the use of Polyaluminum chloride (PACl) (Sumaclear®) as a coagulant aid. In 2006, the existing storage tanks and feed pumps were relocated and two new tanks were installed. Alum and PACl are fed together at the head of the influent channel flume.
  - The addition of PACl made a significant difference in performance resulting in current average filtered water turbidities of 0.024 NTU (average of last 3 years). However, plant staff is still studying alternative application points and optimal combinations and locations of alum/PACl feed points to optimize the process to reliably meet the regulatory requirements.

- **Powdered Activated Carbon (PAC)**
  - A system is available for delivery of powdered activated carbon. This system mixes the powdered activated carbon with water to create and store slurry, as well as feeds the slurry to the raw water influent flume to control taste and odor. This system was rehabilitated and upgraded as part of the 1996 plant improvements and is only occasionally utilized
  - In 2010 PAC was also used to treat the filter backwash water.

- **Polymer**
  - The plant does not currently have a flocculant aid polymer system.
  - Polymer is used for plant recycle pretreatment and sludge thickening

- **Fluoride**
  - Fluoride is added to the water after filtration.
  - Liquid hydorfluorosilicic acid is stored in a single tank.
  - Added to the flow in the finished water flume.

- **Lime**
  - Lime slurry is fed into the finished water flume to increase alkalinity.
  - Hydrated lime is stored in two silos installed in 1996 as part of the plant upgrade. Silos have bin activators and air fluff systems to improve the lime feed.
  - Lime blenders installed in 1996 did not work well and were redone in 1997. Among other modifications, the concentration of the lime slurry was increased from 3% to 20% resulting in overall better performance with less scaling in the hoses. Even with these modifications, maintenance is still high.

- **Carbonic Acid**
  - Fed to the raw water through a diffuser upstream of the rapid mixer.
  - Fed to the finished water through a diffuser in the final filtered effluent pipe upstream of the clearwells to adjust final pH for corrosion control, PLC controlled pH trim.
  - 50 ton storage cylinder located in yard just south of main plant building.

- Chemical systems can be monitored through the SCADA system but many are manually operated except as noted above. With respect to the manually controlled chemical feed systems, chemical feed rates are manually calculated to match flow depending on solution strength and process requirements and metering pumps are manually adjusted to attain the desired feed rate.

- **Chemical Mixing**
  - Mixing of treatment chemicals with influent flow utilizes a mechanical pumped diffusion flash-mixer which was installed in 2006. Installation of the system reportedly did not improve treatment. The system is sized to provide mixing at a plant flow of 46 MGD and should be more than adequate for current flows of 20 to 30 MGD. The rapid mix system is limited in its effectiveness.

2.2.1.7 Residuals

The residuals drying lagoons collect sludge from the sedimentation basins, the SBE basin, and the DAF thickener. Decant from the residuals drying lagoons is sent to the residuals filtrate recovery tank and then on to the SBE basin that discharges to the DAF. Waste filter backwash water is conveyed to the spent backwash equalization tank and then on to the DAF. Filter to waste flows are conveyed to the filter to waste recovery tank and then returned to the main flow stream just upstream of the rapid mixer. The concrete pad is used for drying and storing the dried residuals. Polymer is used for both plant recycle water and sludge thickening.

The DAF and variable speed pumping system were installed in 2000 to improve the quality of the backwash water returned from the basin to the head of the plant and deliver it steadily to eliminate “slug” loading on the plant process created by the existing backwash water return system. A 700,000-gallon equalization basin to hold filter backwash water and sludge lagoon decant was also constructed at this time. Modifications were made to the filter effluent piping to convert the old backwash water holding tank to a filter-to-waste holding tank.

In 2006 the existing sludge drying beds were demolished and new deep bed sludge dewatering lagoons were constructed. The City also experimented with modifications to the north lagoons to replicate sand drying bed functionality, but these modifications proved to be problematic due to the clogging of the sand and afforded no improvement to the residuals handling process.

2.2.2 Boulder Reservoir Water Treatment Facility (BRWTF) at 63rd Street

The BRWTF was originally constructed in 1971 to provide additional water treatment capacity during summer peak flow periods and to treat water from the City’s C-BT/Windy Gap source. The plant is normally operated in the range of 3.5-8.5 MGD but is commonly run at up to 12 MGD during peak demand periods. The current treatment capacity of BRWTF is 16 MGD. A process schematic for the existing facility is shown on **Figure 5-2**.

The BRWTF generally operates during the peak demand months and can be shut down for the remainder of the year. Several factors dictate the use of the BRWTF, including the relatively high cost of treating water at the BRWTF as compared with BWTF, best use of water resources, and periodic shutdowns at the BWTF or portions of the distribution system. When factors such as the costs of the raw water and raw and treated water pumping are considered, the cost of treated water from the BRWTF is approximately twice the cost of treated water from BWTF.

The following paragraphs describe the BRWTF process facilities in greater detail. An inventory of the major components of the plant is provided in **Table 5-3**.

Table 5-3: Boulder Reservoir Water Treatment Facility Design Data

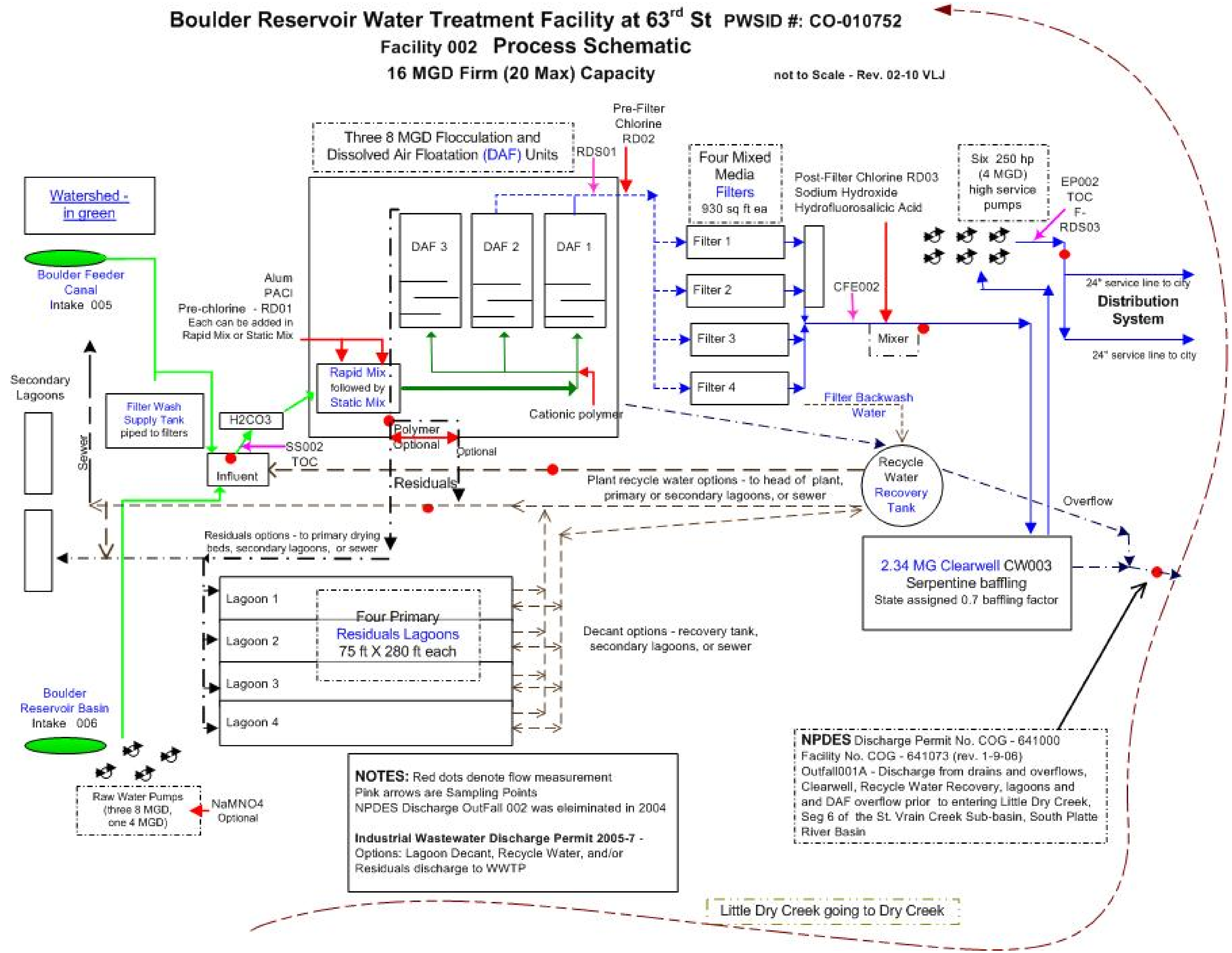
<table>
<tr><th>Item</th><th colspan="2">Design Data</th><th>Notes</th></tr>
<tr><td>Design Flow Rate</td><td colspan="2">16 MGD (avg.)/20 MGD (peak)</td><td rowspan="11">20 MGD peak capacity can only be achieved with adjustment of DAF float scraper mechanisms and resolution of finished water pump performance issues</td></tr>
<tr><td colspan="3">Raw Water Supply</td></tr>
<tr><td>Boulder Feeder Canal</td><td colspan="2">30 MGD</td></tr>
<tr><td colspan="3">Storage</td></tr>
<tr><td>Boulder Reservoir</td><td colspan="2">12,800 acre ft</td></tr>
<tr><td colspan="3">Raw Water Pumps</td></tr>
<tr><td>Type</td><td colspan="2">Vertical turbine</td></tr>
<tr><td>Number</td><td>3</td><td>1</td></tr>
<tr><td>Capacity</td><td>5,600 gpm</td><td>2,800 gpm</td></tr>
<tr><td>TDH</td><td>27 feet</td><td>27 feet</td></tr>
<tr><td>Rated hp</td><td>60</td><td>30</td></tr>
<tr><td colspan="4">Influent Piping</td></tr>
<tr><td colspan="3">Flow Measurement</td><td rowspan="7"></td></tr>
<tr><td>Type</td><td colspan="2">Magnetic Flow Meter</td></tr>
<tr><td>Operating Range</td><td colspan="2">0-25 MGD</td></tr>
<tr><td colspan="3">Flash Mixer</td></tr>
<tr><td>Type</td><td colspan="2">Pumped Diffusion Flash-Mixer</td></tr>
<tr><td colspan="3">Static Mixer</td></tr>
<tr><td>Size</td><td colspan="2">42 inches</td></tr>
<tr><td colspan="4">Flocculation/Clarification</td></tr>
<tr><td colspan="3">Flocculation Basins</td><td rowspan="19">Surface loading rate at 8 MGD per basin; current limit based on float scraper elevation</td></tr>
<tr><td>Number</td><td colspan="2">3</td></tr>
<tr><td>Type</td><td colspan="2">3-Stage Rectangular/Serpentine</td></tr>
<tr><td>Dimensions</td><td colspan="2">29' × 41.5' × 11' swd</td></tr>
<tr><td>Detention Time (ADF)</td><td colspan="2">18 minutes</td></tr>
<tr><td colspan="3">Flocculator Units</td></tr>
<tr><td>Type</td><td colspan="2">Vertical Shaft, Hydrofoil</td></tr>
<tr><td>Number Per Basin</td><td colspan="2">6</td></tr>
<tr><td>Rated hp</td><td colspan="2">2</td></tr>
<tr><td colspan="3">Clarification Basins</td></tr>
<tr><td>Number</td><td colspan="2">3</td></tr>
<tr><td>Type</td><td colspan="2">Dissolved Air Flotation (DAF)</td></tr>
<tr><td>Dimensions</td><td colspan="2">29' × 39' × 11' swd</td></tr>
<tr><td>Detention Time</td><td colspan="2">17 minutes</td></tr>
<tr><td>Surface Loading Rate</td><td colspan="2">4.9 gpm/ft^2</td></tr>
<tr><td colspan="3">Skimming Mechanism</td></tr>
<tr><td>Type</td><td colspan="2">Reciprocating</td></tr>
<tr><td>Number Per Basin</td><td colspan="2">1</td></tr>
<tr><td>Rated hp</td><td colspan="2">0.5</td></tr>
<tr><td colspan="3">Recycle Pumps</td><td rowspan="6">Common to all DAF Basins</td></tr>
<tr><td>Type</td><td colspan="2">Horizontal End Suction</td></tr>
<tr><td>Number of Units</td><td colspan="2">4</td></tr>
<tr><td>Capacity</td><td colspan="2">556 gpm</td></tr>
<tr><td>TDH</td><td colspan="2">250 feet</td></tr>
<tr><td>Rated hp</td><td colspan="2">75</td></tr>
</table>

Item	Design Data	Notes
Air Compressor System		
Type	Rotary Screw	
Number of Units	2	
Capacity	45 scfm	
Pressure (Maximum)	125 psig	
Rated hp	15	
Saturator Vessels		
Type	Vertical	
Number of Units	2	
Vessel Diameter	6.5 feet	
Vessel Height	14 feet	
Packing Depth	4 feet	
Operating Pressure	60-90 psig	
DAF Float Pumps		
Type	Progressive Cavity	
Number	3	
Capacity	34 gpm	
TDH	20 feet	
Rated hp	3	
Filtration		
Number	4	Filter loading rate with one filter offline at 20 MGD
Type	Constant-head	
Media	Mixed – anthracite/sand/garnet	
Surface Area, each	930 ft^2	
Loading Rate	5 gpm/ft^2	
Backwash		
Wash Water Pumps		
Number	1	
Capacity, each	1,071 gpm	
Wash Water Supply Tank		
Type	Welded Steel	
Diameter	36 feet	
Water Depth	25 feet	
Volume	190,000 gallons	
Recovery Tank		
Type	Concrete	
Diameter	65 feet	
Water Depth	25 feet	
Capacity	620,000 gallons	
Return Pumps		
Number	2	
Capacity, each	900 gpm	

Item	Design Data	Notes
Chemical Systems		
Polyaluminum Chloride	Liquid Sumaclear 803B	Primary Coagulant
Storage Tanks	Two at 10,000 gallons each	
Feed Pumps		
Number, feed rate	Two at 108 gph each	
Type	Peristaltic, WM 624U	
Feed Range	1.8 to 216 gph total	
Average Dosage		
Source: Reservoir	0.09 mg/L (active polymer)	
Source: Big Thompson	0.03 mg/L (active polymer)	
Aluminum Sulfate		Alternate Primary Coagulant
Storage Tanks	Liquid	
Feed Pumps	Two at 7,000 gallons each	
Number, feed rate	Two at 108 gph each	
Type	Peristaltic, WM 624U	
Feed Range	1.8 to 216 gph total	
Average Dosage		
Source: Reservoir	50 mg/L	
Source: Big Thompson	25 mg/L	
Cationic Polymer (Peak)	Liquid Peak Poly	Coagulant/flocculation aid
Storage Tanks	One at 100 gallons (storage); One at 30 gallons (day)	
Feed Pumps		
Number, feed rate	One at 186 maximum gph	
Type	Progressive Cavity	
Feed Range	0 to 186 gph	
Average Dosage		
Source: Reservoir	0.1 to 0.3 mg/L	
Source: Big Thompson	0.1 to 0.3 mg/L	
Caustic Soda (NaOH)		pH adjustment
Storage	Two at 11,500 gallons each	
Feeder		
Number, feed rate	Two at 42 gph each	
Type	Pulsa 880	
Feed Range	0 to 84 gph	
Average Dose	15 mg/L	
Fluoride		Background levels of fluoride are between 0.2-0.3 mg/L depending on source
Storage	Hydrofluorosilicic acid	
Feeder:	9,000 gallons	
Number, feed rate	One at 12.75 maximum gph	
Type	Pulsa 680	
Feed Range	0 to 12.75 gph	
Average Dose		
Source: Reservoir	0.7 mg/L	
Source: Big Thompson	0.7 to 0.8 mg/L	

Item	Design Data		Notes
Disinfection			
Type	Liquid Sodium Hypochlorite		
Storage Tanks			
Type	Circular, FRP		
Number	4		
Volume	1,875 gallons each		
Maximum Dose Range			
Pre-DAF	5 mg/L		
Post-DAF	5 mg/L		At 20 MGD
Final Filtered Effluent	5 mg/L		
Metering Pumps			
Type	Gear		
Number	3	3	
Capacity	0.6-5.5 gph	5.5-30.5 gph	
TDH	70 feet	70 feet	
Rated hp	0.5	0.5	
Clearwell			
Number	1		Located below filters 1 and 2
Capacity	185,000 gallons		
Treated Water Storage Reservoir			
Number	1		
Type	Concrete, rectangular		
Capacity	2.34 MG		
Overflow Elevation	5,181		
Water Depth	19 feet		
Treated Water Supply			
High Service Pumps			
Zone	1		
Pumps			Pump performance issues limit several pumps to flows in the range of 2,400 – 2600 gpm
Number	6		
Capacity, each	2,800 gpm		
TDH	260 feet		
Motor hp, each	250		
Residuals Handling			
Type	Lagoons, Rectangular, Asphalt Lined		
Number	4		
Dimensions	280’ × 70’		

Figure 5-2: Boulder Reservoir Water Treatment Facility Process Schematic



2.2.2.1 Raw Water Intakes

Raw water can be brought into the BRWTF in two ways, by diverting it from the BFC or by pumping from Boulder Reservoir. Direct diversion from the canal is preferred because water will flow to the plant by gravity, which saves the cost of pumping from the reservoir. The quality of the water diverted from the canal is also generally better and easier to treat. The City has investigated options of replacing the BFC with a pipeline directly from Carter Lake. This would further improve source water quality. The BFC only operates for about 6 months (April 15 – October 15) coinciding with the irrigation season. BRWTF is required to use water from Boulder Reservoir when the BFC is offline.

Raw water from the BFC is diverted through a bar screen set into the side of the canal channel. The screen is manually cleaned and requires an operator to inspect and clean it several times per day. Water is conveyed to the plant by gravity in a 42-inch pipeline.

Alternatively, water can be pumped from the reservoir by vertical turbine pumps that draw water through an intake strainer mounted in the reservoir. The intake strainer was recently replaced with a fixed level intake that enhances operator flexibility in avoiding certain seasonal raw water quality problems such as algae or manganese.

2.2.2.2 Flocculation/Clarification

In 2005, the single flocculation/sedimentation basin was removed and replaced with two new flocculation and DAF clarifier trains. This work included the installation of a 42-inch influent pipe, insertion style flow meter, flash mixing, static mixer, and a flow splitter box to feed each of the trains. In 2010, a third flocculation/DAF train was added to improve plant redundancy. Since the DAF trains were installed, the effluent turbidity has significantly improved from a typical value of 2.5 NTU to less than 1.0 NTU. The DAF basins also provide much higher solids concentration as compared to the old flocculation/sedimentation basin, which eases the load on the residuals handling process.

2.2.2.3 Filtration

There are four filters, two built with the original plant in 1972, and two built when the plant was expanded in 1998. Filters are mixed media, garnet and silica sand with anthracite cap. Operations Staff report that media loss during backwashing is not a problem.

Two filters are used when the plant is operating in the range of 3.5-8 MGD. A third filter is put on line when the treatment rate goes above 8.5 MGD. The fourth unit is kept clean and ready for service when another unit requires backwashing.

Water for backwashing the filters is pumped from the finished water clearwell to a backwash reservoir. Backwashing is accomplished by gravity flow from the reservoir. A surface wash system is also installed on each filter. Backwash water and various plant drains are routed to a recovery tank which is pumped back to the head of the plant without any additional treatment. In 2010 yard piping improvements were made to allow for the backwash water to be pumped to the residuals lagoons.

During the design of the DAF system, consideration was given to discharging backwash water to the sanitary sewer system rather than recycling it to the head of the water treatment plant. However, permitting issues related to this disposal method prevented it from being implemented.

The filters currently do not have filter to waste capability.

2.2.2.4 *Chemical Addition*

Chemical systems include facilities for the addition of the following chemicals:

- **Carbonic Acid**
  - Raw water pH adjustment for enhanced coagulation by stabilizing the influent pH and improved TOC removal
  - Stored as liquid CO_2 in 60 ton outdoor tank
  - Fed at chemical injection vault in yard
  - PLC controlled flow pacing and pH trim

- **Polyaluminum Chloride (Sumaclear®)**
  - Primary coagulant
  - Stored and fed as liquid
  - Fed either at the flash mixer or the static mixer prior to the flocculation/DAF train flow splitter box
  - Manually controlled flow pacing from SCADA

- **Aluminum Sulfate**
  - Alternative primary coagulant
  - Stored and fed as liquid
  - Fed either at the flash mixer or the static mixer prior to the flocculation/DAF train flow splitter box
  - Manually controlled flow pacing from SCADA

- **Cationic Polymer (Peak)**
  - Coagulant/flocculation aid
  - Stored and fed as a liquid
  - Fed at the flocculation/DAF train flow splitter box
  - Manually controlled pump speed from SCADA, no flow meter

- **Sodium Hypochlorite**
  - Fed at Pre- or Post-DAF locations
  - Fed after filtration for disinfection and to maintain a residual out into the distribution system
  - PLC controlled flow pacing and chlorine residual trim

- **Fluoride**
  - Fluoride is added to the water after filtration
  - Liquid Hydrofluorosilicic acid is stored in a single tank and added to the flow in the finished water flume
  - Manually controlled flow pacing from SCADA

- **Sodium Hydroxide**
  - Raw water contains sufficient alkalinity that supplemental alkalinity addition is not required. Final pH adjustment using caustic soda is the only chemical stabilization adjustment made for corrosion control.
  - PLC controlled flow pacing and pH trim

- The City has recently installed a temporary **sodium permanganate ($NaMnO_4$)** feed system at the Raw Water Pump Station to assist with taste and odor and manganese removal from the Reservoir water. Insufficient information is available at this time to assess the effectiveness of this system.

- **Chemical Mixing**
  - Mixing of treatment chemicals with influent flow utilizes a mechanical pumped diffusion flash-mixer followed by a static mixer.
  - The application points for final chlorination, fluoride, and sodium hydroxide are located in the 42-inch plant effluent pipe, which was designed for an ultimate plant flow of 24 MGD. However, since the current plant flow rate is typically in the range of 3.5-8 MGD, velocities in the pipeline are low resulting in poor mixing.

2.2.2.5 Finished Water Storage and Pumping

Finished water flows by gravity to a 2.34 million gallon concrete finished water storage reservoir located on the plant site. The original plant construction included an 185,000 gallon clearwell located below filters 1 and 2. No additional clearwell was built when the new filters 3 and 4 were added. Flow from filters 1 and 2 is piped to the clearwell while the effluent piping from filters 3 and 4 is connected to the clearwell outlet pipe such that it flows directly to the finished water storage reservoir without passing through the clearwell. In 2005, baffles were installed in the 2.34 million gallon finished water storage reservoir in order to allow the operational flexibility to operate the clearwell at lower levels while continuing to meet the requirements of the Colorado Department of Public Health and Environment (CDPHE) with respect to clearwell detention time, and to meet the City's own 1.5-log *Giardia* removal goal using disinfection.

Water is pumped from the finished water storage reservoir into Zones 1 and 2 of the water distribution system by high-service pumps located on the plant's lower level. There are six pumping units, three installed in 1972 when the plant was originally built, the fourth installed in 1996 when the new filters were added, and fifth and sixth installed in 2005 with the DAF pretreatment improvements. All of the pumping units are constant speed, horizontal split case type, rated for 2800 gpm.

All treated water produced at the BRWTF is pumped into the distribution system. This is the main reason the cost of treated water from the BRWTF is approximately twice the cost of treated water from the BWTF. This cost differential is a dominating factor, along with water quality, in determining plant production and water resource usage.

2.2.2.6 Residuals

In 2005, four asphalt lined residuals lagoons were construction on the west end of the site. Sludge is wasted from a single float channel located at the end of the three DAF trains and is pumped from the channel using progressive cavity pumps which discharge to the lagoons. A second, and utilized as an emergency sludge discharge point, is to the City's wastewater system, which flows by gravity to the IBM lift station and is lifted to the 75th Street Wastewater Treatment Plant (WWTP).

2.3 Treated Water Distribution System

Treated water is distributed to customers throughout the City's service area by a system of buried pipes. The City has over 400 miles of distribution piping. Most of the piping was installed in the 1950s through the 1970s and was typically cast iron pipe and ductile iron pipe. The distribution system also includes facilities for controlling pressure within the system, storing water to provide reserves for peak demand and emergency situations and for the generation of electricity using excess pressure in the system. The Water Utility Planning Area and associated distribution system is shown on **Figure 5-3**. **Figure 5-4** shows a schematic of the water distribution system and associated zones.

2.3.1 Pressure Zones

Elevations within the City's service area range from approximately 5,150 to 5,750 feet. To facilitate the maintenance of water pressures within an acceptable range in all parts of the system, the distribution system is divided into three zones based on topographic relief. The approximate service elevation range for each zone is as follows:

Zone	Service Elevation (USGS Datum)
1	Up to 5420 (approximate elevation of Gunbarrel storage tank overflow)
2	Up to 5615 (approximate elevation of Kohler/Maxwell storage tank overflows)
3	Up to 5852 (approximate elevation of Chautauqua, Devil's Thumb, and Booton storage tank overflows)

In general, Zone 1 includes the east and northeast sections of the service area. Zone 2 covers the largest portion of the service area including the downtown area and the University of Colorado. Zone 3 extends along the west side of the service area. Zone 3 is separated by lower Zone 2 elevations along Boulder Creek. Pressure reducing valves (PRVs), hydroelectric generators, and pumping facilities allow the controlled flow of water between the various pressure zones.

Figure 5-3: Pressure Zone Boundaries, Major Facilities and Pipes

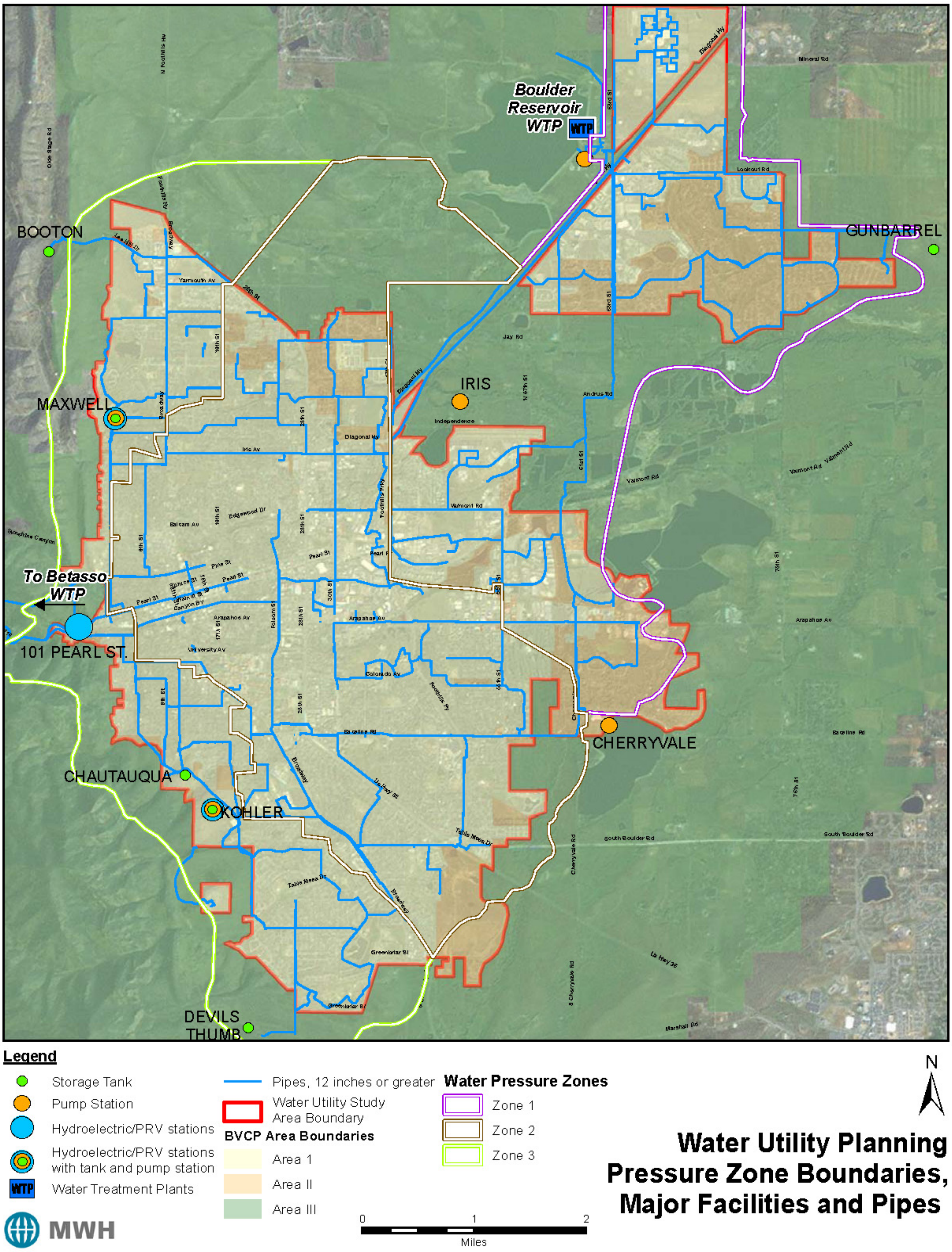
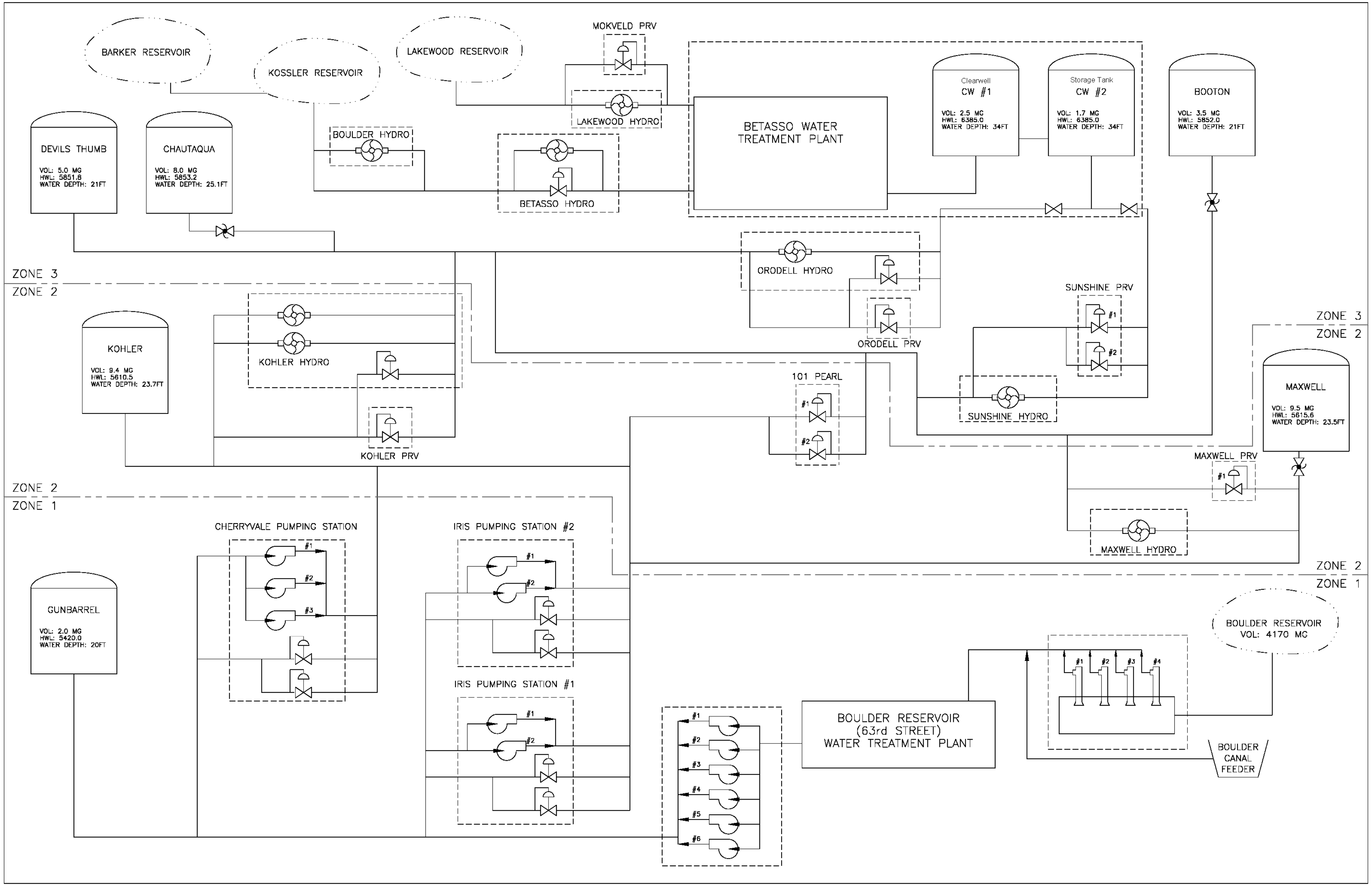


Figure 5-4: Water Distribution System Schematic



2.3.2 Treated Water Transmission

Treated water is conveyed to the distribution system by gravity from the BWTF and by pumping from the BRWTF. In general, water from BWTF feeds into Zones 2 and 3. Zone 1 is fed primarily from the BRWTF with supplementary flow from BWTF through Zone 2. Recent improvements to the pipes and pump stations fed from the BRWTF allow better distribution of water from Zone 1 into Zone 2, which enlarges the area that can be fed from the BRWTF.

The BRWTF can deliver treated water to Zone 1. The facility is located in the northeast side of town and it delivers treated water into this area of town. It also can be delivered to the remaining portion of the distribution system via two transmission mains. A 16-inch line runs adjacent to the Diagonal highway from the plant to the Iris Pump Station #1 and Iris Pump Station #2. The other is a 24-inch main that connects the plant to the Cherryvale pump station. The recent improvements to those systems allow more flexibility in pumping to either Zone 1 or Zone 2.

Water from the BWTF is conveyed to the City's distribution system by two major transmission mains. One pipeline follows Boulder Canyon and the other enters by Sunshine Canyon. Both pipelines originate at the BWTF clearwells and are individually metered. The accuracy of these flow meters has been questioned. Replacement of the existing meters with new factory calibrated units would be necessary to achieve certifiable accuracy.

Parts of the Boulder Canyon pipeline were used to transport water into Boulder before the BWTF was constructed. Sections of this line were constructed of pipe manufactured before the turn of the century (1896). From the BWTF, a 24-inch pipeline runs to the Orodell Hydroelectric/PRV station where pressure is reduced. In the early 2000's the original pipe that was still in service below the Fourmile PRV station was rehabilitated by lining with high-density polyethylene pipe. A new control valve was installed at the Orodell Hydroelectric/PRV station to provide backpressure to the turbine as well as two turbine bypass control valves and the Fourmile PRV station was abandoned in 2005. This effectively increased the capacity of the Boulder Canyon Pipeline to approximately 20 MGD.

The City of Boulder's 2008 Utilities Division Annual Report summarizes the testing of the capacity of the Boulder Canyon pipeline. The following is an excerpt from the report:

> *"The capacity of the Boulder Canyon Pipeline was determined in order to facilitate taking the Sunshine Canyon pipeline out of service for inspection. The Sunshine Canyon Pipeline has been in continuous service since it was constructed in the 1970's. To take the Sunshine Canyon Pipeline out of service, the Utilities Division has estimated that we will need to be able to move 20 MGD through the Boulder Canyon Pipeline.*
>
> *A bypass pressure reduction valve station was added outside the Orodell Hydro Station to allow more water past the hydraulic restriction at Orodell but the capacity of the pipeline was not fully tested. To move 20 MGD down the Boulder Canyon Pipeline, pressures higher than those initially set in the controls of the bypass pressure reduction valve were needed. The controls were adjusted and the flow test completed during high system demands in July 2008.*
>
> *The flow test was conducted up to downstream pressure of over 100 psi which corresponded to flows of over 17 million gallons per day without noticeable vibration or cavitation in the bypass valves. However, at that point in the test the existing internal bypass and the external bypass valves needed coordinated adjustment to continue to*

increase the flow through the external bypass valve. At this point the test was concluded to ease reinstatement of normal operation."

The Sunshine Canyon pipeline conveys water from the BWTF into Zone 3. This welded-steel, 30-inch pipeline was built at the same time as the BWTF making it about 45 years old. Pressure and flow are regulated at the Sunshine Canyon Hydroelectric and PRV stations.

After reducing pressure from the BWTF through the Orodell and Sunshine Hydro/PRV stations, water flows through a series of transmission pipes into Zone 3 storage tanks, Booton (far north), Chautauqua (central), and Devil's Thumb (far south).

Zone 2 is fed from Zone 3 through PRVs at the 101 Pearl station near the downtown area, and at Maxwell in the north and Kohler in the south. It is also fed from Zone 1 via the Iris and Cherryvale pump station in the northeast and southeast respectively.

2.3.3 Treated Water Facilities

The following discussion provides descriptions of the major facilities in the water distribution system. A summary of facility characteristics is provided in **Table 5-4**.

Table 5-4: Treated Water System Facilities Design Data

Item	Design Data	Notes
Pressure Reducing Stations		
Zone 3		
Sunshine PRV	Two at 6-inch Bailey Polyjet®	
Orodell PRV	One bypass PRV in Hydro building Two smaller PRVs in separate PRV structure outside.	Bypass vault piping was recently modified, but not the PRV vault. A PRV was installed upstream near Boulder Hydro for Betasso Hydro capacity testing and it discharges raw water to Boulder Creek.
Zone 2		
101 Pearl PRV	Two at 10 inches, Bailey Polyjet®	
Kohler PRV	One at 8 inches and one at 10 inches Bailey	
Maxwell PRV	One at 8 inches and one at 10 inches Bailey	
Zone 1		
Iris #1 PRV	One at 8 inches and one at 2 inches	Iris #1 constructed 1996, electric controls installed in 2010 and 8 inch PRV internal parts and gasket replaced
Iris #2 PRV	One at 8 inches and one at 2 inches	Iris #2 constructed in 2010
Cherryvale PRV	One at 8 inches and one at 2 inches	Cherryvale PRV was not updated as part of 2010 refurbishment.

Item	Design Data	Notes
Hydroelectric Stations		
Zone 3		
Sunshine Hydro		2009 usage: 3,007,938 kWh ($84,397 in revenue)
Upstream Pressure	300 psi	
Downstream Pressure	75 psi	
Pump/Turbine Units	1	
Capacity	800 kW	
Orodell Hydro		2009 usage: 700,343 kWh ($25,897 in revenue)
Upstream Pressure	220 psi	
Downstream Pressure	42-120 psi	
Pump/Turbine Units	1	
Capacity	200 kW	
Zone 2		
Kohler		2009 usage: 708,208 kWh ($29,324 in revenue)
Upstream Pressure	112 psi	
Downstream Pressure	6 psi	
Pump/Turbine Units	2	
Capacity	120 kW	
Maxwell		2009 usage: 541,606 kWh ($22,896 in revenue)
Upstream Pressure	104 psi	
Downstream	6 psi	
Pump/Turbine Units	1	
Capacity	90 kW	
Zone 1 –N/A		
Pump Stations		
Zone 3		
NCAR		Part of private system. Pumps run in lead/lag mode after 10:30 pm to fill a 300,000 gallon tank with 25,000-75,000 gallons of water for use the following day.
Zone	Boosts Zone 3 pressure into private system	
Pumps		
Number	2	
TDH	450 feet	
Rated hp, each	60	
Zone 2 to 3		
Kohler		Emergency use only. Pump/turbine units can normally operate in parallel as turbines when reducing pressure from Zone 3 to Zone 2. Capable of operating in series to pump water from Zone 2 to Zone 3.
Turbine/Pumps:		
Number	2	
Rated hp, each	83	

Item	Design Data	Notes
Maxwell		Emergency use only. Pump/turbine unit normally operates as a turbine when reducing pressure from Zone 3 to Zone 2. Capable of operating in series with the booster pump to move water from Zone 2 to Zone 3.
Pump/Turbine:		
Number	1	
Capacity, each	1,550 gpm	
TDH	221 feet	
Rated hp, each	125	
Booster Pump:		
Number	1	
Rated hp, each	40	
Zone 1 to 2		
Iris #1		
Pumps:		
Number	2	
Capacity, each	1,688 gpm	
TDH	240 feet	
Rated hp, each	150	
Rpm	1,780	
Iris #2		
Pumps:		
Number	2	
Capacity, each	1,688 gpm	
TDH	240 feet	
Rated hp, each	150	
Rpm	1,780	
Cherryvale		
Pumps:		
Number	3	
Capacity, each	1,688 gpm	
TDH	240 feet	
Rated hp, each	125	
Rpm	1,780	
Zone 1		
Boulder Reservoir		
Pumps:		
Number	6	
Capacity, each	2,800 gpm	
TDH	260 feet	
Rated hp, each	250	

Item	Design Data	Notes
Storage Reservoirs		
Zone 3		
Devil's Thumb		
Type	Welded Steel	
Capacity	5.0 MG	
Overflow Elevation	5,851.8 ft above sea level	
Water Depth	21 feet	
Chautauqua		
Type	Concrete	
Capacity	8.0 MG	
Overflow Elevation	5,853.2 ft above sea level	
Water Depth	25.1 feet	
Booton		
Type	Welded Steel	
Capacity	3.5 MG	
Overflow Elevation	5,852 ft above sea level	
Water Depth	21 feet	
Zone 2		
Kohler		
Zone	2	
Type	Concrete	
Capacity	9.4 MG	
Overflow Elevation	5,610.5 ft above sea level	
Water Depth	23.7 feet	
Maxwell		
Zone	2	
Type	Concrete	
Capacity	9.5 MG	
Overflow Elevation	5615.6 ft above sea level	
Water Depth	23.5 feet	
Zone 1		
Gunbarrel		
Type	Welded Steel	
Capacity	2.0 MG	
Overflow Elevation	5,420 ft above sea level	
Water Depth	20 feet	

2.3.3.1 Orodell Hydroelectric Station and PRV

This facility is located in Boulder Canyon approximately four miles west of the City. Hydroelectric power is generated from the pressure in the Boulder Canyon finished water line from the BWTF. A bypass PRV is independent of the hydroelectric station and allows water to flow around the Orodell station and down the canyon. The upgraded bypass PRV allows the Boulder Canyon pipeline to be able to carry up to 20 MGD at all times. The upgrade to the bypass vales include: two “Roll Seal” control valves installed at the Orodell Hydro 12” bypass in an aboveground structure along Boulder Creek. The structure, fabricated by Engineered Fluid, Inc. in Illinois was trucked to the hydro site is a tilt-back hinged design with electric controls and a thermostatically controlled heating unit. Prior to this installation, water was running into the

Orodell meter station vault. Two leaks were detected in the 24" high pressure steel transmission line upstream and repaired as part of this project. (City of Boulder 2005 Utilities Division Annual Report).

Equipment in the Orodell Hydro Station includes a turbine and generator system, turbine isolation plug valve, bypass PRV valve, bypass upstream and downstream isolation butterfly valves, downstream flow control valve, miscellaneous valves and piping, and a battery back-up and charging system for instrumentation and control (I&C).

The FourMile Valve House was abandoned, and a new butterfly valve installed upstream, to facilitate the planned conversion of the 16" Zone 3 steel transmission pipe into Zone 2 use. A new air relief valve was installed on the existing Zone 2 line. (City of Boulder 2005 Utilities Division Annual Report).

2.3.3.2 101 Pearl PRV Station

This facility was built in 1996 to replace the 6th and Canyon PRV station. The station consists of two 10-inch, 150-psi, and Bailey sleeve valves, which operate during summertime peak flow months to reduce pressure on flow transferring from Zone 3 to Zone 2. Flow is shut off during off-peak months, which eliminated this as a potential hydroelectric generation site under current operation. The facility was set up to allow installation of a hydro generator if future operations make it economically viable.

2.3.3.3 Sunshine Hydroelectric Station and PRV

The hydroelectric facility is located on the Sunshine Canyon line, the main transmission line from the BWTF to the City. A PRV had been installed at this location when the pipeline was built and the hydroelectric generation facility was constructed in 1986 to make use of the available energy. The hydroelectric generation equipment consists of an 800 kW Francis turbine, an induction generator, a 20-inch ball type isolation valve, turbine bypass PRV and necessary electrical, instrumentation and control gear. This facility operates continuously except during maintenance operations.

The PRV facility is located adjacent to the Sunshine Hydroelectric Station. The PRVs control bypass-flow around the hydroelectric facility and reduce pressure in the Sunshine Canyon line to Zone 3 pressure. This facility predates the hydroelectric facility and originally was the main PRV on the Sunshine Canyon line from BWTF into the City. During a complete renovation, begun in 1996 and completed in 1998, the original 16-inch motor operated plug valves were replaced with Bailey Polyjet® sleeve valves. Valve controls allow for remote control through the City's System Control and Data Acquisition (SCADA) system or local control to maintain a pressure set point via a local PLC. The 1996 renovation also provided for improved access to the vault by replacing the original manhole access with a walk-in door. This improved operator safety by replacing ladder access with walk in entry, eliminating a confined space entry and providing for faster emergency egress, and made it generally easier for operations staff to inspect and maintain this critical facility.

2.3.3.4 Devil's Thumb Reservoir

The Devil's Thumb Reservoir provides storage and surge protection to the southern portion of Zone 3. The 5.0 MG reservoir is a fully enclosed welded steel tank sitting at grade. The overflow level is elevation 5851.8. A single 30-inch pipeline serves as both inlet and outlet to the tank. The water level in the tank floats without regulation by a control valve. Only a manual isolation valve is provided in a vault adjacent to the tank. Valve operation and status cannot be accessed through the SCADA system.

2.3.3.5 Chautauqua Reservoir

Chautauqua Reservoir is an 8.0 MG covered concrete tank partially buried in the hillside. This facility provides storage and surge protection to the central portion of Zone 3. The reservoir overflow level is elevation 5,853.2. The reservoir is connected to the system by an 18-inch inlet/outlet line with an altitude valve to control flow. The altitude valve can be adjusted remotely via the SCADA system. Other piping associated with the reservoir includes:

- 12-inch cast iron siphon inlet/outlet fitting that penetrates the wall near the top and terminates several feet above the reservoir floor and a 12-inch motor-operated valve
- 12-inch steel siphon in the northeast corner, which penetrates high on the reservoir wall and terminates several feet above the reservoir floor
- 12-inch cast iron bottom inlet/outlet in the northeast corner
- 14-inch steel floor drain in the northeast corner, which discharges to a nearby creek

2.3.3.6 Booton Reservoir
Booton Reservoir is located at the extreme north end of Zone 3, and provides storage and surge protection. The tank is circular, welded steel construction, built as a "tank within a tank" jointly by the City and Pinebrook Hills Water and Sanitation District. The center portion of the tank is separated from the outer, annular portion by an inner wall and piping is arranged to provide separate connections to each system. The Pinebrook Hills District uses the inner tank while the outer, annular space provides the City with 3.5 million gallons (MG) of storage. The design maximum water level is elevation 5,852.0 at a water depth of 21 feet.

2.3.3.7 Zone 2
The Maxwell and Kohler facilities are complementary, serving similar functions at the northwest and southwest corners of Zone 2. These facilities generate electricity from the pressure differential between Zone 3 and Zone 2 using generation units comprised of centrifugal pump units adapted to "run backwards" to generate electricity by driving an induction generator. Under extreme emergency conditions such as a major fire in Zone 3 or an interruption in operation at the BWTF, the generator units can be used to pump water from Zone 2 to Zone 3. These two facilities generate a significant amount of electricity continuously year round. At each facility, a bypass PRV allows flow in excess of turbine capacity to bypass the facility and pass directly to the reservoir.

2.3.3.8 Maxwell Reservoir and Hydroelectric Facility
The Maxwell facility is located at the base of the foothills in the northwest part of the City. This station has one generator/pump unit and one pump only unit. Under normal operating conditions the Maxwell pump/generator operates to generate electricity and the pump unit is in standby isolated by valves. Under emergency conditions, the two units would operate as pumps in series to produce enough pressure to move water from Zone 2 to Zone 3. The station bypass is located in a separate vault. A 1998 upgrade replaced the original motor operated plug valve with a 10-inch Bailey sleeve valve in a separate vault.

Maxwell reservoir is a 9.5 MG underground concrete tank with an overflow level of 5,615.6.

2.3.3.9 Kohler Reservoir and Hydroelectric Facility
The Kohler facility is located at the base of the foothills in the southwest part of the City. This installation has two generator/pump units. In normal operation, both units operate in parallel to generate electricity with flow passing from Zone 3 to Zone 2. Under emergency conditions, the two units would operate as pumps in series to produce enough pressure to move water from Zone 2 to Zone 3. A 1998 upgrade replaced the original motor operated plug valve with a 10-inch Bailey sleeve valve. A new vault was constructed for the new bypass valve.

Kohler reservoir is a 9.4 MG underground concrete tank with an overflow elevation of 5,610.5.

2.3.3.10 Zone 1

Zone 1 is supplied with water from the BRWTF by the plant's high service pumps. The Cherryvale and Iris pump stations allow water to transfer between Zones 1 and 2. Water will pass from Zone 2 into Zone 1 when the BRWTF is not operating or when Zone 1 demand exceeds the output of the BRWTF. PRVs in the stations control the flow and the pumps remain off. Originally the PRVs had motorized pilot valves, which have been removed and the valves set for Zone 1 pressure. The pumps can be used to transfer water from Zone 1 to Zone 2 optimizing use of water resources by making C-BT water available to Zone 2 as well as Zone 1.

2.3.3.11 Cherryvale Pump Station and PRV

The Cherryvale Pump Station is located in the southeast part of the system and receives water from BRWTF. This station houses three identical horizontal split case pumps arranged for parallel operation to transfer water from Zone 1 into Zone 2. Recent modifications (2010) to this pump station included the replacement of the three pumps and improvements to the electrical service system. The Cherryvale PRV is used to transfer Zone 2 water into Zone 1 when required.

2.3.3.12 Iris Pump Stations and PRVs

The Iris Pump Stations are located in the northeast part of the system and also receives water from BRWTF. In 2005, the pumps were replaced in the original pump station. This, along with the new 24-inch pipeline along the Diagonal Highway, allowed BRWTF to deliver up to 12 MGD and allowed transfer of water from the BRWTF into the western part of the distribution system. In 2010, a second, “sister” pump station was added (Iris Pump Station #2) increasing BRWTF distribution delivery capacity. Each pump station houses two, identical, horizontal, split-case pumps rated at 1,688 gpm, at 240 TDH and are driven by 150 Hp, 1,785 rpm, constant speed motors. The Iris #1 and Iris #2 PRVs are used to transfer Zone 2 water into Zone 1 when required.

2.3.3.13 Gunbarrel Reservoir

Gunbarrel Reservoir provides storage and surge protection to Zone 1. Located in the extreme northeast corner of the zone, the 2.0 MG reservoir is a fully enclosed welded steel tank sitting at grade. The overflow level is elevation 5,420.0.

2.3.4 Treated Water System Components

The following list summarizes the water distribution system components that comprise the City's treated water system. The 2010 data was taken from the City's Geographical Information System (GIS).

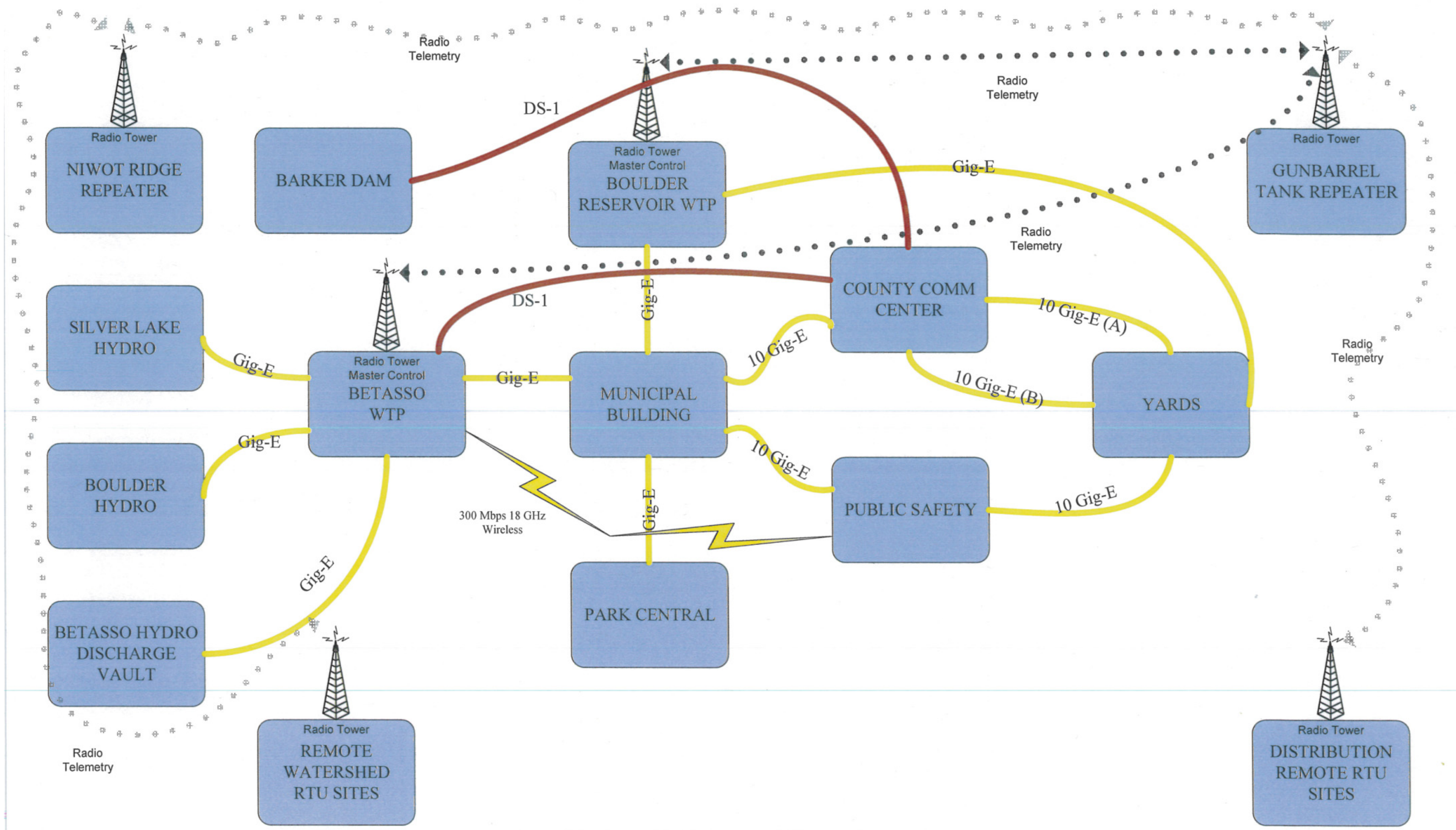
- Water Distribution System Piping — 475 miles (23 miles are owned and maintained privately)
- Valves — 6465
- Fire Hydrants — 4624
- Steel Pipe Corrosion Protection Devices — 70
- Water Meters and Accounts — 28,773

2.4 System Control

The operation of the water distribution system is monitored at the BWTF by means of the system-wide Supervisory Control and Data Acquisition (SCADA) system. This system provides for continuous monitoring of all, pressure reduction valves, system pressures, storage reservoir levels, and hydroelectric generation units and pump operations. The system also provides for remote control of most of the pressure reducing valves, bypass valves, pumps and generators in the system such that the operators can largely control the distribution of treated water within the system from BWTF. As presently configured, the SCADA system does not provide for automatic operation of any of the systems facilities. The SCADA system does, however, provide for the recording of detailed operating data. The SCADA network is shown on **Figure 5-5.**

During the summer of 2010 a wildfire damaged the fiber optic and Qwest-provided T1 lines to the Betasso WTP, resulting in a loss of communications between the SCADA system at Betasso WTP and the SCADA system at Boulder Reservoir WTP. The remote distribution sites communicate only to the SCADA system at Betasso WTP over a licensed radio network and, therefore, could not be monitored at Boulder Reservoir WTP after the fire. The fire brought to light a weakness in the SCADA network that could be improved with the addition of an independent, redundant, communication path between the water treatment plants or a communication path directly to the Boulder Reservoir WTP from the remote distribution sites. It is understood that a communication path directly to the Boulder Reservoir WTP from the remote distribution sites was in place but was decommissioned after the coordination between the SCADA system at Betasso WTP and the SCADA system at Boulder Reservoir WTP became unmanageable.

Figure 5-5: City of Boulder SCADA Overall Network Diagram



City of Boulder SCADA Overall Network Diagram

2.4.1 1996 SCADA Radio Telemetry Report Summary

In 1996 the City of Boulder engaged CyberLink Corporation to prepare a report detailing the wireless and telecommunications options available to the City for use in the water and hydropower SCADA system. As part of the report, CyberLink evaluated the City's existing radio frequency licenses and other potentially available licenses in the area, and examined the applicability of those licenses in transmitting and receiving telemetry data from remote watershed and water distribution sites. CyberLink shows the viability of both the VHF bands (170.325 MHz) and 900 MAS bands (928.01875 & 952.01875) for use in the network, both of which were licensed to the city at the time of the report for this purpose. The results of computer-generated radio path studies for both bands are summarized below:

Table 5-5: 1996 SCADA Radio Telemetry Report Results of Computer-Generated Radio Path Studies

Band and Site	Path Distance (Miles)	Received Signal Level (dBm)	Signal Level Above Threshold (dB)
Transmission from Site to Gunbarrel Tank Repeater for 900 MAS Band:			
Boulder Reservoir WTP	2.9	-58.2	+58.8
Betasso WTP	10.2	-85.1	+31.9
Transmission from Site to Gunbarrel Tank Repeater for VHF Band:			
Betasso WTP	10.2	-70.6	+46.4

The recommendations of the CyberLink report shows that a reinstatement of the radio link between the remote distribution sites through the Gunbarrel Tank Repeater to the Boulder Reservoir WTP over the 900 MAS band would create a reliable redundant path for the telemetry data. However, previous issues associated with the SCADA database should be investigated prior to re-establishing this redundant path.

The City of Boulder is currently exploring the addition of a high bandwidth 18GHz, licensed radio link, with connection speeds up to 300Mbps, between Betasso WTP and the Public Safety Building. Considering that Boulder Reservoir WTP is currently linked to the Public Safety Building through multiple high bandwidth datalink paths (as shown in Figure 5-5), the new 18GHz radio link could provide an extra level of redundancy for SCADA data routed between the two water treatment plants. It should be noted that, though providing a great deal more redundancy than currently exists, the system would still be vulnerable to an interruption in service if a failure of the radio link between the Gunbarrel Tank Repeater and the Betasso WTP occurs. A reinstatement of the 900 MAS radio link between the Gunbarrel Tank Repeater and Boulder Reservoir WTP, as discussed in the previous paragraph, is the only recommendation that would provide fully redundant communication paths for remote distribution site SCADA data.

Further, it appears that a holistic review of the water and hydropower SCADA network has not been conducted since 1996. Through radio license re-farming, new telecommunications services, and improvements in public network data encryption, the wide area network options have substantially changed since 1996. The City could realize improvements in reliability and reduced recurring costs by reevaluating the entire SCADA system.

3 Water Quality Regulations and Goals

The review and water quality regulations and goals provided in this Chapter expands upon those summarized in the **Volume 3 – Water Quality Strategic Plan (WQSP)** and interprets the WQSP specific to the drinking water system.

3.1 Water Quality Regulations

U.S. drinking water standards have developed and expanded over the past 100 years as knowledge of the health effects of contaminants has increased and the treatment technology to control contaminants has improved. The principal driving force behind development of drinking water standards and regulations is protection of public health. This section provides an overview of past, present and future drinking water regulations with emphasis on their applicability to the City of Boulder as a provider of treated water to the public. A historical discussion of treatment regulations in the United States that date up to the 1996 Amendments to the Safe Drinking Water Act are briefly summarized in **Table 5-8.** Afterwards this section focuses on the 1996 SDWA Amendments onwards and how they apply to the City of Boulder.

3.1.1 Historical Overview

Table 5-8 is a chronological progression of major water quality regulations in the United States up until 1996.

Table 5-8: Historical Regulations 1893 through 1996

Date	Regulation	Purpose
1893	Quarantine Act (U.S. Statutes 1893)	The surgeon general of the U.S. Public Health Service (USPHS) was empowered
1913	Launch of review of drinking water concerns	Realization that "the most sanitary drinking water cups would be of no value if the water placed in them was unsafe"
1914	First Federal Drinking Water Standards	"Treasury Standards" were implemented by USPHS, which was part of the US Treasury Department. Included a 100/cc (100 organisms/mL) limit for total bacterial plate count. Further, they stipulated that not more than one of five 10/cc portions of each sample examined could contain *Escherichia coli* (*E. coli*)
1925	USPHS 1925 Regulations	1 coliform per 100 mL and standards for lead, copper, zinc, and excessive soluble mineral substances
1941	USPHS formed advisory committee	Advisory committee reviewed the 1925 standards
1942	USPHS 1943	New initiatives, including: • Samples for bacteriological examination obtained from points in the distribution system, a minimum number of bacteriological samples for examination each month was established, and the laboratories and procedures used in making these examinations became subject to state or federal inspection at any time. • Maximum permissible concentrations were established for lead, fluoride, arsenic, and selenium. Salts of barium, hexavalent chromium, heavy metals, or other substances having deleterious physiological effects were not allowed in the water system. • Maximum concentrations, not to be exceeded where more suitable alternative water sources were available, were set for copper, iron plus manganese, magnesium, zinc, chloride, sulfate, phenolic compounds, total solids, and alkalinity.
1962	1962 federal drinking water standards	28 constituents, including mandatory limits for health-related chemical and biological impurities and recommended limits for impurities affecting appearance, taste, and odor. Accepted by all 50 states, but were limited in enforcement.
1970	Community Water Supply Study (CWSS)	Survey of 969 public water systems, found that 41% did not meet 1962 guidelines. Study found that several million people were being supplied water of an inadequate quality and that 360,000 people were being supplied potentially dangerous drinking water.
1973	General Accounting Office (GAO) Report	446 community water systems tested, only 60 complied with USPHS standards.
December 16, 1974	**Safe Drinking Water Act (SDWA) (Public Law 93-523)**	• SDWA became the principal law governing drinking water safety in the United States. Required for all public water systems and made the standards legally binding. Established National Interim Primary Drinking Water Regulations (NIPDWRs). • These regulations established maximum contaminant levels (MCLs) for 10 inorganic chemicals, six organic chemicals, two radioactive contaminants, turbidity, and coliform organisms. The interim rules were amended several times before the first primary drinking water regulation was issued.
1977	SDWA Amendments of 1977, Public Law 95-190	Revisions of the National Academy of Sciences study, reflecting new information on microorganisms, particulate matter, inorganic solutes, and radionuclides

Date	Regulation	Purpose
1979	Amendments	MCL for total trihalomethane (TTHM) compounds was added in 1979
1979	SDWA Amendments of 1979, Public Law 96-63	Reauthorization of the SDWA, including a 3 year extension of the authorizations
1980	SDWA Amendments of 1980, Public Law 96-502	Minor amendments including exemption extensions, allowed alternative procedures for underground injection control program, limited grant to states that have not assumed primary enforcement, provided grants to systems that demonstrate new or improved methods for meeting more stringent standards
1986	Fluoride revision	MCL for fluoride was revised in April 1986
1986	SDWA Amendments of 1986,Public Law 99-339	• Established Phase I, II, IIb, and V rules regulating 69 contaminants over a five-year period. In each rule, USEPA set limits on the contaminants, prescribed the schedule under which water systems must test for the presence of the contaminants, and described the treatments which systems may use to remove a detected contaminant. • For each contaminant, USEPA set a health goal, or Maximum Contaminant Level Goal (MCLG). This is the level at which a person could drink two liters of water containing the contaminant every day for 70 years without suffering any ill effects. This goal was not a legal limit with which water systems must comply; but based solely on human health risk. For known cancer-causing agents (carcinogens), USEPA set the MCLG at zero, under the assumption that any exposure to the chemical could present a cancer risk. • The rules also set a legal limit, or Maximum Contaminant Level, for each contaminant. USEPA set legal limits as close to the health based MCLG as possible, keeping in mind the technical and financial barriers that existed. Except for contaminants regulated as carcinogens, most legal limits and health goals are the same. Even when they are less strict than the health goals, the legal limits set provided substantial public health protection. • Along with their long-term effects, nitrate and nitrite were determined to be acute health risks for infants, meaning that they could cause immediate health problems even when consumed in tiny doses.
8 July 1987	Phase I Rule	Limited exposure to eight Volatile Organic Chemicals (VOCs) that industries use in the manufacture of rubber, pesticides, deodorants, solvents, plastics, and other chemicals and could potentially be in tap water. The rule required water systems to monitor and, if levels exceed legal limits, take corrective action to ensure that consumers receive water that does not contain harmful levels of the chemicals
31 Oct 1988	Lead Contamination Control Act, Public Law 100-572	Amended the SDWA to direct the USEPA to consider drinking water coolers with lead-lined tanks as imminently hazardous consumer products which must be repaired, replaced, recalled, or refunded by their manufacturers and importers within one year of this Act's enactment.

Date	Regulation	Purpose
29 June 1989	Total Coliform Rule	• The Rule set both health goals (MCLGs) and legal limits (MCLs) for total coliform levels as an indicator organism in drinking water. The rule also detailed the type and frequency of testing that water systems must perform. • For water systems which collect at least 40 samples per month, if no more than 5.0 percent of the samples collected during the month were total coliform positive, the system was considered to be in compliance. • Under the Rule, if a sample tests positive for coliforms, the system must collect a set of repeat samples within 24 hours. When a routine or repeat sample tests positive for total coliforms, it must also be analyzed for fecal coliforms and *E. coli*, which are coliforms directly associated with fresh feces. If either fecal or *E. coli* bacteria are present, it signifies an acute MCL violation. Rapid state and public notification by electronic media (TV or radio) is required within 72 hours because it represents a direct health risk. Under the coliform rule, states are allowed to disregard speciated coliform-positive tests that are not of fecal origin.
29 June 1989	Surface Water Treatment Rule	• The Rule was established to prevent waterborne diseases caused by viruses, *Legionella*, and *Giardia lamblia*. The rule requires that water systems filter and disinfect water from surface water sources to reduce the occurrence of unsafe levels of these microbes. • Filter systems are required to maintain a minimum disinfection residual of 0.2 mg/L for water entering the distribution system. A detectable disinfectant residual must be maintained within the distribution system for a minimum of 95 percent of all samples analyzed on a monthly basis. Where no residual is detected, and a heterotrophic plate count (HPC) analysis indicates less than 500 colonies per ml, the sample is considered acceptable. Sampling frequencies and locations must be the same as required by the Coliform Rule. • In the Rule, filtration systems are required to maintain 99.9% (3-log) removal or inactivation for *Giardia* cysts and 99.99% (4-log) removal for enteric viruses. Conventional granular media filtration can remove a high percentage of *Giardia* cysts and viruses. Filtration can achieve 99.5% (2.5-log) removal of *Giardia* cysts and 99% (2-log) removal of viruses. To achieve the minimum required 99.9% (3-log) cyst and 99.99% (4-log) virus removal or inactivation criteria, the disinfection system must provide a minimum additional 0.5-log inactivation of cysts and 2-log inactivation of viruses. Virus inactivation in excess of a 4-log reduction is typically achieved when conditions for 3-log removal or inactivation of *Giardia* cysts are maintained. USEPA recommends specific minimum *Giardia* cyst removal ranging from 3-log to 5-log (October, 1990), depending upon the degree of cyst contamination in the source water. To assist in monitoring the effectiveness in the filtration process, turbidity (a measurement of water clarity) is monitored at 4-hour intervals. The combined filter effluent turbidity is not to exceed 5 nephelometric turbidity units (NTU) as a maximum and 0.5 NTU at the 95th percentile for all measurements taken during any month, based on monitoring every four hours.
30 January and 1 July 1991	Phase II and IIb Rules	Legal limits on 38 contaminants were updated or created with these rules, many were frequently-applied agricultural chemicals while others are more obscure industrial intermediate. For 36 of the 38 contaminants that the Phase II and IIb rules address, USEPA set both health goals and legal limits. The other two contaminants that USEPA regulated through the rules, Acrylamide and Epichlorohydrin, are chemicals that some water systems add during the water treatment process. The rules limit the amount of these chemicals that systems may add to water during the treatment process.

Date	Regulation	Purpose
7 June 1991	Lead and Copper Rule	• USEPA set health goals (MCLGs) and action levels for lead and copper. All community public water systems have been required to monitor and, if necessary, control the amount of lead and copper in the potable water system. Lead and copper is monitored at user fixtures within the distribution system. Based on first-draw samples, lead and copper concentrations must be less than 0.015 mg/L and 1.3 mg/L in 90 percent of the samples, respectively. • When a water system exceeds either action level, it must also assess its source water. In most cases, there will be little or none of either contaminant in the source water and no treatment will be necessary. When there are high levels in the source water, treatment of that water, in conjunction with corrosion control, further lessens the chance that consumers will have elevated levels of lead and copper at the tap. Monitoring data and corrosion control study results must be submitted to the state, which then approves the required treatment. • The rule also requires systems that exceed the lead action level to educate the affected public about reducing its lead intake. Finally, a system which continues to exceed the lead action level after completing corrosion control and source water treatments may have to replace some of its lead water mains.
17 July 1992	Phase V Rule	The Phase V Rule set standards for 23 more contaminants including inorganic chemicals such as cyanide that are present naturally in some water, though only at trace levels. Industrial activity accounts for the potentially harmful levels of these contaminants in drinking water. Other Phase V contaminants are pesticides. These chemicals enter water supplies through run-off from fields where farmers have applied them or by leaching through the soil into ground water.
14 May 1996	Information Collection Rule	To support the Microbial-DBP rulemaking process, it required large public water systems serving at least 100,000 people to monitor and collect data on microbial contaminants, disinfectants and DBPs for 18 months. Monitoring programs began in July 1997 and were completed by December 1998. The data provided USEPA with information about disinfection byproducts, disease-causing microorganisms, including *Cryptosporidium*, and engineering data to control these contaminants. This information was used in part to create the final Enhanced Surface Water Treatment Rule and the Stage 2 Disinfectants/Disinfection Byproducts Rule. The City of Boulder participated in the ICR at the BWTF from 7/97 to 12/98.

3.1.2 Overview of Regulations

The rules of the SDWA apply to all public water systems. The City of Boulder is regulated because it owns and operates a public water system. Public water systems are further broken down into different types. Rules apply differently based on the size of the system and classification of the water source. Monitoring and reporting requirements vary significantly depending upon the size of a system. With a service area population of approximately 113,000 people the City of Boulder is classified as a very large water system. The regulations also differ depending on whether a system relies on surface water, groundwater or a combination of both. The City of Boulder uses surface water exclusively. For clarity, the remainder of this section will focus on those provisions of the regulations that apply to Boulder as a very large system using exclusively surface water. States and Indian Tribes are given primary enforcement responsibility “primacy.” This allows the Colorado Department of Public Health and Environment’s (CDPHE’s) Water Quality Control Division to enforce the federal rules as a minimum and the ability to enforce more strict requirements, if necessary.

3.1.3 SDWA 1996 Amendments

On August 6, 1996, the President signed new SDWA amendments into law as Public Law 104-182. These amendments made sweeping changes to the existing SDWA, created several new programs, and included a total authorization of more than $12 billion in federal funds for various drinking water programs and activities from fiscal year (FY) 1997 through FY2003.

The 1996 SDWA Amendments establish an emphasis on preventing contamination problems through source water protection and enhanced water system management. This emphasis transformed the previous law, with its largely, after-the-fact and regulatory focus, into a statute that provides for the sustainable use of water by our nation’s public water systems and their customers. Inherent in the act is closer interaction with the states in creating and focusing prevention programs, and helping water systems improve operations and avoid contamination problems.

In addition, the Amendments specify that the public be provided with or given access to data collected, analyses done or implementation strategies developed under new SDWA programs. These consumer information provisions provide for public involvement in safe drinking water, founded on the idea that the understanding and support of the public will be vital to address and prevent the growing threats to drinking water quality in the years ahead.

Key provisions of the 1996 amendments include the following:

- Consumer Confidence Reports
- Source Water Protection
- Capacity Development
- Operator Certification
- New risk-based contaminant selection
- Cost-benefit analysis and research for new standards
- Unregulated Contaminant Monitoring Regulation
- Drinking Water State Revolving Fund
- Rules:
  - Radon, Arsenic, Disinfection Byproducts (DBP)/Interim Enhanced Surface Water Treatment Rule (IESWTR), Sulfate

A decade of experience under the 1986 SDWA revealed several areas where responsibly exercised flexibility supported by sound scientific evidence and a better prioritization of effort could improve protection of public health compared to the relatively inflexible approach of the 1986 statute.

New Risk-Based Contaminant Selection: The requirement that USEPA regulate an additional 25 contaminants every three years was eliminated. Instead, USEPA was given the flexibility to decide whether or not to regulate a contaminant after completing a required review of at least five contaminants every five years. USEPA must use three criteria to determine whether or not to regulate a contaminant: that the contaminant adversely affects human health; it is known to or is substantially likely to occur in public water systems with a frequency and at concentrations high enough to be of public health concern; and regulation of the contaminant presents a meaningful opportunity for health risk reduction. [102/1412(b)(1)]

Cost-Benefit Analysis and Research for New Standards: For all future drinking water standards, USEPA is to conduct a thorough cost-benefit analysis and provide comprehensive, informative, and understandable information to the public. USEPA is also required to use the "best available, peer-reviewed science and supporting studies" in carrying out actions within the standard setting section "to the degree that an Agency action is based on science." [103/1412(b)(3)]

Small System Technologies, Variances, and Exemptions: A fundamental problem with the previous law was that, in setting standards based on technology that large systems could afford, it did not recognize the often-different economics of small systems. The new law contains multiple remedies. First, as part of a new drinking water standard, USEPA is to identify technologies that comply with the standard and are specifically affordable for each of three groups of smaller systems [105/1412(b)(4)(E)]. Second, where such technologies do not exist for a certain group of smaller systems or quality of source water, a "variance" technology must be identified that need not meet the standard but must provide the maximum protection affordable for such groups of smaller systems and source waters. [111/1412(b)(15)] Within two years, USEPA must identify affordable compliance and, where appropriate, variance technologies for existing regulations, and issue regulations for small system variances.

Compliance Time Frames: The Amendments extend to three years the previous 18-month deadline for systems to comply with new regulations, unless USEPA determines an earlier date is "practicable." USEPA or States (for individual systems) may give an additional two years if necessary for capital improvements. [108/1412(b)(10)]

Monitoring Reforms: States may grant "interim monitoring relief" to systems under 10,000 (exempting them from additional quarterly monitoring) if monitoring done at the time of "greatest vulnerability to the contaminant" fails to detect it, and the State finds that further monitoring is unlikely to detect it. This relief may not cover any microbiological contaminants (or their indicators), disinfectants, or disinfection or corrosion byproducts [125(b)/1418(a)].

Enforcement: The Amendments streamline processes for administrative compliance orders and penalties up to $5,000 that raise the administrative and emergency penalty caps, and make enforceable many SDWA provisions and requirements imposed under them by USEPA or primacy States, and give up to a two-year enforcement moratorium for violations being remedied by a specific plan to consolidate with another system. States must also adopt administrative penalty authority for primacy. These measures will facilitate more effective enforcement, encouraging compliance while keeping safeguards for systems [113/1414].

The creation of a Drinking Water State Revolving Fund (SRF), to assist communities in installing and upgrading safe drinking water treatment facilities, is among the new statute's most dramatic departures from the past, and among the most important changes in the nation's drinking water program since passage of the original SDWA in 1974. The President proposed the SRF in 1993 to advance the same kind of national commitment to safe drinking water as America has made to wastewater treatment and clean water.

Drinking Water State Revolving Fund: The SRF was authorized at $599 million for FY1994, and $1 billion annually thereafter through FY2003. The full span of this authorization is meaningful because the law permits appropriation in future years of any funds authorized but not appropriated in prior years. Funds are allotted to all primacy states through FY1997 based on the current formula for Public Water System Supervision grants, and thereafter based on the results of the most recent SRF needs survey. The fiscal year 2009 appropriation for the SRF program was $829,029,000.

SRF Grants to States for Prevention Programs and Projects: One of the most notable features of the law is the authorization to States to use SRF funds for the new prevention programs. Up to 10 percent of their capitalization grants may be used for source water protection, capacity development, and operator certification programs, as well as for the State's overall drinking water program.

The 1996 SDWA Amendments required the City of Boulder to prevent contamination problems through source water protection and enhanced water system management. It also required the City to be more transparent in their reporting and notifications.

3.1.3.1 Interim Enhanced Surface Water Treatment Rule (IESWTR)

Over time, improved analytical techniques identified specific microbial pathogens, such as *Cryptosporidium*, which are highly resistant to traditional disinfection practices as well as being difficult to remove through conventional treatment processes. In 1993, *Cryptosporidium* caused 400,000 people in Milwaukee to experience intestinal illness. More than 4,000 were hospitalized, and at least 50 deaths have been attributed to the disease. There have also been cryptosporidiosis outbreaks in Nevada, Oregon, and Georgia.

The Interim Enhanced Surface Water Treatment Rule (IESWTR) (published 16 December 1998/effective December 2001) amended the 1989 SWTR to strengthen microbial protection, including provisions specifically to address *Cryptosporidium*, and to address risk trade-offs with disinfection byproducts. The IESWTR applied to surface water and groundwater under the direct influence of surface water systems serving over 10,000 people. The rule included the requirement for at least a 2-log removal of *Cryptosporidium*, credits for *Cryptosporidium* removal based on properly functioning filters, strict filter effluent turbidity performance requirements, and clearly defined reporting requirements.

The Long Term 2 Enhanced Surface Water Treatment Rule (adopted in 2006) superseded the IESWTR. The effect these rules had on the City of Boulder is discussed later in this chapter.

3.1.3.2 Stage 1 Disinfectants and Disinfection Byproduct Rule (D/DBPR)

For some time, it has been a major challenge for water suppliers to balance the risks from microbial pathogens and disinfection byproducts. It is important to provide protection from these microbial pathogens while simultaneously ensuring decreasing health risks to the population from DBPs.

The Stage 1 D/DBRP (published 16 December 1998/effective 1 December 2001) attempted to reduce the levels of exposure to disinfectants and disinfection byproducts in drinking water supplies. The Stage 1 D/DBPR updated and superseded the 1979 regulations for total trihalomethanes. In addition, it set limits for exposure to three disinfectants and many disinfection byproducts. The rule provided public health protection from exposure to haloacetic acids, chlorite (a major chlorine dioxide byproduct) and bromate (a major ozone byproduct). The rule established maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) for three chemical disinfectants – chlorine, chloramine and chlorine dioxide. **Table 5-9** shows the maximum contaminant level goals (MCLGs) and maximum contaminant levels (MCLs) for total trihalomethanes, haloacetic acids, chlorite and bromate.

Table 5-9: Stage 1 D/DBPRs

Disinfectant Residual	MRDLG (mg/L)	MRDL (mg/L)	Compliance Based On
Chlorine	4 (as Cl_2)	4.0 (as Cl_2)	Annual Average
Chloramine	4 (as Cl_2)	4.0 (as Cl_2)	Annual Average
Chlorine Dioxide	0.8 (as ClO_2)	0.8 (as ClO_2)	Daily Samples
DBPs	**MCLG (mg/L**	**MCL (mg/L)**	**Compliance Based On**
Total trihalomethanes (TTHM)[1]	N/A[2]	0.080	Annual Average
Chloroform[3]	N/A		
Bromodichloromethane	0		
Dibromochloromethane	0.06		
Bromoform	0		
Haloacetic acids (five haloacetic acids [HAA_5])[4]	N/A	0.060	Annual Average
Dichloroacetic acid	0		
Trichloroacetic acid	0.3		
Chlorite	0.8	1.0	Monthly Average
Bromate	0	0.010	Annual Average

[1]Total trihalomethanes is the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

[2]N/A – Not applicable because there are individual MCLGs for TTHMs or HAA HAA_5s, unless otherwise noted.

[3]The USEPA removed the value of zero for the MCLG for Chloroform from its National Primary Drinking Water Regulations, effective May 30, 2000, in accordance with an order of the U.S. Court of Appeals for the District of Columbia Circuit.

[4]Haloacetic acids (five) are the sum of the concentrations of mono-, di-, and trichloroacetic acids and mono- and dibromoacetic acids.

[5]Note: Stage 1 D/DBPR was superseded by Stage 2 D/DBPR

Water systems that use surface water and use conventional filtration treatment are required to remove specified percentages of organic materials, measured as total organic carbon (TOC) that may react with disinfectants to form DBPs. The level of removal of TOC is specified in **Table 5-10** and the routine monitoring requirements are included in **Table 5-11**.

Table 5-10: Required Removal of Total Organic Carbon

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)[1]		
	0-60	> 60-120	> 120[2]
>2.0-4.0	35.0%	25.0%	15.0%
>4.0-8.0	45.0%	35.0%	25.0%
>8.0	50.0%	40.0%	30.0%

[1]Systems meeting at least one of the alternative compliance criteria in the rule are not required to meet the removals in this table.

[2]Systems practicing softening must meet the TOC removal requirements in the last column to the right.

Table 5-11: Routine Monitoring Requirements for Conventional Filtration Treatment Plants

Requirement	Location for sampling	Large Surface Water System with Conventional Filtration
TOC and Alkalinity	Source Water (TOC and Alkalinity sample must be at same location and time)	1 sample/month/plant
TTHMs and HAA_5	25% in distribution system at maximum residence time, 75% at distribution system representative locations	4/plant/quarter
Chlorine and Chloramines	Same points as total coliform in TCR	Same times as total coliform in Total Coliform Rule (TCR)

Compliance with the Stage 1 D/DBPR was required at the state level by December 17, 2001. Reduced monitoring limits are available if the source water annual average TOC, before any treatment, is less than 4.0 mg/L and then annual average of TTHM is less than 0.040 mg/L, and the annual average of HAA_5 is less than 0.030 mg/L (1996 SDWA Programs).

The Stage 2 D/DBPR (adopted in 2006) superseded the Stage 1 D/DPBR. The effect these rules had on the City of Boulder is discussed later in this chapter.

3.1.3.3 Consumer Confidence Reports (CCRs)

The Consumer Confidence Report rule was created by the 1996 reauthorization of the Safe Drinking Water Act. The Environmental Protection Agency published the final regulation on August 19, 1998 (Federal Register, Volume 63, and Number 160). The rule requires community water systems to provide annual reports to their customers on the quality of their drinking water. The Consumer Confidence Reports inform water system customers about the quality, safety, and reliability of their drinking water.

All water utilities are required to provide the reports by July 1 of each year. The CCR does not replace annual monitoring and reporting requirements of the SDWA. Water utilities must deliver the report directly to each customer by hand or through the regular mail service.

Consumer confidence reports summarize information that water systems already collect to comply with current regulations. The federal rule has specific requirements for mandatory language and reporting detected contaminants. The required information for the CCR is summarized below.

- Name and location of water source(s)
- Type of water (groundwater, surface water, imported water)
- Concentrations of regulated contaminants detected in the water
- Concentrations of unregulated (monitoring only) contaminants detected in the water
- Concentrations of disinfection byproducts
- Concentrations of microbial contaminants
- Allowable Maximum Contaminant Levels for each contaminant monitored
- Health effects of contaminants exceeding any allowable MCL
- Probable sources of any contaminants
- Violations of monitoring, reporting, treatment, or record keeping requirements
- Public involvement opportunities
- Sources of additional information

Utilities may include additional information to explain or help customers interpret the CCR data.

The City of Boulder is required to produce consumer confidence reports annually to the citizens of Boulder. The most recent 2010 report is available online on the City's website:

3.1.3.4 Source Water Protection

Every state with primacy is required to develop a Source Water Assessment and Protection Program (SWAP) as a means of protecting water used for public drinking water supplies. SWAP calls for the states to conduct an assessment, coordinated with existing information and programs, to determine the vulnerability of drinking water sources within their boundaries. The concept was not new, as it had been employed ten years before with the wellhead protection program, a preventive approach to protecting ground water sources of drinking water. Source water expands the concept to include surface water sources as well.

SWAP is a two-phased process; assessment and protection. The assessment phase must include four elements: Involvement of the public in the design and implementation of the source water assessments; delineation of the source water assessment areas (SWAAs) for each public water system (PWS); an inventory of significant potential sources of contamination (PSOCs) within the SWAA; and a determination of the susceptibility of the PWS intake or well to the inventoried contaminants. The protection phase utilizes the information obtained from the assessment phase and encourages the public water providers to employ measures within the SWAA that will help ensure the long term integrity of the water source. A SWAA becomes a source water protection area (SWPA) with the development of a protection plan and implementation of protection measures.

SWAP in Colorado is organized by watershed. These are subdivided into hydrologic units and sub-units within the SWAAs that are defined. Organization of SWAP by watershed coincides with federal and state policies to manage water quality within this context.

The Safe Drinking Water Act specifies that the following tasks must be undertaken to adequately assess a PWS' source water:

- Delineate the area or zone through or over which contaminants, if present, are likely to migrate and reach the drinking water well or surface water intake.
- Inventory PSOCs. Assemble data on regulated and unregulated PSOCs along with information on the structure of the wells and intakes, and the hydrogeology within the delineated SWAA.
- Analyze the susceptibility of the drinking water source to the contaminants identified.
- Rate the PWS as having high, moderate, or low susceptibility to the type of contaminants or contaminant sources identified.

The CDPHE Water Quality Control Division performed the source water assessment for Boulder as well as other Colorado systems based on existing databases. The protection phase is voluntary.

3.1.3.5 *Capacity Development*

The 1996 Amendments create a program to build nationally on the demonstrated success of several States in strengthening the managerial, technical and financial capacity of water systems to reliably deliver safe drinking water. State programs must have two main components: (1) legal authority to ensure that new water systems have sufficient technical, managerial, and financial capacity to meet drinking water standards; and (2) a strategy to identify and assist existing water systems needing improvements in managerial, technical, or financial capacity or aid to comply with standards.

These amendments to the 1996 SDWA impacted on the State of Colorado's program more than the City of Boulder.

3.1.3.6 *Operator Certification*

Ensuring the knowledge and skills of public water system operators is widely considered one of the most important, cost-effective means to strengthen drinking water safety. To that end, the Amendments require all States to carry out a program of operator certification. Each State must either: (a) implement a program that meets the guidelines established by USEPA, or (b) enforce an existing State program, provided it is substantially equivalent to or meets the overall public health objectives of USEPA's guidelines.

The City of Boulder Water Treatment Facilities are classified by the State of Colorado to be "A" facilities. Boulder fulfills the "A" classification requirement with State of Colorado certified "A" operators at both facilities. These certified operators along with mechanics, electronic technicians, SCADA Administrator, and process optimization specialists ensure that the water quality from the two treatment facilities meets and exceeds the requirements for water treatment set by CDPHE.

3.1.3.7 *Public Notification Rule*

In 2000 the USEPA Public Notification (PN) Rule set new strict requirements on the form, manner, content, and frequency of public notices. The notices must contain:

- A description of the violation that occurred, including the potential health effects
- The population at risk and if alternate water supplies need to be used
- What the water system is doing to correct the problem
- Actions consumers can take
- When the violation occurred and when the system expects it to be resolved
- How to contact the water system for more information
- Language encouraging broader distribution of the notice

The regulation divides the public notice into three tiers:

Tier 1, for violations and situations with significant potential to have serious adverse effects on human health as a result of short-term exposure. Notice is required within 24 hours of the violation.

Tier 2, for other violations and situations with potential to have serious, but not immediate, adverse effects on human health. Notice is required within 30 days, or as soon as possible, with extension of up to three months for resolved violations at the discretion of the State or primacy agency.

Tier 3, for all other violations and situations not included in Tier 1 and Tier 2. Notice is required within 12 months of the violation, and may be part of a single annual report, including in some cases the annual CCR already required by EPA.

The PN Rule forces the City of Boulder to inform the community of any violation in treatment quality via the three tiers listed above.

3.1.3.8 Unregulated Contaminant Monitoring Regulation (UCMR)

The first cycle of the Unregulated Contaminant Monitoring Regulation (UCMR 1) (published September 17, 1999/effective January 1, 2001) is used to support the "sound science" approach to future drinking water regulations. The requirements for unregulated contaminant monitoring were first established by the 1986 SDWA Amendments. Since its inception in 1988, the UCM program has collected occurrence data to help USEPA determine which contaminants USEPA should regulate based on contaminant concentrations in PWSs and the contaminants' adverse health effects levels. Data generated by this rule will be used to: (1) evaluate and prioritize contaminants on the Contaminant Candidate List (CCL) and refine the CCL; (2) support the Administrator's determination of whether to regulate a contaminant under the drinking water program; and, (3) support the development of drinking water regulations.

The program includes: (1) a new list of contaminants; (2) a representative sample of PWSs serving 10,000 or fewer person to monitor; (3) placement of the monitoring data in the National Drinking Water Contaminant Occurrence Database (NCOD), and; (4) notification of consumers that the monitoring results are available.

UCMR 1 covered the period 2001 through 2005 and is currently superseded by UCMR 2 which covers the period 2007 through 2011. UCMR 2 (effective on February 5, 2007) is the final rule which describes the design for the second UCMR cycle. Under UCMR 2, USEPA requires the monitoring of 25 chemicals using five different analytical methods. UCMR 2 monitoring will occur during 2008 through 2010.[1]

The most recent CCL (CCL3) is listed later in this section.

3.1.3.9 Arsenic

On January 22, 2001 the USEPA adopted a new arsenic MCL of 10 ppb, which replaced the previous standard of 50 ppb. The new Arsenic Rule became effective on February 22, 2002 and water treatment systems were required to comply with the new rule by January 23, 2006. The MCLG for arsenic is 0 ppb.

The City of Boulder monitors arsenic at the entry point to the distribution system once annually. The City also voluntarily monitors arsenic monthly at the entry point to the distribution system at each WTF, which is not required by CDPHE.

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[1] http://www.epa.gov/fedrgstr/EPA-WATER/2007/January/Day-04/w22123.htm.

3.1.3.10 Stage 2 D/DBPR

The Stage 2 D/DBPR was implemented in 2006 and revises the original Stage 1 D/DBPR. The rule only applies to utilities serving more than 10,000 consumers. The following presents a general overview of the rule:

- Initial Distribution System Evaluation (IDSE) – Surface water systems and groundwater systems were required to conduct one year of monitoring at sample locations that are separate from the current DBP compliance sample locations. The sample locations were determined based on the type of distribution system residual maintained by the system.

- The results of the IDSE were then used to determine those sites in the distribution system that have the highest DBPs and to select from these sites four new DBP compliance monitoring locations per plant.

- Compliance with the Stage 2 D/DBPR is determined using a Locational Running Annual Averages (LRAA), rather than system-wide averages, using the same MCL's as the Stage 1 D/DBPR. This means that the results from DBP sampling are no longer averaged across the entire distribution system. Instead, the results of sampling are averaged each quarter at each sampling site and the running annual average of the results at each location must meet the MCL's. Compliance will begin in 2012.

Best available technology for meeting the Stage 2 MCLs, as defined by EPA, is enhanced coagulation (or softening), and granular activated carbon (GAC) adsorption with empty bed contact times of 10 or 20 minutes.

The City collects data on TOC removal and alkalinity, disinfection byproducts (TTHM, HAA5), Chlorine MRDL, and Chlorine at various points in the raw water and/or distribution system. A detailed discussion of the City's regulatory compliance as related to the Stage 2/DBPR is included in **Section 5.1.3 Regulatory Compliance.**

The BWTF complies with an alternative compliance criteria of having the treated water TOC level less than 2 mg/L.

The City of Boulder has had to use an alternative compliance method for TOC removal at the BRWTF because the required TOC removal was not always met. The source water Specific UV-absorption (SUVA) calculation is used for the BRWTF, which is less than or equal to 2 L/mg-m.. Further details on how the BRWTF is meeting the requirements using a carbonic acid system is described in **Section 5.1.2.**

3.1.3.11 Long Term Enhanced Surface Water Treatment Rule (LT2ESWTR)

The LT2ESWTR was adopted in 2006 and applies to surface water and groundwater under the direct influence of surface water sources, it provides new information and supersedes the IESWTR. The objective of the rule is to reduce the risk associated with *Cryptosporidium* and other microbial pathogens in drinking water and address risk-risk tradeoffs with the control of disinfection byproducts. Sampling of raw water sources for *Cryptosporidium* is required under the LT2ESWTR. The following presents a general overview of the LT2ESWTR:

- Surface water systems serving greater than 10,000 people were required to conduct monitoring for Cryptosporidium (and E. coli) for 24 months to determine the source water concentration of Cryptosporidium for a given system.

- Each utility determined a bin classification based on the *Cryptosporidium* sample results. Bins are calculated by averaging individual sample results from one or more years of monitoring. Specific procedures vary depending on the frequency and duration of monitoring. Treatment bins are shown in **Table 5-12**.

If the level of *Cryptosporidium* requires additional treatment beyond conventional filtration, a number of methods of meeting the treatment requirement are available, including membrane filtration and disinfection with ultraviolet (UV) light.

Table 5-12: USEPA Bin Classification Table and Treatment Requirements for Filtered Public Water Systems under LT2ESWTR

For Public Water Systems that Are...[1]	Bin	Average *Cryptosporidium* Concentration	Additional Treatment Requirements for Systems with Conventional Treatment
Required to monitor for *Cryptosporidium*	1	Crypto < 0.075 oocysts/L	No action
	2	0.075/L < Crypto < 1.0/L	1.0-log treatment (0.5-log removal + 0.5-log inactivation or 1.0 log or greater from microbial toolbox)
	3	1.0 < Crypto < 3.0/L	2-log treatment (with at least 1.0 log inactivation – e.g., UV, O_3, ClO_2, membranes, bag filters or bank filtration)
	4	Crypto > 3.0/L	3-log treatment (with at least 1.0 log inactivation – e.g., UV, O_3, ClO_2, membranes, bag filters or bank filtration)
Serving fewer than 10,000 people and NOT required to monitor for *Cryptosporidium*[1]	1	N/A	No action

[1]Filtered PWSs serving fewer than 10,000 people are not required to monitor for *Cryptosporidium* if they monitor for E. coli and demonstrate a mean concentration of E. coli less than or equal to 10/100 mL for lake/reservoir sources or 50/100 mL for flowing stream sources or do not exceed an alternative State-approved indicator trigger (see section IV.A.1).

CDPHE requires the City of Boulder to report the results of a Microscopic Particulate Analysis (MPA) from samples taken on the raw water and the combined filter effluent of both facilities annually (with rotating quarters – e.g., 2010 was in the fourth quarter of the year).

The City of Boulder conducted the required monitoring programs for the BRWTF from January 2001 – October 2004 with follow-up sampling in June 2006 and for the BWTF from January 2001 – October 2004 with follow-up sampling in October 2008.

The City of Boulder will be required to monitor for *Cryptosporidium* again in 2015 and reevaluate the Bin Classification in 2017.

3.1.3.12 Filter Backwash Recycling Rule (FBRR)

On June 8, 2001, USEPA published the final Filter Backwash Recycling Rule in the Federal Register. The following presents a summary of the FBRR:

1. Applies to surface water and groundwater under the direct influence of surface water systems that utilize conventional or direct filtration (as defined in the Code of Federal Regulations) that

practice recycle of filter backwash water, thickener supernatant, or liquids from dewatering processes.

2. By December 8, 2003, systems that recycle filter backwash water, thickener supernatant, or liquids from dewatering processes must have notified the State of the following: (a) plant schematic showing origin of all flows that are recycled, hydraulic conveyance used to transport the flows and location where they are returned to treatment plant, (b) typical recycle flow in gallons per minute, (c) highest observed plant flow during the previous year, (d) design flow for the treatment plant in gallons per minutes, (e) State approved operating capacity for the treatment plant (if the State had made such a determination).

3. Any system that recycles (spent filter backwash water, thickener supernatant, or liquids from dewatering processes) must have returned flows through all processes of the system's existing conventional or direct filtration plant (or an alternate location approved by the State) by June 8, 2004.

4. If a system needed to make capital improvements to comply, these improvements must have been completed by June 8, 2006.

5. Systems must have recordkeeping requirements (to be reviewed during sanitary surveys) including (a) copy of notification and information submitted to the State as described above, (b) list of all recycle flows and frequency with which they are returned, (c) average and maximum backwash flow rate through filters, average and maximum duration of the filter backwash cycle, (d) typical filter run length and a written summary of how filter run length is determined, (e) if applicable, type of treatment provided for recycle flow, (f) information on physical dimensions of any equalization and/or treatment units, typical and maximum hydraulic loading rates, type of treatment chemicals, average dose and frequency of use, and frequency at which solids are removed, if applicable.

The objective of the Filter Backwash Rule is to prevent the return of concentrated contaminants removed by filters. On June 8, 2001, USEPA published the final Filter Backwash Recycling (FBR) Rule in the Federal Register. The City of Boulder has records which comply with the requirements for this rule.

3.1.3.13 Radionuclides Rule

EPA revised the radionuclide rule on December 7, 2000. The rule retained the existing MCLs for combined radium-226 and radium 228 of 5 pCi/l, gross alpha particle radioactivity of 15 pCi/l, and beta particle and photon emitters at 4 mrem/yr. The rule now regulates uranium with a MCL of 30 μg/l. MCLGs for all of the regulated radionuclides are zero.

The City of Boulder monitors Uranium, $\text{Radium}_{226,228}$, and Gross Alpha at the entry point into the distribution system every 9 years. The next monitoring will need to occur in 2011.

3.1.4 Future Regulations

3.1.4.1 Contaminant Candidate List 3 (CCL3)

In October 2009, USEPA published a final list of contaminants which may require regulation under the SDWA. This final Contaminant Candidate List 3 (CCL3) includes 104 chemicals of chemical groups and 12 microbiological contaminants which are known or anticipated to occur in public water systems. The list includes chemicals used in commerce, pesticides, waterborne pathogens, DBPs and biological toxins. The Agency evaluated approximately 7,500 chemicals and microbes and selected 116 candidates for the CCL3 that have the potential to present health risks through drinking water exposure. The CCL3 list is included below in **Table 5-13.**

3.1.4.2 Unregulated Contaminant Monitoring

US Environmental Protection Agency recently outlined its plans to have certain utilities monitor for 30 contaminants under the third Unregulated Contaminant Monitoring Rule, (UCMR3). The City of Boulder will be part of this effort and will monitor 24 of the targeted contaminants in the CCL3. The City will be part of 4,800 utilities to start the third round of Assessment Monitoring in 2013 for 22 unregulated contaminants — including seven hormones; 1,4, dioxane; nine volatile organic compounds (VOCs); four metals; and chlorate. In addition the USEPA is considering a Screening Survey for six perfluorinated alkyl acids.

This information was announced in April of 2010 and will be used by the EPA to make future regulatory determinations.

3.1.4.3 Revised Total Coliform Rule

In 2007, USEPA decided to establish a committee under the Federal Advisory Committee Act. This charge to the Total Coliform Rule/Distribution System Advisory Committee (TCR/DSAC) was to develop an agreement in principle regarding recommendations to USEPA on revisions to the TCR and on what information about distributions is needed to better understand and address possible public health impacts from potential degradation of drinking water quality in distribution systems. On September 18, 2008, the TCRDSAC signed an Agreement in Principle that recommended revisions to the 1989 TCR. In 2010, the USEPA proposed revisions to the 1989 TCR. The 2010 proposed revisions to the TCR will:

- require public water systems that are vulnerable to microbial contamination to identify and fix problems, and
- establish criteria for systems to qualify for and stay on reduced monitoring, thereby providing incentives for improved water system operation.

The City of Boulder currently monitors total coliform and chlorine by collecting 120 samples monthly within the distribution system. This information is reported to CDPHE within 10 days after the month’s end.

Table 5-13: Contaminant Candidate List 3 (CCL3)

Chemical Contaminants		
Common Name – Registry Name		
1,1,1,2-Tetrachloroethane	Estrone	RDX
1,1-Dichloroethane	Ethinyl Estradiol (17-alpha Ethynyl Estradiol)	sec-Butylbenzene
1,2,3-Trichloropropane	Ethoprop	Thiodicarb
1,3-Butadiene	Ethylene glycol	Thiophanate-methyl
1,3-Dinitrobenzene	Ethylene oxide	Toluene diisocyanate
1,4-Dioxane	Ethylene thiourea	Tribufos
17 alpha-Estradiol	Fenamiphos	Triethylamine
1-Butanol	Formaldehyde	Triphenyltin hydroxide (TPTH)
2-Methoxyethanol	Germanium	Strontium
2-Propen-1-ol	Halon 1011 (bromochloromethane)	Tebuconazole
3-Hydroxycarbofuran	HCFC-22	Tebufenozide
4,4'-Methylenedianiline	Hexane	Tellurium
Acephate	Hydrazine	Terbufos
Acetaldehyde	Mestranol	Terbufos sulfone
Acetamide	Methamidophos	Urethane
Acetochlor	Methanol	Vanadium
Acetochlor ethanesulfonic acid (ESA)	Methyl bromide (Bromomethane)	Vinclozolin
Acetochlor oxanilic acid (OA)	Methyl tert-butyl ether	Ziram
Acrolein	Metolachlor	
Alachlor ethanesulfonic acid (ESA)	Metolachlor ethanesulfonic acid(ESA)	**Microbial Contaminants**
Alachlor oxanilic acid (OA)	Metolachlor oxanilic acid (OA)	Adenovirus
alpha-Hexachlorocyclohexane	Molinate	Caliciviruses
Aniline	Molybdenum	*Campylobacter jejuni*
Bensulide	Nitrobenzene	Enterovirus
Benzyl chloride	Nitroglycerin	*Escherichia coli* (0157)
Butylated hydroxyanisole	N-Methyl-2-pyrrolidone	*Helicobacter pylori*
Captan	N-nitrosodiethylamine (NDEA)	Hepatitis A virus
Chlorate	N-Nitrosodimethylamine (NDMA)	*Legionella pneumophila*
Chloromethane (Methyl chloride)	N-Nitroso-di-npropylamine (NDPA)	*Mycobacterium avium*
Clethodim	N-Nitrosodiphenylamine	*Naegleria fowleri*
Cobalt	N-nitrosopyrrolidine (NPYR)	*Salmonella enteric*
Cumene hydroperoxide	Norethindrone (19-Norethisterone)	*Shigella sonnei*
Cyanotoxins	N-Propylbenzene	
Dicrotophos	o-Toluidine	
Dimethipin	Oxirane, methyl-	
Dimethoate	Oxydemeton-methyl	
Disulfoton	Oxyfluorfen	
Diuron	Perchlorate	
Equilenin	Perfluorooctane sulfonic acid (PFOS)	
Equilin	Perfluorooctanoic acid (PFOA)	
Erythromycin	Permethrin	
Estradiol (17-beta estradiol)	Profenofos	
Estriol	Quinoline	

3.1.4.4 Revised Lead and Copper Rule

The Lead and Copper Rule is on target to be revised in the spring of 2012, with finalization in 2014. Revisions are likely to include revisions to the current sample tiers, changes to lead service line replacement requirements, and sampling at schools and child care facilities.

3.1.4.5 Endocrine Disrupting Compounds and Pharmaceuticals and Personal Care Byproducts

Another area of possible future regulatory activity is the regulation of a broad range of emerging contaminants that include pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs). EDCs are chemicals that interfere with the natural function of the endocrine system (glands and hormones) in both humans and animals. Continuing research into refining analytical methods, significantly lower detection limits, and occurrence of these compounds in the environment has captured the attention of the general public. Endocrine disrupting compounds are ubiquitous in the environment and can be found in both point and non-point sources. EDCs in drinking water may originate from 1) surface water, groundwater, or reservoir source water that was contaminated by point or non-point source pollution, 2) chlorinated or oxygenated compounds that are produced as byproducts during water treatment processes, and 3) contact with material in the water supply system.

For humans, exposure to EDCs can occur through food, water, and air. Compounds classified as potential EDCs vary among regulatory and environmental organizations around the world. There is still a need for agreement on the specific effects that would be required to classify a substance as a potential endocrine disrupting compound. A complete listing of known EDC and PPCP compounds is lengthy and EPA's prohibitively costly plan to eventually test the full universe of 87,000 known chemicals for endocrine disrupter activity will further lengthen this list. Presently, the best approach is to focus on those compounds where analytical methodologies have been developed and survey work has demonstrated frequent occurrence. General categories of PPCPs detected with greatest frequency are included in **Table 5-14**.

Table 5-14: Categories of PPCPs Detected with Greatest Frequency in Unites States Geological Society (USGS) Urbanized Stream Reconnaissance Survey, (2002) Kolpin, et. al.

Category	Compounds	Frequency Detected
Steroids (fecal indicators)	Coprostanol Cholesterol	86% 85%
Insect Repellent	DEET	75%
Nonprescription Stimulant	Caffeine	60%
Nonprescription Nicotine Metabolite	Cotinine	38%
Nonprescription Stimulant Metabolite	1,7-dimethylxanthine	30%
Fire Retardant	Tri(2-chloroethyl)phosphate	58%
Antimicrobial Household Disinfectant	Triclosan	58%
Detergents	4-Nonylphenol 4-Nonylphenol monoethoxylate 4-Octylphenol monoethoxylate 4-Nonylphenol diethoxylate	52% 46% 44% 38%
Plasticizers	Ethanol-2-butoxy-phosphate	46%
Polymer Ingredient	Bisphenol-A	42%
Antioxidants (food preservatives)	5-methyl-1H-benzotriazole	33%
Polyaromatic Hydrocarbon	Fluoranthene (priority pollutant) Pyrene (priority pollutant)	31% 29%
Antibiotics	Trimethoprim	27%

Presently, there is no consensus on the use and validity of toxicity tests for the evaluation of the toxic hazard to humans from EDCs. Many challenges exist for EDC assessment. Some effects are demonstrable at very low dosage exposures; however, the levels of contamination known to cause effects are dramatically lower than current testing procedures are able to measure. Dose-response curves do not necessarily follow the classic assumption that as the dose increases so too does the effect. For some endocrine disrupting compounds, effects may disappear at higher levels, or become qualitatively different. Under other circumstances, there may be no threshold level below which there is no effect. Contaminant exposures take place in mixtures and these mixtures can interact additively, synergistically, or not at all. This means that toxicological tests conducted for most regulatory decisions must be repeated at environmentally relevant (i.e., much lower) levels. In the meantime, this means the USEPA, Food and Drug Administration, and industry are lacking in scientific guidance for regulatory decisions related to EDCs.

In 2007, the Water Research Foundation implemented the Strategic Research Initiatives Program's "Distribution System Water Quality and EDC s/PPCPs in Drinking Water." This program will help to develop methods to detect and quantify these compounds in drinking water, assess the occurrence of these compounds, evaluate the toxicological relevance to human health, develop cost effective source control and treatment alternatives, and develop effective tools and strategies for outreach and communication with drinking water customers. (Water Research Foundation (2010) Endocrine Disrupting Compounds/Pharmaceuticals and Personal Care Products Strategic Research Initiative – Strategic Plan).

In addition, nanoparticles (particles with a dimension of 100 nm or less) used in PPCPs have recently become a point of concern. Nanoparticles immediately adsorb onto the surface of some larger molecules. Nanoparticles have been used as a drug delivery mechanism to direct the drug to a specific location, sometimes a specific cell, in the body. Depending on the dose and solubility, these nanoparticles can either dissolve to impact living organisms as the chemical was designed, or others tend to accumulate in biological systems. There is a lot of research into these nanoparticles and their effect on health and the environment.

Currently, there are no regulations specific to EDCs in the U.S., but the USEPA has designed an approach to select its first set of chemicals for screening under the Endocrine Disruptor Screening Program (EDSP). Since pesticides are the most commonly found EDC in water sources, this program aims to determine if exposure to pesticides has a hormonal effect caused by disruptions to the endocrine system. The initial screening process is a series of assays that will identify substances with the potential to interact with estrogen, androgen, or thyroid hormone systems, while subsequent testing will determine if these substances can affect the endocrine system. USEPA plans to screen about 87,000 compounds identified as EDC candidates. In addition, some EDCs and PPCPs are included in the UCMR3 for future regulatory consideration.

As indicated above, a good deal of public interest has been aroused regarding the potential environmental and health effects of EDCs. The book, Our Stolen Future, published in 1996, gained notoriety for concluding that, "the weight of the evidence indicates that the presence of EDCs is ubiquitous" and that their presence "…involves impairments to reproduction, alterations in behavior, diminishment of intellectual capacity, and erosion in the ability to resist disease." However, these conclusions with respect to humans are subject to debate.

More recently, a series of studies have related the presence of estrogenic compounds to the feminization of fish populations in streams impacted by treated wastewater. There have been some documented instances of sex abnormalities in aquatic organisms in relation to wastewater discharge, and other possible influences in locations across the county, that are consistent with hormonal imbalances in which EDCs may play a role.

Locally, an ongoing fish feminization study is being performed by the University of Colorado (David Norris). This study is comparing the sex ratios of white suckers in Boulder Creek above and below the Boulder Wastewater Treatment Plant outfall. Several estrogenic compounds are found in Boulder wastewater effluent. These include the natural estrogens, estradiol and estriol, the synthetic estrogen (from birth control pills) ethynylestradiol, a synthetic estrogen breakdown product, nonylphenol and a component of polycarbonate plastic with estrogenic effects, bisphenol A.

To date, this study has found a disturbance in sucker sex ratios from a 1:1 female to male ratio above the outfall to a 5:1 female to male ratio below the outfall. In addition, intersex fish are found downstream of the outfall while none are found upstream of the outfall. These results clearly demonstrate the existence of ecological impacts from the release of treated wastewater. However, the impact to humans is not clear. This issue is complicated by the fact that consumption or contact with drinking water is only one of many pathways by which humans can be exposed to estrogenic compounds and other EDCs.

It should be remembered that EDCs have been found at extremely low concentrations in drinking water. With respect to humans, it appears that even when EDCs are present in drinking water, it is likely that they are present at concentrations which are far below those that elicit a measurable physiological response.

The City of Boulder has a proactive approach to monitoring for upcoming contaminants of concern. The City has recently started monitoring raw and finished water and is participating in regional efforts with Northern Water and other CBT entities to share costs. Below are specific discussions of potential future regulations.

A few of the City's source waters have the potential of being impacted by wastewater effluent, including Barker Reservoir (via Nederland WWTP and septic tanks near Barker Reservoir) and Boulder Reservoir (via septic tanks near the reservoir and the BFC). Both of these sources are monitored frequently and sourcewater improvements have been investigated. The Nederland WWTP is upstream of a series of reservoirs and a significant amount of dilution occurs prior to entering the BWTF. The Carter Lake Pipeline would remove Boulder Reservoir as a source and pipe water directly from Carter Lake (further information is available in the City's 2007 Integrated Evaluation of the BRWTP Source Water Protection and Treatment Improvements Study).

The City of Boulder is participating in several Water Research Foundation projects, including:

- EDC/PPCP Benchmarking and monitoring (# 4260),
- Building a National Utility Network to Address EDC/PPCP Issues (#4261)
- Opportunity and Challenges of Nanomaterials in Drinking Water (#4311)
- Evaluating the Removal of Perflurorinated Chemicals by North American Water Treatment Practices (Proposed) (#4322)
- Consumer Perceptions and Attitudes Towards EDCs and PPCPs in Drinking Water (Project Advisory Committee) (#4323)

3.1.4.6 Algal Toxins

Blue-green algae (cyanobacteria) are also a contaminant of concern primarily because of their ability to release harmful toxins that can contaminate drinking water supplies. The Water Research Foundation is pursuing a significant amount of work on the topic to determine the occurrence of these cyanobacteria and methods that can be used to manage it. Toxic cyanobacteria blooms should be managed in the sourcewater, but also water treatment technology, especially the use of activated carbon can be used to deal with the algal toxins.

Boulder Reservoir, RWTF has shown an increase in blue-green algae, which has been shown to impact taste and odor and is an issue for the BRWTF. Microscopic analysis has shown that the blue-green algae comprise 0.6% of the biovolume (July 2010 sample). The BRWTF may require activated carbon to address the taste and odor problems, but the pilot sodium permanganate pre feed also should help resolve the issue. The City is proactively checking for the presence of these algal toxins, but has not had any problems with cyanobacteria blooms in the reservoir. Cyanotoxins are included in the CCL3.

3.1.4.7 Nitrosamines

Another class of contaminants of possible future regulatory concern is nitrosamines. Nitrosamines are a family of contaminants that may be produced by the interaction of nitrogen compounds and disinfectants during the wastewater treatment process. There are other industrial sources for nitrosamines as well. Some nitrosamine compounds have been shown to cause cancer in laboratory animals. The nitrosamine family of contaminants includes:

- N-Nitrosodiethylamine (NDEA)
- N-Nitrosodimethylamine (NDMA)
- N-Nitrosodi-n-propylamine (NDPA)
- N-Nitrosodi-n-butylamine (NDBA)
- N-Nitrosomethylethylamine (NMEA)
- N-Nitrosopiperidine (NPIP)
- N-Nitrosopyrrolidine (NYPR)

At present, neither the USEPA nor CDPHE has established regulations for nitrosamines in drinking water nationally or in Colorado respectively. However, in part because of concerns over indirect potable reuse, the State of California has established “Notification Levels” and “Response Levels” for certain nitrosamines. A Notification Level is a level that, when detected, requires that the local governing board for the utility be notified of the presence of the contaminant in the drinking water source. In California, the Notification Level is typically set at a lifetime cancer risk of 10-6 (1 in 1,000,000 risk). The Response Level is the level at which the State recommend that the source be taken out of service. In general, California drinking water utilities have voluntarily complied with these levels. **Table 5-15** presents the Notification and Response Levels for nitrosamines in California.

Table 5-15: Notification and Response Levels for Nitrosamines in California

Nitrosamine	10-6 Risk Level (ng/L)	Notification Level (ng/L)	Response Level (ng/L)
N-Nitrosodiethylamine (NDEA)	1	10	100
N-Nitrosodimethylamine (NDMA)	2	10	200
N-Nitrosodi-n-propylamine (NDPA)	5	10	500
N-Nitrosodi-n-butylamine (NDBA)	3	-	-
N-Nitrosomethylethylamine (NMEA)	1.5	-	-
N-Nitrosopiperidine (NPIP)	3.5	-	-
N-Nitrosopyrrolidine (NYPR)	1.5	-	-

The City of Boulder participated in the monitoring of 6 nitrosamines as part of the UCMR2 in 2009. None were detected. The USEPA is reviewing the results of the UCMR2 and will soon determine whether monitoring is warranted.

3.1.4.8 Carcinogens

The USEPA is considering a new strategy to tighten restrictions on four waterborne compounds that can cause cancer. The four compounds to be addressed as a group are tetrachloroethylene (PCE), an organic compound used in dry cleaning; trichloroethylene (TCE), an organic compound used as an industrial solvent; acrylamide, a compound used in manufacturing; and epichlorohydrin, an organic compound used in plastic manufacturing. Under the new strategy being explored by USEPA, the agency would address chemical contaminants as a group for more expeditious and cost-effective enforcement. This strategy would also foster development of new water-treatment technologies, and partnerships with states to better monitor public water systems.

3.1.4.9 Drinking Water Strategy

The USEPA announced in early 2010 that a new drinking water strategy is being developed to address a range of drinking water quality concerns and is expected to streamline and accelerate the regulatory development process. The USEPA's March 2010 Fact Sheet on this matter states that there will be four principles that will provide greater protection of drinking water. The four principles are:

- Address contaminants as a groups rather than one at a time so that enhancement of drinking water protection can be achieved cost-effectively.
- Foster development of new drinking water technologies to address health risks posed by a broad array of contaminants.
- Use the authority of multiple statutes to help protect drinking water.
- Partner with states to share more complete data from monitoring at public water systems (PWS).

3.1.5 State of Colorado Regulations

3.1.5.1 Cross Connection Control Policy

Backflow prevention, also known as cross-connection control, helps protect water service connections so that degraded water, bacteria, and chemicals cannot be pulled back into the drinking water system. Backflow can result in the undesired reversal of water flow in the water distribution system due to changes like pressure fluctuation or main breaks. A backflow prevention assembly is a testable mechanical plumbing device that prevents water and any associated contaminants from returning back into the city distribution system.

Article 12 of the Colorado Primary Drinking Water Regulations (Article 12) requires the installation and testing of testable devices, called "backflow prevention assemblies (assemblies) on all hazardous cross-connections. This regulation is enforced by CDPHE who inspects the Backflow Prevention Program for compliance triennially during Sanitary Survey's (inspection of the distributions system, treatment systems and related regulatory programs).

Due in part to the 2008 outbreak of Salmonella in the Alamosa, Colorado drinking water system, CDPHE ramped up efforts in 2009 to both inspect and enforce program compliance. Prior to 2008, Sanitary Surveys primarily sought to verify the presence or absence of backflow prevention programs. Today, state engineers look more in depth at a city's Backflow Prevention Program during sanitary surveys. When a backflow prevention assembly has not been installed a major deficiency may be issued. Minor deficiencies are issued when a backflow prevention assembly has been installed but has not been tested within the last calendar year.

Backflow prevention assemblies must be installed at the point of containment (after the meter and prior to any plumbing branches) and must be tracked. Assemblies must be tested upon installation and at least annually thereafter. Only certified backflow prevention assembly testers as recognized by Article 12, CPDWR are allowed to test backflow prevention assemblies and submit test reports. The city must keep test reports for 3 years.

3.1.5.2 Waste Impoundment Regulations

As a result of subsection 25-8-202(7) of the 1989 amendments to the Colorado Water Quality Control Act (Senate Bill 181), a memorandum of agreement (MOA) was implemented on July 31, 2008, by and between the Water Quality Control Commission (WQCC), Water Quality Control Division (WQCD), and the Hazardous Materials and Waste Management Division (HMWMD) to provide a procedure for coordination among the Colorado State agencies that are responsible for protecting the quality of the state waters. The MOA states that the HMWMD will be the agency responsible for implementing site-specific standards for discharges into state ground waters through a rulemaking process and consultation with the WQCC and WQCD. The HMWMD rule will be established to protect present and future beneficial uses of groundwater.

As a result of the Senate Bill 181 and the MOA, the HMWMD is currently in the process of modifying Section 9 of the solid waste regulations (6 CCR 1007-2). The rule will apply to all waste impoundments where deposit and final treatment of solid waste occurs, and where storage, treatment, utilization, processing, or disposal of solid waste occurs. The HMWMD has targeted November 2010 for adoption of the Section 9 regulation.

Municipal utilities that possess solid waste impoundments will be confronted with new regulatory requirements and associated compliance schedules. The following are examples of impoundments at water treatment facilities that are likely to be affected:

- Filter backwash ponds
- Post-process waste storage ponds
- Washwater recovery ponds
- Drying/evaporation beds/pads

Exemptions to the regulations are defined in the draft regulation and include storm water and raw water impoundments, tanks, and impoundments that contain water in process.

Two categories of waste impoundments are defined based on their potential environmental threat: Type A and Type B impoundments. Classification will be determined by evaluating the waste stream characteristics and geologic, hydrogeologic, and engineering characteristics of the facility. Factors such as waste constituents, toxicity, mobility, and persistence in the environment will also be considered in determining a facility's classification.

Type A impoundments do not require additional engineering controls beyond those already in existence as of the effective date of the regulations. Impoundments that contain low-threat wastes and allow controlled seepage through their liner are classified as Type A impoundments. Seepage is only allowed from Type A impoundments that have no impact to the groundwater.

Type B impoundments are designed to prevent seepage or migration of leachable contaminants to groundwater and allow no seepage beneath their liner. Type B impoundments require additional engineering controls beyond to prevent the migration of leachable constituents to groundwater.

3.1.5.3 Residuals Treatment and Disposal

The disposal of solid wastes from water treatment residuals/sludge (WTRs) is under dual authority of the CDHPE and the local body having jurisdiction, typically the County's health department. Disposal of solid waste can be through beneficial reuse (land application or composting) or direct disposal (landfill). Beneficial reuse is regulated by 5 CCR 1003-7 Regulations pertaining to the Beneficial Use of Water Treatment Sludge. The key component of 5 CCR 1003-7 requires that the producer of the sludge to obtain a "Beneficial Use Certification" from CDPHE for land application. Parameters that must be monitored in water treatment plant sludge for Beneficial Use Certification are shown in **Table 5-16**.

Table 5-16: Parameters to be Measured in Water Treatment Plant Sludge

TSS	Nitrate	Total cadmium	Total lead	Total selenium
pH	Total potassium	Total chromium	Total mercury	Total zinc
Organic nitrogen	Total aluminum	Total copper	Total molybdenum	Total alpha activity
Total ammonia	Total arsenic	Total iron	Total nickel	Total phosphorous

Per 5 CCR 1003-7, the parameters listed above must be less than those established in 40 CFR 503 Standards For The Use Or Disposal of Sewage Sludge to obtain a Beneficial Use Certification. Of particular importance is the total alpha activity parameter. Per 5 CCR 1003-7 any dry sludge which exceeds 40 pCi/gm total alpha activity cannot be land applied. If the water treatment plant waste is co-applied with wastewater treatment plant biosolids, the requirements of Biosolids Regulation No. 64 are also applicable.

Direct disposal of WTRs is regulated through the Hazardous Materials and Waste Management Division of CDPHE. A key regulation is 6 CCR 1007-3 Part 261, Identification and Listing of Hazardous Wastes. To be disposed of in a non-hazardous landfill, the solid must pass limits set for the Toxicity Characteristic Leaching Procedure (TCLP) described in Part 261.24. Water treatment plant sludges routinely pass the TCLP and can be disposed of in non-hazardous landfills. Requirements defining the responsibilities of the facility accepting the sludge are defined in 6 CCR 1007-2, Part 1 Regulations Pertaining to Solid Waste Sites and Facilities. Section 12 of 6 CCR 1007-2, Part 1, specifically establishes criteria for water treatment plant sludge disposal facilities.

3.1.5.4 Technologically Enhanced Naturally Occurring Radioactive Materials (TENORMs)

Specific regulations regarding the disposal of WTRs containing TENORMs are unclear at present. The USEPA has released a guidance document for WTRs titled: "A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Technologies." The CDPHE has released an Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado (February, 2007) to provide disposal policy, general guidance and suggested criteria for the control and release of technologically enhanced naturally occurring radioactive material. The interim policy describes a tiered, graded approach acceptable to the CDPHE for disposal or reuse of TENORM, primarily from the treatment of drinking water, but may also be applied to other diffuse sources on a case-by-case basis.

Section 12 of the Solid Waste Regulations (6 CCR 1007-2 Regulations Pertaining to Solid Waste Disposal Sites and Facilities.) spells out the requirements for disposal of drinking water treatment plant sludge. Disposal also includes the requirements of Sections 2 and 3 of the Solid Waste Regulations.

- **12.1.4 Surface and Groundwater Monitoring –** states that surface and groundwater monitoring may be required. Facilities that are out of compliance with current standards may be required to upgrade to meet surface and groundwater protection.

- 12.2.1 – this section has the 40 pCi/g gross alpha notification requirement for alum sludge for drinking water treatment plants.

- 12.2.2 – this section has design, operation and closure requirements for monofills. Subsequent sections have requirements for fencing, maps, and record keeping.

- 12.3 – this section has sludge Acceptance criteria concerning pH and the presence of free liquids and other parameters. No other type of waste may be accepted by a monofill without approval by the Department, consistent with local land use authority.

3.1.6 City of Boulder Regulatory Compliance Status

At the present time, the City of Boulder is required to be in compliance with the Colorado Primary Drinking Water Regulations and the National Primary Drinking Water Standards. The regulatory requirements specifically applicable to the City of Boulder and the City's current status relative to the regulatory limits are presented in the following paragraphs.

3.1.6.1 The City of Boulder's Regulatory Drinking Water Quality Monitoring Schedule

Table 5-17 shows the drinking water quality monitoring schedule. Note that the table includes regulatory and supplemental monitoring. The table does not include regular process monitoring within the treatment facilities, source water monitoring, or special studies. The table was provided by the City of Boulder.

Table 5-17: City of Boulder Water Quality Monitoring

Contaminant	Sample Location	Frequency	Report To CDPHE
Regulatory			
Inorganics			
Fluoride	Entry point to the distribution system	Annually	10 days after results received
Metals (Sb, As, Ba, Be, Cd, Cr, Hg, Ni, Se, Na, Tl)	Entry point to the distribution system	Annually	10 days after results received
Nitrate	Entry point to the distribution system	Annually	10 days after results received
Nitrite	Entry point to the distribution system	Every 9 years – next monitoring in 2017	10 days after results received
Turbidity	Entry point to the distribution system	Daily (six times/day) and continuous	End of month + 10 days
Organics			
Synthetic organics	Entry point to the distribution system	Triennially – next monitoring in 2012	10 days after results received
Volatile organics	Entry point to the distribution system	Annually	10 days after results received
Disinfection Byproducts and Precursors			
TOC removal and alkalinity (plus DOC and UV_{254} for Specific UV-absorption (SUVA) calculation at BRWTF)	Raw water entry point to distribution system	Monthly – one set paired samples (source and treated)	End of quarter + 10 days
Disinfection byproducts (TTHM, HAA_5)	Distribution system	Quarterly – 8 sites in third month of each quarter	End of quarter + 10 days
Chlorine MRDL	Distribution system	Monthly – 120 samples using chlorine residual data from total coliform rule monitoring	End of quarter + 10 days (with TCR report)
Chlorine	Entry point to distribution system	Daily (six times/day) and continuous	End of month + 10 days
Total Coliform Rule			
Total coliform	Distribution system	Monthly – 120 samples	End of month + 10 day
Lead and Copper Rule			
LCR at the tap (copper, lead, pH, alkalinity, hardness)	At customer taps	Triennially – 50 samples. Next monitoring in 2011	End of sample period + 10 days
LCR Corrosion Control (pH, alkalinity, hardness)	Distribution system and entry points to distribution system	~Quarterly – 10 sites twice every 6 months (usually performed quarterly)	End of 6 months + 10 days
Surface Water Treatment Rule			
Microscopic particulate analysis	Raw water and combined filter effluent	Annually – rotating quarters. Quarter 4 in 2010	10 days after results received

Contaminant	Sample Location	Frequency	Report To CDPHE
Radionuclides			
Uranium, Radium$_{226,228}$, Gross Alpha	Entry point to distribution system	Every 9 years – next monitoring in 2011	10 days after results received
Supplemental Monitoring, Regularly Scheduled			
Metals (Cu, Pb, As)	Entry point to distribution system	Monthly, Each WTF	*Not required*
DBPs (TTHM, HAA_5)	Entry point to distribution system	Monthly, Each WTF	*Not required*
Chlorine, turbidity, pH, conductivity, and temperature	Booton and Chautauqua tanks and Iris and Cherryvale pump stations	Continuous	*Not required*

3.1.6.2 National Primary Drinking Water Standards

A National Primary Drinking Water Regulation (NPDWR or primary standard) is a legally-enforceable standard that applies to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water. The primary standards take the form of Maximum Contaminant Levels or Treatment Techniques.

The Primary Drinking Water Standards (CFR 40 Part 141) regulate a broad range of chemical, physical, and microbial contaminants in drinking water. The regulations also stipulate frequency of water quality monitoring, analytical methods, reporting and record keeping requirements, and public notification of compliance failures. The Primary Drinking Water Standards, including the MCLs, and monitoring requirements as they apply to the City of Boulder are summarized in **Table 5-18, 5-19**, and **Table 5-20**. In each of these tables the column headed "Boulder" presents average water quality data as reported by the City, for comparison to regulatory limits. Values listed as "less than" indicated by the symbol "<" represent measurements that were below the numerical limit given as the lowest detectable concentration. A reported value of "ND" indicates that the constituent was not detected by the method used without stating the numerical detection limit concentration. Both designations signify that the given parameter was not present in the tested sample. A reported value of "NM" indicates the constituent was not measured, likely because it was not required.

As can be seen in the following tables, the City has had no problem meeting the requirements of the National Primary Drinking Water Regulations. The following tables present the data from the following types of samples:

- **Inorganics Sampling** results from the Safe Drinking Water Act analysis conducted at the BWTF and BRWTF indicate that there are no inorganic contaminants at levels of concern at this time.
- **Synthetic Organic Compounds Sampling** results from the Safe Drinking Water Act analysis conducted at the BWTF and BRWTF indicate that there are no Synthetic Organic Compound contaminants at levels of concern at this time.
- **Volatile Organic Compounds Sampling** results from the Safe Drinking Water Act analysis conducted at the BWTF and BRWTF indicate that there are no Volatile Organic Compound contaminants at levels of concern at this time.

Table 5-18: National Primary Drinking Water Regulations – Inorganic Chemicals

Contaminants	MCL or TT (mg/L)	Boulder[1] (mg/L)	Health Effects from Contaminant	Monitoring Requirements
Antimony	0.006	<0.001	Increase in blood cholesterol; decrease in blood glucose	Once per year for surface waters not including Asbestos, Lead and Copper, Nitrate, Nitrite and Radionuclides
Arsenic	0.010	<0.001	Skin damage; circulatory system problems; increased risk of cancer	
Asbestos (fiber > 10 micrometers)	7 MFL	NM	Increased risk of developing benign intestinal polyps	Asbestos – Once every nine years
Barium	2	0.028	Increase in blood pressure	
Beryllium	0.004	<0.001	Intestinal lesions	
Cadmium	0.005	<0.0006	Kidney damage	
Chromium	0.1	<0.02	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis	
Copper	Action Level = 1.3; TT	0.0023	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage.	Same as lead
Cyanide (as free cyanide)	0.2	NM	Nerve damage or thyroid problems	
Fluoride	4.0	0.73	Bone disease (pain and tenderness of the bones); Children may get mottled teeth.	
Gross Alpha Emitters	15pCi/L	ND	Cancer Risk	Gross alpha and beta: Every four years – quarterly samples
Gross beta Particle and Photon Emitters	4mrem	ND	Cancer Risk	
Lead	Action Level = 0.015; TT	<0.0005	• Infants and children: Delays in physical or mental development • Adults: Kidney problems; high blood pressure	Follow-up monitoring is every six months after corrosion controls are initiated or optimized. Systems consistently meeting action levels can reduce monitoring to annually and then to every three years.
Inorganic Mercury	0.002	<0.0002	Kidney damage	
Nitrate (measured as Nitrogen)	10	<0.2	"Blue baby syndrome" in infants under six months – life threatening without immediate medical attention.	Nitrate: Groundwater annually; Surface water quarterly

Contaminants	MCL or TT (mg/L)	Boulder[1] (mg/L)	Health Effects from Contaminant	Monitoring Requirements
Nitrite (measured as Nitrogen)	1	<0.1	"Blue baby syndrome" in infants under six months – life threatening without immediate medical attention.	Nitrite: One sample every three years.
Radium	5 pCi/l combined	<1 pCi/l combined	Cancer risk	Radium: Every nine years
Selenium	0.05	<0.001	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	
Thallium	0.002	<0.001	Hair loss; changes in blood; kidney, intestine, or liver problems	
[1]Data represents City of Boulder – Average data – Finished water – 1/1/99-8/26/10.				

Table 5-19: National Primary Drinking Water Regulations – Synthetic Organics

Organic Chemicals[1]	MCL or TT (mg/L)	MCLG (mg/L)	Boulder (mg/L)	Health Effects from Contaminants
Synthetic Organics				
Dioxin (2,3,7,8-TCDD)	3×10^{-8}	0	$<5 \times 10^{-9}$	Reproductive difficulties; increased risk of cancer
2,4,5-TP (Silvex)	0.05	0.05	<0.0002	Liver problems
2,4-D	0.07	0.07	<0.0001	Kidney, liver, or adrenal gland problems
Acrylamide	TT	N/A	NM	Nervous system or blood problems; increased risk of cancer
Alachlor	0.002	0	<0.00005	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer
Aldicarb	0.003[2]	0.001	<0.0005	
Aldicarb sulfoxide	0.004[2]	0.001	<0.0005	
Aldicarb sulfone	0.002[2]	0.001	<0.0005	
Atrazine	0.003	0.003	<0.00005	Cardiovascular system problems; reproductive difficulties
Carbofuran	0.04	0.04	<0.0005	Problems with blood or nervous system; reproductive difficulties.
Chlordane	0.002	0	<0.0001	Liver or nervous system problems; increased risk of cancer
Dalapon	0.2	0.2	<0.001	Minor kidney changes
Di(2-ethylhexyl)adipate	0.4	0.4	<0.0006	General toxic effects or reproductive difficulties
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	0	<0.00001	Reproductive difficulties; increased risk of cancer
Di(2-ethylhexyl)phthalate	0.006	0	<0.0006	Reproductive difficulties; liver problems; increased risk of cancer
Dinoseb	0.007	0.007	<0.0002	Reproductive difficulties
Diquat	0.02	0.02	<0.0004	Cataracts
Endothall	0.1	0.1	<0.005	Stomach and intestinal problems
Endrin	0.002	0.002	<0.00001	Nervous system effects
Epichlorohydrin	TT	N/A	NM	Stomach problems; reproductive difficulties; increased risk of cancer
Ethelyne dibromide	0.00005	0	<0.00001	Stomach problems; reproductive difficulties; increased risk of cancer
Glyphosate	0.7	0.7	<0.006	Kidney problems; reproductive difficulties
Heptachlor	0.0004	0	<0.00001	Liver damage; increased risk of cancer
Heptachlor epoxide	0.0002	0	<0.00001	Liver damage; increased risk of cancer
Hexachlorobenzene	0.001	0	<0.00005	Liver or kidney problems; reproductive difficulties; increased risk of cancer
Hexachlorocyclopentadiene	0.05	0.05	<0.0005	Kidney or stomach problems
Lindane	0.0002	0.0002	<0.00001	Liver or kidney problems
Methoxychlor	0.04	0.4	<0.00005	Reproductive difficulties
Oxamyl (Vydate)	0.2	0.2	<0.0005	Slight nervous system effects
Benzo(a)pyrene (PAHs)	0.0002	0	<0.00002	Reproductive difficulties; increased risk of cancer

Organic Chemicals[1]	MCL or TT (mg/L)	MCLG (mg/L)	Boulder (mg/L)	Health Effects from Contaminants
Polychlorinated biphenyls (PCBs)	0.0005	0	ND	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer
Pentachlorophenol	0.001	0	ND	Liver or kidney problems; increased risk of cancer
Picloram	0.5	0.5	<0.00001	Liver problems
Simazine	0.004	0.004	<0.00005	Problems with blood
Toxaphene	0.003	0	<0.0005	Kidney, liver, or thyroid problems; increased risk of cancer

[1]The aldicarbs are currently under an "administrative stay" due to litigation. No limit is in effect until resolved.

[2]Monitoring Requirements Original monitoring required four quarterly samples every three years. After one round of no detects; systems > 3,300 reduce to two samples per year every three years.

[3]Systems < 3,300 reduce to one sample every three years. Monitoring may be reduced or eliminated based on the results of the vulnerability assessment.

[4]Data represents: City of Boulder – Average data – Finished water – 1/1/99-8/26/10

Table 5-20: National Primary Drinking Water Regulations – Volatile Organic Chemicals

Organic Chemicals[1]	MCL or TT (mg/L)	MCLG (mg/L)	Boulder (mg/L)	Health Effects from Contaminants
1,1,1-Trichloroethane	0.2	0	<0.0005	Liver, nervous system, or circulatory problems
1,1,2-Trichloroethane	0.005	0.003	<0.0005	Liver, kidney, or immune system problems
1-1-Dichloroethylene	0.007	0.007	<0.0005	Liver problems
1,2,4-Trichlorobenzene	0.07	0.07	<0.0005	Changes in adrenal glands
1,2-Dichloroethane	0.005	0	<0.0005	Increased risk of cancer
1-2-Dichloropropane	0.005	0	<0.0005	Increased risk of cancer
Benzene	0.005	0	<0.0005	Anemia; decrease in blood platelets; increased risk of cancer
Carbon tetrachloride	.005	0	<0.0005	Liver problems; increased risk of cancer
Chlorobenzene	0.1		<0.0005	Liver or kidney problems
cis-1, 2-Dichloroethylene	0.07	0.07	<0.0005	Liver problems
Dichloromethane	0.005	0	<0.0005	Liver problems; increased risk of cancer
Ethylbenzene	0.7	0.7	<0.0005	Liver or kidney problems
o-Dichlorobenzene	0.6	0.6	<0.0005	Liver, kidney, or circulatory system problems
Para-Dichlorobenzene	0.075	0.075	ND	Anemia; liver, kidney or spleen damage; changes in blood
Styrene	0.1	0.1	<0.0005	Liver, kidney, and circulatory problems
Tetrachloroethylene	0.005	0	<0.0005	Liver problems; increased risk of cancer
Toluene	1	1	<0.0005	Nervous system, kidney, or liver problems
trans-1,2-Dichloroethylene	0.1	0.1	<0.0005	Liver problems
Trichloroethylene	0.005	0	<0.0005	Liver problems; increased risk of cancer
Vinyl chloride	0.002	0	<0.0005	Increased risk of cancer
Xylenes (total)	10	10	<0.0005	Nervous system damage

[1]Monitoring Requirements VOCs: Original monitoring required four quarterly samples during the first three years. Monitoring annually beginning in 1996 if no detects. Monitor every three years after three years of no detects Monitoring may be reduced based upon results of vulnerability assessment.

[2]Data represents: City of Boulder – Average data – Finished water – 1/1/99-8/26/10.

3.1.6.3 *Secondary Standards*

National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. USEPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards. **Table 5-21** below summarizes the secondary standards.

Table 5-21: Secondary Standards

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	Noncorrosive
Fluoride[1]	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
PH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

[1]When fluoride levels exceed 2.0 mg/L; public notification in accordance within Article 9 is required.

3.1.6.4 *Total Coliform Rule*

The City of Boulder collects 120 total coliform samples per month in the distribution system as required by the TCR. Bacteriological sampling conducted since 1997 has shown an excellent history of “safe” samples in the distribution system. Current practices are adequate to meet the requirements of this rule, however, operational or infrastructure modifications may result in improved disinfection performance and bacteriological stability.

A more detailed discussion of regulatory compliance is included in **Section 5.1.3**.

3.1.6.5 *Surface Water Treatment Rule*

Turbidity levels at the water treatment plants are meeting the 1 NTU maximum and the 0.3 NTU limit at the 95th percentile monthly based on 4-hour monitoring intervals. Current disinfection practices result in adequate disinfection residual leaving the water treatment plants. However, due to long residence times and chlorine demand, the free chlorine residual has infrequently fallen to near zero in parts of the distribution system. Long residence times are compounded by poor treated water storage reservoir circulation, which has occurred in Gunbarrel reservoir. Ongoing projects related to valves and online monitoring at Gunbarrel are focused on improving circulation.

A more detailed discussion of regulatory compliance is included in **Section 5.1.3**.

3.1.6.6 Lead and Copper Rule

Lead and copper sampling (**Table 5-16)** has shown that the 90th percentile concentrations in the City's water have been below the Safe Drinking Water Act established drinking water action levels of 1.3 mg/l for copper and 0.015 mg/l for lead. For the purposes of the rule, the City of Boulder is considered as having optimized treatment for corrosion control and no further actions are required at this time. Boulder will remain on the minimum required monitoring schedule for these two corrosion by-product parameters.

A more detailed discussion of regulatory compliance is included in **Section 5.1.3**. In summary, The City of Boulder has not exceeded Action Levels for either lead or copper in any of the monitoring done to date. Since the monitoring began in 1992, the number of residences exceeding the 0.015 mg/L lead limit has varied between 0 and 10% (most recent monitoring 0%). To date, no sites have exceeded the 1.3 mg/L copper action limit.

3.1.6.7 Arsenic

The MCLs for Arsenic is 10 ppb. The City of Boulder's water quality data indicates that arsenic levels are undetectable or less than 1 ppb, well below the MCL.

3.1.6.8 Stage 2 D/DBPR and LT2ESWTR

The City completed the IDSE in 2009 and will begin compliance monitoring and DBP locational running annual average reporting in 2012.

The LT2ESWTR was adopted in 2006 and applies to surface water and groundwater under the direct influence of surface water sources. The objective of the rule is to reduce the risk associated with *Cryptosporidium* and other microbial pathogens in drinking water and address risk-risk tradeoffs with the control of disinfection byproducts. The city requires no additional treatment for Bin 1 classification. The City of Boulder will begin required Cryptosporidium monitoring again in 2015 to reevaluate the Bin classification in 2017.

A more detailed discussion of regulatory compliance is included in **Section 5.1.3**.

3.1.6.9 Filter Backwash Rule

The City of Boulder has records which comply with the requirements for this rule.

3.1.6.10 Radionuclides Rule

The City meets the requirements of this rule. Boulder is in compliance with all of the existing radiological parameters.

3.1.6.11 3.1.6.4.8 City of Boulder Enforcement of Cross-Connection Control

The city requires commercial, industrial, and multifamily properties to comply with backflow prevention requirements. Enforcement focuses on all non-single family dwellings, unless a property has a well, dedicated fire line or similar hazard which requires backflow prevention be installed and tested annually. Multifamily properties, as evidenced by other cities (e.g., Denver), require backflow prevention when a certain threshold is met such that the multifamily property is considered to be more commercial than residential in nature as determined by the city.

The city has a backflow prevention ordinance (Chapter 11 of the Boulder Revised Code (section 11-1-25)) and Design & Construction Standards (Chapter 5, Section 5.11). The city increased Backflow Prevention Program efforts in response to State directives and began actively targeting non-compliant customers in 2009 and continues those efforts to date.

The city tracks backflow prevention assemblies using the Utility Billing Database [CIS] backflow module. Customers are required to hire a private inspector to test backflow prevention assemblies and passing test reports are submitted to and recorded by the Backflow Prevention Program. Owners must repair or replace and retest failed assemblies to achieve a passing test report and submit to the Backflow Prevention Program. The city mails letters annually to remind customers that their annual test is due.

For any properties where a variance has been allowed, the proof of proving the property does not represent a hazard falls to the city indefinitely. Because the city cannot typically prove a property is not a hazard and cannot continually monitor properties for hazards, backflow prevention is universally required at all affected properties without variance.

3.2 City of Boulder Water Quality Goals

The City's Water Treatment Operations Group operates the treatment and distribution facilities following various internal procedures and guidelines developed over time to ensure that treated water quality objectives are consistently met. To facilitate treatment operations, most water providers use a set of internal standards for key water quality parameters as targets to guide process control decisions. Typically, the targets are more stringent than the applicable regulatory requirements so that operating treatment processes to meet the internal targets ensures that the treated water delivered to customers not only complies with all regulatory requirements but is of the highest practical quality. Boulder's treatment facilities are currently operated to meet a set internal standards developed from process performance criteria commonly used in the water industry and recommended by USEPA and AWWA. These operating targets meet the Utility's objectives for protecting public health and providing high quality treated water. **Table 5-22** shows the overall summary of operating targets for both facilities.

Table 5-22: Water Treatment Plant Overall Internal Operating Targets

Parameter	Regulatory Requirements	BWTF	BRWTF
Turbidity			
Post Sedimentation	N/A	<1.0 NTU	<1.0 NTU
Filtered Water	< 0.3 NTU in 95% of samples, never > 1.49 NTU	<0.1 NTU	<0.1 NTU
Finished Water	N/A	<0.1 NTU	<0.25 NTU
Filtration			
Filter Run Time	N/A	48 hrs	60 hrs
Initial turbidity spike	< 0.5 NTU within 4 hours of filter start-up < 1 NTU within 15 minute filter start-up	< 1 NTU w/in 15 min of filter startup	< 1 NTU w/in 15 min of filter startup
Particle Counts	N/A	<100	<100
Finished Water Alkalinity	15-98 mg/L (per CDPHE). Cannot exceed more than 9 days in 6 month period.	45 ± 3.0 mg/L	15-98 mg/L
pH	7.1 – 8.2 (SMCL). Cannot exceed more than 9 days in 6 month period.	7.8 ± 0.2	7.8 ± 0.2
Fluoride	4.0 mg/L (MCL) 2.0 mg/L (SMCL)	0.9 ± 0.1 mg/L	0.9 ± 0.1 mg/L
Free Chlorine	Not < 0.2 mg/L for more than 4 hours or < 4.0 mg/L in distribution system	1.0 ± 0.1 mg/L	1.0 ± 0.1 mg/L

With these targets met, the water treatment plants can reliably produce high quality water for the citizens of Boulder. The goals specific to each treatment facility, including actions to be taken is included in **Appendix B**.

3.2.1 Process Optimization

The City of Boulder has an optimization program for the water treatment plants. The objective of the program is to identify operational and physical factors that could be limiting current treatment performance and facilitate improvements that would enhance performance, fully utilize facilities and resources, and, when possible, reduce operating costs. Currently, the operations staff includes two process optimization specialists. Their efforts are coordinated and directed by a team comprised of the Water Treatment Operations Coordinator, the two Water Treatment Plant Supervisors, the Water Quality Group Supervisor, and a Representative from the Project Management Group.

4 Treatment and Distribution Facilities Studies

A summary of each of the following reports can be found in this section:

- City of Boulder Water Conservation Futures Study; Hydrosphere Resource Consultants, Inc. (1999)
- 2000 Treated Water Master Plan; Integra Engineering (2000)
- 2000 Treated Water Master Plan Recommendations and Implementation Plan Findings and Basis for Plan, Integra Engineering (2000)
- Boulder Reservoir Water Treatment Plant Predesign Report (2003), Including an Evaluation of Mid-Term and Long-Term Improvements for the Facility
- Boulder Reservoir Water Treatment Plant Source Water Quality Planning Study (Phase I Study) (2003)
- City of Boulder Zone 1 Distribution System Analysis (2003)
- Betasso Water Treatment Plant Facility Improvement Plan (2005)
- Integrated Evaluation of the BRWTP Source Water Protection and Treatment Improvements Study (Integrated Study) (2007)
- AWWA Peer Review Report (2008)
- City of Boulder Water Conservation Plan (2009)

4.1 City of Boulder Water Conservation Futures Study; 1999, Hydrosphere Resource Consultants, Inc.

This study was prepared to 1) examine Boulder's existing water use patterns and recent trends, 2) update Boulder's future water demand projections and reliable supply capability, and 3) reassess the role of water conservation programs in helping to meet Boulder's needs, not only in the area of treated water supply, but in several important and related areas. Most of the information presented in this document was updated in Volume 2 and in the Source Water Management Plan.

Key recommendations from this report included:

- Adopt the Comprehensive Conservation Scenario as defined in the Water Conservation Futures Study. The Comprehensive Conservation scenario promotes the indoor and outdoor conservation measures most likely to have a lasting impact on demand in the City. This program would increase the City's current water conservation budget substantially, but would reduce future peak demand to a level that can be handled by current facilities upgraded to their rated capacities.
    - Move into the design phase to flesh out the specific elements of the program and solicit community input.

- Develop environmental and community-based conservation targets and rewards. Citizens have expressed a strong desire to conserve water because “it is the right thing to do” for the environment and Boulder’s watershed. The City should develop a program of annual conservation goals and rewards. Under this program, the City would pledge to dedicate raw water to in-stream flow and other beneficial purposes (community gardens, agricultural leasing, etc.) if annual conservation targets are achieved. These goals should include annual peak water demands and specific program level of effort goals such as the installation of ULF toilets, or distribution of clothes washer and Xeriscape rebates.
- Develop an independent, comprehensive program of monitoring, evaluation, and reporting to ensure that the conservation program is accomplishing the established goals. Consideration should be given to linking the conservation program to an allocation billing system.
- Evaluate the City's water treatment plant flow meters, and implement system-wide leak detection if necessary. The reported 8.4 percent unaccounted for water may not be correct due to underreporting by the flow meters at the City's water treatment plants. The City should hire an independent expert to examine and evaluate the flow meters at both plants. If necessary, meters should be replaced so that the true extent of the unaccounted water in the City's system can be determined. If the treatment plant meters have been underreporting, the City should correct its water accounting accordingly, and implement a leak-detection and repair program if called for.

- Adopt a peak ratio of 2.6 for water treatment plant capacity planning purposes. Assuming that additional conservation measures aimed at peak demand reductions are pursued, this peak ratio could be further reduced.

- Study the allocation billing system option. An allocation billing system would develop a specific water allocation for each account in the City’s system based on factors specific to each account. An allocation water billing system could be an effective conservation tool and an extremely fair method for apportioning costs by charging users according to the burden they place upon the system over and above reasonable levels of use.

The 1999 Water Conservation Futures Study was used to develop the Water Conservation Plan which was adopted by the City of Boulder and approved by the Colorado Water Conservation Board in 2009. Most of the information presented in this document was updated in the Water Conservation Plan as well as Volume 1 and 2 of the Source Water Management Plan.

4.2 Treated Water Master Plan; 2000, Integra Engineering

The 2000 TWMP was the previous update to the overall treated water system. The key findings of this report associated with the treatment and distribution systems as reported in December of 2000 include:

- The report defined the study area, service area, and planning period (20 years) for the study. It also projected an average day water use of 21.6 MGD (24,159 acre-ft). With water conservation measures in place, it could be as low as 19.4 MGD. The Peak Day and Peak Hour estimates for 2020 were estimated to be 56.2 MGD (50.4 MGD with water conservation) and 96.1 MGD (86.3 MGD with water conservation) respectively.

- **BWTF**
  - The BWTF was evaluated to have the capacity to treat a peak flow of approximately 40 MGD to the level required by the regulatory requirements.
  - The plant is limited by the flocculation/sedimentation process. Performance data indicated that sedimentation capacity is less than the theoretical capacity because of entrained air, poor flocculation and possibly poor coagulation.
  - Additional improvements will be needed to the flocculation and sedimentation basins to provide a fully effective treatment barrier with consistent performance necessary to reliably meet the regulatory requirements at a capacity of 50 MGD.

- **BRWTF**
  - The BRWTF (2000) has the capacity to treat a peak flow of somewhat less than 10 MGD to the level required by regulatory requirements.
  - Capacity is limited by the flocculation sedimentation process which performance data suggests is over capacity when operating at 8.5 MGD.
  - The other processes were reported to have capacities equal to or greater than 12 MGD. Hydraulic capacity was reportedly limited to 12 MGD due to overflowing with the hydraulic jump.

- **Distribution System**
  - The distribution system was evaluated and no deficiencies were identified with the transmission mains, hydroelectric generating facilities, most PRVs (with exceptions below), treated water storage.
  - Identified improvements included: replacement of PRVs and pumping improvements at the Iris and Cherryvale pump stations, the 4-Mile PRV facility needed to be rebuilt or eliminated.
  - Improvements to standardize the system operating procedure were recommended.
  - A number of valves were identified that block specific pipes and create pressure zone boundaries. Valve failure in one of these locations could be problematic.
  - An evaluation on pipe breaks was performed, but no specific correlation was found with respect to pressure.
  - The average age of pipe in the system is 34 years. Over 83 percent of the pipes are older than 25 years old and nearly one third is over 40 years old.
  - The distribution system was modeled using *H_2ONET* hydraulic analysis software to determine flow and pressure problems within the distribution system and storage capacity adequacy. High and low pressure areas were identified in multiple locations. Storage capacity was determined to be adequate, although hydraulic problems exist.

4.3 2000 Treated Water Master Plan Recommendations and Implementation Plan Findings and Basis for Plan

- The City's treated water service area will not expand significantly. Extension of service into new areas outside the existing service area will be very limited.
- Build-out within the treated water service area under current land use plans will be reached by 2020.
- Service area population at build-out will be between 126,000 and 127,000.
- The Comprehensive Conservation Program will be adopted and successfully implemented.
- Average daily water use at the 2020 build-out will be between 19.4 and 21.6 MGD with peak day water use between 50 and 56 MGD depending on effectiveness of water conservation efforts.
- Future regulatory requirements and the desire to maximize public health protection will increase the demands on treatment facilities for higher and more consistent levels of performance and place increasing emphasis on protecting water quality at the source and throughout the distribution system.

- **Issues Identified**
  - **Water Treatment Plant Capacity:** The City's reliability criteria require a total capacity of 55 to 62 MGD whereas the two treatment plants only have a combined capacity of 48 to 50 MGD.
  - **Water Quality Criteria:** Deterioration of the Lakewood pipeline feeding the BWTF and poor performance of the flocculation/sedimentation processes at the BRWTF limits the capacity of both facilities.

- **Public Health Protection:** Improving raw water quality, limiting disinfection byproduct formation, and removing pathogenic organisms from the water, and maintaining the quality of the water in the distribution system will help to protect public health.

- **Operability and Reliability:** The following were issues identified in this category:
  - Operation of the BRWTF is of the most notable operability issues identified. Seasonal switching and start/stop operation are difficult to manage.
  - High turbidity during summer runoff events can cause treatment issues.
  - Inefficient performance of the flocculation/sedimentation process at both facilities.
  - SCADA improvements are needed.
  - Standardization of operating procedures is needed.

- A recommendation for the capital improvement program (CIP) is included in this report. Improvements were prioritized, costs developed, and an implementation schedule identified.

- **Future Studies:** Implementation of the recommendations will require further study of many of the recommendations. The report lists the recommended studies.

- **Planning Process:** The report recommends both public participation and coordination with related planning programs to ensure a continued evaluation of the master plan goals and implementation of the identified recommendations.

4.4 Boulder Reservoir Water Treatment Plant Predesign Report (2003), Including an Evaluation of Mid-Term and Long-Term Improvements for the Facility

This report presented the near-term, mid-term, and long-term recommendations for improvements to BRWTF in 2003.

Near-term improvements included:

- DAF pretreatment
- Clearwell Baffling
- Pumps
- Residuals Lagoons
- I&C improvements
- Pilot Facility – purchase used pilot facility from DAF manufacturer as part of BRWTF equipment procurement

Mid-term Improvements included:

- Chlorine dioxide for pre-oxidation.
- Additional residuals lagoons and/or accelerated dewatering system for all residuals production at 10 MGD average annual flow rate.
- Decant/filtrate pumps and piping for lagoon decant return to BRWTF.
- I&C improvements, including PLC integration, automated backwash, filter instrumentation, SCADA reconfiguration, and enhanced process trending.
- New raw water pump.
- Waste washwater treatment with stand-alone structure with gravity plate settler units
- Conversion of remainder of pretreatment basin to conventional settling presedimentation unit with plate settlers.
- CO_2 pH adjustment system.

Long-term improvements include:

- Supervisory control and data acquisition (SCADA) expansion.
- New clearwell reservoir.
- New pretreatment train.
- UV disinfection for control of *Cryptosporidium* (not warranted if membrane filtration is used).
- Emergency power addition.
- Membranes (warranted if plant hydraulics ultimately limit capacity of granular media filters).
- GAC caps in existing granular media filters (if membranes not used). Used to control taste and odors.

Order of magnitude costs for O&M and capital costs were prepared for all of the improvements. This report includes the preliminary design information for the near-term improvements.

4.5 Boulder Reservoir Water Treatment Plant Source Water Quality Planning Study (Phase I Study) (2003)

This study evaluated the alternatives available to improve and protect the BRWTF source water quality. The primary source of BRWTF raw water is Carter Lake. Raw water is delivered through a 21 mile open canal known as the BFC. The BFC can discharge water either directly to the BRWTF or to Boulder Reservoir for pumping to the BRWTF. Based on historical monitoring of the raw water entering the BRWTF, additional removal treatment for *Cryptosporidium* will be required under this operational mode as part of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The alternatives evaluated for source water quality management included:

- Existing Source Water System (to be used as a baseline)
- Boulder Reservoir Management (using Boulder Reservoir as a year-around terminal reservoir)
- Full Containment from Carter lake to the BRWTF (21-mile raw water gravity pipeline from Carter Lake to BRWTF for year-around basis)
- Partial Containment from Nelson Road to the BRWTF (partial canal, partial gravity pipeline. When canal is out of service for winter, water would have to be pumped from the Boulder Reservoir)
- New Terminal Reservoir (new reservoir upstream of the Boulder Reservoir)
- New Forebay (new earthen forebay to allow for dilution and settling to reduce contaminant load)

The alternative evaluation resulted in the narrowing down of the list to two alternatives: the Boulder Reservoir Management and the Full Containment alternative. The full containment option was preferred, however would involve a major commitment of capital funds by the City. The Boulder Reservoir management option would provide immediate reductions in the occurrence of microbial pathogens and compliance with the LT2ESWTR, but the City would need to take steps to address the seasonal uptake of manganese.

The result of this evaluation was to recommend a Phase 2 investigation into these two alternatives, including the following tasks:

- Consider the preferred source water management alternatives identified in this Phase 1 study in conjunction with the potential BRWTF treatment alternatives.
- Further define the scope and cost of source water and treatment alternatives as necessary to perform final evaluation.
- Develop recommended long-term plan and prioritize implementation of key elements.
- Perform utility cash flow scenarios and develop a capital improvements program based on projected financial conditions.
- Develop facility planning documents as required to guide the implementation of improvements for both the BRWTF source water supply and treatment facilities.

4.6 City of Boulder Zone 1 Distribution System Analysis (2003)

This report investigated the impacts to Zone 1 of the City of Boulder treated water transmission system resulting from expanding the capacity of the BRWTF from 11.5 to 20 MGD (peak hour flows). A hydraulic analysis was performed to determine the system's ability to accommodate the additional flow and identify needed improvements. The analysis focused on the following areas:

- High headloss in the Zone 1 transmission mains and resulting low pressures.
- Pumping capacity at the BRWTF high service pump station.
- Pumping capacity at the Zone 1 Pump Stations (Cherryvale PS and Iris PS).
- Storage capacity in Zone 1.

The modeling effort focused on evaluating the system's ability to meet major performance criteria, including:

- Minimum dynamic pressure
- Minimum emergency pressure
- Minimum pressure along Airport Road
- Maximum acceptable velocity
- Average day demand
- Low day and peak hour demand

Several different demand scenarios were evaluated, chosen to simulate the desired higher rates of production from the BRWTF and corresponding lower production rates from the BWTF. Each scenario consisted of flows from both WTFs, demand by zone, total system demand, and pumping requirements from Zone 1 to Zone 2 pump stations.

Three of the four scenarios evaluated represented controlling scenarios for certain factors. The Low Demand scenario resulted in the highest Zone 1 to 2 pumping, the Average Summer Day scenario was a controlling scenario for pump selection, and the Peak Hour scenario was used to determine additional pumping requirements at the BRWTF High Service Pump Station (HSPS).

The report goes on to detail the distribution system evaluation, which was split into a pipeline evaluation and a pump station evaluation. The pipeline evaluation presented three alternatives for pipeline construction based on maintaining acceptable pressures and minimizing cost. Costs were presented and Alternative 1 was recommended.

Pump station evaluation included a SCADA data evaluation to ensure that the actual pumps performed as indicated by the curves given in the model, and a modeling evaluation to determine if the existing pumps were adequately sized to handle the new conditions. Detailed results of the evaluation can be found in the original report. The evaluations found that the following additional equipment was recommended:

- BRWTF HSPS: two additional pumps, similar to the capacity of the existing pumps.
- Cherryvale Pump Station: Refurbish the entire facility, including three existing pumps and VFD's, PRV's of varying sizes, flow meters, pressure sensing equipment, and expansion to the existing building to increase electrical equipment capacity.
- Iris Pump Station: Refurbish the entire facility, including three new 200 HP pumps and VFD's, PRV's of varying sizes, flow meters, associated pipe and appurtenances, and a new building adjacent to the existing structure.

The City was considering constructing a new storage tank near the Cherryvale pump station and requested an evaluation of Zone 1 storage capacity. The report found that Zone 1 storage was deficient by nearly 2.0 MGD, but also that Zones 2 and 3 had an excess storage volume of 11.7 MGD each. Since Zones 2 and 3 are at higher elevations than Zone 1, their excess storage can feed Zone 1 by gravity. The report concluded that Zone 1 storage was sufficient.

In conclusion, the report found that the Zone 1 distribution system could not handle the proposed increase in production at the BRWTF without significant improvements, which included approximately 18,800 linear feet of parallel pipe in the Diagonal Highway right-of-way (ROW), and increased pumping capacity at all of the Zone 1 pump stations. The estimated total cost for all of the above improvements ranged from $5.7 million to $7.0 million. The report concludes with a detailed discussion of project budgeting and construction phasing.

4.7 Betasso Water Treatment Plant Facility Improvement Plan (2005)

This report evaluates and recommends improvements needed for the BWTF to provide safe working conditions, improve the reliability of the water treatment process for public health, comply with new safe drinking water act regulations and extend the life of the plant. The improvement plan evaluated the capacity and performance of each of the unit processes and residual handling facilities based on water demand, regulatory requirements, and internal City water quality goals. This information was then used as the basis for process alternative identification, evaluation, and selection. Improvements were categorized as near-term, mid-term, and long-term and prioritized based on a range of categories. In summary, the recommended improvements are as follows:

Near-term improvements included:

- Contract residuals dewatering support facilities
- Add residuals drying pad
- Improvements to the south lagoons
- Sand replacement for the north lagoon
- Pump diffusion flash mixing
- CO_2 improvements for pH control
- PACL improvements for coagulation

Mid-term Improvements included:

- Flocculation/Sedimentation Improvements, including
  - Inlet baffle
  - Serpentine baffles
  - Flocculation Equipment Modifications
  - Flocculation aid polymer addition
  - Flocculation to sedimentation baffles
  - Sedimentation effluent weirs
- Modifications of north lagoon, including north engineered sand drying beds
- DAF or Plate Settlers
- Clearwell No. 2 baffle wall

Potential long-term improvements include:

- UV disinfection (if raw water quality degrades)
- Membranes, or
- Filter media replacement

4.8 Integrated Evaluation of the BRWTP Source Water Protection and Treatment Improvements Study (Integrated Study) (2007)

The Integrated Study was performed within the context of an ongoing effort by the City of Boulder to establish definitive drinking water quality and quantity goals as a framework for planning and implementing future improvements throughout the City's drinking water system. One central strategy for achieving the City's water quality goals is to implement a multi-barrier approach to protecting the City's drinking water supply from biological and chemical contaminants. These barriers may include source water protection measures that either reduce or prevent introduction of contaminants or minimize their passage throughout the drinking water system through treatment.

Raw water is conveyed to the BRWTF from Carter Lake through a 21-mile long, open, earthen canal, referred to as the Boulder Feed Canal, which ultimately discharges into Boulder Reservoir. Between April and October, the City diverts raw water from the BFC just upstream of Boulder Reservoir, and delivers it through a pipeline directly to BRWTF. During the remaining months, when BFC is not in operation, raw water is pumped from the Boulder Reservoir to BRWTF for treatment. Both BFC and Boulder Reservoir have several features that make them vulnerable to source water quality degradation.

This study included a review and extensive analysis of existing historical, biological, physical and chemical water quality data of raw water sources, including Carter Lake, BFC, and Boulder Reservoir. Based on this evaluation, it was determined that Carter Lake has superior overall water quality as a raw water source when compared to BFC and Boulder Reservoir. Of particular concern are the introduction of chemical contaminants and pathogenic microorganisms during raw water conveyance through BFC and storage in Boulder Reservoir, as well as increased salt content due to dissolution of naturally occurring minerals in Boulder Reservoir sediments. Also of concern are objectionable tastes and odors that result from seasonal algal blooms and increased manganese levels due to oxygen depletion in Boulder Reservoir. Carter Lake is much less susceptible to these types of water quality degradation because of its surrounding topography and protection of water sources. This study states that it is believed that the water quality of Carter Lake will continue to be suitable as a water source for BRWTF for decades to come.

Although the BRWTF currently and is expected in the future meet or exceed all National regulatory requirements, finished water quality is vulnerable to short-term degradation due to seasonal variation in Boulder Reservoir and acute contamination episodes either in the BFC or the Boulder Reservoir. Finished water quality is vulnerable to:

- Source water microbial contamination in both the BFC and Boulder Reservoir
- Source water contamination by organic micropollutants in both the BFC and Boulder Reservoir
- Source water variation in Boulder Reservoir resulting in taste and odor problems and manganese uptake
- Treated water disinfection byproduct formation
- Non-uniform concentrations of TDS and sulfate across the distribution system when Boulder Reservoir is used.

As part of the evaluation of the multibarrier alternatives, the Kepner-Tregoe® (K-T®) decision analysis procedure was used to evaluate six alternatives. They were screened for applicability based on several factors, including integration with the existing treatment process train, probable performance, and economic considerations. Potential conceptual improvements were evaluated based on their ability to address one or more of the contaminant barriers identified including microbial pathogens, DBPs, organic micropollutants, manganese, taste and odor, TDS, and sulfate. Greater consideration was given to alternatives that addressed more than one contaminant barrier. The six alternatives ranged from improved treatment, using anything from UV disinfection, GAC adsorption, or ozone oxidation, to installing a pipeline directly from Carter Lake to feed the BRWTF. The preferred solution was the following:

Alternative 6: Carter Lake pipeline for turbidity, suspended solids, manganese, taste and odor, organics, DBP, and inorganics control followed by chlorine dioxide preoxidation for additional pathogen taste and odor, organics, and DBP control.

This preferred alternative meets all of the City's water quality goals, and provides at least one barrier for each contaminant category evaluated. Its noneconomic performance score was 0.942 while the other alternatives clustered between 0.5 and 0.6. The estimated life cycle costs of all of the alternatives ranged from $5.2 million to $53.4 million, while the preferred alternative was estimated to have a net present value of $17.1 million. This alternative was selected because it had a number of compelling benefits that are not provided by the other alternatives, including:

- It treats the best available water source with the simplest and most robust combination of processes.
- Has the best non-economic performance by satisfying 22 of 28 criteria evaluated as well or better than other alternatives.
- It alone addresses the near and long term potential for continued degradation of water quality in existing BRWTF sources due to continued residential development, extensive agricultural land use, and increasing recreational use. Preventing source water contamination provides a more robust barrier than subsequent treatment as the first line of defense in protecting public health.
- Other regional drinking water providers also desire to use a dedicated pipeline from Carter Lake for raw water delivery to their facilities. Combining raw water conveyance to BRWTF with that of other providers allows more efficient use of scarce regional water resources.
- Full containment of raw water conveyance from Carter Lake to BRWTF would provide additional flexibility in managing the City's water resources portfolio. Other water delivery alternatives require seasonal storage of raw water in Boulder Reservoir for use when BFC is not in service. Year-round storage in Carter Lake would remove the need to project annual seasonal storage required in Boulder Reservoir, and thus avoid the undesirable consequences that result if seasonal Boulder Reservoir storage is substantially overestimated.
- Conveyance of raw water through a Carter Lake pipeline would be consistent with the City's historical policy of protecting source water quality by providing full containment from its other water sources.

- Full containment from Carter Lake to BRWTF would provide a much more uniform raw water quality, substantially simplifying treatment optimization and increasing treatment process reliability.

- This alternative is the only BRWTF water delivery approach that provides at least one robust barrier for each contaminant category considered in this study.

4.9 AWWA Peer Review Report; 2008

The AWWA Peer Review Report, prepared by QualServe™ for the City of Boulder is a report that was compiled by a team of utility peers. The purpose of the report was to identify areas of strength and opportunities for improvement. The Peer Review team provided specific strengths and opportunities for improvement in the following categories:

- Leadership and Organization
- Human Resources Management
- Continuous Improvement
- Health and Safety Management
- Emergency Planning and Response
- Capital Improvement Program
- Strategic Planning
- Finance and Fiscal Management
- Plant and Property Management
- Purchasing
- Information management
- Engineering
- Customer Service
- Customer Strategy and Satisfaction
- Customer Accounts Management
- Government, Business, and Community Relations
- Collection System O&M
- Wastewater Treatment O&M
- Industrial Pretreatment Program
- Biosolids Management
- Permitting/Air and Water Quality
- Water Resources and Watershed Management
- Water Treatment O&M
- Water Distribution O&M
- Drinking Water Quality Management

The overall key findings of the Peer Review Team, as taken directly from the report, are:

- **Strengths**
  - The Staff in all the work groups are dedicated, competent, and caring employees.
  - The Utility is very proactive in several work groups on regulating and legislative issues.
  - The development and prioritization of the capital improvements program is excellent.
  - Proactive maintenance and cleaning program in collection system.
  - Data management and training/safety programs at wastewater plant.
  - Well run industrial pretreatment program.
  - Process for review, approval, and construction of developer projects provide excellent seamless service for those customers.
  - Good overall purchasing program that provides ease and flexibility for purchasing by personnel.
  - Customer service representatives and meter readers are highly motivated and provide efficient and effective customer service.
  - Supportive and articulate workforce that seems to truly appreciate the coworkers.
  - Clean well kept facilities and equipment.
  - Employees have passion for protection of the Utility's natural resources.

- **Opportunities for Improvement**
  - Work toward de-compartmentalization of the work groups. Cross training and working across work groups lines will help the Utility be more unified.
  - Management and accounts payable staff should review purchases through the “informal process” to insure that actual quotes are being received and documented.
  - Integration of workgroups within the Utility.
  - Continued expansion of GIS integration to improve work systems.
  - Establish a vision, values and goals to guide employees in improving the Utility’s performance.
  - Produce as-built drawings in a timelier manner so GIS maps can be accurately updated with new facilities. This will provide the information to field crews which will allow them to work more efficiently.
  - Implement E-care to provide customers on-line access to their accounts and insure the IVR system provides information for the correct customer.
  - Strive to improve vertical communication and establish and encourage horizontal communication.
  - The attempt by management to not “micro-manage” has resulted in a separation between management and the rank and file where management is seen as lacking leadership and being indifferent. A closer relationship and better understanding between groups needs to be developed.

Staffing philosophy differs from utility to utility. Boulder should decide if it is best to staff for (or almost all) needs, or staff for a base level and employ contractors, consultants, and others for needs above the established base.

4.10 City of Boulder Water Conservation Plan (2009)

The following summary is an excerpt directly from the Water Conservation Plan, written by the City of Boulder in 2009:

Conservation has long been an important component of the City of Boulder’s (the city’s) water management strategy, including outreach, education, and technical assistance programs that date back over 20 years. The purpose of this Water Conservation Plan is to provide guidance in updating and implementing the city’s Water Conservation Program in a way that is compatible with the city’s water supply system, existing conservation programs, water resources management strategy, and values of the community.

The city provides potable water to approximately 113,000 residents in its service area, which encompasses a total of just under 26 square miles. The city’s total annual treated water demand is approximately 18,600 acre-feet (2007 demand), primarily supplied by surface water withdrawn from Boulder Creek, and secondarily from the Colorado-Big Thompson and Windy Gap Projects on the western slope. Residential single-family users make up most of the 28,500 connections in the service area. Across all sectors, citywide annual demand per connection totaled approximately 213,000 gallons in 2007. The city’s total daily per capita water use has varied from year to year, from a low of 148 gallons per capita per day (gpcd) in 2004 and 2007 to a high of 209 gpcd in 1988. Since the adoption of the city’s comprehensive conservation program following completion of the Water Conservation Futures Study in 1999, per capita water use has significantly declined, particularly from the severe drought year of 2002 to present.

The City of Boulder is approximately 90 percent built out and any additional improvements or additions to its water system will focus more on improving system operating flexibility than increasing capacity. In 2007, water revenues totaled over $19,385,000 for all customer classes in Boulder. Single family residential customers contributed approximately 40 percent of revenues, followed by commercial and industrial users (26 percent), and finally multifamily residential and sprinkler users (19 and 15 percent). As of 2007, the city has used a five-block rate structure based on established "water budgets" for each type of customer, an important component of the city's overall water conservation strategy.

In 1999, the city completed its Water Conservation Futures Study to examine existing water use patterns and recent trends, update future water demand projections and reliable supply capability, and reassess the role of water conservation programs in helping to meet the city's needs. The Water Conservation Futures Study led to the adoption of a Comprehensive Conservation Scenario to aggressively manage and conserve water. The study was followed in 2000 by the Treated Water Master Plan, which provides guidance for improvements to the city's water system. In 2003, a Drought Response Plan was developed that established water use reduction measures to be implemented in the event of a severe drought that would quickly, but temporarily, greatly reduce water demands during the critical drought period. The drought response measures work in concert with, but are separate from, the city's on-going water conservation efforts. In April 2009 the Source Water Master Plan was completed, and the Water Quality Strategic Plan was finalized in June 2009. Both plans address water conservation, to some degree. An update of the Drought Response Plan was initiated in early 2009. Volume I will be completed in the fall of 2009 and the update of Volume II will be completed in 2010.

Today, the city operates a wide range of conservation programs that address both indoor and outdoor water use, as well as a variety of customer categories. City Council has adopted a comprehensive water conservation program for the city to achieve an overall reduction of water use at build-out. Implementation of the city's goal has been accomplished through an extensive water conservation program that continues to develop. Achievement of these targets will result in an expected overall reduction in total demand in the range of 19 percent at build-out as compared to water use at build-out absent a Water Conservation Program.

Per capita water use at build-out may be greater than 2007 levels due to increases in the population to jobs ratio but will be less than without the Water Conservation Program. As its Water Conservation Program has evolved, the city has developed a number of criteria to screen both existing programs and potential new programs. These criteria, along with ongoing and potential new conservation programs, will be integrated into modifying forecasts as part of an update of the 2000 Treated Water Master Plan, which the city anticipates will take place in the next couple of years.

Completion and approval by the Colorado Water Conservation Board of this Water Conservation Plan is anticipated to occur by fall 2009. Monitoring of the city's water conservation progress will be carried out in a variety of ways, including but not limited to the tracking of billing system data, daily water and wastewater treatment and production, daily operations of the city's surface water supply system, annual program costs, number of rebates, and feedback from the public.

5 Facilities Evaluation

The City's existing water treatment and distribution facilities were described in **Section 2**. This chapter provides an evaluation of those facilities to determine specific areas where improvements are needed.

5.1 Water Treatment Plants

The City's two water treatment plants were evaluated to establish their ability to consistently produce high quality finished water that exceeds all regulatory requirements and drinking water industry standards for public health protection. Each unit process was analyzed on the basis of standard design criteria to determine its performance potential. These results were combined with operating data and information gathered during plant inspection tours and interviews with plant operations staff. To establish a basis for current treatment capacity, the various treatment process elements have been analyzed for their capability to treat the raw water typical for that facility to meet regulatory requirements and City standards, with consideration given to in-progress improvements.

5.1.1 Betasso Water Treatment Facility

The operations staff at the BWTF reports the following challenges in operating the facility and producing treated water:

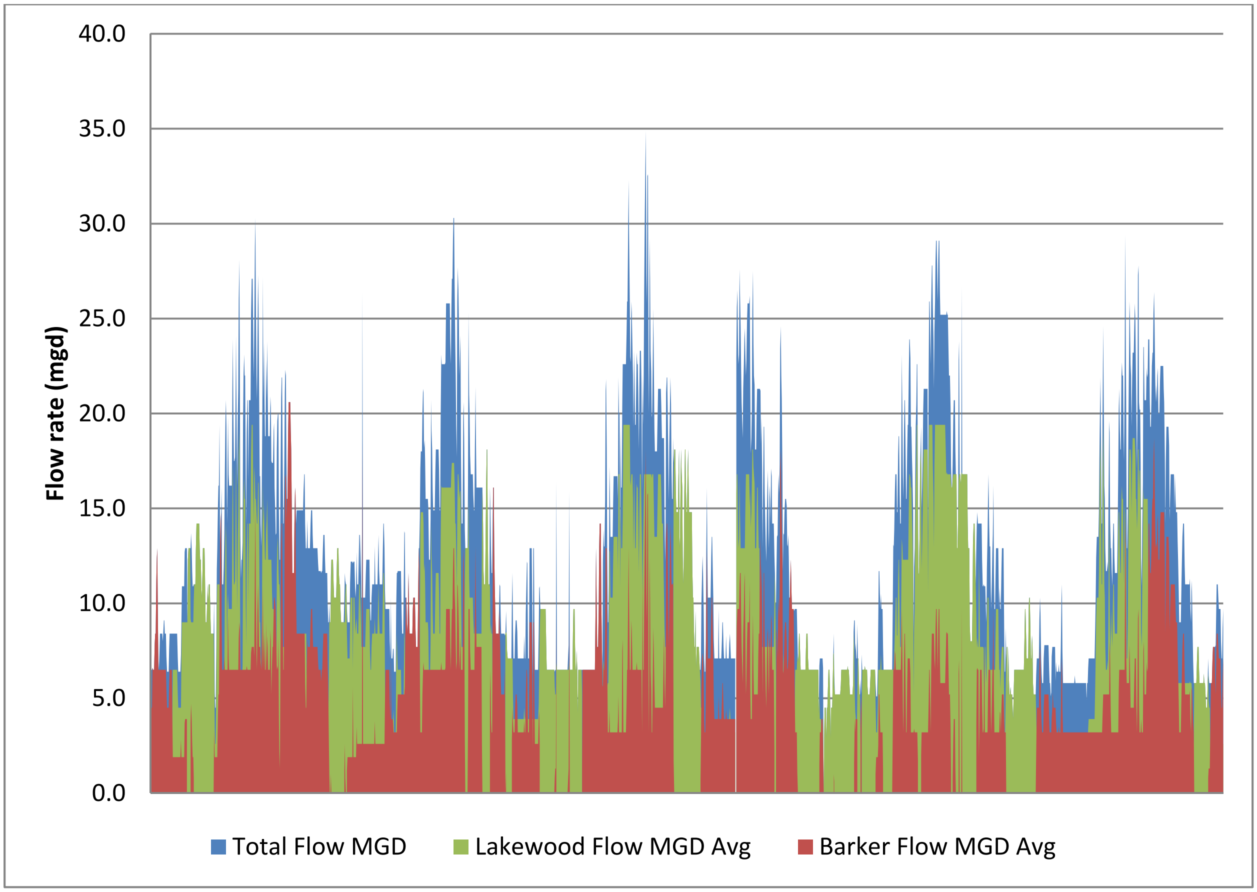
- The pumped-diffusion rapid mixer is ineffective at dispersing the applied chemicals.
- At flows in excess of 30 to 35 MGD, the pretreatment is inadequate to sustain effective treatment.
- During periods of high concentrations of color and total organic carbon in the source water, the filters are limited in run time by a breakthrough in turbidity.
- The residuals thickening, dewatering, and drying processes are insufficient to treat the dilute concentration of the solids.
- Plant operations staff has managed through the challenges by shifting water production to the BRWTF when needed.

In an effort to resolve the challenges, an evaluation of water quality and operations records from 2004 through 2009 as well as current documentation of the operation of the facility was performed. The data was reviewed to determine trends and potential areas for improvements in plant performance.

5.1.1.1 Source Water Flows and Turbidity

A summary of the flows from the two supply sources, Lakewood and Barker Reservoirs, is presented in **Figure 5-6**.

Figure 5-6: BWTF Historical Flow Data – 2004-2009

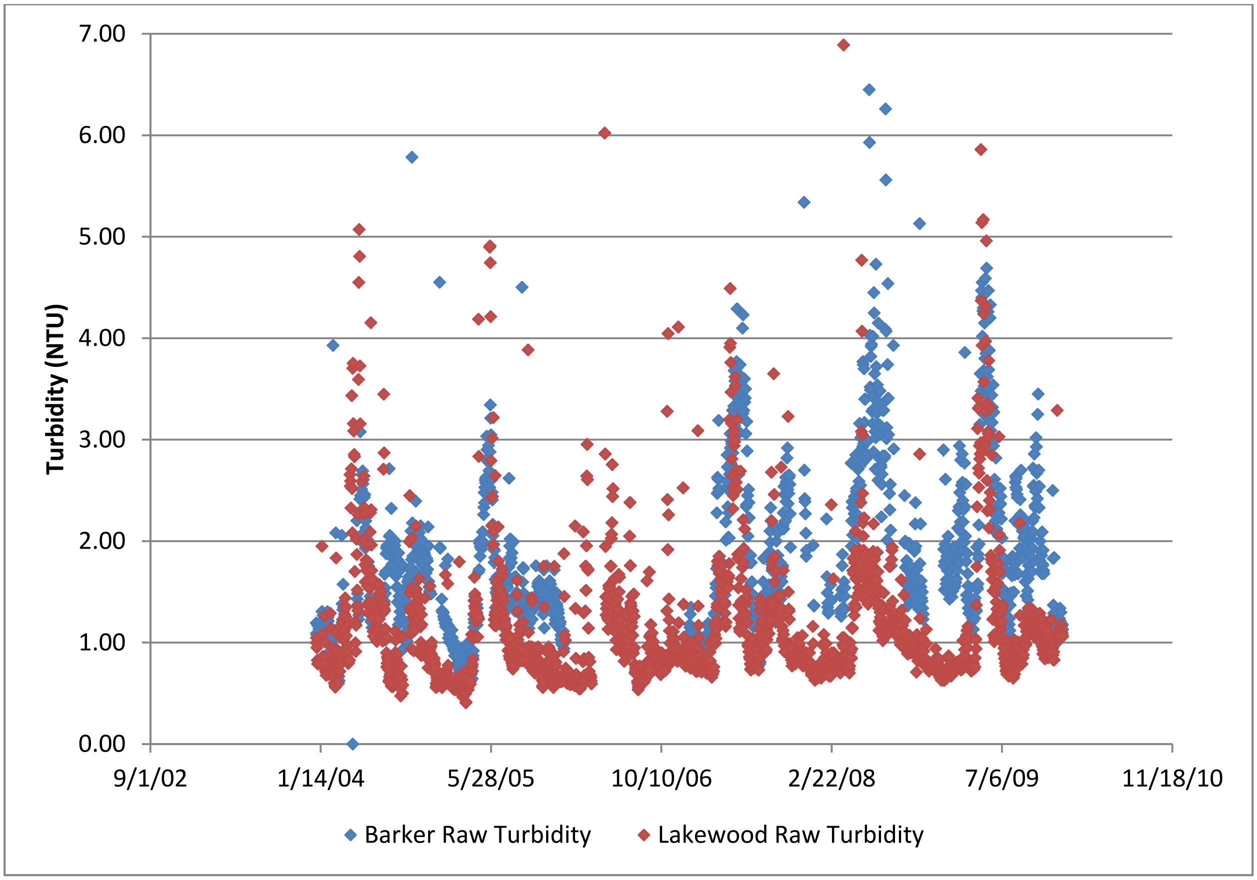


A review of the information in **Figure 5-6** reveals:

- The maximum flow to the BWTF is below the stated 50 MGD capacity of the facility.
- Throughout the year, water is withdrawn from the two sources individually or combined to meet the demands. Most of the flow comes from the Lakewood Reservoir.
- There is a distinct seasonal variation in flow with the minimum flow at approximately 7 MGD and the maximum flow at approximately 30 MGD.

To characterize the water quality of the two sources, an evaluation of the turbidity and color constituents was performed. The results of the analyses are shown in **Figures 5-7 and 5-8**.

Figure 5-7: BWTF Source Water Turbidity – 2004-2009



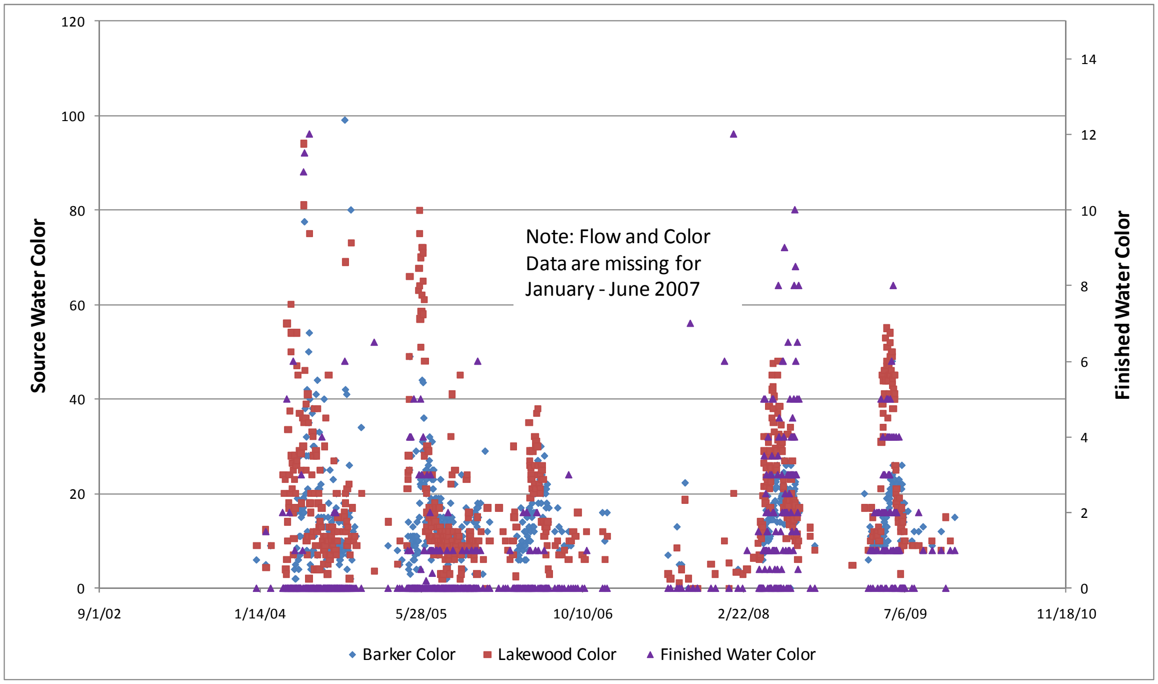
The following observations can be made regarding turbidity in the source water:

- There is a seasonal variation in turbidity with Barker Reservoir generally having higher turbidities than Lakewood Reservoir.
- The variation in the turbidity of Barker Reservoir is more erratic than the Lakewood Reservoir.
- Peak turbidities occur in the spring and summer and are probably associated with spring runoff and snow melt.
- Turbidities are generally less than 5 NTU, and average between 1 to 2 NTU.

More diagrams summarizing the evaluations of turbidity appear in **Appendix B**.

The results of the analysis of the concentration of color in the source and finished water are shown in **Figure 5-8**.

Figure 5-8: BWTF Source Water Color vs. Finished Color



Regarding color in the source and finished water, the following should be noted:

- Lakewood Reservoir has the highest concentration of color of the two sources of supply.
- There is a correlation between color in the finished water and color in the source water, as expected.
- A seasonal variation in the concentration of color exists with the peaks occurring in the spring and summer.

Additional diagrams presenting the results of the evaluations of the color are shown in **Appendix B**.

5.1.1.2 Pumped-Diffusion Mixing

Plant staff has indicated dissatisfaction with the performance of the existing pumped diffusion flash mixing system, installed in 2007. An investigation of the existing system was performed to determine the likeliest cause of these complaints. The flash mix pump, PMP-22-0201, was selected to deliver 800 gpm at 30.3 ft TDH. The maximum plant flow rate is 46 MGD, or 31,944 gpm. Therefore, the flash mix pump was designed to deliver 2.5% of the maximum plant flow rate, which is in line with the recommended 2-5% of plant flow rate recommended in Section 3.2.3 of Integrated Design of Water Treatment Facilities, Kawamura 1991. However, the outlet nozzle for the flash mixer system outputs 800 gpm at 7 psi, or 16.2 ft of head. Assuming a conservative 2 ft of friction and minor losses in the suction and discharge piping, a total of 18.2 feet of headloss is produced at 800 gpm, which is well below the selected pump curve. Estimates indicate that the actual pump output is roughly 950 gpm, or 3% of the maximum plant flow, which is still within the recommended limits.

Performance degradation likely occurs when plant flow is significantly less than the maximum. The flash mix pump was installed without a VFD or motorized throttling valves, meaning that pump capacity is fixed at approximately 950 gpm, regardless of plant flow. As a result, at the minimum plant flow of 8 MGD, or 5,555 gpm, the flash mix system delivers 17% of the plant flow rate, several times higher than the recommended range.

5.1.1.3 Flocculation/Sedimentation

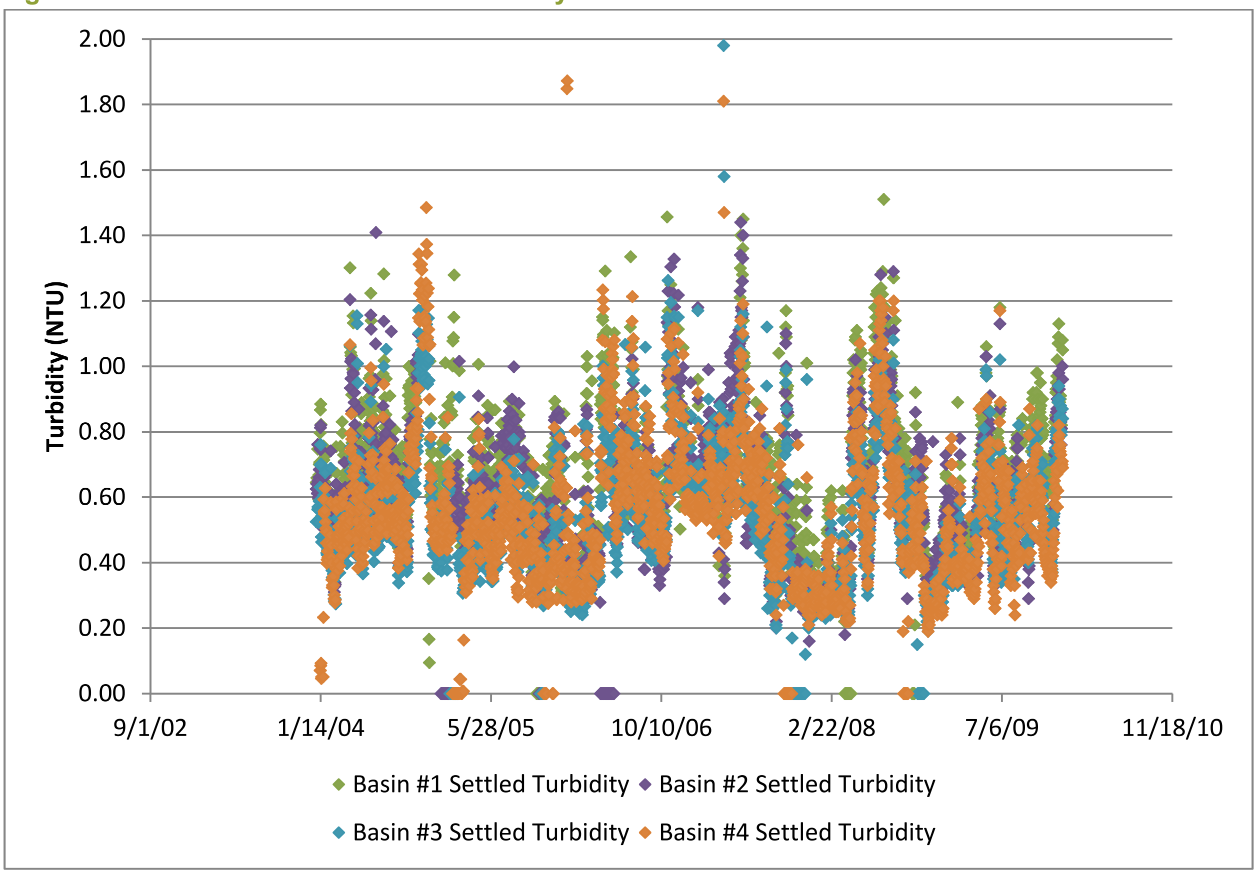
The flocculation process is rated on the basis of available detention time and mixing energy, the number of mixing stages and capability for adjusting the mixing energy to optimize the process and provide tapered mixing energy. At the BWTF, flocculation and sedimentation occur in successive sections of common basins. Each flocculation zone is approximately 80 feet wide by 36 feet long by 10 feet deep. Water enters the flocculation zone through a ported wall that promotes uniform distribution of flow. Each flocculation zone has three horizontal-paddle-wheel type mixers. The mixers are driven by variable speed drives to allow the mixing energy in each stage to be varied for best performance and provide for tapered mixing which reduces the mixing energy in each successive stage to promote the progressive formation of large floc. The flocculator drives of basins one and two have the original mechanical speed controls. These are worn, making it difficult to make precise adjustments. The mechanical speed controllers on the basin three and four flocculators have been replaced with adjustable-frequency drives. This type of drive makes it easy to change flocculator speeds and make precise adjustments to the mixing energy in each stage.

Flocculation process facilities are rated based on the available detention time provided, with allowances made for the quality of flow control and mixing provided. Typically, a detention time of 20 to 30 minutes is considered adequate. At a flow rate of 50 MGD, the Betasso basins would provide a detention time of 25 minutes, midway in the typical range, which would normally provide adequate performance. However, the baffles that divide the flocculation zone into stages only extend from the ceiling to about half-depth in the basin. This arrangement does not provide three true mixing stages. Flow through the process is encouraged to short circuit along the floor of the basin resulting in shorter effective detention time and reduced floc particle interaction. This potential for short-circuiting is further promoted by the location of the ports through which the flow enters the basin. The ports are centered on a line approximately the same height above the floor as the centerline of the flocculator paddle wheels and in line with the bottom edge of the baffles. Thus, currents can be induced in the lower portion of the flocculation zone that would pass under the baffles and carry through into the sedimentation zone. This non-ideal flow pattern results in a net reduction in the rate at which water can be effectively flocculated. If the minimum allowable detention time were set at 30 minutes the rated capacity of the flocculation process would be only 42 MGD. In fact, with the existing baffle arrangement a detention time of more than 30 minutes may be needed for optimum flocculation resulting in a further reduction in capacity. Based on available detention time, the existing flocculation basins have adequate volume to treat 50 MGD. However, the existing baffle arrangement results in a substantial capacity reduction. To achieve the desired capacity it would be necessary to modify the baffles to establish a controlled, uniform flow pattern and create three distinct flocculation zones. Replacing the worn mechanical speed controllers of basins one and two with adjustable frequency drives to facilitate mixing energy adjustment would also be needed to attain optimum process performance and reliability.

Although definitive testing has not been done to prove it, there is some evidence to suggest that flocculation may be impaired during certain times of the year due to low particle density. When this condition exists, the low-particle density will result in too little particle interaction in order to form settleable floc, thus resulting in reduced removal efficiency. In essence, the raw water is too clean to be effectively treated by conventional processes. Additional testing would be needed to determine whether this particle limitation condition is actually operative at Betasso and if so whether it poses a potential health threat from pathogens passing through the process.

To assess recent performance of the flocculation and sedimentation process analysis of the settled water turbidity under average and challenge conditions for the years 2004-2009 was conducted. A diagram presenting the performance of the four flocculation/sedimentation basins under average conditions is shown in **Figure 5-9**.

Figure 5-9: BWTF Settled Water Turbidity – 2004-2009



As shown above, average settled water turbidities are less than 1 NTU.

It is also important to evaluate the performance of the basins under challenging conditions such as high flows, and high raw water turbidities and color. The performance of the basins under challenge conditions, which include a plant flow in excess of 24 MGD, a turbidity of greater than 4 NTU in either supply source, and a high concentration of color are shown in **Figures 5-10, 5-11, 5-12 and 5-13** for comparison.

Figure 5-10: BWTF High Flow Days (> 24 MGD) Settled Water Turbidity

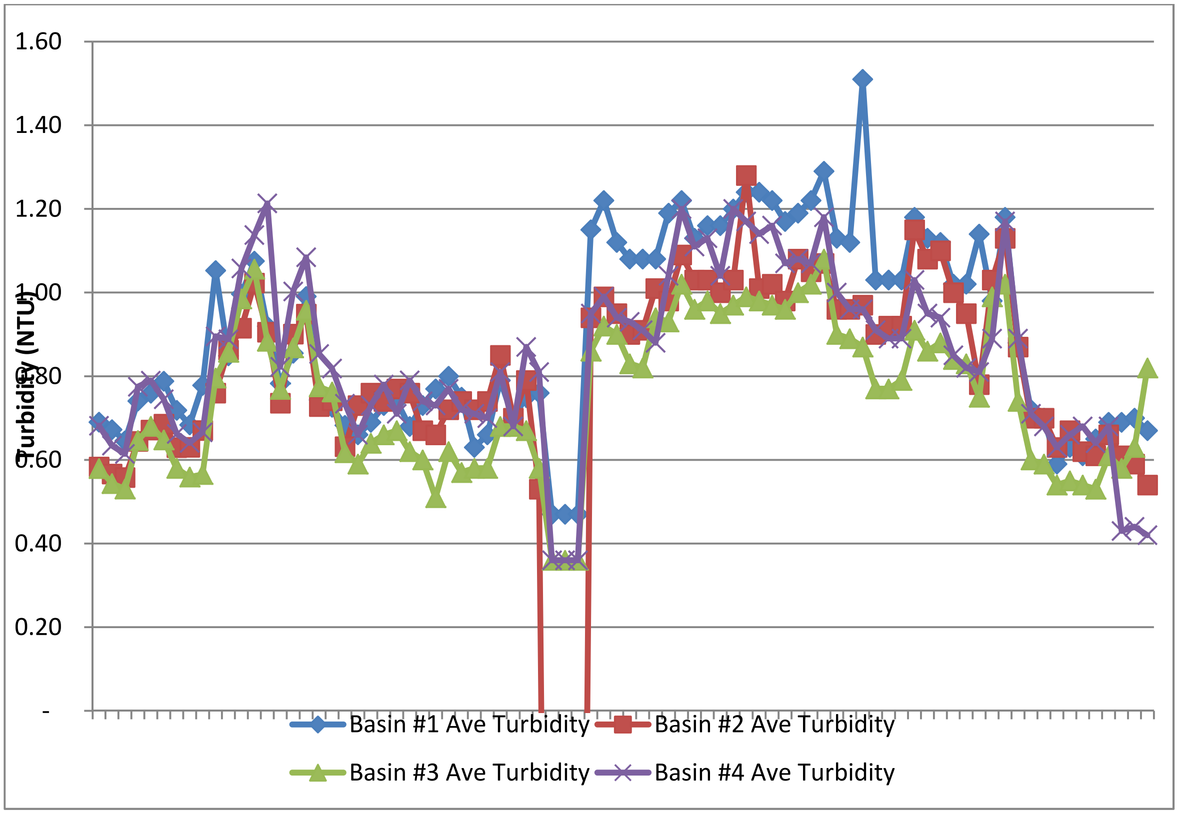


Figure 5-11: BWTF Barker High Turbidity Days (>4 NTU) Settled & Raw Water Average Turbidity

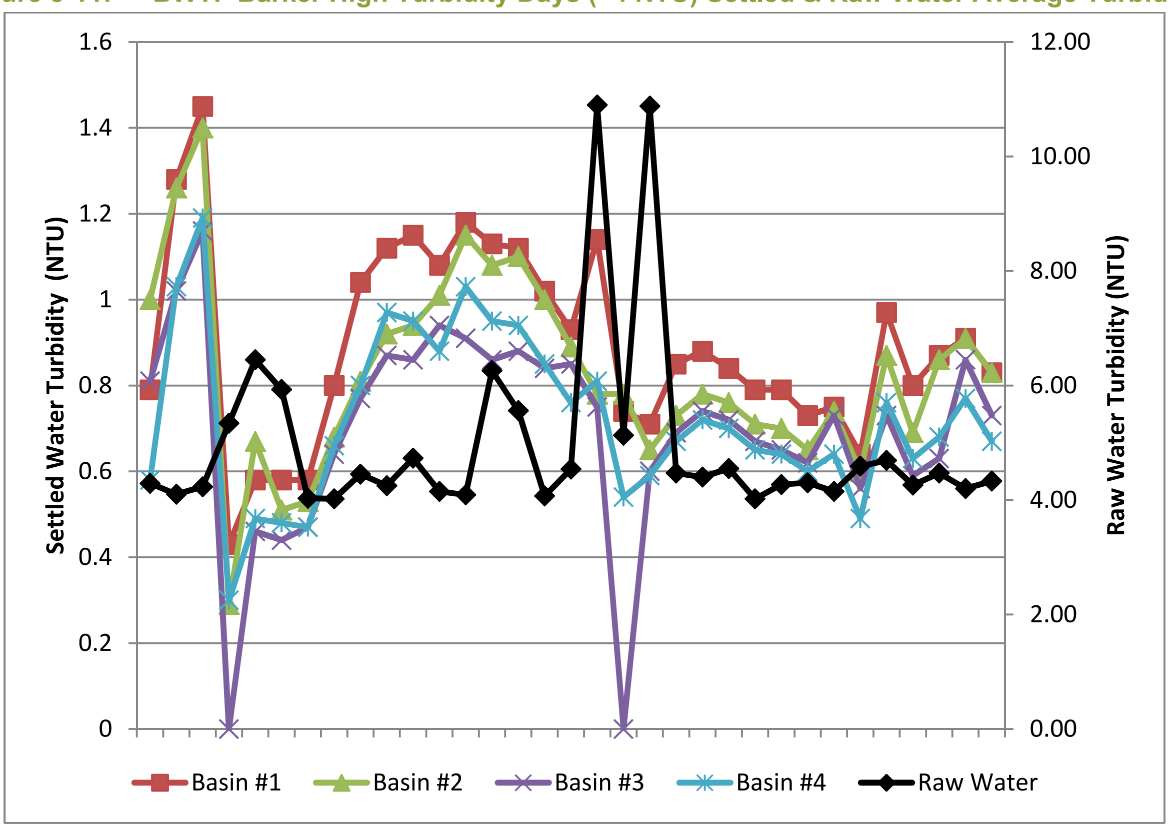
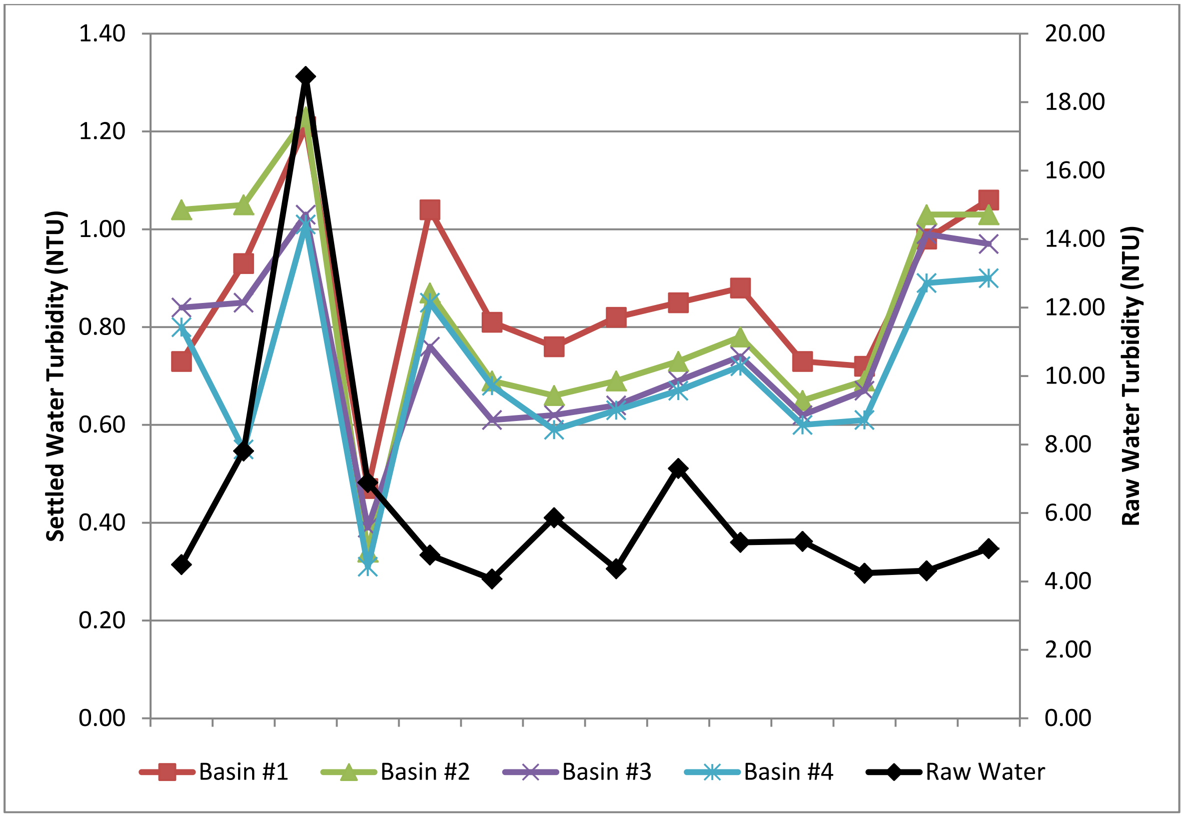


Figure 5-12: BWTF Lakewood High Turbidity Days (> 4 NTU) Settled and Raw Water Average Turbidity



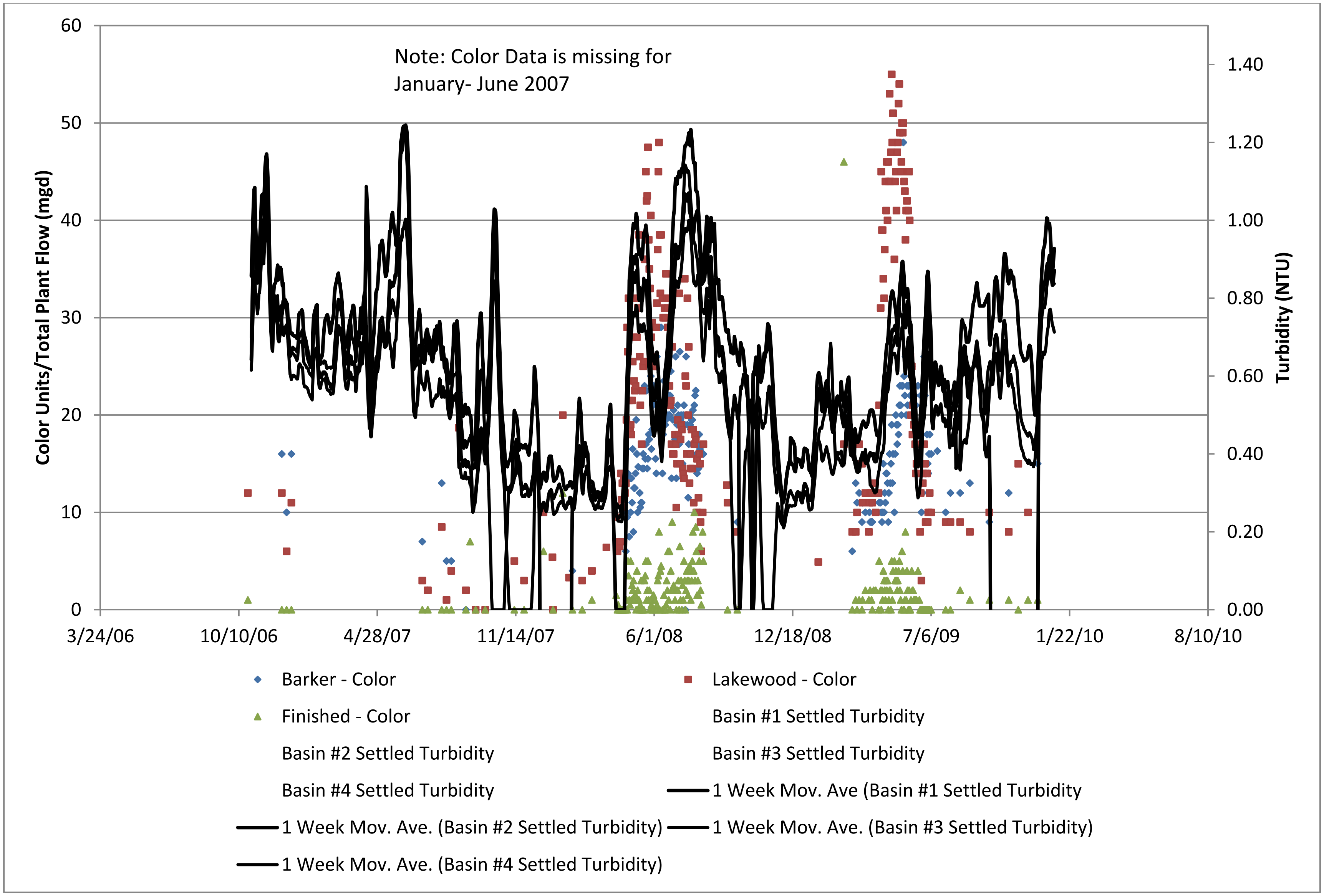
Under challenge conditions such as high plant flows and high turbidities in the source water, Basins 3 and 4 outperform Basins 1 and 2, Basin 2 outperforms Basin 1, Basin 3 generally has the best performance, and Basin 1 is consistently the worst performer. The settled water turbidity is less than 2 NTU and averages about 1 NTU during the challenging conditions. It is important to note that these values are in line with conservative industry standards for sedimentation basin performance.

There is no apparent correlation between high color in the raw water and settled water turbidity. Treating waters with high color does not appear to adversely affect the performance of the flocculation/sedimentation process.

Appendix B presents additional evaluations of settled water turbidity.

The concentration of settled solids being removed from the sedimentation basins is reported to be less than 0.5%. With an average turbidity of 1 to 2 NTU for the raw water, there are not a lot of solids to remove and the dilute solids concentration of the settled solids reflect this condition.

Figure 5-13: BWTF Source Water Color and Settled Turbidity

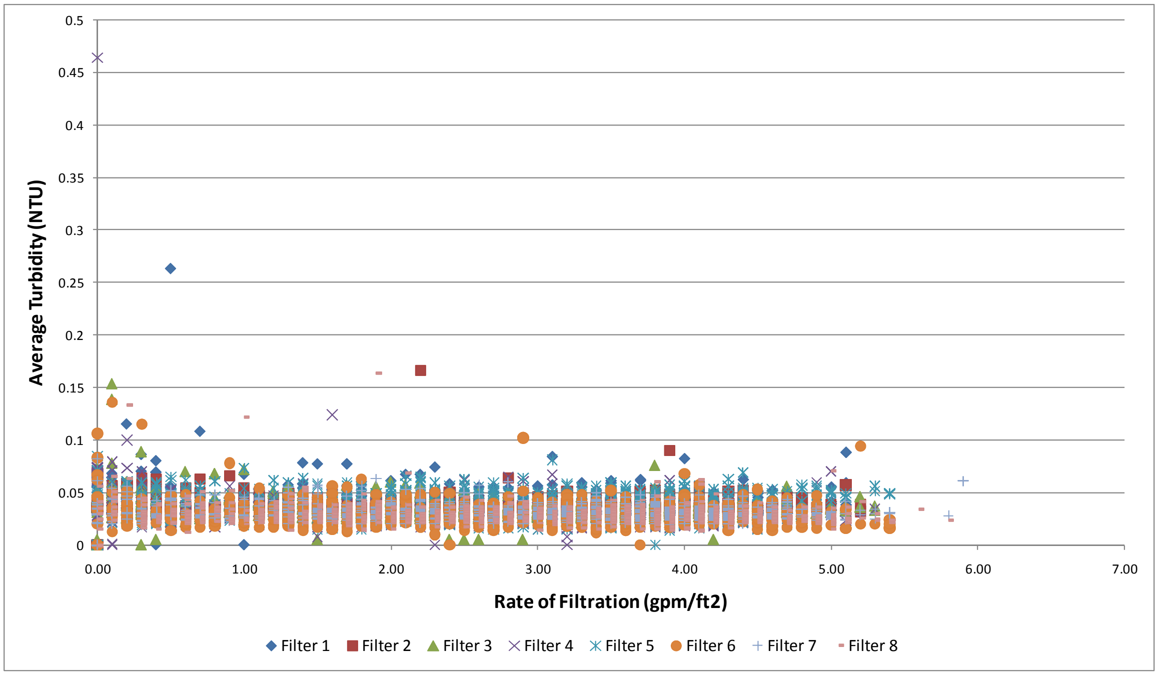


5.1.1.4 Filtration

Indicators of filter performance include the turbidity and particle count of the filtered water and the unit filter run volume (UFRV). A summary of the evaluation of the filtered water turbidity and the UFRV is presented in the following sections.

A plot of the average filtered water turbidity versus rate of filtration is presented in **Figure 5-14**.

Figure 5-14: BWTF Filters – Rate of Filtration vs. Average Filter Turbidity

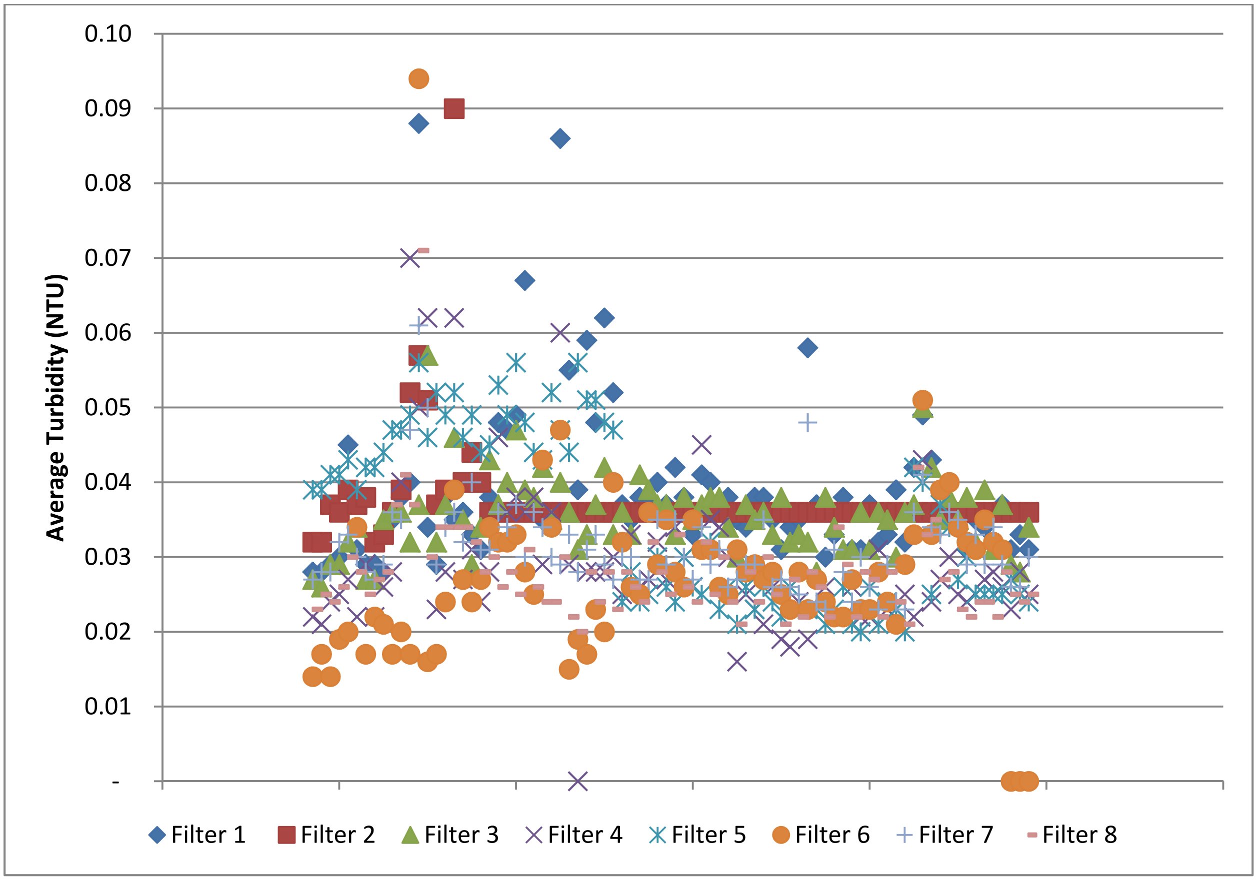


In reviewing the information in **Figure 5-14** it is noted that the average turbidity at all filtration rates is about 0.03 NTU with a maximum typically less than 0.1 NTU. Filter performance is therefore independent of the rate of filtration for rates up to 5 gpm/ft^2.

It is significant to note that the filters are managed to remove a filter from service once the filtered water turbidity exceeds 0.1 NTU so it is expected that the turbidity values will be consistently less than 0.1 NTU.

An evaluation of the average filter turbidity at plant flows greater than 24 MGD is shown in **Figure 5-15**.

Figure 5-15: BWTF High Flow Cases (> 24 MGD) Average Filter Turbidity

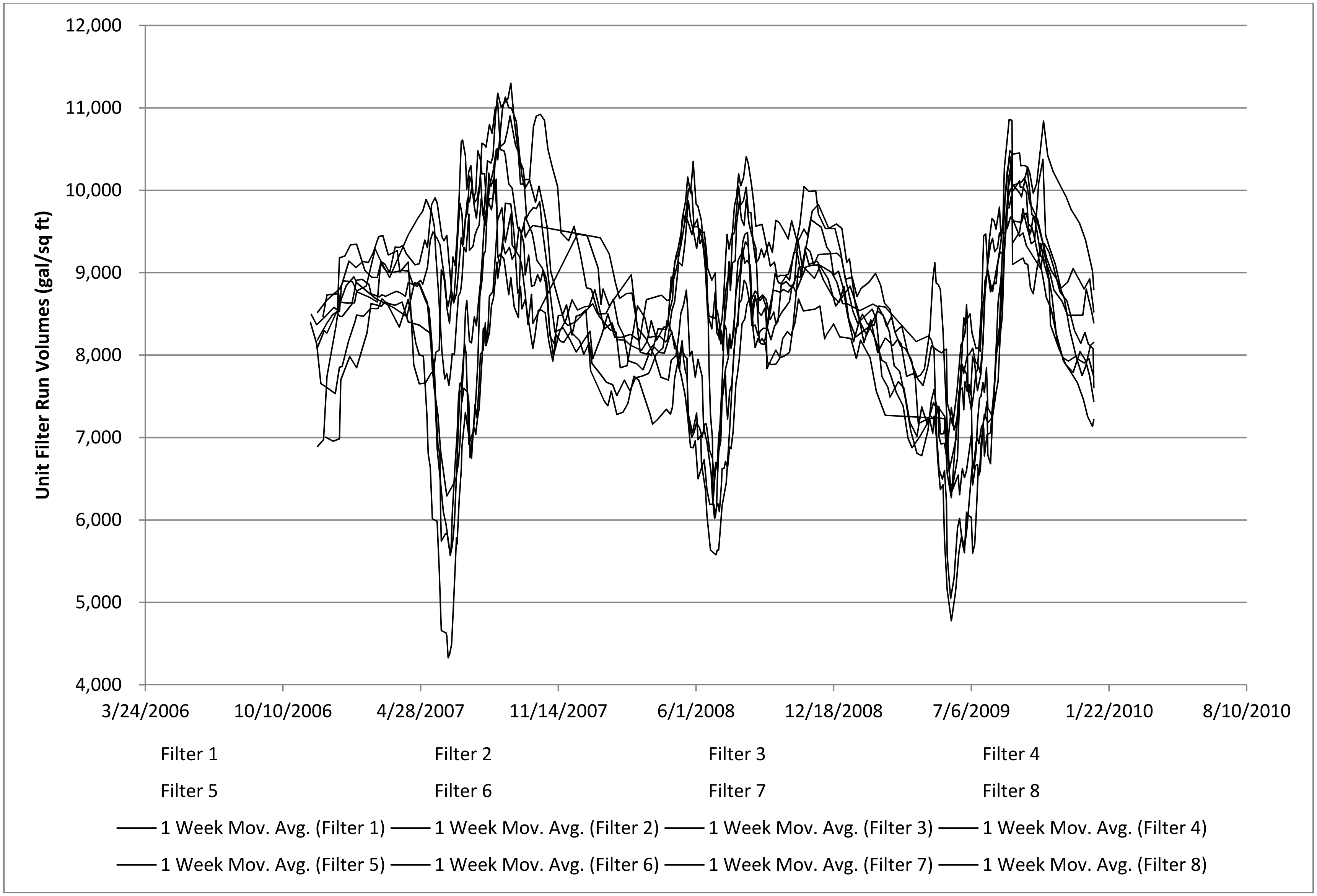


Under challenge conditions of high plant flow (> 24 MGD), the performance of the filters does not degrade. This again can be explained in part by the method in which the filter operation is managed, at filter breakthrough of 0.1 NTU as opposed to allowing the filter run to continue and produce higher turbidities.

Additional figures presenting the results of other analysis such as rate of filtration versus maximum filter turbidity and individual filter performance during spring runoff are shown in the **Appendix B**.

A plot of the trend lines for the one-week moving average of unit filter run volumes (UFRV) is shown in **Figure 5-16**. It is important to note that the trend lines are one week moving averages so the UFRVs of the individual filter runs are considerably lower.

Figure 5-16: BWTF Historical UFRV Data Trendlines Only – One Week Moving Averages



The diagram shows seasonal variation in the UFRV with a distinct and significant decrease in performance in the spring/summer of the year. The sharp decrease in the one-week moving average UFRV takes place over a time frame of about three months each year, coincident with the spring runoff.

The seasonal decrease in the UFRV results in a loss of a production of approximately 400 MG/yr of finished water based on one-week moving averages of UFRV's.

The cause of the seasonal decrease in UFRV was investigated. The comparison includes an evaluation of the individual filter performance as well as a comparison of changes of filter performance against changes in source water quality.

The evaluation of the individual filter performance revealed a difference in the performance of filter banks. Filters 1 through 4 were constructed together and comprised one bank. An expansion of the BWTF was made with the addition of Filters 5 through 8, which make up the second bank. In addition, it is likely that filters 1-4 were most affected by the previous air entrainment issues in the source water supply. It is suspected that the finer media in the filters was removed. The air entrainment problem has now been resolved. There also may be an unequal flow split to the basins that should be evaluated.

The performance of Filters 1 through 4 and 5 through 8 are shown in **Figures 5-17 and 5-18**, respectively. In comparing the information in the two figures, it is noted that Filters 1 through 4 exhibit a more severe seasonal depression in UFRV than Filters 5 through 8.

When filter performance was compared against water quality in the source water, a correlation between the concentration of color in the source water and a decrease in the filter UFRV is observed. A presentation of this correlation is shown in **Figure 5-19**. This observance is consistent with the operations staff reported problems of turbidity breakthrough while treating waters with a high color concentration. An explanation for the decrease in UFRV is the change in floc characteristics associated with removing dissolved constituents as opposed to removing particulate that is associated with turbidity. The change in the floc can change its filterability characteristics.

During conditions of high color in the water supplies, an average UFRV of 7,200 gal/ft^2 is assumed. A filter run time of approximately 25 hours is estimated at a filtration rate of 4.7 gpm/sf. A filter run time of 25 hours will require the filter to be washed on the order of once a day.

Based on site observations and operations staff input, rehabilitation of the filter gallery including valve and actuator replacement and repainting of the gallery piping is needed.

Figure 5-17: BWTF Historical UFRV Data – Filters 1-4 Only

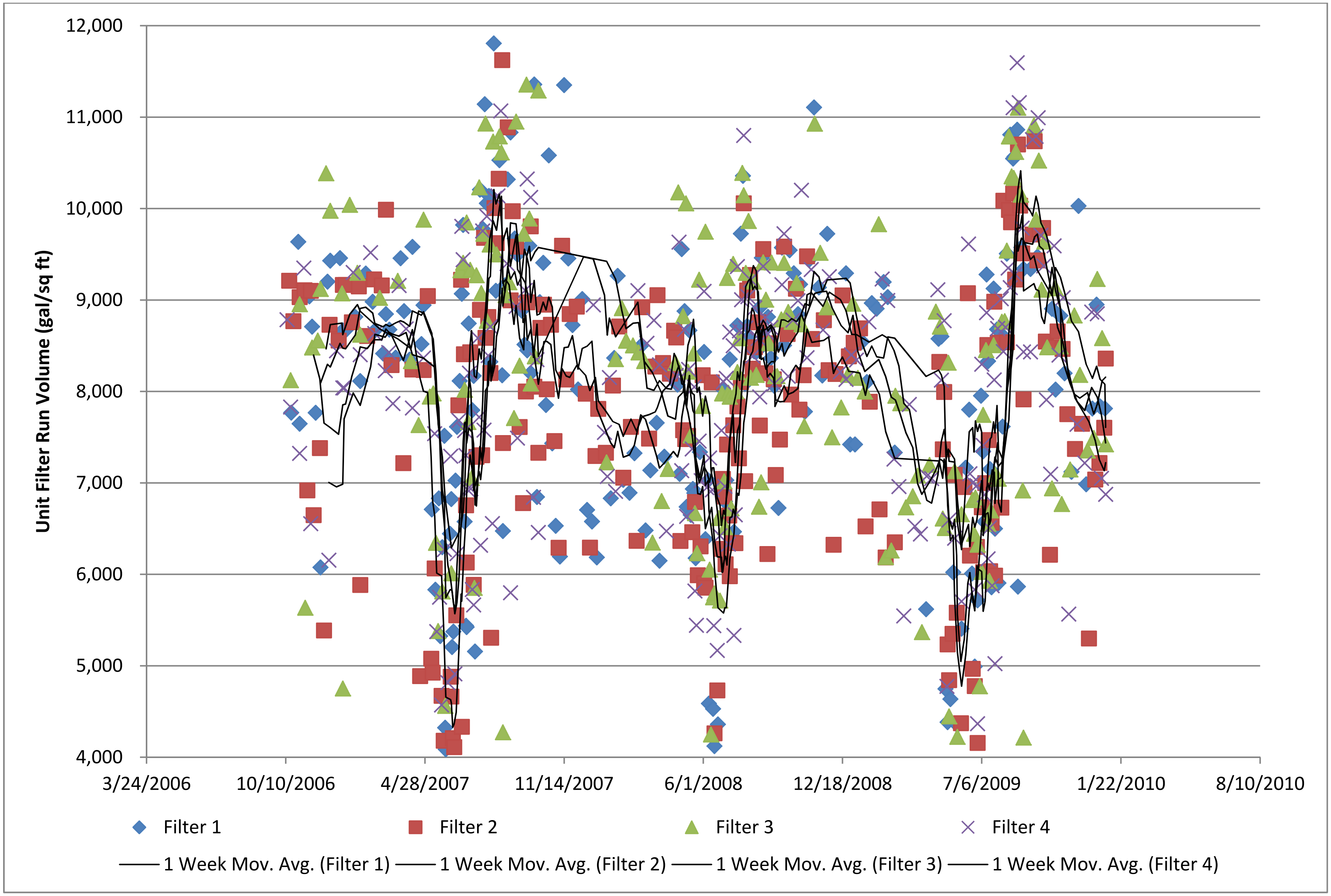


Figure 5-18: BWTF Historical UFRV Data – Filters 5-8 Only

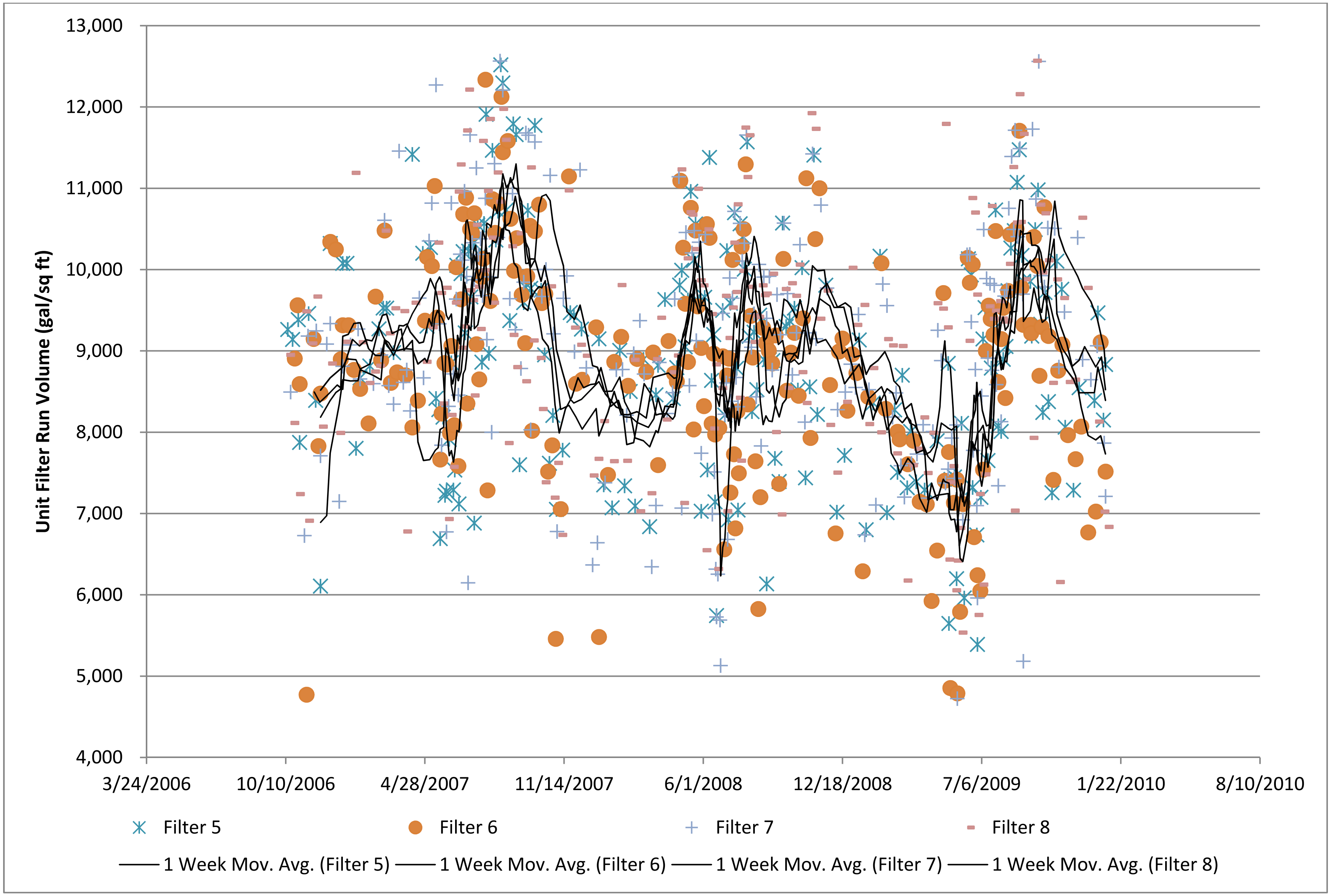
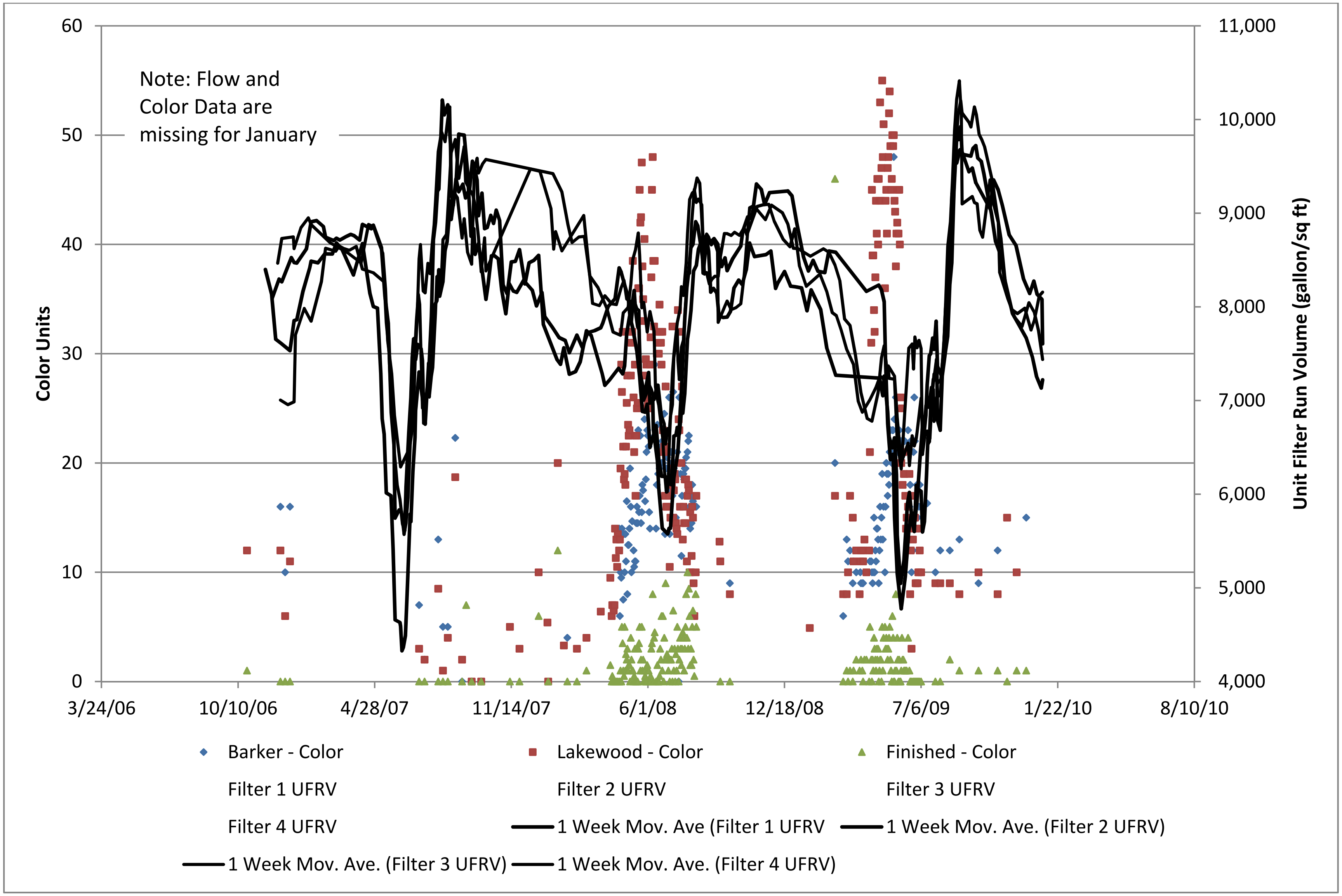


Figure 5-19: BWTF Historical Source Water, Finished Water Color and UFRV



The City of Boulder has performed some experiments on filters at BWTP. The findings are presented in the following documents; Filter Run Time and Analysis Report Betasso Water Treatment Plant dated July 27, 2009, and Filter #2 Surveillance and Evaluation Report Betasso Water Treatment Plant dated November 20, 2008. MWH reviewed these reports and can offer the following comments:

- The shorter filter runs for filters 1-4 is clear evidence that either the media itself or the washing of the media is not ideal.
- The “eruptions” noted in the first report may or may not indicate that the underdrains or gravel layer are damaged. The findings in the second report show the media is dirty even after washing, so the eruptions may be from uneven or inefficient media cleaning. Damage to underdrains or disruption of the gravel layer typically results in premature turbidity breakthrough during the filter run, and this has not been reported.
- The media coring shows dirt accumulation in the upper reaches of the bed; a symptom of the media loss noted in the report. With this much media loss, the bed never expands into the surface washing zone to receive the additional agitation.
- The report discusses the duration of the wash, but does not describe the sequence of surface and backwashing. This is something that should be investigated after the media is restored to proper depth. The two need to overlap for a minute or two, usually with the surface wash starting first.
- If continued floc retention monitoring shows the media is still not getting clean, the refurbishment of the surface wash system should be considered. Depending on condition, replacement with an alternative surface wash design or an air scour design may be needed.
- Also, it appears that the media in filters 1-4 is mismatched in size, promoting intermixing at the interface between the coal and sand. This increases headloss, shortens filter runs, and contributes to dirt retention in this region. If restoring the media depth and adjustments to the wash sequence do not work to lengthen the filter runs, complete replacement of filter media may be required.

5.1.1.5 Filter Backwash System and Backwash Water Supply System

The surface wash system at BWTP is older, and if replacements are being made to the filters, it is recommended that the surface wash system is also upgraded at that point in time.

The filter backwash water supply system is comprised of two 972 gpm pumps to fill a 200,000 gallon tank. Assuming a Unit Back Wash Volume of 150 gal/sf, a backwash volume of 158,000 gallons is calculated for washing one filter. To replenish the water supply tank with 158,000 gallons, it takes one of the 972 gpm pumps about 2.7 hours. Therefore, the most that each of the eight filters can be washed is once daily, considering the capacity of the washwater supply system.

There are currently no strict requirements to leave a filter for a set time before returning it to service. However, operations staff tries to maximize the "rest time" of every filter before returning it to service by utilizing good rotation of the filters. Most of the year, the filters are allowed to rest for 12 hrs or longer after a wash before returning them to service. However, during high production days, and specifically high color in the raw water, it is not uncommon to need to return a filter to service immediately after washing.

5.1.1.6 Disinfection

Disinfection at the BWTF is accomplished by application of sodium hypochlorite solution. The conversion to liquid sodium hypochlorite from gaseous chlorine was completed in early 2000. The new liquid chemical storage and feed facilities were designed to feed up to 5 mg/L at a plant flow rate of 50 MGD providing capacity consistent with the BWTF design capacity. The sodium hypochlorite is fed upstream of the filters.

Since the installation in 2000 by treatment plant staff, the following changes to the system have taken place:

- The pre-basin NaOCl feed points were moved downstream of the coagulant feed
- Operations staff have all but stopped using pre basin chlorination due in an effort to minimize DBP formation potential
- A “post-basin” feed system was installed by water treatment staff in 2004. This system includes feed lines that are located on the basin lines that run from each basin and connect to the main header piping before the filters.
- The feed system includes a total of four Watson Marlow peristaltic feed pumps. Each pump is dedicated to a single basin effluent line. The pumps for this system are located in the hypochlorite room within the containment wall.
- Operations staff manually controls the flow of each pump as there are no flow-meters currently installed on this system.
- This post basin system was originally fitted with orifice meters to measure the flow of each pump. These meters had to be eliminated due to constant plugging.
- A double “Y” strainer system was installed (and remains) on the suction line to the post basin pumps to filter out particulate matter that could potentially clog the pumps or flow meters.
- Minor piping modifications and general maintenance (such as tank inspection/repair) has taken place since install.
- The floor is scheduled to be re-sloped and repainted with epoxy in Sept. 2010. This work is needed due to major deterioration of the epoxy coating and concrete floor. The containment wall and floor joint will also be sealed to fix the leaking wall. The floor of the hypochlorite containment area was originally designed for 1 ton Cl_2 gaseous tanks and was not properly retrofitted when it was converted for use as hypochlorite storage/containment room.

As discussed later in this section, CDPHE requires a minimum contact time prior to the first customer tap of 30 minutes at peak design flow to meet disinfection requirements. At a flow rate of 50 MGD a volume of 1.04 MG of effective storage volume would be required to provide the minimum chlorine contact time. The required volume can be provided by any combination of pipes and storage tanks following the filtration step. Storage tank volume is derated to account for the potential for short-circuiting by applying a factor to the total volume. Factors used by CDPHE range from 0.1 for unbaffled tanks to 0.7 for well baffled tanks. Pipeline volume is assessed using a factor of 1.0. The Betasso plant’s two treated water storage reservoirs have a total volume of 4.2 MG. Tank No. 1 has a volume of 2.5 MG and is well baffled. As a result a factor of 0.7 is applied to the total volume to obtain an effective volume of 1.75 MG. Tank No. 2 is unbaffled resulting in the 1.7 MG total volume being reduced to 0.17 MG effective volume by applying a factor of 0.1. Without considering the available volume in pipes, the combined total effective volume of 1.92 MG provided by the storage reservoirs would provide the required 30 minute contact time for a peak flow of 92 MGD. This provides approximately 1.8 times the minimum volume required to meet minimum CDPHE requirements for a flow of 50 MGD, which offers a substantial range of operating flexibility.

5.1.1.7 Flow Measurement

Raw Water Flow Metering: Low measurement is an ongoing concern at the BWTF. Influent flow is currently measured upstream of the plant in two main locations: in a new pitot tube flow meter on the new Betasso pipeline, downstream of the Betasso Hydroelectric Facility, and in two ultrasonic flow meters on the Lakewood pipeline, downstream of the Lakewood Hydroelectric Facility. These flow meters should be accurate, but there is no way to independently confirm their accuracy because there is no way to accurately measure combined influent flow at the head of the BWTF. There is an existing combined influent 5 foot Parshall flume at the head of the plant, but it is not used for flow measurement due to inaccuracies caused by turbulence.

Treated Water Flow Metering: The plant also has effluent Venturi Tube flow meters on both the Sunshine Canyon and the 6th and Canyon effluent pipelines. These flow meters are essential for determining efficiencies in delivery and recording of treated water downstream of the treatment plant, as well as for determining losses through the treatment process. The effluent flow meters are theoretically highly accurate, but there is no way to independently confirm their accuracy, and there are several potential issues that can degrade the accuracy of Venturi Tube flow meters. Discussions with plant staff confirm that these flow meters are unreliable and it also was a concern raised in The City of Boulder Water Conservation Futures Study, performed in 1999 by Hydrosphere Resource Consultants, Inc., which states that 8.4% of the City of Boulder's treated water is unaccounted for, some of which may be due to poor flow measurement.

5.1.1.8 Chemical Systems

Each of the chemical systems used at the BWTF was analyzed for its capacity to supply the required dosages of treatment chemicals over the design range of flow rates. The results are summarized below.

Aluminum sulfate (alum) is used as a primary coagulant. Alum is stored in liquid form and fed directly to the influent raw water at the inlet to the Parshall flume. Two metering pumps are in place, each with a capacity of 66 gallons-per-hour (gph). Assuming an active solution concentration of 50 percent, this system has a firm capacity to treat up to 79 MGD at an average dose of 12 mg/L. Alternatively; this system could deliver up to 20 mg/L of alum at a plant flow of 50 MGD with one metering pump out of service. With both pumps in service, the system could deliver up to 40 mg/L of alum at a plant flow of 50 MGD.

The possible locations for feed points are limited due to the physical limitations of the facility. There are no current plans to move the feed points at this time. Other feed locations have been tried in the past with mixed results.

Polymerized aluminum chloride (polyaluminum chloride, PACl) can be added to the influent raw water along with the alum, as a coagulant aid. PACl is stored and fed as a liquid with a solution strength of 50 percent active PACl. Currently, this system has one metering pump that has a maximum capacity of 70 gph, which could feed up to 22 mg/L of PACl at a plant flow of 50 MGD. The average application dosage used at BWTF is 5 to 7 mg/L.

Polymer as a floc-aid has never been trialed or used on a long term basis. Occasionally, operators have hand-dosed summaclear or alum to the filter influent during high color/turbidity events with good results. They take a small beaker containing coagulant and pour it into the influent channel of the filter (or sometimes on top of the filter media) when the filter is first brought on-line which reduces ripening time and minimizes turbidity spikes.

A system for feeding powdered activated carbon (PAC) to the influent raw water is in place, but has never been used. This system was designed to store PAC slurry at a concentration of 1 lb of PAC per gallon of slurry and to feed up to 1.0 mg/L at a plant flow rate of 50 MGD.

Lime is added after filtration in the filtered water flume as part of the corrosion control treatment. Lime is stored in powder form and is fed as a slurry. The dry chemical is metered by two volumetric screw type feeders having a capacity of 3,800 lb/day each. The target concentration of lime slurry that is added to the finished water flume is 30%. The existing system could supply that dose to a flow of 32 MGD. At a plant flow rate of 50 MGD, the system could supply a dosage of 18 mg/L. The lime feeders are maintenance intensive and the scale buildup is a source of frustration for the operations staff. The City of Fort Collins, Colorado has a newer lime slaking system that can maintain a constant temperature close to the required 185 degrees F where the lime surface area is maximized. The greater the lime surface area, the more consistent and reactive the lime will be, which will result in a more accurate dose. In addition, the higher the quality of hydrated lime, the less scaling will occur.

Fluoride is added using liquid hydrofluosilicic acid. A single metering pump with a capacity of 300 gpd provides the capacity to add up to 1.2 mg/L of fluoride at plant flow rate of 50 MGD with a solution strength of 20 percent. Again, assuming a solution strength of 20 percent, this system could maintain a 1.0 mg/L fluoride concentration at a flow rate of up to 60 MGD.

Carbon dioxide (CO_2) is added to the finished water after lime addition to adjust the Langlier index for corrosion control. CO_2 is fed as a gas through a diffuser grid mounted in treated water reservoir No. 1. The existing system has the capability to feed up to 5,000 lb/day which is sufficient to apply up to 12 mg/L at a plant flow of 50 MGD.

This analysis indicates that, except for the lime feed system; the existing chemical systems have enough capacity to supply the required quantities of treatment chemicals at a peak day plant flow of 50 MGD. Assuming an average 28 mg/L lime dose continues to be required, it would be necessary to increase the lime feed capacity to 11,700 lb/day from the existing 7,600 lb/day.

Chemical feed rates are currently adjusted manually based on plant flow and water quality demands. Systems are monitored remotely through the SCADA system, but the plant operators determine the appropriate dose for each chemical at intervals through the operating day and manually adjust the feed equipment set points. Although the SCADA system does provide for remote monitoring of the chemical systems, this is a manual system because the operators have to determine the set points and adjust the feed equipment by hand. The plant operating staff indicated that more efficient chemical use and higher levels of water quality could be achieved more consistently if the SCADA system was used to automatically make more frequent and more precise adjustments to the chemical feed systems than is possible with the existing manual adjustment procedure.

The existing storage facilities for liquid chemicals have developed by adapting existing storage and feed equipment as beneficial changes in treatment chemicals were made. For example, polyaluminum chloride is currently stored in tanks that were originally used to store alum. These arrangements have been workable as temporary facilities. However, long term, operability and reliability would be enhanced by upgrading these facilities. In addition, the plant operating staff has determined that in order to optimize process performance a flocculant aid polymer system and possibly a filter aid polymer system may be needed. All of these improvements were originally part of the Residuals Project but were eliminated to reduce project costs when project bids exceeded available funds.

5.1.1.9 Process Instrumentation and Control

Effective process performance is dependent on accurate measurement of the water quality parameters that reflect current operating conditions. This information is used to determine the need for and magnitude of adjustments to chemical feed rates and other process controls to maintain optimal performance. As previously discussed, the plant SCADA system provides for remote monitoring, but process control is manual. The SCADA system also records plant operating data in great detail.

Plant influent flow is measured separately on the Barker and Lakewood pipelines using pitot tube flow meters. A combined influent flow meter is desired to measure total inflow to the BWTF.

The flow split among the operating flocculation/sedimentation basins is monitored by individual flow tubes at each basin. It is believed that the flow split to each basin is not even and improvements to the flow splitting structure are recommended. Accurate control of the flow to each basin will facilitate optimization of the processes.

Flow to individual filters is measured by flow tubes. Flow to each filter is currently controlled by pneumatically actuated butterfly valves, which are worn and should be replaced as part of the next capital improvements project.

A turbidity meter installed at the Lakewood pipeline intake provides information on raw water turbidity changes to allow the plant operators to respond to turbidity spikes. Otherwise, there is no water quality instrumentation on the raw influent water lines ahead of coagulation.

Settled water turbidity is measured individually on the effluent from each basin and collectively in the distribution header to the filters. No accuracy concerns were reported by staff, but the data for the individual sedimentation basins is difficult to access from the SCADA system and is not regularly used in process operation.

Individual turbidity meters and particle counters are installed on each filter effluent. These are reported to give acceptable results. One improvement to allow better assessment of filter performance could be to replace the turbidity meters with laser turbidity meters to provide better resolution at very low turbidities, however the City does not need the additional resolution at this point in time.

A streaming current monitor is installed in the piping between the Parshall flume and the flocculation/sedimentation basins to provide data on performance of the coagulation process and is reported by staff to work well.

The zeta potential meter in the plant lab is used to measure coagulation performance. Components of this meter were updated in 2006 and it is reportedly working well.

The Venturi tube flow meters used to measure plant effluent discharged to the Sunshine Canyon and 6th and Canyon transmission mains leaving the plant were identified by the Water Conservation Futures Study as possibly being inaccurate and in need of recalibration or replacement to facilitate accurate water use data.

An on-line pH meter is used to determine lime and CO_2 feed rates for chemical stabilization. It was not reported to be presenting difficulties to operations staff. Online alkalinity meters are no longer used because they were found to not perform well and did not provide useful data, there are currently no plans to replace the alkalinity meters.

In addition to the need for automation of chemical systems previously noted, plant staff indicated that better access to the data currently being measured by existing instruments and recorded by the SCADA system is essential to optimizing plant performance. The existing SCADA system is reported to have the capability to present data more readily in easy to use formats but additional software and programming is needed. Operators also indicated that a general upgrading of the on-line instrumentation would reduce the amount of laboratory work needed and provide operators with critical data faster, thereby facilitating more responsive operation.

5.1.1.10 *Residuals Management*

Despite the projects implemented in 1999 and 2006, the residuals handling capacity at BWTF is still inadequate and this is considered one of the top priority issues by plant operations and project management staff. For the preliminary evaluation of the solids handling process presented in this report, MWH interviewed plant Operations and Maintenance (O&M) staff and reviewed the 2005 Carollo report and subsequent project design drawings.

MWH has estimated the solids production for the BWTF based on influent water turbidity, plant flow, and typical and maximum reported coagulant dosing. Based on aluminum contribution of PACl and Alum coagulants, 0.58 pounds of PACl produces the equivalent amount of solids (predominantly aluminum hydroxide) as one pound of Alum. The solids production estimates are calculated from the following equation:

$$S = 8.34 \times [(Alum \times C) + (PACl \times C \times 0.58) + (NTU \times F)]$$

Where: S = Solids production in dry lb/MG water treated
8.34 = conversion factor [(lb/MG)/(mg/L)]
Alum = Alum dose in mg/L
PACl = PACl dose in mg/L
C = conversion factor (lb alum/lb dry solids)
NTU = Influent Turbidity
F = Turbidity to suspended solids conversion factor [(mg/L TSS)/NTU]

The average daily solids production (dry lb/day) for each scenario is the solids production multiplied by the flow (Q) in MGD. A summary of the estimated solids production is shown in **Table 5-23.**

Table 5-23: Estimated Solids Production at BWTF

Description	Unit	Quantity				Origin
		Average Day	Peak Day	Peak Week	At 46 MGD	
Plant Flow Rate (Q)	MGD	14	40	25	46	Given
Raw Water Turbidity (NTU)	NTU	4	4	4	4	Given
NTU to TSS Conversion (CONV)	mg/L/NTU	1.23	1.23	1.23	1.23	Carollo 2005
Alum Dose	mg/L	11.1	16.2	16.2	16.2	Given
Sumaclear (PACl) Dose	mg/L	6.9	14	14	14	Given
Solids Produced	dry lbs/MG	74	94	94	94	Calculated
Daily Solids Production	dry lbs/day	1,033	3,751	2,344	4,313	Calculated

Drying residuals via lagoons is a relatively long term method in comparison to the available dewatering options. There needs to be sufficient capacity in order for this method to be effective since lagoon operation repeats and the overall cycle time for each lagoon varies depending on filling, drying, and excavation times.

At the average day rate of 1,033 dry lbs/day of estimated solids produced, approximately 377,045 lbs is produced per year. This is used to estimate the total size of the sludge drying beds required to handle the solids production flows at the BWTF, which is shown in **Table 5-24**.

This evaluation is provided to illustrate the capacity needed to manage the solids production and the possible options available to meet these needs. Further studies and field tests need to be conducted to determine the appropriate design criteria for sizing of lagoons. Loading rates may vary between 6 to 12 lbs/ft^2/yr. In addition, because of variations in weather and solids production, it is common to provide excess drying time.

Table 5-24: Estimated Surface Area Required, Based on Average Day Solids Production of 1,033 Dry lbs/day

Drying Period	Total Lagoon Surface Area Required (ft^2) Solids Loading Rates		
	6	8	12
(months)	(lbs/ft^2/yr)	(lbs/ft^2/yr)	(lbs/ft^2/yr)
12	31,420	47,131	62,841
15	39,276	58,913	78,551
18	47,131	70,696	94,261

Assuming it takes a full 12 months for one drying bed to be sufficiently loaded with solids, decanted, dried and then excavated, some contingency is applied if the drying period were to be extended to 15 months or even 18 months. In keeping consistent with solids loading rate of 8 lbs/ft^2/year from the 2005 Carollo report, and selecting 15 months as the drying period, a total surface area of approximately 59,000 ft^2 is required. Ideally, the plant would be able to cycle through four lagoons each with a surface area of 14,750 ft^2, however, according to the 2005 Carollo report; the total surface area at the plant is currently 34,000 ft^2. This illustrates the shortfall in lagoon capacity which has been experienced and reported by the plant's staff.

If land space were not an issue, then the existing sludge lagoons can be expanded and modified to accommodate the BWTF's solids production, but this is not the case. There have been improvements made to the South Lagoon to allow for more effective decanting, but dewatering capacity has been reduced with the lining of the lagoon.

The underdrain system for the east half of the North Drying Beds is broken and no longer operational. The beds are essentially operating as decanting lagoons. The remainder of the residual drying is achieved by evaporation. The beds are cleaned periodically and the residuals stored on the residuals drying pad until disposed of offsite.

To keep up with inadequate capacity of the existing lagoons, the BWTF currently uses private contractors to dewater the excess solids. This is a temporary arrangement and the staff will require a more robust solution.

Due to potential pretreatment capacity limitations of the existing flocculation/sedimentation process described in **Section 5.1.1.3**, two approaches can be taken for residuals handling solutions at the BWTF. The first approach is to address the issues separately which allows for separate analysis, planning, funding, and implementation schedules. The second approach is couple them together based on a conversion to dissolved air flotation (DAF) for pretreatment which is similar to one of the alternatives presented in the 2005 Facility Plan for pretreatment capacity and performance improvements (Note: The DAF alternative in the 2005 Facility Plan only includes 22 MGD of DAF capacity). This second approach requires simultaneous analysis, planning, funding and implementation schedules for the pretreatment and residuals handling improvements. Depending on the City's needed and desired implementation schedule for each of these improvements, the second approach may introduce undesirable funding and/or scheduling constraints. Brief descriptions of these alternatives are presented below with advantages/disadvantages summarized in **Table 5-25** along with budgetary capital costs.

Alternative 1 includes the addition of a gravity thickener and a mechanical dewatering process to handle residuals flows from the current sedimentation basins to provide a dewatered (approximately 20% solids) sludge for disposal. For the purposes of this planning level analysis it is assumed that the mechanical dewatering process is accomplished using centrifuges. When further analysis of residuals handling improvements is made, it is recommended that belt filter presses and centrifuges be compared from cost and operations perspectives with City staff to determine the best equipment choice for the BWTF. It is assumed that either process will require polymer addition for effective dewatering.

Based on the solids quantities from **Table 5-23**, two 20-foot diameter gravity thickeners loaded at approximately 6 lbs/ft^2/day are required to accommodate a 46 MGD plant capacity. The dewatering centrifuges are assumed to be located on the second floor of a dewatering and residuals load out building. **Figure 5-20** indicates a potential site layout for these facilities. Note that the drawing is schematic only and an alternate location may be necessary to continue use of the Residuals Drying Pad if the project is phased (e.g., only thickening installed) or for constructability or other reasons.

Alternative 2 includes the addition of a mechanical dewatering process to an early implementation of pretreatment capacity and performance upgrades with DAF that includes the following:

- Demolition of two existing flocculation/sedimentation basins
- Fill concrete floor to required elevation
- Construct new interior walls for 3-stage flocculation and DAF floatation
- Install eight DAF trains and associated equipment, 5.75 MGD each train
- Peak SOR = 6.25 gpm/ft^2 at 46 MGD

Since a DAF pretreatment process typically produces a 2-6% float, a separate pretreatment residuals thickening process (i.e., gravity thickening) can be eliminated. As with Alternative 1, dewatering is assumed to be accomplished using centrifuges. The dewatering and residuals load out building is assumed to be located as indicated in **Figure 5-20** for Alternative 1.

Figure 5-20: BWTF Site Plan Showing Location of Gravity Thickeners and Centrifuge Building

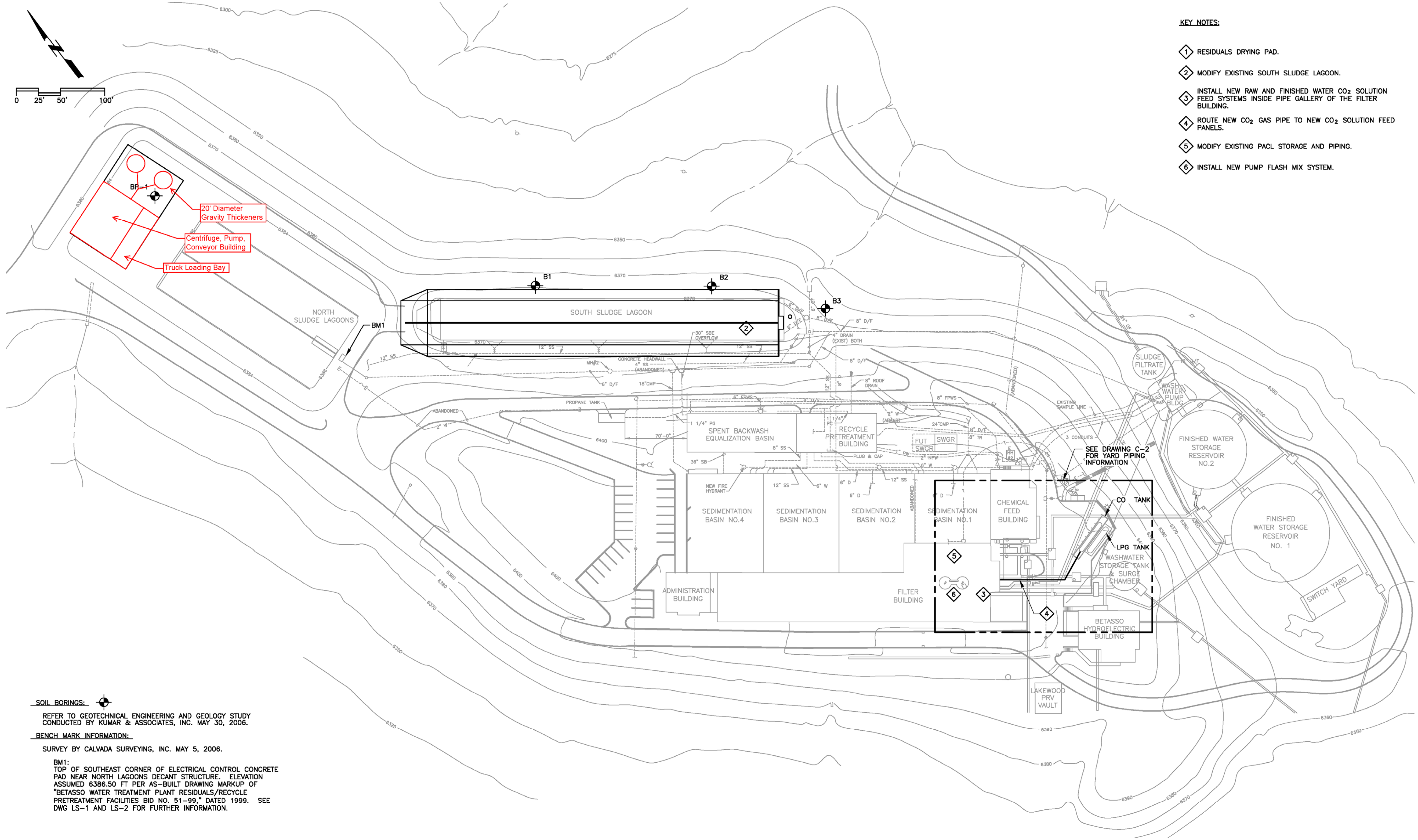


Table 5-25: Residuals Handling Improvements Alternatives

Alt.	Description	Advantages	Disadvantages	Capital Cost
1	Existing Floc./Sed. Process with Gravity Thickener and Centrifuge Dewatering	• Lower initial and overall capital cost • Prevents "early" expenditure of funds for pretreatment improvements	• May result in "throw away" thickening process if DAF process is chosen for future pretreatment upgrades	$2,858,000[1]
2	Conversion to DAF and Centrifuge Dewatering	• Smaller overall footprint • Pretreatment consistency with BRWTF	• Requires pretreatment improvements be implemented "early" along with dewatering • Increases pretreatment power consumption • Higher overall residuals handling and pretreatment improvements costs[1]	$25,000,000

[1]Alternative 1 does not include upgrades to the pretreatment improvements whereas Alternative 2 inherently does. To make this an equal comparison, an estimate 2010 capital cost of $13.1 M would need to be added to Alternative 1 to add plate settling and associated flocculation pretreatment improvements in all four existing flocculation/sedimentation basins per the 2005 Facility Plan, resulting in a total of $15,958,000.

Based on the advantages and disadvantages and costs of the two alternatives, it is recommended that Alternative No. 1 be evaluated further with respect to optimized sizing for the range of flows and loads and desired redundancy, site layout, and preferred mechanical dewatering equipment (centrifuges or belt filter presses).

5.1.1.11 Plant Hydraulics

The process flow conveyance network of pipes and channels was analyzed previously for hydraulic capacity. At a peak flow of 50 MGD no hydraulic limitations were identified. This hydraulic study was performed for the 2000 update to the TWMP. If any changes to the piping or process flow has or will change, another evaluation of the hydraulics through BWTF should be performed.

5.1.1.12 Betasso Water Treatment Facility Capacity

The results of the evaluation of major unit processes and systems of the BWTF are summarized in **Table 5-26**.

This evaluation indicates that the BWTF currently has the capability to treat a peak flow of approximately 40 MGD to the level required to meet current regulatory requirements. The evaluation indicates that the BWTF currently has the capability to treat a peak flow of approximately 40 MGD to the level required to meet current regulatory requirements. Capacity is limited by the flocculation and filtration processes. Performance data suggests that actual sedimentation capacity is less than the theoretical value due to poor flocculation, possibly poor coagulation and the less than optimum sedimentation basin configuration. Performance data also suggests that the actual filtration capacity maybe less than the design value of 5 gpm/ft2 due to low UFRV's particularly in filters 1-4 and during periods of high color. In general, a UFRV that is less than 5,000 gal/ft2 is unacceptable because of the extremely short filter run lengths and UFRV's less than 10,000 gal/ft2 indicate less than desirable filter performance. Low UFRVs can result from inadequate pretreatment, excessive or fine mudballs in the filter media (inadequate cleaning), mineral precipitates in the underdrains, air binding, non-ideal media conditions (i.e. depth, size, match) or hydraulic restrictions causing inadequate head between the filters and the clearwells. The actual cause(s) of the low UFRV's and the corresponding capacity limitation at the BWTF is likely a combination of one or more of these conditions and requires further study for a conclusive determination. All other processes have capacities equal to or greater than 50 MGD and process piping has the hydraulic capacity to convey 50 MGD without restriction. Replacement of the Lakewood Pipeline has reduced previous entrained air problems in the raw water, which has improved the performance of the flocculation and sedimentation processes. However, elimination of the entrained air alone has not increased the capacity of these processes to 50 MGD. Additional improvements will be needed to the flocculation and sedimentation basins and filters to provide a fully effective treatment barrier with the consistent performance necessary to reliably meet current and future regulatory requirements at a capacity of 50 MGD.

5.1.1.13 Miscellaneous

The standby generator capacity at BWTF is at its maximum capacity. If additional loads are added, the capacity of standby generation will need to be increased.

5.1.1.14 Chemical and Energy Efficiency Patterns

Chemical usage varies due to seasonal and source water quality changes. Discussions with staff indicate that the City makes significant efforts toward chemical optimization. Continued monitoring, optimization, and experimentation efforts will likely lead to further improvements with regard to chemical efficiency.

Chemical efficiency can also be improved through the automation of various chemical feed systems found throughout the plant, with the addition of PLC controlled flow pacing and trim capability. Utilizing feedback from process controls instruments, continuous adjustments can be made automatically through the PLC logic in order to consistently provide the proper chemical doses at all times.

Energy efficiency at the BWTF can be improved over time with the use of higher efficiency pumps and premium efficiency motors as part of the maintenance replacement program and as part of facility upgrade designs.

5.1.1.15 O&M Procedures and Maintenance Programs

Based upon site visits and discussions with O&M staff, there is some room for improvement with regard to the completion of routine maintenance operations. Budgetary and manpower limitations generally limit maintenance activities to those items with mid to high priority, leaving items with low to mid priority unattended to. It should be expected that as the equipment and facilities age, maintenance needs will increase, and there could be a need for additional budget and manpower to properly maintain the facility and avoid premature replacement of equipment.

The City is in the process of transitioning toward the use of computerized maintenance management software. This system will allow the City to more easily schedule and plan for routine maintenance activities. It is reported that a large commitment of time is required to enter all the necessary data for the system to become fully functional, it is likely to be several years before the system is fully functional.

5.1.1.16 Needs for Continued Water Quality Compliance

At this time there appear to be no water quality compliance issues when treating within the inherent capacity limitations identified in previous sections.

Table 5-26: BWTF Capacity Evaluation

Process	Criteria	Rated Capacity	Potential Capacity	Comments
Raw Water Conveyance	Pipe Hydraulic Capacity	• 47.7 MGD • Barker at 27.7 MGD • Lakewood at 20 MGD	• Under emergency conditions, flows could reach up to 30.1 from Barker and 30 mgd from Lakewood, totaling 60.1 MGD	27.7 MGD is the normal max for the Barker supply. For very short term emergencies of up to a day or so, the max capacity could be 40 MGD because Kossler can be drawn down since the gravity line would not be keeping up that level of flow. However, this might do some lining damage to the Betasso Penstock if it continues very long. In a longer term emergency, the additional water would have to travel through the gravity line at the same rate as is being used to avoid draining Kossler, 30.1 MGD is assumed for a longer term emergency, however, 35 MGD would need to be put in the upper end of the gravity line to get 30 MGD out.
Coagulation		50 MGD	50 MGD	Assumed rapid mix equipment was going to help (especially with chemical consumption), however after installation, no improvements were seen. There may be additional coagulation optimization for dealing with high color periods to increase pretreatment performance.
Flocculation	Hydraulic Detention Time	<42 MGD at HDT > 30 minutes	50 MGD at HDT = 25 minutes	Baffle configuration does not provide optimum flocculation conditions
Sedimentation	Surface Loading Rate	52 MGD at SLR = 0.6 gpm/ft^2	60.5 MGD at SLR = 0.7 gpm/ft^2	Assumes installation of baffles to improve basin length-to-width ratio.
Filtration	Hydraulic Loading Rate	40 MGD (approx.)	53.2 MGD at HLR = 5 gpm/ft^2	Allows for one filter off line for backwashing. Rated capacity is lower than design/potential capacity due to pretreatment and filter issues (see text above). BWTF has never run at the design rates and has typically been run at rates 33% lower. It is expected that design rates would cause operational issues such as high turbidities and short UFRVs. The actual maximum loading rate for current operating conditions needs to be verified.
Disinfection	Sodium Hypochlorite System at 5 mg/L	50 MGD	50 MGD	To meet CDPHE requirements
	Chlorine Contact Time = 30 minute minimum	92 MGD	92 MGD	

5.1.1.17 Future Water Quality Issues

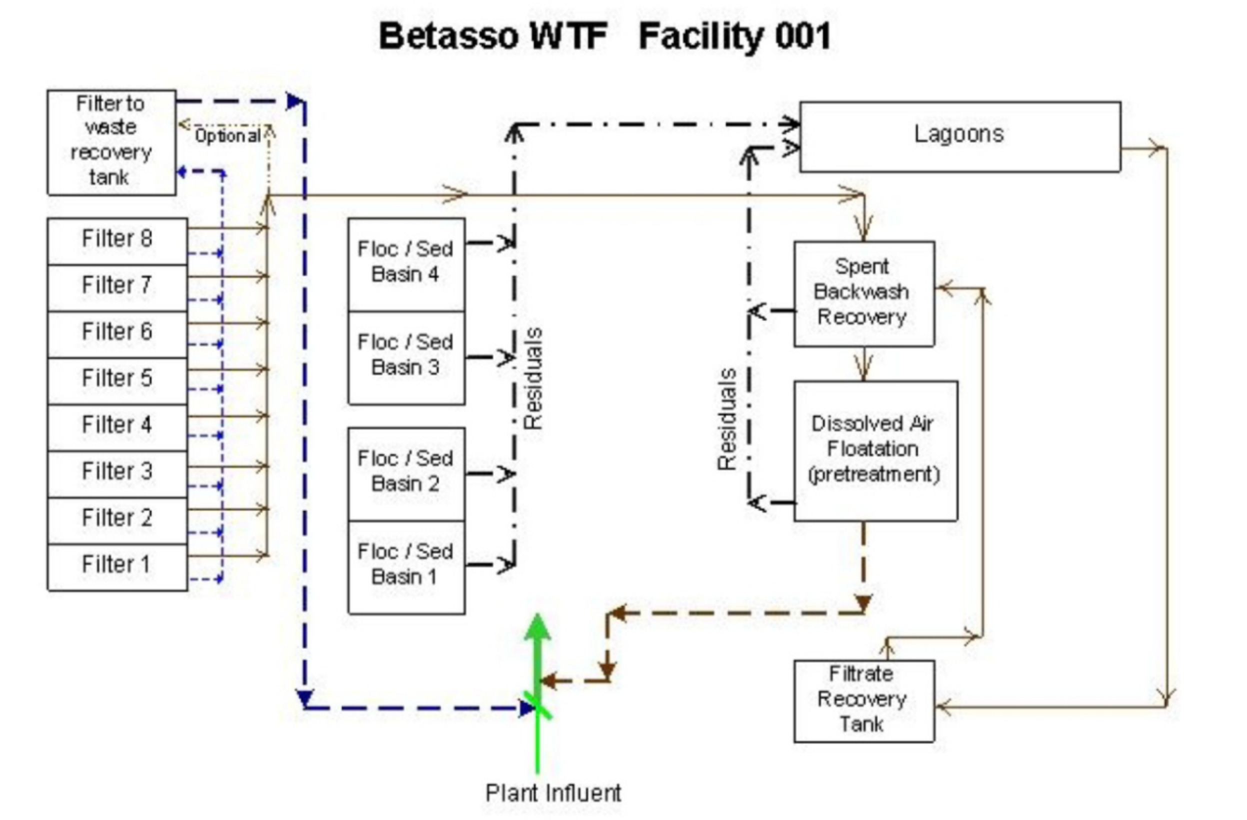
If the regulatory limits for DBPs are lowered significantly in the future, the City may not be able to comply. Should the running annual average limits be lowered to 0.040 mg/L for TTHMs and 0.030 mg/L for HAA_5 as has been speculated, disinfection byproduct concentrations would need to be reduced well below current levels to achieve compliance. Since relatively high levels of source water control for the BWTF have already been implemented and NOM material seems to be related to spring run-off conditions, additional changes to disinfection practices or preoxidation treatment with chlorine dioxide may become necessary to meet future DBP limits.

5.1.1.18 Waste Impoundments

MWH performed a preliminary identification and evaluation of the existing waste impoundments at the BWTF. The evaluation of the impoundments at these facilities is based on discussions with laboratory and plant operations staff and summarized in the following sections.

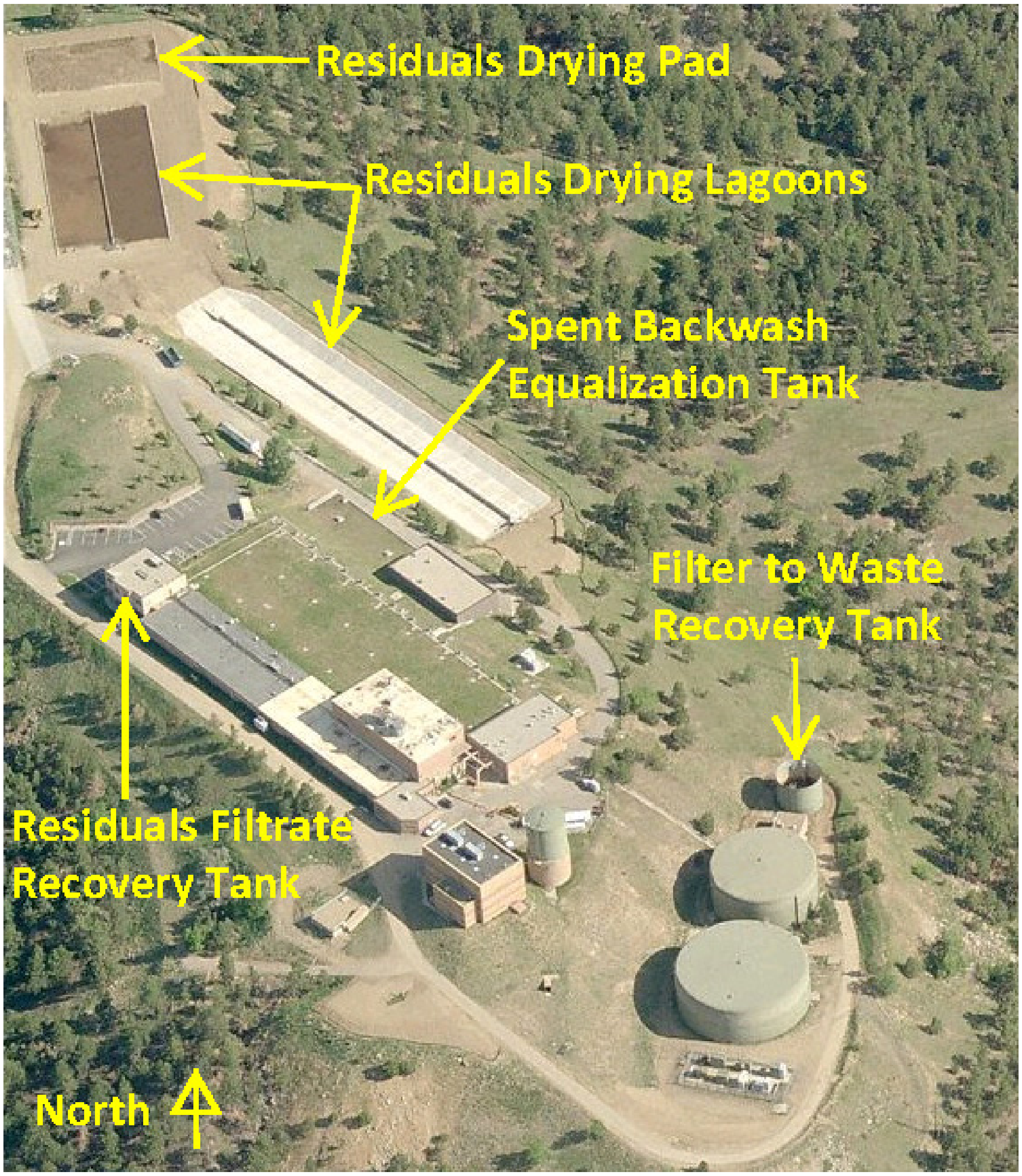
Waste impoundments at the BWTF include a residuals filtrate recovery tank, spent backwash equalization tank, filter to waste recovery tank, a concrete pad, and residuals drying lagoons. Decant from the residuals drying lagoons is sent to the residuals filtrate recovery tank and then on to the spent backwash equalization (SBE) tank that discharges to a DAF thickener. Waste filter backwash water is conveyed to the spent backwash equalization tank and then on to the DAF. Settled solids from the sedimentation basins and float from the DAF are sent to the residuals drying lagoons. Filter to waste flows are conveyed to the filter to waste recovery tank and then returned to the main flow stream just upstream of the rapid mixer. The concrete pad is used for drying and storing the dried residuals. A schematic of the residual flow streams are shown in **Figure 5-21**.

Figure 5-21: BWTF Residual Flow Streams



There are two types of construction for the existing residuals drying lagoons. The south lagoons are built of reinforced concrete walls and floors and the north lagoon are constructed of asphaltic concrete floors and reinforced concrete walls. The filtrate tank is a fabricated steel tank. Both the backwash concentrating and the backwash equalization tanks are constructed of reinforced concrete walls and floors. An aerial photograph of the existing plant site showing the waste impoundments is presented in **Figure 5-22**.

Figure 5-22: Existing Waste Impoundments at the BWTF



5.1.1.19 Residuals Sampling

The City of Boulder received the results of the residuals sampling that was performed in August of 2010 on the BWTF residuals. The results of these samples are included in **Table 5-27 and 5-28.**

Table 5-27: Analytical Results from BWTP Residuals

Analyte	Result[1]	Units
Aluminum	**68,000**	mg/Kg
Arsenic	**6.2**	mg/Kg
Cadmium	**ND**	mg/Kg
Chromium	**13**	mg/Kg
Copper	**31**	mg/Kg
Iron	**20,000**	mg/Kg
Lead	**30**	mg/Kg
Molybdenum	**ND**	mg/Kg
Nickel	**ND**	mg/Kg
Potassium	**1,300**	mg/Kg
Selenium	**ND**	mg/Kg
Zinc	**69**	mg/Kg
Mercury	**57**	µg/Kg
Ammonia	**310**	mg/Kg
Nitrogen, Kjeldahl	**5,600**	mg/Kg
Nitrate as N-Soluble	**ND**	mg/Kg
Total Phosphorus	**ND**	**mg/Kg**
Orthophosphate as P-Soluble	**ND**	mg/Kg
Total Organic Carbon	**96**	**g/Kg**
Percent Moisture	**63**	%
Total Solids	**42**	**%**
Soluble		
pH adj. to 25 deg C-Soluble	**6.74**	SU
Specific Conductance – Soluble	**170**	umhos/cm

[1]Results from: Analytical Report by TestAmerica 7/20/2010 Water Treatment Residuals Analyses, job number 280-4779-1.

Table 5-28: Radiochemical Analysis Results from BWTP Residuals[1]

Analyte	Result – Sample 1[1]	Result – Sample 2[1]	Units	Regulatory Limits for Disposal to meet Exempt Status[2,3]
^{226}Ra	0.810	0.810	pCi/g	
^{228}Ra	1.07		pCi/g	
$^{226/228}Ra$	**1.88**		pCi/g	<3
^{234}U	1.68	1.57	pCi/g	
^{235}U	0.0764	0.0722	pCi/g	
^{238}U	1.34	1.77	pCi/g	
^{NAT}U	**3.0964**	**3.4122**	pCi/g	<30
^{228}Th	1.00	1.11	pCi/g	
^{230}Th	0.364	0.734	pCi/g	
^{232}Th	0.610	0.909	pCi/g	
^{NAT}Th	**1.974**	**2.753**	pCi/g	<3
Alpha	5.87	4.96	pCi/g	<40

[1]Results from: Analytical Report by TestAmerica 8/11/2010 Water Treatment Residuals Analyses, job number 280-4779-2.
[2]February 2007 Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado. Rev 2.1, Final Draft for Comment, CDPHE.
[3]Per 5 CCR 1003-7 any dry sludge which exceeds 40 pCi/gm total alpha activity cannot be land applied.

Results from the sampling indicate that the residuals are exempt from any TENORM related regulations for disposal. The City has determined that they do not plan on closing any of the waste impoundments at the BWTF or the BRWTF, regardless of the new requirements for waste impoundments. Testing of the residuals for constituents of concern has been ongoing and will continue to be tested.

5.1.2 BRWTF at 63rd Street

According to the plant's designer, the BRWTF was designed in 1969 to treat 8 MGD to then-current water quality standards. The plant design provided for treatment of up to 12 MGD for short durations under conditions referred to as “overload.” Two new filters were added in 1997. In 2005 the flocculation/sedimentation clarifier was replaced with two trains of flocculation basins and DAF units, two new high service pumps were added; and the four residuals lagoons were built. In 2010, a third flocculation/DAF train was constructed, another pump was added to the Raw Water Pump Station, a carbonic acid feed system was installed, and a liquid sodium hypochlorite system was installed to replace the mixed oxidant generation system. The BRWTF currently has a firm capacity of 16 MGD to treat to the level required to meet current regulatory requirements. Some relatively minor modifications and resolution of equipment performance issues would increase firm capacity to 20 MGD.

The following evaluation discusses needed improvements of generally high to mid priority. A complete list of improvements including those of lower priority can be found in **Section 7** of this report.

5.1.2.1 Raw Water Delivery

Raw water reaches the BRWTF either by gravity diversion from the BFC or by pumping from Boulder Reservoir. The raw water intake at the BFC has historically presented an operational problem caused by accumulation of floating material and other contaminants originating from nearby farming activities during certain times of the year. A slide gate was installed to effectively block floating material from reaching the intake. The intake must be inspected and cleaned frequently to prevent plugging. Cleaning is done manually, which is a difficult operation with safety risks. Improvements to the access way and platform are required to mitigate safety risks, as the current structure is reported to be badly corroded and poorly constructed. Additionally, there is currently no power at the intake structure to support the installation of an automatic trash rack and lighting to further improve the safety and security related to this location.

The raw water intake in Boulder Reservoir was recently fitted with a fixed level intake structure. This structure allows water to be drawn from a mid level in the reservoir to avoid manganese and algae, thereby allowing the facility to treat the best quality water from the reservoir at a lower treatment cost.

The pumps used to draw water from Boulder Reservoir have the capability to deliver up to 28 MGD in increments of 4 MGD with all pumps operational. This pump station includes three 8 MGD pumps and one 4 MGD pump. With one of the larger pumping units out of service, the system provides a firm pumping capacity of 20 MGD. Three of these pumps were installed in the early 1980’s, and the fourth was installed in 2010 along with a new PLC located in the pump station and new fiber optic lines between the main plant site and the remote Raw Water Pump Station. Although it has proven to be difficult to justify from power consumption and capital cost standpoints, operations staff could benefit from the installation of a variable frequency drive on at least one of the pumps. The flow from this pump station is currently modulated using a 48-inch butterfly valve located in the yard near the DAF building which has been reported to be well worn and difficult to position.

5.1.2.2 *Raw Water Quality*

Raw water treated at the BRWTF is diverted from the headwaters of the Colorado River and conveyed to the plant via the Windy Gap and C-BT transmountain diversion facilities. At the source, the water is of very high quality but is subject to degradation during conveyance. The C-BT facilities consist of a series of pipelines, tunnels, open canals and reservoirs. While mostly remote or protected from contamination by human activities, the open reservoirs and canals offer opportunities for pathogens and chemical contaminants to enter. In particular, the Boulder feeder canal that carries water on the last segment of the system from Carter Lake to Boulder Reservoir is an open channel that is vulnerable to contamination particularly from agricultural activities. This is also true for the natural drainage channels that are tributary to Boulder Reservoir.

Boulder Reservoir receives drainage from the plains and foothills to the west, which has a different water quality from the C-BT water delivered by the canal. In addition, various minerals tend to accumulate over time in a reservoir. Of particular concern is the accumulation of manganese in the reservoir sediments. When anaerobic conditions develop at the bottom of the reservoir, manganese will be released into the water. This dissolved manganese must be oxidized early in the treatment process to ensure removal so that staining of customers' clothing and plumbing fixtures does not occur.

Although the BFC is the preferred source for the BRWTF, it does present its own challenges. The canal is vulnerable to contamination by runoff entering via forty three stormwater outfalls that drain directly into the canal. Land uses in the areas tributary to these outfalls include agricultural (crops and cattle grazing), industrial, and residential; presenting the potential for various types of contamination that could go undetected. City Water Quality staff also report that the water carried in the canal is the City's most protozoan contaminated raw water source. The canal is also prone to severe turbidity spikes associated with summer storms. Reportedly, turbidity may reach 700-800 NTU within minutes due to storms that may be located many miles from the plant site. Currently the solution is to shut down the plant until the turbidity spike passes. Another issue associated with use of water from the canal is difficult-to-treat tastes and odors attributed to algae. The installation of online monitoring of basic raw water quality parameters such as turbidity, TOC, and ORP upstream of the intake structure would aid the City in anticipating severe water quality events. When water is not flowing in the canal (typically Nov. 1 to Apr. 1) Boulder Reservoir water must be used.

One of the most significant factors affecting the operation of the BRWTF is the difference in water quality between water drawn directly from the BFC and water drawn from the Reservoir. **Figure 5-23** shows that water drawn from the reservoir is generally higher in turbidity than water taken from the canal. However, the canal is vulnerable to sharp, large turbidity spikes that can quickly overwhelm the treatment process. As shown on **Figures 5-24 and 5-25**, pH and alkalinity also differ between the reservoir and the canal. Water from the reservoir has an average pH of just over 8 while the pH of water from the canal averages over 8.2. Alkalinity varies sharply between the two sources. Water from the reservoir has alkalinity typically in the range of 50 to 90 mg/L but water from the canal ranges from 25 to 45 mg/L. Since the plant does not have the capability to adjust alkalinity the alkalinity of the finished water tends to vary over the same ranges as the raw water, resulting in operational problems and complaints from commercial users who have manufacturing processes that are sensitive to water chemistry.

5.1.2.3 *Coagulation*

As at the BWTF, coagulation at BRWTF is enhanced by chemical addition. Systems are in place for the addition of polyaluminum chloride or aluminum sulfate as the primary coagulant, and cationic polymer as a coagulant aid. Chemical feed systems are evaluated later in this section. In 2005, a flash mixer and a static mixer were added to the 42-inch raw water line in the pretreatment building, providing the City with reliable means for mixing chemicals with the raw water.

Figure 5-23: BRWTF Raw Water Turbidity

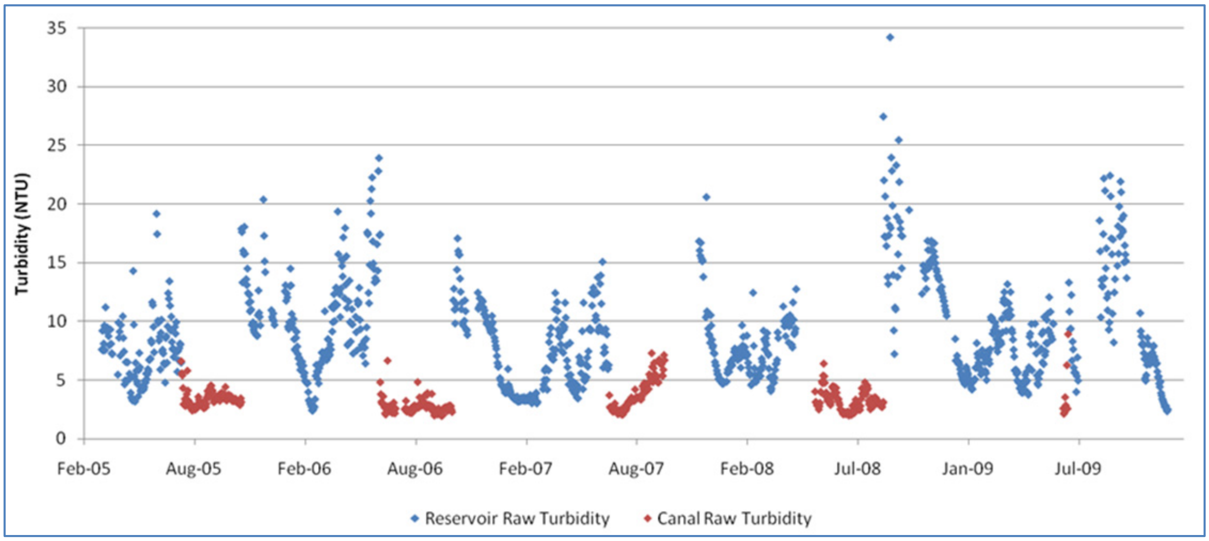


Figure 5-24: BRWTF Raw Water pH Probability – 2005-2009

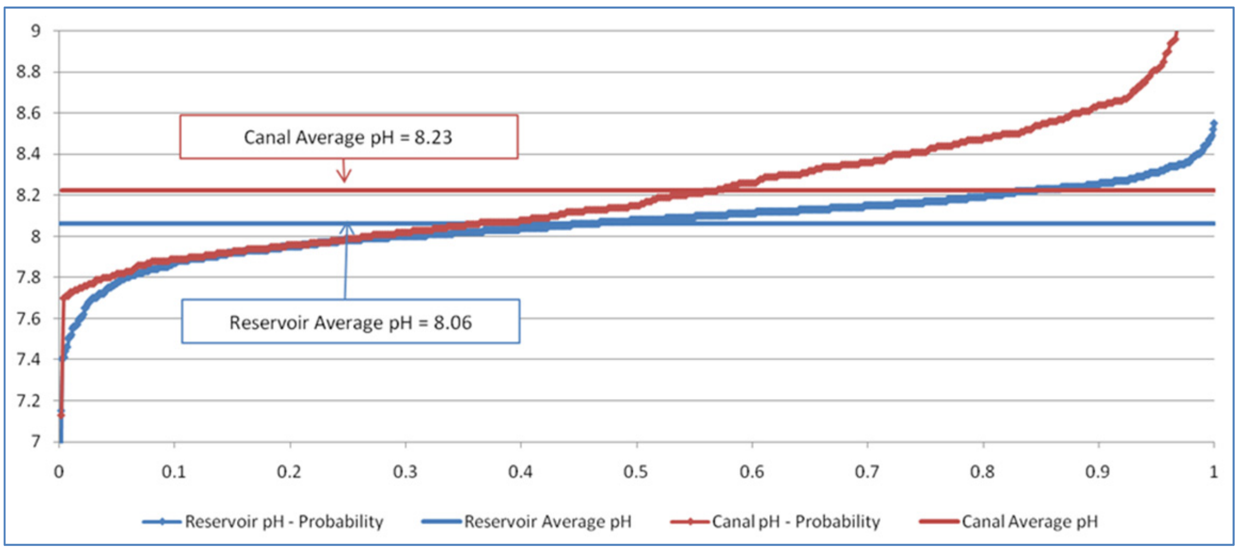
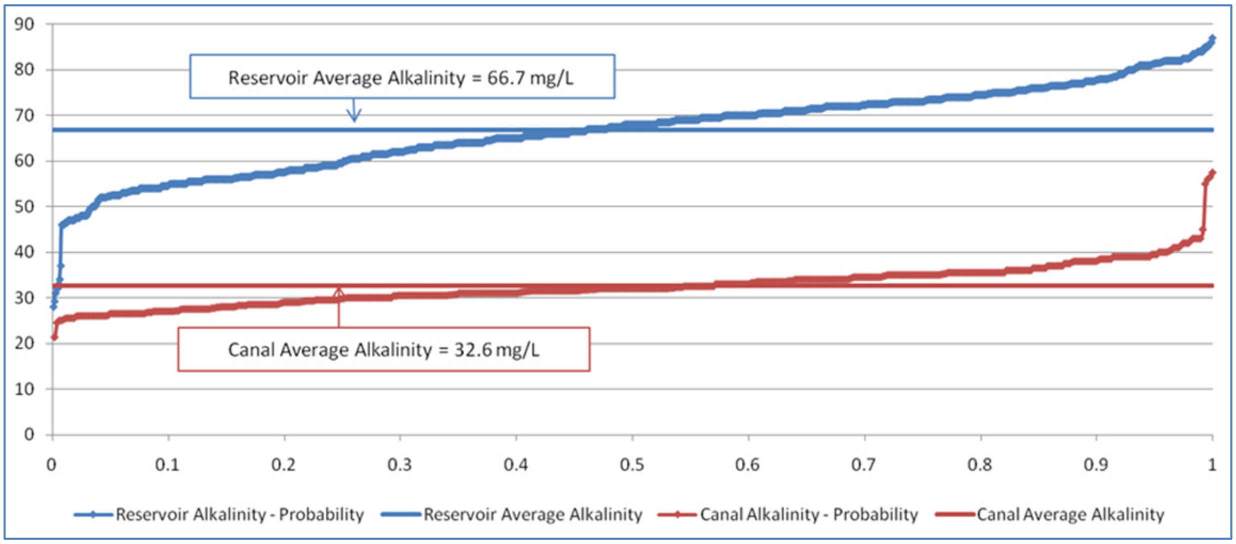


Figure 5-25: BRWTF Raw Water Alkalinity Probability – 2005-2009

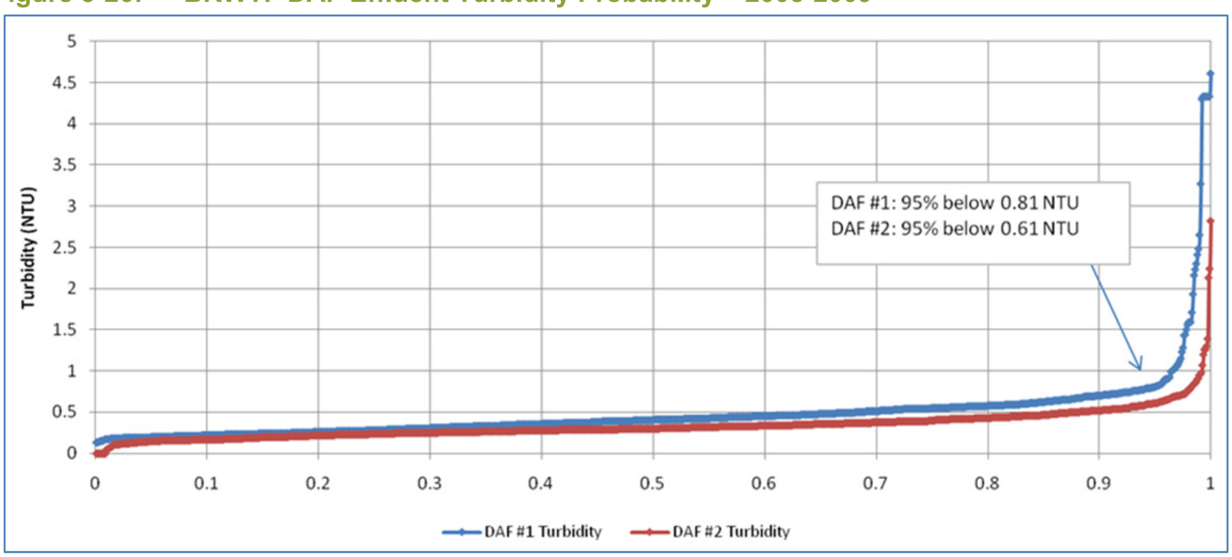


5.1.2.4 Flocculation/Clarification Basins

Preliminary treatment at the BRWTF consists of three trains of three-stage Flocculation and DAF. The capacity of this type of process is typically evaluated on the basis of surface overflow rate. Each of the three DAF basins at the BRWTF are 39 feet long and 29 feet wide providing a surface area of 1,131 ft^2 each. At the average design flow of 8 MGD per basin, the surface overflow rate is 4.9 gpm/ft^2. Each DAF basin is capable of treating up to 10 MGD but to achieve this flow, the effluent weirs need to be adjusted to prevent the float beach from becoming submerged. The weirs are currently adjusted to allow for treatment of lower flows of just under 4 MGD and up to 8 MGD. The DAF system is supported by 4 recycle pumps (one for each basin, plus one standby) and two saturator tanks. Each saturator tank has a capacity of 20 MGD and the system can be operated with either saturator running singly or both saturators in parallel.

Data collected since the DAF system was installed in 2005 is presented in **Figure 5-26**. The DAF effluent water falls below the City's internal operating standard of 1.0 NTU more than 95 percent of the time.

Figure 5-26: BRWTF DAF Effluent Turbidity Probability – 2005-2009



5.1.2.5 Filtration

The BRWTF has four mixed media rapid sand filters capped with anthracite. Each filter has an area of 930 ft^2. Based on the CDPHE design criteria of 5 gpm/ft^2 at peak flow rate, the filter capacity is rated at 20 MGD with one filter off line for backwashing. The filters typically run at flow rates much less than the peak (3.3 gpmft^2). The actual filter loading rate should be verified by future studies.

Figures 5-27 and 5-28 show finished water turbidity from 2005 to 2009. Based on these operating data, filtered water turbidity of 0.1 NTU (the City's internal operating standard for filtered water turbidity) or less are reported 95 percent of the time, with the exception of filter #4 which performs slightly worse than the others possibly due to the fact that the media in filter #4 is approximately one year older than in the other filters. Slightly more sporadic performance occurred shortly after the time that the DAF basins were placed into service, but the overall filter performance has been gradually improving over the last several years.

There is a desire to begin planning filter rehabilitation activities in the near future to ensure continued satisfactory process performance and reliability from this process as well as updating the filter control consoles to more current and automated technology.

Figure 5-27: BRWTF Filter Effluent Turbidity

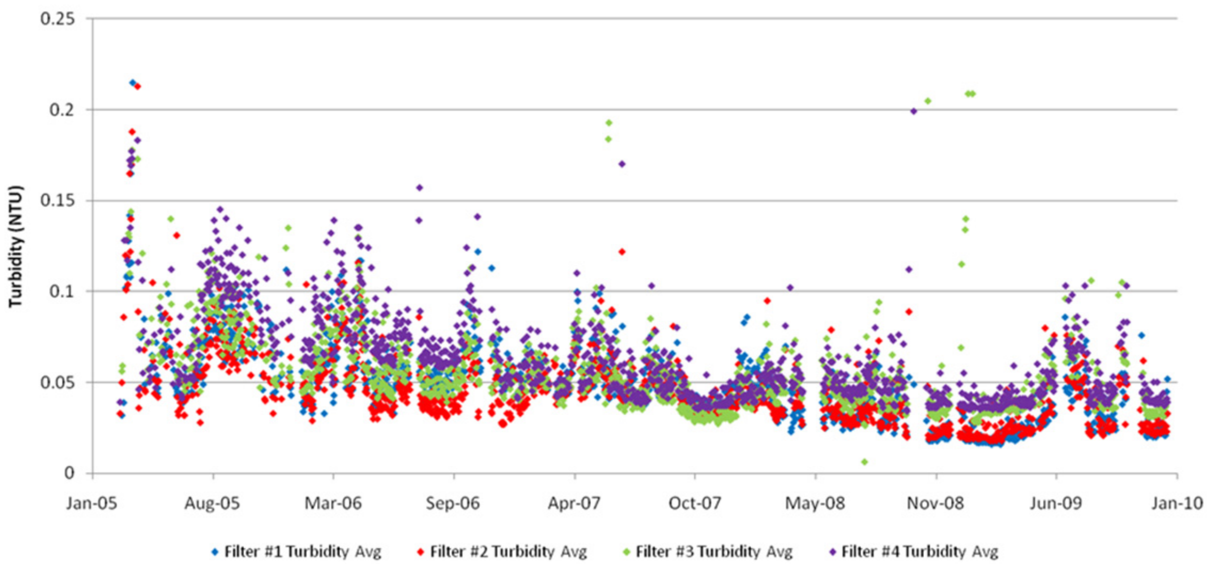
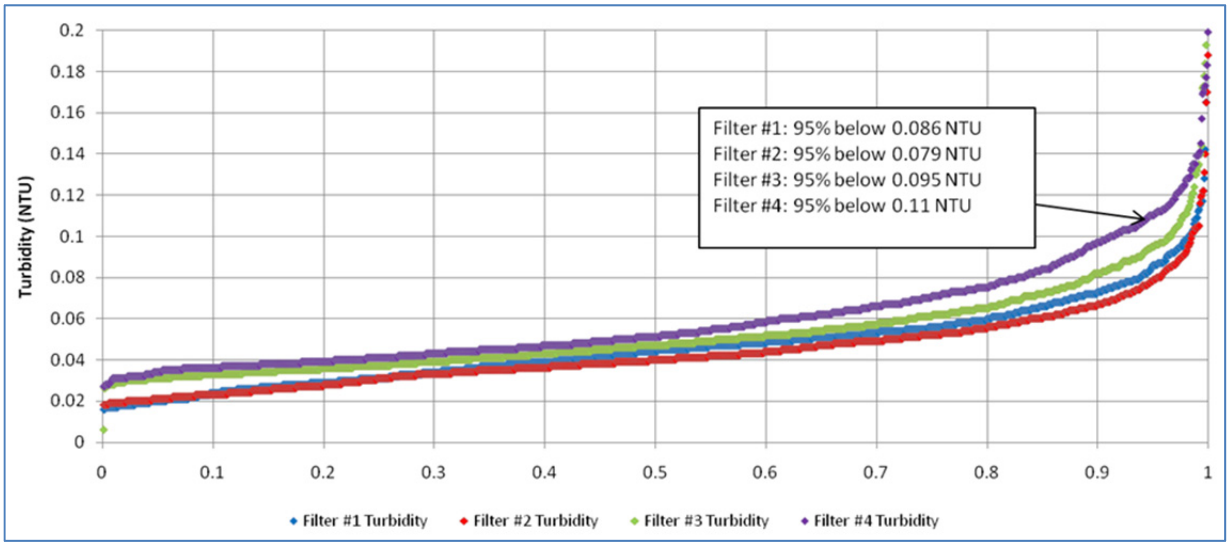


Figure 5-28: BRWTF Filter Effluent Turbidity Probability – 2005-2009



5.1.2.6 Disinfection

Until 2004, disinfection was accomplished using chlorine gas, at which time an on-site mixed oxidant generation system (MIOX) was installed. In 2010 a liquid sodium hypochlorite system with bulk storage was installed to replace the MIOX system. The new liquid sodium hypochlorite system has the capability to deliver a dose of up to 5 mg/L at a plant flow rate of 20 MGD at each of three separate feed points. The three feed points are as follows:

1. Pre-DAF
2. Post-DAF
3. Post-Filters

At a flow rate of 20 MGD, a storage volume of 417,000 gallons would be required to provide the minimum 30 minute chlorine contact time required by CDPHE. The existing treated water storage reservoir at the plant site has a storage volume of 2.34 MG. The clearwell basin located under filters 1 and 2 has a volume of about 185,000 gallons making the combined total volume 2.52 MG. Baffles were added to the clearwell in 2005. When the volume reduction factor of 0.7 for baffled tanks is applied to determine the available contact time a volume of 1,764,000 gallons is obtained. This volume would provide approximately 30 minutes of contact time at a flow of 85 MGD. Additional contact time would be achieved during passage through the plant filter effluent and treated water pump suction piping and in the transmission and distribution piping prior to the first customer connection. Thus, facilities are available to provide adequate disinfectant contact time in accordance with CDPHE requirements at a peak flow rate of 20 MGD.

A memorandum from MWH to the City of Boulder in January of 2003, titled "*Reservoir Contact Time Improvements*," discusses is the existing clearwell size and configuration which limit the ultimate BRWTF capacity to 16.9 MGD with a full (18-foot depth) clearwell and worst case raw water quality from Boulder Reservoir. Such limitations are not related to regulatory contact time compliance, but rather with respect to the City's internal goal of an additional 1.5 log *Giardia* inactivation by the disinfections process.

5.1.2.7 *Finished Water Pumping*

All of the water produced by the BRWTF must be pumped into the distribution system. Six constant speed horizontal split-case centrifugal pumps are installed on the lower level of the filter building. Each pump has a rated capacity of 4 MGD making the firm pumping capacity 20 MGD with one unit out of service. The need to pump all of the water produced results in a significantly higher unit cost per gallon for water treated at the BRWTF compared with the cost for water produced at BWTF. Plant staff estimates that the cost difference may be as much as a factor of two attributed primarily to an unfavorable power cost rate structure.

The high service pumps currently installed at BRWTF are the source of one of the more major concerns at the facility. It is also reported that the pumps do not provide the rated flow rate, although it is unclear at this time if this is related to the damage due to cavitation or not. The pumps are reported to be cavitating, and require rehabilitation more often than should be expected. It has also been noted that the high velocity of the water leaving the pumps is severely damaging the check valves such that they often stick in the open position. This pump station may also be benefited by the installation of variable frequency drives (VFDs) to improve on plant and distribution system operations.

5.1.2.8 *Chemical Systems*

Each of the chemical systems used at the BRWTF was analyzed for its capacity to supply treatment chemicals in the required dose.

Carbonic acid is used to adjust the raw water pH to optimize the flocculation process when using either alum or polyaluminum chloride. The optimization of the flocculation process aids in the ability to remove TOC. The system is sized to provide a wide range of CO_2 feed rates between 5 and 200 lb/hr of CO_2. As discussed previously, the raw water alkalinity varies greatly between the basin and the canal. This coupled with diurnal variations in pH significantly impact the amount of CO_2 that is required to adjust the pH to the desired setpoint. The 60 ton storage tank has sufficient storage for 25 days of continuous operation at 200 pounds per hour. If at some point in the future, additional capacity is required of the system, the City has a larger control valve and diffuser element on the shelf which can be installed to increase the CO_2 feed rate to 350 lb/hr.

Polyaluminum chloride (PACl) is used as a primary coagulant. PACl is stored in liquid form and fed directly to the influent raw water pipe in the DAF Building either at the flash mixer or the static mixer. Two peristaltic pumps are in place, each with a capacity of 108 gph. The required dosage varies according to the source water. 15 mg/L is typically applied to water diverted from the BFC and 25 mg/L is typically required for water drawn from Boulder Reservoir. At an average dose of 15 mg/L this system has a firm capacity to treat up to 40 MGD. Alternatively, this system could deliver up to 15 mg/L at a plant flow of 20 MGD with one metering pump out of service.

Aluminum Sulfate (Alum) is used as an alternate primary coagulant. Alum is stored in liquid form and fed directly to the influent raw water pipe in the DAF Building either at the flash mixer or the static mixer. Two peristaltic pumps are in place, each with a capacity of 108 gph. The required dosage varies according to the source water. 25 mg/L is typically applied to water diverted from the BFC and 50 mg/L is typically required for water drawn from Boulder Reservoir. At an average dose of 50 mg/L this system has a firm capacity to treat up to 20 MGD. Alternatively, this system could deliver up to 25 mg/L at a plant flow of 20 MGD with one metering pump out of service.

Cationic polymer can be added at either the DAF splitter box as a flocculant aid or to the DAF effluent channel as a filter aid. Polymer is delivered in drums and stored in a 100 gallon tank; the polymer is then metered to a 30 gallon day tank and mixed with water to the desired solution strength. This system has one 1 progressive cavity feed pump providing a capacity to feed up to 186 gph of neat polymer solution to a plant flow of 20 MGD. Typical dosage is currently 0.1 to 0.3 mg/L.

Sodium hydroxide (caustic soda, NaOH) is used to adjust finished water pH for corrosion control. NaOH is stored and fed as a liquid at a concentration of 25 percent. Two metering pumps each provide a capacity of 42 gph, which is sufficient to deliver an average dose of 15 mg/L to a plant flow of 21 MGD with one pump out of service or 42 MGD with both pumps operational.

Fluoride is added using liquid hydrofluosilicic acid. One metering pump with a capacity of 12.75 gph provides the capacity to add up to 15 mg/L of hydrofluosilicic acid at a plant flow rate of 20 MGD. Average required doses range from 0.7 to 0.8 mg/L.

This analysis indicates that the existing chemical systems have enough capacity to supply the required quantities of treatment chemicals at a peak day plant flow of 20 MGD.

The sodium hypochlorite and carbonic acid feed systems have both been installed in the last year and are up to date with the industry's latest components and control elements. It has been reported by plant staff that all other chemical feed systems at the BRWTF are aging and are currently manually controlled (except the sodium hydroxide system which is automated). Recommended updates to these systems would involve at a minimum the replacement of pumps and installation of instrumentation to allow for more automated control.

5.1.2.9 Waste Impoundments

MWH performed a preliminary identification and evaluation of the existing waste impoundments at the BRWTF. The evaluation of the impoundments at these facilities is based on discussions with laboratory and plant operations staff and summarized in the following sections.

The waste impoundments at the BRWTF include a washwater recovery basin, primary and secondary lagoons, and a residuals drying pad. Waste filter backwash water is sent to the washwater recovery basin and from there it is pumped back to the influent flow stream to the facility. The primary lagoons receive float from the dissolved air floatation (DAF) process. Decant from the lagoons is returned to the influent flow stream. The DAF float is dewatered and partially dried in the primary lagoons. Further drying and storage of the residuals from the lagoons is provided for in the residuals drying pad. The secondary lagoons serve as redundant backup for the primary lagoons. **Figure 5-29** presents a schematic of the residual flow streams for the BRWTF.

The washwater recovery basin is a tank of reinforced concrete construction. Reinforced concrete walls and asphaltic concrete floors comprise the construction of the primary lagoons and the residuals drying pad. The secondary lagoons are constructed of earthen embankments and bottoms. **Figure 5-30** presents the existing waste impoundments at the BRWTF on an aerial photograph of the facility.

Figure 5-29: BRWTF Residual Flow Streams

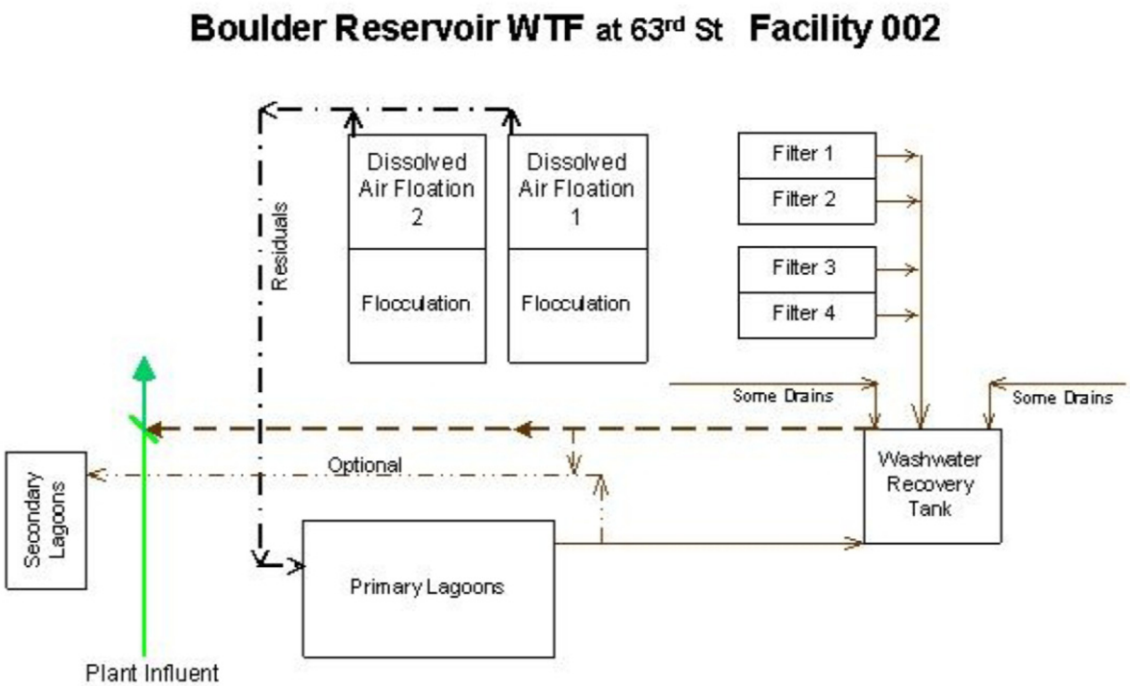


Figure 5-30: Existing Waste Impoundments at the Boulder Reservoir Water Treatment Facility

Table 5-29: Analytical Results from BRWTP Residuals

Analyte	Result[1]	Units
Aluminum	**23,000**	mg/Kg
Arsenic	**7.5**	mg/Kg
Cadmium	**ND**	mg/Kg
Chromium	**20**	mg/Kg
Copper	**31**	mg/Kg
Iron	**24,000**	mg/Kg
Lead	**19**	mg/Kg
Molybdenum	**ND**	mg/Kg
Nickel	**22**	mg/Kg
Potassium	**2,700**	mg/Kg
Selenium	**ND**	mg/Kg
Zinc	**89**	mg/Kg
Mercury	**39**	µg/Kg
Ammonia	**ND**	mg/Kg
Nitrogen, Kjeldahl	**970**	mg/Kg
Nitrate as N-Soluble	**ND**	mg/Kg
Total Phosphorus	**ND**	**mg/Kg**
Orthophosphate as P-Soluble	**ND**	mg/Kg
Total Organic Carbon	**15**	**g/Kg**
Percent Moisture	**16**	%
Total Solids	**88**	**%**
Soluble		
pH adj. to 25 deg C-Soluble	**8.35**	SU
Specific Conductance – Soluble	**170**	umhos/cm

[1]Results from: Analytical Report by TestAmerica 7/20/2010 Water Treatment Residuals Analyses, job number 280-4779-1.

Table 5-30: Radiochemical Analysis Results from BWTP Residuals[1]

Analyte	Result – Sample 1[1]	Result – Sample 2[1]	Units	Regulatory Limits for Disposal to meet Exempt Status[2,3]
^{226}Ra	1.76	pCi/g		**^{226}Ra**
^{228}Ra	1.10	pCi/g		**^{228}Ra**
$^{226/228}Ra$	**2.86**	pCi/g	<3	**$^{226/228}Ra$**
^{234}U	2.03	pCi/g		**^{234}U**
^{235}U	0.0452	pCi/g		**^{235}U**
^{238}U	1.38	pCi/g		**^{238}U**
^{NAT}U	**3.4552**	pCi/g	<30	**^{NAT}U**
^{228}Th	0.945	pCi/g		**^{228}Th**
^{230}Th	0.402	pCi/g		**^{230}Th**
^{232}Th	0.686	pCi/g		**^{232}Th**
^{NAT}Th	**2.033**	pCi/g	<3	**^{NAT}Th**
Alpha	8.15	pCi/g	<40	**Alpha**

[1]Results from: Analytical Report by TestAmerica 8/11/2010 Water Treatment Residuals Analyses, job number 280-4779-2.
[2]February 2007 Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado. Rev 2.1, Final Draft for Comment, CDPHE.
[3]Per 5 CCR 1003-7 any dry sludge which exceeds 40 pCi/gm total alpha activity cannot be land applied.

Results from the sampling indicate that the residuals are exempt from any TENORM related regulations for disposal. The City has determined that they do not plan on closing any of the waste impoundments at the BWTF or the BRWTF, regardless of the new requirements for waste impoundments. Testing of the residuals for constituents of concern has been ongoing and will continue to be tested

5.1.2.10 Process Instrumentation and Control

Instrumentation and control at the BRWTF is similar to the BWTF. As at BWTF, process control is manual except for a handful of chemical feed systems as previously noted which are all controlled automatically (primarily flow paced), from PLCs. The SCADA system provides for remote monitoring of chemical systems and records plant operating data in great detail. The plant's online process analyzer instruments and data collection through SCADA have improved such that several process parameters reported to the State are taken from the plant SCADA system rather than from laboratory data. The City has indicated that instrumentation equipment is currently up to date and no further upgrades are desired at this time.

Plant operating staff indicated the need for automation of chemical systems. The desire to automate plant operation to permit unmanned operation for at least a portion of every day was discussed as a potentially effective way to eliminate staffing problems due to seasonal variations in treated water demand.

The recent AWWA Peer Review study recommended plant automation upgrades to allow for extended periods of unmanned operations. A cost estimate compiled in 2009 estimated the cost of such upgrades at $4.3 Million.

The City's in-house programming and integration capabilities allow for continuous modifications to the plant control systems, and periodic automation features to be added when instrumentation hardware is available without the need to outsource the work.

Plant influent flow is measured by a new magnetic flow meter installed in 2010 in the plant main influent line located in a vault in the yard.

A streaming current monitor is installed in the piping ahead of the flocculation/clarification basins to provide data on performance of the coagulation process and is reported by staff to work well.

The DAF system, placed into service in 2005, is PLC controlled while it is running. The system must be started manually, and is capable of automatic shutdown, but the influent flow must be stopped manually.

Settled water turbidity is measured on the effluent from each individual DAF train.

Individual turbidity meters and particle counters are installed on each filter effluent. These are reported to give acceptable results but the operating staff indicated that given the increasing importance being placed on finished water turbidity, supplementing the existing meters with laser turbidity meters and particle counters could provide better resolution at very low turbidities and allow better assessment of filter performance, however the City has indicated that they are not needed at this point in time.

Flow through individual filters is measured by flow tubes in the filter effluent piping. The flow to each filter is controlled by electric-motor-actuated butterfly valves. Filter backwashing is currently done manually.

A venturi type meter is used to measure plant effluent discharged to the distribution system. Plant staff has indicated that this meter has not functioned well at times and requires periodic maintenance to maintain any level of accuracy; however, in the 2010 Mid-Term Improvements staff opted to replace the influent flow meter as they felt it was of greater importance.

5.1.2.11 *Plant Hydraulics*

The hydraulic capacity of the process piping and channels was evaluated from the hydraulic jump at the head of the plant to the treated water storage reservoir as part of the 2000 master plan and as part of the project upgrades in 2004. This analysis found that the existing facilities can pass a peak flow of 20 MGD without hydraulic restriction. The concerns with regard to the hydraulics at the hydraulic jump have since been eliminated when the hydraulic jump was replaced with piping in 2005. The DAF splitter box and all piping and components upstream of that box were designed for 20 MGD capacity.

5.1.2.12 *BRWTF Treatment Capacity*

The results of the evaluation of major unit processes and systems of the BRWTF are summarized in **Table 5-31**. This evaluation indicates that the BRWTF currently has a firm capacity of 16 MGD to the level required to meet current regulatory requirements. Some relatively minor modifications to the DAF scraper mechanisms and resolution of finished water pump performance issues would increase firm capacity to 20 MGD. At 20 MGD, capacity is limited by multiple processes requiring more substantial modifications.

Table 5-31: BRWTF Capacity Evaluation

Process	Criteria	Rated Capacity	Potential Capacity	Comments
Raw Water Conveyance	Pipe Hydraulic Capacity	30 MGD	30 MGD	Firm capacity with 28 MGD installed. Potential capacity assumes one more 8 MGD pump can be added.
	Raw Water Pumping	20 MGD	28 MGD	
Coagulation	Hydraulic Capacity	20 MGD	20 MGD	
Flocculation/ DAF	Surface Loading Rate = 6.1 gpm/ft^2	16 MGD	20 MGD	Rated capacity is based on current installed elevation of sludge removal scrapers. Scrapers can be adjusted upward to provide the potential capacity. Capacity rated performance includes clarified water turbidity below 1.0 NTU more than 95 percent of the time.
Filtration	Hydraulic Loading Rate = 5 gpm/ft^2	20 MGD	20 MGD	Allows for one filter off line for backwashing.
Disinfection	Sodium Hypochlorite at 5 mg/L	20 MGD 85 MGD 16.9 MGD	20 MGD 85 MGD 16.9 MGD	To meet CDPHE requirements.
	Chlorine Contact Time = 30 minutes minimum			To meet City's Goals
Finished Water Conveyance	Finished Water Pumping	17 MGD	20 MGD	Firm capacity (5 of 6 pumps running) with 24 MGD total installed capacity. All pumps are constant speed. Current pump performance issues are reducing the rated capacity.

5.1.2.13 *Miscellaneous*

As with many facilities, the BRWTF is susceptible to periodic power outages. The plant currently has only a single power feed from the grid, and one emergency generator which lack the capacity to run the plant in even a limited fashion. Under the condition that the BWTF is unable to produce water, and power is lost at the BRWTF, the City is at risk of being unable to maintain water supply to the City. Two alternatives exist which can be evaluated to determine the most appropriate solution; either a second power feed can be routed to the plant from a different utility substation or additional engine driven generators can be installed to produce the required power.

The BRWTF currently has a firm capacity to treat 20 MGD, but according to plant staff, the facility has only been run continuously up to 12 MGD, and has only momentarily been run at 16 MGD. It has been recently observed that the plant influent lines collect large amounts of sedimentation due to low velocities when running the plant at flows equal to or less than 8 MGD, such sedimentation is scoured from the pipes at 20 MGD flows making the water impossible to treat until the sediment passes.

Also concerning to staff is the ability to pump 20 MGD into the distribution system. It has been reported that the last time 16 MGD was pumped into the system, several distribution mains were ruptured. It has been reported that improvements to the distribution system have been made since this attempt, but further attempts to test the capacity of the distribution system have not occurred.

Related to the previous concern is the ability to pump water from Zone 2 to Zone 3. Equipment is in place to perform this operation, but it is reported that this system has not been fully or regularly tested to determine the actual capabilities of this system.

Regular testing of the facility’s ability to produce and distribute 20 MGD would benefit the City in that staff would become more familiar with the procedures required to perform such an operation and when faced with an unexpected failure at BWTF and the need to bring the BRWTF to full capacity they would be able to do so in an organized and expedient manner.

Miscellaneous security improvements have been identified and recommended by the Vulnerability Assessment in 2008.

5.1.2.14 *Chemical and Energy Efficiency Patterns*

Chemical usage varies due to seasonal and source water quality changes. Discussions with staff indicate that the City makes significant efforts towards chemical optimization. Continued monitoring, optimization, and experimentation efforts will likely lead to further improvements with regard to chemical efficiency.

Chemical efficiency can also be improved through the automation of various chemical feed systems found throughout the plant, with the addition of PLC controlled flow pacing and trim capability. Utilizing feedback from process controls instruments, continuous adjustments can be made automatically through the PLC logic in order to consistently provide the proper chemical doses at all times.

Improvements are needed to improve the flash mixing at the filter effluent post flume in order to further optimize the effect of the finished water chemical addition.

Energy efficiency has been gradually improved over time with the use of higher efficiency pumps, premium efficiency motors, etc.; as the technology and consciousness of efficient designs progress. Perhaps the single largest potential for energy savings exists with improvements to the High Service Pump Station. A study should be conducted to evaluate the performance of the existing high service pumps with regard to the hydraulic efficiency of the pumps and cavitation issues that have been identified. This study should also include an evaluation of the potential energy savings related to placing these pumps on variable frequency drives.

5.1.2.15 O&M Procedures and Maintenance Programs

Based upon site visits and discussions with O&M staff, there is some room for improvement with regard to the completion of routine maintenance operations. Budgetary and manpower limitations generally limit maintenance activities to those items with mid to high priority, leaving items with low to mid priority unattended to. Fortunately, many systems at the BRWTF are five years old and less. It should be expected that as the equipment and facilities age, maintenance needs will increase, and there could be a need for additional budget and manpower to properly maintain the facility and avoid premature replacement of equipment.

The City is in the progress of transitioning toward the use of computerized maintenance management software. This system will allow the City to more easily schedule and plan for routine maintenance activities. It is reported that a large commitment of time is required to enter all the necessary data for the system to become fully functional, and it is likely to be several years before the system is fully functional.

5.1.2.16 Needs for Continued Water Quality Compliance

At this time there appears to be no shortcomings related to water quality compliance at BRWTF.

5.1.2.17 Future Water Quality Issues

As discussed previously in **Section 4.5**, a study conducted by Black and Veatch in 2003 concluded that a second phase study needs to be conducted to evaluate two viable alternatives for mitigating the source water challenges.

As further discussed in **Section 5.1.3**, if future regulatory limits with regard to DBP's are significantly lowered, the City may not be able to meet those limits. TOC removal should be enhanced by the recently installed carbonic acid feed system, but since there is limited data available since this system was installed, it is unclear at this time if further systems such as preoxidation with chlorine dioxide will be required to meet more stringent DBP limits.

In the late summer of 2010, the City noted a dramatic increase in bluegreen algae (Anabaena planctonica, Aphanizomneon gracile, Aphanizomneom flos-aquae, and Lyngbya limnetica) from the Boulder Reservoir source. The bluegreens in the August sample comprised 10% of the total phytoplankton biovolume, up from 0.6% in July. Bluegreens are notorious for producing earthy, musty, and dirty tastes in drinking water.

5.1.3 Regulatory Compliance

Section 3 presented a detailed discussion of the current and pending regulations that establish the water quality standards that water supplied by the City of Boulder must meet. The City is currently in full compliance with all existing regulations. Available monitoring data indicate that continued compliance with regulatory limits for inorganic chemicals (IOCs), synthetic organic chemicals (SOCs), volatile organic chemicals (VOCs), and radionuclides should not require either facility improvements or operational changes. The following sections present the results of evaluation of the performance of the City's existing facilities in meeting specific regulatory requirements in the future. This evaluation is based on operating data from 2004-2009.

5.1.3.1 Microbiological Contaminants

Boulder's raw water supply originates entirely from surface water. As such, the system is regulated under the Surface Water Treatment Rule of the Safe Drinking Water Act. This regulation requires that the City's water treatment system achieve a minimum 99.9 percent (3-log) combined removal/inactivation of *Giardia* and a 99.99 percent (4-log) removal/inactivation of viruses. The IESWTR amends the existing SWTR Rule to strengthen microbial protection, including provisions specifically to address *Cryptosporidium*, and to address risk trade-offs with disinfection byproducts. The IESWTR went into effect in December 2001. Under the IESWTR the City has to achieve a minimum 99.0 percent (2-log) removal of Cr*yptosporidium*, while continuing to meet existing SWTR requirements for *Giardia* and viruses.

Filtered water turbidity is the treatment performance parameter used to measure compliance with both the SWTR and IESWTR. This parameter provides a direct, easily measured indicator of physical removal of pathogens by sedimentation and filtration. At the time the SWTR was promulgated, monitoring directly for human pathogens was determined by USEPA to be beyond the capability of many public water suppliers. Therefore, turbidity was selected as the best surrogate parameter to measure the removal of potential microbiological contaminants. The SWTR turbidity standard requires that at least 95 percent of the composite filtered water have turbidity below 0.3 NTU every month based on measurements made every four hours and that turbidity never exceed 1.0 NTU. As long as these turbidity standards are met, conventional treatment as practiced at the City's treatment plants is assumed to remove 99.7 percent (2.5 logs) of *Giardia* and 99.0 percent (2.0-log) of viruses. The remaining fraction of the required total removal/inactivation for *Giardia* and viruses (0.5-log and 2.0-log, respectively), must be achieved through disinfection. The ISWTR lowered the turbidity limits to 0.3 NTU monthly average and the not to exceed maximum to 1.0 NTU to provide a 99.0 percent (2-log) removal of *Cryptosporidium*.

The City of Boulder has developed a set of interim internal operating standards to ensure compliance with regulations and optimize removal of pathogens. The City's current target values for settled and filtered water turbidity are 1.0 NTU and 0.1 NTU, respectively, significantly more stringent than the regulatory requirements. Comparison of measured turbidities with these goals provides a mechanism for initiating corrective actions well before the regulatory turbidity standard is exceeded. The establishment of these more stringent goals also has aided operating personnel in the optimization of process performance. The settled water turbidity goal is used to optimize the flocculation and sedimentation processes prior to filtration.

The daily average finished water turbidity values from 2004 to 2009 indicate that both the BWTF and BRWTF consistently met the SWTR turbidity standards currently in effect, at current water production levels and with current operating practices. Finished water turbidity levels are also consistently below the 0.3 NTU monthly average and 1.0 NTU maximum turbidity levels required under the IESWTR. **Figures 5-31 through 5-38** depict the turbidity levels reported at each of the City's water treatment facilities from 2004 to 2009. These data substantiate that the water produced by the City's treatment facilities consistently meets both current and upcoming regulatory limits.

Figure 5-31: BWTF Settled Water Turbidity – 2004-2009

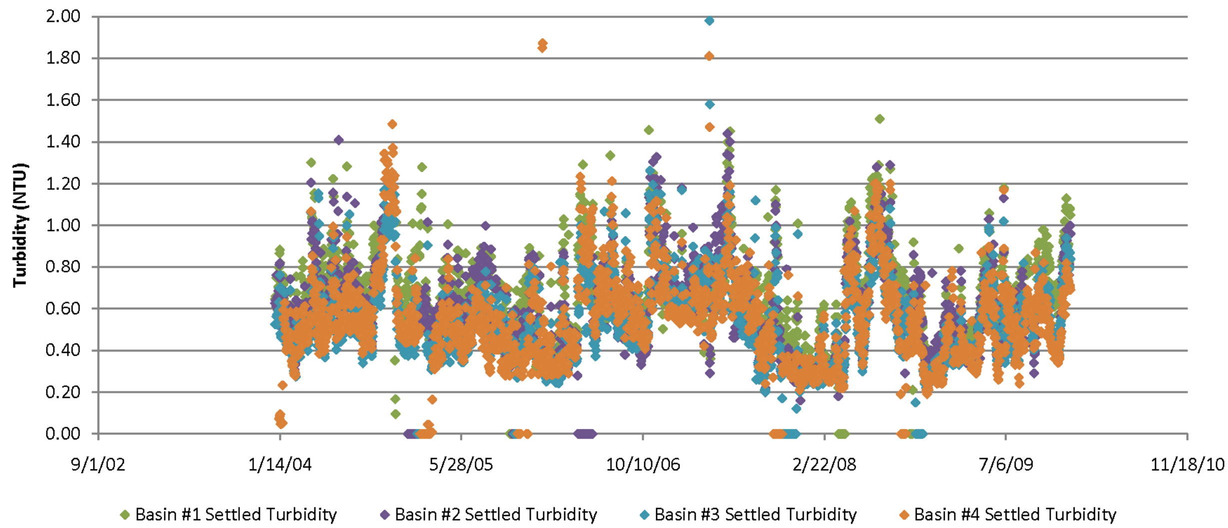


Figure 5-32: BWTF Settled Water Turbidity Probability Plot – 2005-2009

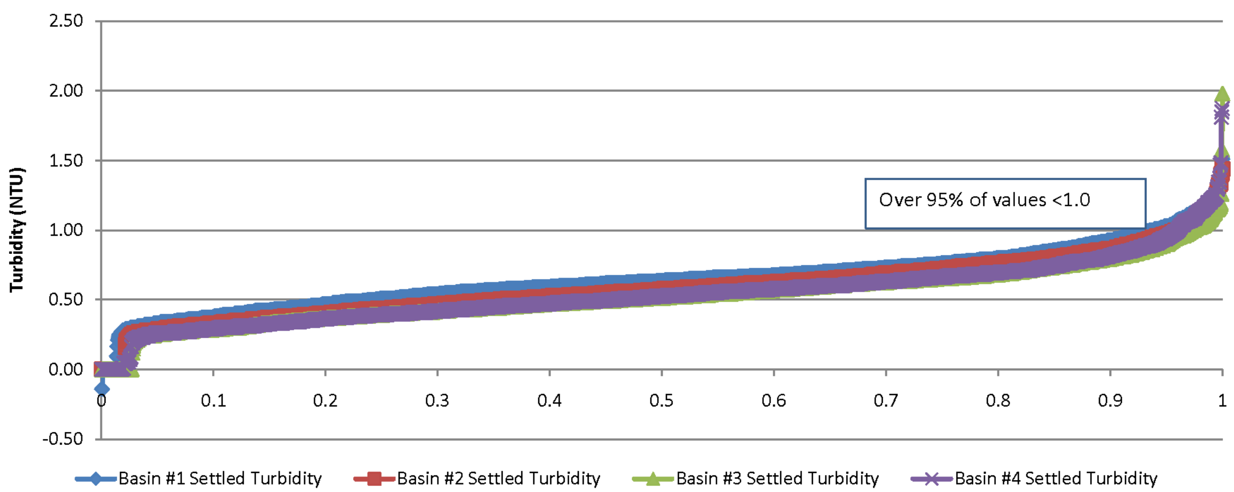


Figure 5-33: BWTF Filtered Water Turbidity – 2005-2009

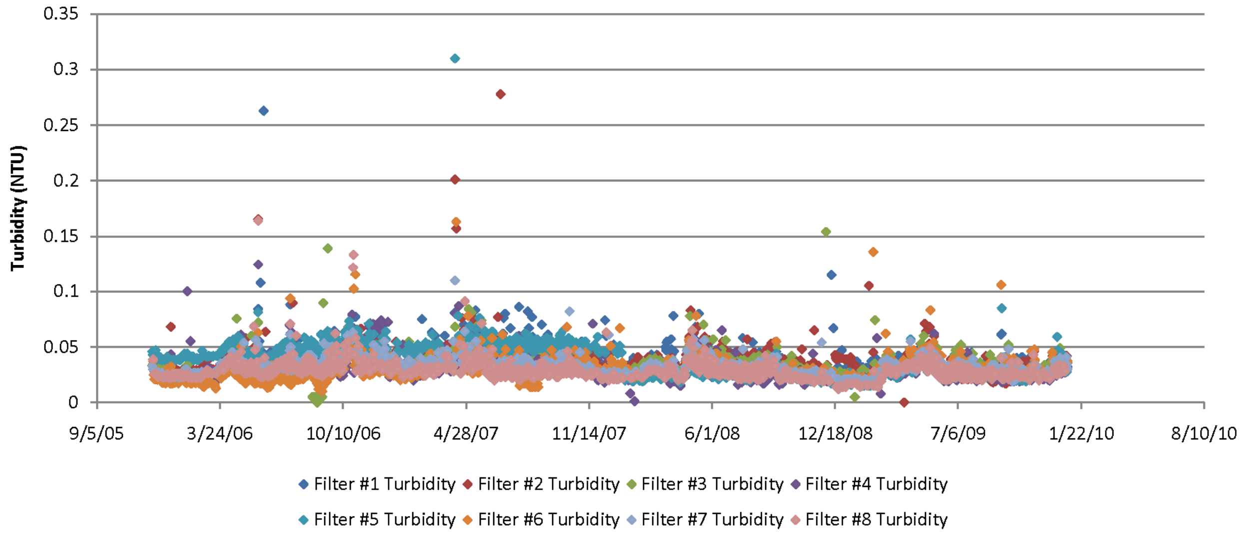


Figure 5-34: BWTF Filtered Water Turbidity Probability Plot – 2005-2009

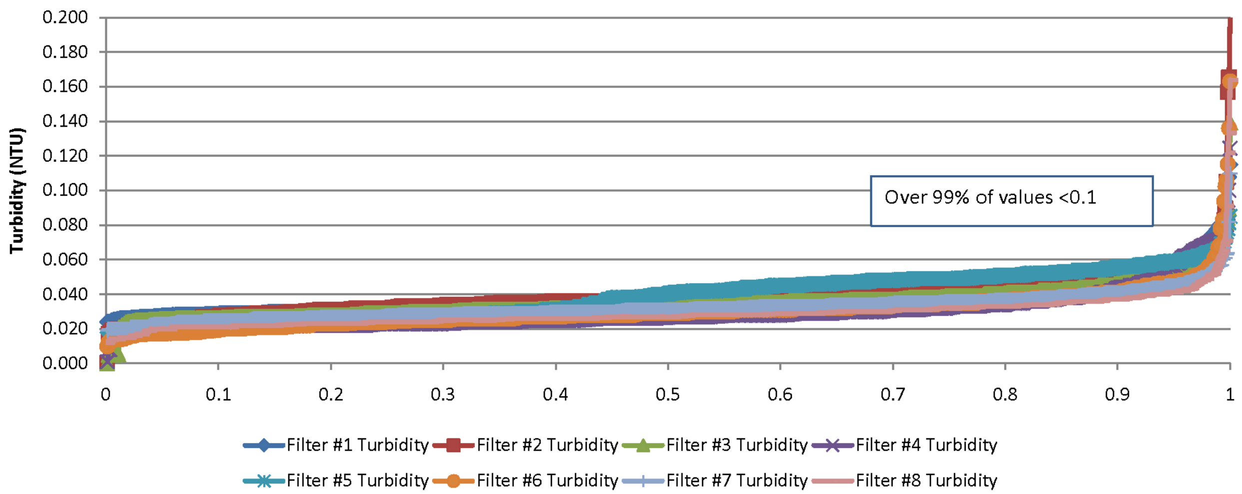


Figure 5-35: BRWTF Settled Water Turbidity – 2005-2009

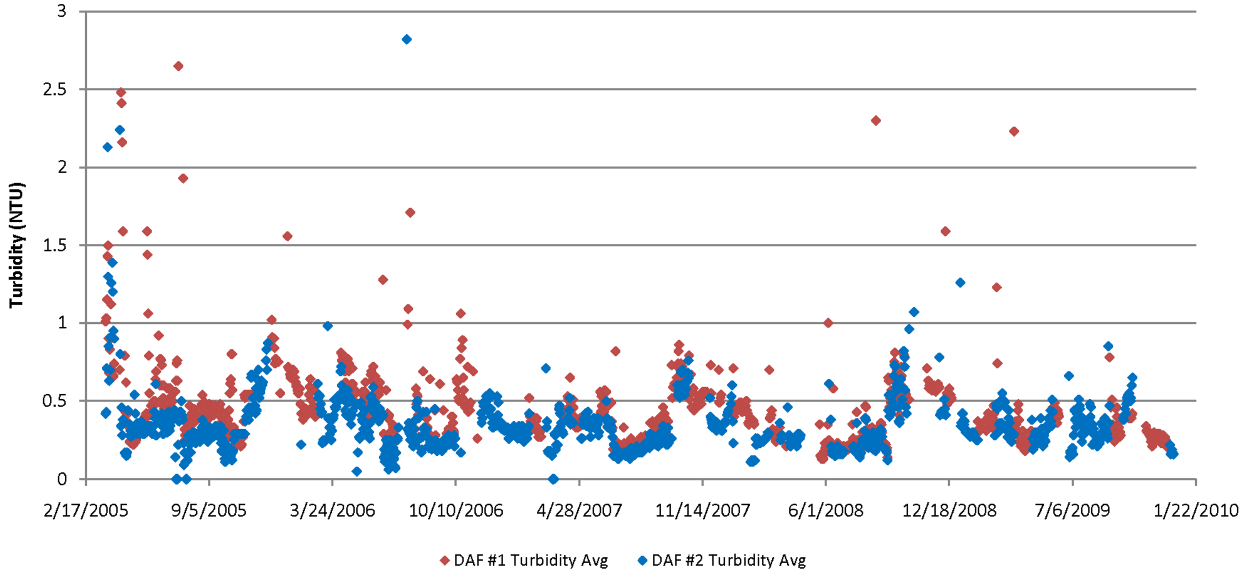


Figure 5-36: BRWTF Settled Water Turbidity Probability Plot – 2005-2009

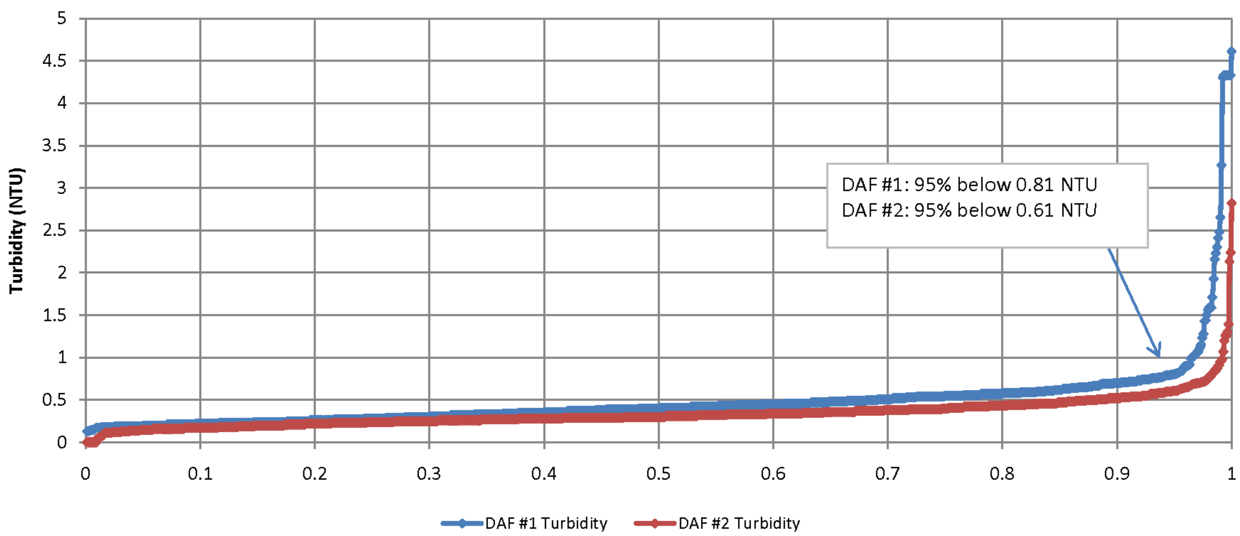


Figure 5-37: BRWTF Filter Turbidity – 2004-2009

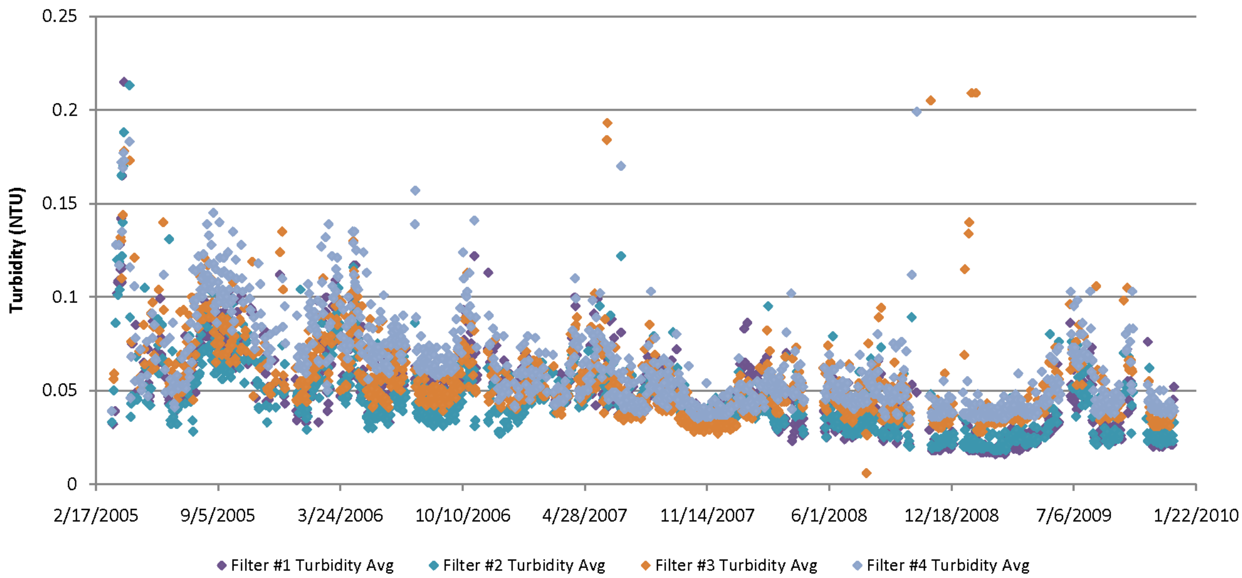
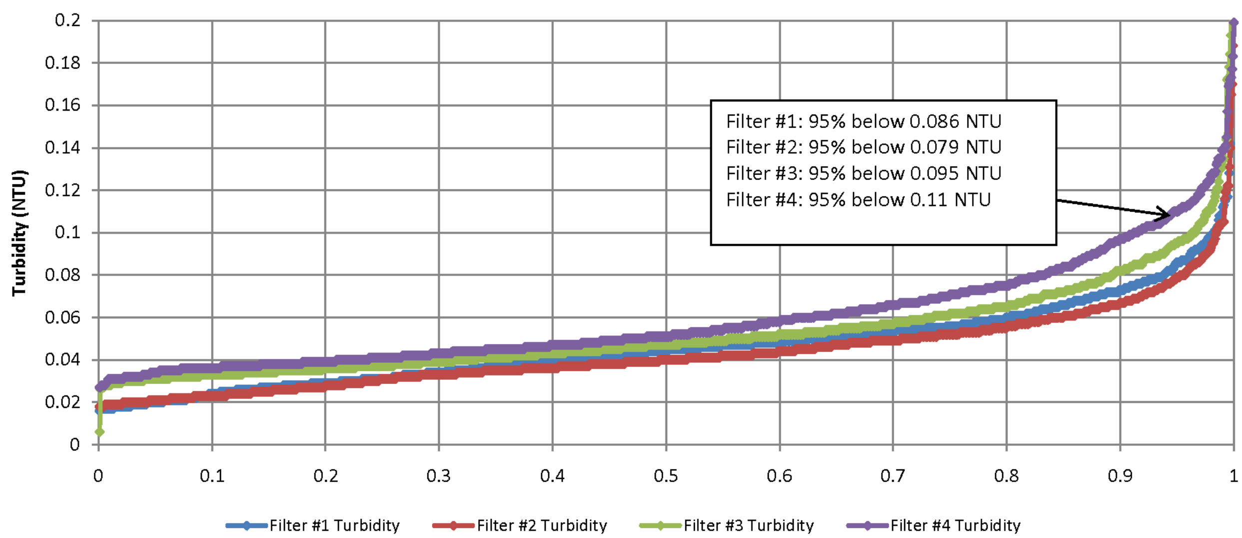


Figure 5-38: Boulder Reservoir WTF Filter Turbidity Probability Plot – 2005-2009



5.1.3.2 Disinfection

The SWTR contains three disinfection performance criteria:

- Sufficient disinfection must be practiced prior to the first customer of the public water supplier to fulfill the required 3.0-log (99.9%) and 4.0-log (99.98%) removal/inactivation requirement for *Giardia* and viruses, respectively.
- At all times, at least 0.2 mg/L of disinfectant residual must be present in the water leaving the water treatment plant. However, the chlorine residual must not exceed 4.0 mg/L.
- A disinfectant residual must be present in at least 95 percent of samples collected in the distribution system at the same sites and frequency as the total coliform monitoring program. In

cases where no residual disinfectant is detected, samples with heterotrophic bacteria counts less than 500 per milliliter (ml) may be considered as having a disinfectant residual present.

Based on monitoring data from 2004 to 2009, the City is consistently in compliance with the disinfection requirements of the SWTR. Chlorine is used as the disinfectant and a residual in excess of 0.2 mg/L of free available chlorine has been present at all times in the water leaving both treatment plants. **Figures 5-39** and **5-40** show that the chlorine residual in the finished water from the BWTF averages 1.2 mg/L and from the BRWTF typically ranges averages 1.15 mg/L. On-line continuous chlorine analyzers meet the monitoring requirements of the SWTR. Although City staff indicated some concern regarding compliance with increasingly stringent water quality criteria within the distribution system, based on the available data, detectable disinfection residuals are consistently found, and the heterotrophic bacteria levels are below 500 per ml with few exceptions.

Figure 5-39: BWTF Effluent Chlorine Residuals – 2004-2009

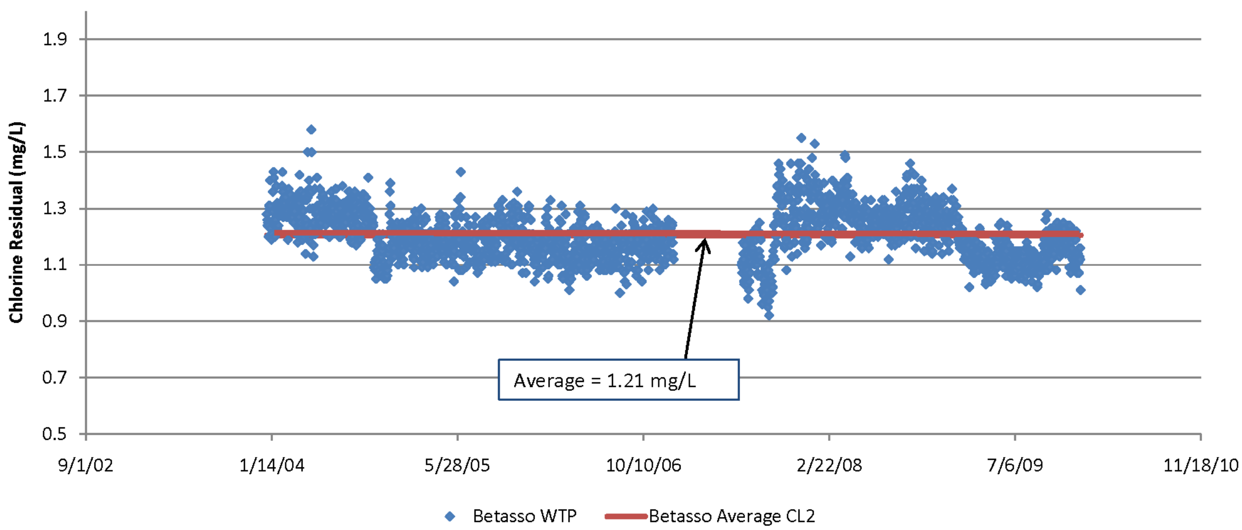
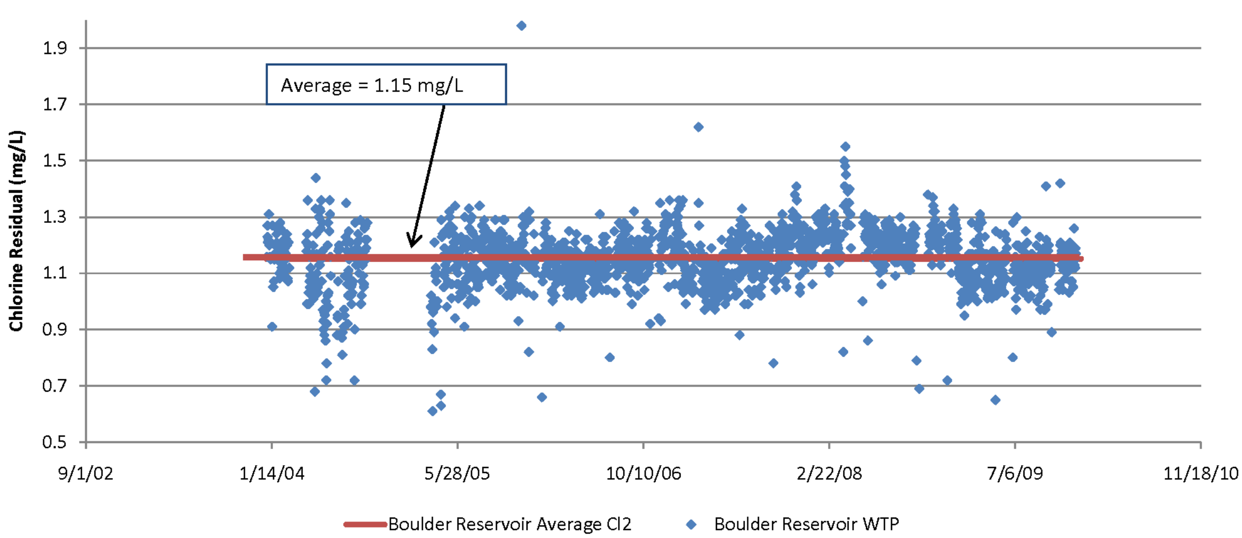


Figure 5-40: BRWTF Effluent Chlorine Residuals – 2004-2009



To meet the 0.5-log and 2.0-log inactivation requirements for *Giardia* and viruses, the USEPA requires that minimum CT (concentration × time) requirements be met. The contact time required to achieve the required inactivations vary depending on the temperature, pH and degree of inactivation required. CDPHE administers this requirement by stipulating that all water providers with surface water supplies that use conventional treatment processes must provide at least 30 minutes of actual contact time following filtration. The available contact time following filtration is calculated using peak design flow and the total volume of treated water storage prior to the first customer, including tanks and pipelines. Tank volume is adjusted by a factor that relates storage tank hydraulic configuration to theoretical contact time. This factor ranges from 0.1 for unbaffled storage tanks to 0.7 for tanks with very good baffling. A factor of 1.0 is applied to the volume in a pipeline. As discussed previously, both treatment plants have adequate treated water storage volume to provide the minimum 30 minute contact time at their design peak flow rates. Estimating the actual CT required using USEPA guidelines indicates that under worst case temperature (0.5°C) and pH (8.0) conditions the contact time would be 51 minutes assuming a chlorine concentration of 1.0 mg/L. As the water temperature rises and the pH goes down, the CT value would reduce such that at water temperatures of 5°C and pH at 7.8 the CT would be about 34 minutes and at a temperature of 10°C the CT would be about 25 minutes. Again, both treatment plants have more than adequate storage tank and piping volume to exceed CDPHE disinfection contact time requirements at peak design flow rates. The treated water storage reservoirs at the BWTF have sufficient volume after derating to provide over 55 minutes of contact time at a flow rate of 50 MGD, sufficient to meet the worst case conditions. Some additional time would be provided in the plant piping. No credit is taken for time in the distribution piping because the first customer tap is within a short distance of the plant. Treated water storage reservoirs at BRWTF after derating have sufficient volume to provide over 120 minutes of contact time at a flow rate of 20 MGD, sufficient to meet the worst case conditions.

5.1.3.3 DBPs

In the early 1970s, it was determined that the disinfection practices that had for many years provided protection against waterborne diseases resulting in dramatic improvements in public health can also impart chemical byproducts which are suspected of adverse chronic health consequences for people subjected to long-term exposures at low concentrations. Since then, the control of DBPs has been the subject of intense scrutiny by the regulatory, drinking water, and public health communities. In 1979, USEPA established a drinking water standard for total trihalomethanes; a group of four byproducts formed with free chlorine present. Still in effect, this standard requires a running annual average TTHM concentrations below 0.1 mg/L, based on quarterly samples collected at multiple locations in the distribution system. In December, 2001 under the Stage 1 D/DBPR the TTHM limit was lowered to 0.080 mg/L and the maximum contaminant limit for the HAA_5 was lowered to 0.060 mg/L. In the late 1990's the Information Collection Rule required large public water systems serving at least 100,000 people to monitor and collect data on microbial contaminants, disinfectants and DBPs for 18 months. The information collected from the study (which the City of Boulder participated in) resulted in the Stage 2 D/DBPR. This rule did not change the respective MCLs for TTHM and HAA_5; but as of April 2012 the method of determining compliance will be based on a locational running annual average (LRAA) of the previous four quarters of samples at each approved distribution system compliance location, rather than an average across sampling points within the system.

Figures 5-41 and **5-42** present the disinfection byproduct data for the Boulder distribution system sampling program, using the LRAA method, from November 2004 through November 2009. As can be seen on **Figure 5-42**, since October 2005 the LRAA concentrations for TTHMs were consistently below the regulatory limit of 0.080 mg/L (80 ppb). Similarly, the HAA_5 concentrations were consistently below the 0.060 mg/L limit.

Figure 5-41: Boulder Distribution System TTHM for D/DBPR Compliance Points – Locational Running Annual Average

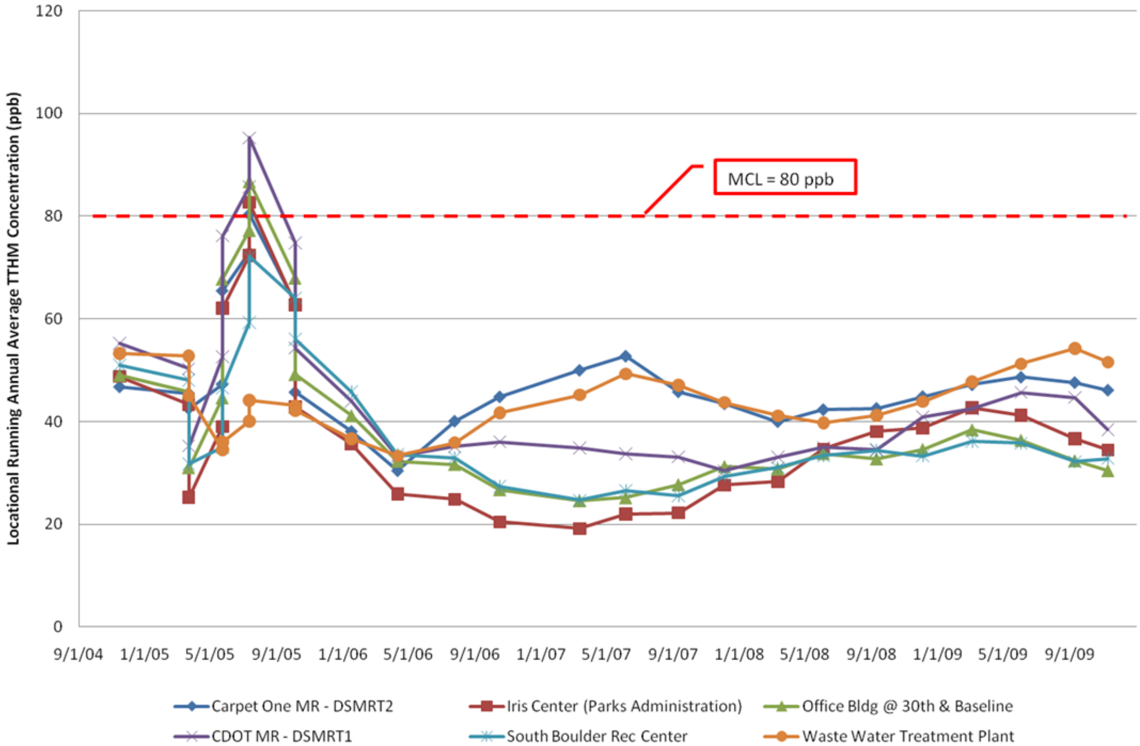
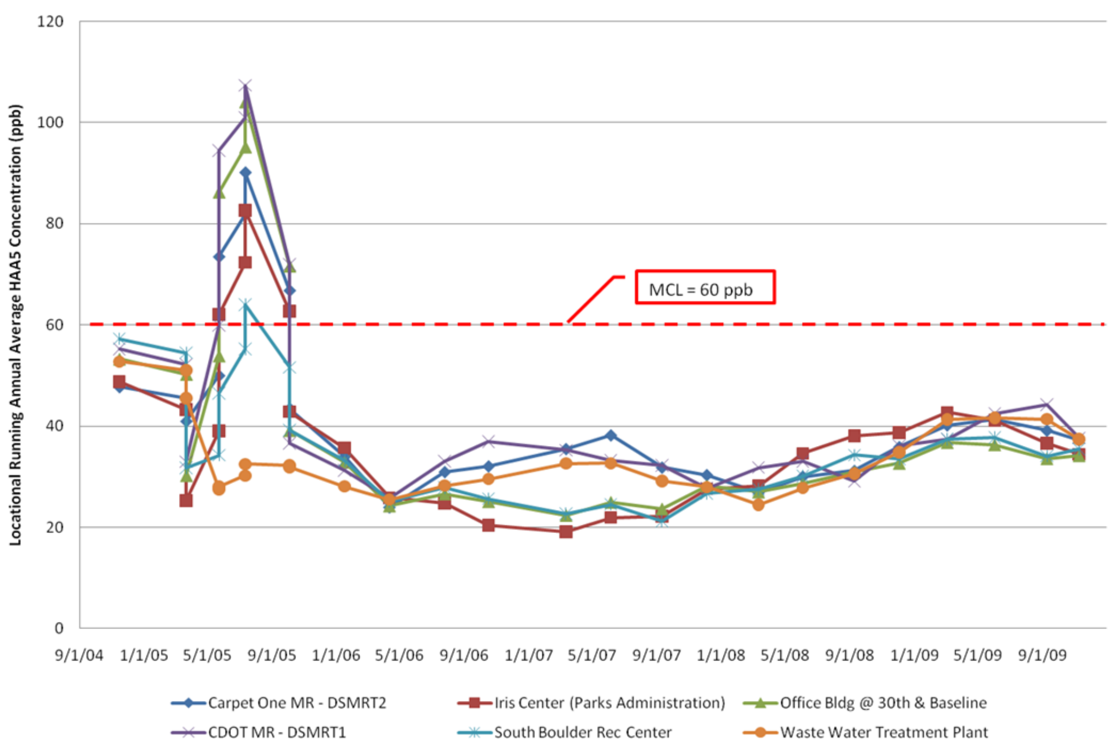


Figure 5-42: Boulder Distribution System HAA_5 for D/DBPR Compliance Points – Locational Running Annual Average



Figures 5-43 and **5-44** respectively present the TTHM and HAA_5 concentrations in the finished water from both plants. Both of the City's water treatment facilities have chlorine feed points in the process piping before (pre-chlorination) and after filtration (post-chlorination). Prior to summer 2006, the pre filtration chlorine was added to the raw water before flocculation and sedimentation. This practice has been linked to increased formation of DBPs through reaction with naturally occurring organic matter (NOM) present in the raw water. From the available historical data it is apparent that the elevated DBP levels coincide with the spring runoff period indicating the presence of greater concentrations of DBP precursors, primarily NOM. At the same time, raw water pH and alkalinity drop to lower than normal levels, which can affect the performance of the pre-treatment process with respect to removal of DBP precursors.

In response to the observed high DBPs levels, particularly in the summer 2005 and 2006 periods, the City modified its disinfection practices to eliminate routine pre-chlorination and now applies free chlorine to the settled water. This change, as well as the increased control/optimization of the pre-treatment process through the use of streaming current monitors, has help stabilize the distribution system DBP levels and keep the City well within the compliance levels. It is important to note that optimizing the coagulation/flocculation/sedimentation processes for turbidity removal does not necessarily coincide with optimization of these processes for TOC removal.

DBP formation can also be significantly affected by the operation of the distribution system. The kinetics of DBP formations are such that DBPs continue to form as long as the chlorine and precursors are in contact with each other. As a result, the length of time water remains in the distribution system after treatment has a direct influence on the concentration of DBPs formed. Operating practices that focus on maintaining maximum volumes in the storage reservoirs along with reported problems with moving water into and out of storage reservoirs can result in long detention times in the system that contribute to the elevation of DBP levels. Based on the data presented in this section, it is apparent that the majority of the DBPs are generated in the treatment process. While this implies that long residence times may not be a major contributor to DBP formation under current system operational practices, these operations should be carefully monitored and storage needs continuously balanced with water quality implications.

If the regulatory limits are lowered significantly in the future, the City may not be able to comply. Should the running annual average limits be lowered to 0.040 mg/L for TTHMs and 0.030 mg/L for HAA_5 as has been speculated, disinfection byproduct concentrations would need to be reduced well below current levels to achieve compliance. For a long-term vision of reducing the disinfection byproduct levels in the distribution system, the City should continue to investigate ways to improve the pre-treatment process for TOC removal, through bench scale and full-scale optimization studies, and evaluation of alternative disinfectants.

Figure 5-43: BWTF and BRWTF Effluent TTHM Concentrations

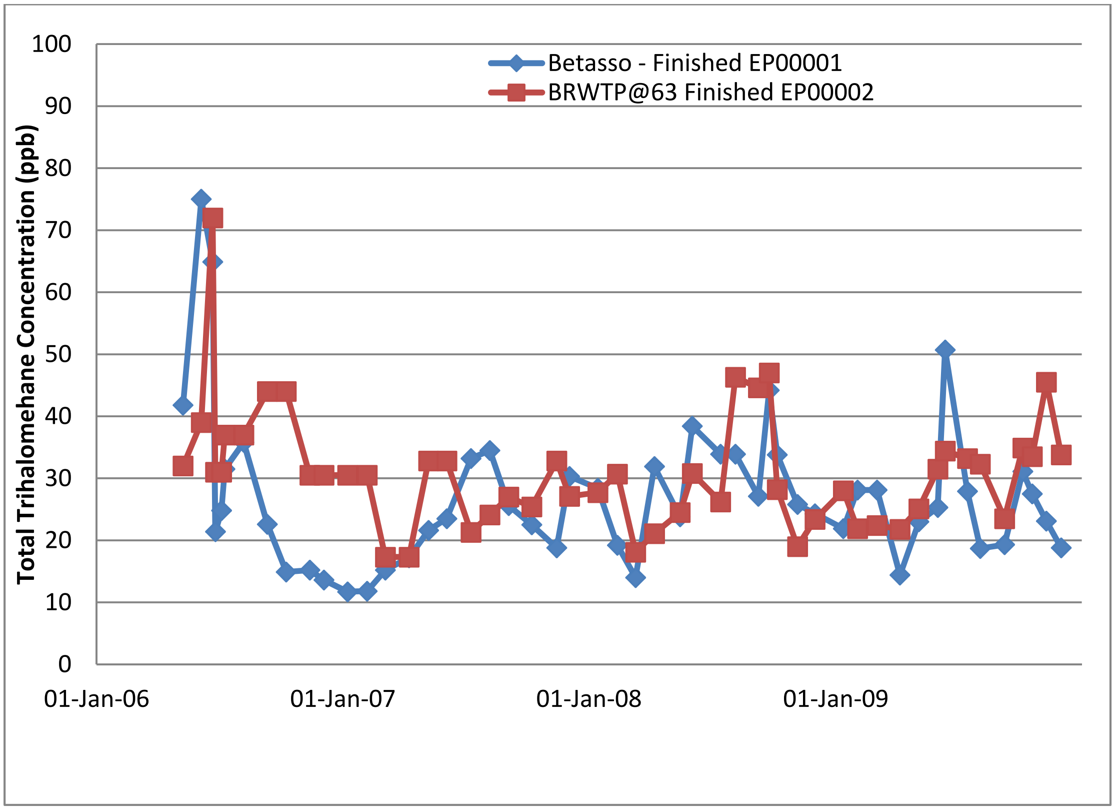
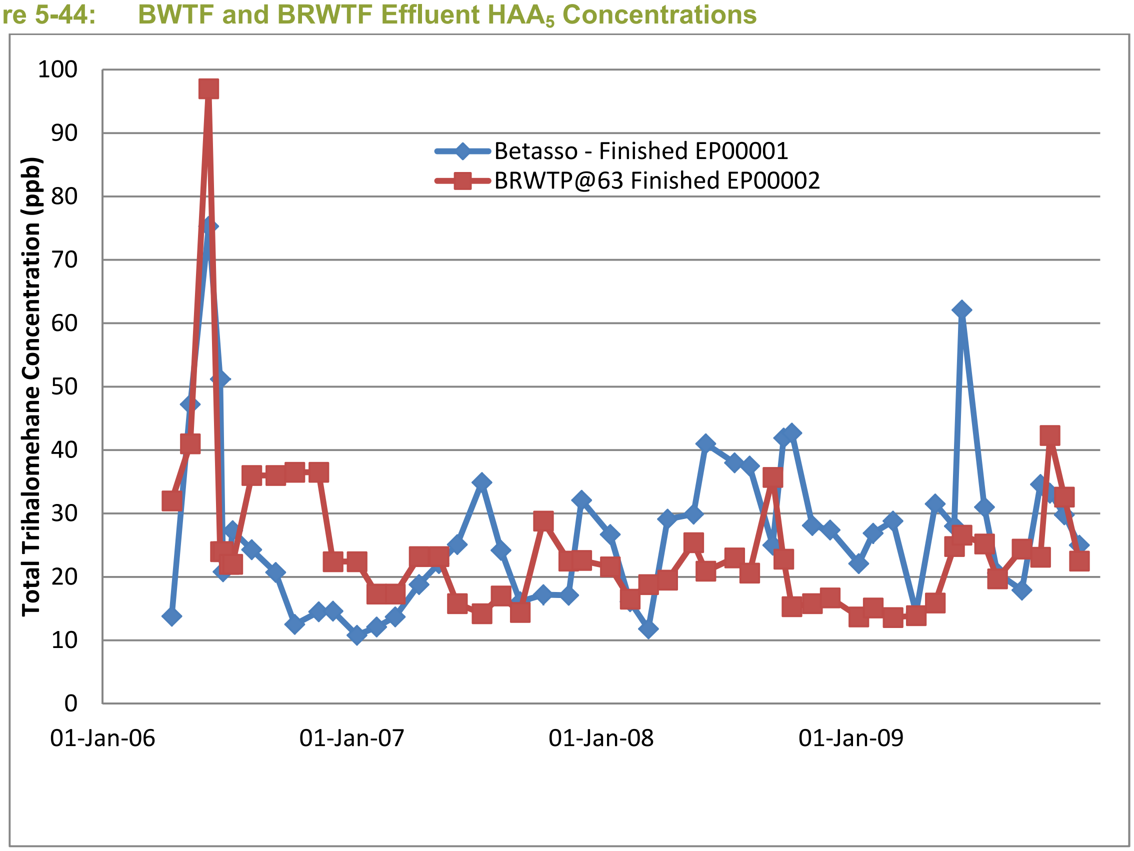


Figure 5-44: BWTF and BRWTF Effluent HAA_5 Concentrations



5.1.3.4 Lead and Copper Rule

In 1991, USEPA promulgated the Lead and Copper Rule (LCR) requiring all large systems to demonstrate that optimal corrosion control treatment is being practiced at their facilities. To meet these requirements, the City practices chemical stabilization at both water treatment plants. The objective is to maintain the water within a chemically stable range by maintaining pH and calcium carbonate ($CaCO_3$) alkalinity within specific limits such that metal ions will not be picked up by the water as it passes through pipes. To achieve this stability, a pH of 7.8 to 8.0 and an alkalinity of 35 to 40 mg/L as $CaCO_3$ were established as criteria for finished water. To meet these criteria, capital improvements were made at both water treatment plants to add or improve chemical feed systems. Since the raw water quality is different at each plant, different chemicals are used to attain the desired finished water stability.

The raw water treated at BWTF is low in alkalinity. To raise the alkalinity to the target range, lime is added. CO_2 is added after the lime to stabilize pH within the target range. The CO_2 system was installed and the existing lime storage and feed equipment was replaced in 1996. At the BRWTF, an engineering predesign study determined that the raw water had sufficient alkalinity at all times so that chemical adjustment would not be needed. Caustic soda (sodium hydroxide, NaOH) was selected as the best chemical to use for pH adjustment. A caustic soda storage and feed system was installed along with other miscellaneous improvements in 1993.

Figures 5-45 and **5-46** present finished water pH and alkalinity data from 2004 to 2009. It can be seen that both the pH and alkalinity of the BWTF treated water are, on average, within the target range, thereby meeting the requirements of the lead and copper rule. But, there is some variability, particularly in alkalinity. However, since effective corrosion control is a function of long-term average water characteristics, the short-term variations do not adversely affect the performance of the process. The variability in alkalinity does reflect the difficulty of controlling the lime feed system with precision as reported by plant operating staff, indicating a possible need for improvements to the lime mixing and feed equipment.

Figure 5-45 indicates that although the pH of the finished water from the BRWTF is typically within the target range, control using NaOH is not as precise as it is at BWTF using lime and CO_2. The lack of an alkalinity adjustment system is apparent from the wide variability in that parameter. Of particular concern is the difference in finished water alkalinity (**Figure 5-46**) depending on whether raw water is being drawn from Boulder Reservoir or the BFC. Water drawn from the reservoir during the non summer months has more than adequate alkalinity and no further adjustment is needed for corrosion control. However, water taken from the canal has significantly lower alkalinity resulting in finished water alkalinity near or below the lower limit of the target range. In addition, the sharp change in alkalinity when the raw water source is switched causes problems for users with water quality sensitive industrial processes and has resulted in complaints from industrial customers.

Figure 5-45: BWTF and BRWTF Finished Water pH – 2004-2009

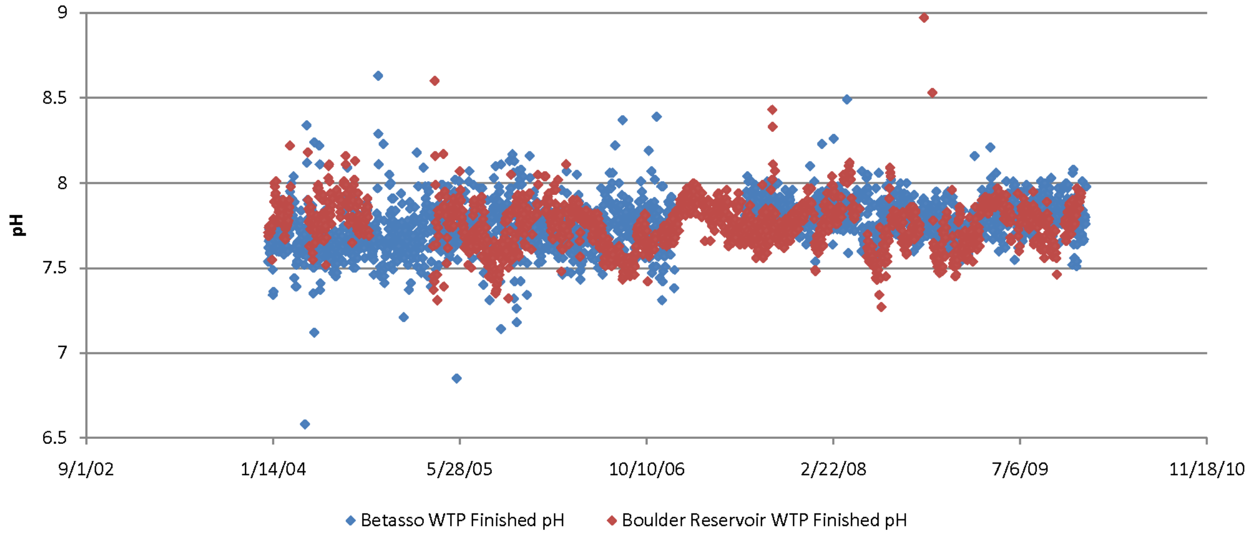
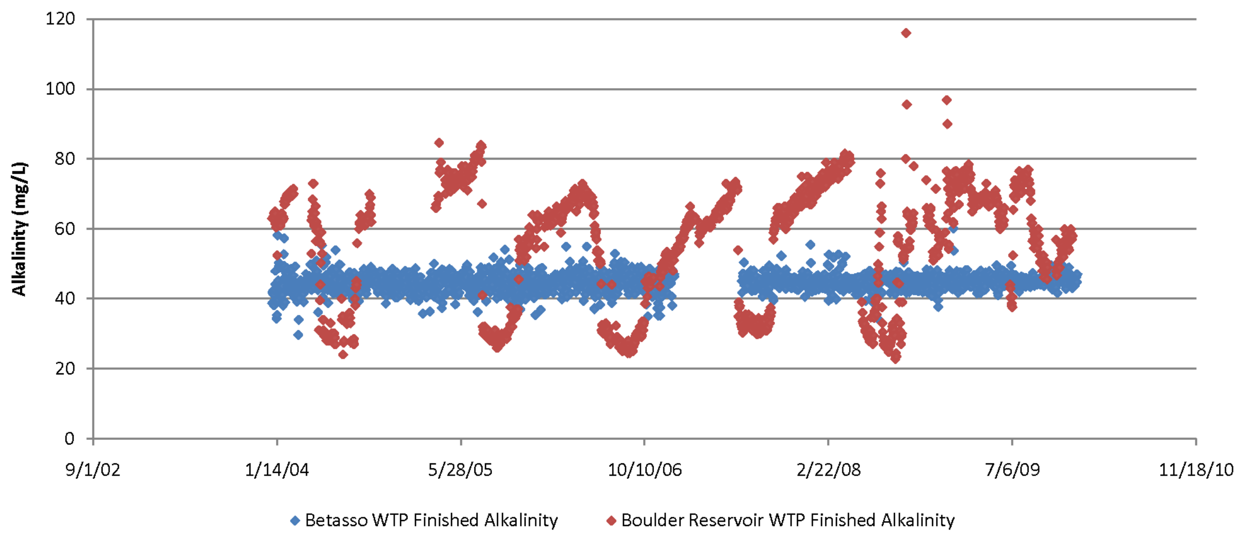


Figure 5-46: BWTF and BRWTF Finished Water Alkalinity – 2004-2009



5.1.3.5 Sanitary Survey

CDPHE completes a Sanitary Survey of each of the water treatment facilities in Colorado every 3-5 years, depending on performance. The City of Boulder recently received a letter from CDPHE, dated September 22, 2010 summarizing the results of this Sanitary Survey. Several of the deficiencies cited in the sanitary survey have already been addressed and City staff is working to address the remaining deficiencies as soon as practical. The deficiencies found were categorized into significant deficiencies and minor deficiencies and are discussed in the sections below:

Significant Deficiencies (must be fixed and reported to CDPHE)

- Betasso WTF – the clearwell vents were not protected with a 24-mesh non-corrodible screen to exclude insects, birds, and animals
- Kohler Storage Reservoir – the roof penetrations are exposed and not protected with a 24-mesh non-corrodible screen to exclude insects, birds, and animals
- Booton Storage Reservoir – the access hatch was not designed to prevent contamination from entering the tank. The new flush-fitting hatch lids were not sealed with a gasket, or did not overlap the framed opening and extend down around the frame at least 2 inches.

Minor Deficiencies (must be fixed and reported to CDPHE)

- Booton Storage Reservoir – storage facility openings were protected with a coarse screen, but must have a 24-mesh non-corrodible screen or a flap valve to prevent entrance of contaminants.
- Gunbarrel Storage Reservoir – overflow pipe does not terminate 12 to 24 inches above a splash pad and needs to be extended to prevent erosion of the foundation soil at the base of the tank.
- Maxwell Storage Reservoir – storage facility openings need to be protected with a 24-mesh non-corrodible screen or flap valve to prevent entrance of contaminants.
- Devils Thumb Storage Reservoir – all storage facility openings were protected with a coarse screen, but must have a 24-mesh non-corrodible screen or a flap valve to prevent entrance of contaminants. Also the overflow pipe does not terminate 12 to 24 inches above a splash pad and needs to be extended to prevent erosion of the foundation soil at the base of the tank.
- Kohler Storage Reservoir – storage facility openings need to be protected with a 24-mesh non-corrodible screen or flap valve to prevent entrance of contaminants.
- Chautauqua Storage Reservoir – storage facility overflow pipe needs to be protected with a 24-mesh non-corrodible screen or flap valve to prevent entrance of contaminants

There were no monitoring violations or MCL violations during the past year, however there was one violation listed:

Violation No. 109, Date = 3/10/2010, Type: Single Combined Filter Effluent (IESWTR/LT1), Compliance Period 1/1/2010-1/31/2010. This violation has been responded to with the Compliance Assurance section.

Other Observations/Recommendations/Comments include:

- The distribution system operator should have an operator Level 3 certification. The current distribution system operator in charge is a Level 4, however compliance with this regulation is noted.

- Free residual chlorine at the extremity of the system was measured as 0.2 mg/L, which is in compliance.

- Chautauqua Reservoir's roof vents terminated in an inverted 'U' construction with the openings less than 12-inches above the roof surface. The WQCD recommends a distance of more than 12-inches. In addition, there is graffiti on the side of one of the distribution system tanks along with stones on the roof indicating a breach in security.

- BRWTF's and BWTF's fluoridation systems were inspected and are in compliance with the requirements.

5.2 Distribution System Facilities

This section evaluates the major distribution system facilities owned by the City. The distribution system was evaluated based upon on-site observations, information provided by operating staff, and information collected from previous reports. Computer modeling was used to assess distribution system performance and identify deficiencies.

5.2.1 System Hydraulics

The distribution system was modeled to simulate the system hydraulics. This summary is presented in **Section 5.2.7** and the hydraulic model is included in **Appendix C**. A discussion of the major pipelines is included here.

The Boulder Canyon pipeline was originally built in the late 1800s. Improvements made to the pipeline in the early 2000s including removing the Fourmile PRV station and repairing the 16-inch Zone 2 line have resolved many of the deficiencies in this area. Several leaks have been identified on the 24-inch Boulder Canyon Pipeline between the Orodell Hydro/PRV station and the old Fourmile PRV station. This section of pipe is planned to be replaced in the near future. Testing of the pipeline, completed in 2008 demonstrated that the pipeline can carry at least 17 MGD. The design flow of the pipeline is 20 MGD.

The Sunshine pipeline is the primary transmission main for carrying water from the BWTF to the City. No deficiencies were noted with this pipeline.

Improvements in 2005 to the distribution system from BRWTF included a new, 24-inch pipeline along the Diagonal Highway to the improved Iris Pump station allowing BRWTF to deliver up to 12 MGD. Further improvements, completed in 2010 included a “sister” pump station, Iris #2 and the replacement of the pumps at the Cherryvale pump station. These improvements increased the capacity of the system to 20 MGD to be supplied out of BRWTF. Out of the 20 MGD delivered from BRWTF, 3.4 MGD goes to Zone 1 and 12.7 MGD can be delivered to the Iris #1, Iris #2, and Cherryvale Pump Stations for delivery to Zone 2. The remainder of the flow is required to be pumped from Zone 2 to Zone 3 in order to realize the 20 MGD capacity of the BRWTF. No further capacity improvements to the Zone 1 system have been identified.

Similarly, no deficiencies were identified in the transmission piping that carries all water from the BRWTF to the Zone 1 distribution system. Computer modeling did, however, indicate problems with some of the Zone 3 transmission mains that feed the Zone 3 tanks. This is discussed in more detail below in the section on Treated Water Storage. The design conditions limit the flow from BRWTF to 16.1 MGD when only Zones 1 and 2 are being fed from BRWTF. Currently up to 3.4 MGD goes directly to Zone 1 while the other 12.7 MGD goes through the pump stations at Iris and Cherryvale to Zone 2. In the event that the BRWTF is required to provide water to Zone 3, the new Iris #2 pump station and the new distribution pipeline along the Diagonal allows for the potential capacity up to 20 MGD that can be delivered to Zone 1 and Zone 1 pump stations, then from Zone 2 to Zone 3 from BRWTF, matching the plant capacity. Additional pumps within the system are able to transfer water from Zone 2 to Zone 3. A standard operating procedure for this transfer exists, but more frequent testing of this procedure is recommended.

5.2.2 Hydroelectric Generating Facilities

The city's distribution system has four hydroelectric power generating facilities. These facilities allow the recovery of a significant amount of energy from the excess pressure available in the treated water distribution system. A condition assessment was made for the four facilities and is included in **Appendix D**. The following is a summary of that inspection report. Overall recommendations include that a master equipment list be generated for each facility including manufacturer details, date of install, date of last service, maintenance interval, and any other special information.

5.2.2.1 Orodell Hydroelectric Station and PRV

The Orodell Hydroelectric Station's turbine/generator, turbine isolation plug valve, downstream flow control valve, upstream butterfly valves, bypass PRV valve, and miscellaneous valves and piping are all reported to be fair to good. In poor condition are the bypass downstream isolation butterfly valve and the battery backup and charging system for instrumentation and control.

5.2.2.2 Sunshine Hydroelectric Station and Flow Control Facility

The Sunshine Station's system equipment is all reported as good to fair. No improvements are needed at this time. The PRV is located in a separate vault and reportedly needs attention. The PRV needs rehabilitation or replacement of the control system. In addition, a flow meter needs to be replaced for the facility's 30-inch pipeline.

5.2.2.3 Maxwell Pump Station and Hydroelectric Plant

The overall rating for this facility was GOOD (Rating = 2). Individual components were rated as fair to good.

5.2.2.4 Kohler Hydroelectric Station and Flow Control Facility

The overall rating for this facility was FAIR (Rating = 3). Individual components were rated as fair to good.

5.2.2.5 Kohler and Maxwell Emergency Pump Mode

The Kohler and Maxwell Hydroelectric Stations are typically used to break pressure and generate electricity between pressure Zones 3 and 2. However, these facilities are set up to operate in pumping mode to supply flow to Zone 3 in case of an emergency or drought. Tests of this emergency mode were performed and summarized in a City of Boulder report in August 2009. The report found that a supply of 3.7 MGD to zone 3 was required during emergency situations. The pump tests found that a total of 4.23 MGD can be produced by Maxwell and Kohler, and if the Maxwell turbine were rebuilt or replaced, the total capacity would be roughly 4.7 MGD. Therefore, sufficient capacity is available from Zone 2 to 3.

5.2.3 PRV Facilities

There are a total of seven operating pressure reducing valve stations in the Boulder distribution system. Four of these control bypass flows at the Orodell, Sunshine, Kohler and Maxwell hydroelectric generating stations. All of these valves are rated in fair to good condition. The PRVs throughout the system are used as needed based on production at the two plants and overall system demands. The remaining PRVs are as follows.

5.2.3.1 101 Pearl PRV

The PRV station at 101 Pearl is primarily used only when a large amount of water has to be moved from Zone 3 to Zone 2. This usually occurs during high demand/production periods in the summer. 101 Pearl is rarely used at any other time since it in essence takes water somewhat directly from BWTF and pushes it into Zone 2, where it is used without greatly impacting the reservoirs in either Zone 3 or 2. Operations have observed that use of this station during low demand periods results in decreasing chlorine residuals in the north and south ends of Zone 3 in particular. However it also seems to have some impacts resulting in increased water age in the north and south ends of Zone 2.

This station used to be used more frequently throughout the year. Since changing its operation so that it is primarily used only in high demand situations, there has been a decrease in the number of low chlorine events in both Zone 3 and 2.

A general scenario in which 101 Pearl would be used is as follows. BWTF is producing a large volume of water daily, resulting in a need to pass a significant volume of water from Zone 3 to Zone 2. Operators maximize use of the Maxwell and Kohler Hydro stations; first all generators are started to maximize generation before also using PRVs. If additional water needs to be moved into Zone 2 from 3 then operators use the PRV valves at each hydro station first. Often in this situation Kohler and Maxwell stations are each passing 6-8+ MGD using the hydro and the PRV bypasses. If high volumes of water are going through both stations but more still needs to be moved, operators begin using 101 Pearl to pass additional water. 101 Pearl is operated using a downstream PSI set point from which the valve automatically regulates to maintain the pressure set point. The pressure set point is increased sufficiently to result in the station passing enough water to obtain the desired results in both Zone 3 and 2.

The 101 Pearl Street PRV Station building is in good shape, with the exception of a potential for grading improvement and a gravel or concrete pad for the parking/turn around area. Equipment in the 101 Pearl Street PRV Station includes PRV valves, isolation butterfly valves, and the I&C system. All mechanical equipment is in good condition with no reported problems.

The PRV is rated in GOOD (Rating = 2) condition and no further work is expected.

5.2.3.2 Cherryvale and Iris PRVs

Valves at Cherryvale and Iris #1 and #2 are operated as needed when water must be passed from Zone 2 into Zone 1. This occurs either when the BRWTF is not producing enough to meet the demand in Zone 1 or when the BRWTF is offline. Typically the 2 inch valves are opened first. Then if additional flow is needed the 8 inch ‘Main’ valves are opened. The main valves operate on a downstream pressure control system. If downstream pressure gets too high they will modulate themselves closed. The Cherryvale main valve has a downstream pressure setting of approximately 65 PSI, and the Iris main valve has a setting of about 55 PSI. These settings are intended to be set low enough such that zone 1 pressures would cause the valves to close before the Gunbarrel Tank overflows.

5.2.4 Pumping Facilities

The pump stations in the distribution system were not evaluated as part of this TWMP. The pump stations include:

- BRWTF Pump Station – recently refurbished
- Iris #1 Pump Station – refurbished with new pumps in 2005
- Iris #2 Pump Station – new (built in 2010)
- Cherryvale Pump Station – upgraded with new pumps in 2010
- NCAR Pump Station – condition unknown, private system
- Maxwell Pump Station – evaluated with the hydroelectric facility. Rated in good condition (see Appendix D)
- Kohler Pump Station – evaluated with the hydroelectric facility. Rated in good condition (see Appendix D)

5.2.5 Treated Water Reservoir Storage

The City has 6 treated water storage reservoirs serving the three pressure zones. A structural evaluation and hydraulic capacity evaluation is discussed in this subsection.

5.2.5.1 *Previous Evaluations*

A report was compiled by Black & Veatch in June 2002, titled Report on Chautauqua, Kohler, and Maxwell Reservoirs, which investigated the general physical condition of each reservoir through leak testing and underwater inspections. The report also summarizes various lining alternatives to reduce leakage at each reservoir. A second report was compiled by Rooftech in October 2007, titled Roof Inspection Report, which detailed the condition of the Kohler Reservoir roof and recommended improvements. All significant findings and recommendations of these reports are included in the facilities evaluations below.

5.2.5.2 *Preliminary Structural Evaluation*

A preliminary structural evaluation was performed by MWH for the six (6) water storage reservoirs in May of 2010. The inspection was to assess the overall condition of the reservoirs for asset management planning and to identify any major replacement costs that might be required within the next 20 years. The inspections were limited to a preliminary condition assessment based on visual judgment and did not allow for any in depth inspections. The inspection report is included in **Appendix E** and summarized below.

5.2.5.2.1 Maxwell Reservoir

Maxwell Reservoir is of 360 feet × 200 feet with a capacity of 9.5 MG. The reservoir is covered with concrete double tees supported by concrete beams and columns. The double tees are covered with insulation and topped with asphalt and gravel. The perimeter of the reservoir sticks above the finished grade approximately 5 feet and slopes in the shorter dimension up to the center at approximately a 1.5 percent slope.

The following list was generated describing the external items that need attention and should be maintained on a regular basis:

- Longitudinal crack close to the Southeast corner of the reservoir should be inspected further for the potential causes of the crack and a repair procedure should be developed before the winter season.
- Eroded soil areas along the perimeter of the reservoir should be inspected further for the cause of the erosion and a repair procedure should be implemented. Suggest replacing the grass/soil adjacent to the structure with free draining gravel to help with erosion.
- Construction and movement joints at the corners and at the midpoint of the North and South walls of the reservoir should be sealed from external weather before the winter season.
- The layout surrounding the reservoir ground access area should be investigated and a re-grading solution should be developed and implemented. The steel enclosure should be re-coated and the joints re-sealed.
- The roof at a minimum should be recoated or a new roof system should be developed to minimize trapping moisture against the concrete double tees.
- All coated surfaces should be analyzed to determine the current condition is adequate to prevent corrosion for external elements. Form the current visual inspection, there are many areas that need to be re-coated.
- The CMU Crack at the Hydro building should be inspected further to determine the cause and a repair procedure should be developed and implemented prior to further deterioration.
- The 2002 Rooftech report found that the Maxwell Reservoir exhibited significant leakage and deterioration of the existing composite asphalt lining system.

5.2.5.2.2 Kohler Reservoir

Kohler Reservoir is 330 feet × 230 feet with a capacity of 9.4 MG. The reservoir is very similar to the Maxwell reservoir but is covered with a metal deck roof supported by metal purlins. The metal roof is galvanized steel that has been coated with paint. The reservoir sticks above ground, at the low point, approximately 4 feet with metal decking covering the concrete wall portion that is above grade.

The following list describes the external items that need attention and should be maintained on a regular basis.

- A Roof Inspection Report for the Kohler Reservoir was compiled in October 2007. The report found that the roof panels were originally coated with a green, latex-type coating. The coating is in very poor condition, with shrinkage cracks and paint peeling throughout, as well as some surface rust below the paint.
- The existing roof system consists of 24-gauge galvanized steel panels supported by C-purlins spaced approximately 5'-9" on center, attached with exposed fasteners having rubber washers. The roof panels are somewhat unusual; they only span two purlins, while most roof panels are designed to span a minimum of three purlins. This construction significantly reduces the structural capacity of the panel, and is likely contributing to the numerous buckled panels throughout the roof. The roof is in poor condition and is at the end of its design life cycle. However, the roof is not as likely to leak consistently as is the Chautauqua Reservoir.
- Joints in the concrete walls that have opened up due to wall movements should be sealed and protected from external weather. This is necessary to prevent future erosion problems.
- Coating system on the gutter between roofs has failed and the condition of the gutter should be evaluated to determine if it should be replaced or re-coated.
- Vegetation around the reservoir should be removed and the top layer of soil replaced with free draining material. The finished grade along the reservoir should also be regarded to allow drainage away from the reservoir. This was completed in 2010.
- The 2002 Rooftech report found that the Kohler Reservoir exhibited significant leakage and deterioration of the existing composite asphalt lining system.

5.2.5.2.3 Devil's Thumb Reservoir

Devil's Thumb Reservoir is 102 feet and a capacity of 5.0 MG. The reservoir is an above grade steel tank that sits on a concrete slab-on-grade with a thickened edge. The tank is roughly 20 feet tall with the roof sloping from the center to the outside edge. Along the perimeter of the tank is a metal rain guard that is approximately 12 feet above the ground and protrudes 1 to 1½ feet.

The following list describes the known items that need attention and should be maintained on a regular basis.

- Rock pits surrounding the tank should be cleaned and re-coated on an annual basis.
- Finished Grade around the back side of the tank should be re-graded to allow proper drainage of the site.
- Rocks need to be removed from the roof.
- Further investigation into why the tank roof is dented and deformed is needed to identify if the possibility of the roof collapsing or failing in the near future exists.
- Concrete foundation needs to be protected or repaired.
- Vegetation next to the tank needs to be removed.

- Rain guard might need to be installed facing the opposite direction, further investigation is needed.
- Internal coating needs to be removed and re-coated because it contains lead.

5.2.5.2.4 Chautauqua Reservoir
Chautauqua Reservoir is in the shape of a trapezoid. The base is approximately 250 feet with a top dimension of approximately 180 feet and edges with a length of approximately 260 feet each. The capacity is listed as 8.0 MG.

The following list describes the items that need attention and should be maintained on a regular basis.

- Perimeter wall shrinkage cracks should be "V" grooved and sealed to prevent future erosion.
- Built up roof system has failed and needs replacing. Suggest considering a separate roof system that isolates the roof from the concrete double tees.
- Roof vents need to be re-coated.
- Further investigation of the internal concrete lining should be conducted to determine the condition and remaining service life. The leaking joints can lead to problems along the perimeter of the structure including settlement issues and possible contamination of the reservoir.
- Further investigation of the double tee shear tabs is needed to determine if the roof can perform as originally designed. New tabs might be needed, or the entire roof might need to be replaced.
- The 2002 Rooftech report found that the Chautauqua Reservoir exhibited significant leakage.

5.2.5.2.5 Booton Reservoir
Booton Reservoir is a tank within a tank. The external tank is 173-foot-diameter and the internal tank is 68-feet-diameter with a capacity of 0.6 MG. Both tanks are pre-stressed concrete tanks that are completely below grade.

The reservoir was not accessible for inspections therefore the condition of the buried tanks are unknown. These tanks were constructed within the last 20 years and the City staff has indicated that they have had no problems, so it is assumed that the tanks are in good condition. Regular inspections should be performed to verify the tanks are performing as designed.

5.2.5.2.6 Gunbarrel Reservoir
Gunbarrel Reservoir is an above ground steel tank with a plan diameter of 130 feet and a capacity of 2 MG. The tank is approximately 20 feet tall with a roof that overhangs the side walls by 4 feet.

The following list describes the items that need attention and should be maintained on a regular basis.

- Rock pits should be cleaned and re-coated on an annual basis.
- Vegetation should be kept from growing over the slab-on-grade and ultimately the adjacent soil should be removed and replaced with weed barrier and free draining rock.
- The bird nests and excrement should be removed from behind the soffit and along the tank. After cleaning the area, bird screens or wire mesh should be installed between the soffit and the roof overhang to keep birds from nesting behind the soffit.
- Investigate the purpose of the external box that might contain a corrosion protection device.

5.2.5.3 Reservoir Capacity Evaluation
The storage reservoirs are evaluated to determine whether there is sufficient storage capacity to meet projected, future demands.

5.2.5.3.1 Reservoir Storage Criteria

The total storage required for a water system is evaluated in three parts: 1) storage for operational use 2) storage for fire fighting and 3) storage for emergencies. These three components are determined by pressure zone in order to evaluate the ability of the water system to meet the storage criteria on both a zone-by-zone basis as well as a system-wide basis. These three storage components are discussed in more detail below.

5.2.5.3.2 Operational Storage

Operational storage is defined as the quantity of water that is required to balance daily fluctuations in demand and water production. It is necessary to coordinate the water source production rates and the available storage capacity in a water system to provide a continuous treated water supply to the system. Water systems are often designed to supply the average demand on the maximum day and use reservoir storage to supply water for peak hour flows that typically occur in the mornings and late afternoons. This operational storage is replenished during off-peak hours that typically occur during nighttime, when the demand is less.

AWWA recommends that an operational supply volume ranging from one-quarter to one-third of the demand experienced during one maximum day. It is recommended that each pressure zone in the City's water system have an operational storage of at least 25 percent of MDD. The criterion for the operational storage is consistent with the 2000 TWMP.

5.2.5.3.3 Fire Flow Storage

Fire flow rates and durations for various types of development are given in **Table 5-32** together with the storage volume required to meet these demands. In applying these standards, the worst case of fire flow is assumed for each zone. For example, if the highest fire flow of a zone is 6,000 gpm for duration of 4 hours, the required storage for that zone is 1.44 MG. For analysis purposes, it is assumed that there will only be one fire per pressure zone at any one time.

Table 5-32: Fire Flow Storage Requirements

Land Use	Fire flow, gpm	Duration, hours	Fire Storage Required, gallons
Residential			
Single-family	1,500[b]	2[2]	180,000
Multi-family	3,500[a]	3[1]	630,000
Commercial	3,500[a]	3[1]	630,000
Schools	2,500	2	300,000
Hospitals	6,000[b]	4[2]	1,440,000
Industrial	3,500[a]	3[1]	630,000
[1]1989 North Boulder Area Water and Sewer Master Plan.			
[2]Insurance Services Offices.			

Fire storage should be determined and provided separately for each pressure zone within the distribution system. Recommended storage requirements for the City of Boulder are presented in **Table 5-33**. The criterion for the fire flow storage is consistent with the 2000 TWMP.

Table 5-33: Recommended Fire Flow Storage by Pressure Zone

Pressure Zone	Fire Flow Storage (MG)
1	0.63
2	1.44
3	1.44

5.2.5.3.4 Emergency Storage

The volume of water that is needed during an emergency is usually based on past experience and on the estimated amount of time expected to lapse before the emergency is corrected. Possible emergencies include earthquakes, water contamination, several simultaneous fires, unplanned electrical outages or pipeline ruptures or other unplanned events. The occurrence and magnitude of emergencies is difficult to predict; therefore, the emergency storage criterion is based on past experience and engineering judgment. The emergency situation is assumed to occur at the same time as a fire.

The longest recent general power outage in Boulder occurred in 1983. Power was restored in approximately six hours. Typically, emergency storage is set as a percentage of MDD. It is recommended that emergency storage be set at 25 percent of MDD for each pressure zone. The criterion for the emergency storage is consistent with the 2000 TWMP.

5.2.5.4 Storage Adequacy Evaluation

Based on the storage criteria listed above, a storage adequacy evaluation is performed for the City's storage facilities under 2035 demand conditions. The total required storage for a pressure zone is a sum total of three components:

- operational storage,
- fire-flow storage, and
- emergency storage.

The required storage is compared with the actual storage for the entire system and for each pressure zone. A summary of the required and available storage volumes are presented in **Table 5-34** by pressure zone.

The analysis indicates a storage deficiency of 3.7 MG in Zone 1. Zone 2 and Zone 3 have a combined storage surplus of 11.9 MG. **Table 5-34** indicates that the City has a net surplus of approximately 8.2 MG storage capacity for the system. Surplus storage in Zones 2 and 3 can be used to offset the storage deficiency in Zone 1 by transferring water via pressure regulating stations. Therefore, no recommendations are made for the construction of additional storage reservoirs under 2035 demand conditions.

Table 5-34: Storage Evaluation Summary – Future Demand Conditions (2035)

Pressure Zone	Demands			Storage Required				Storage Evaluation	
Description	ADD[1] (MGD)	MDD[2] (MGD)	PHD[3] (MGD)	Fire Flow[4] (MG)	Operational[5] (MG)	Emergency[6] (MG)	Required (MG)	Available (MG)	Surplus/ Deficit[7] (MG)
Zone 1	3.9	10.1	14.0	0.6	2.5	2.5	5.7	2.0	-3.7
Zone 2	13.0	33.7	46.6	1.4	8.4	8.4	18.3	18.9	0.6
Zone 3	4.1	10.6	14.6	1.4	2.6	2.6	6.7	18.0	11.3
TOTAL							**30.7**	**38.9**	**8.2**

[1]ADD = Average Day Demand
[2]MDD = Maximum Day Demand (2.6 x ADD)
[3]PHD = Peak Hour Demand (3.6 x ADD)
[4]Storage recommended in the City's 2000 TWMP
[5]Operational storage is 25 percent of MDD
[6]Emergency storage is 25 percent of MDD
[7]Negative values indicate storage deficit and positive values indicate storage surplus

5.2.6 System Operation

Operation of the water distribution system is monitored at the BWTF by means of a SCADA system. This system provides for continuous monitoring of all pressure reduction valves, system pressures, storage reservoir levels, hydroelectric generation units, and pump operations. The system also provides for remote control of pressure reducing valves, bypass valves, pumps and generators such that the system operators can control the distribution of treated water within the system. As presently configured, the SCADA system does not provide for automatic operation of any of the system facilities. The SCADA system does, however, provide for the recording of detailed operating data records.

The City is currently in the process of developing System Operating Principles (SOPs) to have a better defined procedure for operating the reservoirs, intra-zone connections, and overall distribution facilities. The preliminary SOP states the following:

> *"The distribution system is operated by water treatment operators using SCADA terminals at the BWTF. In general, operation depends on the production at the two water treatment plants and the demands in various zones. Intra-zone connections are used as needed to fill and drain zones and to maintain the level of reservoirs within appropriate ranges.*
>
> *Production from the two plants depends on factors such as system demands and water rights/supplies. BRWTF is offline more often than BWTF for maintenance, but otherwise it is online year-round. BRWTF generally provides water to Zone 1 and BWTF generally provides water to Zones 2 and 3. When reservoirs in the watershed are low, BRWTF will often treat more water and provide water to Zones 1 and 2 so that BWTF water supplies are conserved. When the reservoirs are high, usually in the spring, and start to spill over from snowmelt, BWTF will increase production to treat all the direct flow, so Zone 1 can get some BWTF water depending on demands. When demands in the system are high, the watershed manager will decide which plant will increase production based on water rights and supplies.*
>
> *Notes May 2010: In the winter, goal is tank fluctuation. In the summer, goal is overall storage numbers."*

Completion of the Distribution System SOP will assist the City to optimize energy and treatment efforts.

System operating practices also have an important effect on water quality. Storage reservoirs in the distribution system serve primarily to provide a reserve for peak demand periods. During normal off-peak periods, however, there may not be sufficient water drawn out of the reservoirs to prevent stagnation. Under these conditions, a significant portion of the reservoir volume can remain in the tank for a long enough time to lose its chlorine residual thereby increasing the risk of bacterial regrowth. Prolonged retention of treated water in the system also favors the formation of DBPs, as discussed earlier in this chapter. Failure to operate the system in such a way that stagnation conditions are minimized can have public health and regulatory compliance consequences that will become increasingly important in the future as regulations become more stringent with regard to maintaining water quality throughout the distribution system.

The most important factor for reservoir detention is keeping a chlorine residual in the storage reservoir. This chlorine residual is easier to maintain in the winter, due to the slower decay curve with colder water. Mixing is also important to keep the reservoir fresh. The City has recently made improvements to the inlet and outlet piping at the Booton and Chautauqua reservoirs to improve mixing in the reservoirs. This was accomplished by separating the inlet from the outlet piping by inserting a tee in the pipe and a duckbill valve. The same improvements need to be made to the Devils Thumb reservoir and the Maxwell and Kohler reservoirs already have a separate inlet/outlet pipe, so only need the duckbill valve. The Gunbarrel tank is a smaller tank, and instead of repairing it, the City has decided to install a chlorine residual monitor in it. This will better assess the perceived issue of low chlorine residual in this area. If older water age becomes a problem in any of the tanks in the winter, it may be useful to either remove the tank from service, or simply operate them at lower levels, if feasible.

Standard operating procedures exist for providing water from Zone 2 to Zone 3, but these procedures need to be tested more frequently in the event that BWTF needs to be taken offline. The ability of BRWTF to treat its maximum flow has been modeled through the computer model, but also should be tested regularly to ensure proper operation of facilities.

5.2.7 Distribution System Maintenance Programs

The City has developed a number of existing distribution system maintenance programs; this subsection describes the recommendations for additional practices of distribution system maintenance.

5.2.7.1 Existing Distribution System Maintenance Programs

The following are the City's existing distribution system maintenance programs, based on those reported as part of the City's 2009 Annual Report.

5.2.7.1.1 Geographic Information System (GIS)/Utilities Maintenance Management System (UMMS)

The City maintains both a Geographic Information System (GIS) and a Utilities Maintenance Management System (UMMS). Both systems help to track and document maintenance in the distribution system. The Water Distribution System GIS is currently housed in an ESRI ArcGIS enterprise geodatabase. This system includes layers for water mains, valves, fire hydrants, meter pits, service laterals, fitting/nodes, corrosion protection devices, and main break locations. Updating of the water system GIS is done through an ESRI ArcMap project with a set of custom editing tools. Updates to the GIS system are promoted on a weekly schedule to a production geodatabase where they are immediately available to other databases and mapping applications. There are no major GIS design changes planned in the near future, however as GIS technology progresses design and programming modification will be required to stay current. Anticipated future enhancements to the GIS are focused more towards data quality and accuracy.

Below are some areas of GIS future development that have been identified, with cost estimates:

- **Locate and improve accuracy of firelines: In-house**
  Because firelines have historically been considered private utilities they have not been consistently mapped. An in-house effort is currently underway to locate and map additional firelines and associated valves. New firelines are mapped from as-builts, existing firelines are being identified and located as part of the backflow inspection program.

- **Water Valve Location (GPS): $60,000**
  Distribution system maintenance crews have long relied on valve ties (measurements to static and easily identified above ground features**)** to record the location of water valve boxes**.** This methodology is very inefficient and has proved unreliable. Valve boxes that have been lost (overlaid by asphalt repair or otherwise not visible at the surface) are difficult and time consuming to locate. The city's water distribution mapping has also proved to be spatially inaccurate and incomplete in many circumstances. These factors have proved very time consuming and costly for distribution maintenance. Accurate and complete locations of all the valves in the water system would provide a benchmark on which the entire water distribution GIS could be made accurate.

- **GIS Integration with UMMS: $10,000**
  Currently only limited maintenance information from UMMS is available within the GIS. Further development is necessary to create a two-way process that will allow more detailed and complete maintenance information to be access from within the GIS system.

5.2.7.1.2 Utilities Maintenance Summary and Future Needs

The "Utilities Maintenance Management System" (UMMS) is an enterprise database application for recording, reporting, and analyzing City of Boulder utilities system maintenance information. The application has a "SQL Server" back end (for data storage) and "Microsoft Access" front end (for data input, analysis, and reporting). The database is used to record all the details related to the maintenance of city utilities including, but not limited to, infrastructure maintained, employee hours, equipment hours, and materials. The database has undergone continual development for more than 25 years from it's inception to improve functionality. The database has been integrated with the city's utilities GIS data. This integration is currently a one-way process that pulls GIS data into UMMS.

Recently an analysis of Cartegraph, a COTS (commercial off the shelf) database application was undertaken. Cartegraph is currently used by the cities Street Maintenance work group to track their maintenance activities and for pavement analysis. This analysis was put on hold due to budgetary considerations. Current development on UMMS was also put on hold for the same reason.

Below are some areas of UMMS future development that have been identified, with cost estimates:

- **Work Order Tools: $10,000**
  A work order tool has been developed for wastewater main maintenance but there are several additional repetitive tasks that could benefit from work order tools. These tools allow the supervisor to create work orders for given activities that list the infrastructure to be maintained. This significantly improves efficiency since it eliminates the need for the employee to list the infrastructure maintained. This also allows for scheduled maintenance for given infrastructure and the use of several other computer analysis tools to improve the effectiveness of the maintenance program.

- **Cost Reporting: $10,000**
  UMMS does not currently have cost reports and costs for a given work record or work activity must be calculated manually. Costs reports can significantly improve system maintenance analysis to improve efficiency.

- **Street Patching Database Integration: $5,000**
  Currently a separate database is used to track utilities cut repair costs. In an effort to improve cost reporting this database should be integrated into the UMMS database providing a direct link between the infrastructure repair activity and cut repair costs, which are often a significant percentage of the cost of the repair activity.

5.2.7.1.3 Cathodic Protection Systems

The City conducts an evaluation of existing cathodic protection systems on water transmission pipelines. The transmission pipelines include any pipe sizes over 16-inches in diameter. Currently, only steel pipes are being evaluated. It ensures that the existing pipes have adequate protection and to replace anodes on vulnerable pipes where necessary. Eventually it is expected that cast iron, ductile iron and reinforced concrete mains will also be evaluated. There are 70 located corrosion protection devices in the City. The corrosion control test stations are at the following locations:

1. Diagonal highway 24-inch DIP pipe
2. Diagonal highway 16-inch steel pipe
3. Zone 2 steel transmission pipe
4. CU north of the Wolff Law building

An evaluation was performed by CH2MHill in April 2009 (Corrosion Mitigation Plan) to evaluate the City's cathodic protection systems and provide recommendations on ways the City can meet its goals with regard to corrosion protection for transmission pipelines. As a result of this evaluation, the City plans to take the following actions to protect its transmission pipelines from corrosion:

- Rehabilitate and regularly monitor the corrosion activity and cathodic protection systems on the transmission pipelines.
- Develop a program to install galvanic anodes to pipelines at locations of pipeline failures or pipeline breaks.
- Develop cathodic protection standards for any new transmission pipelines.

5.2.7.1.4 Unidirectional Flushing (UDF) Program

The City has developed an Unidirectional Flushing (UDF) program based on recommendations made from previous studies. Some of the benefits sometimes realized by UDF programs include improved water quality (primary and secondary water quality standards), improved hydraulics, and reduced maintenance of pipes, valves, and hydrants. The City's UDF design was completed by Mactec in 2007. The City implemented the UDF in 2007 and flushed 450 pipe segments, accounting for approximately 20% of the total pipes that can be effectively flushed. In July of 2008, MACTEC and Merrick & Co. completed the Unidirectional Flushing Program for the City of Boulder Treated Water Distribution System Report on Program Design for 2007. This report evaluated the effectiveness of the City's UDF program. The study found that there was a lack of tangible benefits from implementing the UDF program. The report recommended that instead of continuing the program, the City would benefit more from replacing problematic and old pipes in the system and only occasionally flushing areas where aging, unlined pipes are causing customer dissatisfaction. MWH reviewed this study and concurs with the conclusions presented based on the data provided.

In 2009 MWH Soft developed hydraulic modeling procedures in InfoWater® for UDF. If the UDF program is ever initiated again, or if localized flushing is required, the InfoWater® program provides a UDF design that can easily be implemented. The sequences created in InfoWater® may be actively manipulated to serve specific complaint areas by adding or removing pipes, manipulating valve operations, and by examining the UDF results for settling velocities in the specific sequences and their adjacent pipes. The overview maps and flush journals will serve as a 'road map' for narrowing in on trouble areas that then may be provided to field crews.

5.2.7.1.5 Valve Exercising Program

The City has a program to exercise the isolation valves in the system once every 3 years. Once each valve is exercised and located, it is documented in the GIS and UMMS.

5.2.7.1.6 Hydrant Flushing Program

The City has a program to test all of the fire hydrants once every 3 years. Once the hydrant is tested it is documented in the City's GIS and UMMS.

5.2.7.1.7 PRV and Zone Isolation Valve Removal Program

A program was developed in 2004 to remove the existing zone isolation valves from the distribution system. The purpose of the project was to prevent the accidental mixing of different pressure zones. The City continues to implement recommendations proposed in the 2004 report.

5.2.7.1.8 Distribution System SOP

In 2009, the City started preparing a SOP to document preventative maintenance and emergency response procedures in the distribution system. The SOP will cover topics such as contamination of the distribution system, main breaks, pipe replacement, corrosion control, flushing program, backflow prevention, and others. Compilation of this SOP is still in progress.

5.2.7.1.9 Reservoirs

The City continues to regularly inspect its reservoirs for issues such as corrosion, condition of the interior and exterior paint, and stability of the reservoir roof. AWWA G200 calls for comprehensive inspections every 3 to 5 years and for an external visual inspection to check for environmental damage and inspection of vents and screens every 3 months. It is also advised to increase the number of inspections as tank condition worsens.

5.2.7.1.10 Backflow Prevention Program

Backflow prevention requires utilities to protect water service connections so that degraded water, bacteria, and chemicals cannot be pulled back into the drinking water system. The City, in compliance with CDPHE requirements, requires backflow prevention on all commercial, industrial, and multifamily properties. Backflow prevention is required on all water lines entering applicable properties, including domestic (drinking water) service lines, fire suppression system service lines (fire lines), and dedicated lawn irrigation lines. Backflow prevention assemblies are installed at the point of containment (after the meter and prior to any plumbing branches) and must be tracked. Tracking is accomplished by requiring that the customer hire a certified backflow prevention assembly tester, and that the customer or tester provide a test report annually indicating that the assembly passed. As of 2009, the backflow prevention program tracks 3,900 customer accounts. The City's recently implemented program has been very successful. Previously the City was only 4% compliant and now they are more than 80% compliant. The backflow prevention and cross connection requirements were part of the drinking water ordinances from CDPHE.

5.2.7.1.11 Hydropower

The City has an on-going program of inspection and preventive maintenance at the hydro facilities to protect the investment the City has made in the hydro plants and optimize the return on that investment. Some of the tasks performed as part of the inspection and preventive maintenance program are listed below:

- SOPs have been established for each hydropower plant and are continually updated.
- All hydropower protection relay devices are tested annually and calibrated to minimize equipment damage.
- Internal rotating bearings, electrical cabinetry, and wiring are inspected regularly to reduce safety concerns an unscheduled plant outages.

In addition, discussions are currently on-going with the University of Colorado's researchers to utilize the Boulder Smart Grid transmission distribution management system for efficient energy management.

5.2.7.1.12 Water System Security

The City continues to implement the recommendations proposed in the 2008 system-wide security and vulnerability assessment report which prioritizes security-related capital improvement projects for implementation at the City's major water assets.

One recommendation is to perform some tabletop exercises to simulate response to a contaminant in the distribution system or a major component failure in the system or at the plant.

5.2.7.1.13 Water Quality Monitoring

The City continues to monitor water quality via monitoring instruments installed in 2008 and 2009 at different locations on the distribution system including storage reservoirs and pump stations. The current water quality monitoring stations are located as follows:

- Booton valve house
- Chautauqua valve house
- Iris No. 2 pump station
- Cherryvale pump station
- Gunbarrel vault

The City's water quality monitoring program not only monitors for the state and federal requirements, but also they have monitored for EDC/PPCPs, and other contaminants. This shows the City's proactive work to ensure exceptional water quality for its residents. The City is part of the UCMR3 monitoring, and as part of this will help the USEPA determine what contaminants will be regulated in the future. In addition, the City is participating in several Water Research Foundation projects, as mentioned in Section 3 and participating in a regional effort with Northern Water and other CBT entities to share costs.

The City has some areas of the distribution system that could use some further analysis. These locations are within the distribution system and specifically in reservoirs and in areas of concern. Online monitoring for pH, chlorine residual, and turbidity at each reservoir would assist the City in the detection of operational issues. pH will provide an idea of the corrosivity of the water, chlorine residual provides the age of the water, and turbidity will assist in assessing the condition of the pipes and reservoirs. Accurate level monitoring within the reservoirs would assist the City in determining how well the reservoirs are being exercised. This online monitoring should be input into the City's SCADA system to provide staff with real-time data to make operational changes to reduce water age by implementing localized flushing, or making operational changes to the system. Additional pressure and flow monitoring could also be helpful to investigate issues within the distribution system, especially near the PRVs. This information can also help to calibrate the distribution system model so that it can more accurately reflect the issues within the distribution system.

One location that has been problematic is the “Heatherwood” area, which is in Zone 1, not far from the Gunbarrel reservoir. This area has been shown to have consistent problems with low chlorine residual. These problems may be a result of a stuck altitude valve that now has been fixed, but the City is in the process of installing online chlorine monitors in this area to see if the issue persists. The area has only a few pipes feeding in and out of it, and so the problem may need to be fixed by additional piping of loops in the system. More data will allow the City to pinpoint the problem and develop a good solution. This problem has not shown up in the City’s distribution system model either, so getting further information and data from this area will also help to calibrate the model to the actual conditions in the area.

5.2.7.1.14 Customer Complaints

Customer complaints can be a reflection of water quality. Boulder had 217 customer calls in 2009 with 34 of those calls being information requests. The remaining 183 calls were complaints and based on the graph in the City’s 2009 Annual Report, approximately 26 would be considered customer service complaints, and 157 would be considered technical quality complaints. Per 1000 service connections (assumes 29,000 service connections), Boulder has 5.4 technical service complaints per 1000 service connections and 0.9 customer service complaints per 1000 service connections. These are compared to AWWA’s 2005 benchmarking results shown in **Table 5-35**.

Table 5-35: Technical Quality and Customer Service Complaints (per 1,000 Service Connections)

		City of Boulder	25th Percentile	Median	75th Percentile	Sample Size
Technical Quality Complaints						
Region	West	5.4	2.8	7.6	14.2	59
Size	100,000-500,000	5.4	2.3	8.6	38.1	56
All Participants		**5.4**	**2.8**	**7.2**	**17.4**	**165**
Customer Service Complaints						
Region	West	0.9	0.6	4.0	17.7	49
Size	100,000-500,000	0.9	0.5	4.5	50.9	49
All Participants		**0.9**	**0.7**	**5.7**	**27.3**	**151**
Source data from: Lafferty & Lauer, Benchmarking Performance Indicators for Water and Wastewater Facilities, AWWA, 2005.						

For both technical quality and customer service complaints, Boulder is in the second quartile (25 to 50th percentile, better than median) compared to utilities similar in size and location.

5.2.7.2 Recommendations for Additional Maintenance Practices

MWH recommends the City implement the following maintenance practices. (Some of these may already occur, but were not documented in available data.) These are identified based on a review of standard practices identified in AWWA G200 – Distribution Systems Operation and Management.

5.2.7.2.1 Valve Exercising Program

It is recommended that the City continue to exercise all of the isolation valves on a regular basis (once every 3 years). Larger pipes, air release valves, air-vacuum relief valves, drain valves, and pressure relief valves should be inspected on a regular basis and the frequency may need to be increased as the pipe or valve ages.

5.2.7.2.2 Inspection and Maintenance Programs

Currently two City employees are dedicated to perform utility locates, which averages about 10,000 hours per year. Often utility locates take priority over doing preventative maintenance. One recommendation is that the City devote more time towards the maintenance and inspection of the distribution system, primarily PRVs, ARVs, and larger pipes. The City is just over halfway in changing out the 40 existing ARVs, and these will be completed this year. It is difficult to switch from corrective maintenance to proactive maintenance, but having complete and functional GIS and UMMS systems are critical to starting this transition. An effective preventative maintenance program will be more productive and efficient than a reactive corrective maintenance program. Having temporary staff to help with utility locates could provide more time for effective maintenance programs.

5.2.7.2.3 Fire Hydrant Maintenance and Testing Program

The City recently inherited the operation and maintenance of about 2,000 fire line valves that are located in existing easements and right of ways. City staff has started locating and mapping the valves, and utilizes temporary staff (in part) during the summer to accomplish this work. In addition to this, it is recommended that the City continue to maintain and test all of the fire hydrants on a regular basis (once every 3 years).

5.2.7.2.4 Pump Station Maintenance

Pump stations should undergo similar maintenance procedures as the hydropower facilities. While it is believed that the City undergoes similar maintenance procedures at its pump stations, no documentation was identified that discussed such processes.

5.2.7.2.5 Backflow Prevention Program

Several recommendations have been identified to improve the efficiency and overall compliance of the backflow prevention program. Several city departments currently label and track fire lines, making verification and cross-reference difficult. The City should continue to streamline fire line data so that all city departments can be assured of how many fire lines exist. Similar to fire lines, customers with access to auxiliary water such as wells and ditch water represent a potential cross-connection, and should be identified and tracked. However, there is currently no central database of all known auxiliary water users. The backflow prevention program should review options for monitoring and enforcing backflow prevention requirements on auxiliary water users and develop an approach and timetable for implementation. The City does not have a standard backflow prevention program policy for Consecutive Systems that do not currently have backflow prevention. The backflow prevention program should review its options for enforcing backflow prevention requirements on Consecutive Systems in order to develop a standard approach and timetable for implementation. The backflow prevention program should also review its options for enforcement action, given that enforcement options have not been identified outside of shutting off service. The backflow prevention program should also pursue options that would save resources spent entering data to save costs and improve efficiency. Finally, the backflow prevention program should work with the Planning Department to review and rewrite Chapter 5 of the City's Design and Construction Standards in order to bring consistency to the Standards for backflow prevention construction.

5.2.8 Hydraulic Evaluation

The City has been using a computer model to simulate system hydraulics and operation of the water distribution since before 1980 when the first Boulder water distribution model was developed in KYPIPE. As part of the 2000 City of Boulder TWMP, the model was improved and calibrated using field verified pressures and fire flow tests. In 2005, the City's model was integrated into the MWH Soft InfoWater® software and was upgraded to an all-pipes model. Since that time the City has been maintaining and updating the water distribution model and routinely comparing SCADA data with model results to verify the model output. The model has also been enhanced to perform 24-hour and 30-day extended period simulations (EPS) and includes rule-based logic that allows the model to operate similar to the approach taken by the operators within the City.

The MWH Soft InfoWater® model used for this distribution system evaluation was most recently calibrated by the City for the IDSE Report prepared in 2006. A detailed report on the hydraulic model is provided in **Appendix C** for reference. This section summarizes the report.

The model was used to assist in the evaluation of the distribution system under current and future conditions and to help to identify system deficiencies. **Table 5-36** provides the reliability criteria that the system was measured against.

Table 5-36: Distribution System Hydraulic Reliability Criteria

Category	Criteria	Notes
Pressure	40-80 psi	Target range for normal operating pressure
	150 psi	Maximum target pressure (Note: Pressures at some existing areas in the system reach over 160 psi.)
	20 psi	Minimum allowable pressure during fire flow under a maximum day demand conditions
Velocity	10 fps	Maximum velocity under normal operating conditions
Head Loss	10 feet/1,000 feet	Maximum headloss under normal operating conditions

In addition to these criteria, the distribution system was also evaluated further to understand the need for pressure zone modifications, areas of high water age, and systems operating during system failure scenarios.

The hydraulic model evaluated the scenarios presented in **Table 5-37** for existing and future demands with the peaking factors shown.

Table 5-37: Distribution System Hydraulic Reliability Criteria

Model Scenario	Demand Scenario		Type (SS or EPS)	Model used for Master Planning Tasks	New Model Scenario
Existing Demands = 18.26 MGD*					
Water Age Analysis	Minimum Month	PF of 0.6 10.95 MGD	30 Day EPS	Use MINMONTH_EPS with demand scaled	
Water Age Analysis	Maximum Month	PF of 2.0 36.52 MGD	30 Day EPS	Use MINMONTH_EPS with adjustments for Max Month	
2035 Demands = 20.9 MGD*					
Pressure Zone Analysis	Minimum Day	PF of 0.6 12.54 MGD	7 Day EPS	Adapt from MINMONTH_EPS using WUMP_2035 demand distribution and SS option	MINDAY
Failure Scenario 1					MINDAYF1
Failure Scenario 5					MINDAYF5
Fire Flow Analysis	Maximum Day	PF of 2.6 54.34 MGD	SS	Adapt from MAXDAY_SS using WUMP_2035 demand distribution	MAXDAY35
Failure Analysis Scenario 4	Maximum Day	PF of 2.6 54.34 MGD	7 Day EPS		MAXDAYF4
Hydraulic Capacity Analysis	Peak Hour	PF of 3.6 75.24 MGD	SS		PKHR2035
Failure Scenario 2	Maximum Month	PF of 2.0 42.8 MGD	30 Day EPS	Adapted from MAXMONTH_EPS with demand	MAXMONF2
Failure Scenario 3	Maximum Month	PF of 2.0 42.8 MGD	30 Day EPS	Adapted from MAXMONTH_EPS with demand	MAXMONF3

The first step of the hydraulic evaluation was to determine if any additional calibration would be needed for the most recent model. It was determined that none was required.

The distribution system evaluation was performed by using a both steady-state and extended period simulation analysis in the calibrated hydraulic model under a variety of demand conditions. The City and MWH established a methodology for performing the hydraulic analysis which was designed to specifically meet the objectives defined by the team. The results of each evaluation are summarized below:

5.2.8.1 Hydraulic Capacity Evaluation

The water distribution system was evaluated based on the reliability criteria presented in the table above. The result was that the water distribution system is able to meet Peak Hour demands without causing wide-spread violation of the reliability criteria. There are some locations within the City that show pressures less than 40 psi, however most are due to high elevation and are not the result of high headloss. The result of the evaluation was that the Boulder water distribution system does not have significant capacity issues and is able to adequately meet pressure and velocity requirements throughout the City.

5.2.8.2 Fire Flow Analysis

The model shows that the majority of the system is able to provide 1,500 gpm of available fire flow or greater. Only two percent of the system was estimated to provide less than 1,500 gpm. These locations are mainly on dead end pipes or small diameter pipes.

5.2.8.3 *Additional Pressure Zone Analysis*

The distribution system is known to have areas with high system pressure. The reliability criterion establishes a target pressure range of 40-80 psi, but areas in the system are known to have pressures that exceed 150 psi. High pressures are present along the boundary between Zones 2 and 3 and between Zones 1 and 2. In addition high pressure nodes stretch the entire north-south extents of the City. To resolve these high pressure zones, an evaluation was performed to find out if there was justification for additional sub-zones to reduce this pressure. It was determined that adding sub-zones would complicate operations and could impact the City's ability to transfer water across the system.

5.2.8.4 *Water Age Analysis*

A water age analysis was performed using the 30-day EPS model with existing (2010) minimum month and maximum month demands to simulate water age throughout the water distribution system. Water age was used as a surrogate for water quality in this analysis.

This evaluation showed that water age is greater for the minimum month simulations as compared with the maximum month scenario. Approximately 50 percent of model nodes in the minimum month scenario have water that is greater than four days old. However in the maximum month scenario, only 12 percent of the model nodes have water age that is greater than four days old. For the purpose of this analysis, it is assumed that the minimum month scenario represents a winter condition when temperatures are lower and a maximum month represents a summer time condition. Assuming that water quality is affected by temperature, it would be reasonable that higher water ages in the distribution system would be acceptable during the winter months when temperatures are colder.

5.2.8.5 *System Failure Analysis*

Five different system failure scenarios were modeled to understand how the City of Boulder could meet demand during a variety of variety of failure conditions.

The five scenarios were:

1. BWTF out of service with minimum day demands being met entirely from the BRWTF through pump stations

2. Sunshine pipeline out of service with maximum month demands being met from the BRWTF and BWTF through the Canyon pipeline only, in combination with the Iris, Cherryvale, Maxwell and Kohler pump stations, hydroelectric facilities, and PRVs as needed.

3. BRWTF out of service with maximum month demands being met entirely from the BWTF through the Maxwell, Kohler, Iris, and Cherryvale hydroelectric facilities and PRVs as needed.

4. Canyon pipeline out of service with maximum day demands being met from the BRWTF and the BWTF through the Sunshine Pipeline only, in combination with the Iris, Cherryvale, Maxwell, Kohler, Iris, and Cherryvale hydroelectric facilities and PRVs as needed.

5. Sunshine pipeline and BRWTF out of service with minimum day demands being met from the BWTF through the Canyon Pipeline only and the Maxwell, Kohler, Iris, and Cherryvale hydroelectric facilities and PRVs as needed.

Model results from each scenario were compared against the reliability criteria to determine how well the system was able to meet demand while maintaining level of service under each scenario. For all system failure scenarios, the City's water distribution system is able to meet the demand condition without dramatically impacting level of service within the distribution system.

5.2.9 Distribution System Piping

5.2.9.1 Pipeline Aging

Although not included in the hydraulic analysis above, equally important in an evaluation of the distribution system is the age of the pipes. Over 70 percent of the pipes in the distribution system are over 30 years old. A summary of the relative pipe age is shown in **Table 5-38**.

Table 5-38: Summary of Distribution System Piping[1]

	1950s	1960s	1970s	1980s	1990s	2000s	TOTAL
Total Pipes Installed	1245	1412	2205	545	886	580	6873
Total Length of Pipes (mile)	85	86	124	35	52	29	412
Percentage of Total Pipe Length[2]	21%	21%	30%	8%	13%	7%	
[1]Table generated from information in the City of Boulder Technical Memorandum, dated 2-9-09.							
[2]The 2010 GIS Summary suggests 475 total miles of total system pipe.							

An analysis performed previously indicates that the average age of pipes in the City's system is over 40 years. However, it should be recognized that the inventory data base does not provide the actual year of construction for pipes installed before 1950, suggesting that the actual average age of the system is somewhat older. As the City does not have a program for replacing pipeline appurtenances such as air and vacuum release valves unless a specific problem develops, it can be assumed that these items have about the same average age as the associated pipes.

While age by itself is not a reliable indicator of pipeline condition, deterioration does progress with age and ultimately any individual pipe will require replacement. Economic analyses typically use 50 years as the useful life of pipelines. This assumption takes into account that some pipes won't last 50 years, while others will last much longer, which in some cases give the impression of an indefinite life span. Pipe materials, construction standards, and installation techniques have all improved over time, implying that older pipelines could be approaching the end of their useful lives. At present the City does not have a program in place for systematically assessing the condition of pipelines or their appurtenances. As a result, with a large proportion of the system over 50 years of age there is a concern that the City could possibly be forced to replace a large amount of pipe within a short time to prevent widespread system failures. There is also some concern that system performance could be affected or pipelines damaged as a result of failures of air and vacuum relief valves, which could go undetected for extended periods due to the lack of a regular inspection and replacement program.

5.2.9.2 Pipe Materials

The older pipes in the distribution system were typically cast iron or ductile iron pipe, while the newer pipes are typically PVC. **Table 5-39** shows the distribution of piping across the system:

Table 5-39: Pipe Material Distribution

Pipe Material	Length (miles)	% of Total
Asbestos Cement	18	4%
Cast Iron	152	34%
Ductile Iron	137	30%
Pre-stressed Concrete Cylinder	14	3%
Polyvinyl Chloride (PVC)	107	24%
Steel	16	3%
Unknown	8	2%
Total	**452**	**100%**

Approximately four percent of the system is comprised of asbestos cement (AC) pipe. Although AC pipe does contain asbestos, its presence in the distribution system is not considered a public health threat. Testing for asbestos in the water has repeatedly resulted in asbestos concentration limits well below the limits set by USEPA and the City has been exempted from further testing by the CDPHE.

The total system pipe length is 475 miles, 452 of those miles are owned and maintained by the City while 23 miles are privately owned.

5.2.9.3 Pipeline Leaks

The City currently has an average of 16.1 leaks/100 miles of pipelines. Comparing this to benchmarking data, the City is much lower than average compared to others in the Western United States and those of similarly-sized cities as shown in **Table 5-40**.

Table 5-40: Comparison of Water Distribution System Integrity (Leaks/100 miles of Pipeline)

Comparison Criteria	25th Percentile	Medium	75th Percentile	City of Boulder
West Region	16.9	36.4	59.6	16.1
Population of 100,000 to 500,000	27.7	52.1	94.2	
Source: Angela L. Lafferty and William C. Lauer, Benchmarking Performance Indicators for Water and Wastewater Utilities: Survey Data and Analyses Report, American Water Works Association, 2005.				

5.2.9.4 Pipeline Breaks – Historical Studies

The City's distribution system analysis has changed over the last ten years since the 2000 TWMP. Some of this information was gathered from the Pipe Replacement Technical Memorandum dated February 9, 2009 prepared by the City. The following summary is taken from this memorandum.

The City of Boulder began an intense analysis of the distribution system in 2002 with Integra Engineering. A point system was developed to rate pipes based on age, material, size, soil type, and relative location in the City. The point system and methodology was integrated into the water main and main breaks databases and has been used for the prioritization of pipe replacement since 2002.

In 2007, the City created a prediction model using Integra's methodology. The model used the a statistical function called the Weibull function to correlate pipeline failure with the number of pipeline breaks. The results of this analysis produced pipe replacement costs ranging from $6 million to $10 million per year.

In April 2008, the City hired HDR to critique the original Integra analysis and the Weibull function results. They improved the pipe break prediction, and they also attempted to correlate the pipe breaks to other pipe characteristics. They found a correlation when Age-Material-Soil groups were plotted with the Breaks per Mile. They used this correlation to create a model to show which pipes should be replaced first. This model grouped pipes into similar groups and the assumption was made that the groups would fail at a similar time relative to other groups. A cut off value was chosen which was called a service level that would determine which groups of pipes should be replaced based on the number of acceptable breaks per year. The model was used to evaluate three different service levels based on the service level the City currently provides. The results of this analysis produced pipe replacement costs ranging from $4.8 million to $10.6 million per year.

Unfortunately, this model was not considered to be an accurate representation of the distribution system because of the limited data available to use. One benefit of the HDR evaluation was a recommendation to evaluate pipeline breaks per unit length of pipe rather than per pipeline segment due to varying lengths of pipelines within the water system.

Next the City staff began to evaluate other methods of failure prediction and pipe replacement selection. The critical break area method utilized GIS spatial mapping to locate hot spot areas where multiple breaks have occurred. An assumption was made that all pipe within the hot spot area should be a priority for replacement within the next 20 years. The results of this analysis produced pipe replacement costs at approximately $4.7 million per year.

In 2008, the City looked into other correlations in Breaks vs. Operating Pipe Pressure. The City was able to finalize and run the City water distribution system model in MWH's InfoWater® program which provided additional data for analysis. Little correlation was found between system pressure and pipeline breaks, so the City continued to look at other prediction methods.

In 2009, the City again reviewed its use of the Weibull function for use in predicting pipeline breaks. The City recognized that considering a single break on a pipeline does not necessarily constitute a failure in that pipeline. The current approach is to use the number of breaks in a single pipeline in evaluating when a pipeline would fail. This method is more realistic in allowing the City to select the number of pipe breaks that appeared to be reasonable in terms of cost, and is also responsible in terms of providing a stable water distribution system for its citizens.

The findings of the pipe break study recommended that the threshold for the number of breaks per pipe be kept at two for CIP purposes, which allows funding of $2.1 million to be maintained during the next decade. With the aging distribution system, pipe breakage is likely to be a more common event that needs adequate money reserved. In addition, the City currently provides excellent service to its water customers and this will allow this service to continue.

5.2.9.5 Recommended Pipeline Replacement Program

The previous studies summarize the significant amount of work in evaluating the pipeline leakage data and considering the sensitivity of the number of times a single pipeline breaks on the total value of the pipeline replacement program. The program has significantly reduced the number of breaks in the system. Over the last two decades the City has averaged 76 pipeline leaks in the distribution system annually. Compared to other agencies in the region, 120 annual breaks is average, and 220 annual breaks would cause the City to operate at the worst level. The results of the City's effort have been clear, over the past 5 years, the City has reduced the number of breaks to less than 40 per year. This has been accomplished by a proactive pipeline replacement program and operational (pressure-related) changes

The following issues remain unresolved on the City's pipeline replacement program:

- Continuation of existing practices may lead to increased number of pipeline breaks as system pipelines continue to age.
- Pipeline breaks are not the only factor that would lead to pipeline replacement. Pipeline breaks are often not evident from the ground surface; unknown underground leaks could lead to significant amounts of water loss even though the breaks are not visible on the surface.
- Procedures have not been developed to specifically rank and prioritize which pipelines should be replaced.

For these reasons, MWH recommends a continued focus on the pipeline replacement program, replacing not only those pipelines with actual pipeline breaks, but also those pipelines with similar characteristics (material, soil type, system pressure) as those that have experienced a large of pipeline breaks.

MWH also recommends refining the risk-based ranking system to prioritize the City's pipeline replacement program. A risk-based approach considers two components: the probability of failure and the consequence of failure.

5.2.9.5.1 Probability of Failure

The probability of failure is a scoring system that predicts the probability of any single pipeline failing, based on predictive deterioration and failure history. While the historical number of pipeline breaks is a key component in probability of failure, other factors including age, system pressure, or pipeline breaks in similar pipelines may warrant consideration in developing scores identifying the probability of failure. Each pipeline segment would be ranked with a condition score ranging from excellent to very poor.

5.2.9.5.2 Consequence of Failure

The consequence of failure is a scoring system that predicts the effects of a failed pipeline. Not all pipeline breaks are equal: some are catastrophic and have significant effects on the surrounding community when the break when large sinkholes appear in the roadway or lead to property destruction, either due to the sinkholes created or due to flow water. Other breaks may have a significant impact on the community's water system, lead to shutdowns of water supplies to large portions of the City or to major facilities (such as hospitals and schools). Other criteria, such as the ability to deliver fire flow, could also be included in developing the consequence of failure scores. Each pipeline segment would be ranked with a score of low impact, medium impact, or high impact.

5.2.9.5.3 Risk Rating

Combining the probability of failure and consequence of failure, a risk rating can be developed. This risk rating would guide the City in their pipeline replacement programs, as those pipelines with the highest risk rating would be replaced first as shown in **Figure 5-47**.

Figure 5-47: Prioritization for Pipeline Replacement Program

Risk Ranking		Probability of Failure (Condition)				
		Excellent	Good	Fair	Poor	Very Poor
Consequence of Failure	Low Impact	Very Low Priority	Very Low Priority	Very Low Priority	Low Priority	Medium Priority
	Medium Impact	Very Low Priority	Very Low Priority	Low Priority	Medium Priority	High Priority
	High Impact	Very Low Priority	Low Priority	Medium Priority	High Priority	Very High Priority

5.2.10 Transmission Pipelines

The following is a first approach look at the needs for a Pipeline Condition Assessment program for the City of Boulder, Colorado. This assessment is for larger diameter transmission pipes defined as 14-inches and larger. An assessment is already underway and consists of a spreadsheet method listing all of the significant pipelines within the City water supply system. Each pipe is listed at to the type, size, length, construction date, initial cost and projected replacement cost. However, each pipeline is shown with a 'total useful life' of 75 years. Pipe materials range through the following materials

- ACP (asbestos cement pipe),
- DIP (ductile Iron pipe)
- Steel (steel pipe)
- PVC (polyvinylchloride pipe)
- CIP (cast iron pipe)
- PCCP (pre-stressed concrete cylinder pipe)
- RCCP (reinforced concrete cylinder pipe)

No information is provided as to the current condition, original wall thickness or pressure class of the pipe. This is a large range in pipe materials and it would be expected that the design service life for the pipelines would be also largely different.

Pipeline life expectancy information presented in the industry varies by pipe use, material type and source of the data (test or manufacturer). Most of the information on pipeline life is provided by the pipeline manufacturers who are vested in the information presented. A range of pipeline life observed from an internet search reviled pipeline life expectancies from 50 to 2830 years (refuted by another manufacturer). An interesting article also brought the time of manufacture into the equation, indicating that pre-world war II pipe materials appeared to out-perform post WWII products.

The life of the pipeline is dependent on a lot of factors; some of these are listed below:

- **Oxidation** – rusting of the base material due to expose to air (oxygen).

- **Corrosion** – various forms – chemical, electrolysis.

- **Erosion** – produced by high velocity and grit in the stream.

- **Degradation** – reaction of the pipe or coating system with the surrounding environment, such as softening of PVC and HDPE in high hydrocarbon saturated soils.

Therefore the best that can be provided is an approximate life expectancy range. **Table 5-41** shows the typical industry standards for life expectancy in a corrosive environment, and the City's anticipated transmission pipe life expectancy.

Table 5-41: Transmission Pipe Life Expectancy

Pipe Type	Typical Life Expectancy	City of Boulder's Anticipated Life Expectancy	Life Expectancy Used in Asset Management Replacement Forecasts	City of Boulder's Experience with Life Expectancy
ACP (asbestos cement pipe)	20 to 50 years	50 years	50 years	• No experience of problems
DIP (ductile Iron pipe)	30 to 70 years	60 years	60 years	• Experience of external corrosion due to construction deficiencies
Steel (steel pipe)	30 to 70 years	70 years	100 years[1]	• No experience of problems. Believed that construction and inspection techniques were good.
PVC (polyvinylchloride pipe)	50 to 100 years	100 years	100 years	• No experience of problems. Not subject to corrosion
CIP (cast iron pipe)	50 to 75 years	75 years	75 years	• Pipe has exhibited superior performance to DIP with respect to corrosion due to additional wall thickness typical of CIP
PCCP (pre-stressed concrete cylinder pipe)	30 to 50 years	50 years	100 years[1]	• No experience of problems. Believed that construction and inspection techniques were good.
RCCP (reinforced concrete cylinder pipe)	30 to 75 years	75 years	100 years[1]	• No experience of problems. Believed that construction and inspection techniques were good.

[1]Life expectancy for fiscal analysis was increased based on judgement of City staff. Continued monitoring will be performed to verify this approach through the coming years.

The information shown above is not to be considered conclusive, it is only provided to define the potential pipe life that might be expected. Various applications for these materials have provided much shorter and much longer service life for the respective pipe materials

The order of precedence that is recommended for pipe condition assessment by pipe type is as follows.

- ACP (asbestos cement pipe),
- PCCP (pre-stressed concrete cylinder pipe)
- Steel (steel pipe)
- DIP (ductile Iron pipe)
- RCCP (reinforced concrete cylinder pipe)
- CIP (cast iron pipe)
- PVC (polyvinylchloride pipe)

This order is based on general industry observations for pipe failures. The **ACP pipe** not only is carcinogenic but it also grows radially while under pressure, and is highly brittle and susceptible to shock failures caused by surge pressures. Hoop expansion is the result of the AC fibers pulling in the cement matrix in the pipe wall. **PCCP pipes** of the 1970's used pre-stressing wire that is highly susceptible to corrosion due to the manufacturing process used. The wire, in some cases, can corrode from both the interior and the exterior (wire drawing process created a hollow core). It is only recently that the PCCP pipe manufacturer have banded together to develop a more stringent standard for the manufacture of this type of pipe. **Steel pipe** is a highly corrosive material due to electrolysis and is very reliant on the applied coating system for protection. The standard coating system 20 to 30 years ago was coal tar enamel, which breaks down with time and exposure. **DIP pipe** is a less corrosive material than steel due to the graphite particles in the matrix. However, the graphite particles are surrounded by the ductile iron material which is susceptible to corrosion. **RCCP pipe** is an embedded steel cylinder within a reinforced concrete pipe. The mortar lining and coating usually provide excellent buffering for the steel core cylinder, thus protecting it from corrosion. **PVC pipe** is the least corrosive influenced material, however, it is susceptible to fatigue (cyclic stress) and surge shock pressures (material becomes more brittle with age).

A recommended approach to the condition assessment of the pipelines in the City's system is shown in **Table 5-42**. A condition assessment checklist is included in **Appendix G**.

Table 5-42: Condition Assessment Process

Stage 1: Criteria for selecting condition assessment	➡	• Review Records • Define Corrosion Environments • Geotechnical Review of Area • Develop List of Methods For Inspection • Define Risk Based Criteria • Definition of data gathering process • Workshop and review • Stage 1 Technical Memorandum
Stage 2: Field condition assessment program and survey	➡	• Internal inspection and remove and test sections with joints • Corrosion Potential Study • External (Corrosivity, concrete condition, and remaining wall thickness) • Leak tests • Invasive Testing – Smart Ball/Sahara • Stage 2 Technical Memorandum • Data Compatible with City GIS
Stage 3: Analysis of condition assessment data	➡	• Current Factor of Safety (FOS and condition grade • Failure probability vs. age curves • Structural evaluation, hydraulic evaluation and options for capacity • Stage 3 Technical Memorandum
Stage 4: Preparation of cost intervention, rehabilitation and replacement program	➡	• List of pipes for intervention • Best rehab/replacement options identified • Optimum time for future intervention identified • Workshop and review • Stage 4 Technical Memorandum with cost asset management program
Stage 5: Develop Pipe Condition report and implementation plan	➡	• Hold workshop to review report implementation plan • Written report summarizing the Pipe Condition Assessment and Implementation Plan
Stage 6: Archive	➡	• Archive the following information of all new and existing pipes: • Engineer of Record • Materials Specifications • Manufacturer and Submittals • Construction Specifications – embedment material, type of joint, joint restraint technique • Construction Drawings

6 Asset Management

Asset management has become an important process for the City of Boulder to estimate and justify the overall renewal and replacement CIP and maintenance budgets in a strategic, defensible manner. Through a variety of recent asset management projects, including this one, the City is establishing a foundation of understanding on which it can build a more proactive asset management program to better strategically manage its water infrastructure, prioritize improvements, and maintain the value of its water asset base investment while maintaining the levels of service its customers expect.

Going forward, the City may wish to take advantage of the asset management work to date on water assets with similar approaches for wastewater, stormwater, and flood management assets and tie-in an associated framework of enabling strategies, processes, data structure, and technology. These will help to coordinate and operate a successful, ongoing asset management program for the City.

As a key strategy, Boulder should commit to monitoring and managing its wet infrastructure assets according to risk, and tie-in ongoing alignment of levels of service targets for reliability and risk management with the funding levels allocated for ongoing proactive asset renewal. The purpose of this approach is to dedicate more of Boulder's limited resources toward assets that present the most risk to FCU in terms of providing reliable services to its customers. By focusing on these higher risk assets, FCU should get the most value in terms of managing its risks for every dollar invested.

6.1 Previous Asset Management Studies

Two previous asset management studies were performed recently, and are describe in the sections following:

- Betasso Water Treatment Plant Asset Management Pilot (2009)
- Iris and Cherryvale Pump Stations – Asset Management Update (2010)

6.1.1 Betasso WTP Asset Management

The Draft Betasso WTP Asset Management Pilot report, completed by Carollo Engineers in 2009, consisted of an assessment of existing asset management practices and information systems used at the BWTF, recommendations of an approach and improvements for asset and data management, and implementation of a pilot for the facility sludge lagoon and drying bed facilities.

The Betasso Asset Management Pilot included enhancements to each of the three primary information systems involved in managing asset data for the facility including the FastMaint CMMS, a base AutoCAD drawing, and the Asset Management Spreadsheet. In addition, it provided an implementation plan for further upgrades, including:

1. Update rehabilitation and replacement cost estimates in the Asset Management Spreadsheet
2. Complete synchronization of FastMaint and Asset Management Spreadsheet Asset IDs
3. Complete development of AutoCAD Asset Management Base Drawing

4. Conduct criticality evaluation and risk assessment for all assets
5. Conduct evaluation of CMMS Alternatives for asset management support
6. Implement enhancements to FastMaint (SQL Server, Web) or other CMMS
7. Formalize asset management business process documentation

For further information, the reader is referred to the Draft Betasso WTP Asset Management Pilot report.

6.1.2 Iris and Cherryvale Pump Stations Asset Management

In 2010, Richard P. Arber Associates conducted an asset valuation of the Iris and Cherryvale pump station facilities as part of the Water Utility Master Plan Update. In the Final Technical Memorandum, Arber presented the updated asset matrix for these facilities and its basis.

6.2 Asset Management

As part of this Treated Water Master Plan, MWH performed an asset management update for the BRWTF and stranded facilities (treated water hydroelectric and PRV facilities and treated water storage reservoirs). The objective of this task was to develop a more comprehensive asset management approach to help the City better estimate the overall renewal and replacement CIP and maintenance budgets.

The information was derived through workshops, desktop analysis, and field observations to evaluate, refine, and update the condition scores and replacement cost estimates of facility assets at the BRWTF and stranded facilities. The stranded facilities considered in this analysis included:

- 101 Pearl and Sunshine PRV facilities
- Sunshine, Orodell, Maxwell and Kohler hydroelectric facilities
- Gunbarrel, Maxwell, Booton, Devil's Thumb, Kohler, and Chautauqua reservoirs

Primary activities included:

- **Asset Data Review and Gap Filling:** The City's asset data for the facilities mentioned above were reviewed and analyzed for completeness for condition-based planning purposes. Analyses of the asset base included completeness and distributions of key parameters such as asset use, size, material, age, and condition. Data gaps were addressed using City and MWH staff knowledge, as well as professional judgment.

- **Asset Condition Scoring:** Condition scores were developed for each asset through workshops, desktop analysis, and field observation using industry best practices.

- **Renewal Cost Forecasting and Budget Scenario Analysis:** Long term (50-year) cost forecasts were developed for the City's facility assets. The results of these long-term forecasts enable the City to determine budget levels needed for the long-term renewal and replacement of its assets.

Findings highlights from this analysis include:

- Data for the BRWTF were more complete than for the stranded assets. However, further review of project and facility documents helped to fill gaps. Some asset details remain to be investigated and quantified to further refine some estimates.

- The condition scores for BRWTF assets were generally good. However, the condition of some dams and treated water reservoir tank roofs and piping was generally worse.

Facility data workbooks of the BRWTF and stranded facility assets were adapted into new spreadsheet files for the purposes of probability of failure scoring and renewal forecasting. MWH prepared the initial workbooks and several subsequent revisions for review, comment, and revision by City staff. As part of the scope of this effort to be consistent with the previously completed asset management Pilot project, this asset management effort is built off of the output format, condition fractions, and cost factors developed during the Pilot. It took an additional step to develop a more robust analysis tool for the City utilize for consequence-based asset analysis for capital improvements planning into the future, which will serve as an important foundation for a more strategic risk based analysis down the road.

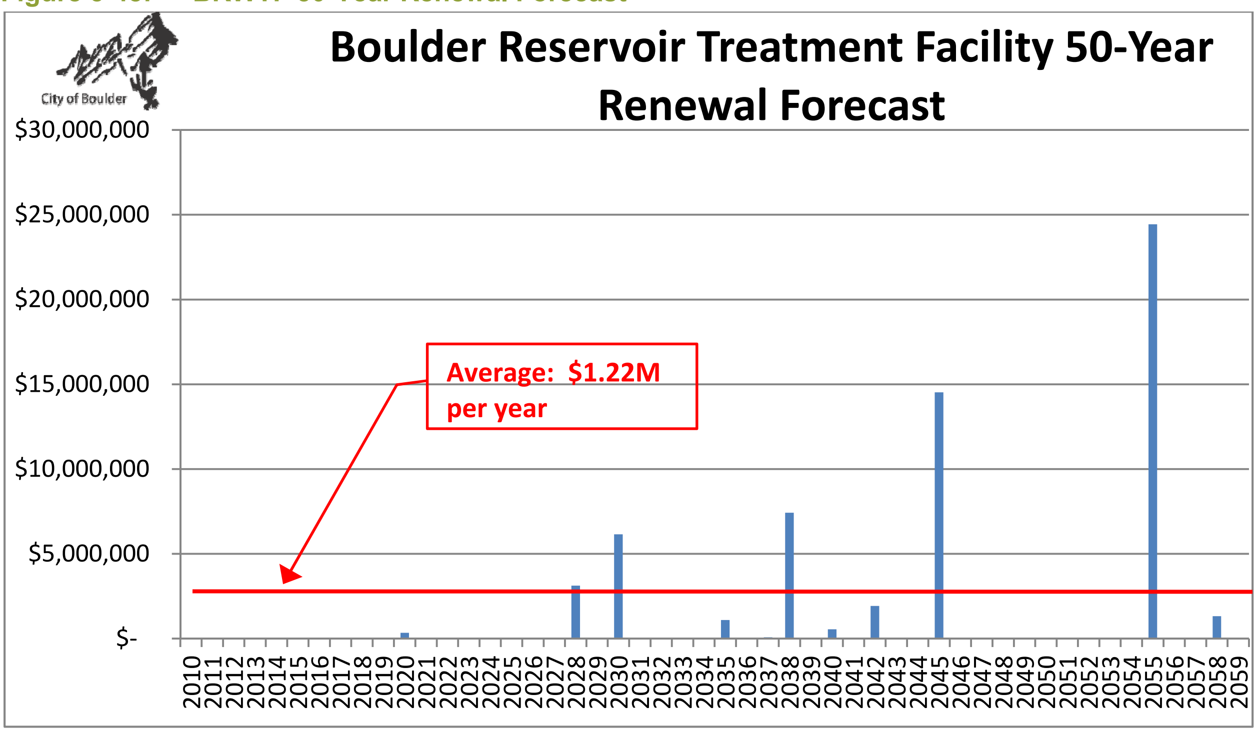
Additionally, City staff performed asset management updates for other water utility facilities including the BWTF, treated water pump stations, and treated water transmission lines using existing spreadsheet tools and adaptations of the asset management workbooks prepared by MWH. Ultimately, in order to facilitate consistency between the asset management workbook output/results and the City's financial and budgeting processes, the final asset management workbooks were prepared by City staff. A summary of the output from the finalized workbooks is presented in the following sections. However, workbook revisions and adaptations made by City staff to obtain the necessary consistency were not reviewed in detail by MWH. The full asset management report can be found in **Appendix G**.

6.2.1 Boulder Reservoir Water Treatment Facility at 63rd Street

The BRWTF asset management results are summarized in **Figure 5-48**.

As shown in **Figure 5-48**, average repair and renewal costs for the BRWTF are estimated at a 50-year investment need of $61M, or $1.2M per year.

Figure 5-48: BRWTF 50-Year Renewal Forecast



Projected costs well above the annual average occur in the following years as indicated below.

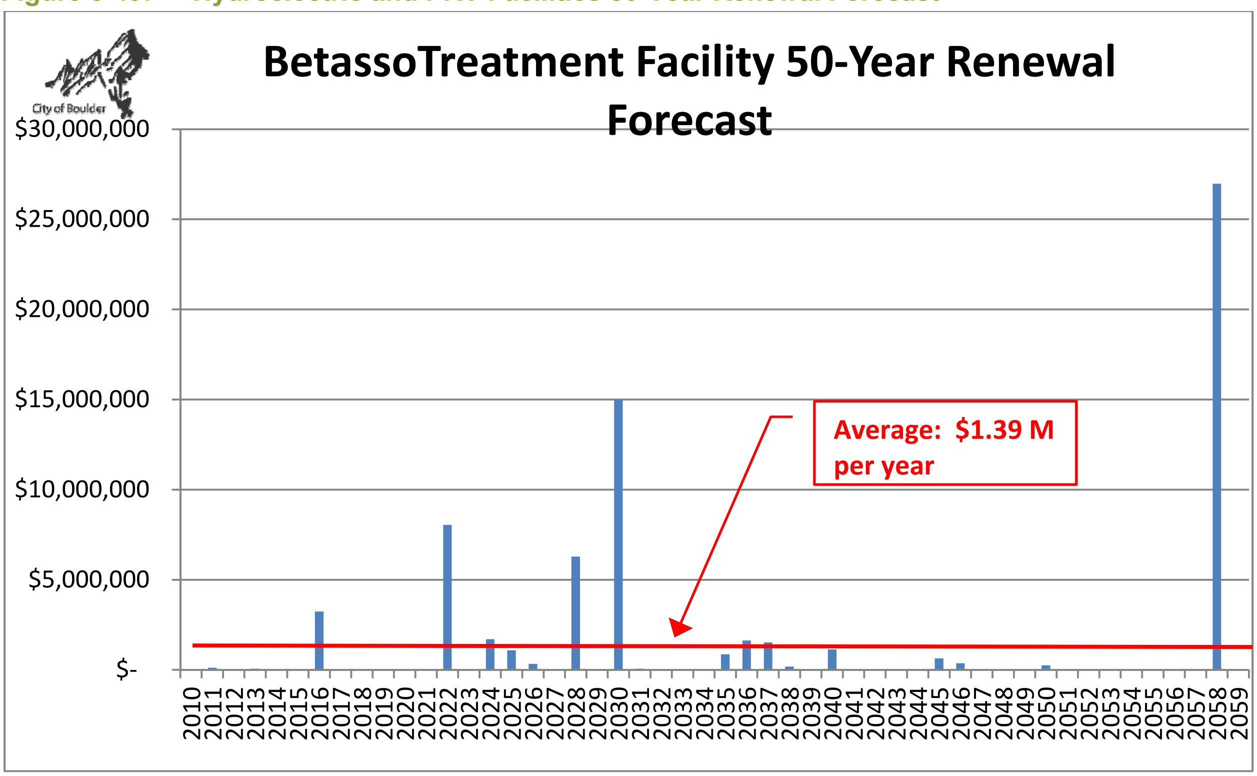
- **2030:** DAF mechanical, piping, and I&C and electrical renewal at $6.2M.
- **2038:** Filter Building and High Service Pump Station renewal and Administration Building I&C renewal totaling approximately $7.4M.
- **2045:** $14.5M in renewal needs are expected in 2045, mostly for the DAF building including $4.8M for DAF equipment, $2.1M for I&C, and $3.4M for MCCs and panels.
- **2055:** $24.4M predominantly for Filter Building filters 3 and 4 renewal.

6.2.2 Betasso Water Treatment Facility

An asset management spreadsheet was previously prepared by Carollo Engineers outside of the master plan project but was updated by City staff for consistency with master plan financial and budgeting process. The updated results are summarized in in **Figure 5-49**.

As shown in **Figure 5-49**, average repair and renewal costs for the BWTF are estimated at a 50-year investment need of $69.5M, or $1.39M per year.

Figure 5-49: Hydroelectric and PRV Facilities 50-Year Renewal Forecast



Projected costs well above the annual average occur in the following years as indicated below.

- **2022:** $8M in renewal needs are expected in 2022, $4.8M for filter media replacement, $1.7 M for residuals handling, and $2.7M in miscellaneous piping, valves, and vault renewal.
- **2028:** $6.2M in renewal needs is expected in 2028 with $3.4M for preliminary treatment sludge collectors and $1.2M for diesel generator replacement.
- **2030:** Approximately $15M in renewal needs are expected in 2045, with $4.7M for the DAF pumping system, $7.7M for Finished Water Reservoir No. 2, and $1.3M for the filter surface wash water system.
- **2058:** Approximately $27M the majority of which is for renewal of Finished Water Reservoir No. 1.

6.2.3 Asset Management for Other Facilities

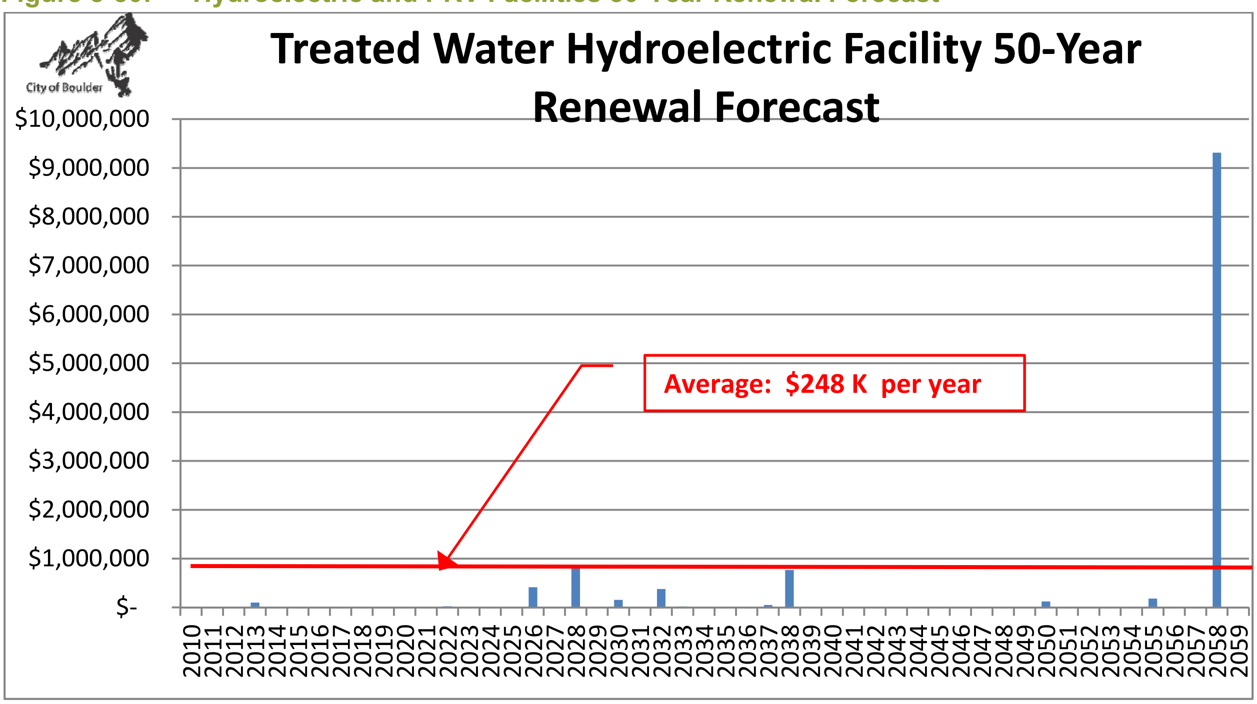
In addition to the treatment facilities, other facilities including PRV, hydroelectric, pump stations, and storage facilities were analyzed.

6.2.3.1 Asset Management for Treated Water Hydroelectric and PRV Facilities

Estimates for hydroelectric and PRV facilities total to about $12M over 50 years, or a $0.25M average annual expenditure.

The results of the hydroelectric and PRV analysis are presented in **Figure 5-50**.

Figure 5-50: Hydroelectric and PRV Facilities 50-Year Renewal Forecast



Projected costs well above the annual average occur in the following years as indicated below.

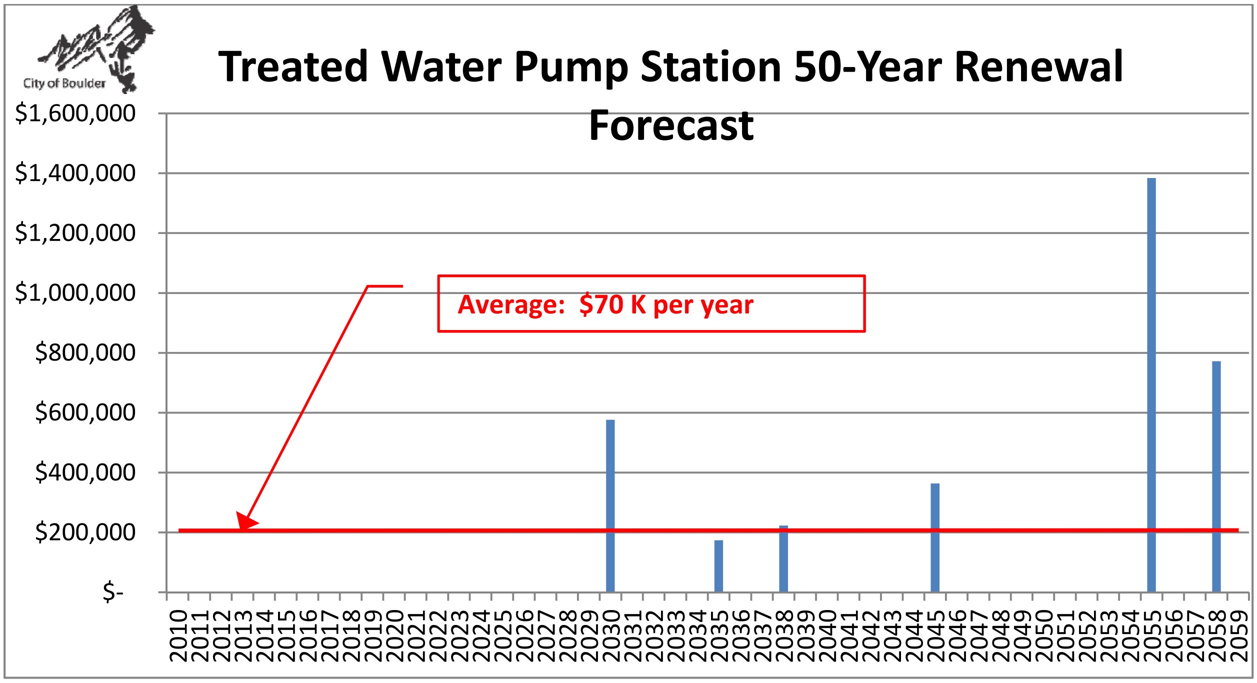
- **2058:** Approximately $9.3M with $7.5M allocated for renewal of the Sunshine Hydro facility.

The $7.5M is mostly comprised of needs for renewal of a large portion of its original components and its turbine/generator.

6.2.3.2 Treated Water Pump Stations

As shown in the figure below, average repair and replacement costs for treated water pump station facilities are estimated at $0.07M per year, or about $3.5M over 50 years.

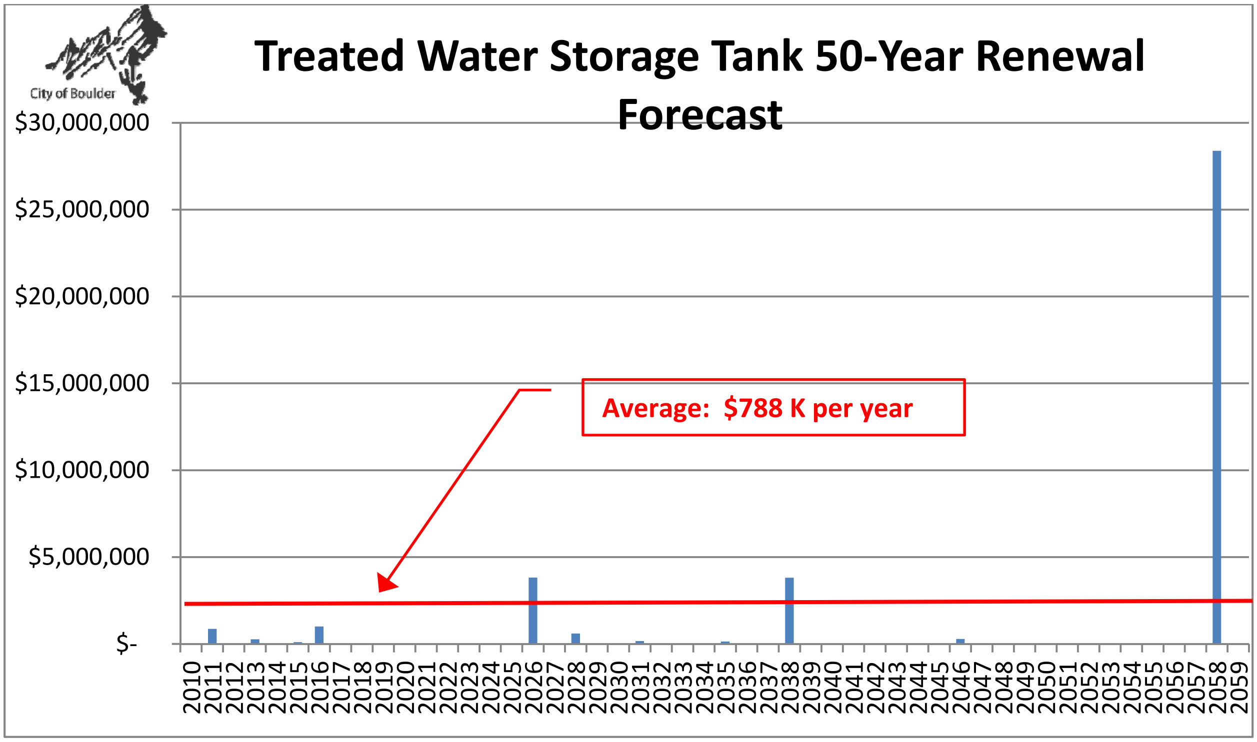
Figure 5-51: Pump Station 50-Year Renewal Forecast



6.2.3.3 Asset Management for Treated Water Storage Facilities

As shown in the figure below, average repair and replacement costs for treated water storage facilities are estimated at $0.79M per year, or about $39M over 50 years.

Figure 5-52: Water Storage 50-Year Renewal Forecast



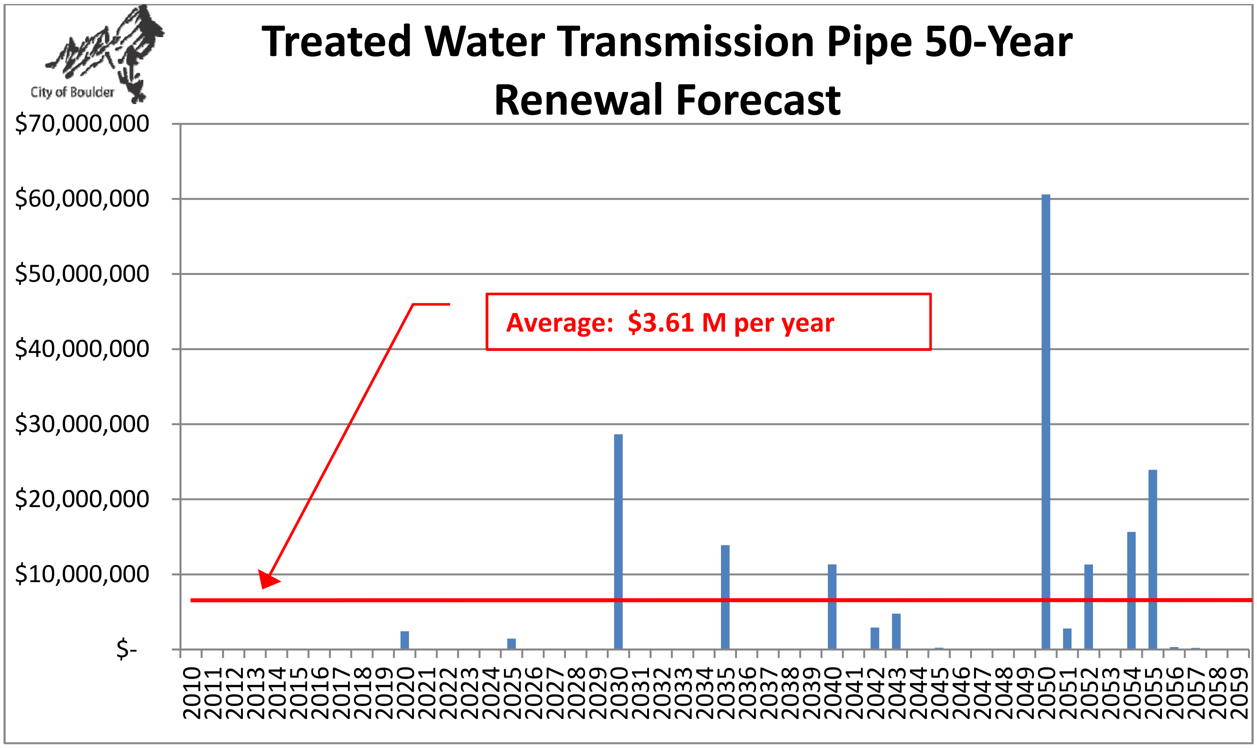
Projected costs well above the annual average occur in the following years as indicated below.

- **2058:** Approximately $28.3M largely for the replacement/renewal of the Devils Thumb Reservoir.

6.2.4 Asset Management for Treated Water Transmission Mains

The City of Boulder updated the asset management spreadsheets for the treated water transmission mains. The 50-year renewal forecast for transmission mains (pipes 14-inches and larger) was generally developed based on age and useful life with the exception of a few known problematic areas in the system. The results of this analysis are presented in **Figure 5-53.**

Figure 5-53: Transmission Main 50-Year Renewal Forecast



Projected costs well above the annual average occur in the following years as indicated below.

- **2030:** $28.6M in renewal needs are expected in 2030, $7.8M for Pressure Zone 1 pipeline renewal/replacement, $13.8 M for Pressure Zone 2 pipeline renewal/replacement, and $7.1M for Pressure Zone No. 3 pipeline renewal/replacement.
- **2035:** $13.9M in renewal needs are expected in 2035, $4.7 M for Pressure Zone 2 pipeline renewal/replacement, and $9.2M for Pressure Zone No. 3 pipeline renewal/replacement.
- **2040:** $11.3M in renewal needs are expected in 2040, $4.8M for Pressure Zone 1 pipeline renewal/replacement, $5.4 M for Pressure Zone 2 pipeline renewal/replacement, and $1.2M for Pressure Zone No. 3 pipeline renewal/replacement.
- **2050:** $60.6M in renewal needs are expected in 2050, $6M for Pressure Zone 1 pipeline renewal/replacement, $17.8 M for Pressure Zone 2 pipeline renewal/replacement, and $36.7M for Pressure Zone No. 3 pipeline renewal/replacement.
- **2054:** $15.7M in renewal needs are expected in 2054 all for Pressure Zone No. 3 pipeline renewal/replacement.
- **2055:** $23.9M in renewal needs are expected in 2055 all for Pressure Zone 2 pipeline renewal/replacement.

6.2.5 Overall Asset Management Results

Based on the analysis performed, approximately $7.3M per year should be budgeted to ensure the sustainable repair and renewal of these water system facilities to attain the 50-year needs of $365M. With this project, the City has taken important first steps in enhancing its approach to asset management for its water utility facilities. Several of these achievements pertaining to these facilities are listed below:

- Gap filling and reconciliation of asset data
- Assigning initial condition scores to determine the probability of failure – an important first step to being able to develop risk scores
- Developing long term (50-year) renewal forecasts
- Constructing asset management workbooks the facility categories

Potential near-term enhancements to the City's existing asset management approach to consider include:

- Migrating asset data into one database driven application for more robust capabilities.
- Establishing a data framework to have a clear and consistent asset hierarchy and asset registry.
- Incorporating the consequence of failure analysis to enhance the condition-based analysis of this task to strive for an enhanced asset renewal forecast that is risk-based.
- Establish a process to enable and support ongoing and regular updating of data, scores, and overall asset management strategy.

This proactive and comprehensive understanding of the City's condition profile will allow the City to address its current and expected future asset needs through careful planning and management of its inspection, maintenance, and asset repair and replacement activities.

6.3 Summary of Boulder's Overall Asset Management Strategy

Asset management has become an important process for the City of Boulder to estimate and justify the overall renewal and replacement CIP and maintenance budgets in a strategic, defensible manner. Through a variety of recent asset management projects, including this one, the City is establishing a foundation of understanding on which it can build a more proactive asset management program to better strategically manage its water infrastructure, prioritize improvements, and maintain the value of its water asset base investment while maintaining the levels of service its customers expect.

Going forward, the City may wish to take advantage of the asset management work to date on water assets with similar approaches for wastewater, stormwater, and flood management assets and tie-in an associated framework of enabling strategies, processes, data structure, and technology. These will help to coordinate and operate a successful, ongoing asset management program for the City.

As a key strategy, Boulder should commit to monitoring and managing its wet infrastructure assets according to risk, and tie-in ongoing alignment of levels of service targets for reliability and risk management with the funding levels allocated for ongoing proactive asset renewal. The purpose of this approach is to dedicate more of Boulder's limited resources toward assets that present the most risk to Boulder in terms of providing reliable services to its customers. By focusing on these higher risk assets, the City should get the most value in terms of managing its risks for every dollar invested.

Additional recommendations for asset management at the City include:

1. Efficiently **assess** its asset management capabilities against industry best practices across strategy, people, processes, data, tools, and performance to identify "quick win" improvements to attain stakeholder buy-in and chart a roadmap to improvement across these areas.

2. Develop an ongoing, **programmatic approach** to asset management to drive more proactive asset strategy throughout the organization in a coordinated manner and realize benefits associated with more defensible renewal budgets and utility performance. A quality asset management program will have both planning and implementation components, build on existing efforts, staff knowledge, and tools, and reach across water, wastewater, stormwater and flood management vertical (i.e, facilities) and horizontal (i.e., pipes) assets.

3. Create an overarching **vision and guiding policies** and a plan to communicate them to attain staff buy-in, understanding, and coordinated and useful contributions to better asset management.

4. Identify the targeted **levels of service to customers** that the City idealizes through enhanced asset management and associated performance metrics to help steer priorities and decisions related to the ongoing maintenance, repair, and replacement of assets.

5. Structure a **data framework** to have a clear and consistent asset hierarchy and asset register, communicable throughout the organization, that can be used to consistently structure and organize asset data, as well as enable better data version control, completeness, utilization, and integration in and between software platforms including UMMS, GIS, and CAD.

6. Apply a highly defensible and transparent, proactive **risk based** approach to renewal forecasting across vertical and horizontal assets to consider the criticality of assets in addition to just their condition for repair or replacement across all asset groups. The risk based approach could be similar, but more proactive than the one currently utilized for reactive maintenance of pipelines.

7. Analyze the City's **key enterprise IT systems**, including those for the UMMS, financial management, CIS, GIS, document management system and other key technology as well as their current use, performance, and objectives. Weigh Commercial Off-the-Shelf options with needs and against the City's present enterprise systems to determine the best tools, processes, and integration to meet the needs and visions of the City across its asset base and consider an overall asset management platform tool and dashboard.

8. Establish **business processes** to enable and support ongoing enhanced asset management, regular updating of condition/risk scores, and asset management strategy.

9. **Roll-in climate adaptation planning** and vulnerability assessment of source water asset and others into risk based asset management planning.

7 TWMP Recommendations and Conclusions

7.1 Treatment Facilities

The following are recommendations related to mid to high priority items taken from the CIP list. Due to the "visionary" nature of the lower priority items contained in the CIP list, no discussion or recommendations are provided for these items as they are not expected to reach a sufficient priority level to warrant discussion prior to the next master plan update.

7.1.1 Betasso Water Treatment Facility

The evaluations of the water quality and plant operating data yielded the following conclusions which form the basis of the recommendations provided in the subsequent section.

- The BWTF has the capability to treat a peak flow of approximately 40 MGD to the level required to meet current regulatory requirements. Capacity is limited by the flocculation and filtration processes. All other processes have capacities equal to or greater than 50 MGD and process piping has the hydraulic capacity to convey 50 MGD without restriction.

- Performance data suggests that actual sedimentation capacity is less than the theoretical value due to poor flocculation, possibly poor coagulation and the less than optimum sedimentation basin configuration.

- Performance data suggests that the actual filtration capacity maybe less than the design value of 5 gpm/ft2 due to low UFRV's particularly in filters 1-4 and during periods of high color. The actual cause(s) of the low UFRV's and the corresponding capacity limitation at the BWTF is likely a combination of one or more issues and requires further study for a conclusive determination.

- To go beyond the current sustainable plant flow, the UFRV of Filters 1 through 4 and for the period of high color needs to be increased.

- The operations staff has done well to manage the operation of the plant during challenge conditions, to produce high quality treated water, and to shift the treated water production to the BRWTF when the existing capabilities of the BWTF are reached. As a result, a clear picture and definitive understanding of the reported pretreatment capacity problems at plant flows of 30 to 35 MGD was not achieved. This is thought to be primarily due to the fact that there is limited plant performance data to review at these flows.

- The lagoons are at their capacity for storing the dilute sludge from the sedimentation basins. A thickening process would help to reduce the sludge volume significantly.

- Filters 1 through 4 were constructed at a different time than filters 5 through 8 and as a result they may have different underdrain systems, which could account for some of the differences in UFRV between the filters. In addition, some of the fines may have been removed in filters 1 through 4 during the episodes of air entrainment, which now have been resolved.

- Filters 1 through 4 have been in operation longer than what Filters 5 through 8 have been. Being in operation for a longer period of time provides more of an opportunity for the underdrains to become clogged with mineral deposits.

- Improving the filterability of the floc formed through the treatment for color removal will have a marked improvement on the overall treated water production as color has to be removed from the source water about 25% of the time.

- The City has determined that they do not plan on closing any of the waste impoundments at the BWTF.

The following recommendations are made based on these conclusions:

7.1.1.1 Studies

1. Perform a series of bench-, pilot-, and plant scale tests to evaluate plant performance at flows near the desired capacity of 46 MGD. The test should be performed during the spring runoff when the concentration of color is at peak values. Consideration should be given to evaluating flocculation and filtration aids and alternative strategies for improving the filterability of the floc. The plant-scale test will provide an opportunity to further investigate the reported pretreatment problems at flows in excess of 30-35 MGD and to verify the maximum filter hydraulic loading rate.

2. Perform an inspection of the filter underdrains in Filter Nos. 1 and 5 to check for clogged passages.

3. Perform a grain-size distribution and sieve analysis of the media in Filter Nos. 1 and 5 to determine and compare characteristics of the media.

4. To determine the accuracy of the flow measurement at BWTF it is advisable to hire a consultant who specializes in this type of flow measurement to perform a thorough review of all measurement devices, their installation and signal conversion from meter readings to flow output on the control panel. This study would confirm whether the flow meters are properly installed and calibrated, and whether any modifications are required. It is also advisable to investigate potential locations and flow measurement technologies for combined influent flow measurement at the head of the plant. This flow measurement should take place upstream of any side-stream processes. Accurate combined influent flow measurement is essential to be able to confirm upstream flow measurement and losses through the treatment process. Accurate treated water flow measurement is equally important to determine the treated water capacity of the plants and also to ensure efficiency throughout the system.

5. The City should perform sampling and testing of waste streams flowing into the BWTF waste impoundments to determine type of impoundment and if improvements are needed. The results of this study should include recommended improvements and suggest a timeline for inclusion in either the capital improvements or operations and maintenance budget.

6. Pilot studies should be performed on thickening options for the residuals from the sedimentation basins.

7. Develop viable workforce strategy that includes appropriate succession planning and knowledge transfer.

8. Investigate changes or other systems that could improve operational ease of the lime feed system.

9. Investigate cost of converting from fluorosilicic acid to sodium fluorosilicate to reduce trace contaminants.

Capital Improvements

1. Improve performance of the pumped-diffusion mixer by adding either a VFD on pump or a flow control valve and providing an additional coagulant feed point in the pump header immediately upstream of the spray nozzle.

2. Improve the residuals thickening, dewatering, and drying process by constructing two new gravity thickeners to thicken the suspended solids coming from the sedimentation basins and installing a centrifuge-type dewatering facility to treat the float from the DAF and gravity thickeners. This may be best accomplished through two projects: thickening and dewatering.

3. Pending the results of the plant-scale testing and the recommended plant capacity evaluation, decide whether to: 1) install flocculation/sedimentation basin baffling and equipment rehabilitation, or to 2) retrofit new flocculation facilities and lamella plate sedimentation system in existing basins.

4. Rehabilitate filter gallery including valve and actuator replacement and repainting of gallery piping.

5. Add more standby generator capacity. The current capacity is maximized.

6. Tie chemical feed control to SCADA.

7. Upgrade chemical storage facilities.

8. Add residual aluminum analyzer

9. Upgrade on-line instrumentation and SCADA reports.

7.1.2 Boulder Reservoir Water Treatment Facility (BRWTF) at 63rd Street

Evaluation of the BRWTF indicated that the plant is expected to be capable of consistently meeting known and foreseeable water quality requirements at a flow rate of 20 MGD. A number of improvements were identified, however to enhance operability and reliability and to provide effective multiple-barrier protection and consistently high finished water quality. The evaluation of the BRWTF yielded the following conclusions which form the basis of the recommendations provided in the subsequent section.

- Significant improvements have been recently implemented to establish a firm capacity of 16 MGD under current and foreseeable regulatory requirements. Some relatively minor modifications to the DAF scraper mechanisms and resolution of finished water pump performance issues would increase firm capacity to 20 MGD. At 20 MGD, capacity is limited by multiple processes requiring more substantial modifications.

- The raw water intake at the BFC is reported to be unsafe. The corroded and poorly constructed access way and platform is in need of replacement. Additionally, the cleaning of the screen is currently done manually.

- The filters are currently in need of rehabilitation including the replacement and updating of internals, media, valves, actuators, filter control consoles, and instrumentation. The concrete walls are also in need of being recoated.

- The filter to waste capability and backwash pretreatment would be improvements that may be related to future regulatory requirements.

- The high service pumps have been problematic with evidence of cavitation and the inability to achieve design rated capacities.

- Operability of the plant is not as effective as it could be due to the inability to automatically respond to changes in plant flow and critical process parameters.

- If there are waste impoundments that the City plans to decommission in the near future, preparation of a closure plan and certification for the impoundments should occur before promulgation of the Section 9 Waste Impoundment Regulation.

- One of the most significant problems associated with operating the BRWTF is the difficulty in providing operating staff 24 hours a day during the peak use months while providing no operating staff during the off peak months. Remote operation of the facility has been discussed, but current instrumentation and controls would need to be greatly enhanced to allow this to occur.

- The new carbonic feed system needs to be monitored and evaluated for TOC removal effectiveness.

- Taste and odor concerns related to the presence of bluegreens in Boulder Reservoir should continue to be monitored by the City and these events should be recorded including any complaints that are received which could be related.

- BRWTFs reliability could be improved with the addition of backup power since the facilty currently relies on a single power feed from the local electric utility company.

- The reliability of BRWTF coming online and running at full capacity due to an unexpected shutdown at BWTF needs to be tested and evaluated.

- The City has determined that is does not plan on closing any of the waste impoundments at the BRWTF.

The following recommendations are made based on these conclusions:

7.1.2.1 City of Boulder Activities

- The City should monitor the effect of the new carbonic acid feed system as it relates to enhanced TOC removal. It is important to determine if further TOC removal enhancement such as preoxidation with chlorine dioxide will be necessary to meet lower DBP limits if this becomes the case at some point in the future.

- With the ever present possibility of requiring BRWTF to run at full capacity due to unexpected shutdowns at BWTF, the City should consider creating standard operating procedures for use during such events. Further to the standard operating procedures, the City should also consider implementing a regular schedule in which to test the functionality of the treatment plant and distribution system components under various outage conditions. Such regularly scheduled tests would aid the City's staff in determining weak points, refining procedures to allow for smooth transitions, and increasing the general preparedness for the unexpected. Particular items of concern include but are not limited to:

  - Ensuring treatment plant influent lines are kept relatively clean so that the scouring of sediment will not impact the ability of the plant to treat at full flow
  - Ensuring that the plant's chemical systems and general treatment capability are up to par and ready to treat the full 20 MGD
  - Verifying that the distribution system is capable of handling 20 MGD sourced from the BRWTF
  - Verifying that water can be lifted to Zone 3 in sufficient quantity
  - Miscellaneous security improvements defined by the Vulnerability Assessment should be reviewed and implemented as necessary.
  - Develop viable workforce strategy than includes appropriate succession planning and knowledge transfer.
  - Improve chemical mixing at the filter effluent post flume.

7.1.2.2 Studies

- A detailed evaluation of the existing filters should be conducted to determine the extent to which rehabilitation is required, particularly with regard to the underdrains and other components which can't be easily seen. As part of this study, the 2000 recommendation for adding filter to waste capability and backwash pretreatment should be revisited, especially with regards to future regulatory requirements.

- A study should be conducted to accurately define the problems with the finished water high service pumps, explore alternative pump styles and/or configurations, and perform a net present worth analysis to determine if the cost associated with the installation of VFD's can be justified.

- Taste and odor concerns related to the presence of bluegreens in Boulder Reservoir should continue to be monitored by the City and these events should be recorded including any complaints that are received which could be related. Depending on the frequency and severity of such events, the City may wish to initiate a study to determine preventative and/or treatment options to mitigate the issues related to the presence of bluegreens. The options investigated in this study may include the following:

  - The addition of Powder Activated Carbon (PAC) which may prove sufficient if the taste and odor issues are mild.
  - The use of Granular Activated Carbon (GAC) which has been shown to be reasonably effective.
  - The use of Ozone which is a strong oxidant and can be used to control more severe taste and odor events.
  - The implementation of reservoir management techniques which could reduce the formation of bluegreens in the source water.

- A study should be conducted to evaluate and recommend alternatives for redundant or back up power to the facility. Two alternatives include the installation of a second power feed from a different utility substation, or the installation of engine driven generators with sufficient capacity to run the BRWTF at full capacity. The results of this study should recommend a preferred alternative and suggest a timeline for inclusion in the capital improvements budget.

- The City should perform sampling and testing of waste streams flowing into the waste impoundments at the BRWTF to determine type of impoundment and if improvements are needed. The new lagoons should be evaluated to determine the structural integrity of basins and to determine if site drainage issues exist. The results of this study should include recommended improvements and suggest a timeline for inclusion in either the capital improvements or operations and maintenance budget. Should the City decide to decommission the old lagoons based on impoundment type and required upgrades, it should do so prior to promulgation of the Section 9 Waste Impoundment Regulation. A closure plan and certification for an impoundment will remove the impoundment from the regulation.

7.1.2.3 Capital Improvements

- Raw water delivery safety concerns and operator interaction with this intake can be minimized with the installation of an automated self-cleaning screen. When performing these upgrades, the City should also ensure that power and communication lines be routed to this location to allow for lighting and communication at this location.

- Automation of chemical systems has been identified as an operability issue that has the potential to improve treatment process performance and make more efficient use of chemicals. Chemical feed systems would be controlled to automatically respond to changes in plant flow and critical process parameters. Feed rates would be adjusted in small increments at frequent intervals so that the dosage at any given time will match the required dosage more closely than is possible with the current manual feed adjustment system. Automating the chemical feed systems would involve modifying or replacing any existing chemical feeders and metering pumps not capable of responding to control signals from a remote location. The plant SCADA system could be reprogrammed by City staff to provide the automatic control for the chemical systems. Additional instrumentation for flow and other process parameters would be needed to send signals to the SCADA system for analysis and conversion to control signals to the chemical feed systems.

- One of the most significant problems associated with operating the BRWTF is the difficulty in providing operating staff 24 hours a day during the peak use months while providing no operating staff during the off peak months. One option would be to provide the necessary instrumentation and controls to allow the plant to operate unmanned during the evening and overnight with remote monitoring and control from BWTF via the SCADA system. This would require the automation of the chemical feed systems, which would involve modifying or replacing any existing chemical feeders and metering pumps not capable of responding to control signals from a remote location. The SCADA system would be reprogrammed to provide the automatic control for the chemical systems. Additional instrumentation for flow and other process parameters would be needed to send signals to the SCADA system for analysis and conversion to control signals to the chemical feed systems and to trigger alarms for critical equipment failures or indicators of unacceptable process performance. Provisions for remotely shutting down the plant would also be provided for emergency situations such as failure of the disinfection system. Plant site security and monitoring would also need to be improved to prevent unauthorized entry and ensure safe operations during unmanned hours. In addition to providing adequate alarm systems and possibly surveillance cameras, the site would need to be closed during unmanned hours, which would impact users from other departments and agencies that use facilities at the site. The 2009 cost estimate for this work is $4.3 Million.

As regulatory requirements become increasingly stringent, accuracy and sensitivity in measurements for process monitoring and control becomes increasingly important. To maintain the necessary level of confidence and control necessary for optimal performance, on line instrumentation will need to be upgraded as new and better equipment is developed. A total organic carbon (TOC) analyzer and an improved alkalinity analyzer would enhance process monitoring and control. Other instruments identified by plant staff as useful are an in line manganese analyzer for Boulder Reservoir and a UV spectrophotometer.

The City currently has on-line turbidity monitoring on BFC water. However, the City may benefit from monitoring other water quality parameters such as TOC and/or ORP at this location in order to help the operators anticipate poor raw water quality events on the BFC water.

7.2 Distribution System Recommendations

Based on the discussion of the various distribution system components, the following recommendations are made in **Section 5**.

7.2.1 GIS/UMMS Recommendations

Below are some areas of GIS future development that have been identified, with cost estimates. Further explanation is provided in Section 5:

- Water Valve Location (GPS): $130,000
- GIS Integration with UMMS: $10,000

Below are some areas of UMMS future development that have been identified, with cost estimates. Further explanation is provided in Section 5:

- Work Order Tools: $10,000
- Cost Reporting: $10,000
- Street Patching Database Integration: $5,000

7.2.2 Hydroelectric Generating Facility Recommendations

The following recommendations are made for the hydroelectric generating facilities:

- The CMU Crack at the Maxwell Hydroelectric Station building should be inspected further to determine the cause and a repair procedure should be developed and implemented prior to further deterioration.

- Sunshine Hydroelectric Station has some minor damage to the stacked rock retaining wall around the perimeter. Additionally, based on discussions with field crews, a flow meter to the Sunshine hydro facility 30-inch diameter pipeline is recommended.

- The Orodell Hydroelectric Station needs a new actuator for the 12-inch bypass downstream isolation butterfly valve and a new battery backup for instrumentation and control.

7.2.3 PRV Station Recommendations

The following recommendation is made to the PRV stations:

- The 101 Pearl Street PRV has the potential for a grading improvement and a gravel or concrete pad for the parking/turn area.
- Based on discussions with field crews, a rehabilitation or replacement of the control system at the Sunshine PRV is recommended.

7.2.4 Storage Reservoir Recommendations

Based on interviews with operations staff, the following storage reservoir recommendations are made:

- Replace differential pressure sensors at Chautauqua Reservoir and Devil's Thumb Reservoir with level sensors.
- Improvements to allow for greater treated water reservoir mixing have occurred on Chautauqua, Kohler, Booton and Maxwell, and are planned for the others.
- Install new, redundant level sensors in all of the treated water reservoirs.
- The results of the 2010 CDPHE Sanitary Survey will require minor improvements to the reservoirs, including the installation of mesh screens on all openings on the reservoirs, and extensions on a couple of overflow pipes to ensure erosion does not occur.

Additionally, the following recommendations are made for the storage reservoirs from the structural evaluation.

The following recommendations are made for **Maxwell Reservoir**:

- Longitudinal crack close to the Southeast corner of the reservoir should be inspected further for the potential causes of the crack and a repair procedure should be developed before the winter season.
- Eroded soil areas along the perimeter of the reservoir should be inspected further for the cause of the erosion and a repair procedure should be implemented. Suggest replacing the grass/soil adjacent to the structure with free draining gravel to help with erosion.
- Construction and movement joints at the corners and at the midpoint of the North and South walls of the reservoir should be sealed from external weather before the winter season.
- The layout surrounding the reservoir ground access area should be investigated and a re-grading solution should be developed and implemented. The steel enclosure should be re-coated and the joints re-sealed.
- The roof at a minimum should be recoated or a new roof system should be developed to minimize trapping moisture against the concrete double tees.
- All coated surfaces should be analyzed to determine the current condition is adequate to prevent corrosion for external elements. Form the current visual inspection, there are many areas that need to be re-coated.

- Further investigation of the internal concrete floor and composite asphalt lining should be conducted to determine the condition and remaining service life. The leaking joints can lead to problems along the perimeter of the structure including settlement issues and possible contamination of the reservoir.

The following recommendations are made for **Kohler Reservoir**:

- The roof coating system has failed and should be repaired or the entire roof should be replaced. Further investigation is needed to determine the condition of the metal decking as well as the roof steel support framing members. It might be necessary to replace the entire roof system.
- Joints in the concrete walls that have opened up due to wall movements should be sealed and protected from external weather. This is necessary to prevent future erosion problems.
- Coating system on the gutter between roofs has failed and the condition of the gutter should be evaluated to determine if it should be replaced or re-coated.
- Further investigation of the internal concrete floor and composite asphalt lining should be conducted to determine the condition and remaining service life. The leaking joints can lead to problems along the perimeter of the structure including settlement issues and possible contamination of the reservoir.

The following recommendations are made for **Devil's Thumb Reservoir**:

- Rock pits surrounding the tank should be cleaned and re-coated on an annual basis.
- Finished Grade around the back side of the tank should be re-graded to allow proper drainage of the site.
- Rocks need to be removed from the roof.
- Further investigation into why the tank roof is dented and deformed is needed to identify if the possibility of the roof collapsing or failing in the near future exists.
- Concrete foundation needs to be protected or repaired.
- Vegetation next to the tank needs to be removed.
- Rain guard might need to be installed facing the opposite direction, further investigation is needed.
- Internal coating needs to be removed and re-coated because it contains lead.

The following recommendations are made for **Chautauqua Reservoir**:

- Perimeter wall shrinkage cracks should be "V" grooved and sealed to prevent future erosion.
- Built up roof system has failed and needs replacing. Suggest considering a separate roof system that isolates the roof from the concrete double tees.
- Roof vents need to be re-coated.

- Further investigation of the internal concrete floor and composite asphalt lining should be conducted to determine the condition and remaining service life. The leaking joints can lead to problems along the perimeter of the structure including settlement issues and possible contamination of the reservoir.

- Further investigation of the double tee shear tabs is needed to determine if the roof can perform as originally designed. New tabs might be needed, or the entire roof might need to be replaced.

The following recommendations are made for **Booton Reservoir**:

- Rock pits should be cleaned and re-coated on an annual basis.

- Vegetation should be kept from growing over the slab-on-grade and ultimately the adjacent soil should be removed and replaced with weed barrier and free draining rock.

- The bird nests and excrement should be removed from behind the soffit and along the tank. After cleaning the area, bird screens or wire mesh should be installed between the soffit and the roof overhang to keep birds from nesting behind the soffit.

- Investigate the purpose of the external box that might contain a corrosion protection device.

7.2.5 Distribution System Maintenance

The following recommendations are made for the distribution system:

- Continue the ongoing pipeline replacement program. A risk-based prioritization for the replacement program is recommended.

- Install online monitoring of chlorine residual, turbidity, and pH in key points in the distribution system, including at reservoirs and problematic areas. Connecting these online samplers to the SCADA system will allow staff to determine where problems exist and identify areas where localized flushing needs to occur or operational adjustments need to be made.

- Additional pressure and flow metering throughout the system is also recommended to confirm operational strategies and model accuracy. C-factor modeling is also recommended to determine the roughness in key pipes in the distribution system.

- Based on operator interviews, additional water quality sampling stations are recommended throughout the distribution system.

7.2.6 Further Studies

The following additional studies are recommended for the distribution system.

- There are some locations with pressures from the hydraulic model below 40 psi. Each of these should be investigated further to evaluate whether improvements need to be made to address these deficiencies.

- There are some locations with fire flow capacities from the hydraulic model below 1500 gpm. Each of these should be investigated further to evaluate whether improvements need to be made to address these deficiencies.

- Develop a risk-based approach to the pipeline replacement program to prioritize facility replacement.

- Staffing needs need to be evaluated and methods for knowledge retention developed with much of the workforce retiring over the next several years.

- A holistic review of the water and hydropower SCADA network has not been conducted since 1996. Through radio license re-farming, new telecommunications services, and improvements in public network data encryption, the wide area network options have substantially changed since 1996. The City could realize improvements in reliability and reduced recurring costs by reevaluating the entire SCADA system.

- A pipeline condition assessment study could assist the City in identifying problem areas of the distribution system.

7.3 Asset Management Recommendations

Based on the asset management analysis, approximately $7.3M per year should be budgeted to ensure the sustainable repair and renewal to attain the 50-year needs of the water utility facilities included in the analysis totaling $365M. With this project and the prevous pilot asset management project, the City has taken important first steps in enhancing its approach to asset management for its facilities.

Near-term recommendations for the City's existing asset management approach include:

- Migrating asset data into one database driven application for more robust asset management capabilities.

- Establishing a data framework to have a clear and consistent asset hierarchy and asset registry.

- Incorporating the consequence of failure analysis to enhance the condition-based analysis of this task to strive for an enhanced asset renewal forecast that is risk-based.

- Establish a process to enable and support ongoing and regular updating of data, scores, and overall asset management strategy.

Longer term recommendations for the City's asset management strategy include:

1. Efficiently **assess** its asset management capabilities against industry best practices across strategy, people, processes, data, tools, and performance to identify "quick win" improvements to attain stakeholder buy-in and chart a roadmap to improvement across these areas.

2. Develop an ongoing, **programmatic approach** to asset management to drive more proactive asset strategy throughout the organization in a coordinated manner and realize benefits associated with more defensible renewal budgets and utility performance. A quality asset management program will have both planning and implementation components, build on existing efforts, staff knowledge, and tools, and reach across water, wastewater, stormwater and flood management vertical (i.e, facilities) and horizontal (i.e., pipes) assets.

3. Create an overarching **vision and guiding policies** and a plan to communicate them to attain staff buy-in, understanding, and coordinated and useful contributions to better asset management.

4. Identify the targeted **levels of service to customers** that the City idealizes through enhanced asset management and associated performance metrics to help steer priorities and decisions related to the ongoing maintenance, repair, and replacement of assets.

5. Structure a **data framework** to have a clear and consistent asset hierarchy and asset register, communicable throughout the organization, that can be used to consistently structure and organize asset data, as well as enable better data version control, completeness, utilization, and integration in and between software platforms including UMMS, GIS, and CAD.

6. Apply a highly defensible and transparent, proactive **risk based** approach to renewal forecasting across vertical and horizontal assets to consider the criticality of assets in addition to just their condition for repair or replacement across all asset groups. The risk based approach could be similar, but more proactive than the one currently utilized for reactive maintenance of pipelines.

7. Analyze the City's **key enterprise IT systems**, including those for the UMMS, financial management, CIS, GIS, document management system and other key technology as well as their current use, performance, and objectives. Weigh Commercial Off-the-Shelf options with needs and against the City's present enterprise systems to determine the best tools, processes, and integration to meet the needs and visions of the City across its asset base and consider an overall asset management platform tool and dashboard.

8. Establish **business processes** to enable and support ongoing enhanced asset management, regular updating of condition/risk scores, and an overall asset management strategy.

9. **Roll-in climate adaptation planning** and vulnerability assessment of source water asset and others into risk based asset management planning.

7.4 Treated Water Improvement Project Recommendations

The purpose of this TWMP is to establish a record of the condition and needs of the City's treated water system for the next 20-year planning period. As part of this effort, a list of needed improvement projects was developed through discussions with City staff and recommendations from this master plan. AACE International Class 5 cost estimates were developed for each item on the list based on limited definitions of scope developed by MWH and City staff. The expected accuracy range for the estimates are from –20% to -50% on the low side and +30% to 100% on the high side, depending on technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Ranges could exceed those shown in unusual circumstances (AACE International Recommended Practices and Standards). The estimates were developed for long-range capital planning purposes.

Through a workshop setting, a funding priority of 1, 2, or 3 was assigned to each item on the project list by the City's staff. The funding priorities established are as follows:

1. Fiscally Constrained = projects that would be completed under a fiscally constrained funding scenario

2. Action Plan = projects in addition to those included in the Fiscally Constrained priority that would be completed under an action plan funding scenario

3. Vision = projects in addition to those included in the Fiscally Constrained and Action priorities that would be completed under an vision plan funding scenario

For a more complete description of the funding priorities and the associated funding scenario assumptions see Volume 6 – Consolidated Capital Improvements Plan. Following assignment of the project funding priorities, City staff analyzed the project list to determine which projects would be completed using capital funds and which projects would be funded using operating funds. Further funding source identification for capital projects includes projects funded by the general Capital Improvements Program Fund, previously identified ongoing specific project funds, and future project bond funds. Further funding source identification for operating fund projects included determination of which City work group would provide the necessary funding including project management, water quality, water resources, water treatment, and utilities maintenance.

Table 5-43 presents the project improvement list developed as part of the TWMP and includes a project description, identification as a capital or operations project type, estimated costs, funding priorities, funding source, planned funding year and comments**.**

Table 5-43: Consolidated Recommended Improvements Project List

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
1	1	Betasso	North lagoon sand replacement	Capital	$ 30,000	2005	$ 34,857	1	2012	Ongoing Betasso WTF Project	NE has broken underdrain (replacement not included in price). Interim measure until final residuals option is implemented.
2	2	Betasso	Pump diffusion flash mixing	Capital	$ 100,000	1905	$ 116,190	2	N/A	N/A	Note that original '05 Carollo estimate for pumped mixing was $791,000. New estimate is for study plus minor modifications. Not required based on MWH WUMP analysis/recommendations.
3	3	Betasso	CO_2 feed improvements	Capital	$ 294,000	2005	$ 341,599	2	TBD	Operating Funds	Step wise improvements will be made based on operations data using annual operating funds.
4	4	Betasso	Floc/sed inlet baffle	Capital	$ 35,000	2005	$ 40,667	1	2016	Betasso WTF Bond Proceeds 2016	These improvements are grouped together and are one alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit).
5	5	Betasso	Floc/sed serpentine baffles	Capital	$ 2,082,000	2005	$ 2,419,076	1	2016	Betasso WTF Bond Proceeds 2016	These improvements are grouped together and are one alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit).
6	6	Betasso	Floc equipment modifications	Capital	$ 1,361,000	2005	$ 1,581,346	1	2016	Betasso WTF Bond Proceeds 2016	These improvements are grouped together and are one alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit).
7	7	Betasso	Baffles between floc and sed	Capital	$ 842,000	2005	$ 978,320	1	2016	Betasso WTF Bond Proceeds 2016	These improvements are grouped together and are one alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit).
8	8	Betasso	Sedimentation basin effluent weirs	Capital	$ 97,000	2005	$ 112,704	1	2016	Betasso WTF Bond Proceeds 2016	These improvements are grouped together and are one alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit).
9	9	Betasso	Pretreatment upgrades – DAF	Capital	$ 7,501,000	2005	$ 8,715,412	N/A	N/A	N/A	DAF pretreatment improvements were determined to not be cost effective in Workshop #2.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
10	10	Betasso	Pretreatment upgrades – Plate Settlers	Capital	$ 6,550,000	2005	$ 7,610,445	2	2026	Betasso WTF Bond Proceeds 2026	Plate settler pretreatment improvements are a third alternative for obtaining 46 MGD of facility capacity (32 MGD = approx. current capacity limit)
11	11	Betasso	Floc aid polymer addition	Capital	$ 235,000	2005	$ 273,047	1	2016	Betasso WTF Bond Proceeds 2016	Not using; currently Alum/PACL only. Jar testing should be commenced as soon as possible (jar test study included #21 below)
12	12	Betasso	Study to optimize pre-treatment and residuals handling	Capital	$ 100,000	2010	$ 100,000	1	2013	Ongoing Betasso WTF Project	The goal of the study would be to determine the optimized solution for pretreatment improvements to obtain 46 MGD of capacity while resolving the residuals capacity limitations of the facility to eliminate or reduce contract hauling requirements. (Note that this study can be combined with #20 and #21)
13	13	Betasso	North engineered sand drying beds	Capital	$ 3,395,000	2005	$ 3,944,651	1	N/A	N/A	Preference for residuals dewatering solution in Item #148. Could be re-evaluated as part of pre-treatment/residuals management study.
14	14	Betasso	Clearwell No. 2 Baffle Wall	Capital	$ 209,000	2005	$ 242,837	3	2026	Betasso WTF Bond Proceeds 2026	Disinfection contact time issue; limited 10 approx. 10 MGD if Clearwell #1 off-line.
15	15	Betasso	Filter rehabilitation (media, underdrain, valves etc.)	Capital	$ 631,000	2005	$ 733,159	1	2016	Betasso WTF Bond Proceeds 2016	Staff also desire the addition of air scour for filter backwash if feasible. Blowers could be located on the south side of the filter building.
16	16	Betasso	Replace/upgrade valves in filter piping gallery	Capital	$ 160,200	2010	$ 160,200	1	2016	Betasso WTF Bond Proceeds 2016	Valves and actuators are 40 – 45 years old and have reached the end of their useful life. Lots of leaks. 4 valves/filter, 8 filters.
17	17	Betasso	Replace actuators in filter piping gallery with electric actuators	Capital	$ 209,600	2010	$ 209,600	1	2016	Betasso WTF Bond Proceeds 2016	Valves and actuators are 40 – 45 years old and have reached the end of their useful life. Lots of leaks. 4 valves/filter, 8 filters.
18	18	Betasso	UV disinfection	Capital	$ 631,000	2005	$ 733,159	3	N/A	N/A	Consider in future, if needed for regulatory compliance
19	19	Betasso	Membranes	Capital	$ 10,000,000	2005	$ 11,619,000	3	N/A	N/A	Long-term option not considered necessary in the current planning period.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
20	20	Betasso	Monitor raw water quality	O&M	$ 150,000	2010	$ 150,000	1	TBD	Operating Funds	Priority 2 = Basic parameters – turbidity, TOC, ORP; Priority 3 = Sophisticated parameters – emerging contaminants, etc.
21	21	Betasso	Study of lime and CO2 addition points for pH and alkalinity control and jar testing for floc aid polymer addition	O&M	$ 50,000	2010	$ 50,000	2	TBD	Operating Funds	Improvements were made in 2009, but effluent application points and controls need to be studied for optimization.
22	22	Betasso	Replace back-up power generator	Capital	$ 253,800	2010	$ 253,800	2	2016	Betasso WTF Bond Proceeds 2016	Existing is 250 kW Kohler diesel that is not sufficient for any additional loads. Staff desire new generator to be propane fueled to eliminate fuel storage issues (i.e., double containment).
23	23	Betasso	DAF pilot to determine feasibility for improving residuals handling issues	Capital	$ 50,000	2010	$ 50,000	2	N/A	N/A	DAF pretreatment improvements were determined to not be cost effective in Workshop #2.
24	24	Betasso	Carbon (PAC) feed system improvements	Capital	$ 200,000	2010	$ 200,000	2	2016	Betasso WTF Bond Proceeds 2016	During workshop #3 it was determined that MWH estimate ($9900) was low. More reasonable estimate for the full supersac feeder replacement is $200k.
25	25	Betasso	Pipe gallery cleaning/repainting	Capital	$ 23,300	2010	$ 23,300	3	TBD	Operating Funds	
26	26	Betasso	Chlorine scrubber demolition	Capital	$ 14,600	2010	$ 14,600	3	2012	Ongoing Betasso WTF Project	Create more need storage space.
27	27	Betasso	Chemical (hypo, alum, fluoride) storage tank replacement	Capital	$ 209,700	2010	$ 209,700	2	2016	Betasso WTF Bond Proceeds 2016	Planning for replacement needs to begin now.
28	28	Betasso	Sodium hypochlorite feed room needs to be re-piped	Capital	$ 6,600	2010	$ 6,600	2	2012	Ongoing Betasso WTF Project	Re-piping is needed for better use of space, maintenance access and to accommodate future tank replacement
29	29	Betasso	Miscellaneous energy efficiency improvements	Capital	$ 25,000	2010	$ 25,000	3	2012	Ongoing Betasso WTF Project	Improvements to be identified by McKynstre energy audit were minimal. During Workshop #3, COB stated that another study is required. ($25,000 is reserved for each WTF)
30	30	Betasso	Combined influent flow metering	Capital	$ 38,700	2010	$ 38,700	2	2013	Ongoing Betasso WTF Project	Staff desire the addition of a combined (two influent pipelines and recycle) flow meter.
31	31	Betasso	Effluent flow meter replacement	Capital	$ 54,500	2010	$ 54,500	2	2013	Ongoing Betasso WTF Project	Standardize on magmeters. Current venturi's not accurate or scalable over the plant flow range.
32	32	Betasso	Miscellaneous security improvements	Capital	$ 25,000	2010	$ 25,000	2	2012	General Fund; $25,000 allocated in 2012	Improvements identified in the VA; details omitted from Master Plan for security purposes.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
33	33	Betasso	Monitor system-wide and Betasso water demand	O&M	$ 50,000	2010	$ 50,000	2	TBD	Operating Funds – Water Treatment	Test system supply capacity from BRWTP, with new pumps/meters.
34	34	Betasso	Perform stress test on floc/sed basins	O&M	$ 50,000	2010	$ 50,000	1	TBD	Operating Funds – Project Management	Test needs to be repeated during May/June runoff period – schedule for 2011. (Note that this study can be combined with #12 and #21)
35	35	Betasso	Perform bench/pilot test of cationic polymer	O&M	$ 50,000	2010	$ 50,000	1	TBD	Operating Funds – Water Treatment	Related to Item #11 above. (Note that this study can be combined with #12 and #21)
36	148	Betasso	Solids Dewatering Facility	Capital	$ 2,858,000	2010	$ 2,858,000	1	2016	Betasso WTF Bond Proceeds 2016	See tab "OPCC – Solids Dewatering Facility" for detailed cost estimate
37	149	Betasso	Filter surface wash replacement	Capital	$ 266,400	2010	$ 266,400	1	2016	Betasso WTF Bond Proceeds 2016	MWH cost estimate
38	150	Betasso	Lime feeder replacement	Capital	$ 188,500	2010	$ 188,500	1	N/A	N/A	More maintenance friendly lime feeder needed. Workshop #3 discussions indicated the existing lime feeder was functioning as well as anything available. Issue will be revisited during 2016 bond project design process.
39	151	Betasso	SCADA upgrades for chemical feed and process control	Capital	$ 250,000	2010	$ 250,000	1	2016	Betasso WTF Bond Proceeds 2016	SCADA upgrades needed. Should include better to read data formats. Final cost is dependent on scope of work included.
40	152	Betasso	Laser turbidity meters on filter effluent	Capital	$ 60,000	2010	$ 60,000	N/A	N/A	N/A	Workshop No 3 – Decided new turbidity meters were not required (cost was $5k each x 8 filters + $20k for install). No funding in planning period.
41	36	Betasso/BRWTF	Perform sampling and testing of waste streams flowing into waste impoundments to determine type of impoundment and if impoundment improvements are needed.	O&M	$ 30,000	2010	$ 30,000	1	TBD	Operating Funds – Water Treatment	Sampling and subesequent study to determine waste impoundment regulation impacts at both Betasso WTF and Boulder Reservoir WTF
42	165	Betasso/BRWTF	Evaluate Rapid Toxicity Test	O&M	$ 5,000	2010	$ 100,000	3	TBD	Operating Funds – Water Quality	Evaluate conducting a rapid toxicity test (bioluminescent assay) basline and clibration to enable determination of contamination of treated water.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
43	37	BRWTF	Pre-oxidation improvements	Capital	$ 1,888,000	2008	$ 2,101,155	2	2020	Boulder Reservoir WTF Bond Proceeds 2020	Requires further investigation related to pH adjustment, TOC removal, and DBP formation. ClO2 is currently considered overkill by staff. This item is retained to help address taste and odor concerns although specific T&O compounds have not been identified. Currently piloting potassium permanganate which would also help prevent spread of zebra mussels. Expand study to include other options.
44	38	BRWTF	Upgrade effluent flow meter to mag meter	Capital	$ 60,000	2008	$ 66,774	2	2014	Ongoing Boulder Rservoir WTF Project	City staff repaired existing venturi meter; long term vision includes replacement with magmeter
45	39	BRWTF	Automate Chemical Feed and Process Controls Tuning	Capital	$ 20,800	2010	$ 20,800	3	2013	Ongoing Boulder Rservoir WTF Project	Flow-pacing of 6-10 chemicals (caustic, alum, acid (new), fluoride, SumaClear,…); replace/upgrade instrumentation, resolve sampling issues and flow metering
46	40	BRWTF	Monitor Feeder Canal	Capital	$ 183,700	2010	$ 183,700	2	TBD	Operating Funds – Water Quality	Priority 2 = Basic parameters – turbidity, TOC, ORP; Priority 3 = Sophisticated parameters – emerging contaminants, etc.
47	41	BRWTF	Canal Intake Improvements	Capital	$ 80,000	2000	$ 112,800	2	2010/2011	Boulder Feeder Canal Project	Improvements were made to make maintenance somewhat safer, but safety is still a concern. Additional improvements are desired including metal access stair, corrosion control issues, and an automatic trash rack.
48	42	BRWTF	Install VFD's on High Service Pumps	Capital	$ 80,000	2000	$ 112,800	2	2013	Boulder Reservoir High Service Pump Station Project	Goes with plant automation. Existing estimate of cost appears low.
49	43	BRWTF	Washwater Pretreatment	Capital	$ 617,000	2007	$ 686,659	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	Cost includes only 1st phase, according to MWH 2003. Requires bigger tank; 10% recycle currently. Item #43 is a new facility alternative to these upgrades.
50	44	BRWTF	Filter to Waste Capability	Capital	$ 250,000	2000	$ 352,500	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	Likely tied to plant automation
51	45	BRWTF	Plant Recycle Pretreatment Facility	Capital	$ 1,500,000	2000	$ 2,115,000	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	Same as item #41, but new facility that includes decant water from lagoons

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
52	46	BRWTF	New Online Floc Monitoring Equipment	Capital	$ 35,000	2003	$ 46,715	3	N/A	N/A	Determined at Workshop #3 that cost outweighs any benefits. Therefore no funding planned.
53	47	BRWTF	Presedimentation	Capital	$ 1,076,000	2003	$ 1,436,137	3	N/A	N/A	Only necessary if raw water quality degrades and/or Carter Lake Pipeline is not constructed. Should be considered with preoxidation item above (Item #40).
54	48	BRWTF	UV Disinfection	Capital	$ 2,145,000	2003	$ 2,862,932	3	N/A	N/A	Would require new/upgraded electrical service. Could move up in priority if *Crypto* increases. Not anticipated in 20-year CIP.
55	49	BRWTF	Emergency Power	Capital	$ 400,000	2003	$ 533,880	2	2020	Boulder Reservoir WTF Bond Proceeds 2020	Current system is only sufficient for shutting down the plant in the event of a power failure. Would need this with automation. Estimate of cost seems low.
56	50	BRWTF	Membranes	Capital	$ 8,995,000	2003	$ 12,005,627	3	N/A	N/A	Suggested in AWWA Peer Review. Potential long-term improvement. Not anticipated in 20-year CIP.
57	51	BRWTF	Granular Activated Carbon Filter Cap	Capital	$ 250,000	2003	$ 333,675	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	Should be studied along with preoxidation (Item #40). Price seems low.
58	52	BRWTF	High Service Pump Cavitation and Efficiency Study	Capital	$ 50,000	2010	$ 50,000	2	2012	Operating Funds – Water Treatment	Should be evaluated with replacement or rebuild to get better efficiency equipment
59	53	BRWTF	Facility Automation	Capital	$ 4,300,000	2010	$ 4,300,000	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	Includes $20.8K from #42
60	54	BRWTF	Line old lagoons and evaluate structural integrity and site drainage issues; determine waste impoundment regulation impacts	Capital	$ 338,200	2010	$ 338,200	1	N/A		Need to study soon in light of new regulations (See Comprehensive List Item #36)
61	55	BRWTF	Filter rehabilitation planning	Capital	$ 50,000	2010	$ 50,000	3	2014	Ongoing Boulder Rservoir WTF Project	Includes filter controls upgrades and evaluation of enclosing filters (similar to Betasso). May need rehab within 10 yrs.
62	56	BRWTF	Filter rehabilitation	Capital	$ 2,828,800	2010	$ 2,828,800	2	2030	Boulder Reservoir WTF Bond Proceeds 2030	
63	57	BRWTF	Raw water pump VFDs	Capital	$ 75,000	2010	$ 75,000	3	TBD	Ongoing Boulder Reservoir Intake and Pumping Project	

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
64	58	BRWTF	Fiber optic line to RWPS and PLC	Capital	N/A	2010	N/A	3	2011	Boulder Reservoir WTF Mid-Term Improvements Project	Security issue. Project will be completed in 2011 as part of the Mid-Term Improvements RWPS upgrades project.
65	59	BRWTF	Miscellaneous energy efficiency improvements	Capital	$ 25,000	2010	$ 25,000	3	2012	Ongoing Boulder Rservoir WTF Project	Improvements to be identified by McKynstre energy audit were minimal. During Workshop #3, COB stated that another study is required. ($25,000 is reserved for each WTF)
66	60	BRWTF	Solar energy farm	Capital	N/A	N/A	N/A	2	N/A	N/A	Started up at 75th Street WWTP; considering program expansion. City would not construct or own the facility.
67	61	BRWTF	Washwater recovery tank expansion	Capital	$ 500,000	2010	$ 500,000	3	2030	Boulder Reservoir WTF Bond Proceeds 2030	
68	62	BRWTF	Electrical power to canal intake location	Capital	$ 100,000	2010	$ 100,000	2	2010/2011	Water System Security Project	Safety/security issue – lighting
69	63	BRWTF	Upgrade/replace all pressure and flow instruments	Capital	$ 150,000	2010	$ 150,000	3	2020	Boulder Reservoir WTF Bond Proceeds 2020	Standardize on Rosemount
70	64	BRWTF	Curb and gutter and drainage improvements around plant	Capital	$ 100,000	2010	$ 100,000	3	2020	Boulder Reservoir WTF Bond Proceeds 2020	
71	65	BRWTF	Combined filter effluent post flume flash mix improvements	Capital	$ 80,300	2010	$ 80,300	2	2013	Ongoing Boulder Rservoir WTF Project	Existing paddle mixer is not providing adequate mixing for CFE chemicals (caustic, fluoride, chlorine)
72	66	BRWTF	Additional chemical storage	Capital	$ 167,000	2010	$ 167,000	3	2020	Boulder Reservoir WTF Bond Proceeds 2020	As it currently stands, we need to make sure we have 3 empty tanks before we can accept a load of hypo. Right now that doesn't pose much of a problem but if we ramp up and start treating more than 8-12 MGD, we could run into a problem with having enough hypo to get us through an unexpected delivery problem.
73	67	BRWTF	Demo scrubber room equipment	Capital	$ 14,600	2010	$ 14,600	3	2013	Ongoing Boulder Rservoir WTF Project	This could facilitate additional chemical storage
74	68	BRWTF	Upgrade filter controls	Capital	$ 53,300	2010	$ 53,300	2	2014	Ongoing Boulder Rservoir WTF Project	For improvement of reliability and update to current technology
75	69	BRWTF	Cover filters	Capital	$ 460,800	2010	$ 460,800	3	N/A	N/A	Energy conservation during winter. Low priority. Not anticipated in 20-year CIP.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
76	70	BRWTF	Improved TOC removal	Capital	See Comprehensive List Item #37	See Comprehensive List Item #37	See Comprehensive List Item #37	2	2020	Boulder Reservoir WTF Bond Proceeds 2020	See preoxidation item (#37) above
77	71	BRWTF	Security improvements	Capital	$ 25,000	2010	$ 25,000	2	2013	Ongoing Boulder Reservoir WTF Project; $25,000 allocated in 2013	ID specific projects from VA.
78	71	BRWTF	Upgrade polymer feed system (dry batching capability)	Capital	$ 100,000	2010	$ 100,000	3	2020	Boulder Reservoir WTF Bond Proceeds 2020	
79	73	BRWTF	Miscellaneous security improvements	Capital	N/A	N/A	N/A	N/A	N/A	N/A	Repeat of Comprehensive List Item #71.
80	153	BRWTF	Emergency Power Alternative Study	Capital	$ 30,000	2010	$ 30,000	2	2013		Determine options for emergency power for BRWTF
81	169	BRWTF	Evaluate Drinking Water Lab Expansion and Needs	O&M	$ 5,000	2010	$ 10,000	1	TBD	Operating Funds – Water Quality	
82	170	BRWTF	Evaluate Drinking Water Lab Capabilities, Needs, and Certifications by Constituent	O&M	$ 10,000	2010	$ 10,000	1	TBD	Operating Funds – Water Quality	
83	172	BRWTF	Replace filter valves and actuators	Capital	#REF!	2010	#REF!	2	2020	Boulder Reservoir WTF Bond Proceeds 2020	
84	141	Colorado River Water Source	Boulder Feeder Canal Stormwater Diversions – Phase 1	Capital	$ 287,155	2010	$ 287,155	1	2011	Capital Improvement Program Funds	$81,000 remaining available in the 2011 budget for this project.
85	142	Colorado River Water Source	Boulder Feeder Canal Stormwater Diversions – Phase 2	Capital	TBD		TBD	3	N/A	N/A	No money budgeted in the 20 year CIP for this project contemplating Carter Lake Pipeline.
86	143	Colorado River Water Source	Carter Lake Pipeline	Capital	$ 25,000,000	2010	$ 25,000,000	1	2017 and 2018	Capital Improvement Program Funds	$989,000 available in the 2011 budget for permitting and land acquisition. $2,608,367 budgeted in 2017 (design) and $26,083,667 budgeted in 2018 (construction)
87	144	Colorado River Water Source	Carter Lake Pipeline Hydro	Capital	$ 5,500,000	2010	$ 5,500,000	1	2017 and 2018	Capital Improvement Program Funds	$500,000 budgeted in 2017 (design) and $5,000,000 budgeted in 2018 (construction)
88	145	Colorado River Water Source	Farmer's Ditch Exchange Potential Pipeline	Capital	$ 25,000,000	2008	$ 25,000,000	3	N/A	N/A	No money budgeted in the 20 year CIP for this project.
89	146	Colorado River Water Source	Wittemyer Ponds	Capital	$ 4,058,600	2010	$ 4,058,600	2	2021 and 2022	Capital Improvement Program Funds	$469,718 budgeted in 2021 (design) and $4,697,183 budgeted in 2022 (construction)
90	147	Colorado River Water Source	Farmers Ditch Capacity Restoration	Capital	$ 1,950,000	2010	$ 1,950,000	3	2019	Capital Improvement Program Funds	$106,090 budgeted in 2019 for evaluation. No other money budgeted in the 20 year CIP for this project.

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
91	74	Distribution System	Replace differential pressure sensors in system storage tanks with level sensors	O&M	$ 16,400	2010	$ 16,400	2	TBD	Operating Funds – Project Management	Chautauqua, Devils Thumb tanks currently use DP sensors translated to a level which introduces inaccuracies
92	75	Distribution System	Add WQ stations	Capital	$ 100,000	2010	$ 100,000	2	2011	Water System Security Project or Distribution System Water Quality Improvement Project	Cost is dependent on number of WQ monitoring stations
93	76	Distribution System	Add flow meter and controls to Sunshine hydro facility 30" pipeline Flow meter and feedback control loop for control of bypass valves during hydro shutdown	Capital	$ 48,000	2010	$ 48,000	3	2017	Sunshine Transmission Pipe Project	Sunshine shut down or significant changes in flow causes back-up into Betasso clear well, and bypass valve must be manually opened. Flow meter would allow for proactive adjustments to be made.
94	77	Distribution System	Rehabilitation/Replacement of control system at Sunshine PRV	Capital	$ 192,400	2010	$ 192,400	3	2017	Sunshine Transmission Pipe Project	
95	78	Distribution System	Treated water reservoir mixing improvements	O&M	$ 76,400	2010	$ 76,400	1	TBD	Operating Funds – Water Quality	Base further study and necessary improvements on hydraulic modeling results and system water quality monitoring.
96	79	Distribution System	Miscellaneous security improvements	Capital	$ 25,000	2010	$ 25,000	2	TBD	Ongoing Water System Security Project	ID specific projects from VA.
97	80	Distribution System	Cherryvale Pump Station	Capital	N/A	2010	N/A	3	N/A	N/A	Cherryvale pump station project complete – no further upgrades needed for current planning period.
98	81	Distribution System	Iris Pump Station	Capital	N/A	2010	N/A	3	N/A	N/A	Iris pump station project complete – no further upgrades needed for current planning period.
99	82	Distribution System	Kohler Storage Tank	Capital	$ 920,000	2010	$ 920,000	3	2015-2016	N/A	$1,100,000 to Reroof Kohler in 2016-2017
100	83	Distribution System	Chautauqua Storage Tank	Capital	$ 870,000	2010	$ 870,000	2	2011	Chautauqua Storage Tank Project 2011	Structural evaluation of double T shear tabs, seal shrinkage cracks, coat roof vents, evaluate internal lining (previous lining estimate was $213,000 in 2002)
101	84	Distribution System	Betasso Storage Tank	Capital	$ 250,000	2008	$ 265,225	2	2017	Capital Improvement Program Funds	Paint outside and possible cathodic protection.$281,377 in 2017
102	85	Distribution System	Gunbarrel Storage Tank	Capital	$ 250,000	2008	$ 250,000	2	2013	Capital Improvement Program Funds	Paint interior and possible cathodic protection $250,000 in 2013

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
103	86	Distribution System	Zone Isolation Valves	Capital	Included in Item #88.	2008	Included in Item #88.	1	TBD	Ongoing Waterline Replacement Project	Work will be funded as part of on-going waterline replacement project..
104	87	Distribution System	Cathodic Protection	Capital	$ 25,000	2010	$ 25,000	1	TBD	Ongoing Cathodic Protection Project	Develop cathodic protection standards for new transmission pipelines and develop program to add cathodic protection.
105	88	Distribution System	Waterline Replacement	Capital	$2,100,000	2008	$ 2,100,000	1	2011-2032	Ongoing Waterline Replacement Project	No escalation of costs from 2008 – 2013.
106	89	Distribution System	Sunshine Transmission Pipe	Capital	$ 999,728	2010	$ 999,728	1	2011 and 2013	Sunshine Transmission Pipe Project	$267,615 for pipe inspection, minor repair work and installation of access manholesin 201; another $800,000 in 2013 for manways and lining rehabilitation.
107	90	Distribution System	Zone 1 Transmission Facilities	Capital	See asset management spreadsheets	N/A	See asset management spreadsheets	3	See asset management spreadsheets	Zone 1-3 Transmission Projects	Modeling indicates no large capital improvements required. Improvements and funding based on asset management spreadsheets.
108	91	Distribution System	Zone 2 Transmission Facilities	Capital	See asset management spreadsheets	N/A	See asset management spreadsheets	3	See asset management spreadsheets	Zone 1-3 Transmission Projects	Modeling indicates no large capital improvements required. Improvements and funding based on asset management spreadsheets.
109	92	Distribution System	Zone 3 Transmission Facilities	Capital	See asset management spreadsheets	N/A	See asset management spreadsheets	3	See asset management spreadsheets	Zone 1-3 Transmission Projects	Modeling indicates no large capital improvements required. Improvements and funding based on asset management spreadsheets.
110	93	Distribution System	Boulder Canyon – Orodell to Fourmile	Capital			$ 500,000	1	2011	Orodell to Fourmile Project	24" pipeline replacement.
111	94	Distribution System	Automated Meter Reading	Capital	$ 500,000	2008	$ 530,450	1	2011-2013	Ongoing Automated Meter Reading Project	
112	95	Distribution System	Maxwell Tank Improvements	Capital	$ 920,000	2008	$ 920,000	2	2020	Maxwell Storage Tank Project	Roof replacement.
113	96	Distribution System	Orodell Hydroelectric 12-inch Isolation BFV (downstream)	Capital	$ 8,000	2010	$ 8,000	2	2011	Orodell to Fourmile Project	
114	97	Distribution System	Orodell New I&C Battery Back-Up	O&M	$ 10,000	2010	$ 10,000	1	TBD	Operating Funds – Water Resources	
115	98	Distribution System	101 Pearl Street Turbine Generator Improvements	Capital	$ 200,000	2008	$ 200,000	3	2019	Turbine Generator Project	
116	101	Distribution System	Maxwell Reservoir	O&M	$ 10,000	2010	$ 10,000	1	TBD	Operating Funds – Utilities Maintenance	Crack/joint repair, recoating

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
117	102	Distribution System	Maxwell Reservoir Regrading and Erosion Control	O&M	$ 5,000	2010	$ 5,000	1	TBD	Operating Funds – Utilities Maintenance	Erosion control
118	103	Distribution System	Devils Thumb Reservoir	Capital	$ 814,161	2010	$ 814,161	3	2022	General Fund	Paint inside and outside. $1,250,542 budgeted in 2022 from asset management spreadsheet.
119	104	Distribution System	Booton Reservoir	O&M	$ 5,000	2010	$ 5,000	1	TBD	Operating Funds – Utilities Maintenance	Tanks appear to be in good condition, regular inspections should be continued, but no major costs anticipated at this time. Vegetation control, bird nest removal, and bird screen installation.
120	105	Distribution System	Pipeline Replacement Program	Capital	N/A	N/A	N/A	N/A	N/A	N/A	Duplication of Comprehensive List Item #88.
121	106	Distribution System	Further Investigation of Low Pressure and Potential Insufficient Fire Flow Capacities	O&M	$ 30,000	2010	$ 30,000	2	TBD	Operating Funds – Water Treatment	2010 TWMP modeling results indicate some areas with these potential issues. Further investigation (study) is required to confirm and define extent.
122	107	Distribution System	Kohler Reservoir Roof	Capital	$ 918,900	2007	$ 1,063,443	1	2016	Kohler Storage Tank Project	Kohler roof in poor condition, but not as bad as Chautauqua
123	108	Distribution System	Chautauqua Reservoir Roof	Capital	$ 619,020	2007	$ 716,392	2	2011	Chautauqua Storage Tank Project 2011	Chautauqua roof is in extremely poor condition
124	161	Distribution System	Chautauqa Reservoir Lining	Capital	$ 267,600	2010	$ 267,600	2	2022	Capital Improvement Program Funds	
125	162	Distribution System	Maxwell Hydroelectric Building Inspection and Repair Plan	O&M	$ 10,000	2010	$ 10,000	1	TBD	Operating Funds – Water Resources	
126	163	Distribution System	101 Pearl Street PRV Site Grading and Parking Turn Area Improvements	O&M	$ 5,000	2010	$ 5,000	2	TBD	Operating Funds – Water Resources	
127	164	Distribution System	Evaluate SO4 Tracer Study	O&M	$ 7,000	2010	$ 7,000	2	TBD	Operating Funds – Project Management	Evaluate conducting an SO4 tracer study to confirm zone boundaries, mixing zone characteristics, and to determin origin of treated water at a given location in the system.
128	166	Distribution System	DBP Formation Potential Study	O&M	$ 50,000	2010	$ 5,000	2	TBD	Operating Funds – Water Quality	
129	167	Distribution System	Evaluate Value of HPC Monitoring	O&M	$ 5,000	2010	$ 8,000	2	TBD	Operating Funds – Water Quality	

Item No.	Comprehensive List Item No.	Facility	Project Description	Type (Capital or O&M)	Cost/Value	Date of Initial Cost	Current Cost (2010)	Final Funding Priority	Planned Funding Year	Funding Source	Comments
130	168	Distribution System	Water Age Modeling	O&M	$ 10,000	2010	$ 15,000	1	TBD	Operating Funds – Water Quality	Evaluate distribution system water quality parameters such as water age (using results from different operating scenarios in the hydraulic model) and chlorine residual and how these parameters compare to Best Practices. Recommendations for optimized monitoring and sampling plan.
131	171	Distribution System	Test Drinking Water in Areas of Groundwater Contamination	O&M	$ 5,000	2010	$ 5,000	3	TBD	Operating Funds – Water Quality	

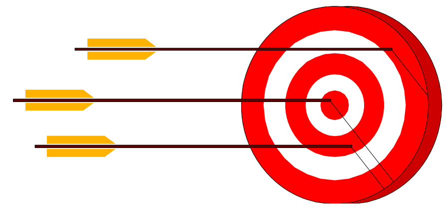
Appendix A:

City of Boulder Treatment Operations Regulatory Requirements

City of Boulder

Water Treatment Operations

Regulatory Requirements



PWSID - CO-0107152

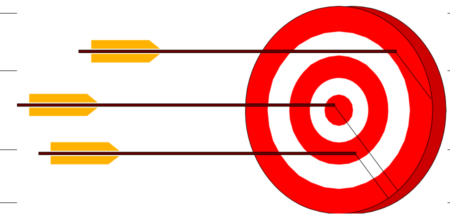
Revised - 05-13-10 - Format only -vlj

Unit Process	Parameter	MCL	Action to be taken
Anytime there is a MCL exceedance contact a **supervisor** immediately and the State as appropriate			
Pre-chemical Feed	Alum		
	Summaclear		
	Lime		
	Chlorine		
	Zeta Potential		
	Zeta pH		
	Zeta Alkalinity		
	Streaming Current		
Sed Basins	Flow Split		
Post Basins	Turbidity		
	pH		
	Chlorine		
Filters	Run time		
	LOH		
	Rate	<= 4 gal/min / sq ft continuous <= 5 gal/min / sq ft short term	
	Initial Turbidity spike	< 0.5 NTU w/in 4 hrs. of filter start-up < 1 NTU w/in 15 min filter start-up	- Take out of service and backwash - If > two consecutive 15 min readings > either limit must report - see regulation - Partnership suggests < 0.3 w/in 4 hrs. of backwash
	Turbidity	< 0.5 NTU Never > 5 NTU	Take out of service and backwash
	hydraulic change/filter		
	Particle Counts		
Combined Filter Effluent (Flume)	**Turbidity**	< 0.3 NTU in 95% of samples **Never** > 1.49 NTU	Shutdown plant and call supervisor if CFE turbidity > 0.5 NTU
	Particle Counts		
	Chlorine		
	pH		
Finished	**Alkalinity**	15 - 98 mg/L - CDPHE designated Cannot exceed more than 9 days in 6 mo. period	Adjust lime as needed
	pH	7.1 - 8.2 (SMCL) Cannot exceed more than 9 days in 6 mo. period	Adjust Carbonic acid feed rate as needed; If pH exceeds 8.2 for three hours notify WQ supervisor
	Flouride	4.0 mg/l (MCL) 2.0 mg/l (SMCL)	Adjust pump setting
	Chlorine	not < 0.2 mg/l for more than 4 hrs. or < 4.0 mg/l in distribution system	Adjust set point or run pump manually; In distribution system at any point there must be > trace in 95% of samples and < 4.0 mg/l
	Turbidity		
	Color		

City of Boulder

Water Treatment Operations

Internal Targets



Betasso WTF

PWSID - CO-0107152

Revised: **9/2007 Targets - per GG and RC (05-13-10 format-vlj)**

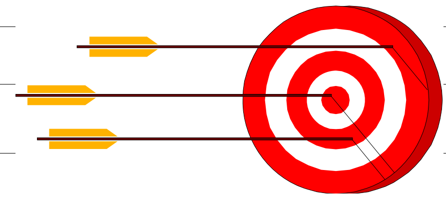
Unit Process	Parameter	InternalTarget	Action to be taken
Anytime there is a MCL exceedance contact a supervisor immediately and the State as appropriate			
Pre-chemical Feed	Alum	As needed to meet Zeta Potential and Zeta pH	Adjust chemical flow rates to meet Zeta Potential, pH and Alkalinity; When feeding Sumaclear do not dose < 2.5 mg/l
	Summaclear		
	Lime		
	Chlorine	Meet pre-filter target (if used)	Only used if Pre-oxidant needed (i.e. high influent Turbidity)
	Zeta Potential	Slightly minus (- 3 works well)	Adjust alum or suma to achieve/maintain zeta targets
	Zeta pH	6.4 - 6.8	Adjust coagulant or pre-Carbonic acid
	Zeta Alkalinity	≥ 9 mg/l	If < 9.0 increase or start feeding Sumaclear to improve settling in basins.
	Streaming Current	0	
Sed Basins	Flow Split	Equal between basins	
Post Basins	Turbidity	< 1.0 NTU	Filters fail if turbidity > 3 NTU
	pH		
	Chlorine	≤ 0.2 mg/l (only if feeding pre-CL2)	Maintain low residual to decrease DBP formation; Adjust pre-chlorine as needed
Filters	Run time	≤ 48 Hours	
	LOH		
	Rate	5gal/min/sqft or ≤ 5 MGD	
	Initial Turbidity spike	< 1 NTU w/in 15 min of filter start-up	- Take out of service and backwash - If > two consecutive 15 min readings > either limit must report - see regulation - Partnership suggests < 0.3 w/in 4 hrs. of backwash
	Turbidity	< 0.15 NTU	Take out of service and backwash
	hydraulic change/filter	<1.0 MGD	
	Particle Counts	Less than 100 total counts	
Combined Filter Effluent (Flume)	Turbidity	< 0.1 NTU	Shutdown plant and call supervisor if CFE turbidity > 0.5 NTU
	Particle Counts	Less than 100 total counts	Evaluate filter performance
	Chlorine	0.1 ± 0.1 mg/L (0.4 ± 0.1 when cleaning basins)	Adjust post Sed Basin chlorine (or pre if not using post Sed Basin)
	pH		
Finished	Alkalinity	45 ± 3.0 mg/L	Adjust lime as needed
	pH	7.8 ± 0.2	Adjust Carbonic acid feed rate as needed; If pH exceeds 8.2 for three hours notify WQ supervisor
	Flouride	0.90 ± 0.1 mg/L	Adjust pump setting
	Chlorine Residual from Hypochlorite	1.0 ± 0.1 mg/L	Adjust set point or run pump manually; In distribution system at any point there must be > trace in 95% of samples and < 4.0 mg/l
	Turbidity	< 0.1 NTU	Confirm with grab - refer to SOP
	Color		Increase Pre-chemicals (especially Sumaclear)

City of Boulder

Water Treatment Operations

Internal Targets

Boulder Reservoir WTF at 63rd Street



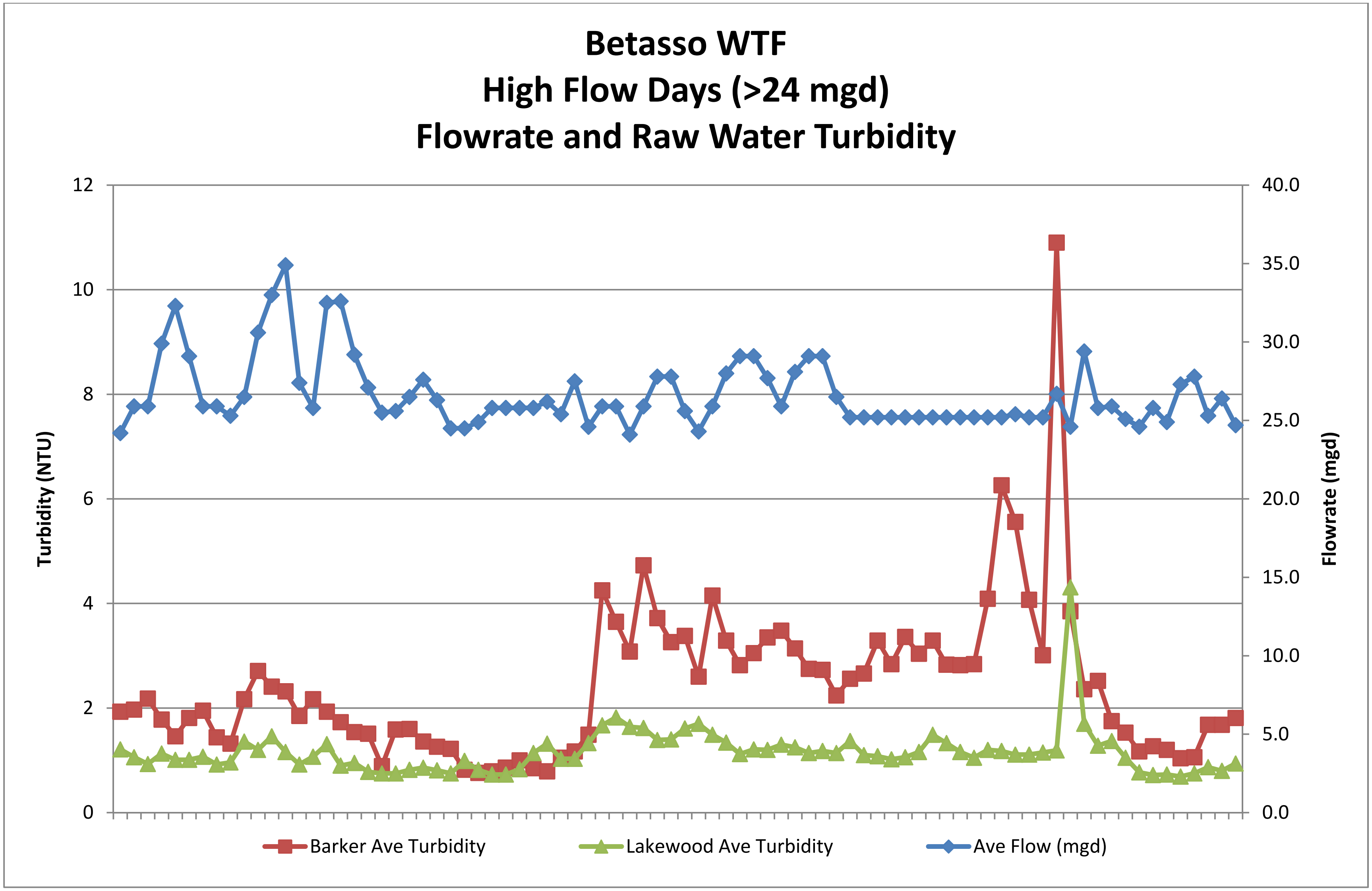
PWSID - CO-0107152

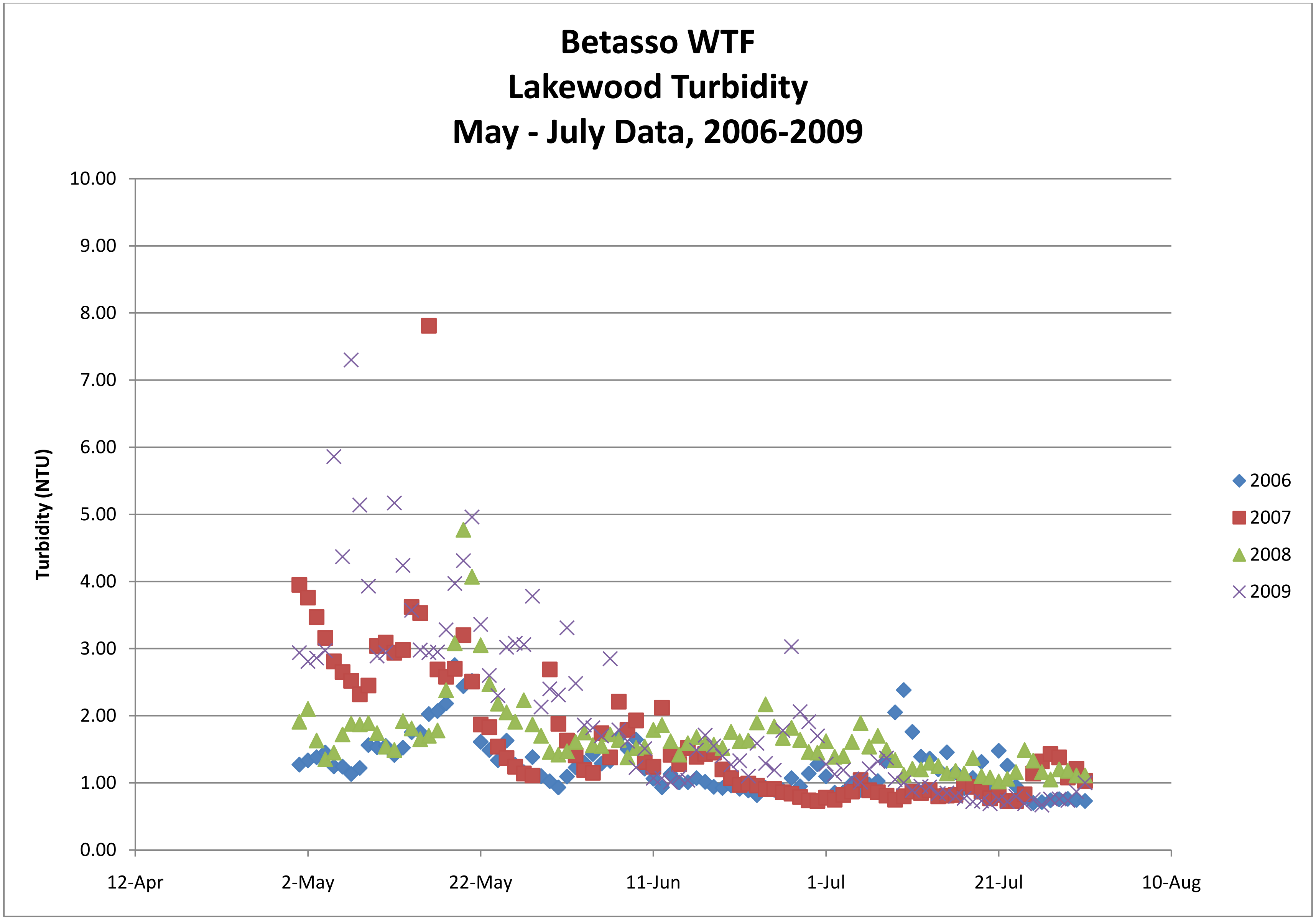
revised: 5/13/2010 - format only - vlj

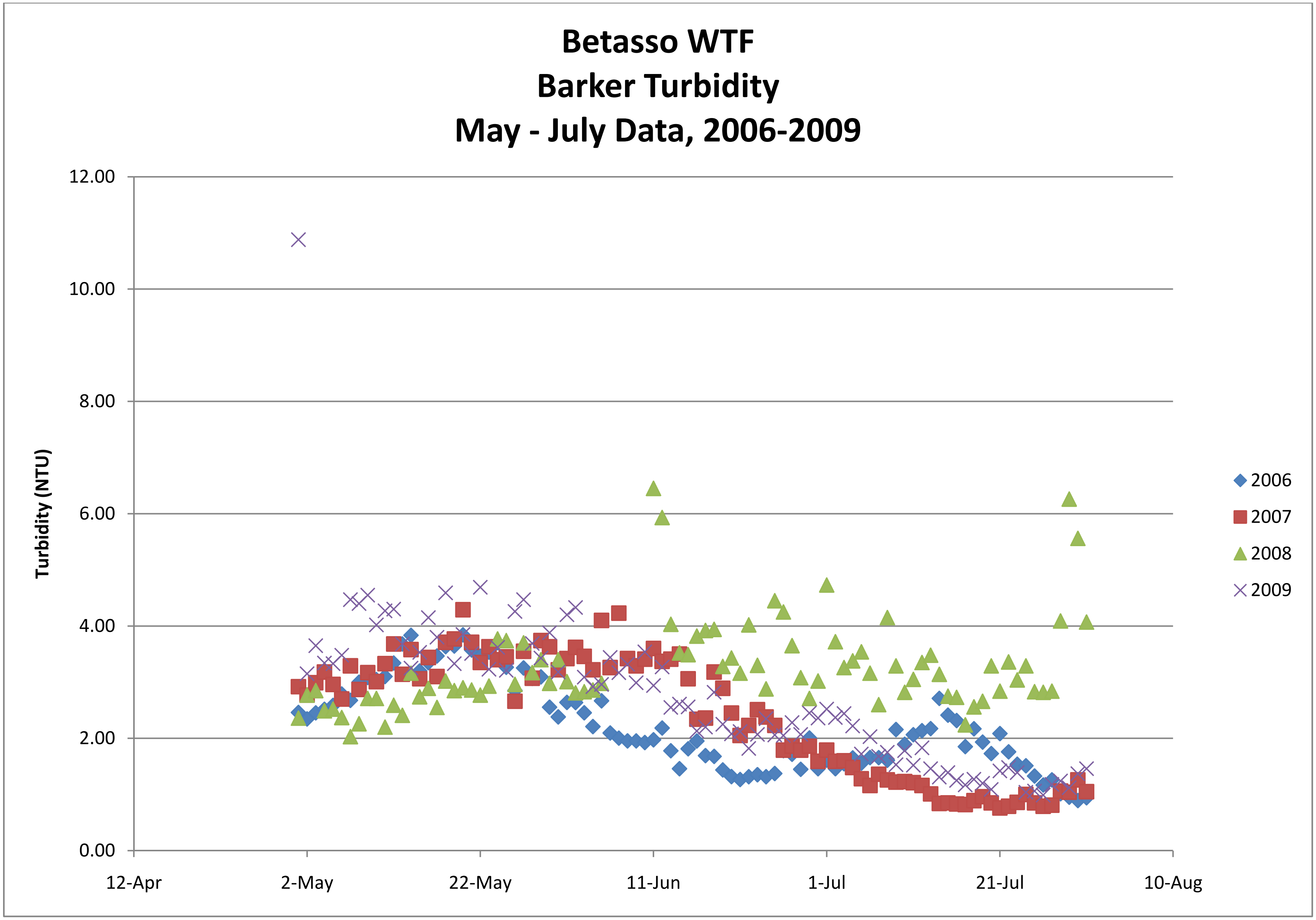
Unit Process	Parameter	InternalTarget	Action to be taken
Anytime there is a MCL exceedance contact a **supervisor** immediately and the State as appropriate			
Pre-chemical Feed	Alum	As needed to meet Zeta Potential,Daf PH	Adjust chemical flow rates to meet Zeta Potential/DAF PH
	Sumaclear 803B		
	Hypochlorite	0.5 ± 0.2 mg/L (in Zeta)	Only used if Pre-oxidant needed for Mn or high influent Turbidity
Raw water	Turbidity	< 100 NTU	Adjust coagulant feed rate or begin shutdown as needed
	Manganese	< 5 mg/L	> 5 mg/l start pre miox at post static mixer
	Dissolved oxygen	> 3 mg/L	< 3 mg/l Dissolved Oxygen/ Test manganese level daily (Day Shift)
DAF	Zeta Potential	- 4 ± 1	Adjust alum or suma to achieve/maintain zeta
	Zeta pH	6.5 - 6.8	Adjust coagulant
	Turbidity	< 1.0 NTU	If > 1.0 NTU for more than 2 hrs - shut down
Filters	Run time	60 Hours	
	Rate	≤ 5 gal/min / sq ft or ≤ 5 MGD	Add filters to meet plant flow target
	Initial Turbidity Spike	< 1 NTU w/in 15 min of filter start-up	- Take out of service and backwash - If > two consecutive 15 min readings > either limit must report - see regulation - Partnership suggests < 0.3 w/in 4 hrs. of backwash
	Turbidity	< 0.15 NTU	Backwash filter if greater
	Differential Flow	< 1.0 mgd	
	Filter conditioning	3 hrs rest	
	Particle counts	< 100 total counts	Backwash filter if greater
Combined Filter Effluent (Flume)	Turbidity	< 0.1 NTU	Check all other parameters begin filter evaluation
	Chlorine	0.4 ± 0.2 mg/L	Adjust post DAF chlorine (or pre, if post DAF not in use)
Post Flume	Chlorine	1.1 ± 0.1 mg/l	Adjust to achieve desired finished value
	pH	7.8 ± 0.2 mg/l	
Finished	Alkalinity	15 - 98 mg/L	
	pH	7.8 ± 0.2	Feed Alum and/or Caustic to achieve desired finished level
	Flouride	0.90 ± 0.1 mg/L	Adjust pump setting
	Chlorine Residual from Hypochlorite	1.0 ± 0.1 mg/L	- Adjust set point or run pump manually to achieved desired finished level - Must be > trace in 95% of samples and < 4.0 mg/l at any point in the distribution system
	Turbidity	< 0.25 NTU	Confirm with grab - refer to SOP
	Manganese	< 0.03 mg/L	Increase Pre DAF Cl2/Source Selection

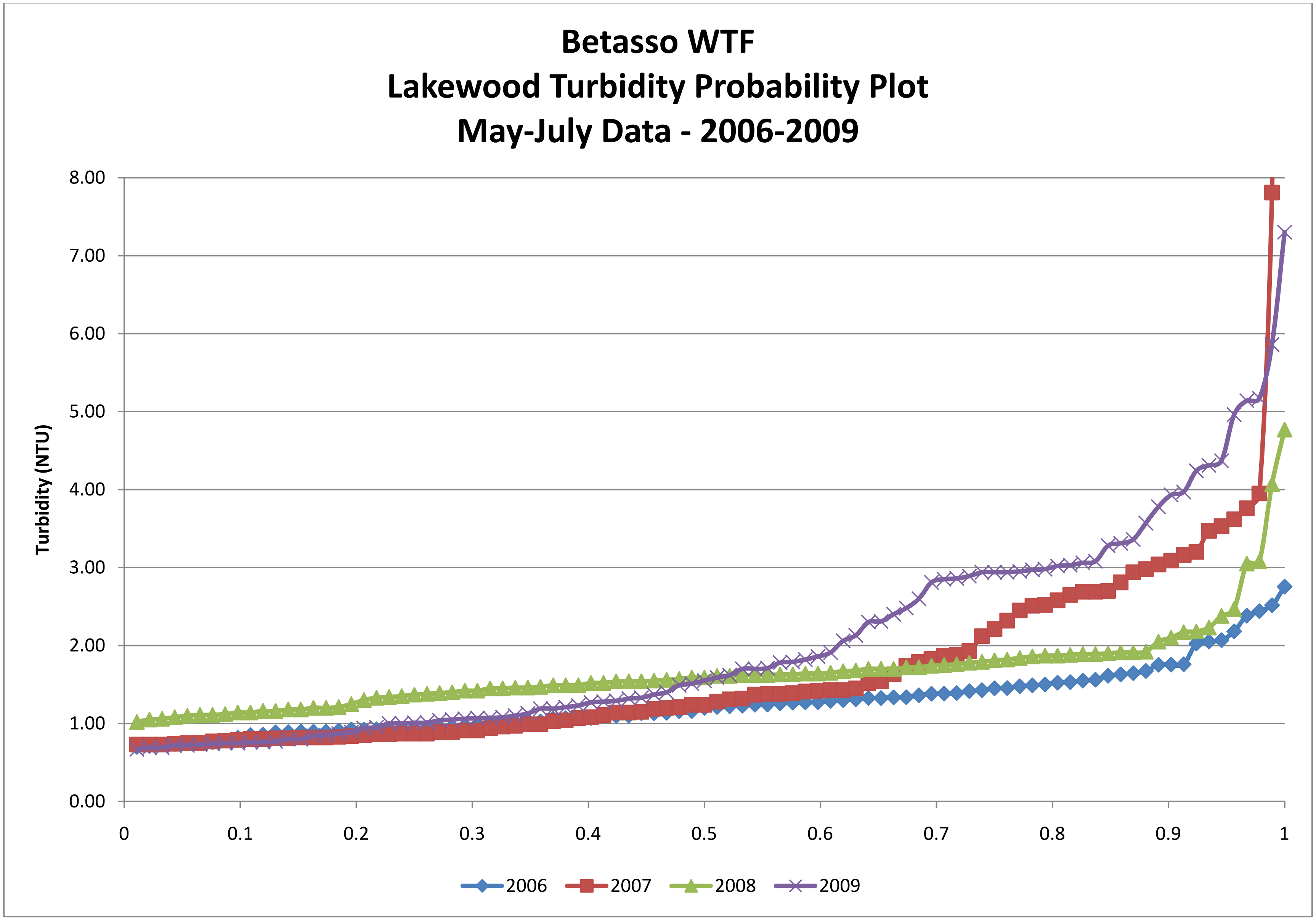
Appendix B:

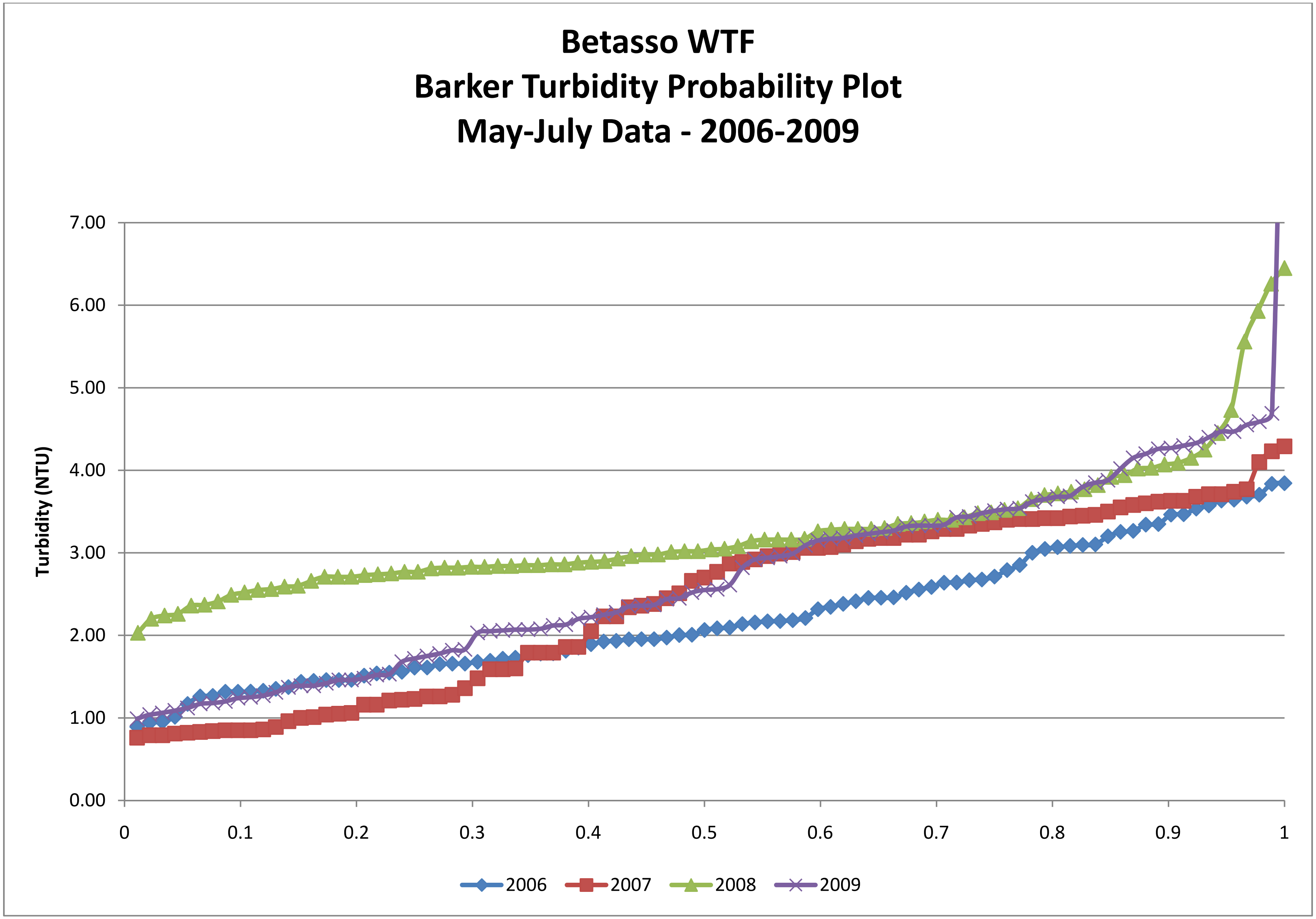
Additional Figures from Evaluations of Water Quality and Betasso Water Treatment Facility Performance


Betasso WTF
High Flow Days (>24 mgd)
Flowrate and Raw Water Turbidity
Turbidity (NTU)
Flowrate (mgd)
0
2
4
6
8
10
12
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Barker Ave Turbidity
Lakewood Ave Turbidity
Ave Flow (mgd)

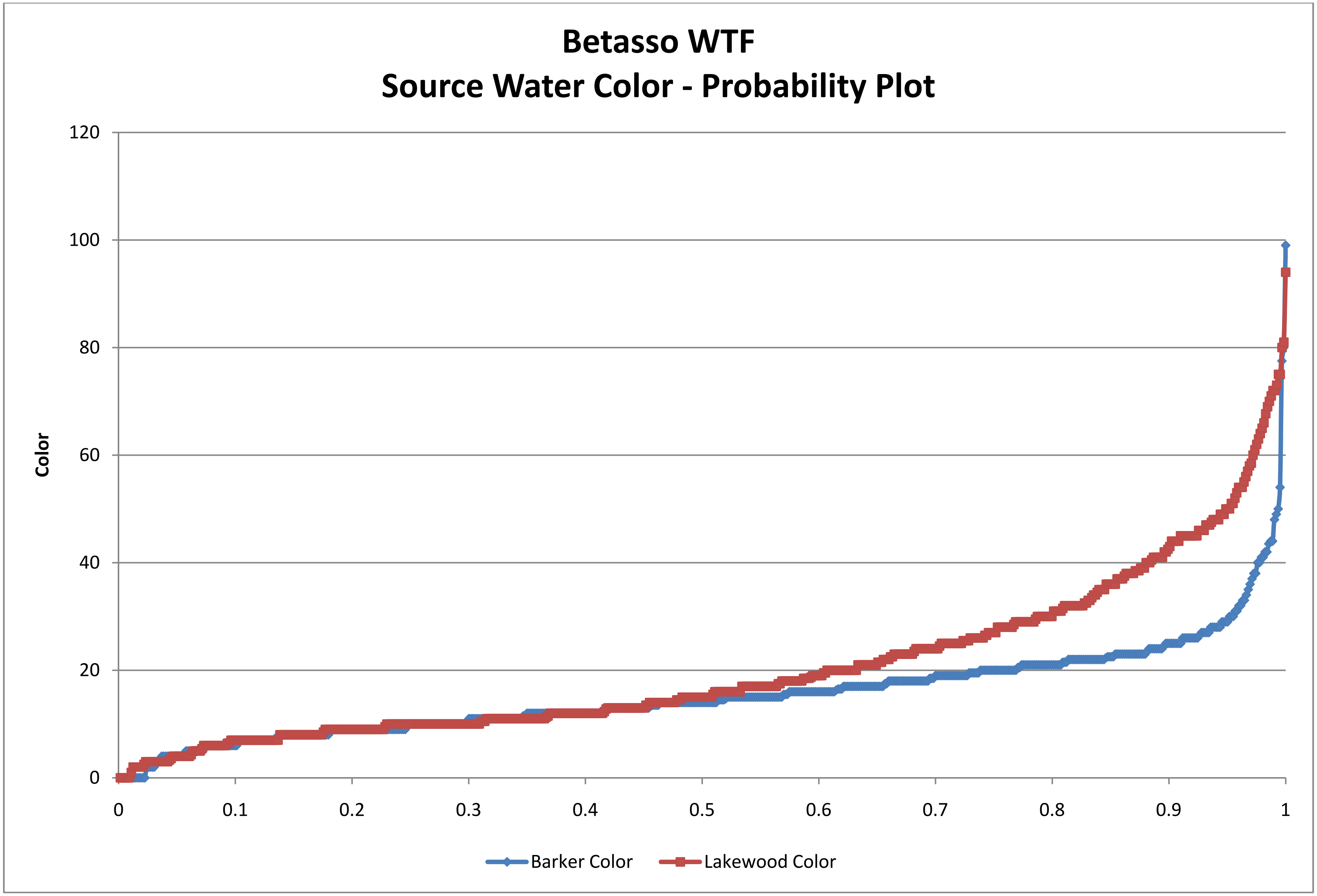

Betasso WTF
Lakewood Turbidity
May - July Data, 2006-2009
Turbidity (NTU)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
2006
2007
2008
2009

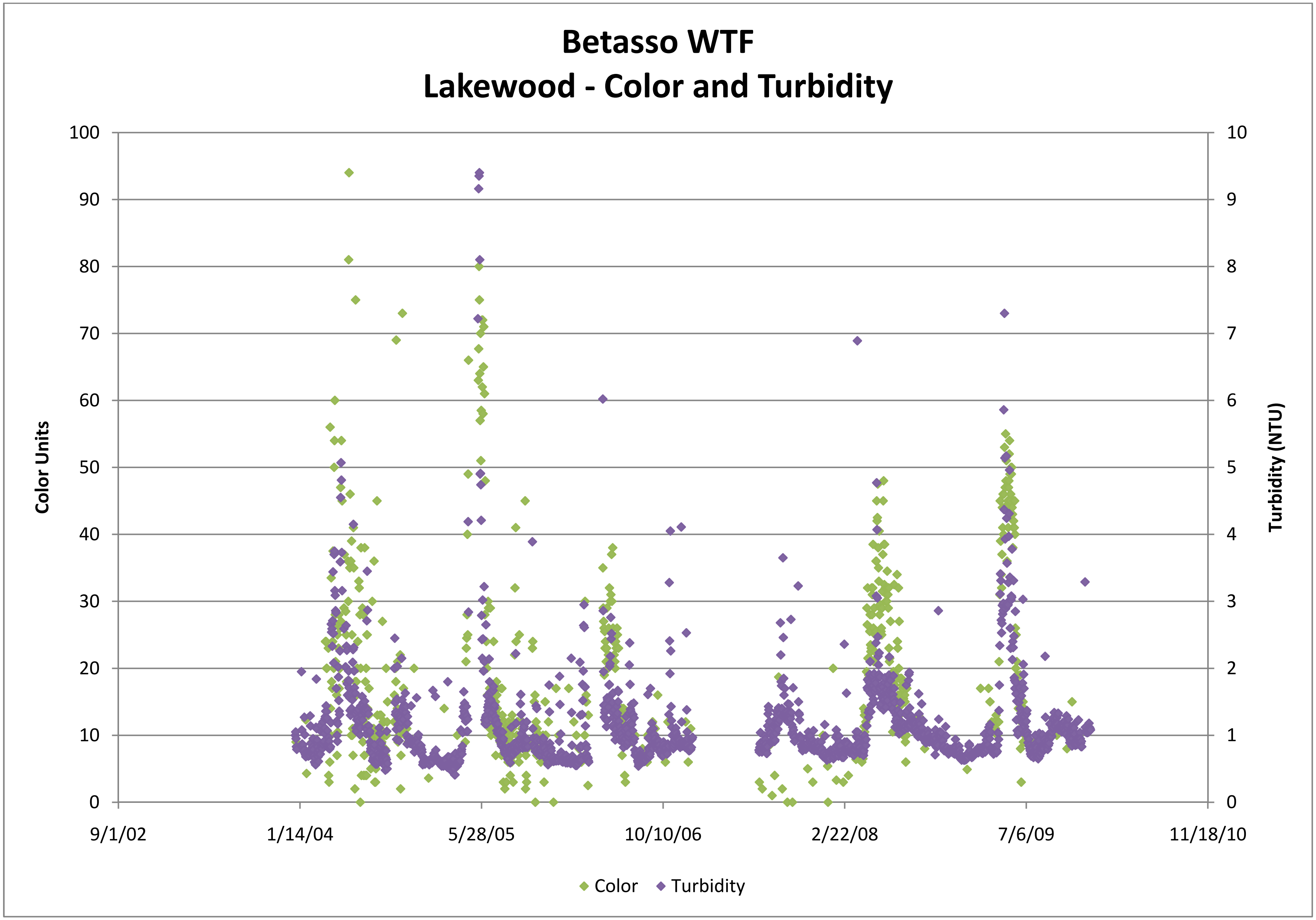

Betasso WTF
Barker Turbidity
May - July Data, 2006-2009
Turbidity (NTU)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
2006
2007
2008
2009

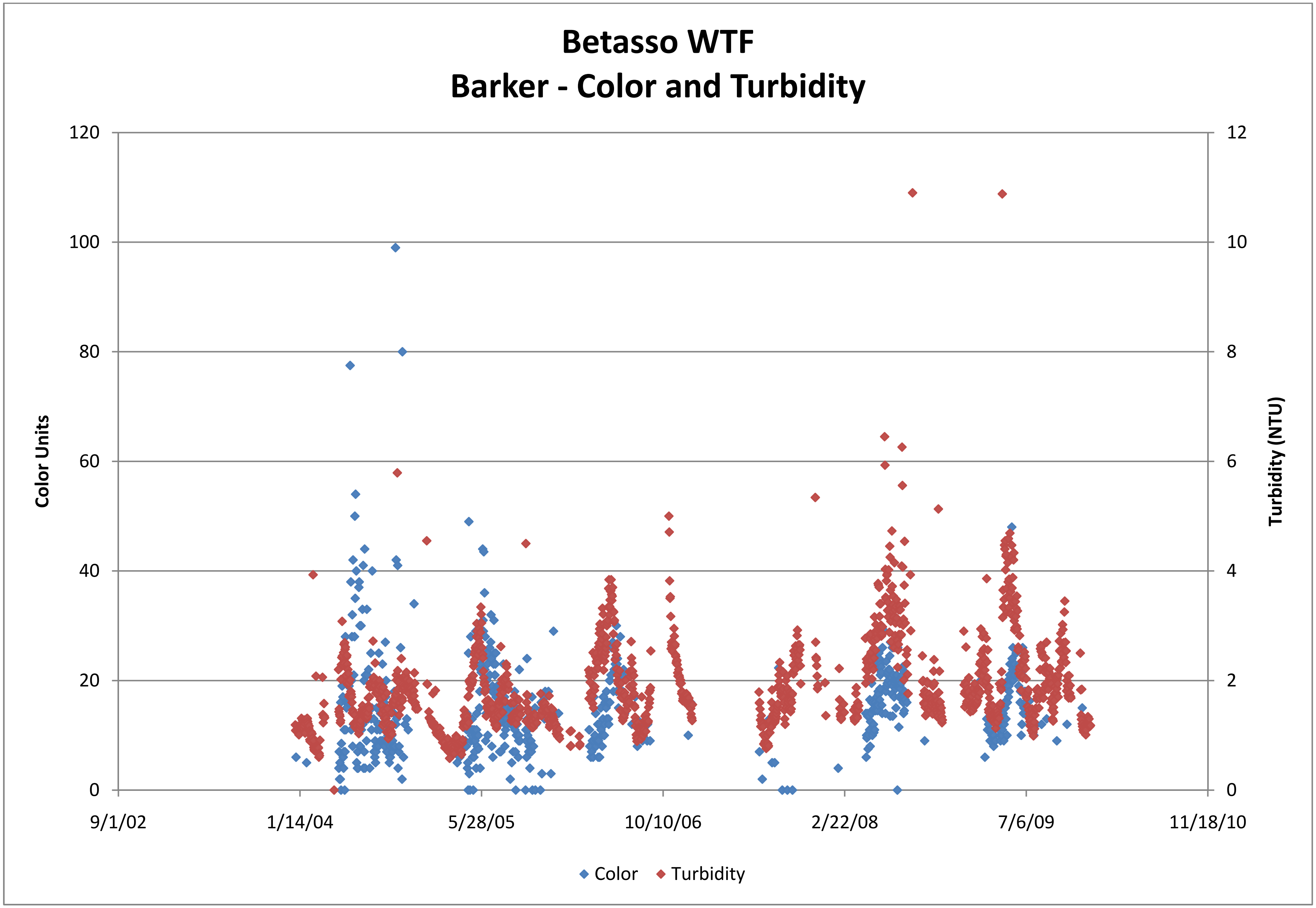

Betasso WTF
Lakewood Turbidity Probability Plot
May-July Data - 2006-2009
Turbidity (NTU)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009

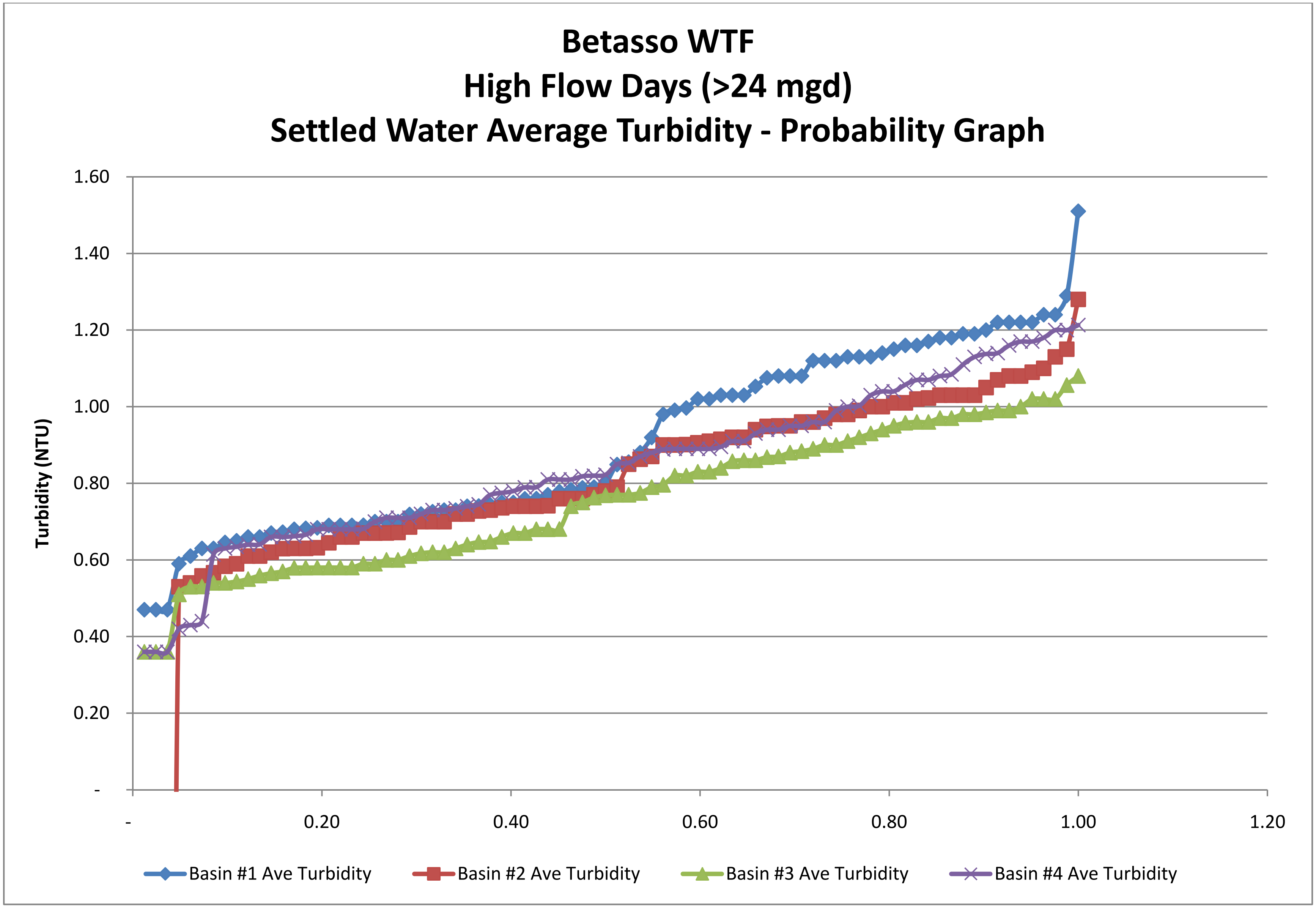


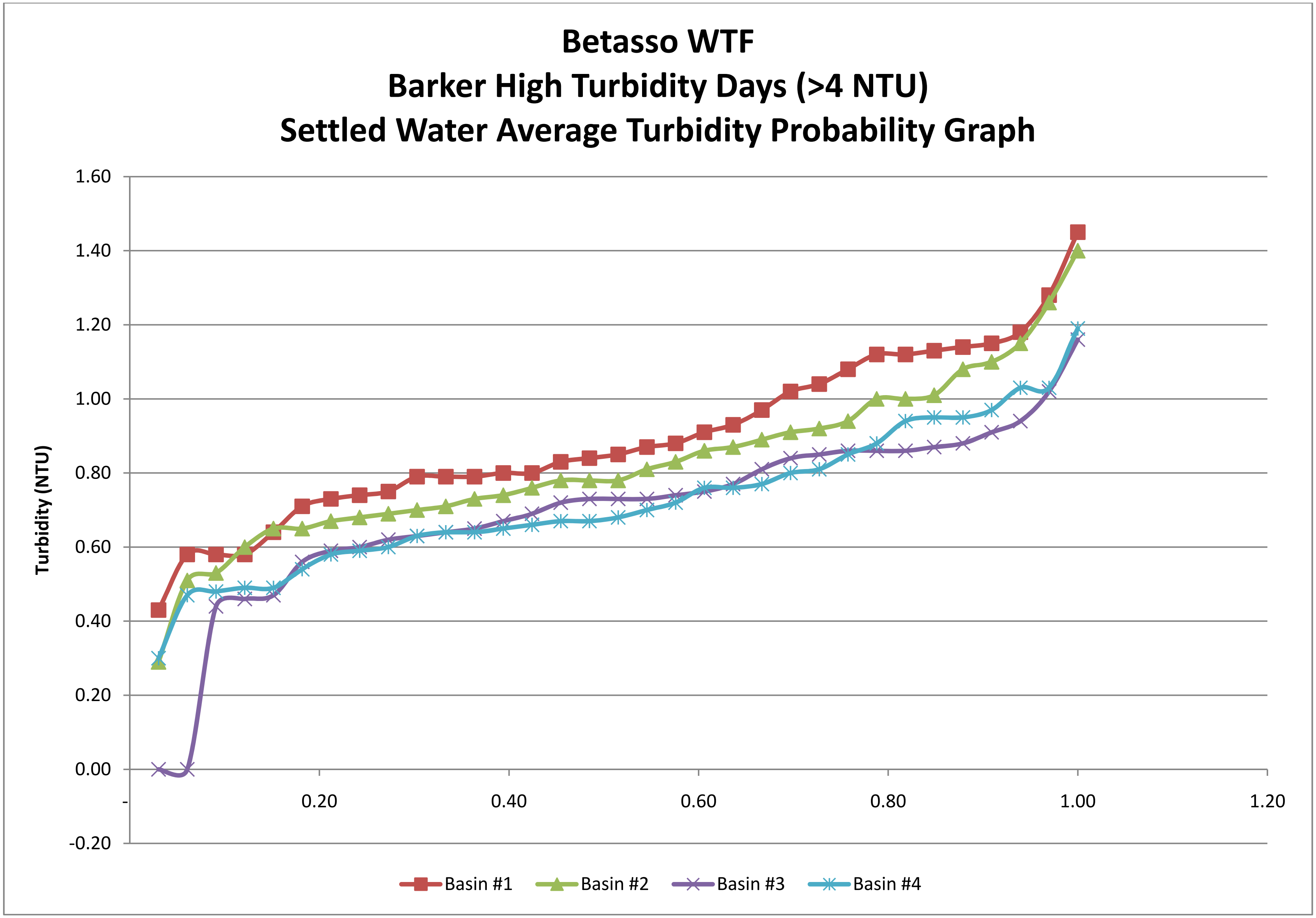
Betasso WTF
Barker Turbidity Probability Plot
May-July Data - 2006-2009
Turbidity (NTU)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009

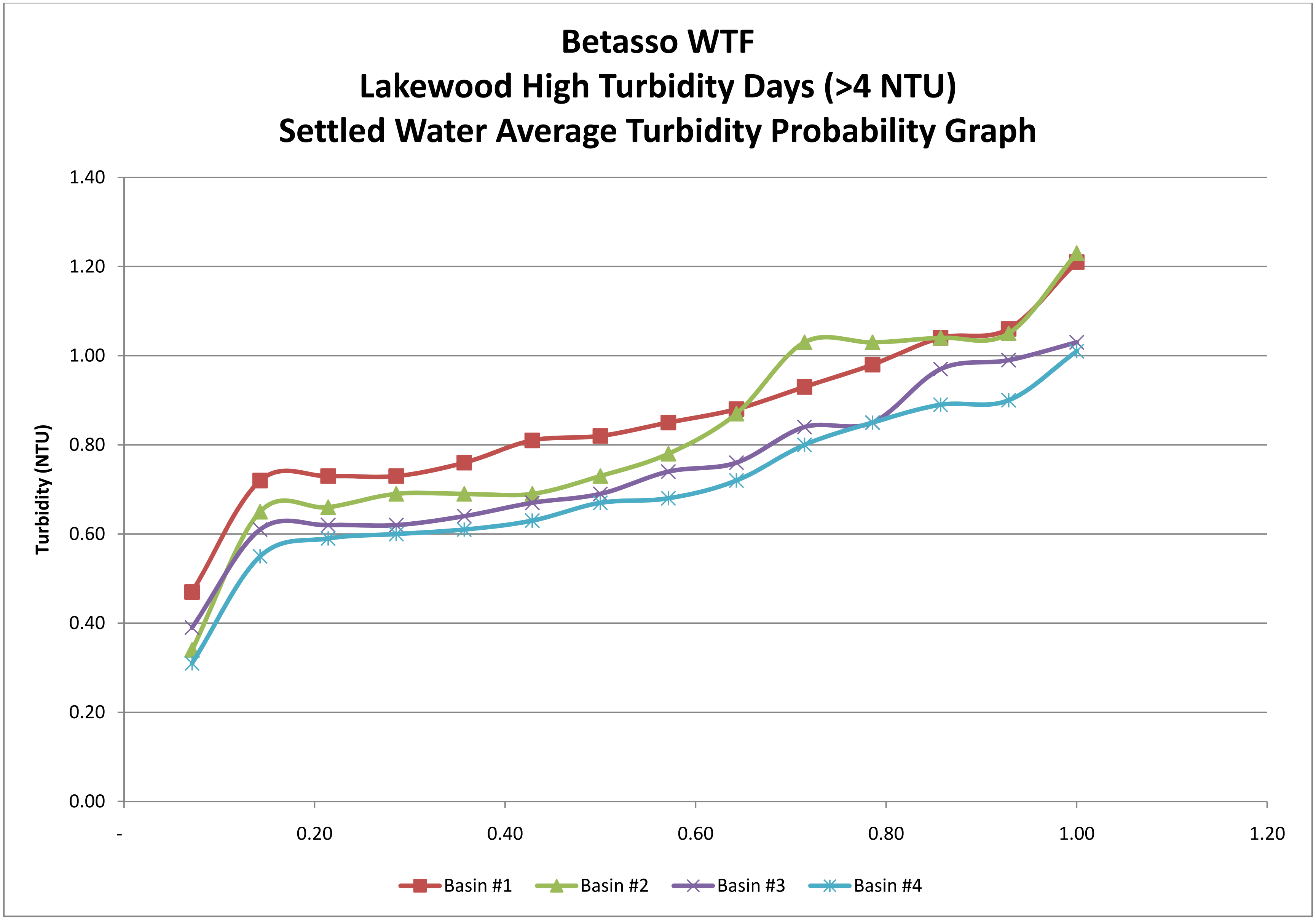

Betasso WTF
Source Water Color - Probability Plot
Color
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Barker Color
Lakewood Color

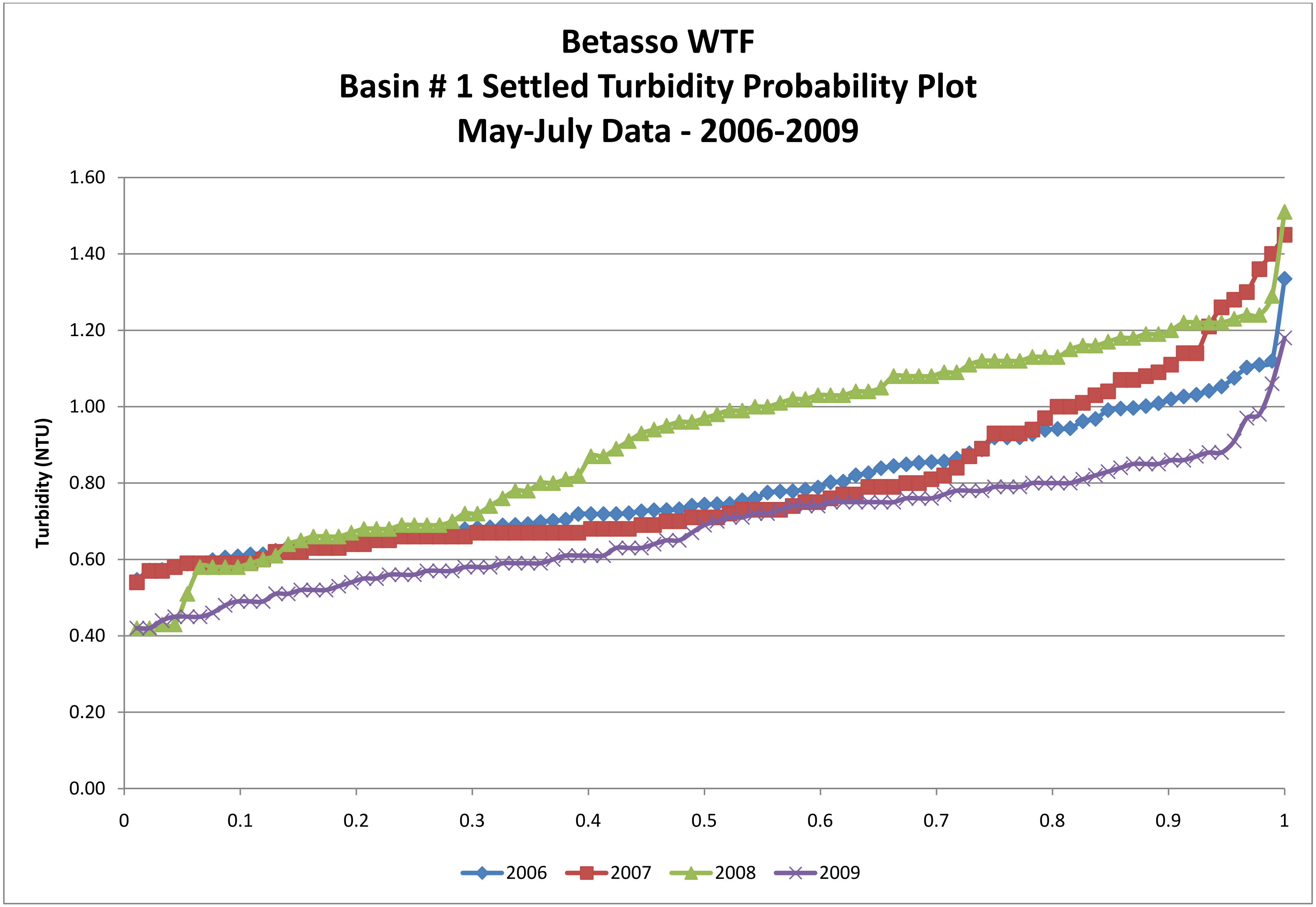

Betasso WTF
Lakewood - Color and Turbidity
Color Units
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
10
9
8
7
6
5
4
3
2
1
0
9/1/02
1/14/04
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
Color
Turbidity

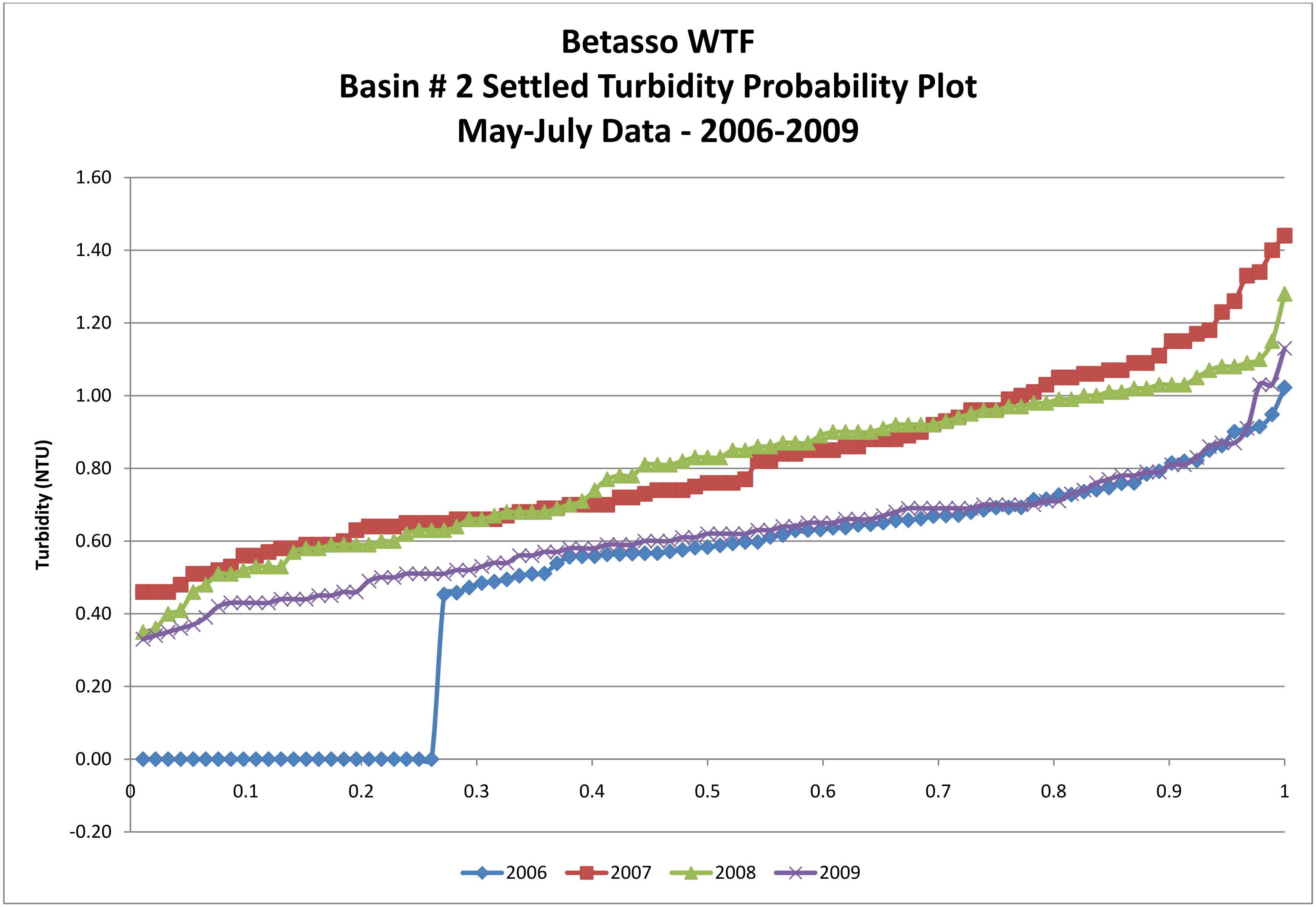

Betasso WTF
Barker - Color and Turbidity
Color Units
Turbidity (NTU)
120
100
80
60
40
20
0
12
10
8
6
4
2
0
9/1/02
1/14/04
5/28/05
10/10/06
2/22/08
7/6/09
11/18/10
Color
Turbidity


Betasso WTF
High Flow Days (>24 mgd)
Settled Water Average Turbidity - Probability Graph
Turbidity (NTU)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
-
0.20
0.40
0.60
0.80
1.00
1.20
Basin #1 Ave Turbidity
Basin #2 Ave Turbidity
Basin #3 Ave Turbidity
Basin #4 Ave Turbidity

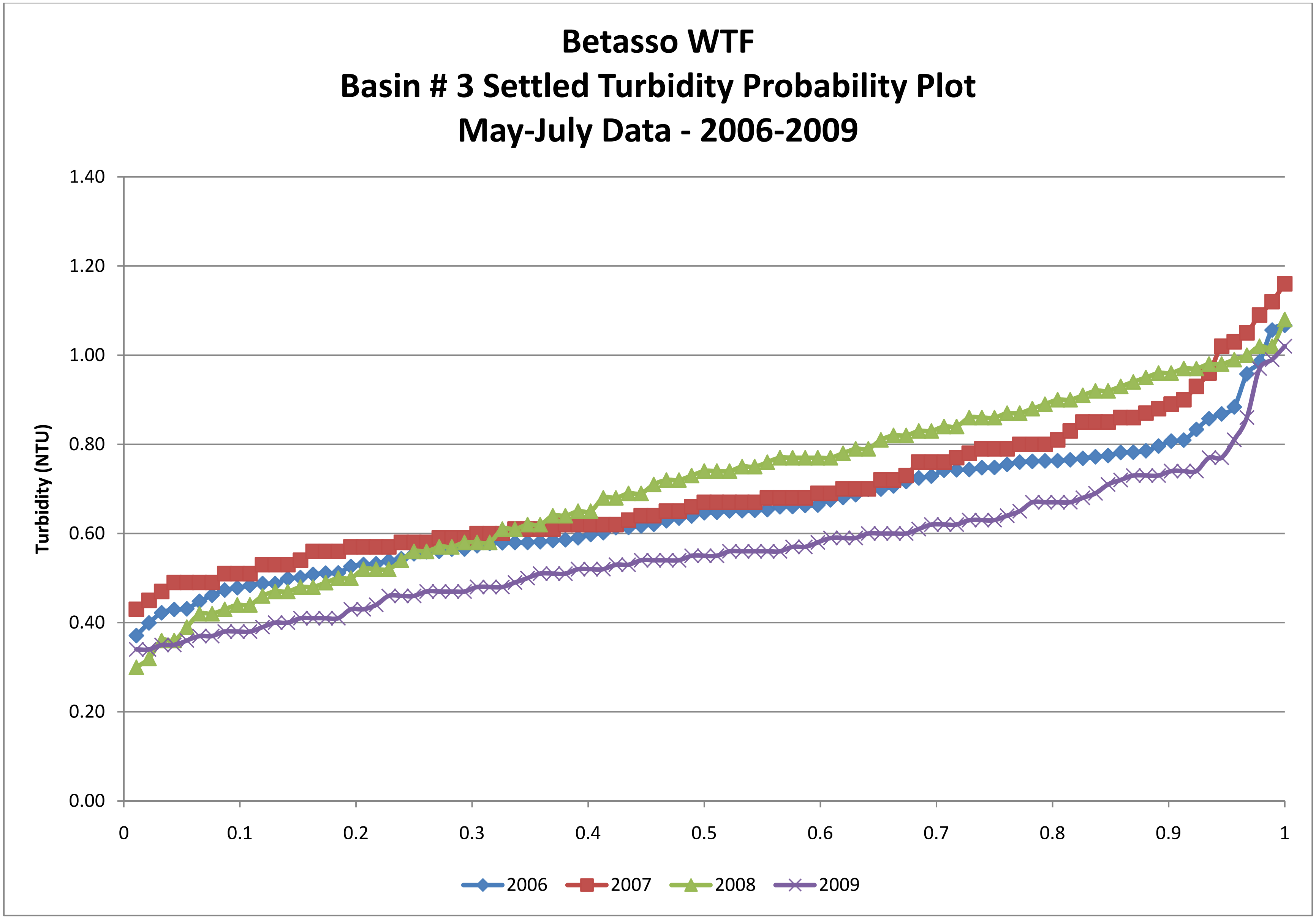

Betasso WTF
Barker High Turbidity Days (>4 NTU)
Settled Water Average Turbidity Probability Graph
Turbidity (NTU)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-
0.20
0.40
0.60
0.80
1.00
1.20
Basin #1
Basin #2
Basin #3
Basin #4

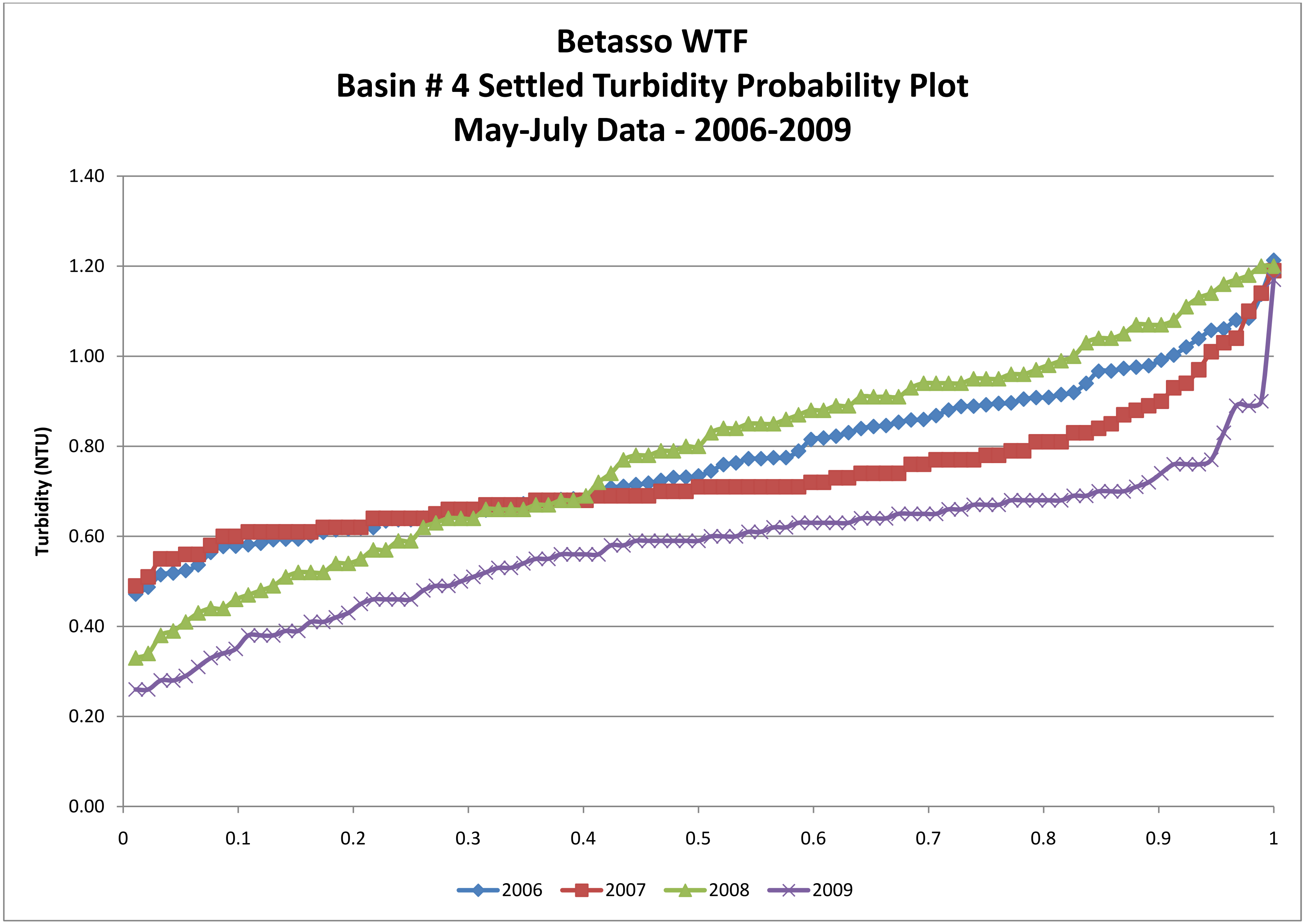

Betasso WTF
Lakewood High Turbidity Days (>4 NTU)
Settled Water Average Turbidity Probability Graph
Turbidity (NTU)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-
0.20
0.40
0.60
0.80
1.00
1.20
Basin #1
Basin #2
Basin #3
Basin #4


Betasso WTF
Basin # 1 Settled Turbidity Probability Plot
May-July Data - 2006-2009
Turbidity (NTU)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009

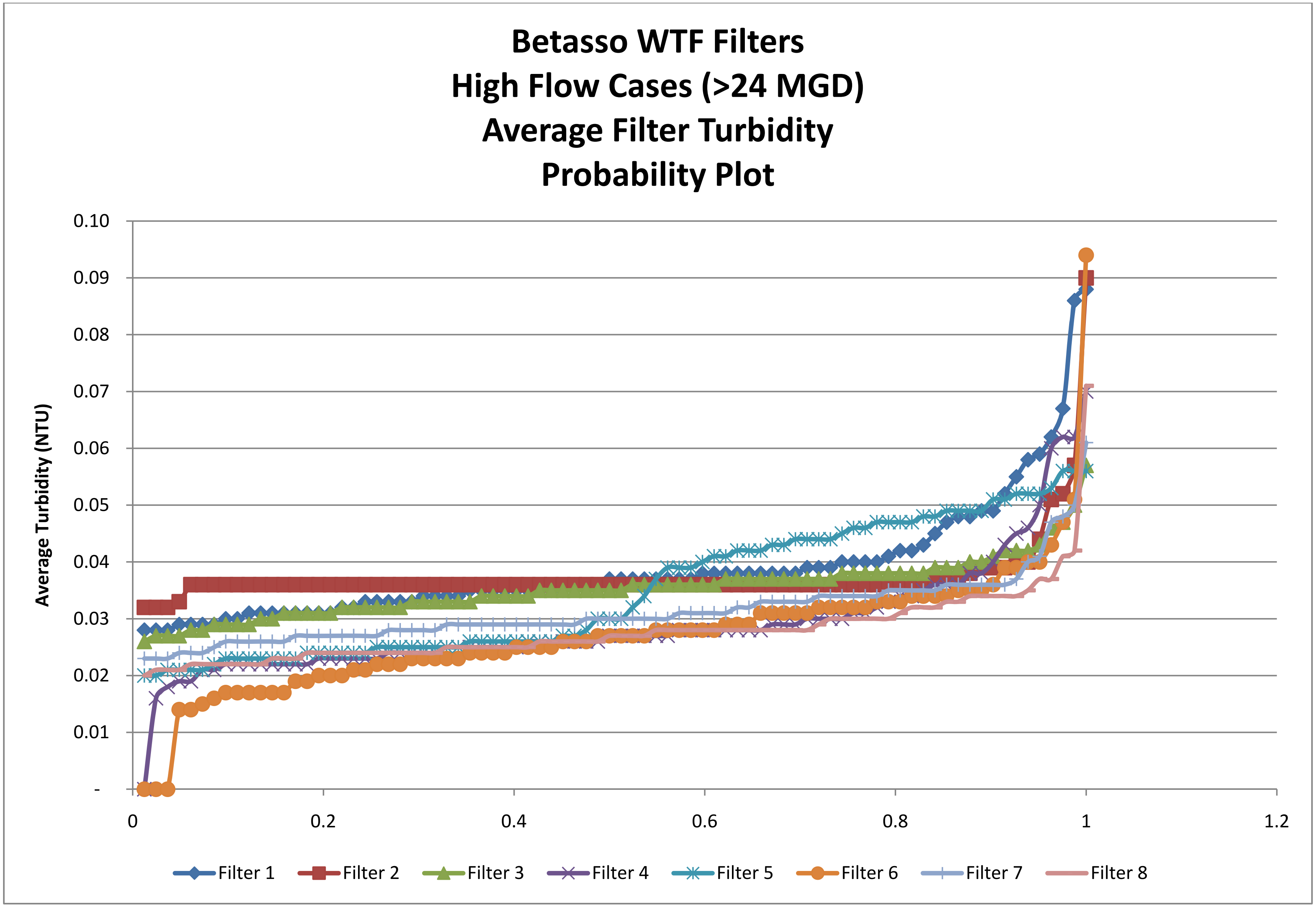


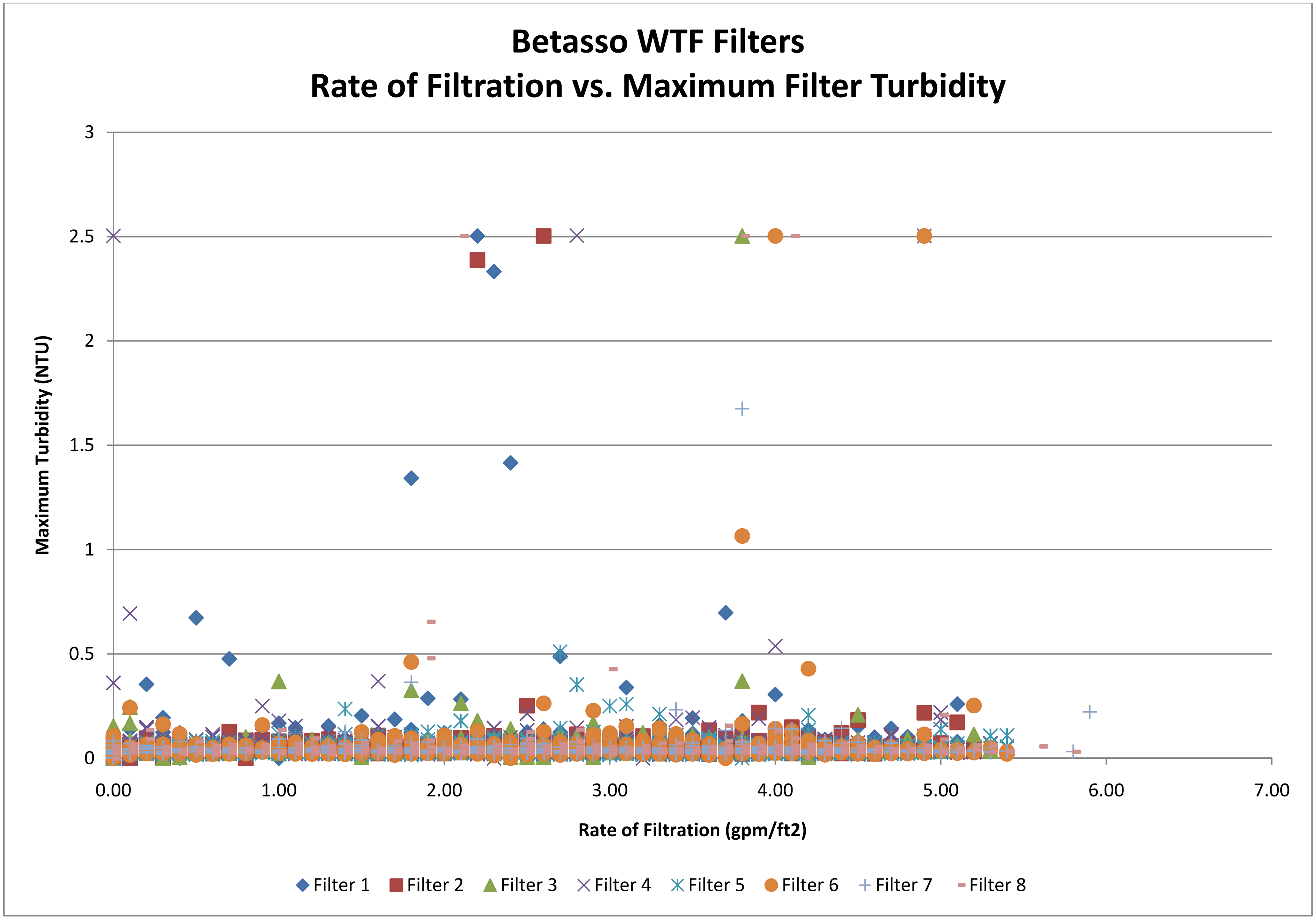
Betasso WTF
Basin # 2 Settled Turbidity Probability Plot
May-July Data - 2006-2009
Turbidity (NTU)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009


Betasso WTF
Basin # 3 Settled Turbidity Probability Plot
May-July Data - 2006-2009
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Turbidity (NTU)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009

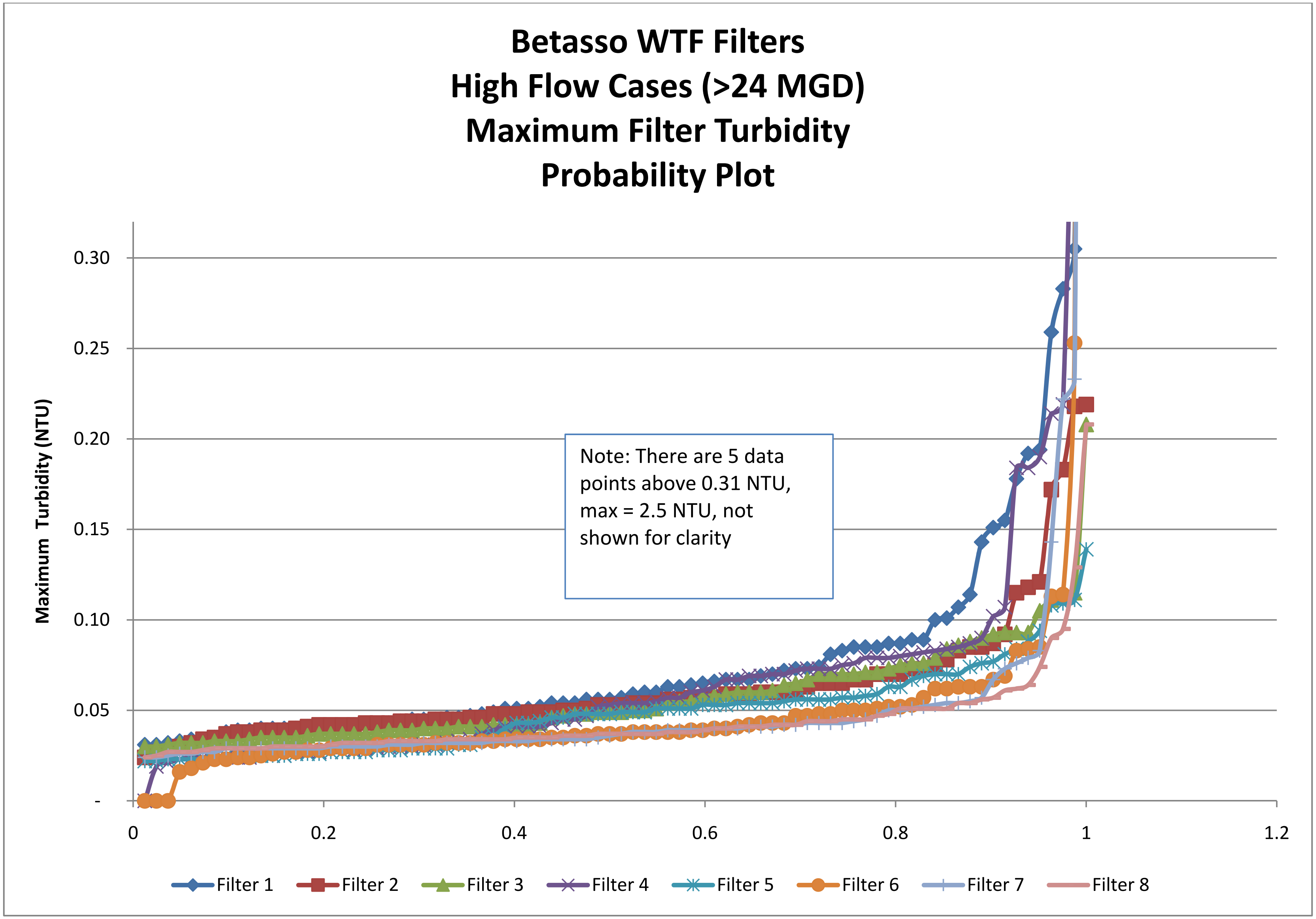


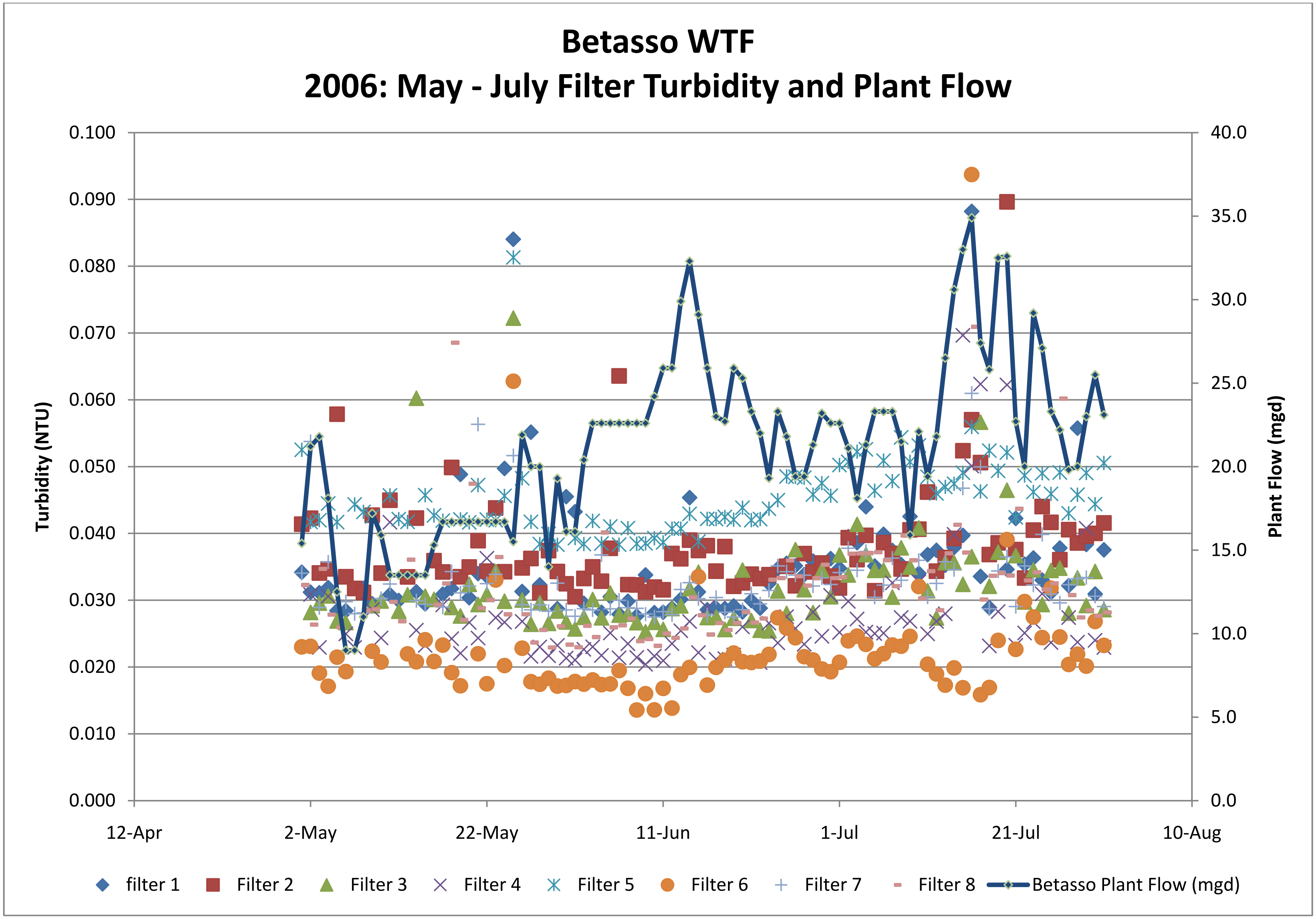
Betasso WTF
Basin # 4 Settled Turbidity Probability Plot
May-July Data - 2006-2009
Turbidity (NTU)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2006
2007
2008
2009

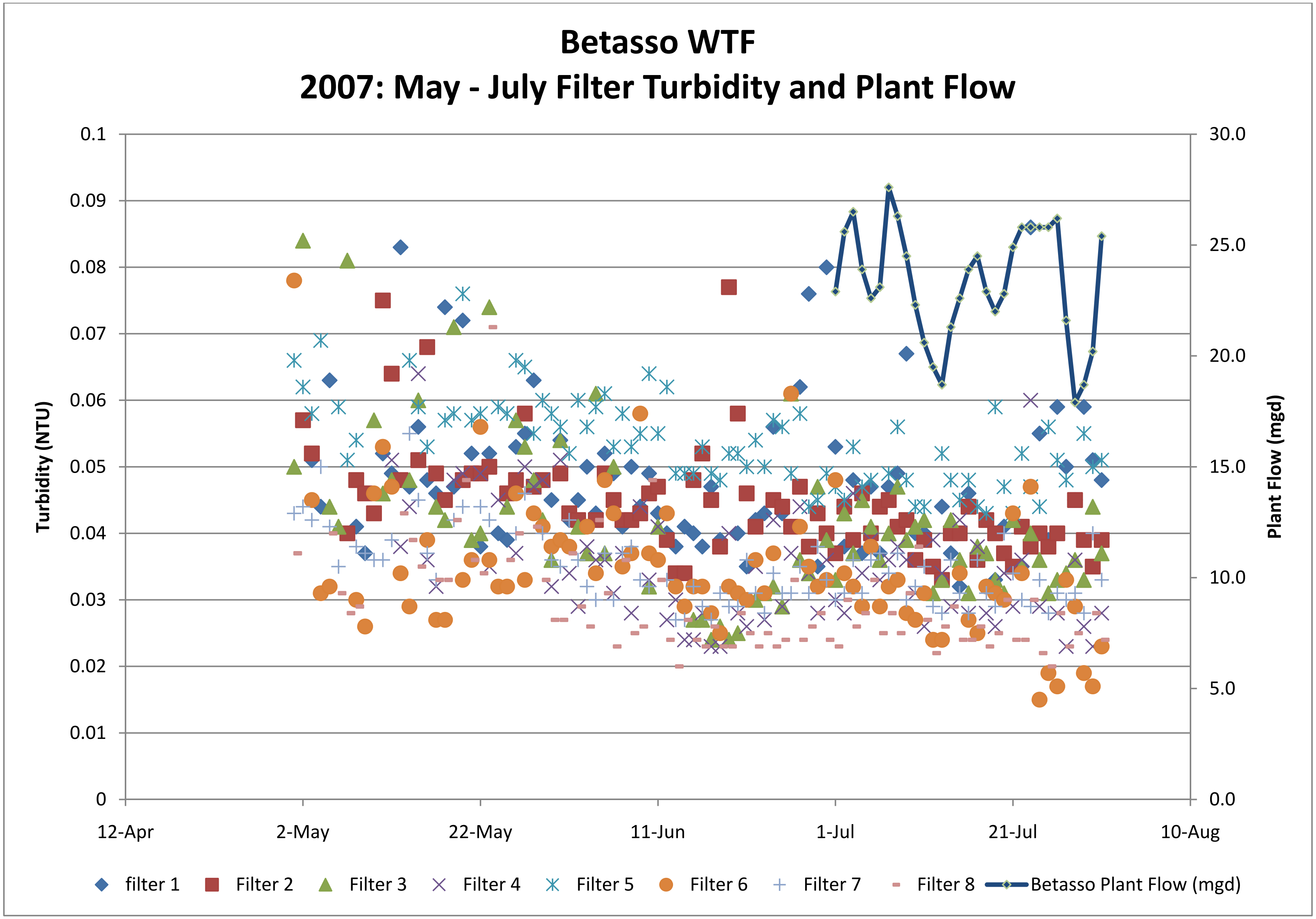

Betasso WTF Filters
High Flow Cases (>24 MGD)
Average Filter Turbidity
Probability Plot
Average Turbidity (NTU)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
-
0
0.2
0.4
0.6
0.8
1
1.2
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8



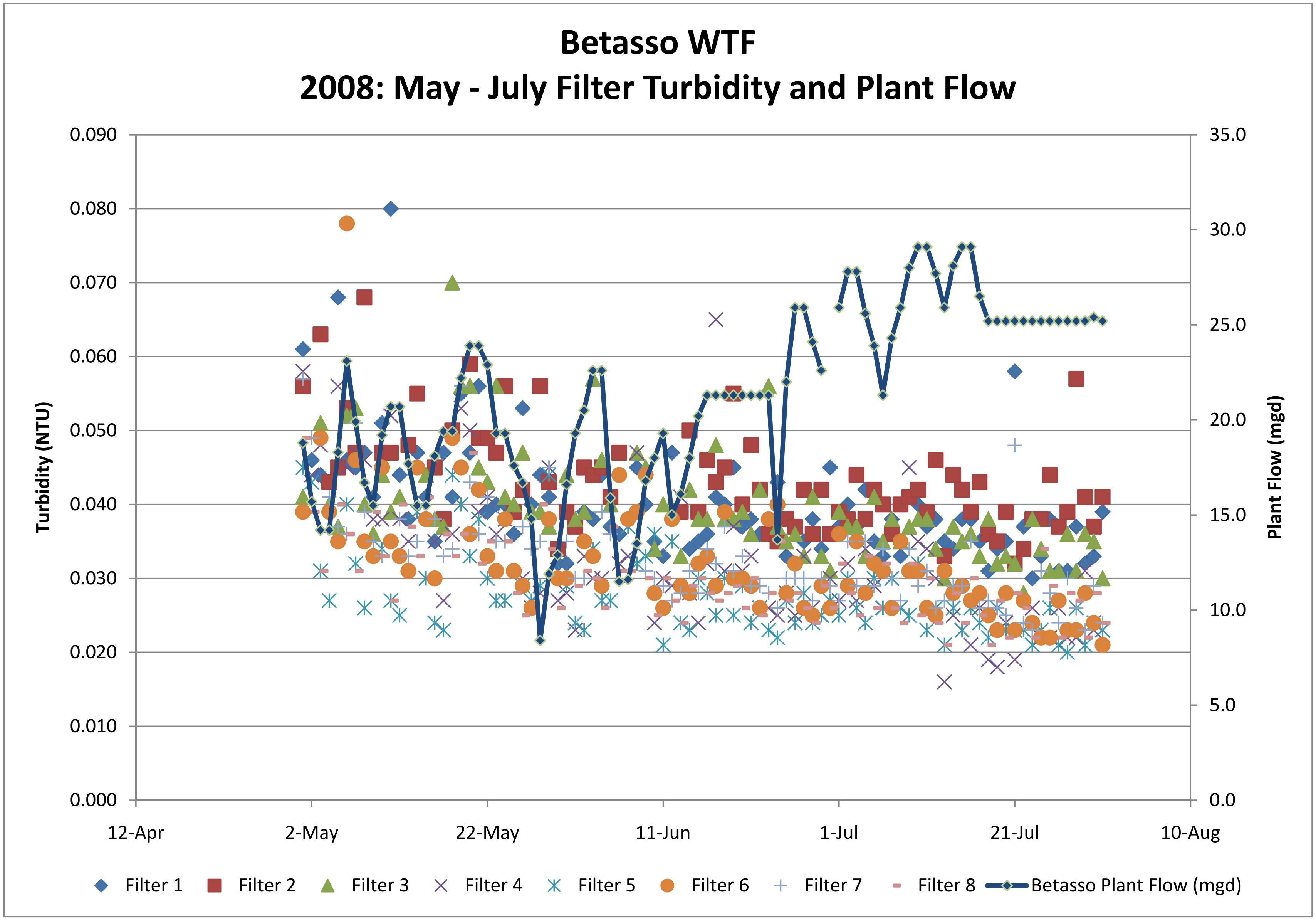
Betasso WTF Filters
Rate of Filtration vs. Maximum Filter Turbidity
Maximum Turbidity (NTU)
3
2.5
2
1.5
1
0.5
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Rate of Filtration (gpm/ft2)
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8

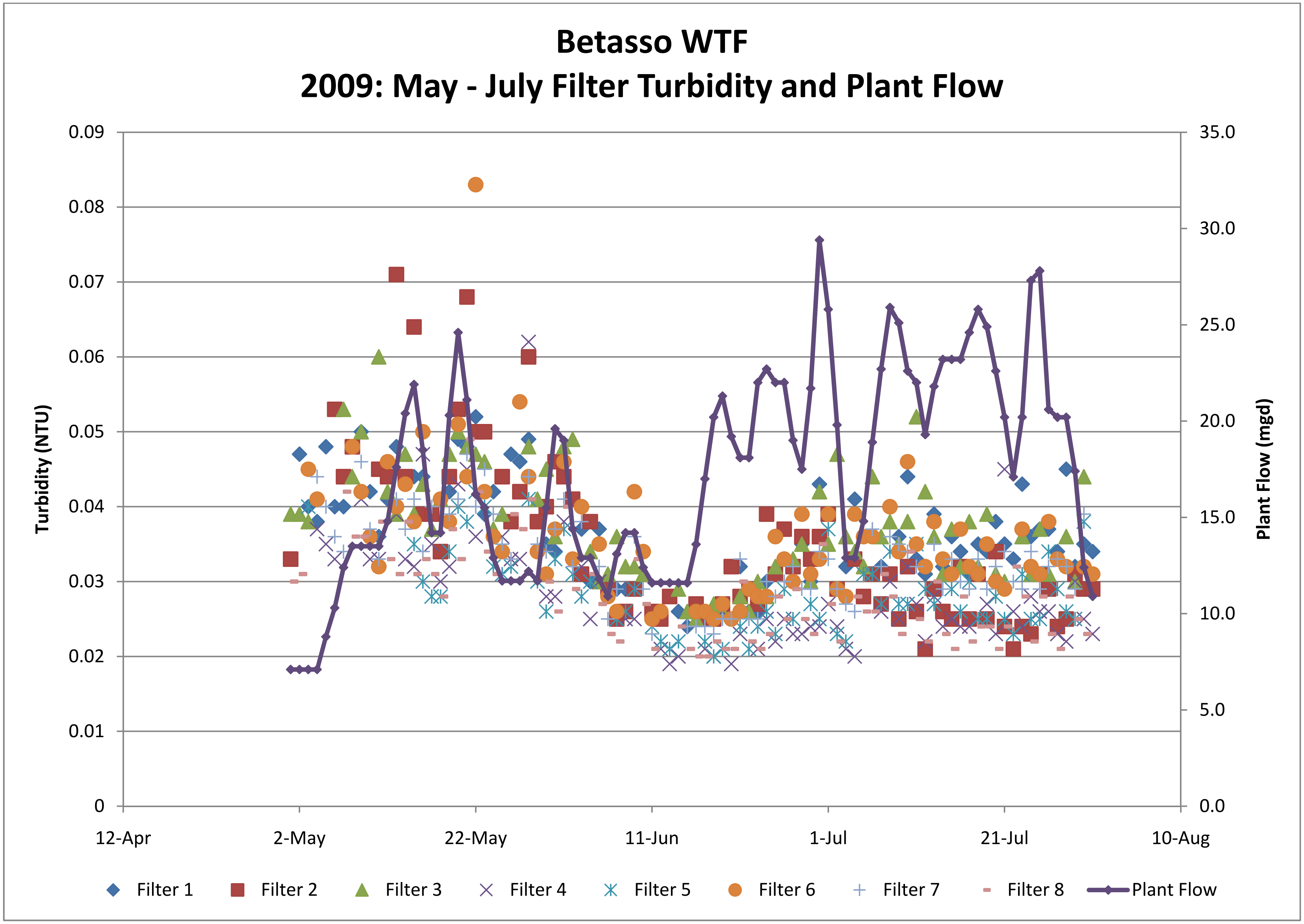

Betasso WTF Filters
High Flow Cases (>24 MGD)
Maximum Filter Turbidity
Probability Plot
Maximum Turbidity (NTU)
0.30
0.25
0.20
0.15
0.10
0.05
-
0
0.2
0.4
0.6
0.8
1
1.2
Note: There are 5 data points above 0.31 NTU, max = 2.5 NTU, not shown for clarity
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8


Betasso WTF
2006: May - July Filter Turbidity and Plant Flow
Turbidity (NTU)
Plant Flow (mgd)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8
Betasso Plant Flow (mgd)



Betasso WTF
2007: May - July Filter Turbidity and Plant Flow
Turbidity (NTU)
Plant Flow (mgd)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8
Betasso Plant Flow (mgd)


Betasso WTF
2008: May - July Filter Turbidity and Plant Flow
Turbidity (NTU)
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Plant Flow (mgd)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8
Betasso Plant Flow (mgd)



Betasso WTF
2009: May - July Filter Turbidity and Plant Flow
Turbidity (NTU)
Plant Flow (mgd)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
12-Apr
2-May
22-May
11-Jun
1-Jul
21-Jul
10-Aug
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Filter 7
Filter 8
Plant Flow

Appendix C:

Water Utility Master Plan Hydraulic Modeling Results

MWH

BUILDING A BETTER WORLD

MEMORANDUM

To: City of Boulder — Date: August 16, 2010

From: MWH

Subject: Water Utility Master Plan
Hydraulic Modeling Results

1. Introduction

The following memorandum summarizes the analysis of the City of Boulder's water distribution system as part of the Boulder Treated Water Master Plan update. The work summarized in this memorandum was developed based on the modeling approach developed by MWH and the city prior to the start of this task.

2. Overview

The City of Boulder's water distribution system was evaluated to understand system performance under current and future conditions and to identify system deficiencies. Model results were analyzed to determine if the water distribution system met the reliability criteria as shown in Table 1 below.

Table 1 – Reliability Criteria

Category	Criteria	Notes
Pressure	40 – 80 psi	Target range for normal operating pressure
	150 psi	Maximum target pressure; Note: Pressures at some existing areas in the system reach over 160 psi.
	20 psi	Minimum allowable pressure during fire flow under a maximum day demand conditions
Velocity	10 feet per second	Maximum velocity under normal operating conditions
Head Loss	10 feet/1000 feet	Maximum headloss under normal operating conditions

In addition to the criteria listed above, the water distribution system was evaluated to further understand the need for pressure zone modifications, areas of high water age and the systems operating during system failure scenarios. The following sections provide a summary of the work performed to evaluate the city's water distribution system. Recommended improvements and further analysis are presented at the end of this memorandum.

3. Existing Distribution Network Model Calibration

3.1. Model Calibration Overview

The city has been using a computer model to simulate system hydraulics and operation of the water distribution since before 1980 when the first Boulder water distribution model was developed in KYpipe. As part of the 2000 City of Boulder Treated Water Master Plan, the model was improved and calibrated using field verified pressures and fire flow tests. In 2005, the city's model was integrated into the MWH Soft InfoWater software and was upgraded to an all-pipes model. Since that time the city has been maintaining and updating the water distribution model and routinely comparing SCADA data with model results to verify the model output. The model has also been enhanced to perform 24-hour and 30-day extended period simulations (EPS) and includes rule-based logic that allows the model to operate similar to the approach taken by the operators within the city.

The model used for this distribution system evaluation was most recently calibrated by the city for the IDSE Report prepared in 2006. The city provided MWH with a copy of the calibrated EPS model and corresponding model set-up and calibration documentation. Model documentation provided by the city for the model calibration is provided in Attachment 1. MWH reviewed these documents and did not perform any additional calibration prior to performing the distribution system evaluation. A summary of the calibration review is provided in the next section.

3.2. Model Calibration Review

The EPS model calibration performed by the city for the IDSE Report included a comparison of SCADA data and model results for a 24-hour and 30-day period in 2006. Results provided by the city show that a comparison of model versus SCADA water levels in the Gunbarrel, Maxwell and Chautauqua tanks for a 24-hour period are in reasonable agreement. However results from the 30-day simulation show that while the range of tank water levels are in general agreement between the model and SCADA data, the timing of the water levels and the shape of the plots are different.

At the time of the model calibration, city staff attributed this difference to the fact that the Boulder water distribution system is manually operated with each operator having a slightly varied approach to meeting system pressures and flows. As a result, over a 30-day period there will be a continual change in the daily system operation that could not be replicated with the rules-based controls established in the model. The city staff felt that the boundary conditions adequately represent the real system and that the rule-based controls used by the model reflect a reasonable approach to operating the system. In addition, no significant changes were made to the underlying assumptions used during the latest model calibration, such as C-factors, minor losses, and system configuration. For these reasons the city staff agreed that the model adequately represented the water distribution system and was a good tool to understand the system hydraulics.

3.3. Model Calibration Comments and Recommendations

Based on review of available data provided by the city, MWH concludes that a reasonable approach was used to verify that the model could produce results that are consistent with flow, pressure and tank level ranges that are seen in the Boulder water distribution system when appropriate system inputs are used in the model. The EPS model calibration performed by the city for the IDSE Report could be further refined by performing targeted field testing to verify the model's ability to replicate system conditions under a variety of demand conditions. Specific examples include the following:

- Perform distribution system pressure monitoring to compare model and actual pressures seen across the distribution system;
- Conduct fire flow simulations to compare the model and actual system's response to stress and confirm local head-loss; and
- Perform loss-of-head tests along targeted pipe segments to refine roughness factors (c-factors) in areas to improve agreement between model and system flow splits (i.e. at Betasso WTF) and tank levels.

Additional field-verified model calibration would enable the city to remain confident in the model's ability to represent system hydraulics and maintain the city's investment in the water distribution system model as a tool for planning and operation.

4. Distribution System Evaluation

4.1. Overview

The distribution system evaluation was performed by using a both steady-state and extended period simulation analysis in the calibrated hydraulic model under a variety of demand conditions. The city and MWH established a methodology for performing the hydraulic analysis which was designed to specifically meet the objectives outlined above. This methodology is summarized in a memorandum dated June 29, 2010. The city provided MWH with a model file in the MWH Soft InfoWater software that contained model scenarios for use in the evaluation. The model simulations provided by the city are outlined in Table 2. A summary of the model boundary conditions and comparison with SCADA for the model provided by the city are provided in Attachment 2.

Table 2 – City Provided Model Scenarios

Demand Scenario	Type (SS or EPS)	Peaking Factor (PF) and Demand	Model Scenario from City
		Existing Demands	
Maximum Day	SS	PF of 2.6 43.13 MGD	Scenario Name: MAXDAY_SS
Peak (Max) Hour	SS	PF of 2.7 44.79 MGD	Scenario Name: MAXDAY_SS
Minimum Month	30 Day EPS	PF of 0.6 9.36 MGD	Scenario Name: MINMONTH_EPS
Maximum Month	30 Day EPS	PF of 2.05 32.1 MGD	Scenario Name: MAXMONTH_EPS

4.2. Model Scenarios

MWH adapted the model files provided by the city to create the ten model scenarios that were used for the distribution system evaluations. Each of the scenarios are outlined in Table 3 below and discussed in more detail in the following section. The failure scenarios are outlined in Table 4.

Table 3 – Model Scenarios for Distribution System Evaluation

Model Scenario	Demand Scenario		Type (SS or EPS)	Model used for Master Planning Tasks	New Model Scenario
Existing Demands = 18.26 MGD*					
Water Age Analysis	Minimum Month	PF of 0.6 10.95 MGD	30 Day EPS	Use MINMONTH_EPS with demand scaled	
Water Age Analysis	Maximum Month	PF of 2.0 36.52 MGD	30 Day EPS	Use MINMONTH_EPS with adjustments for Max Month	
2035 Demands = 20.9 MGD*					
Pressure Zone Analysis	Minimum Day	PF of 0.6 12.54 MGD	7 Day EPS	Adapt from MINMONTH_EPS using WUMP_2035 demand distribution and SS option	MINDAY
Failure Scenario 1					MINDAYF1
Failure Scenario 5					MINDAYF5
Fire Flow Analysis	Maximum Day	PF of 2.6 54.34 MGD	SS	Adapt from MAXDAY_SS using WUMP_2035 demand distribution	MAXDAY35
Failure Analysis Scenario 4	Maximum Day	PF of 2.6 54.34 MGD	7 Day EPS		MAXDAYF4
Hydraulic Capacity Analysis	Peak Hour	PF of 3.6 75.24 MGD	SS		PKHR2035
Failure Scenario 2	Maximum Month	PF of 2.0 42.8 MGD	30 Day EPS	Adapted from MAXMONTH_EPS with demand	MAXMONF2
Failure Scenario 3	Maximum Month	PF of 2.0 42.8 MGD	30 Day EPS	Adapted from MAXMONTH_EPS with demand	MAXMONF3

Table 4 – Failure Scenario Overview

Scenario	System Failure	Demand Condition
1	Betasso WTF out of service	**Minimum day demands** being met entirely from the Boulder Reservoir WTF through the Iris, Cherryvale, Maxwell and Kohler pump stations.
2	Sunshine pipeline out of service	**Maximum month demands** being met from the Boulder Reservoir WTF and the Betasso WTF through the Canyon Pipeline only, in combination with the Iris, Cherryvale, Maxwell and Kohler pump stations, hydros and PRVs as needed.
3	Boulder Reservoir WTF out of service	**Maximum month demands** being met entirely from the Betasso WTF through the Maxwell, Kohler, Iris and Cherryvale hydros and PRVs as needed.
4	Canyon pipeline out of service	**Maximum day demands** being met from the Boulder Reservoir WTF and the Betasso WTF through the Sunshine Pipeline only, in combination with the Iris, Cherryvale, Maxwell and Kohler pump stations, hydros and PRVs as needed.
5	Sunshine Pipeline and Boulder Reservoir WTF out of service	**Minimum day demands** being met from the Betasso WTF through the Canyon Pipeline only and the Maxwell, Kohler, Iris and Cherryvale hydros and PRVs as needed.

4.3. Hydraulic Capacity Evaluation

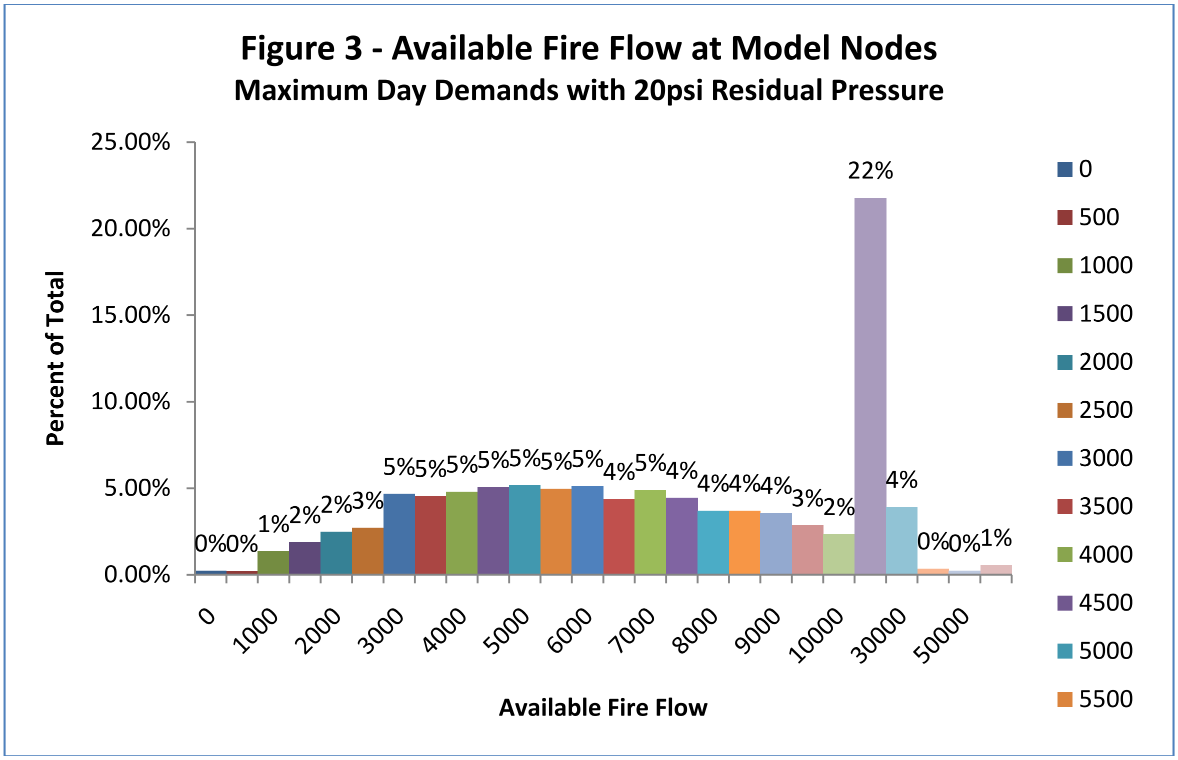
MWH performed a steady-state model simulation with a peak hour demand for the planning year 2035. The water distribution system as evaluated to see how the system performed against the reliability criteria provided in Table 1 above. The node pressure and velocity are color coded according to the reliability criteria and are presented in Figure 1 (attached). As shown in Figure 1, the Boulder water distribution is able to meet Peak Hour demands without causing wide-spread violation of the reliability criteria. There are some locations within the city that show pressures less than 40psi. However the majority of these locations are due to high elevation and are not the result from high headloss.

Velocities greater than 10 feet/second are shown at Betasso WTF and around several other facilities including Maxwell and Kohler. These high velocities however may be more due to the model representation at these facilities rather than true areas of concern. A review of these results on a city wide basis indicate that the Boulder water distribution system does not have significant capacity issues and is able to adequately meet pressure and velocity requirements throughout the city.

4.4. Fire Flow Analysis

A fire flow simulation was performed using the 2035 maximum day demands to identify the available fire flow at model nodes throughout the city's system with a minimum allowable residual pressure of 20 psi. The results from the fire flow analysis are provided in Figure 2 (attached). Available fire flow at each model node is color coded with increments of 500 gpm.

As shown in Figure 2, the majority of model nodes are able to provide 1500 gpm of available fire flow or greater. Specifically, 98% of the modeled nodes are able to provide 1500 gpm or greater during a fire condition and 22% of the model nodes are able to provide between 2000 and 3000 gpm of fire flow. A histogram of the available fire flow at model nodes is shown in Figure 3. Review of Figure 2 shows that model nodes which are unable to provide 1500 gpm of available fire flow are mainly located on dead end pipes or on small diameter pipes.



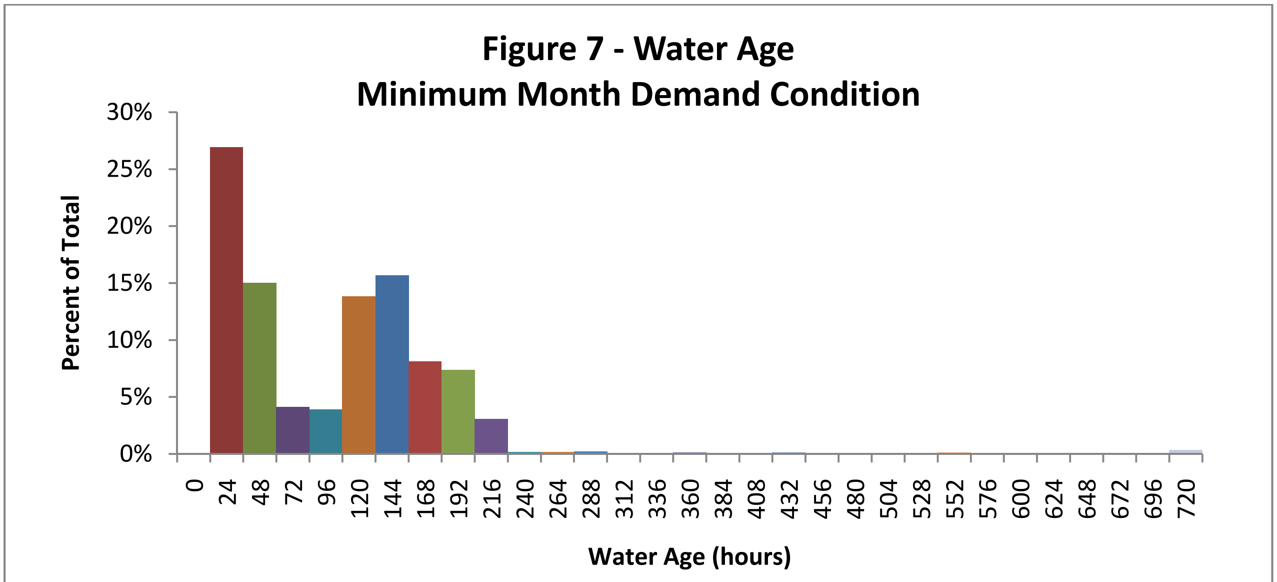
4.5. Additional Pressure Zone Analysis

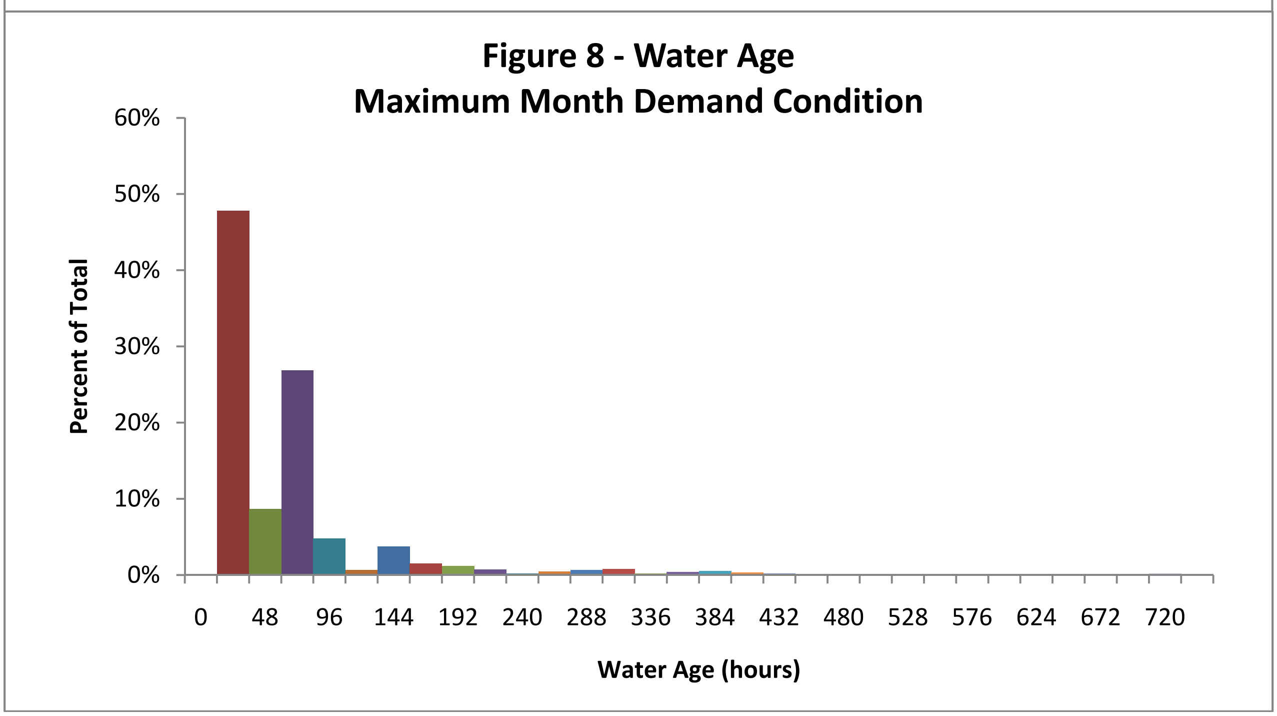
The City of Boulder water distribution system is known to have areas with high system pressure. While the reliability criterion establishes a target pressure range of 40 – 80 psi, areas within the system are known to have pressures that exceed 150 or 160 psi. MWH performed a 7-day EPS with minimum month demands for the planning year 2035 to better understand the extent of high pressures within the city's system. A map showing the system pressures for this simulation are shown in Figure 4. As seen in the figure, system pressures vary from some pressures lower than 40 psi at known high points and other system pressures reaching greater than 150 psi. High pressures are present along the boundary between Zones 2 and 3 and again between the Zone 2 and 1 boundary. In addition, high pressure nodes stretch the entire north-south extents of the city.

MWH facilitated a discussion during the modeling workshop with city staff to better understand the impact high pressures in the water distribution system are having on system operations and maintenance. The city stated that current all residential customers are required to have pressure reducing valves on their water service to bring the pressure down to acceptable levels. In addition, the city stated that the frequency and cost to repair water main breaks is not high enough to justify the previously estimated cost for developing sub-zones to address high pressures. MWH also noted that additional sub-zones could impact the City's ability to transfer water across the system and would likely complicate operations within the water distribution system further.

4.6. Water Age Analysis

A water age analysis was performed using the 30-day EPS model with existing (2010) minimum month and maximum month demands to simulate water age throughout the water distribution system. Water age was used as a surrogate for water quality in this analysis. The city's ultimate goal is to better understand water quality across the water distribution system and identify system operation changes that can be made to improve water quality. The maximum water age from the 30-day EPS is provided in Figure 5 (attached) for the minimum month demand and Figure 6 (attached) for the maximum month demands. A histogram showing water age for the minimum and maximum month demand conditions are shown in Figure 7 and 8 below.





As shown in Figures 5 thru 8, water age is greater for the minimum month simulations as compared with the maximum month scenario. Approximately 50% of model nodes in the minimum month scenario have water that is greater than 4 days old. However in the maximum month scenario, only 12% of the model nodes have water age that is greater than 4 days old. For the purpose of this analysis, it is assumed that the minimum month scenario represents a winter condition when temperatures are lower and a maximum month represents a summer time condition. Assuming that water quality is affected by temperature, it would be reasonable that higher water ages in the distribution system would be acceptable during the winter months when temperatures are colder.

4.7. System Failure Analysis

Five different system failure scenarios were modeled to understand how the City of Boulder could meet demand during a variety of variety of failure conditions. Table 4 previously presented highlights the five failure scenarios modeled as part of the distribution system evaluation. Model results from each scenario were compared against the reliability criteria to determine how well the system was able to meet demand while maintaining level of service under each scenario. Results for each failure scenario are provided in Figures 9 thru 13. In each figure, model nodes are color coded based on pressure and model pipes are color coded based on velocity. The figures are intended to highlight the areas where the reliability criteria are not met.

For all system failure scenarios, the city's water distribution system is able to meet the demand condition without dramatically impacting level of service within the distribution system. Failure Scenarios 1, 4 and 5 were simulated for a 7-day EPS run and Failure Scenarios 2 and 3 were simulated for a 30-day period. Figures 9 thru 13 show the pipes with high velocity and nodes with low pressure at the end of the simulation.

5. Recommendations

Based on results from the model simulations described in Section 4, the following section provides recommendations for the city's consideration in maintaining and improving the condition and reliability of the city's water distribution system.

5.1. Model Maintenance and Calibration

The City of Boulder is a leader among water utilities with their efforts to maintain, modify and use their water distribution system model. Extended period simulations are being performed with the use of rule-based controls that mirror the general logic behind the systems manual operation. Based on MWH's review of the model, the results indicate that the model is able to reasonably represent the actual system under normal conditions. However field verified calibration has not occurred for several years and it is unclear how well the model can predict the system's response under a stressed condition.

Based on MWH's review of the previous model calibration and discussions during the modeling analysis and workshop with the city, several items are identified as areas for further refinement or development of the model that would enhance the city's use and application of the model. These items are listed below and fall into two general categories. The first category is the improvements to the model to more explicitly represent system components such as valves, hydro facilities and pumps. The second category includes best practices of model maintenance and calibration that are relevant for the city to consider at this time.

Recommendations related to explicit representation of system components:

- Addition of pump at Kohler which would represent the backwards flow of water thru the hydropower facility at that location;
- Replacement of head versus flow curve at Sunshine Hydro facility instead of the PRV; and
- Refinement of roughness factors (c-factors) on the discharge lines from the Betasso WTF to generate the appropriate flow split to Sunshine and Orodell facilities and reduce or eliminate reliance on dummy PRV's to manage flow split.

Recommendations for model maintenance and calibration:

- Allocation of large users to a separate demand column in the data set;
- Refinement of system-wide roughness factors (c-factors) based on loss-of-head tests conducted in the field for a variety of pipe material and sizes;
- Field-verified model calibration including pressure monitoring in the distribution system and fire flow tests to test the model's ability to replicate the system's response to a stressed (fire flow) condition;
- Temporary system monitoring of pressure in the distribution system and pressure and flow at the discharge points of key facilities; compare these system-wide results to results seen in the model under similar boundary conditions; and
- On-going system monitoring program with permanent equipment (pressure, flow, chlorine) to improve real-time operation of the distribution system and increase the city's understanding of the relationship between operating procedures and system conditions (high pressure, water quality).

The recommended model maintenance and calibration items could be completed in conjunction with further analysis on the hydraulic capacity and available fire flow as discussed in the sections below. Model calibration activities should be focused on conditions when the system is under stress (peak day or fire flow) or when the city receives information about degraded water quality or increased pressures. The city can also use the model to verify and predict unusual conditions that are often seen during system operations but are not well linked to specific operating procedures.

Continued verification and improvement of the model will improve the reliability of the model and the city's use of the model for planning and operations analysis.

5.2. Hydraulic Capacity Evaluation

Model results show that the Boulder water distribution system is able to meet peak hour demand conditions without significantly impacting the level of service to customers. No significant bottle necks were identified during the analysis which indicates that the system is relatively robust. MWH recommends the city consider the following items to maintain and improve the system's hydraulic capacity:

- Pending verification of roughness and further understanding of the discharge pipelines at Betasso, consider this pipe for further upgrade;
- Pending system monitoring program, obtain field data of headloss and velocities at hydro facilities and at tanks to understand actual system conditions at these facilities and evaluate the need to upgrade or replace components;
- Upgrade detail at system facilities to better reflect system infrastructure and field verified losses;

- Review and further evaluate the pipes and nodes identified in Figure 1 which violate the reliability criteria; identify incremental system benefit from pipe improvements;
- Coordinate with other city agencies to take advantage of roadway or sewer work which may present a opportunity to upgrade pipelines along other construction corridors;
- Review model results as part of on-going pipe replacement program to understand hydraulic benefits to pipe replacements;

5.3. Fire Flow Analysis

Model results show that 98% of the modeled nodes are able to provide 1500 gpm under a maximum day demand condition. The city should consider additional steps to understand area-specific fire flow requirements and needed system improvements. Specific recommendations include:

- Overlay results from fire flow simulation with zoning and land use maps to identify specific areas or properties that would require greater fire flow protection;
- Perform additional simulations along Airport Boulevard to establish required system improvements required to provide adequate fire flow to new hotel development in this area;
- Conduct field testing such as fire flow tests and loss-of head tests for areas identified with low available fire flow to obtain actual available fire flow and pipeline roughness factor; field testing will allow the city to further understand fire flow restrictions in these areas;
- Re-allocation of large users to the most appropriate model node; include large user demand in a separate model database column; identify large-user specific fire flow requirements and document on fire flow map;
- Add additional model detail to provide a model node at each fire hydrant location and improve understanding of available fire flow across the system;
- Coordinate with planning/permitting department to establish procedure and documentation needed to document potential system improvements required to provide adequate fire flow for large developments;
- Evaluate additional demand scenarios looking at specific industrial areas where demand may increase and result in additional fire flow requirements; and
- Leverage on-going flushing program to perform fire flow and loss-of head tests to refine roughness factors.

5.4. Additional Pressure Zone Analysis

The City of Boulder water distribution system experiences high pressures along the boundary between the three zones. In addition, the city has reported low pressures along Airport Boulevard and model results show isolated low pressures near Chautauqua. The city continues to evaluate the need for sub-pressure zones.

Based on feedback from the city and review of available information, the high pressures in Zone 1 are often due to volunteer fire fighters shutting down hydrants too quickly. Low pressures along Airport Boulevard are due to high elevations (resulting from a slight hill) and because the pipe is undersized. Low pressures also appear to be linked to conditions when the city is pumping from Iris and Cherryvale.

However these low pressures along Airport Boulevard are not seen in the model to the extent that they are reported by the city. This is because large users along the Airport Road are not allocated to specific nodes so it is difficult to see the full impact in the model. In addition, low pressures at Chautauqua are not considered by the city to be an issue because there are not customers in this isolated area.

In general, the overall frequency of main breaks in the city's system is within the norm of similar water utilities. In addition, all residential customers have pressure reducing valves and do not experience issues with high pressures in the system. For these reasons, MWH does not recommend that the city move forward with sub-zone development at this time. MWH does recommend that the city follow-up with several tasks that will improve the city's understanding of the relationship between pressure, watermain breaks, and operating procedures. These include the following:

- Develop spatial map showing available data on location, frequency, and operating conditions for breaks;
- Update demand distribution, specifically focusing on proper assignment of large users;
- Develop operations guidelines for fire hydrant exercising and flushing in coordination and discussions with fire department;
- Implement system monitoring program including temporary and permanent press loggers to monitor system pressures and track system pressures with system operating conditions; and
- Perform additional model simulations to determine if additional pumps at Boulder WTF would help increase pressures in the zone.

5.5. Water Age Analysis

Water age analysis can be further advanced with a better understanding of the relationship between water age and water quality. Specifically, the city should consider developing chlorine decay curves to create a relationship between water age and chlorine levels. These curves should be created for each source of supply in addition to curves for various seasons of the year. This information would help the city understand the relationship between water age, water quality and system operation.

MWH also recommends that the city install on-line chlorine analyzers at the system tanks to monitor the chlorine levels at these facilities. The city should record the chlorine results with the system operating procedures to determine what correlation there is between operation and water quality. Pending better information from on-line analyzers, the city can consider adding chlorine booster stations or using portable chlorinators to target specific problem areas.

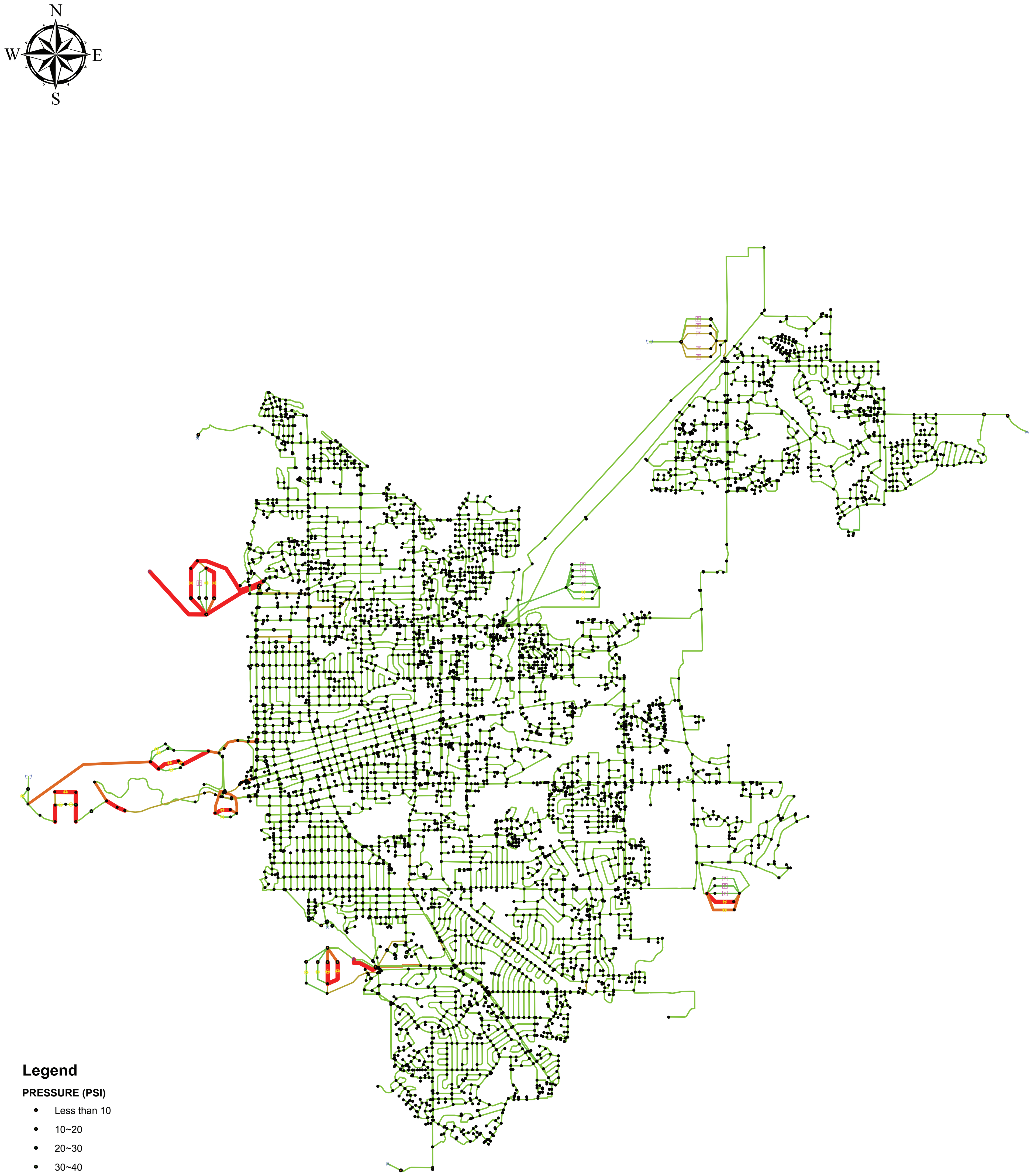
The information collected from on-line analyzers and operation set-points would provide insight into the optimum operating conditions and give the city an understanding of what is considered too old water within the City of Boulder's water distribution system.

Once the city better understands the impact of system operations on water quality and water main breaks, MWH recommends the city consider creating consistent operating rules which can contribute to more consistent water quality and decreased main breaks.

5.6. System Failure Analysis

Simulations were performed for five system failure scenarios identified by the city. Results from all scenarios show that, based on current assumptions and model parameters, the City of Boulder is able to provide adequate flow and pressure during each of these five scenarios. MWH recommends that these scenarios be further evaluated after additional model maintenance and calibration activities are implemented as described above. In addition, PRV settings in the model should be reviewed and updated for specific model scenarios to improve operation of the system and reflect real-time adjustments currently being made by the operations staff.

It should be noted that while the model scenarios show that the Betasso WTF can supply the whole system if the Boulder Reservoir WTF is out of service, the Betasso facility has a treatment capacity limitation, which is currently being studied. The hydraulic model simulation lasted a full seven days; however the known restrictions within the facility would lead to only a few days of maximum output at Betasso before water quality would be diminished.



Legend

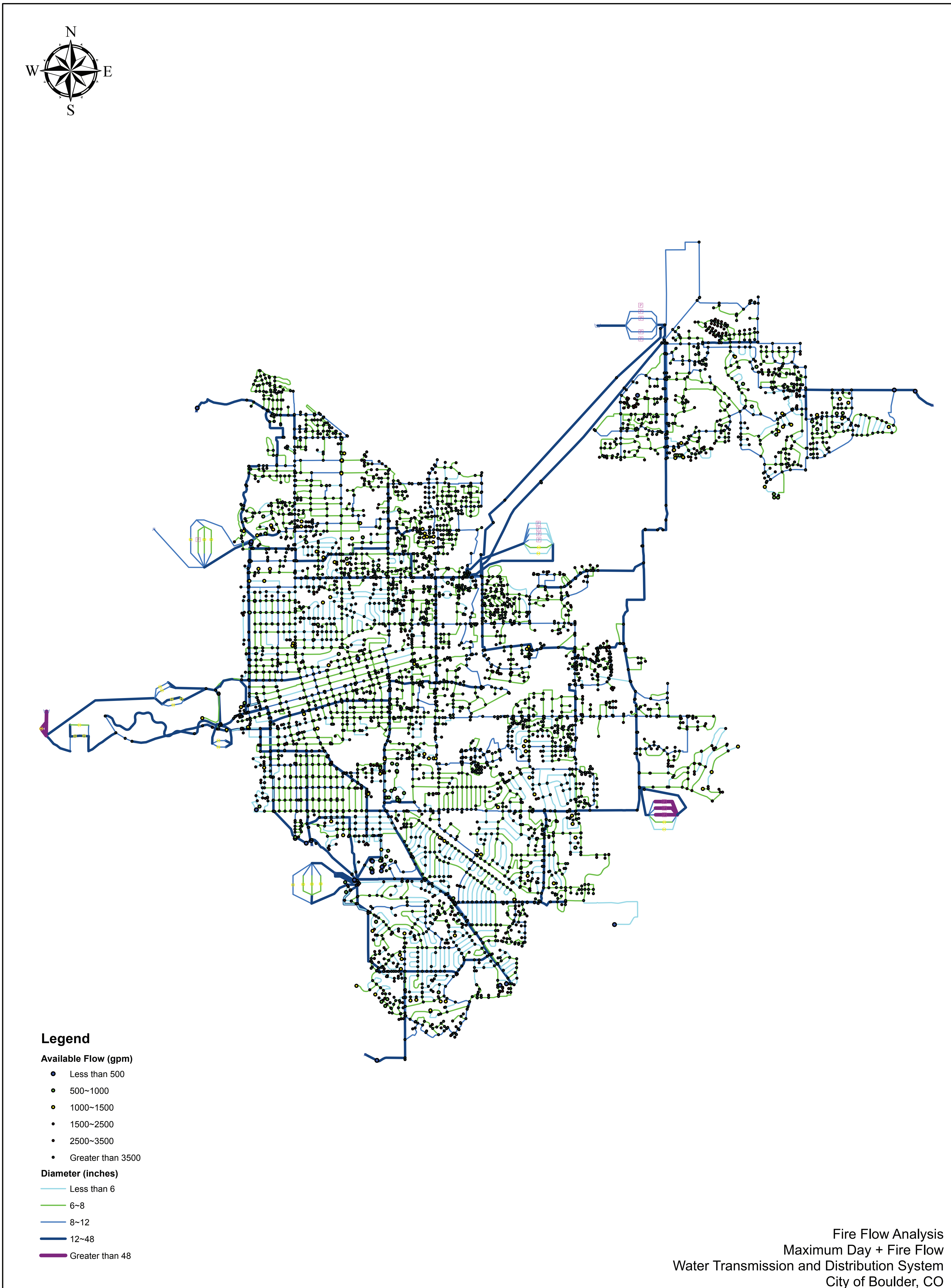
PRESSURE (PSI)

- Less than 10
- 10~20
- 20~30
- 30~40
- 40~100
- 100~110
- 110~120.15
- 120.15~140
- 140~150
- Greater than 150

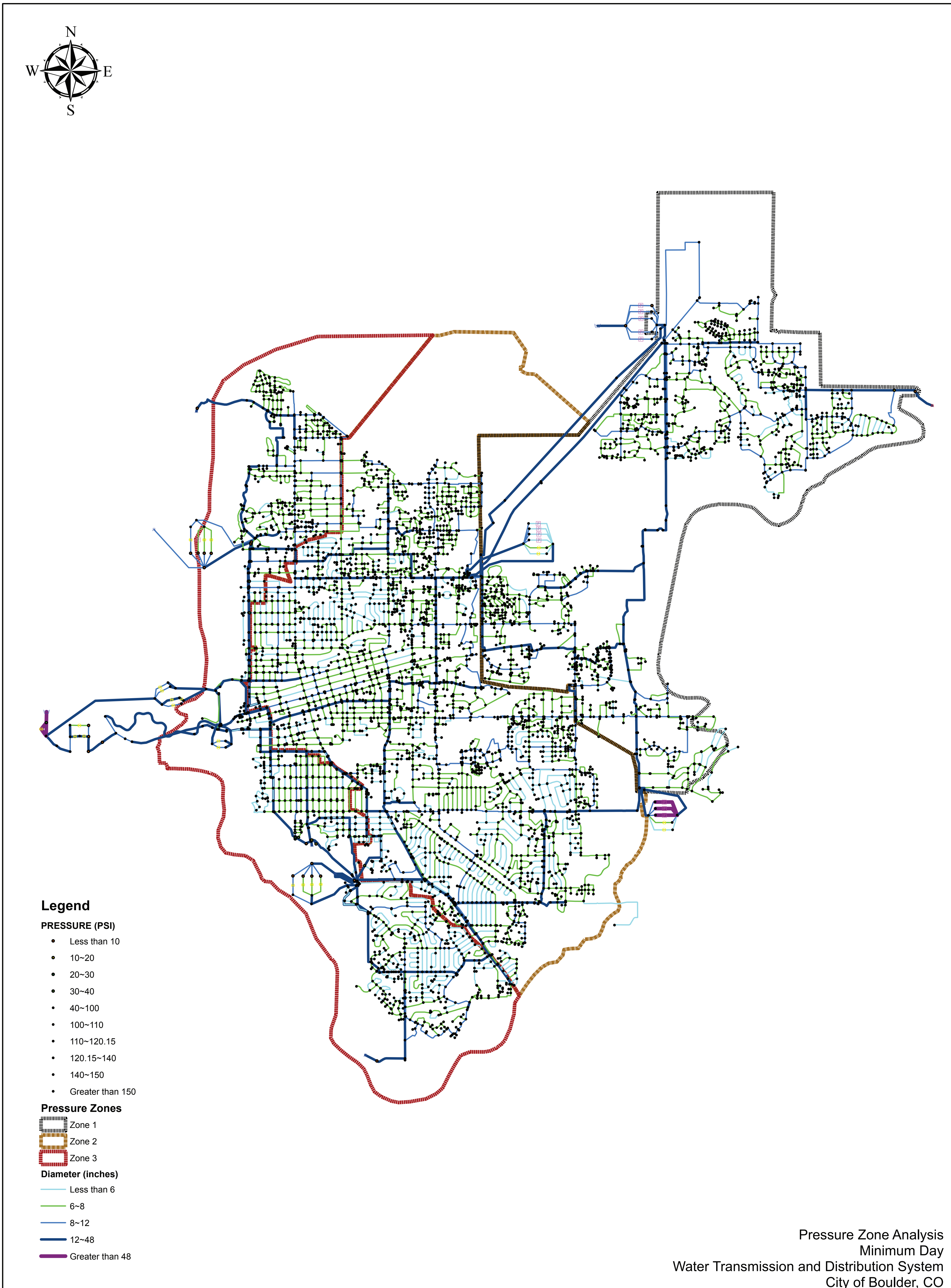
VELOCITY (FT/S)

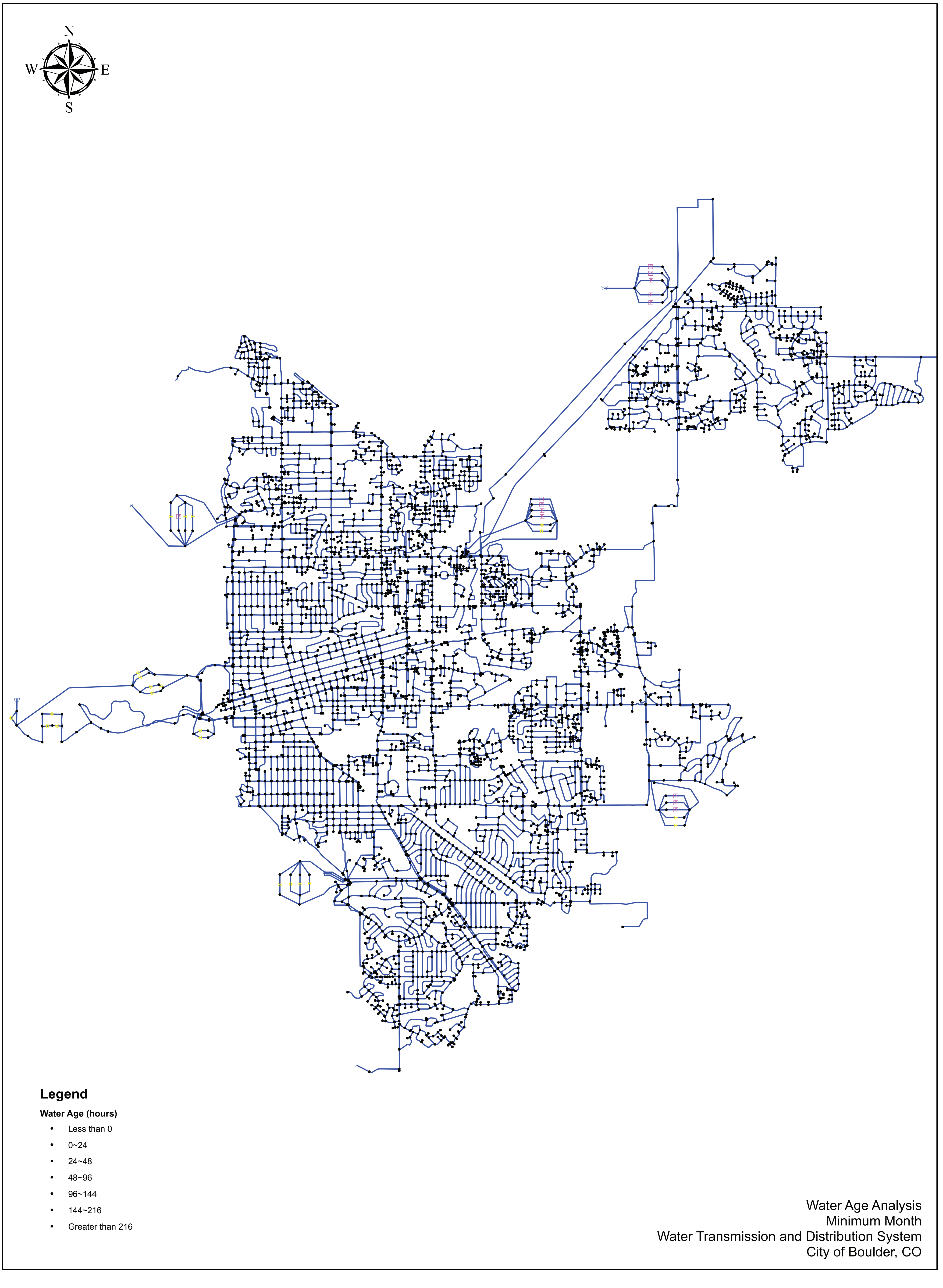
- Less than 0
- 0~5
- 5~7
- 7~10
- Greater than 10

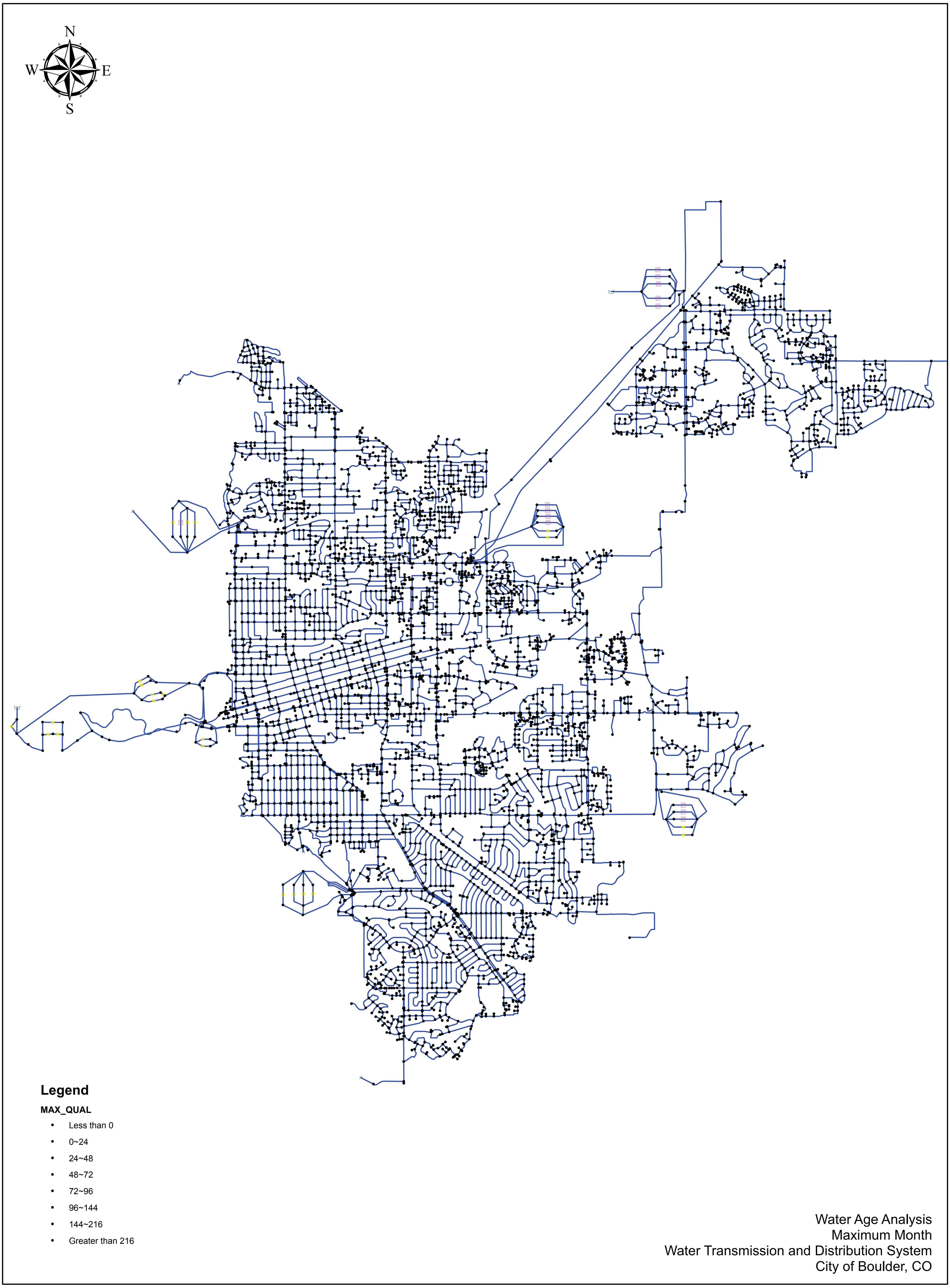
Hydraulic Capacity Evaluation
Peak Hour
Water Transmission and Distribution System
City of Boulder, CO

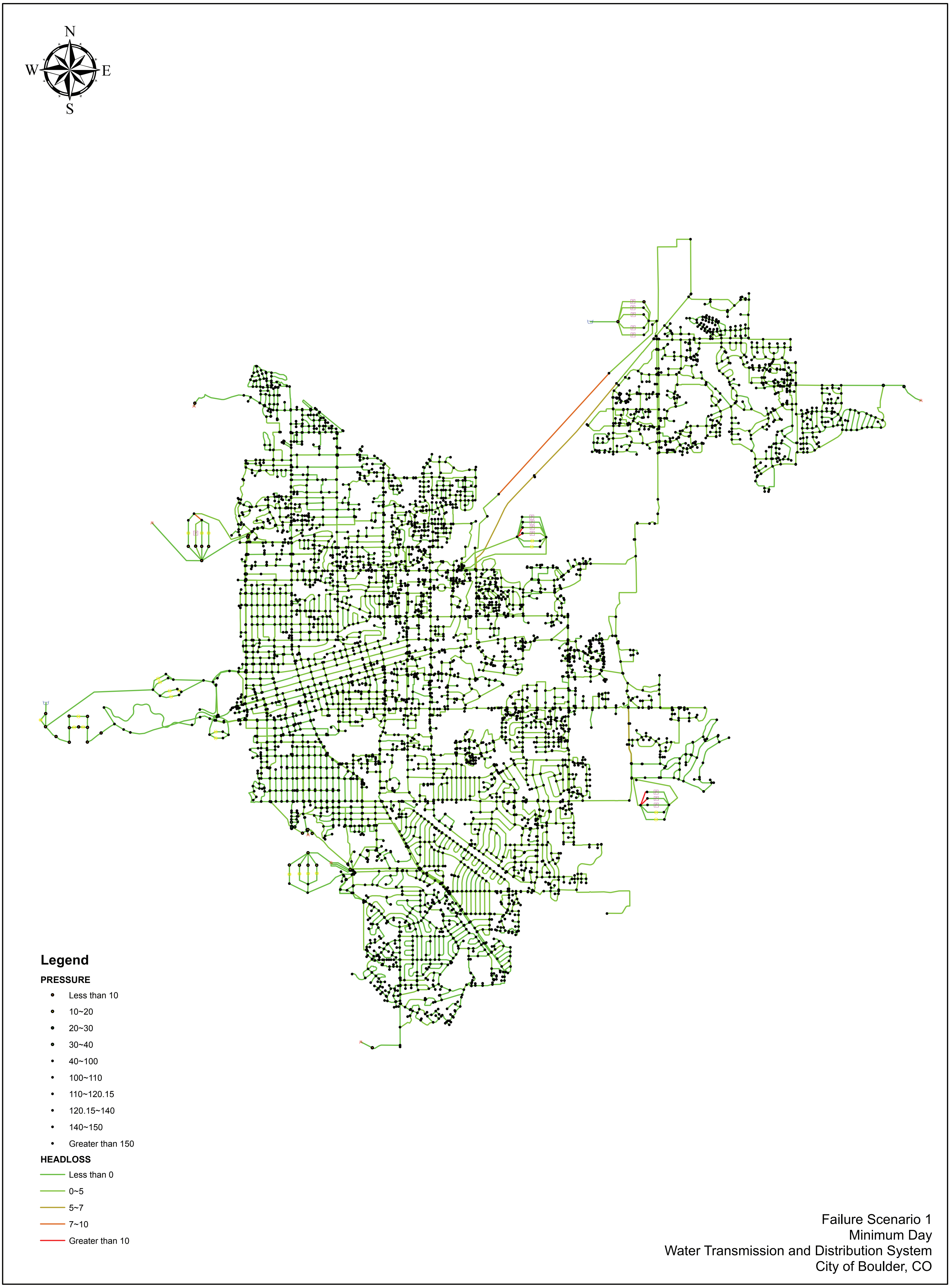


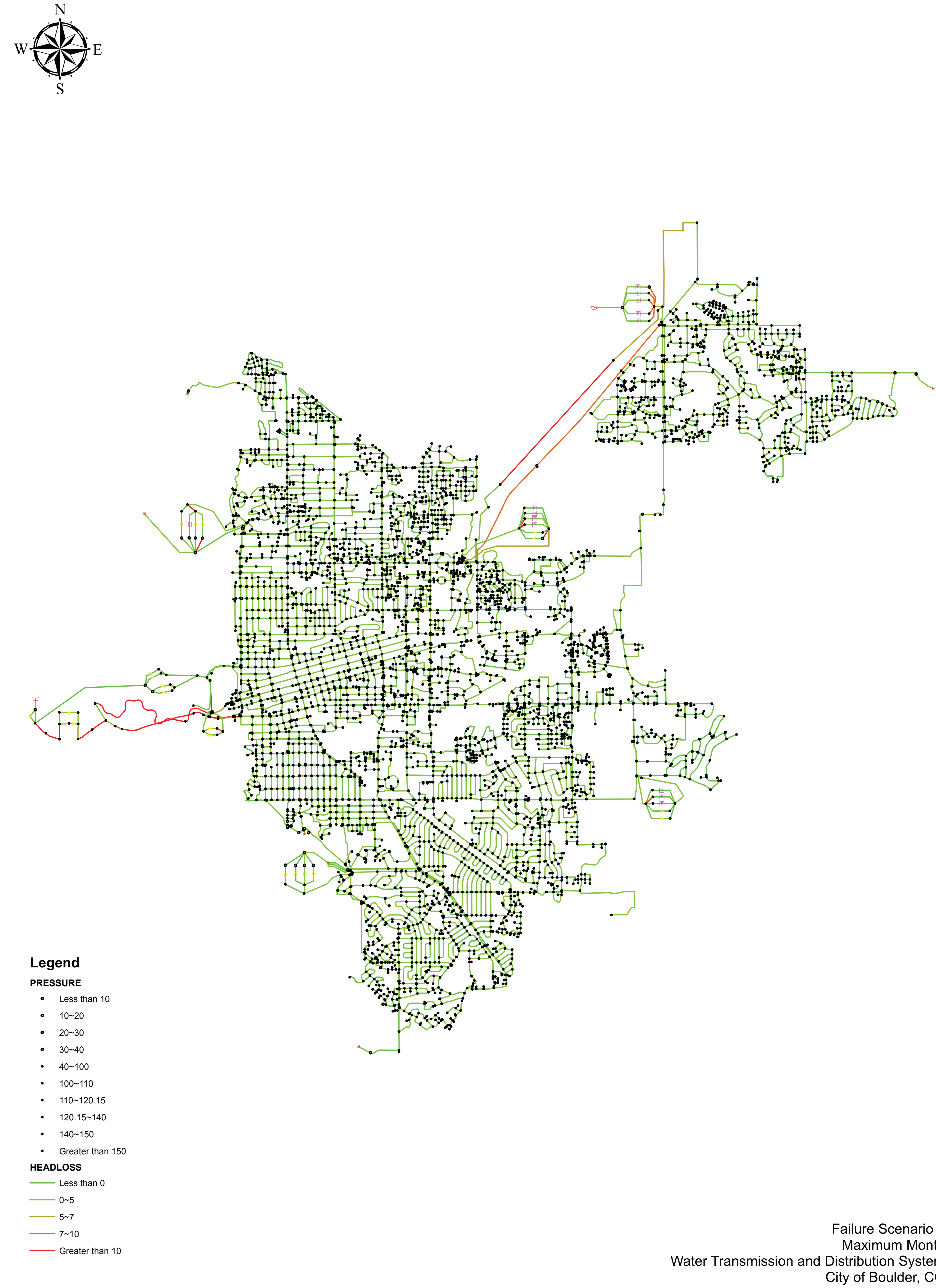
N
W
E
S
Legend
Available Flow (gpm)
Less than 500
500~1000
1000~1500
1500~2500
2500~3500
Greater than 3500
Diameter (inches)
Less than 6
6~8
8~12
12~48
Greater than 48
Fire Flow Analysis
Maximum Day + Fire Flow
Water Transmission and Distribution System
City of Boulder, CO


N
W
E
S
Legend
PRESSURE (PSI)
Less than 10
10~20
20~30
30~40
40~100
100~110
110~120.15
120.15~140
140~150
Greater than 150
Pressure Zones
Zone 1
Zone 2
Zone 3
Diameter (inches)
Less than 6
6~8
8~12
12~48
Greater than 48
Pressure Zone Analysis
Minimum Day
Water Transmission and Distribution System
City of Boulder, CO

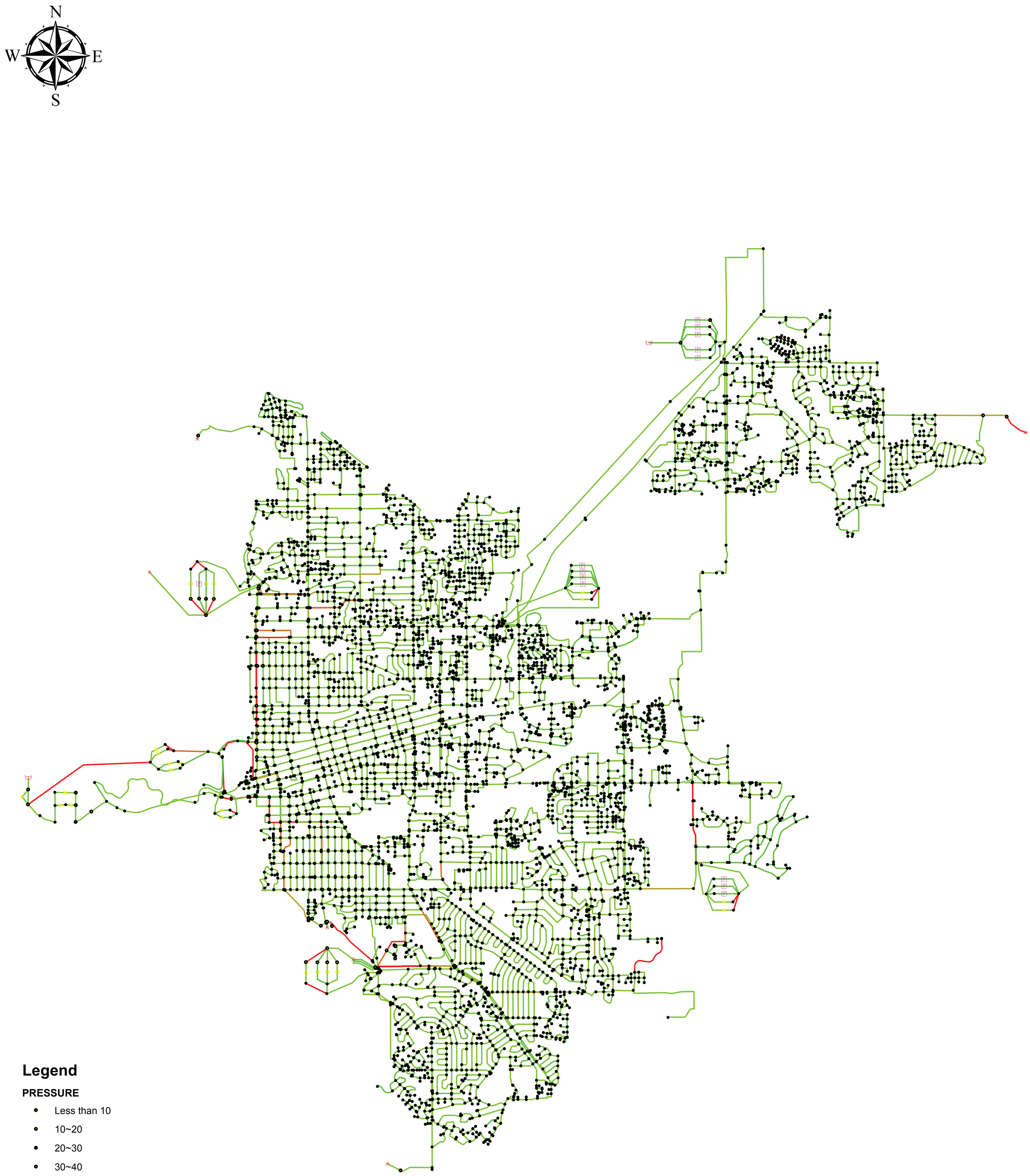

N
W
E
S
Legend
Water Age (hours)
Less than 0
0~24
24~48
48~96
96~144
144~216
Greater than 216
Water Age Analysis
Minimum Month
Water Transmission and Distribution System
City of Boulder, CO


N
W
E
S
Legend
MAX_QUAL
Less than 0
0~24
24~48
48~72
72~96
96~144
144~216
Greater than 216
Water Age Analysis
Maximum Month
Water Transmission and Distribution System
City of Boulder, CO


N
E
S
W
Legend
PRESSURE
Less than 10
10~20
20~30
30~40
40~100
100~110
110~120.15
120.15~140
140~150
Greater than 150
HEADLOSS
Less than 0
0~5
5~7
7~10
Greater than 10
Failure Scenario 1
Minimum Day
Water Transmission and Distribution System
City of Boulder, CO



Failure Scenario 2
Maximum Month
Water Transmission and Distribution System
City of Boulder, CO



Legend

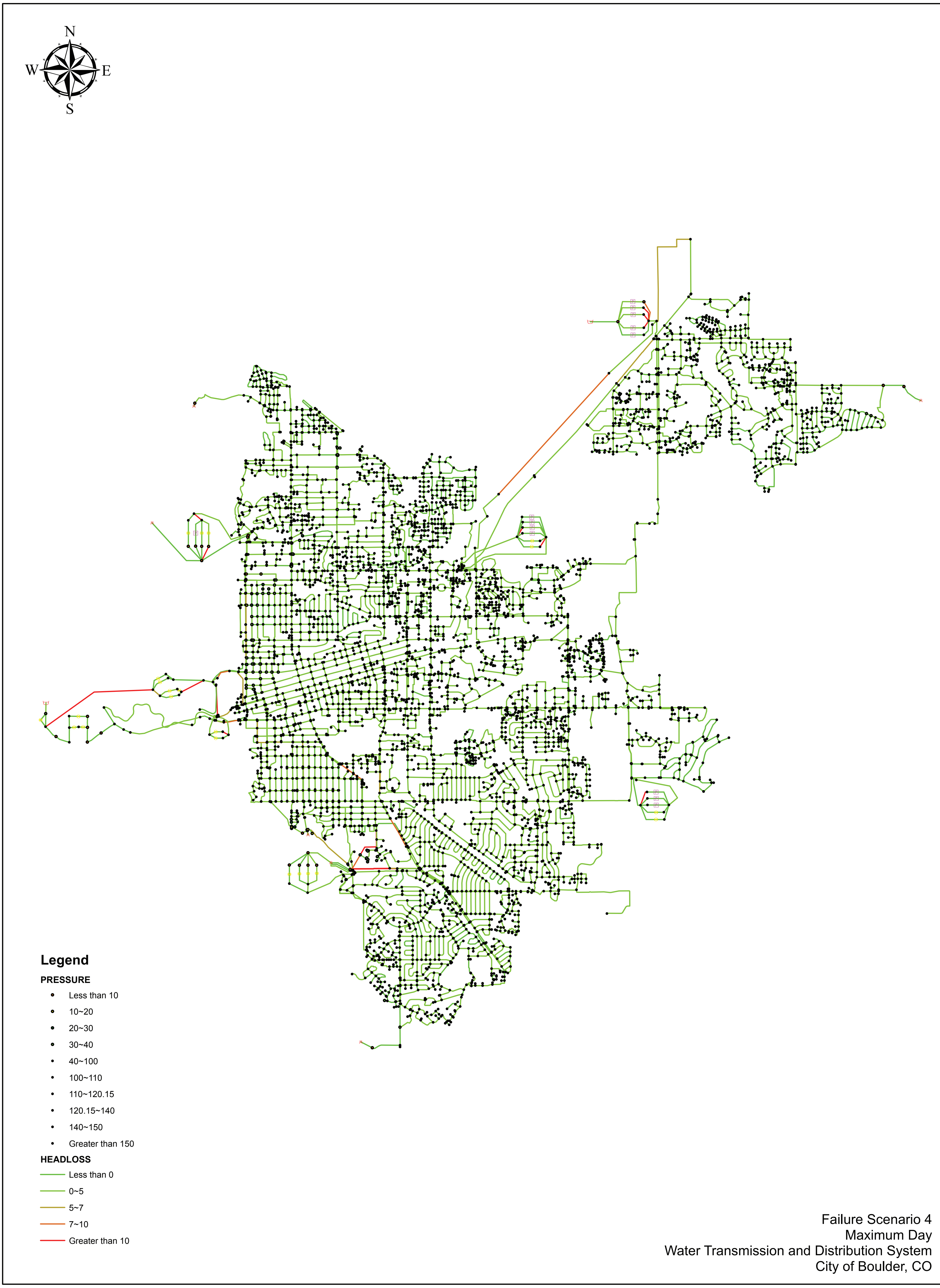
PRESSURE

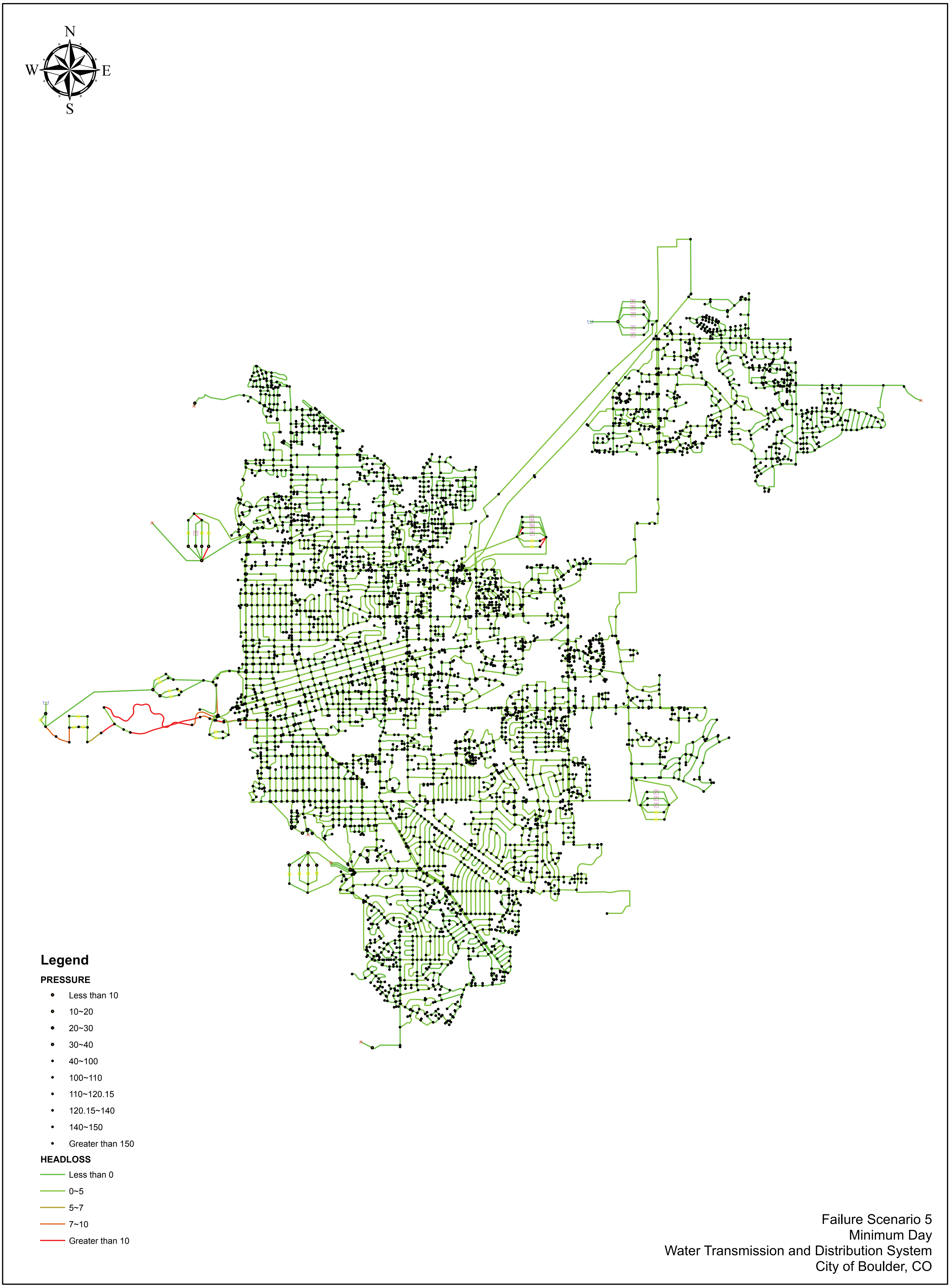
- Less than 10
- 10~20
- 20~30
- 30~40
- 40~100
- 100~110
- 110~120.15
- 120.15~140
- 140~150
- Greater than 150

HEADLOSS

- Less than 0
- 0~5
- 5~7
- 7~10
- Greater than 10

Failure Scenario 3
Maximum Month
Water Transmission and Distribution System
City of Boulder, CO


N
W
E
S
Legend
PRESSURE
Less than 10
10~20
20~30
30~40
40~100
100~110
110~120.15
120.15~140
140~150
Greater than 150
HEADLOSS
Less than 0
0~5
5~7
7~10
Greater than 10
Failure Scenario 4
Maximum Day
Water Transmission and Distribution System
City of Boulder, CO



Failure Scenario 5
Minimum Day
Water Transmission and Distribution System
City of Boulder, CO

Attachment 1 – Model Calibration Documentation

Attachment 2 – Summary of Model Scenarios provided by City of Boulder

SYSTEM OPERATING PRINCIPLES

System Reservoirs:

Zone 1: Gunbarrel Reservoir (2 MG)

Zone 2: Kohler Hydroelectric/PRV/Pump Station and Reservoir (9.4 MG)
Maxwell Hydroelectric/PRV/Pump Station and Reservoir (9.5 MG)

Zone 3: Booton Reservoir (sometimes referred to as North Terminal Tank) (3.5 MG)
Chautauqua Reservoir (8 MG)
Devil's Thumb Reservoir (5 MG)

Intra-zone Connections:

Betasso ➔ Zone 3: Orodell Hydroelectric/PRV Station (down 20" pipeline from Betasso)
Sunshine Hydroelectric/PRV Station (down 30" pipeline from Betasso)

Zone 3 ➔ 2: 101 Pearl PRV Station
Kohler Hydroelectric/PRV/Pump Station and Reservoir
Maxwell Hydroelectric/PRV/Pump Station and Reservoir

Zone 2 ➔ 1: Cherryvale Pump/PRV Station
Iris Pump/PRV Station

OVERVIEW

The distribution system is operated by water treatment operators using SCADA terminals at the Betasso Water Treatment Plant. In general, operation depends on the production at the two water treatment plants and the demands in various zones. Intra-zone connections are used as needed to fill and drain zones and to maintain the level of reservoirs within appropriate ranges.

Production from the two plants depends on factors such as system demands and water rights/supplies. Boulder Reservoir WTP is offline more often than Betasso WTP for maintenance, but otherwise it is online year-round. Boulder Reservoir WTP generally provides water to zone 1 and Betasso WTP generally provides water to zones 2 and 3. When reservoirs in the watershed are low, Boulder Reservoir WTP will often treat more water and provide water to zones 1 and 2 so that Betasso water supplies are conserved. When the reservoirs are high, usually in the spring, and start to spill over from snowmelt, Betasso will increase production to treat all the direct flow, so zone 1 can get some Betasso water depending on demands. When demands in the system are high, the watershed manager will decide which plant will increase production based on water rights and supplies.

Notes May 2010: In the winter, goal is tank fluctuation. In the summer, goal is overall storage numbers. Summer, both Maxwell and Kohler have flows around 8-12 MGD when Z3 is emptying, and all 3 hydros are on the whole time, and PRVs fluctuate with tank level. 101 Pearl is only used when zone 3 is too full, e.g. when Chaut Tank gets to a certain level.

RESERVOIR FLUCTUATION

ZONE 2 AND 3

Zone 2 and 3 reservoirs are fluctuated in a targeted manner to promote low water age and good chlorine residual. Fluctuation is accomplished by passing more or less water between Zone 3 and 2. To drain Zone 3 and fill Zone 2, water is moved into Zone 2 through Kohler and Maxwell stations until Zone 3 begins to drain and Zone 2 starts filling. This typically requires the use of the hydroelectric facilities and often the vault bypasses at both stations, depending on seasonal demand and production requirements.

In order to fill Zone 3 and drain Zone 2, the flow from Zone 3 to 2 has to be decreased substantially or even stopped altogether. Vault bypasses at Kohler and Maxwell stations are closed and often the hydroelectric facilities must also be shut down. After shutting down the hydroelectric facilities, the stations are put into 'pump' mode causing the stations' internal 'Turbine Bypass' valves to close, which stops all flow through the station.

Zone 3 reservoirs are not currently fluctuated separately from one another. However, there is a control valves at Booton Reservoir that could be used in a scenario such as keeping Booton level while filling the other two Zone 3 reservoirs, and then opening Booton to increase the filling rate within that tank in order to improve mixing as the reservoir fills. This is not the current practice.

ZONE 1

Zone 1, with one relatively small reservoir, fluctuates very easily as part of routine operation. When pumping water west, from Zone 1 into Zone 2, pump speeds cannot be adjusted, and the pumps must occasionally be stopped or started to keep Gunbarrel Reservoir in an appropriate range. When water is flowing east through valves, from Zone 2 into Zone 1, the valves are often opened for long enough to fill Gunbarrel Reservoir and then closed once it is getting full. Through this routine operation of pumps and valves the Gunbarrel Reservoir regularly fills and drains.

HYDROELECTRIC FACILITY OPERATION

BETASSO ➔ ZONE 3:

Sunshine Hydro is typically in operation all year long, except when the station is down for service. This station produces more kilowatts per CFS of water passing through it than Orodell does. Thus, when demand is low during winter months and there is not enough production from Betasso to run both Orodell and Sunshine, Orodell is shut down and winterized. During a normal winter, Orodell will be off for months with just a small amount of water being passed down the pipeline to keep the water fresh. The facility's downstream control valve will be set to pass between 1 to 2 CFS down the Canyon. When Orodell is shut down the Betasso clearwell levels are controlled by adjusting flow through the Sunshine station.

ZONE 3 ➔ ZONE 2:

Kohler and Maxwell hydroelectric generators operate anytime water is passing from Zone 3 to Zone 2. At some times of the year, they may be running almost continuously. At other times of the year they may be started and stopped daily.

HYDROELECTRIC CAPACITY TESTS: EFFECT ON DISTRIBUTION SYSTEM OPERATIONS

Betasso WTP is required by contract to perform monthly Hydroelectric Capacity Tests on the three large raw water hydros: Silver Lake, Lakewood, and Betasso Hydroelectric Stations. On an annual basis a longer duration ‘4 Hour Capacity Test’ is required on these same units.

Monthly capacity tests are generally described as either ‘full bore’, ‘moderate’, or ‘reduced’ capacity tests. The amount of generation required and water flows through each hydro is calculated using a complex mathematical equation. This calculation is based largely on monthly power generation figures. Thus the tests are typically run near the end of the month so more complete monthly figures can be used in the calculation.

Typically in the winter when hydro generation is low, operators perform a ‘reduced’ capacity test that only requires a kilowatt generation slightly higher than average monthly production. However ‘reduced’ tests are also partly due to problems that have occurred during winter high generation capacity tests. Reduced capacity tests generally require much less special preparation and abnormal distribution operation than higher generation capacity tests.

At other times of the year, operators generally have to run much higher volumes of water through Betasso WTP during monthly capacity tests in order to meet generation goals. During the summer, the capacity test often requires the plant to produce 35+ MGD for the duration of the one hour test. These higher flow tests require a much greater amount of advanced planning, strain on the WTP process, and abnormal distribution system operation.

SYSTEM PRVS

The various pressure reducing valves (PRVs) throughout the system are used as needed based on production at the two plants and overall system demands. There are no pre-set times when they are to be open or closed.

SUNSHINE PRV

Sunshine Hydroelectric/PRV station has the capability to pass water independent of hydroelectric operation. At times, Sunshine hydro will be running at full kilowatt capacity, and the PRVs will be passing additional water as needed. When the Sunshine hydroelectric generator is off for maintenance, water passes through the PRVs at Sunshine.

ORODELL PRV

The Orodell Hydroelectric/PRV station also has the capability to pass water independent of hydroelectric operation. However, it has a more limited capacity than Sunshine due to the size of the pipeline and the tendency for vibration to occur if too much water is flowing. The maximum amount of water that can flow through Ordell with both the hydroelectric generator and the generator bypass in operation is approximately 11 CFS, about 8 CFS of which flows through the generator. Above 11 CFS the Orodell station develops a major vibration and cavitation problem.

The 'Roll-Seal' valve is completely independent of the station. This valve allows additional water to flow around the Orodell station and more water to pass down the 20" Canyon pipeline. The Roll-Seal valve operates on a manually controlled downstream pressure setting.

A flow test was conducted in 2008 on the Orodell 20" pipeline, using both the external Roll-Seal valve and Orodell station turbine bypass valve. The 20" canyon pipeline was able to flow approximately 20 CFS. The hydroelectric generator was turned off, the turbine bypass valve was passing about 10 CFS, and the manually operated Roll-Seal valve passed about 10 CFS.

101 PEARL PRV

The PRV station at 101 Pearl is primarily used only when a large amount of water has to be moved from Zone 3 to Zone 2. This usually occurs during high demand/production periods in the summer. 101 Pearl is rarely used at any other time since it in essence takes water somewhat directly from Betasso WTP and pushes it into Zone 2, where it is used without greatly impacting the reservoirs in either Zone 3 or 2. Operations have observed that use of this station during low demand periods results in decreasing chlorine residuals in the north and south ends of Zone 3 in particular. However it also seems to have some impacts resulting in increased water age in the north and south ends of Zone 2.

This station used to be used more frequently throughout the year. Since changing its operation so that it is primarily used only in high demand situations, there has been a decrease in the number of low chlorine events in both Zone 3 and 2.

A general scenario in which 101 Pearl would be used is as follows. Betasso WTP is producing a large volume of water daily, resulting in a need to pass a significant volume of water from Zone 3 to Zone 2. Operators maximize use of the Maxwell and Kohler Hydro stations; first all generators are started to maximize generation before also using PRVs. If additional water needs to be moved into Zone 2 from 3 then operators use the PRV valves at each hydro station first. Often in this situation Kohler and Maxwell stations are each passing 6 to 8+ MGD using the hydros and the PRV bypasses. If high volumes of water are going through both stations but more still needs to be moved, operators begin using 101 Pearl to pass additional water. 101 Pearl is operated using a downstream PSI set point from which the valve automatically regulates to maintain the pressure set point. The pressure set point is increased sufficiently to result in the station passing enough water to obtain the desired results in both Zone 3 and 2.

CHERRYVALE AND IRIS PRVS

Valves at Cherryvale and Iris are operated as needed when water must be passed from Zone 2 into Zone 1. This occurs either when the 63rd St. plant is not producing enough to meet the demand in Zone 1 or when the 63rd St. plant is offline. Typically the 2" valves are opened first. Then if additional flow is needed the 8" 'Main' valves are opened. The main valves operate on a downstream pressure control system. If downstream pressure gets too high they will modulate themselves closed. The Cherryvale main valve has a downstream pressure setting of approximately 65 PSI, and the Iris main valve has a setting of about 55 PSI. These settings are intended to be set low enough such that zone 1 pressures would cause the valves to close before the Gunbarrel Tank overflows.

PUMPS

The pumps at Cherryvale and Iris stations are operated in much the same manner as the valves. They are used as needed based on production from 63rd versus Zone 1 demands. If 63rd is producing more water than is needed in Zone 1, pumps are used to move water to Zone 2.

The number of pumps used and when they are turned on or off is dependant on production from 63rd and system demands. The pumps are not on variable frequency drives, so they essentially move water at a set rate. Thus they must be cycled on and off as needed.

To: **MWH** **Date: May 24, 2010**

From: **COB**

Subject: **City of Bolder Water Utility Master Plan**
Model Setup

The following steps were taken to prepare the model for delivery to MWH.

1. Update model and demands

The model was compared to the current water distribution GIS layer and new pipes imported.

I did not have enough time to check for any additional pipes in the model that are no longer in GIS.

Based on 2006-2009 ET-adjusted average production of 18,587 acre-feet, base demand is 16.59 MGD.

Current and future demands were allocated to all nodes; nodes on 12” and larger pipes and near pumps and valves will be removed for future allocations.

The shape file and data from MWH for 2010 usage showed a total usage of 15.7 MGD (this does not include unaccounted for water). After demand allocation in the model, baseline usage for 2010 was 15.6 MGD.

The shape file and data from MWH for 2035 usage showed a total usage of 17.7 MGD. After demand allocation in the model, baseline usage for 2035 was 17.6 MGD.

There is generally about 8% unaccounted for. We discussed adjusting base demand up by 4% but I left it as is after allocation so MWH can decide final base demand.

Note: In order to get correct flow splits from Betasso on the 20” and 30”, valve V70008 exists in the model downstream of Sunshine and valve V70010 exists in the model at Orodell. These don’t actually exist in the system. Pump and hydro curves may need to be adjusted.

2. Update diurnal curve

There is no data in the current SCADA software prior to 6/1/06. Data in previous SCADA software is difficult to access and often corrupted. SCADA data from 6/1/06 – 5/12/10 was used to create an updated diurnal curve.

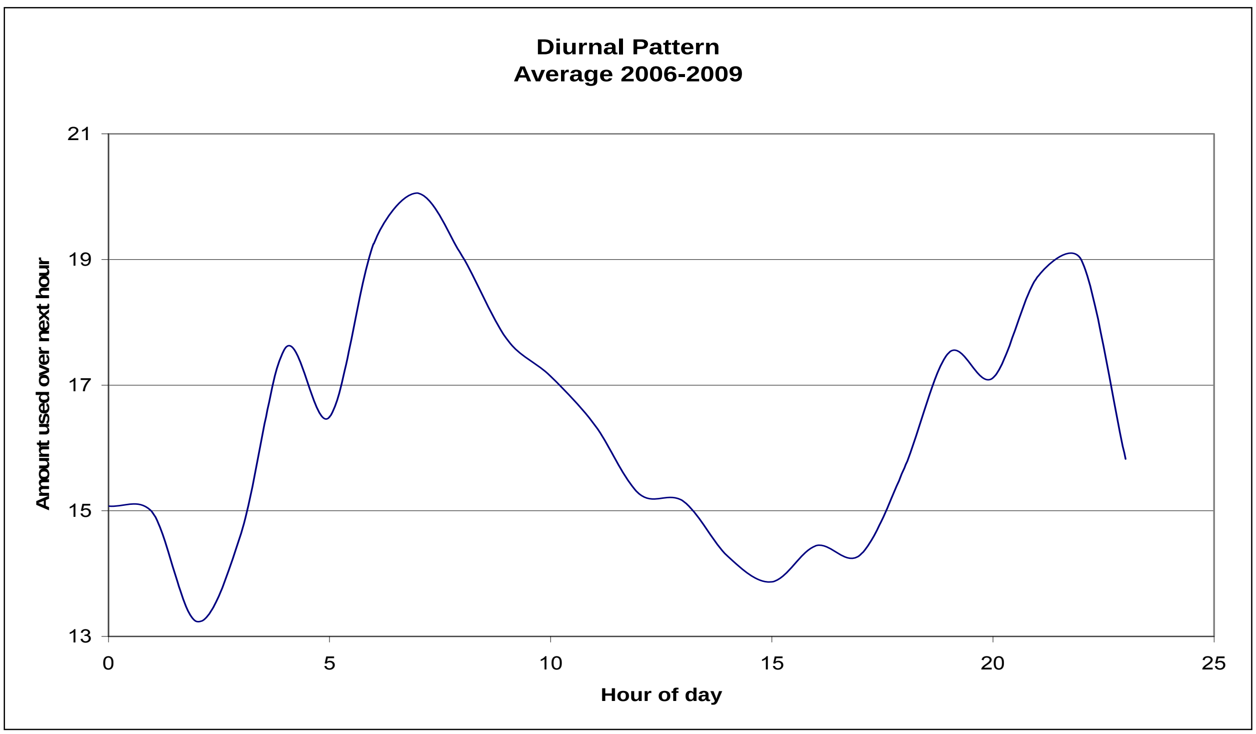
Where data were missing, it was estimated when possible from Operators Daily Log entries. Ultimately there were about 1,500 points that had no hourly usage data and 33,120 hourly usage data points.

'Amount Used Over Next Hour' was calculated as:

Betasso production that hour + Boulder Reservoir production that hour + difference in total system storage between that hour and the following hour

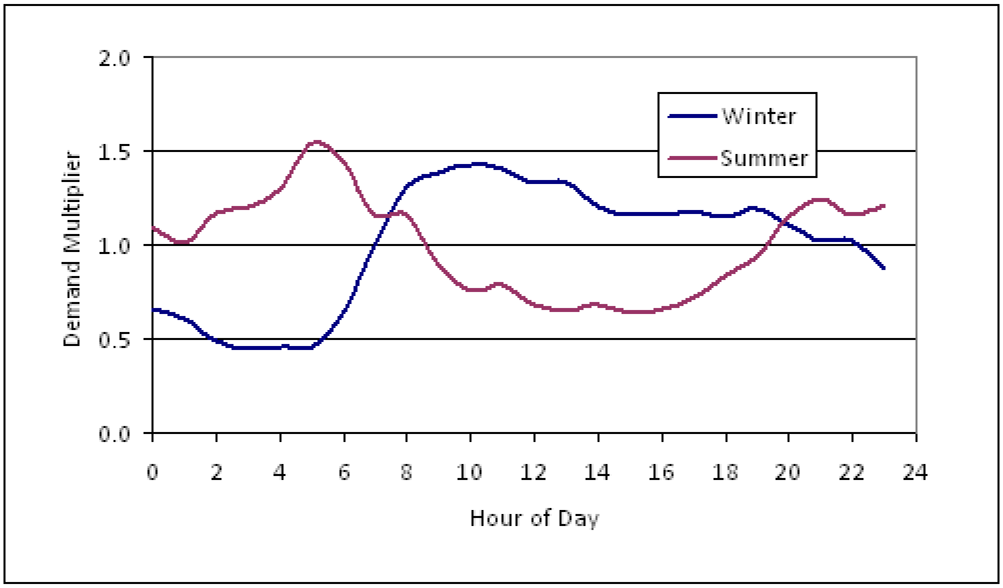
All data were averaged by hour of the day.

The average diurnal pattern:



The average of all hourly data used to create the diurnal pattern is 16.35 MGD, compared to 16.59 MGD from the 2006-2009 ET-adjusted average production.

Winter and summer patterns were very different, so 2 diurnal patterns were assigned:


2.0
1.5
1.0
0.5
0.0
Demand Multiplier
0
2
4
6
8
10
12
14
16
18
20
22
24
Hour of Day
Winter
Summer

3. Operating scenarios

I. MAXDAY_SS. Steady state, max day.
PEAKING FACTORS FROM VOLUME II: Between 2000 and 2009: 95th percentile daily factor 2.6. Max day of 43.1 MGD.

Peak day factor has not exceeded 2.3 since 2001. However the system has changed since 01 (e.g. Diagonal pipeline) so it may be difficult to compare model results to SCADA data for a day in 2001. SCADA data from the ten days in 2006-2009 with the highest usage was reviewed and 7-24-07 selected to model. Operations suggested 7 am as a time when the system is typically at max usage (which concurs with the diurnal pattern data). The demand multiplier in Infowater was changed to 2.15.

Operation on 7-24-07 at 7 am:

Max Day	**SCADA**	**Model**
63rd	7.6 mgd	7.2 mgd
Betasso	25.9 mgd	25.8 mgd
Cherryvale (90100)	No flow[1]	No flow
Iris (90090)	No flow	No flow
Tank level: Boot	12.9	12.9
Tank level: Chaut	18.3	18.3
Tank level: Devils	13.0	13.0
Tank Level: Gunb	9.7	9.7
Tank level: Kohler	14.5	14.5
Tank level: Maxw	16.1	16.1
Maxwell (1040, 1007)	Hydro 2.9 mgd and PRV at 7.0 mgd = 9.9 total	Hydro 2.8 mgd and PRV at 7.1 mgd = 9.9 total
Kohler (1053, 1054)	Both hydros on at 5.6 mgd and PRV closed	Both hydros on at 5.7 mgd and PRV closed
101 Pearl (1045)	2.6 mgd	2.7 mgd
20” from Bet (986NET)	4.1 mgd	4.1 mgd
30” from Bet (985NET)	21.8 mgd	21.7 mgd
County Jail Press (J9452)	52.1 psi	55.5 psi
Chvl Discharge Press (290)	127.5 psi	136.6 psi
Chvl Suction Press (54)	57.5 psi	61.1 psi
Iris Discharge Press (217)	121.9 psi	135.8 psi
Iris Suction Press (40)	48.4 psi	55.9 psi
Kohler Z2 Press (778)	7.8 psi	9.2 psi
Kohler Z3 Press (776)	111.3 psi	112.4 psi
Maxwell Z2 Press (201)	5.0 psi	4.9 psi
Maxwell Z3 Press (779)	103.2 psi	107.8 psi
P101 Down Press (243)	65.1 psi	63.1 psi
Sun Down Press (527)	107.1 psi	108.9 psi
Sun Down PRV Press (479)	97.9 psi	101.5 psi
Sun Up Press (470)	308.7 psi	324.5 psi

[1] CV and Iris pumps and PRVs are continuously cycled on and off even on max days.

II. Extended Period Simulation, min month

Minimum month for 2006-2009 (looking at average use per day) was December 2007: 291,500 gallons for the month and 9.4 MGD average. Set demand multiplier to 0.6.

The tank levels and total storage numbers can vary significantly depending on who is operating the system. The model was setup to be as similar to actual December 2007 operation as possible.

December 2007 operation:

Min Month	SCADA	Model
63rd (151)	1 pump on – ~3.8 mgd	Average 3.7 mgd
Betasso (3214NET)	5.6 mgd	Average 5.6 mgd
Cherryvale (90100)	Not used as much as Iris, and usually not at the same time	No flow
Iris (90090)	1 pump on when Gunbarrel at 15 ft and off at 7 ft	On when Gunbarrel at 15 ft and off at 7 ft
Tank level: Boot	Max 20.7, Min 7.5, Avg 13.4	Max 20.1, Min 8.2, Avg 13.9
Tank level: Chaut	Max 21.5, Min 9.6, Avg 14.6	Max 22.4, Min 9.9, Avg 15.7
Tank level: Devils	Max 20.8, Min 7.2, Avg 13.3	Max 15.7, Min 3.0, Avg 9.0
Tank Level: Gunb	Max 17.1, Min 6.6, Avg 12.2	Max 17, Min 6.6, Avg 11.5
Tank level: Kohler	Max 20.3, Min 6.1, Avg 13.0	Max 18.8, Min 6.6, Avg 12.5
Tank level: Maxw	Max 18.2, Min 8.1, Avg 12.6	Max 17.0, Min 8.7, Avg 12.5
Maxwell (1040, 1007)	Hydro on when Maxwell at 9 and off at 16; PRV closed	Hydro on when Maxwell at 9 and off at 16; PRV closed
Kohler (1053, 1054)	Both hydros on when Kohler at 9 and off at 16; PRV closed	Hydros on and off based on Maxwell tank level instead of Kohler
101 Pearl (1045)	No flow	No flow
20” from Bet (986NET)	0.5 mgd	0.5 mgd
30” from Bet (985NET)	5.1 mgd	5.1 mgd
Sunshine Hydro (V70008)	Off	Off

Note: There are new, bigger pumps at Iris and Cherryvale as of spring 2010, which will affect how closely model data matches SCADA data.

No pressures were compared.

III. Steady state, max hour

PEAKING FACTORS FROM VOLUME II: Between 2000 and 2009: 99th percentile hourly factor 2.7; max hour of 44.8 MGD.

Basically the same as max day operation, just a different peaking factor. Looks like peak hour occurs at 7 am.

7-24-07 7 am, modeled for steady state max day, can be used for max hour scenarios. Amount used in Boulder on 7-24-07 between 7 and 8 am was 44.5 MGD.

IV. Extended Period Simulation, Max month

PEAKING FACTORS FROM VOLUME II: Between 2000 and 2009: 95th percentile peak month factor 2.0

Maximum month for 2006-2009 (looking at average use per day) was July 2008: 993,900 gallons for the month and 32.1 MGD average. Set demand multiplier to 2.05.

The model is set up with a typical summer operation as follows:

Max Month	Typical Operation from SCADA	Model
63rd (151)	2 pumps on – ~8 mgd	Average 8.2 mgd
Betasso (3214NET)	Remaining production ~24.1 MGD	Average 23.9 mgd
Cherryvale (90100)	1 (new) pump on and off based on Gunb tank level	On when Gunb > 15 and off when < 9
Iris (90090)	No flow	No flow
Tank level: Boot	Initial level ~9. Max 20.7, min 10.8, avg 16.5	Initial level ~9. Max 18.5, min 4.6, avg 11.6
Tank level: Chaut	Initial level ~15. Max 20.7, min 13.6, avg 17.1	Initial level ~15. Max 24, min 15, avg 21.8
Tank level: Devils	Initial level ~8. Max 12, min 7.9, avg 10	Initial level ~8. Max 13.2, min 4.3, avg 9.6
Tank Level: Gunb	Initial level ~11. Max 18.5, min 7.1, avg 12.7	Initial level ~11. Max 18.9, min 8.3, avg 13.4
Tank level: Kohler	Initial level ~17. Max 19.9, min 7.1, avg 15.4	Initial level ~17. Max 17.4, min 7.9, avg 12.8
Tank level: Maxw	Initial level ~17. Max 19.3, min 8.5, avg 15.3	Initial level ~17. Max 18.2, min 8.5, avg 13.6
Maxwell (1040, 1007 or 1047, 90000)	Maxw hydro on; PRV setting 23 when Maxw level < 8 and setting 5 when Maxw level > 18.	Flow varies from 2.9 mgd to 10.3 mgd
Kohler (1053, 1054, V1051, 90130)	Kohler hydros on; PRV setting 11 when Kohl level < 8 and setting 6 when Kohl level > 17	Flow varies from 5.5 mgd to 12.4 mgd
101 Pearl (1045)	Setting 65 when Chaut level > 17 and closed when Chaut level < 17	Flow varies from 0 to 4.5 mgd
20" from Bet (986NET)	~6 mgd	Average 6.1 mgd
30" from Bet (985NET)	Remaining Bet flow ~ 18 mgd	Average 17.8 mgd
Sunshine Hydro	On	On

Note: There are new, bigger pumps at Iris and Cherryvale as of spring 2010, which will affect how closely model data matches SCADA data.

No pressures were compared.

Note: This scenario is still being tweaked to get tank levels to match more closely.

To: MWH **Date:** ___________

From: COB

Subject: **City of Bolder Water Utility Master Plan**
Changes to Model Setup since May 25, 2010 delivery

Operating scenarios

Note: The **Steady State, Max day** scenario had the wrong pump curves at Cherryvale; those have been adjusted.

The **Extended Period Simulation, Max month** scenario was adjusted.

July 2008 demand average (from Water Treatment demand spreadsheets) was 32.1 MGD and the Infowater demand multiplier remained at 2.05.

Actual July 2008 production average according to SCADA data was 30.9 MGD. For much of July 2008 there was only 1 pump on at 63rd so comparison between SCADA to model results is very loose. I could not get tank levels to match any closer with SCADA data.

The model is set up with a typical summer operation as follows:

Max Month	Typical Operation from SCADA	Model
63rd (151)	At 32.1 MGD, there would likely be 2 pumps on at 63rd – ~7-8 mgd.	Average 7.2 mgd
Betasso (3214NET)	At 32.1 MGD, there would likely be ~24.1-25.1 MGD at Betasso.	Average 24.9 mgd
Cherryvale (90100)	1 (new) pump on and off based on Gunb tank level	1 pump on when Gunb > 16 and off when < 9
Iris (90090)	No flow	No flow
Tank level: Boot	Initial level ~13.3. Max 20.1, min 10.5, avg 16.2	Initial level ~13.3. Max 19.4, min 7.4, avg 14.1
Tank level: Chaut	Initial level ~15.9. Max 20.9, min 12.6, avg 16.8	Initial level ~15.9. Max 22.2, min 15.9, avg 19.5
Tank level: Devils	Initial level ~10.5. Max 12.1, min 7.4, avg 9.8	Initial level ~10.5. Max 10.5, min 4.8, avg 7.7
Tank Level: Gunb	Initial level ~8.8. Max 17.4, min 6.7, avg 12.8	Initial level ~8.8. Max 16.9, min 7.4, avg 12.2
Tank level: Kohler	Initial level ~14. Max 19.9, min 7.1, avg 14.7	Initial level ~14. Max 15.9, min 10.8, avg 14.1
Tank level: Maxw	Initial level ~17. Max 19.1, min 8.5, avg 15.0	Initial level ~17. Max 17, min 7.3, avg 12.1
Maxwell (1040, 1007 or 1047, 90000)	Maxw hydro on; total plant flow varies from 2.4 (but usu. not lower than 4.8) to 11.4, average 8.4 (would be higher here)	PRV setting 20 when Booton level > 19 and setting 1 when Booton level < 8. Flow varies from 2.9 mgd to 9.7 mgd, avg 5.6
Kohler (1053, 1054, V1051, 90130)	Kohler hydros on; total plant flow varies from 2.8 MGD (but usu. not lower than 5.5) to 8.8 MGD.,	PRV setting 10 when Booton level > 19 and setting 1 when Booton level < 8. Flow varies from 5.6

	average 6. (would be higher here)	mgd to 10.1 mgd, avg 6.7
101 Pearl (V1045, V1023, 90260)	Varies from 0 to 3.2, average 0.9. (would be much higher here because higher flow from Bet.)	One valve open at setting 80 for entire simulation. Flow varies from 5.3 to 6.9 mgd
20" from Bet (986NET)	~6 mgd	Average 5.2 mgd
30" from Bet (985NET)	Remaining Bet flow ~ 18 mgd	Average 19.7 mgd
Sunshine Hydro	On	On

Note: There are new, bigger pumps at Iris and Cherryvale as of spring 2010, which will affect how closely model data matches SCADA data.

No pressures were compared.

IDSE Report for a Modeling SSS

I. GENERAL INFORMATION

Sections or fields marked with an * are required

A. PWS Information*

PWS ID: CO0107152

PWS Name: BOULDER CITY OF

PWS Address: 1094 BETASSO RD

City: BOULDER

State: Colorado

Zip/Postal Code: 80302

Population Served: 168,000 (Enter numbers only)

B. Date Submitted*

Dec 29, 2008

System Type: CWS

Source Water Type: Surface/GWUDI

Buy/Sell: Wholesale

C. PWS Operations

Residual Disinfectant Type: [X] Chlorine [ ] Chloramines [ ] Other ______

Number of Disinfected Sources: Surface 4 GWUDI ____ Ground ____ Purchased ____

D. Contact Person*

Contact Name: KEN CLARK

Title: REGULATORY COMPLIANCE SPECIALIST

Phone : (303) 413-7404 Ext. ____ Fax: (303) 530-1137

E-mail: clarkke@bouldercolorado.gov

II. SSS AND STAGE 2 DBPR REQUIREMENTS*

A. Number of Required Stage 2 DBPR Compliance Monitoring Sites:

8 Total

3 Highest TTHM

3 Highest HAA5

2 Stage 1 DBPR

B. IDSE Schedule

Select Schedule: Schedule 1

C. Stage 2 DBPR Compliance Monitoring Frequency

( ) During peak historical month (1 monitoring period)

(•) Every 90 days (4 monitoring periods)

D. Number of Required SSS Samples

16 Total

III. MODELING INFORMATION

Skip this section if you submitted a modeling study plan with an approved model calibration and your information has not changed, or if you are submitting your plan and report at the same time.

A. How was demand data assigned to the model? (attach additional sheets if needed)

1. What method was used to assign demands throughout the system?	The utility billing data for metered usage was distributed by address in the city's GIS system. Then a proximity routine was run to assign the usage to the closest pipe, excluding the pipes larger than 12 inches in diameter, and then split the usage between the nodes on either end of the pipe.
2. How did you estimate diurnal demand variation? How did you determine total system demand?	Diurnal demand patterns for each pressure zone were calculated using a flow balance into and out of each pressure zone using SCADA data. Total system demand was calculated based on water production records from the water treatment plants and the change in total system storage.
3. How many demand categories did you use?	3 - one for each zone. Each zone has a different percentage of residential, industrial, and commercial users and a different diurnal demand curve.
4. How did you address large water users?	Only the meter data was used; this captured all classes of users and demand categories in a single process. By using the meter data we were able to accurately assess the average water use. The city of Boulder has limited industrial users and few, less than 10, with high water demands (there are 6 users total with 8" meters; all others have 6" meters or less). It was not necessary to adjust specific user demand curves to make modeled tank levels match SCADA tank levels.

B. Describe all calibration activites undertaken* (attach additional sheets if needed)

1. When was the model last calibrated?	September 2007 to match actual conditions in June 2006
2. What types of data were used in the calibration?	SCADA readings for tank levels, pump flows, and system wide pressures were collected on 15 minute intervals.
3. When was the calibration data collected?	June 2006 from meter data and SCADA data
4. What field tests have been performed to collect calibration data?	No field tests were performed.

III. MODELING INFORMATION (Continued)

5. How did you determine friction factors (C-factors)?	Friction factors were carried over from our previous model into the new model for the large (10" and larger) diameter pipes. Small diameter pipes added to create the full pipe model had C-factors assigned based upon age and material. CIP, DIP, and PVC have different friction factors in the model.
6. Was the calibration completed for the peak month for TTHM formation? If not, was the model performance verified for the peak month for TTHM formation?	Yes - the calibration was completed for the peak month of June and verified using SCADA data for tank levels in June 2006.
7. How well do actual tank levels correlate with predicted tank levels during the peak month for TTHM formation? Submit a graph of predicted tank levels vs. measured tank levels for the storage facility with the highest water age in each pressure zone.*	The June 2006 actual tank levels are predicted well by the model. All tank levels are within 11% and 1.3 feet of SCADA values except for one small tank which varies as much as 19% and 2.6 feet, but it begins to self-correct at the end of the 24 hours. See attached graphs (Report Attachment pp. 1&2). Gunbarrel tank (Z1) has the oldest water age in Zone 1, Maxwell (Z2N) in Zone 2, and Chautauqua (Z3M) in Zone 3.
8. If you are using a water quality model, what parameters are modeled?	N/A - we are only modeling water age.
How was the model calibrated?	

III. MODELING INFORMATION (Continued)

C. How was the SSS modeling performed?* (attach additional sheets as needed)

1. Was modeling done for the operating conditions during the peak month for TTHM formation?*

(●) Yes ( ) No

2. How were operational controls represented in the model?

Logical controls for all pump stations and for all valves in use were set to reflect typical summer operations by using tank level set points.

3. How was water age simulated during the peak month for TTHM formation (time steps, length of simulation, etc)?

The water age simulation was run for 720 hours to ensure full turnover of all tanks and establish repeating stable system conditions. Chautauqua Tank (Z3M) had the high average water age.

4. What are the average water age results for your distribution system?

Submit final model output showing 24-hour average residence time throughout the distribution system.*

Submit graph of water age at the longest residence time storage facility in the distribution system showing the prediction for the entire EPS simulation period.*

The average water age was determined to be 10-20 hours based on the most frequently occurring age in the histogram.The average water age for the final 24 hours is given in the attached table (Report Attachment pp. 3-19). Nodes with zero demand have an age approximately equal to 720 hours and were not considered in the analysis for site selection. The graph of water age at the longest residence time storage facility (Chautauqua Tank) is on p. 20 of Report Attachment.pdf.

IV. SSS MONITORING LOCATION SELECTION

How were the SSS monitoring locations selected? (attach additional sheets as needed)

1. What model results were used as the basis for selection?	The average water age model results from the last 24 hours of the 720 hour simulation were analyzed. Nodes were ranked by age and a histogram of water age ranges was created (see Report Attachment p. 21).
2. What criteria were used in selecting average residence time, high TTHM, and high HAA5 sites?	The average water age was determined to be 10-20 hours based on the most frequently occurring age in the histogram. The high TTHM and high HAA5 sites were selected with water ages in the range of 33 to 108 hours, which is the oldest 12% of the water ages in the model (excluding zero demand nodes). Sites were selected to ensure geographical representation of the system and include various pressure zones, mixing zones, and extremities of the system. (See table in Report Attachment p. 22)
3. What additional data was used in the analysis, and how was it used?	Total Coliform Rule sampling data for chlorine residual was examined for each potential sampling site. High water age locations with measurable residual were selected for high HAA5 sites. High water age locations with lower residual chlorine were selected for high TTHM sites.
4. How did you look at practical considerations like accessibility of sampling locations?	Accessible sampling sites served by the same water main were selected as close as possible to the nodes in the model and with equal water age according to the model.
5. How did you verify that your selected sampling locations corresponded to the selected node in your model?	Locations were verified using city GIS streets and parcels layers and comparing the addresses to the information in the hydraulic model.

V. SSS AND STAGE 1 DBPR COMPLIANCE MONITORING RESULTS*

A. TTHM Results

**If you require additional site entry fields, access the 'SSSMReport Section V.A.pdf' file located in the Additional Sheets folder on the CD.

Site ID & Category	Data Type	TTHM (mg/L)				LRAA
Stage 1 Site 1	Sample Date	03/10/2008	6/3/08	9/8/08	12/3/07	
	Sample Result	0.022	0.0505	0.0432	0.0365	0.0381
Stage 1 Site 2	Sample Date	3/10/08	6/4/08	9/8/08	12/3/07	
	Sample Result	0.0182	0.0402	0.0408	0.0317	0.0327
Stage 1 Site 3	Sample Date	3/10/08	6/4/08	9/8/08	12/3/07	
	Sample Result	0.026	0.0389	0.0388	0.0338	0.0344
Stage 1 Site 4	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.034	0.0498	0.0393	0.0417	0.0412
Stage 1 Site 5	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0412	0.0453	0.046	0.0432	0.0439
Stage 1 Site 6	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0332	0.0623	0.0466	0.0463	0.0471
Stage 1 Site 7	Sample Date	3/10/08	6/3/08	9/8/08	12/03/07	
	Sample Result	0.028	0.0443	0.0587	0.0328	0.0410
Stage 1 Site 8	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0359	0.0495	0.0435	0.0413	0.0426
SSS-1 Entry 1	Sample Date		6/2/08			
	Sample Result		0.0344			0.0344
SSS-2 Entry 2	Sample Date		6/2/08			
	Sample Result		0.0384			0.0384
SSS-3 Average 1	Sample Date		6/5/08			
	Sample Result		0.0401			0.0401

Attach additional sheets as needed for SSS and Stage 1 DBPR results.

V. SSS AND STAGE 1 DBPR COMPLIANCE MONITORING RESULTS* (Continued)

B. HAA5 Results **If you require additional site entry fields, access the 'SSSMReport Section V.B.pdf' file located in the Additional Sheets folder on the CD.

Site ID & Category	Data Type	HAA5 (mg/L)				LRAA
Stage 1 Site 1	Sample Date	03/10/2008	6/3/08	9/8/08	12/3/07	
	Sample Result	0.0151	0.0321	0.0268	0.0385	0.0281
Stage 1 Site 2	Sample Date	3/10/08	6/4/08	9/8/08	12/3/07	
	Sample Result	0.0148	0.0385	0.0359	0.0346	0.0310
Stage 1 Site 3	Sample Date	3/10/08	6/4/08	9/8/08	12/3/07	
	Sample Result	0.0214	0.0392	0.0389	0.0376	0.0343
Stage 1 Site 4	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0197	0.0402	0.0351	0.0274	0.0306
Stage 1 Site 5	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0242	0.0295	0.0335	0.0287	0.0290
Stage 1 Site 6	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0186	0.0477	0.0391	0.0341	0.0349
Stage 1 Site 7	Sample Date	3/10/08	6/3/08	9/8/08	12/3/07	
	Sample Result	0.0232	0.0343	0.050	0.0372	0.0362
Stage 1 Site 8	Sample Date	3/11/08	6/3/08	9/9/08	12/4/07	
	Sample Result	0.0209	0.0429	0.0347	0.0263	0.0312
SSS-1 Entry 1	Sample Date		6/2/08			
	Sample Result		0.0248			0.0248
SSS-2 Entry 2	Sample Date		6/2/08			
	Sample Result		0.0410			0.0410
SSS-3 Average 1	Sample Date		6/5/08			
	Sample Result		0.0278			0.0278

Attach additional sheets as needed for SSS and Stage 1 DBPR results.

V. SSS AND STAGE 1 DBPR COMPLIANCE MONITORING RESULTS* (Continued)

C. Where were your TTHM and HAA5 samples analyzed?

○ In-House

Is your in-house laboratory certified? ○ Yes ○ No

◉ Certified Laboratory

Name of certified laboratory: MWH Laboratories

D. What method(s) was used to analyze your TTHM and HAA5 samples?

TTHM

- ☐ EPA 502.2
- ☐ EPA 524.2
- ☒ EPA 551.1

HAA5

- ☐ EPA 552.1
- ☐ EPA 552.2
- ☐ EPA 552.3
- ☒ SM 6251 B

VI. SELECTION OF STAGE 2 DBPR COMPLIANCE MONITORING LOCATIONS

Describe the comparison of sampling and modeling results *(attach additional sheets as needed)*:

1. How well did the sampling results correspond to the modeling results?	There was significant variation between sampling results and modeling water age results. Please see attached graphs (Report Attachment p. 23).
2. For samples that did not match well with model results, what follow-up investigations were performed?	Please see discussion in attachment (Report Attachment pp. 24-30).
3. Were additional samples collected? (Include data on table in Section IV)	No additional samples were collected.
4. Submit a graph of water age versus time for each selected sampling location.*	The graphs shown (Report Attachment pp. 31-33) are from the original model extended period simulation (EPS) run, not the EPS run that was adjusted to more closely match actual system operation. In either scenario, there are often sudden changes in water age at each location due to a tank starting to empty after filling or vice versa, or due to a pump or pressure reducing valve (PRV) station coming on or off.

VII. JUSTIFICATION OF STAGE 2 DBPR COMPLIANCE MONITORING SITES*

Stage2 Compliance Monitoring Site ID	Site Type	Justification
Stage 2 Site 1	Highest TTHM	SSS-10 High average water age in both modeling scenarios, high TTHM results during monitoring. Located in Zone 3. (Note: SSS-7 was eliminated from further consideration, please see Report Attachment p. 28 for discussion).
Stage 2 Site 2	Highest HAA5	SSS-11 Relatively high average water age in both modeling scenarios, high HAA5 results during monitoring. Located in Zone 2.
Stage 2 Site 3	Stage 1 DBPR	Stage 1 Site 6 Average residence time Stage 1 DBPR site with high HAA5 LRAA, relatively high average water age in adjusted model. Located in Zone 1.
Stage 2 Site 4	Highest TTHM	SSS-6 Relatively high average water age in original model, high TTHM results during monitoring. Located in Zone 3. Results at this site are explained in detail in the attachment (Report Attachment pp. 26-27).
Stage 2 Site 5	Highest TTHM	SSS-16 Relatively high average water age in both modeling scenarios, high TTHM results during monitoring. Located in Zone 2.
Stage 2 Site 6	Highest HAA5	SSS-8 Relatively high average water age in both modeling scenarios, high HAA5 results during monitoring. Located in Zone 2.

**If you require additional site entry fields, access the 'SSSMReport Section VII.pdf' file located in the Additional Sheets folder on the CD.

Attach additional copies of this sheet if you need more room.

VIII. PEAK HISTORICAL MONTH

A. Peak Historical Month* JUNE

B. Is Your Peak Historical Month the Same as your Peak Month in Your Modeling Study Plan?

(●) Yes

( ) No

If no, explain how you selected your new peak historical month (attach additional sheets if needed):

IX. PROPOSED STAGE 2 DBPR COMPLIANCE MONITORING SCHEDULE*

Caution: If you intent to send a hard copy version of this plan you should not enter period information that expands past the size of the text box on the form. Anything that appears past the right side of the text box will not show up on the printed document.
**If you require additional site entry fields, access the 'SSSMReport Section IX.pdf' file located in the Additional Sheets folder on the CD.

Stage 2 Compliance Monitoring Site ID	Projected Sampling Date (date or week)1			
	Period 1	Period 2	Period 3	Period 4
Stage 2 Site 1	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 2	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 3	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 4	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 5	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 6	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 7	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1
Stage 2 Site 8	6/2012, wk 1	9/2012, wk 1	12/2012, wk 1	3/2013, wk 1

1 period = monitoring period. Complete for the number of monitoring periods from Section II.C.

Attach additional copies of this sheet if you need more room.

X. DISTRIBUTION SYSTEM SCHEMATIC*

Skip this section if you submitted a modeling study plan and your distrbution system schematic was complete and has not changed from your approved modeling plan, or if you are submitting the plan and report at the same time

ATTACH a schematic of your distribution system. If your schematic has changed or if you did not show your SSS monitoring locations on the distribution system schematic you submitted with your model study plan (Form 4), you must submit a revised distribution system schematic.

XI. ATTACHMENTS

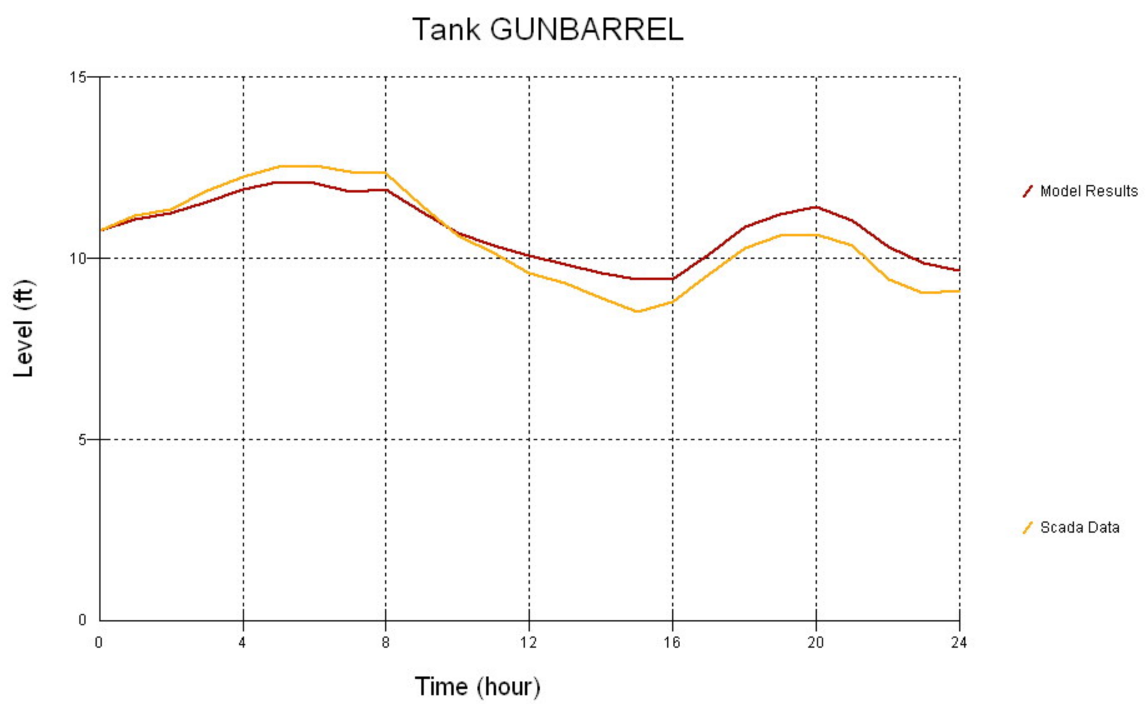
- [ ] Tabular or spreadsheet documentation that your model meets minimum calibration requirements if updated since approved modeling study plan* (Section III).
- [x] Additional sheets for explaining model information/results, including required graphs if not submitted as part of an approved modeling study plan* (Section III)
- [x] Additional sheets for sampling results, if needed (Section V).
- [x] Additional sheets for selection of Stage 2 DBPR compliance monitoring sites (Section VI).
- [x] Graph of water age versus time for all Stage 2 DBPR sites selected* (Section VI).
- [x] Additional sheets for justification of Stage 2 DBPR Compliance Monitoring Sites, if needed (Section VII). **REQUIRED if you are a subpart H system serving more than 249,999 people.**
- [ ] Additional sheets for explaining how you selected the peak historical month (Section VIII).
- [ ] Additional sheets for proposed compliance monitoring schedule (Section IX). **REQUIRED if you are a subpart H system serving more than 249,999 people.**
- [ ] Explanation of deviations from approved study plan.
- [x] Distribution system schematic* (Section X). **REQUIRED if it has changed from your approved model study plan or if monitoring locations were not shown.**
- [ ] Compliance calculation procedures (for Stage 2 Compliance Monitoring Plan).

Total Number of Pages in Your Report: 54

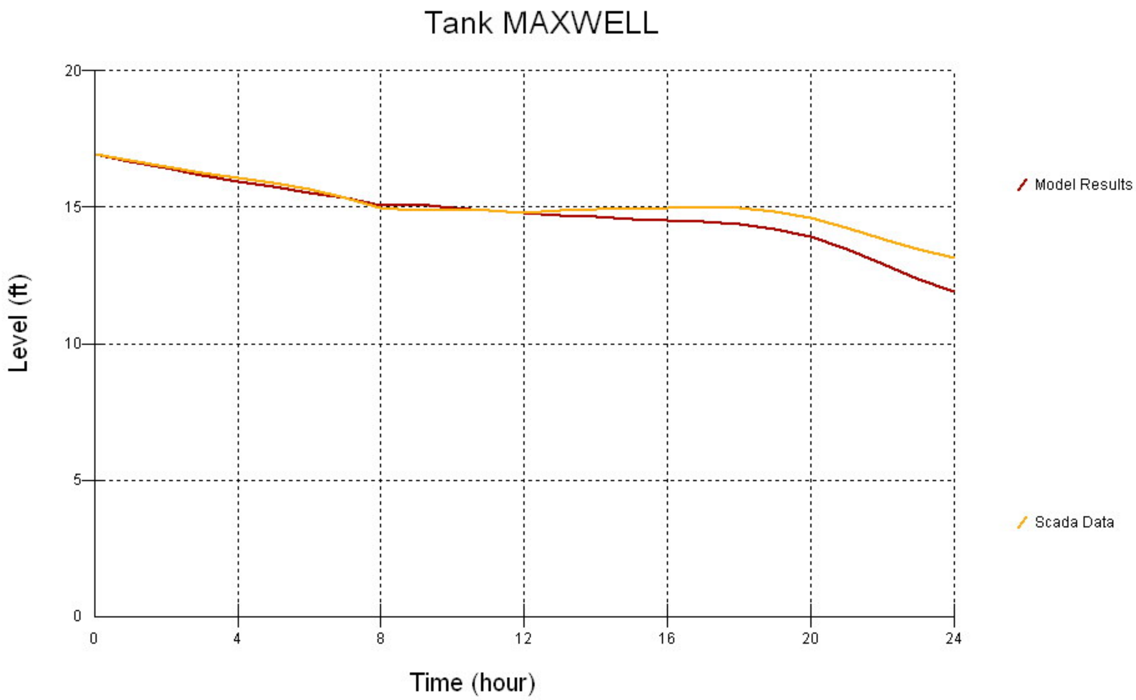
Print Form   Submit by Email

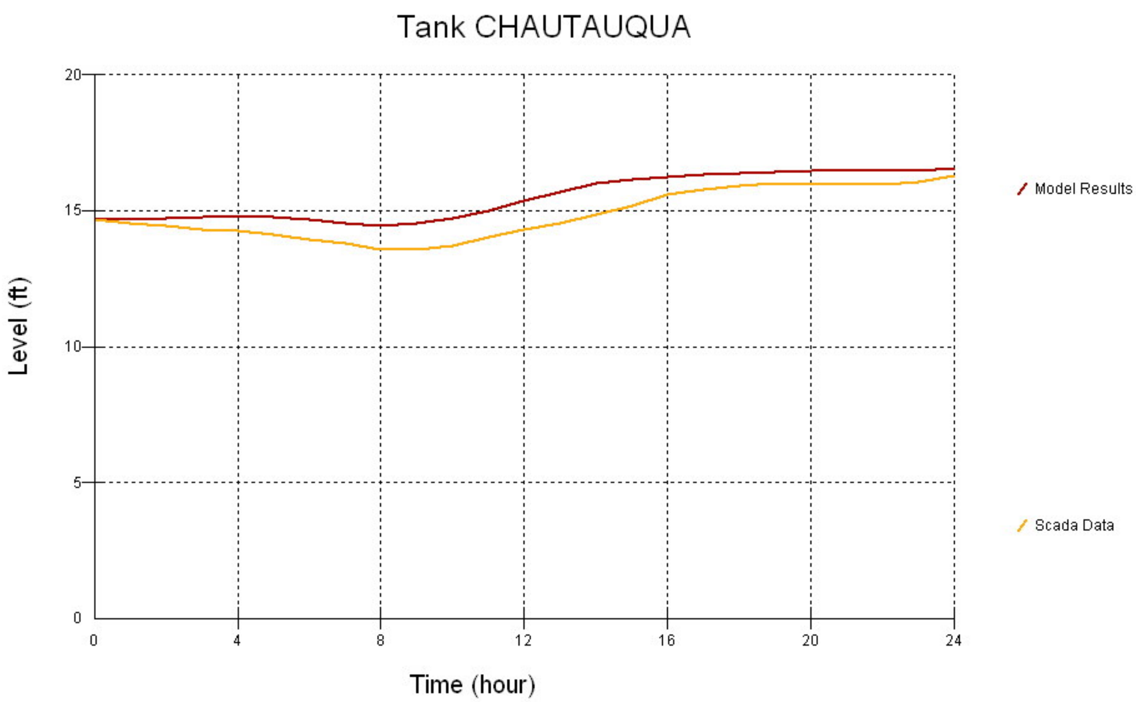
SECTION III.B.7. *Submit a graph of predicted tank levels vs. measured tank levels for the storage facility with the highest water age in each pressure zone.*

Tank	Pressure Zone	Average Water Age (Hours)
Gunbarrel (Z1)	1	83.41
Maxwell (Z2N)	2	35.68
Kohler (Z2S)	2	26
Chautatuqua (Z3M)	3	174.7
Devils Thumb (Z3S)	3	110.85
Booton (Z3N)	3	87.05



Attachment p. 1





Attachment p. 2

SECTION III.C.4. *Submit final model output showing 24-hour average residence time throughout the distribution system.*

ID	Avg Age - last 24 hours
J10666	108.0
J1278	92.0
J1306	90.9
J2248	86.4
J274	84.8
J1276	84.5
J2250	80.9
J2268	79.8
J2264	79.8
J2254	79.5
J2262	79.4
J2256	78.6
J1314	77.9
J6244	76.1
J2270	74.4
J1268	74.1
J6274	73.0
J2272	72.2
J6272	72.0
J272	71.9
J802	71.5
J770	71.1
J2276	70.8
J874	69.8
J312	68.9
J768	67.7
J1868	67.3
J6284	66.5
J6260	65.7
J4876	65.3
J1150	64.9
J6354	64.2
J1144	62.7
J784	62.5
J6298	62.5
J512	62.1
J6254	62.0
J6896	62.0
J6866	61.9
J6940	61.8
J1148	61.5
J6908	61.1
J6936	60.8
J6880	60.6
J6854	60.0

ID	Avg Age - last 24 hours
J11764	29.8
J10262	29.8
J10980	29.8
J11600	29.8
J7148	29.8
J11032	29.8
J5616	29.8
J3226	29.8
J11046	29.8
J5606	29.8
J3224	29.8
J3228	29.7
J5604	29.7
J11592	29.7
J11802	29.7
J3298	29.6
J5322	29.6
J7054	29.6
J10974	29.5
J1132	29.5
J5264	29.5
J7548	29.4
J5082	29.4
J7986	29.4
J3302	29.4
J3110	29.4
J862	29.4
J5314	29.3
J5624	29.3
J8054	29.3
J4556	29.3
J11006	29.3
J7130	29.3
J5582	29.3
J5300	29.3
J6394	29.3
J11002	29.3
J5272	29.2
J5614	29.2
J5268	29.2
J3230	29.2
J5298	29.2
J11008	29.2
J2002	29.2
J5580	29.2

ID	Avg Age - last 24 hours
J10490	14.5
J4822	14.5
J1168	14.5
J7258	14.5
J1648	14.4
J2192	14.4
J7236	14.4
J2478	14.4
J1620	14.3
J5024	14.3
J1228	14.3
J1190	14.3
J4992	14.2
J1020	14.2
J4996	14.2
J4798	14.2
J1178	14.2
J7218	14.1
J630	14.1
J1652	14.1
J1350	14.1
J638	14.1
J1622	14.1
J5938	14.1
J16	14.1
J8406	14.1
J1196	14.0
J1644	14.0
J1624	14.0
J8252	14.0
J5026	14.0
J3830	14.0
J8408	14.0
J710	14.0
J1954	13.9
J8390	13.9
J1626	13.9
J1634	13.9
J1702	13.9
J8168	13.9
J8376	13.8
J1646	13.8
J1654	13.8
J6050	13.8
J4794	13.8

J4872	59.8
J6886	59.5
J6884	59.1
J6944	59.1
J4602	59.0
J6918	58.7
J40010	58.5
J1864	58.5
J776	58.1
J6286	58.1
J6894	58.0
J4246	57.2
J6900	57.2
J3504	57.1
J6890	56.8
J6332	56.8
J4244	56.7
J4266	56.5
J788	56.5
J7636	56.2
J6906	56.1
J6336	55.7
J1870	55.5
J6322	55.1
J6458	54.8
J282	54.7
J6334	54.0
J2596	53.8
J212	53.8
J6338	53.6
J7500	53.5
J6324	53.3
J7632	53.2
J6320	52.7
J732	52.3
J4272	52.1
J6874	52.0
J210	51.9
J4270	51.7
J6340	51.7
J6876	51.6
J6902	51.5
J7158	51.3
J248	51.1
J2528	51.0
J6348	50.6
J4382	50.6
J2504	50.5
J6904	50.5
J6302	50.2

J6418	29.1
J9990	29.1
J5256	29.1
J6466	29.0
J11772	29.0
J6460	29.0
J4194	29.0
J540	29.0
J11012	29.0
J11058	28.9
J11004	28.9
J3856	28.9
J10324	28.9
J11804	28.9
J5330	28.9
J7840	28.9
J5284	28.9
J7998	28.9
J10284	28.9
J8486	28.9
J11064	28.8
J10982	28.8
J11048	28.8
J10994	28.8
J5304	28.8
J5328	28.8
J5550	28.8
J4170	28.8
J4306	28.7
J3236	28.7
J11042	28.7
J4594	28.7
J5254	28.7
J11010	28.7
J2518	28.7
J8002	28.6
J11510	28.6
J7766	28.6
J4312	28.6
J5104	28.6
J6414	28.6
J5228	28.5
J5234	28.5
J7990	28.5
J5286	28.5
J3222	28.5
J10286	28.5
J5600	28.4
J11156	28.4
J3306	28.4

J8194	13.8
J1458	13.8
J8240	13.8
J4818	13.7
J8304	13.7
J8216	13.7
J5448	13.7
J5510	13.7
J2030	13.7
J3674	13.7
J1048	13.7
J8178	13.6
J1632	13.6
J8254	13.6
J9722	13.6
J9456	13.6
J8210	13.5
J9290	13.5
J10448	13.5
J4432	13.4
J5046	13.4
J8190	13.4
J2476	13.4
J9376	13.4
J1456	13.4
J9772	13.3
J2470	13.3
J10456	13.3
J1636	13.2
J7204	13.2
J1090	13.2
J9384	13.1
J5216	13.1
J1356	13.1
J4774	13.1
J8188	13.1
J8224	13.0
J7468	13.0
J7586	13.0
J1486	12.9
J8274	12.9
J1952	12.9
J4496	12.9
J9338	12.9
J8234	12.8
J1630	12.8
J1562	12.8
J11424	12.8
J10442	12.7
J7552	12.7

J228	50.0
J236	49.7
J6948	49.7
J6920	49.6
J4236	49.3
J7584	49.1
J7576	49.0
J8082	49.0
J178	48.8
J6930	48.7
J6352	48.7
J6346	48.4
J726	48.2
J7572	48.1
J266	47.9
J4226	47.9
J542	47.9
J7574	47.6
J7692	47.3
J2614	47.1
J6344	47.0
J2696	47.0
J174	46.9
J7694	46.5
J7492	46.5
J6326	46.4
J156	46.4
J154	46.4
J5492	46.1
J216	46.1
J7696	46.0
J2622	46.0
J4348	46.0
J4328	45.9
J4360	45.9
J6316	45.8
J6360	45.8
J7536	45.7
J214	45.7
J7154	45.7
J970	45.7
J3046	45.6
J6328	45.5
J10748	45.5
J202	45.1
J254	45.0
J206	45.0
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J6968	44.6
J10952	44.6

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J11812	28.3
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J3090	28.3
J11112	28.3
J5602	28.3
J8028	28.3
J10256	28.3
J5274	28.3
J8056	28.3
J5260	28.2
J692	28.1
J7772	28.1
J5308	28.1
J5532	28.1
J3106	28.1
J896	28.1
J894	28.0
J694	28.0
J9634	28.0
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J4004	28.0
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J6382	27.8
J5258	27.8
J2062	27.7
J7954	27.7
J5222	27.6
J7652	27.6
J3334	27.5
J6470	27.4
J6406	27.4
J4130	27.4
J5192	27.4
J4006	27.3
J3280	27.3
J4220	27.3
J3284	27.3
J526	27.3
J3970	27.3
J3728	27.3
J6390	27.3
J2044	27.3
J8140	27.3
J3296	27.3
J7136	27.3
J518	27.3
J3988	27.2

J6218	12.7
J1610	12.7
J7676	12.7
J8228	12.7
J5982	12.7
J2468	12.7
J3874	12.7
J8100	12.7
J7598	12.6
J4824	12.6
J8086	12.6
J10474	12.6
J11484	12.6
J7250	12.6
J5960	12.5
J9804	12.5
J8152	12.5
J9382	12.5
J9266	12.5
J9346	12.5
J5034	12.5
J9764	12.4
J2466	12.4
J7278	12.4
J4772	12.4
J8182	12.4
J8218	12.4
J7530	12.4
J5484	12.3
J8186	12.3
J7528	12.3
J4782	12.3
J4958	12.3
J4430	12.3
J9454	12.3
J5840	12.2
J4720	12.2
J9286	12.1
J626	12.1
J5954	12.1
J4770	12.1
J8084	12.1
J8092	12.1
J11498	12.0
J1998	12.0
J4722	12.0
J5016	12.0
J9668	12.0
J8718	12.0
J4800	12.0

J2904	44.6
J188	44.5
J38	44.4
J7568	44.3
J6868	44.3
J3004	44.2
J8076	44.2
J4278	44.1
J10744	44.1
J6958	44.0
J4372	43.9
J264	43.9
J4354	43.8
J4506	43.8
J4352	43.7
J3656	43.6
J3080	43.6
J6476	43.6
J10738	43.6
J6942	43.5
J3940	43.4
J36	43.4
J4374	43.3
J4330	43.3
J7650	43.3
J224	43.2
J32	43.2
J2652	43.1
J286	43.1
J5490	43.1
J4350	42.9
J10372	42.6
J66	42.6
J3026	42.3
J70	42.2
J8078	42.2
J10780	42.1
J7562	42.1
J3902	42.1
J7540	42.1
J972	42.0
J7504	42.0
J7490	41.9
J4202	41.9
J4456	41.8
J290	41.8
J10170	41.7
J10928	41.7
J2896	41.7
J204	41.6

J5184	27.1
J5208	27.0
J3290	27.0
J11054	27.0
J3294	27.0
J3292	27.0
J7666	27.0
J7956	27.0
J4408	26.9
J4106	26.9
J10	26.8
J10098	26.7
J10070	26.7
J2472	26.7
J7976	26.7
J4516	26.6
J7978	26.6
J736	26.5
J4206	26.5
J7028	26.5
J9596	26.5
J4010	26.5
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J7194	14.8
J2188	14.8
J5006	14.7
J480	14.7
J8846	14.7
J646	14.7
J1472	14.6
J5842	14.6
J1664	14.6
J1222	14.6
J10436	14.6

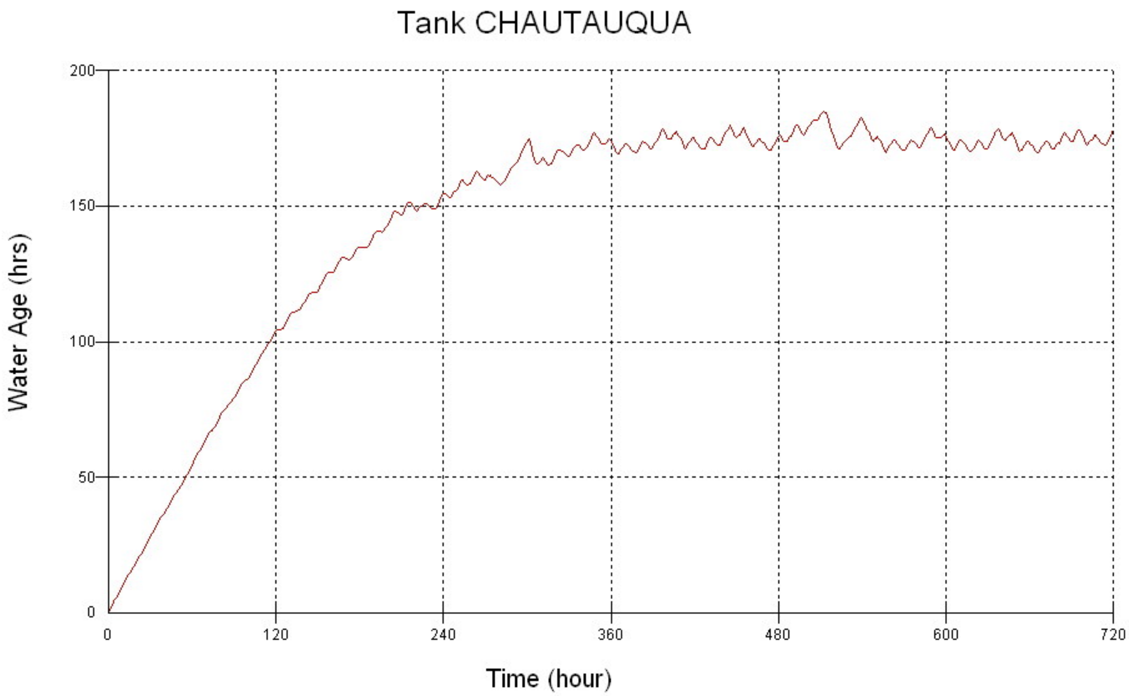
J5770	2.4
J6712	2.4
J6112	2.4
J5720	2.3
J11272	2.3
J6170	2.3
J6216	2.3
J408	2.3
J6210	2.3
J6230	2.3
J6786	2.2
J10636	2.2
J1108	2.2
J6766	2.2
J5676	2.2
J5792	2.2
J6118	2.2
J1490	2.1
J6798	2.1
J10638	2.0
J6102	2.0
J1110	2.0
J404	2.0
J6738	1.9
J6124	1.9
J6154	1.9
J1772	1.9
J6232	1.8
J1790	1.8
J6180	1.8
J6178	1.8
J6214	1.7
J5756	1.7
J6776	1.7
J1114	1.7
J1800	1.6
J1788	1.6
J6152	1.5
J6774	1.5
J6184	1.5
J1098	1.5
J6188	1.3
J6174	1.2
J5856	1.1
J6164	1.1
J6158	1.0
J6162	0.9
J6142	0.8
477	0.6
530	0.6

J11040	29.9
J5250	29.9
J4288	29.8
J11102	29.8

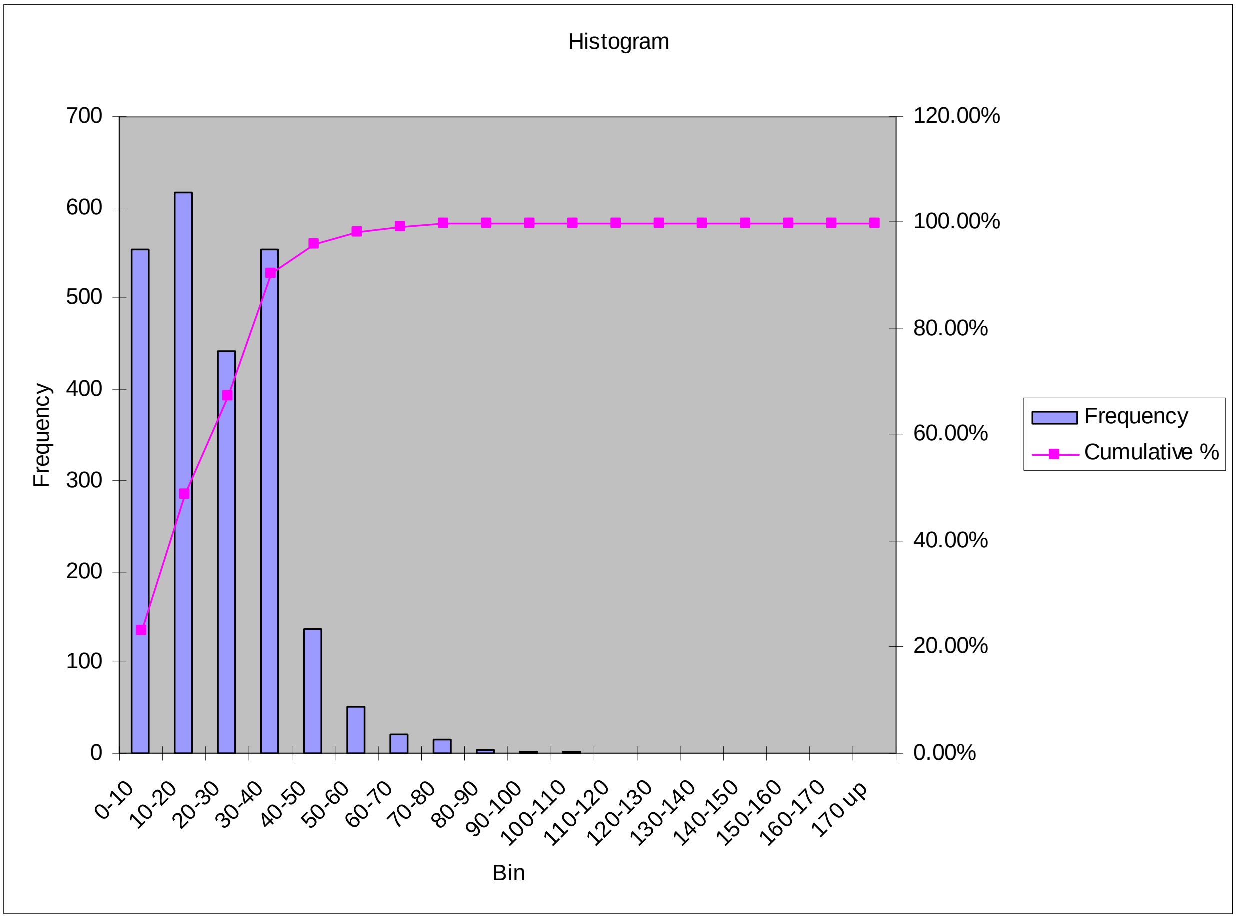
J8280	14.6
J11232	14.6
J10452	14.5
J8402	14.5

J6236	0.5
475	0.4
472	0.3
J5900	0.2
471	0.1

SECTION III.C.4. (contd) *Submit graph of water age at the longest residence time storage facility in the distribution system showing the prediction for the entire EPS simulation period.*



SECTION IV.1. *Histogram of water age ranges.*



Attachment p. 21

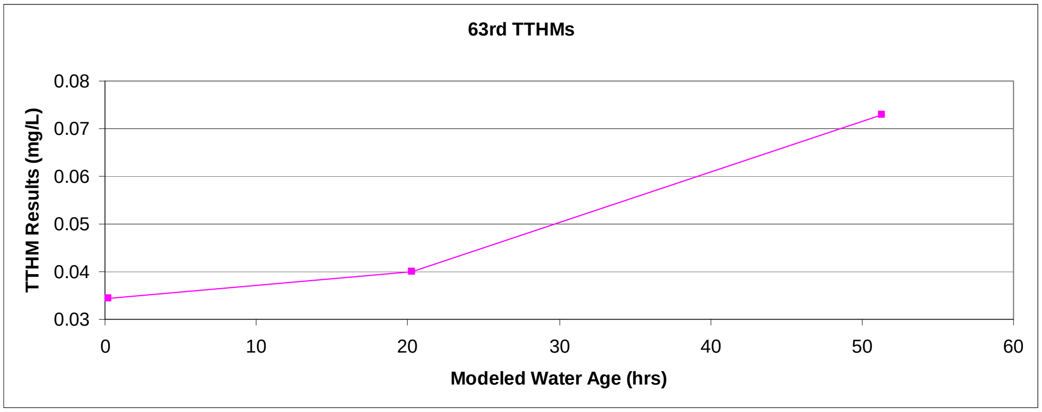
SECTION IV.2. *What criteria were used in selecting average residence time, high TTHM, and high HAA5 sites?*

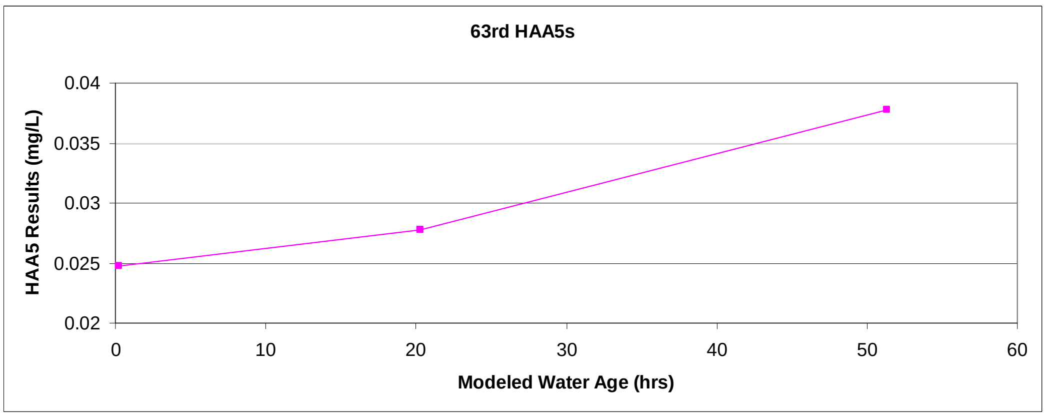
Average Water Age Results for SSS Monitoring Locations (Hour 697 to 720 of simulation)

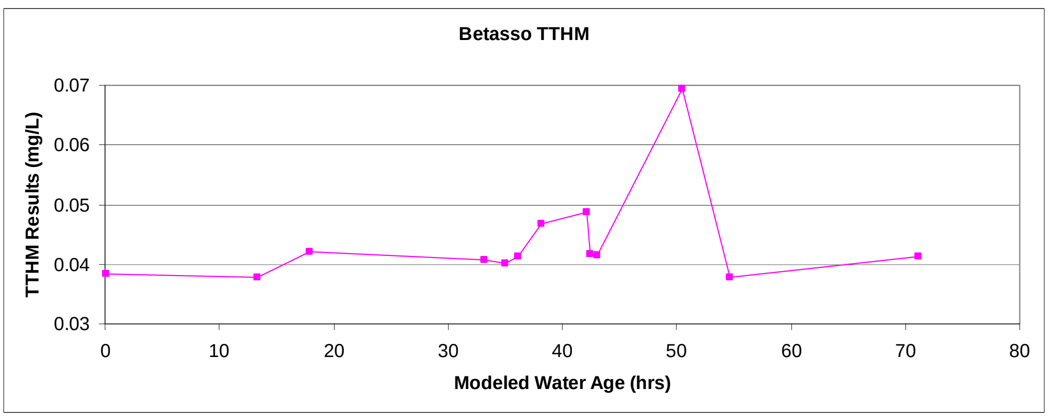
Node	Water Age (hrs)	Preliminary Category	ID
J5900	0.20	Entry 1	SSS-1
471	0.12	Entry 2	SSS-2
J6498	20.30	Average 1	SSS-3
J9148	17.91	Average 2	SSS-4
J4962	11.00	Average 3	SSS-5
J7562*	42.09*	Average 4	SSS-6
J7158	51.30	High TTHM 1	SSS-7
J2622	45.96	High TTHM 2	SSS-8
J770	71.13	High TTHM 3	SSS-9
J2504	50.48	High TTHM 4	SSS-10
J2374	30.66	High TTHM 5	SSS-11
J282	54.68	High TTHM 6	SSS-12
J2708	36.06	High HAA5 1	SSS-13
J5492	46.12	High HAA5 2	SSS-14
J10154	34.66	High HAA5 3	SSS-15
J2920	37.92	High HAA5 4	SSS-16

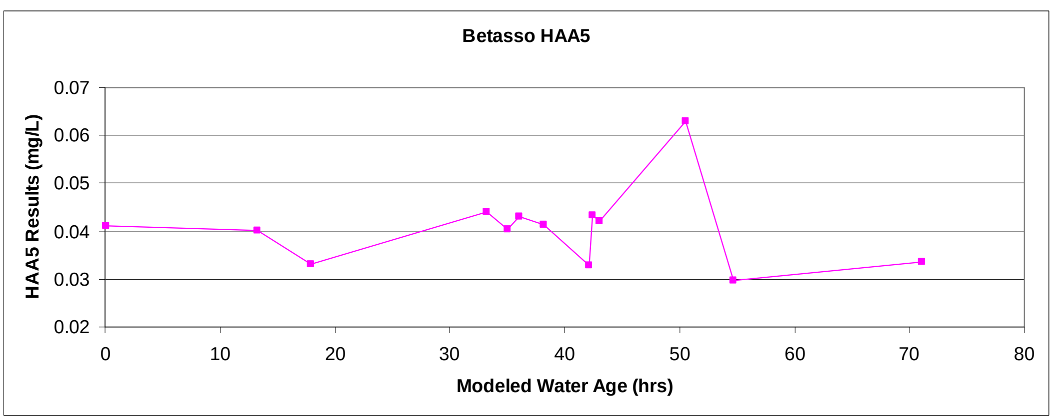
* This sampling site was inadvertently selected using the wrong model output. Its modeled water age does not fall into the average water age of 10-20 hours.

SECTION VI.1. *How well did the sampling results correspond to the modeling results?*
There are two sets of graphs to represent the samples from each water treatment plant.





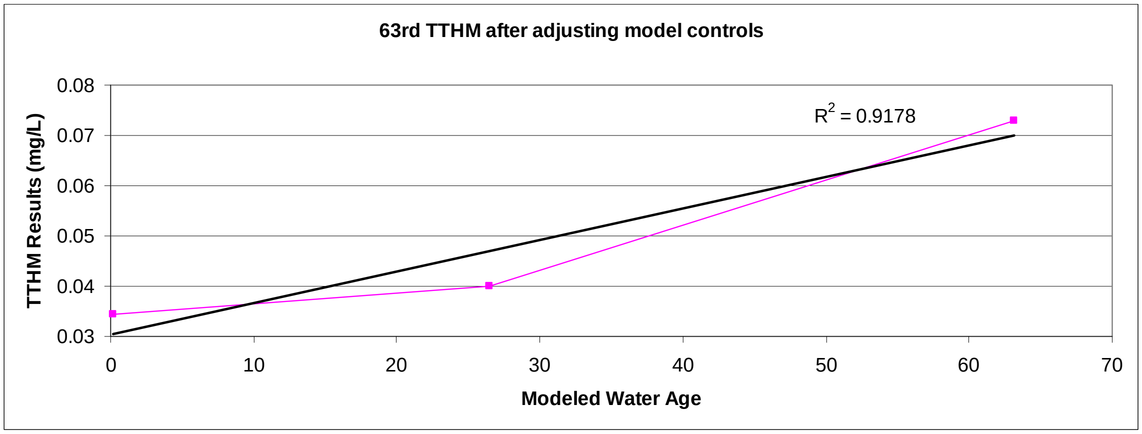


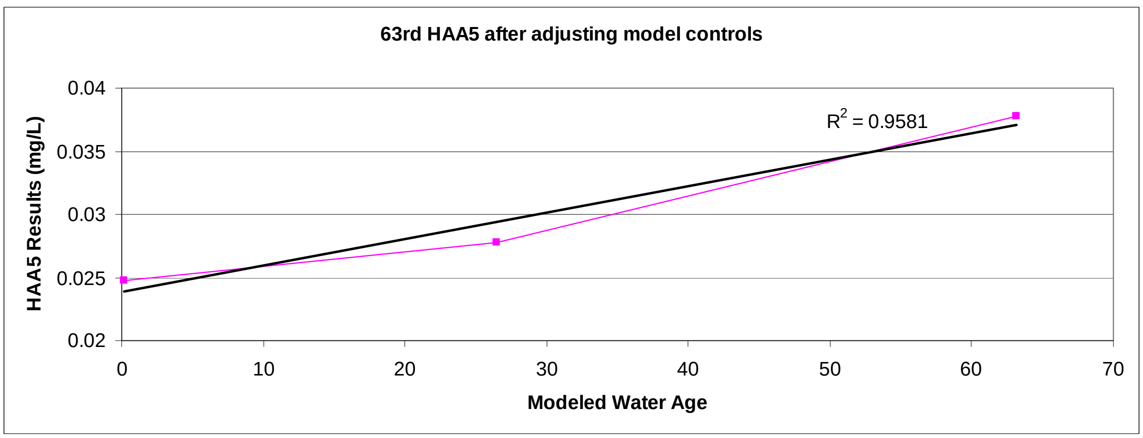


Attachment p. 23

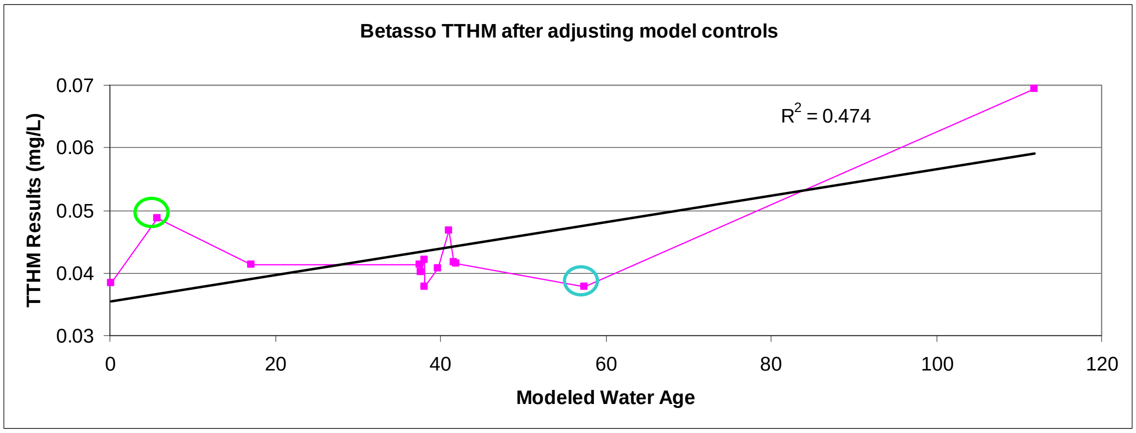
SECTION VI.2. *For samples that did not match well with model results, what follow-up investigations were performed?*

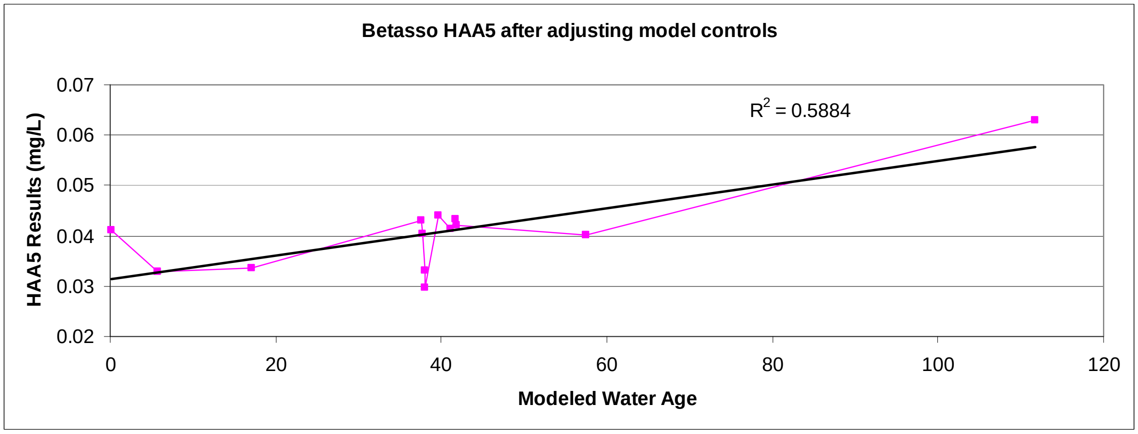
There were some significant differences in controls between the model scenario used to select sample sites and the actual operation of the system at the time of sampling. The most significant was lower actual production at the Boulder Reservoir WTP at 63rd Street (63rd). Controls in the model were adjusted to more accurately represent actual system operation at the time of sampling. Sampling and modeling results correlated more closely after adjusting the controls.





Attachment p. 24



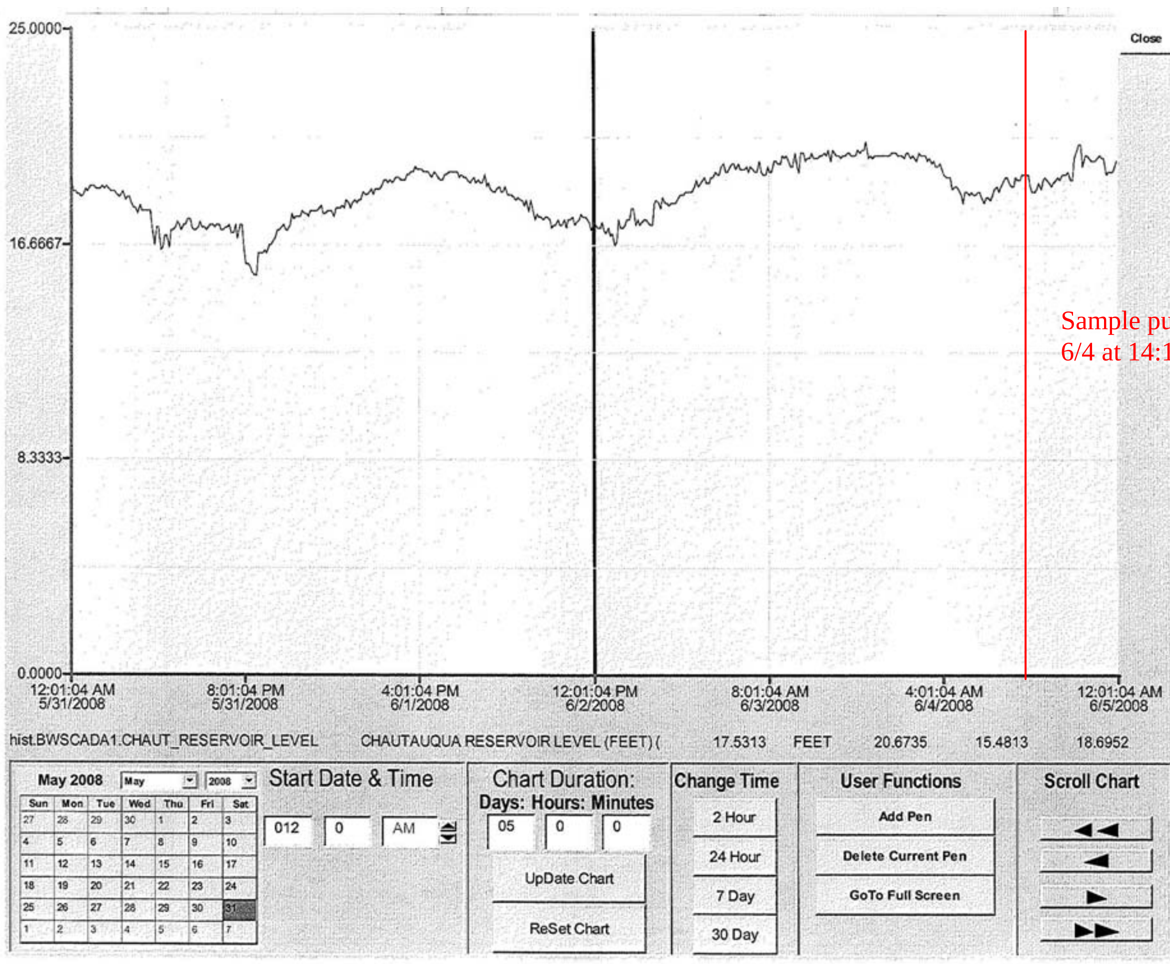


Samples in the distribution system were taken 1-2 days after plant effluent was sampled, and some distribution system DBP results were lower than plant effluent DBP results. This may indicate changing water quality, variations in system operational strategies, or data error.

There is a large amount of variation in how the system can be operated, so even after adjusting controls to more closely represent actual conditions, there were still some sample points with TTHM results that did not match closely with the model's water age predictions. SCADA data from the sample collection dates were compared to model data to explain why these points did not match more closely.

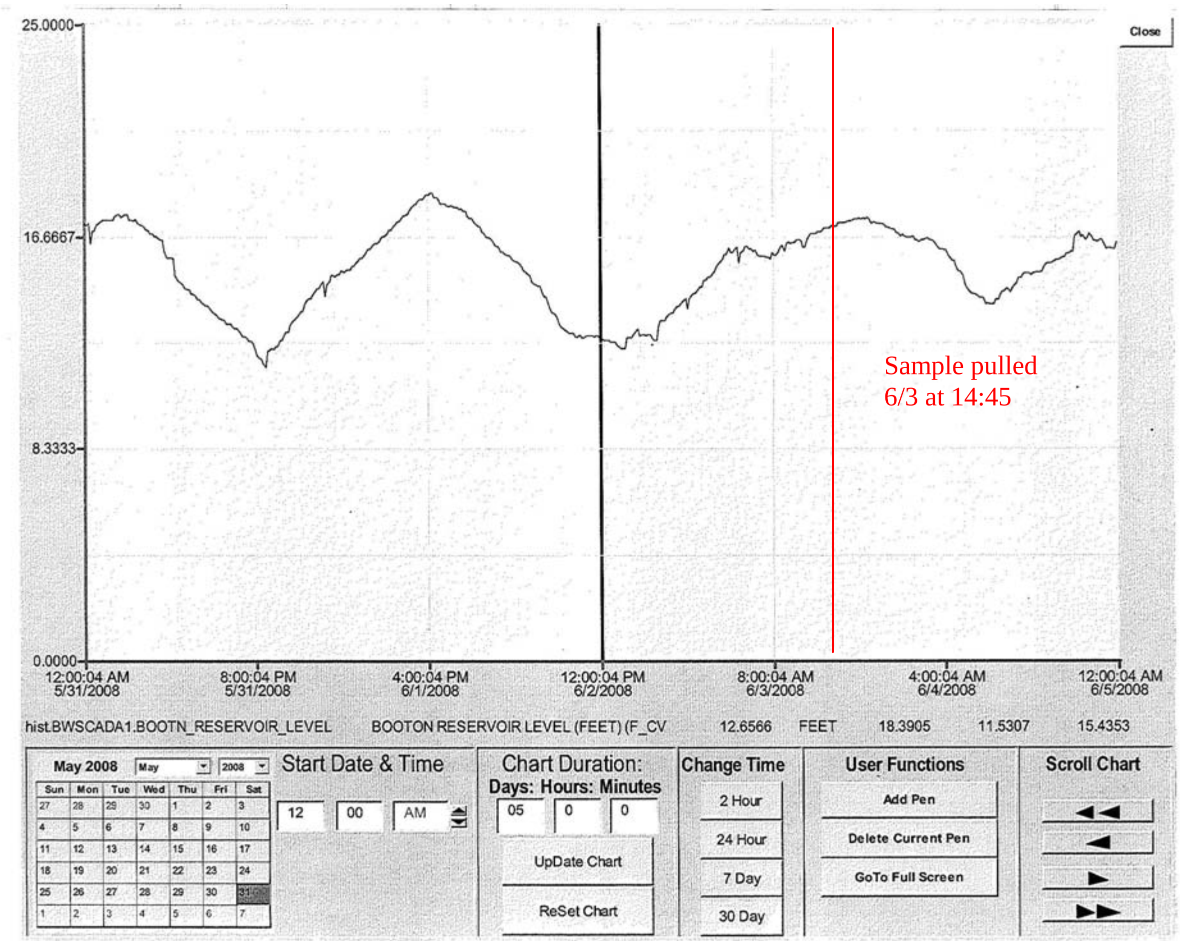
The first point was SSS-5 (circled in blue on the Betasso TTHM graph above). This sample was collected on June 4. TTHM results at this location were lower than expected, because the model predicted a high water age. This location is downstream of the Betasso WTP, and its water age is most directly affected by Chautauqua Tank (Z3M). If Chautauqua is filling, then the SSS-5 area is being fed by water directly from the Betasso WTP and has a low water age. If Chautauqua is emptying then the SSS-5 area is being fed by water from Chautauqua and has a higher water age. During the last 24 hours of the model simulation, Chautauqua is emptying, so SSS-5 has a high water age. But when the sample was pulled, the tank was actually filling, so SSS-5 was receiving younger water from Betasso.

Chautauqua Tank Water Level 5/31/08 – 6/5/08



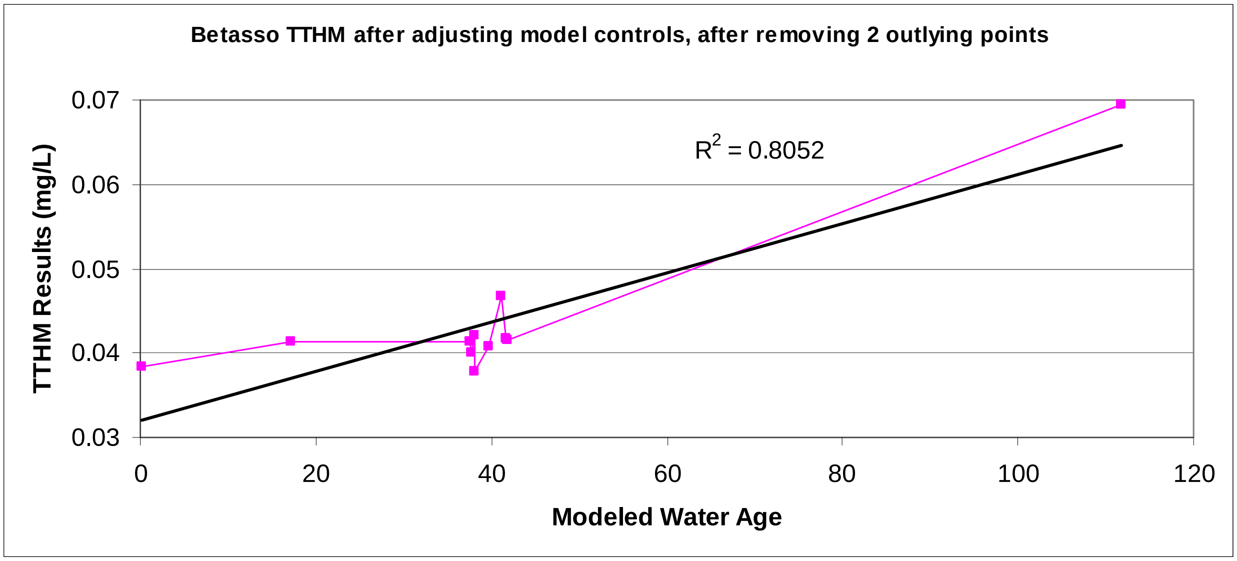
The second point was SSS-6 (circled in green on the Betasso TTHM graph above). This sample was collected on June 3. TTHM results at this location were higher than expected, because the model predicted a low water age. This location is downstream of the Betasso WTP in the city's west pressure zone, zone 3. Its water age is affected by zone 3 tank Booton (Z3N). If Booton is filling, then the SSS-6 area is being fed by water directly from Betasso and has a very low water age. If Booton is emptying then the SSS-6 area is being fed by water from Booton and has a higher water age. During the last 24 hours of the model simulation, Booton is filling so this area has a low water age. When the sample was collected, Booton was also filling. So Booton's level did not explain why the sample results at this point did not match the model prediction.

Booton Tank Water Level 5/31/08 – 6/5/08

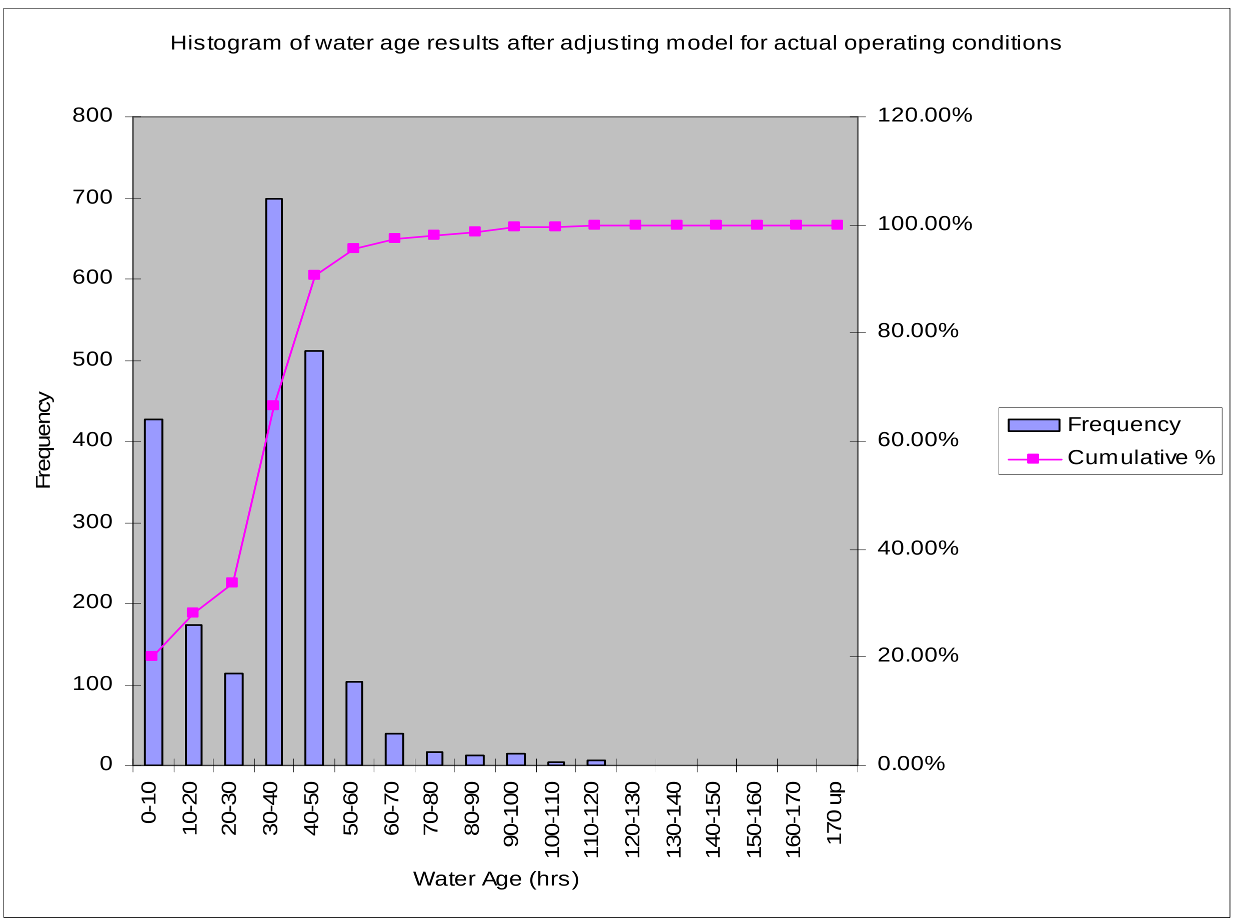


Even though the line feeding SSS-6 is long, almost 200 feet of 1-inch pipe, this location is a busy strip mall, and the sample was collected from a grocery store. Chlorine residual was relatively high. It is the opinion of city staff that this sample was older than predicted by the model, because there was not much water moving to the Maxwell tank (Z2N) downstream from SSS-6. Maxwell tank had been emptying for almost a day and had been low for several days. When Maxwell tank is not filling, demand in the area is significantly reduced, so the water may have aged in transmission pipes. Another possibility is that a pipe may be missing from the model in this area. A model update is currently in progress by city staff.

Without these two points, the TTHM graph now looks like:



After adjusting the model, the average water age changed from 10-20 hours to 30-40 hours. This may be partly due to the reduced demand multiplier to reflect actual usage at the time of sampling. This also reduced the number of nodes with demand. Water quality in the system can vary widely depending on system operation. Chautauqua tank (Z3M) still had the highest average water age after adjustments to match actual operating conditions.



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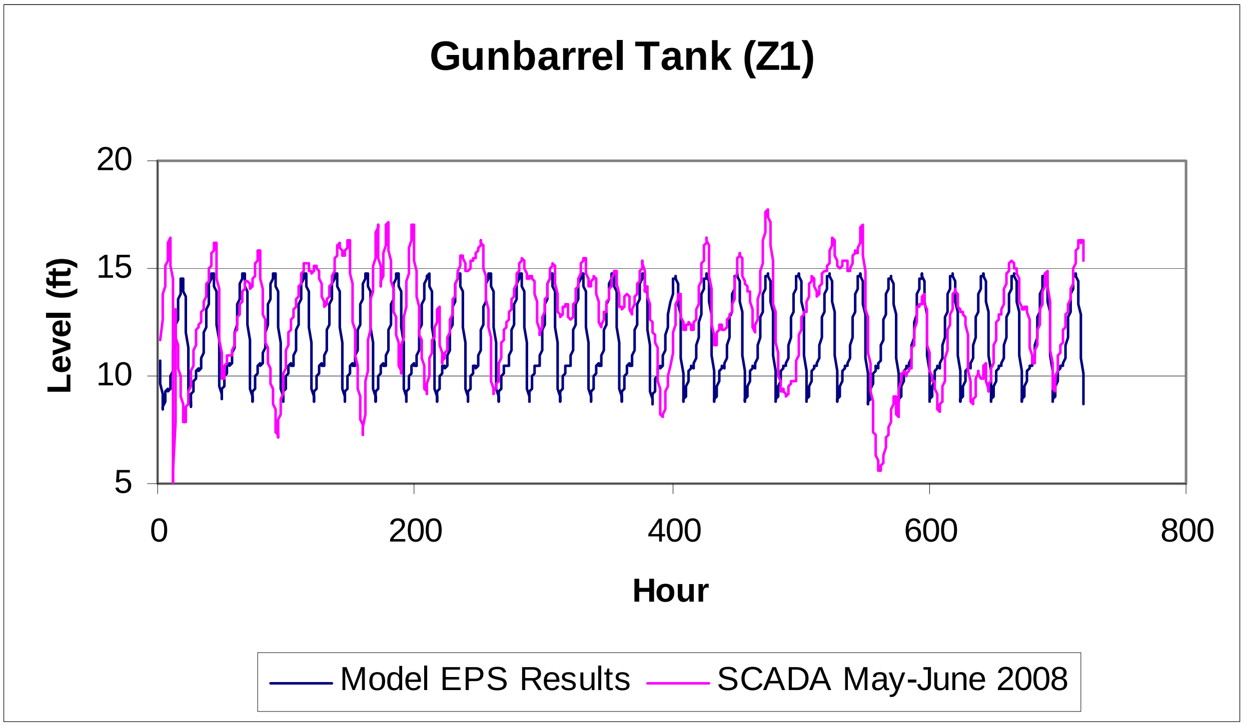
Site SSS-7 was eliminated from further consideration. It is a school and there are access issues in the summer. Also Stage 1 Site 5 is very near to SSS-7 and considered by staff to be more representative of this area. The large difference in TTHM sample results between these two sites is probably due to a recent change in operation of nearby Gunbarrel Tank (Z1) at the time of sampling.

Even though there is a large amount of variation in how the system can be operated, city staff agree that this model is a good representation of the system operation, because the model controls generally represent the boundaries of typical summer operation. A few examples are given below:



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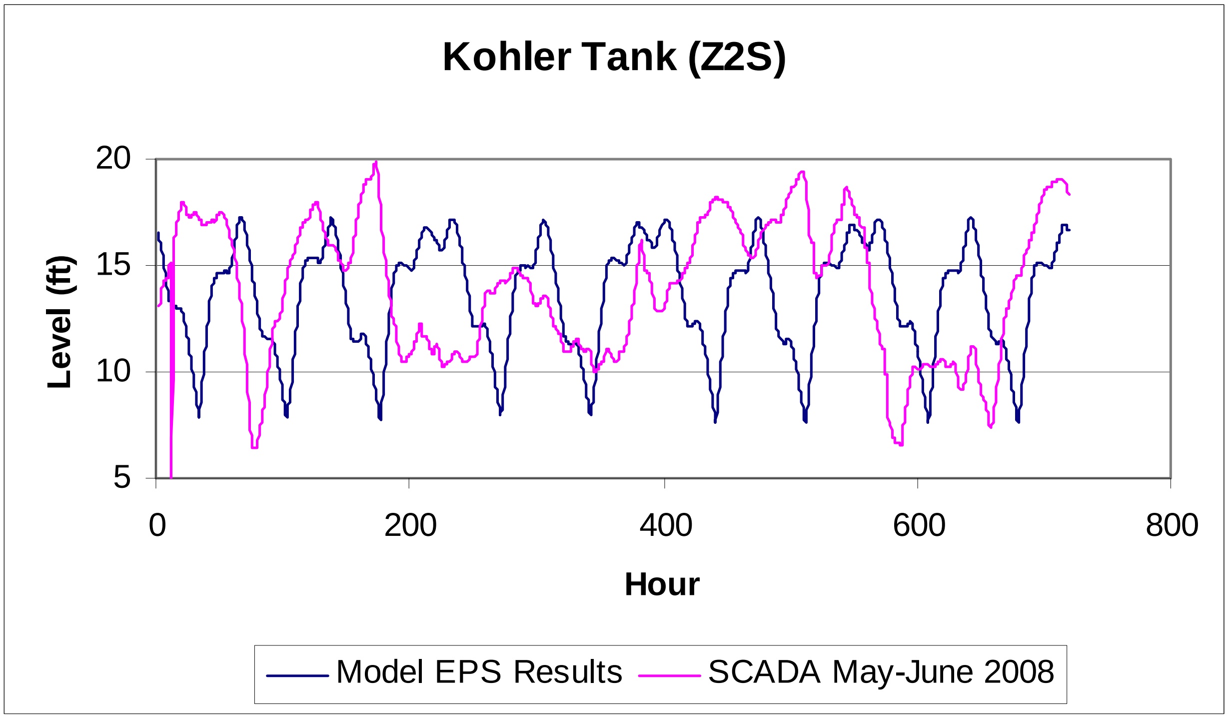
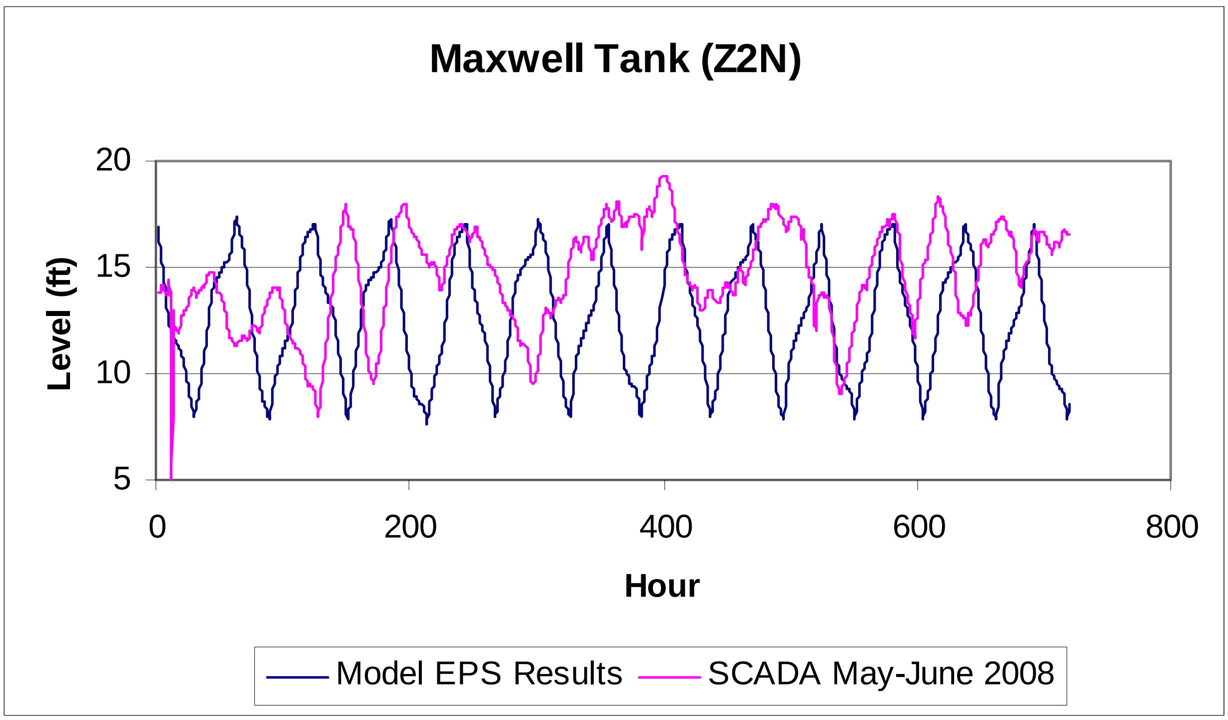
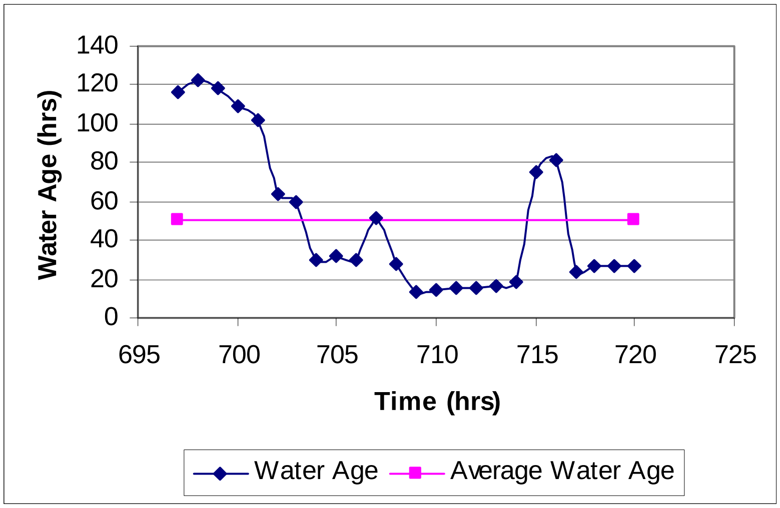




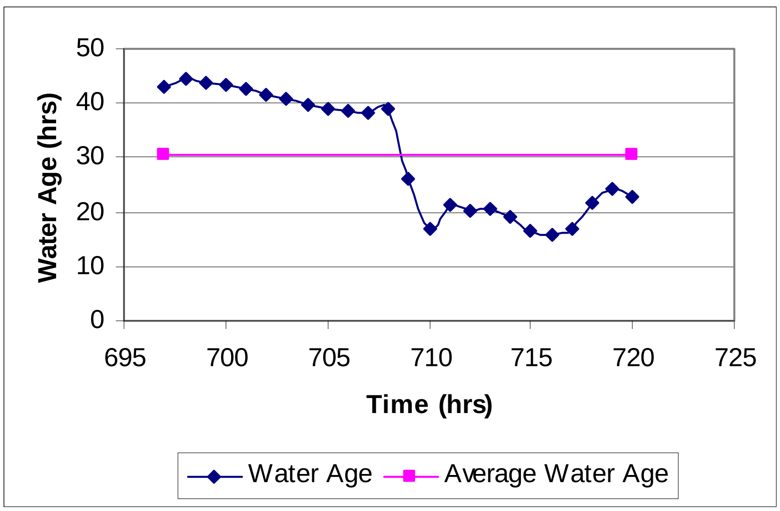
Attachment p. 30

SECTION VI.4. *Submit a graph of water age versus time for each selected sampling location.*

Stage 2 Site 1



Stage 2 Site 2



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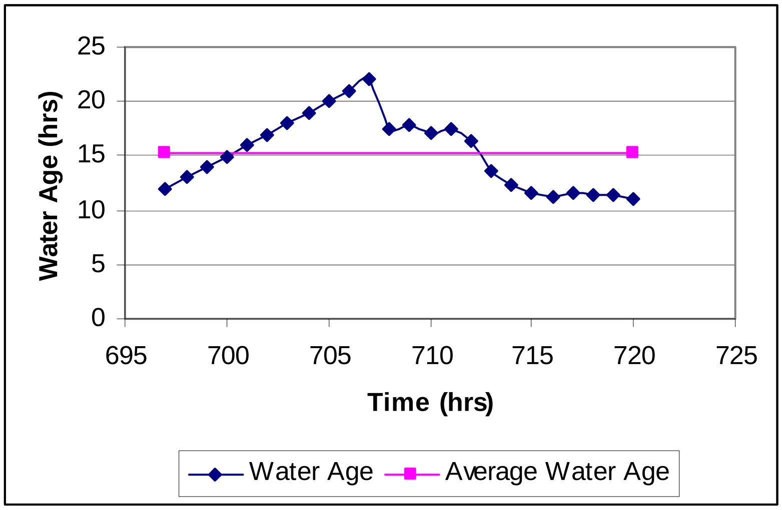
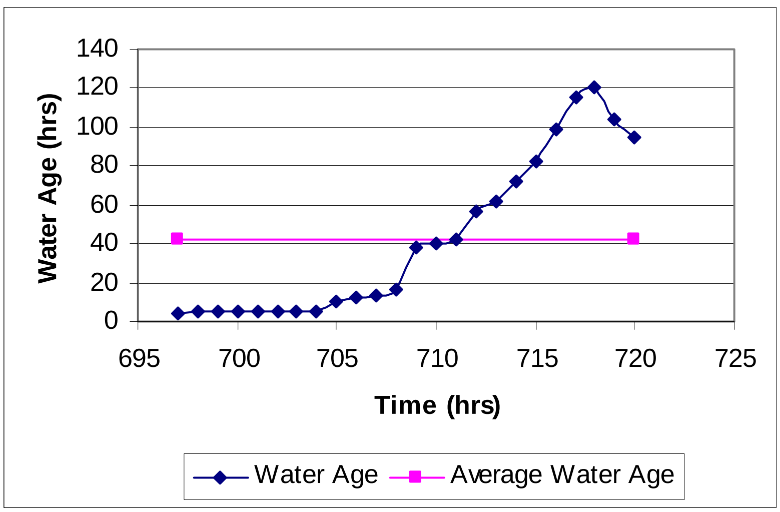
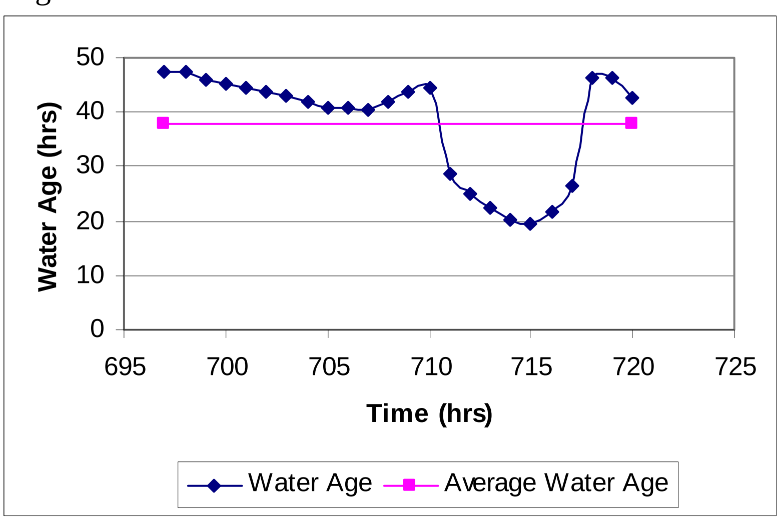
Stage 2 Site 3



Stage 2 Site 4



Stage 2 Site 5



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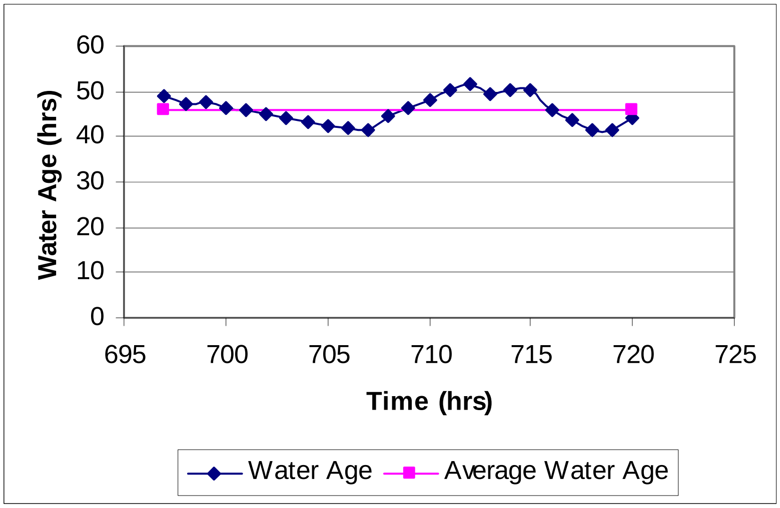
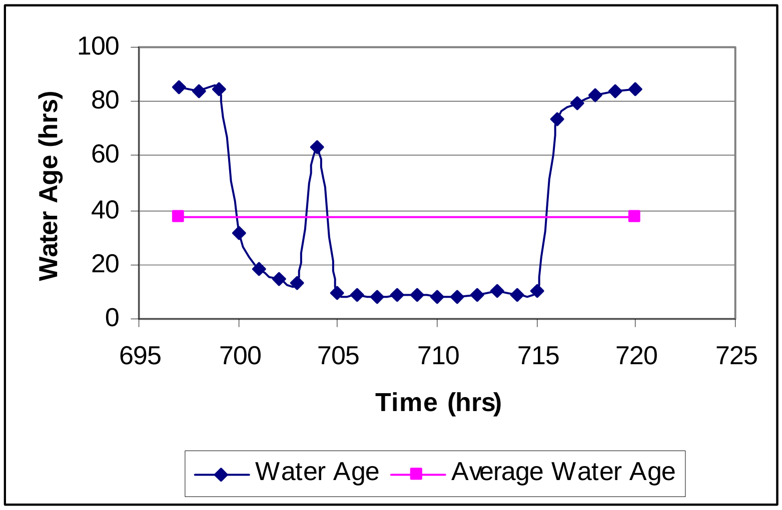
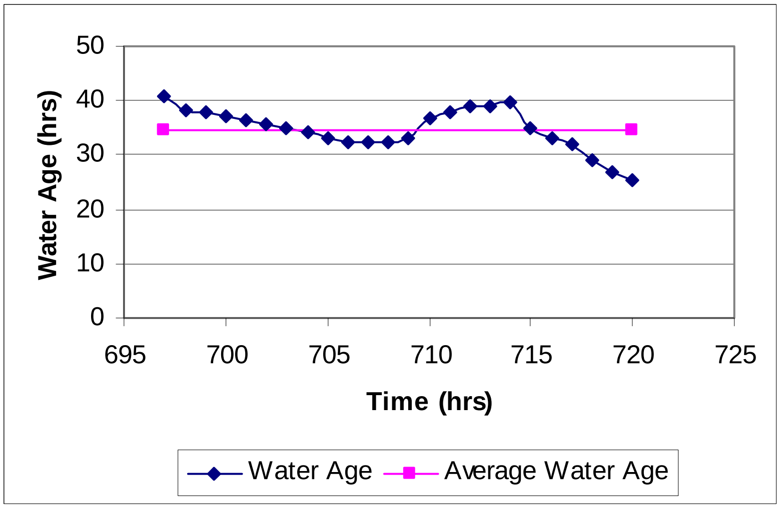
Stage 2 Site 6



Stage 2 Site 7



Stage 2 Site 8



SECTION VII. *Justification of Stage 2 DBPR Compliance Monitoring Sites.*

SSS Sites	TTHM LRAA Results	TTHM Rank	HAA5 LRAA Results	HAA5 Rank	Preliminary Category	Average Water Age (hrs) - Scenario 1	Average Water Age (hrs) - Scenario 2	Zone	Stage 2 DBPR Selected Sites
SSS-1	0.0344	22	0.0248	24	Entry 1	0.20	0.20	1	
SSS-2	0.0384	18	0.041	7	Entry 2	0.12	0.12	3	
SSS-3	0.0401	16	0.0278	23	Average 1	20.30	26.46	1	
SSS-4	0.0421	8	0.033	15	Average 2	17.90	38.01	2	
SSS-5	0.0379	20	0.0402	9	Average 3	11.00	57.46	3	
SSS-6	0.0487	3	0.0328	16	Average 4	42.10	5.69	3	Stage 2 Site 4: TTHM
SSS-7	0.0729	1	0.0378	10	High TTHM 1	51.30	63.14	1	Eliminated
SSS-8	0.0417	9	0.0434	3	High TTHM 2	46.00	41.68	2	Stage 2 Site 6: HAA5
SSS-9	0.0414	11	0.0335	14	High TTHM 3	71.10	17.14	3	
SSS-10	0.0694	2	0.0629	1	High TTHM 4	50.50	111.81	3	Stage 2 Site 1: TTHM
SSS-11	0.0408	15	0.044	2	High TTHM 5	30.7	39.72	2	Stage 2 Site 2: HAA5
SSS-12	0.0378	21	0.0298	20	High TTHM 6	54.7	38.03	2	
SSS-13	0.0414	12	0.0431	4	High HAA5 1	36.10	37.54	2	
SSS-14	0.0416	10	0.042	5	High HAA5 2	46.1	41.86	2	
SSS-15	0.0401	17	0.0403	8	High HAA5 3	34.7	37.70	2	Stage 2 Site 8: HAA5
SSS-16	0.0468	5	0.0413	6	High HAA5 4	37.9	41.07	2	Stage 2 Site 5: TTHM
Stage 1 Site 1	0.0381	19	0.0281	22	Avgres1	14.09	31.15	2	
Stage 1 Site 2	0.0327	24	0.031	18	Avgres2	34.64	37.45	2	
Stage 1 Site 3	0.0344	23	0.0343	13	Avgres3	10.42	25.71	3	
Stage 1 Site 4	0.0412	13	0.0306	19	Avgres4	30.64	50.39	1	
Stage 1 Site 5	0.0439	6	0.029	21	Avgres5	37.37	46.52	1	Stage 2 Site 7: Stage 1
Stage 1 Site 6	0.0471	4	0.0349	12	Avgres6	15.26	44.47	1	Stage 2 Site 3: Stage 1
Stage 1 Site 7	0.041	14	0.0362	11	Maxres1	72	17.36	3	
Stage 1 Site 8	0.0426	7	0.0312	17	Maxres2	15.2	50.95	1	

Appendix D:

City of Boulder Utilities Finished Water Energy Dissipation Stations Inspection Report

CITY OF BOULDER UTILITIES
FINISHED WATER ENERGY DISSIPATION STATIONS
INSPECTION REPORT

Submitted to:

Mr. Robert Harberg
Utilities Planning and Project Management Coordinator
City of Boulder
PO Box 791
Boulder, Colorado 80306

Submitted by:

Kevin Clark, P.Eng.
MWH AMERICAS, INC.
1801 California St.
Suite 2900
Denver, Colorado 80202

Project No. 1008566
August 17, 2010

BUILDING A BETTER WORLD

Overview:

Mr. Kevin Clark of MWH Americas, Inc. inspected the City of Boulder (City) Utilities' Energy Dissipation Stations on May 3, 2010 as part of the overall treated water facilities assessment as part of the TWMP. The inspection was to assess the overall condition of the facilities for asset management planning and to identify any major replacement costs that might be required within the next 20 years. The facilities inspected consisted of (in order of inspection):

- Orodell Hydro Station
- 101 Pearl Street PRV Station
- Sunshine Hydro Station and Flow Control Facility
- Maxwell Pump Station and Hydroelectric Plant
- Kohler Pump Station and Hydroelectric Plant

The limited time for inspections only allowed for a preliminary condition assessment based on visual judgment, and did not allow for any in depth inspections. Most of the data collected on the facilities was critically augmented with discussions and input from the City staff present at the inspections.

Inspection Date: May 3rd, 2010

Orodell Hydro Station

Photo 1 – Orodell Hydro Building

The building was in good to excellent shape (Photo 1) and there was some ongoing construction activity in front of the building related to the pipeline rehabilitation work that the City is having completed on the Orodell Supply penstock pipeline, the Betasso Drain line and the Betasso Hydro supply pipeline.

Photo 2 – Orodell Hydro System Layout

An inspection of the equipment, valving and piping was completed along with the City team, on the inside of the Hydro Building (Photo – 2). Critical initial observations are summarized below in Table 1.

Table 1 – Orodell Hydro Component Assessment

Equipment Item	Comments
Turbine/ Generator	Good condition – maintenance performed regularly every 5 years (last in 2006) Mfctr: Cornell (Francis turbine) - Only run turbine and generator to 70 kW due to; downstream flow restrictions and cavitation issues; Mfctr: Primeline (Generator)
Turbine Isolation Plug Valve	Good Condition - Mfctr: WKM – 12”
Bypass Upstream Isolation B’Fly Valve	Fair Condition – 12” BFV
Bypass PRV Valve	Fair Condition - vibration problems at high flow and OH crane does not reach location making service difficult (Mfctr: GAI – 12”)
Bypass Downstream Isolation B’Fly Valve	Poor Condition – 12” BFV with broken actuator (locked in open position but not a critical valve due to low downstream pressure)
Downstream Flow Control Valve (Pressure Sustaining)	Good Condition - operated as turbine discharge control valve due to vibration problems by limiting flow with back pressure (Mfctr: CLA-VAL 12” Model 100-20)
Miscellaneous Valves and Piping	Fair – no major issues reported
Battery Back-up and Charging System for I&C	Poor - battery back-up system for I&C is outdated and needs replacement. Just completed I&C update (good to very good rating) but the battery system upgrade still required (poor rating)

Table 1 reflects information compiled from meetings and discussions that were held with City staff subsequent to the original inspection. MWH recommends that a master equipment list be updated for each facility with manufacturer details, date of install, date of last service, maintenance interval and any other special information required (i.e. Overhead Crane does not reach and the preferred method of install/disassembly) for each critical component.

References:

The following electronic files were provided to MWH by the City and were used as references for the inspection.

- 1985-1995-Orodell Hydro As-Built Drawings.pdf
- 19637_19649_Orodell.pdf
- Operation-Maintenance Manual.pdf
- Orodell Onsite Operating Procedures Manual

101 Pearl Street PRV Station

The team then travelled to the Pearl Street PRV location and proceeded with inspection of the critical components. The structure was in very good shape (Photo – 3) with the only item noted being on the outside of the building for potential grading improvement and a gravel or concrete pad for the parking/turn around area.

Photo – 3: 101 Pearl Street PRV Station Building

Initial comments from the inspection of the interior systems (Photo – 4) are summarized in Table 2.

Photo – 4: 101 Pearl Street PRV System Layout

Table 2 – 101 Pearl Street PRV Component Assessment

Equipment Item	Comments
PRV Valves No. 1 & No. 2	Good condition and no reported problems
Isolation B'Fly Valves	Good condition and no reported problems
I&C System	Poor - functioning RTU to be replaced with new fiber optic system and tied into fiber optic hub in the facility

The overall condition of the facility was rated as GOOD (Rating = 2). Table 2 also reflects additional information compiled from meetings and discussions that were held with City staff subsequent to the original inspection. MWH recommends that a master equipment list be updated for each facility with manufacturer details, date of install, date of last service, maintenance interval and any other special information required for each critical component.

References:

The following electronic files were provided to MWH by the City and were used as references for the inspections:

- Field Drawing w As Built Notoations.pdf
- 101 Pearl Pressure Reducing Station Drawings.pdf
- Construction Submittals.pdf
- Submittals 2.pdf

- SURGE RELIEF VALVES.pdf

Sunshine Hydro Station and Flow Control Facility

The City and MWH team then proceeded to the Sunshine Hydro Facility location to continue the general inspections. The hydro plant building was in very good shape (Photo – 5) with only some stacked rock retaining wall damage that was noted in the corner of the excavated area (Photo – 6) adjacent to the building.

Photo – 5: Sunshine Hydro Building

Photo – 6: Rock Retaining Wall Damage

An inspection of the equipment, valving and piping was completed along with the City team, on the hydroelectric components inside of the Hydro Building (Photo – 7).

Photo – 7: Sunshine Hydro System Layout

A list of critical initial observations, are summarized below in Table 3.

Table 3 – Sunshine Hydro Component Assessment

Equipment Item	Comments
Turbine/ Generator System	Good Condition – Francis Turbine (Hangzhou HL110-WJ-50), Induction Generator (Hitachi new install in 1997)
Turbine Isolation Ball Valve	Good Condition - Model: 20" Grove B-5 CL300
Discharge Isolation B'Fly Valve	Good Condition – 20" BFV
Surge Relief Valve	Good Condition - Model: 10" CLA-VAL 50A-01B with no problems reported; condition assumed as rarely actuates
Surge Relief Isolation B'Fly Valves	Good Condition – 10" Keystone BFV
Bypass PRV System and Vault	Fair Condition but control issues starting to be noticed in fine tuning pressures/flows; control system and PRV Valves with hydraulic (water) actuated cylinders may need major upgrade in next 5 to 10 years
I&C System	Good Condition but desire to have RTU interface replaced with fiber

	optic system tied into hub at 101 Pearl

Photo – 8 and Photo – 9 show the outside and layout of the Sunshine PRV Vault respectively.

Photo – 8: Sunshine PRV Vault

Photo – 9: Sunshine PRV Vault Layout

The overall condition of the facility was rated as GOOD (Rating = 2). Table 3 also reflects additional information compiled from meetings and discussions that were held with City staff subsequent to the original inspection. MWH recommends that a master equipment list be updated for each facility with manufacturer details, date of install, date of last service, maintenance interval and any other special information required for each critical component.

References:

The following electronic files were provided to MWH by the City and were used as references for the inspections:

- 19830-19848-Sunshine Hydro.pdf
- PRV Valve Improvements – Construction Drawings.pdf
- Sunshine hydroelectric.pdf
- Sunshine Hydro Onsite Operating Manual

Maxwell Pump Station and Hydroelectric Plant

The City and MWH team then proceeded to the Maxwell Hydro and Pump Facility location to continue the general inspections. The hydro-pump plant building was in good shape (Photo – 10) except for a crack in the CMU block facade at the back corner (covered in more depth by structural inspection as part of Tank/Reservoir task).

Photo – 10: Maxwell Pump Station and Hydro


Photo 11 - Maxwell Hydro Building CMU Crack


Photo 12 - Maxwell Hydro-Pump Layout

A list of critical initial observations, are summarized in Table 4.

Table 4 – Maxwell Pump Station and Hydroelectric Plant Component Assessment

Equipment Item	Comments
Pump - Turbine / Generator System	Good Condition - Replaced runner with generator rebuild in 2004; Mfctr: Cornell (Francis Turbine)
Pump – Turbine Isolation Valve	Good Condition – 10" Plug Valve
Booster Pump / Motor System	Good Condition but rarely used – 8 " pump with 1,500 gpm rated capacity but does not perform to full nameplate capacity
Turbine Bypass System	Fair Condition – 8" PRV with 8" Isolation BFV's upstream and downstream, only minor maintenance since originally installed, some small leakage from PRV noted from previous maintenance shut-down period
Altitude Valve & Reservoir System	Fair Condition - not specifically inspected but no major issues reported to team; if major overhaul of valves required no direct overhead access unless remove roof or retrofit other lifting system
Meters, Miscellaneous Valves and Piping incl. Yard	Fair Condition – not specifically inspected but no major issues reported to team; some deterioration in specific pipe segments due to cavitation and/or site specific corrosion/lining deterioration that was noted from previous dismantling during maintenance (to be confirmed/investigated at next scheduled maintenance period)
I&C System	Good Condition but desire to have Alan Bradley PLC system installed with programming upgrades

The overall condition of the facility was rated as GOOD (Rating = 2). Table 4 also reflects additional information compiled from meetings and discussions that were held with City staff subsequent to the original inspection. MWH recommends that a master equipment list be updated for each facility with manufacturer details, date of install, date of last service, maintenance interval and any other special information required for each critical component.

References:

The following electronic files were provided to MWH by the City and were used as references for the inspection

- 16478-16496 Maxwell pump station & hydro.pdf
- Maxwell Pump Station and Hydro Facility O&M Manual-Dec 1985.pdf
- 9B14-M~1.PDF
- Maxwell & Kohler As-Builts.pdf
- Maxwell Onsite Operating Procedures Manual

Kohler Hydro Station and Flow Control Facility

The City and MWH team continued the inspection tour by travelling to the Kohler Hydro and Pump Facility location. The hydro-pump plant building was in very good shape (Photo – 13) with no visible issues.

Photo 13 – Kohler Hydro-Pump Station Layout

An inspection of the equipment, valving and piping was completed along with the City team, on the hydroelectric components inside of the Hydro – Pump Building (Photo – 14).

Photo 14 - Kohler Hydro-Pump System Layout

A list of critical initial observations, are summarized in Table 5.

Table 5 – Kohler Pump Station and Hydroelectric Plant Component Assessment

Equipment Item	Comments
Pump - Turbine System	Good Condition – Replaced turbine runner in Unit 1 in 2004 and new bearing for generator and turbine runner for Unit 2 in 2010 (turbine = Cornell and generator = Marathon XRI)
Pump – Turbine Isolation Valves	Good Condition – 10 " Eccentric Plug Valve Dezurik Series 118 with fitted Water Cylinder Actuators
Turbine Bypass System	Good Condition – 10" CLA-VAL Model 100G
Meters, Miscellaneous Valves and Piping incl. Yard	Fair Condition – not specifically inspected but no major issues reported to team
I&C System	Fair Condition but requirement for new PLC (Allen Bradley) as original (Westinghouse) is now severely outdated

The overall condition of the facility was rated as FAIR (Rating = 3). Table 5 also reflects additional information compiled from meetings and discussions that were held with City staff subsequent to the original inspection. MWH recommends that a master equipment list be updated for each facility with manufacturer details, date of install, date of last service, maintenance interval and any other special information required for each critical component.

References:

The following electronic files were provided to MWH by the City and were used as references for the inspection:

- 16675-16694 – Kohler Pump + Hydro.pdf
- Kohler Equip Submits.pdf
- Kohler Equip Submits - Drawings.pdf
- 26836_26843 – MaxwellKohler.pdf
- Kohler Onsite Operating Procedures Manual

Appendix E:

City of Boulder Utilities Finished Water Reservoirs Inspection Report

CITY OF BOULDER UTILITIES
FINISHED WATER RESERVOIRS
INSPECTION REPORT

Submitted to:

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Submitted by:

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Project No. 1008566
August 13, 2010

BUILDING A BETTER WORLD

MWH
BUILDING A BETTER WORLD

Overview:

Mr. Jed Iverson, P.E. of MWH Americas, Inc. inspected the City of Boulder Utilities' finished water reservoirs on May 3rd and May 4th, 2010. The inspection was to assess the overall condition of the reservoirs for asset management planning and to identify any major replacement costs that might be required within the next 20 years. The City maintains six (6) finished water reservoirs and the inspection of each reservoir will be described below. Because of the nature of the condition assessment, all the inspections were allotted 30 – 45 min each. The limited inspections only allowed for a preliminary condition assessment based on visual judgment, and did not allow for any in depth inspections.

Inspection Date: May 3rd, 2010
Reservoir: Maxwell Reservoir

The as-builts for Maxwell Reservoir show that the reservoir has a plan dimension of 360 feet x 200 feet with a capacity of 9.5 MG. The reservoir is covered with concrete double tees supported by concrete beams and columns. The double tees are covered with insulation and topped with asphalt and gravel. The perimeter of the reservoir sticks above the finished grade approximately 5 feet and slopes in the shorter dimension up to the center at approximately a 1.5% slope.

I started my inspection on the Eastern side of the tank, just above the Hydro building. Approximately 100 feet from the Southeast corner there is a longitudinal crack mid height of the exposed wall. This crack extends approximately 30 – 40 feet and is most likely due to horizontal movement of the roof diaphragm, lateral movement of the base of the wall from external soil pressure, or stem wall settlement from soil erosion. This is an item that should be highlighted as needing attention and should be fixed or at least patched in the near future so freeze thaw cycling does not deteriorate the wall further.

Photo 1 - Maxwell - Longitudinal Crack, Southeast Corner

Continuing along the Eastern wall towards the North, the rest of the wall was in good shape with minor horizontal and vertical cracks. This was also the case for the remainder of the exposed wall segments. The vertical cracks were most likely due to thermal expansion and contraction while the horizontal cracks were most likely due to similar conditions as described in Photo 1.

As I continued around the reservoir, one note of concern was where the finished grade was sunken in adjacent to the exposed wall. These areas were approximately 10 feet long and up to 2 feet deep and occurred every 20 to 30 feet along the reservoir perimeter. This could be from the soil settling, the surface water eroding the soil, or from soil piping along a reservoir leak. This will need to be fixed and can be detrimental to the structure by allowing water to freeze close to the base of the footer. This can result in uplift of the wall, settlement of the wall, or can allow external pressure from the ice expanding against the existing soil. See Photo 2 for a sample of the sunken areas.

Photo 2 - Maxwell - Typical Sunken Area Adjacent to Exposed Wall

At the corners of the reservoir it was clear that the structure was experiencing some movement. A clear separation of the wall segments was visible and a couple of the corners the construction joint was starting to separate up to a 1/4 of an inch. This appeared to be a true movement joint because felt material was visible in the joint. Photo 3 illustrates this separation and should be at a minimum caulked to prevent moisture penetration.

Photo 3 - Maxwell - Typical Separation at Corner

On the North and South wall midpoint between the East and West walls, there was a movement joint at the base of the exposed wall. This movement joint was 1 1/2 inches wide and was showing signs of soil erosion adjacent to the joint. This joint should be repaired as soon as possible to prevent water penetration. Photo 4 illustrates the condition at each side of the tank.

Photo 4 - Maxwell - Typical Midpoint Joint at N/S walls

There is an access entry into the reservoir from the Southwest corner, but the layout of the finished grade around the area should be re-evaluated. The ground slopes toward the entry and seems like there is potential for snow and ice to build up in this area as well as the potential for water to erode and undermine the foundation. The steel enclosure is in good shape, but the coating could use some touch up and the joints should be re-sealed. See Photo 5 for a view of the access from the side. The photo shows one side of the access area and the opposite side is similar to the view shown.

Photo 5 - Maxwell - Access Entry at Ground SW Corner

Next, the roof was inspected and the built up asphalt and gravel portion was determined to be past its service life. The tar is visibly cracked and there are numerous soft spots. The soft spots are where water has seeped into the insulation between the concrete double tees and the asphalt. The current design of protecting the concrete double tees with a built up roof is not a recommended practice and lends its self to trapping moisture. This has the potential to corrode the shear tabs of the concrete double tees and can be seen to be already happening at the Chautauqua reservoir. We accessed the tank at the Southwest Corner, but was not able to get good pictures of the double tee shear tabs. It is apparent though that the roof is retaining moisture and eventually the roof diaphragm system will fail if it hasn't already. MWH suggests installing a different roof system, one that will allow the area above the concrete double tees to breathe and still shed water and snow. Photo 6 is a typical example of the condition of the roof.

Photo 6 - Maxwell - Typical Roof Condition

Besides the roof, the other items that were inspected were the ladders, vents, and hatches. All were in working condition, but the coating on the vents and hatches will need to be re-coated in the near future. I did go into the reservoir through the Southwest hatch, but did not go past the landing platform. The reservoir was in service at the time of inspection and only part of the lining system was visible. For what I could see, the lining system was intact and in somewhat of a working condition, but I was not able to verify the condition of the lining system.

Following the inspection of the reservoir, I was asked to quickly look over the Hydro Building adjacent to the reservoir. The Hydro building is a single story CMU building with a concrete slab on grade. In the back of the Hydro building there is a pump area that is a half story lower than the main floor. At this back area, the outside corner is seeing some cracking in the CMU block. It was difficult to determine the cause of the CMU cracking, see Photo 7. When we looked at the same area from the inside, I noticed the wall was concrete. It appears the wall is concrete and the CMU block outside is just a veneer. I could not verify the construction because design drawings were not available for the Hydro building, but the cracking does not seem to be affecting the stability of the building. Further investigation into the cause of the CMU block cracking is needed to determine the right course of action to repair the CMU block. The rest of the building appeared to be in good condition.

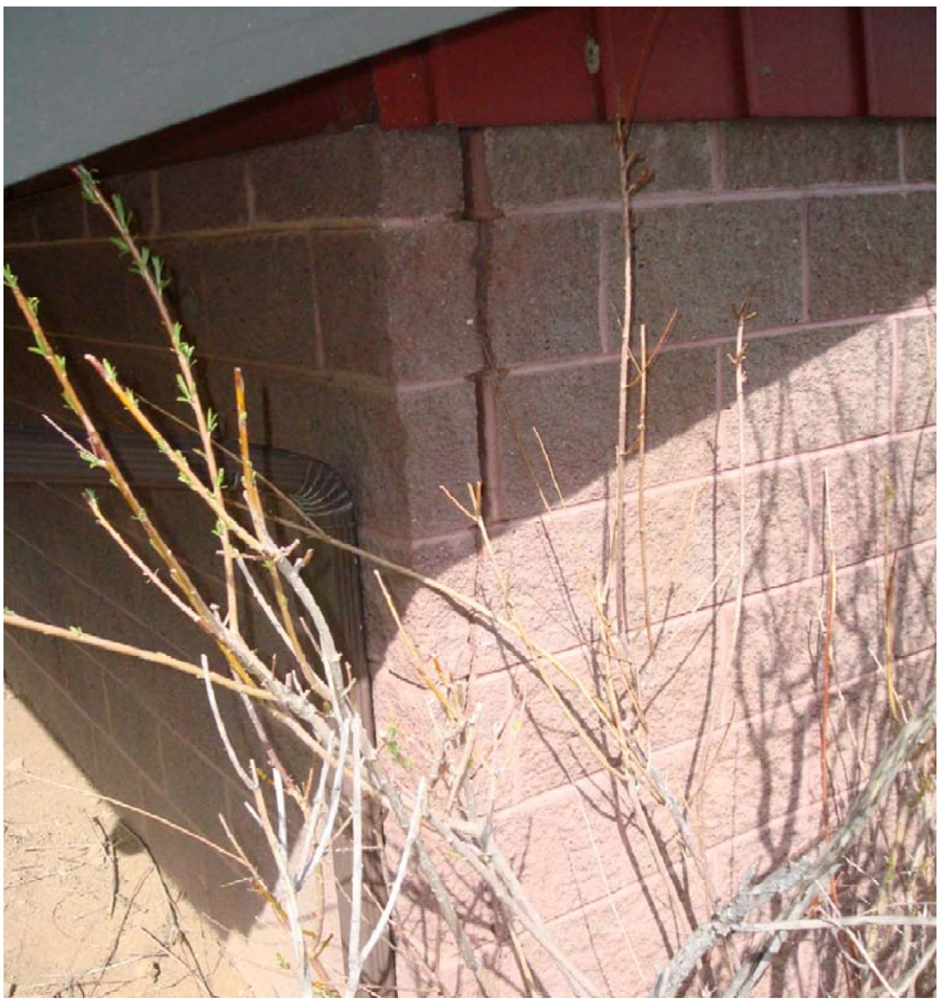

Photo 7 - Maxwell - Hydro Building CMU Crack

Summary:

It is difficult to rate the whole structure by performing such a quick inspection of the reservoir, but there are definitely components of the structure that need attention. The following list describes the external items that need attention and should be maintained on a regular basis.

- Longitudinal crack close to the Southeast corner of the reservoir should be inspected further for the potential causes of the crack and a repair procedure should be developed before the winter season
- Eroded soil areas along the perimeter of the reservoir should be inspected further for the cause of the erosion and a repair procedure should be implemented. Suggest replacing the grass/soil adjacent to the structure with free draining gravel to help with erosion.
- Construction and movement joints at the corners and at the midpoint of the North and South walls of the reservoir should be sealed from external weather before the winter season
- The layout surrounding the reservoir ground access area should be investigated and a re-grading solution should be developed and implemented. The steel enclosure should be re-coated and the joints re-sealed.
- The roof at a minimum should be recoated or a new roof system should be developed to minimize trapping moisture against the concrete double tees.
- All coated surfaces should be analyzed to determine the current condition is adequate to prevent corrosion for external elements. Form the current visual inspection, there are many areas that need to be re-coated.
- The CMU Crack at the Hydro building should be inspected further to determine the cause and a repair procedure should be developed and implemented prior to further deterioration.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 3051-3052 Maxwell Reservoir plan & const..pdf
- 06515_06516-1968-BV4196.02.pdf
- 06517_06529-BV09C.pdf
- Maxwell_Reservoir_Property_1966.pdf

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Inspection Date: May 3rd, 2010
Reservoir: Kohler Reservoir

The as-builts for Kohler Reservoir show that the reservoir has a plan dimension of 330 feet x 230 feet with a capacity of 9.4 MG. The reservoir is very similar to the Maxwell reservoir but is covered with a metal deck roof supported by metal purlins. At the time of the inspection, I was not able to gain access to the inside of the reservoir, so I was not able to visually determine the condition of the roof structure or the reservoir. The metal roof is galvanized steel that has been coated with what appears to be a latex based paint. The roof was originally fastened to the purlins with hex headed screw fasteners and the paint coating was applied over the fasteners. The roof has two major peaks with a pitch of approximately 6H : 1V. In the middle of the two peaks, the metal deck runs into a metal gutter that carries water to the North and South sides of the reservoir. The reservoir sticks above ground, at the low point, approximately 4 feet with metal decking covering the concrete wall portion that is above grade.

Because I was not able to get into the reservoir, the inspection consisted of a visual observation of the condition of the roof, soil adjacent to the structure, and the portion of the concrete exterior wall that was not covered by metal deck. The first area I looked at was the general condition of the roof. The coating on the metal deck has failed and there are large cracks in the paint coating. Photo 8 shows a typical condition of the paint coating and how the screw fasteners have now been exposed to the elements. Further investigation into the condition of the support structure will need to be completed to make a decision on whether to re-coat the metal roof or to replace the system entirely.

Photo 8 - Kohler - Typical Roof Coating Condition

At the corners of the reservoir it was apparent that the concrete was experiencing some movement. Below the metal deck paneling at the corners, one could see large gaps up to 1 1/2 inches wide. These areas should be sealed and protected from water penetration. Photo 9 shows one of the worst corners.

Photo 9 - Kohler - Wost Case Corner Condition

Besides the corner separation, there was also separation at other movement joints. The separation wasn't as bad as at the corner shown, but was approximately 1 inch wide. Photo 10 shows a typical movement joint. These joints should be sealed as soon as practical to prevent water penetration and the possibility of further damage from freeze thaw conditions.

Photo 10 - Kohler - Typical Movement Joint

In the middle of the two peaks the metal deck terminates at a gutter. The gutter runs the length of the structure and slopes to the exterior. The gutter is also galvanized metal that has been coated in paint, but most of the paint coating has been worn off. At a minimum this gutter should be re-coated and fully inspected to determine if there are any localized areas of corrosion. Photo 11 shows the current condition of the gutter. It was also unclear if the ends of the metal deck were open to the reservoir. If so, this could lead to animals nesting or crawling into the reservoir. It might be necessary to seal the ends with closure strips, but further investigation would be necessary.

Photo 11 - Kohler - Gutter Condition

As the roof was being inspected, I was also inspecting the lower portion of the concrete stem wall. For the most part, the portion that was exposed was in good condition with only small hairline cracks. Another item of concern is the vegetation surrounding the reservoir. Almost the entire perimeter had some sort of bush or vegetation growing next to the structure. This was really a problem on the West side where there were even a couple of trees observed to be right next to the reservoir. Photo 12 shows the worst case where trees and bushes are growing adjacent to the concrete stem wall. It is imperative that this vegetation be removed, along with some soil, and replaced with free draining material. There was also evidence of some sink holes and soil erosion adjacent to the wall. Further investigation into why there are sink holes should be performed and a repair solution should be created and implemented. It's important that the ground slopes away from the structure so that water doesn't further erode the soil around the structure. If too much of the soil erodes, frozen water can act on the footing and cause damage to the supporting concrete wall.

Photo 12 - Kohler - Worst Case Vegetation Adjacent to Structure

As I walked around the reservoir, there were a couple of minor items that should be maintained on a regular basis. On the East side of the building where the exposed piping enters the reservoir, it was apparent that the piping needs to be re-coated. The existing coating system has failed and is peeling off. There are also localized areas where the vertical paneling around the reservoir has been damaged by vandalism. The metal decking in these areas has been smashed in, but is still intact. This will need to be fixed or at least re-coated, but is a minor issue.

I also briefly looked at the Hydro facility to gauge its condition. The building was a single story CMU building with a concrete slab on grade. Both the inside of the building and exterior looked in good shape and does not need maintenance at this time. There were a few small shrinkage cracks in the CMU wall, but nothing of concern.

Summary:

It is difficult to rate the whole structure by performing such a quick inspection of the reservoir, but there are definitely components of the structure that need attention. The following list describes the external items that need attention and should be maintained on a regular basis.

- The roof coating system has failed and should be repaired or the entire roof should be replaced. Further investigation is needed to determine the condition of the metal decking as well as the roof steel support framing members. It might be necessary to replace the entire roof system.
- Joints in the concrete walls that have opened up due to wall movements should be sealed and protected from external weather. This is necessary to prevent future erosion problems.
- Coating system on the gutter between roofs has failed and the condition of the gutter should be evaluated to determine if it should be replaced or re-coated.
- Vegetation around the reservoir should be removed and the top layer of soil replaced with free draining material. The finished grade along the reservoir should also be regarded to allow drainage away from the reservoir.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 02488-02489-BV9A.pdf
- 02712-02716-South Storage Reservoir.pdf
- 33420-33423 Kohller Reservoir.pdf
- KOHLER_RES.pdf
- 1C17-1962-Drawing Kohler Reservoir Easements.pdf

Inspection Date: May 4th, 2010
Reservoir: Devils Thumb Reservoir

The as-builts for Devils Thumb Reservoir show that the reservoir has a plan dimension radius of 102 feet and a capacity of 5.0 MG. The reservoir is an above grade steel tank that sits on a concrete slab-on-grade with a thickened edge. The tank is roughly 20 feet tall with the roof sloping from the center to the outside edge. Along the perimeter of the tank is a metal rain guard that is approximately 12 feet above the ground and protrudes 1 to 1 1/2 feet. Adjacent to the tank is a buried vault where the influent/effluent piping is located. The tank was constructed where the existing ground slopes, so on one side of the tank the existing ground is level with the base of the tank and on the opposite side the existing ground is above the top of the tank. To provide access to the tank, there is an 8 foot wide access path around the perimeter of the tank.

At the time of the inspection I was not able to gain access to the inside of the reservoir, so I was only able to inspect the exterior portion of the tank. The inspection started at the drive way entrance next to the valve vault and what I will refer to as 6 o’clock as looking at the tank from above. The inspection started at the tank access hatch and went counter clockwise around the tank. From the access hatch to the 5 o’clock position, it is apparent that people come up to this location to throw rocks at the tank. In this area there are spray paint markings and multiple small rock pits on the side of the tank. Many of these rock pits have chipped away the tank coating and localized corrosion has stated to occur. Photo 13 shows one of the worse rock pit areas, but many of the smaller pits are in a similar condition. If these are left un-repaired, the corrosion process will continue to erode the steel and eventually cause the tank to leak. It is recommended that these pits be cleaned and recoated on a regular basis.

Photo 13 - Devils Thumb - Typical Rock Pits

The remainder of the tank vertical surface is in relatively good condition with only localized areas of rock pits. The next noticeable area that needs attention is the finished grade around the backside of the tank. At the 2 o'clock point, there was a large low spot with water in the access path. This area does not pose an immediate problem to the foundation, but it is apparent that the area is retaining surface water. This was not the only location where standing water was occurring. From the 1 o'clock position to the 9 o'clock position, water was trapped in the drainage swell. The standing water in the drainage swell was also not posing a problem to the foundation. Photo 14 shows the first area where there is the largest volume of water being retained. It is recommended that the access path surrounding the tank be re-graded to allow proper surface drainage.

Photo 14 - Devils Thumb - Standing Water in Access Path

Because the surrounding grade on the back side of the tank is as tall as the tank, this allowed me to climb up the hill side and perform a visual inspection of the roof from a distance. The first thing that I noticed is that vandals have thrown small rocks on top of the tank. I was not able see if these rocks were leaving similar rock pits, but It can be assumed that the rocks are damaging the roof coating. Besides the rock pits, it is very evident that there is something structurally wrong with the roof. There are many depressions, low spots, and areas where the steel is dented in. It is also apparent that the roof has deflected to the point of holding water. These problems can be seen in Photo 15. Further investigation is needed to determine the cause of the low spots in the tank, the rocks need to be removed, the damaged roof sections need to be repaired, and the coating system needs to be touched up. If the tank is to be replaced, it might be necessary to replace with a pre-stressed concrete tank, or installing a fence to prevent people from throwing rocks on the tank.

Photo 15 - Devils Thumb - Roof Damage

Next I inspected the concrete foundation and the adjacent finished grade. Along the hill side of the tank, there were a couple of areas where the concrete was starting to erode. This can be seen in Photo 16. It is recommended to either protect these areas from further erosion or to repair the area with a topping mortar.

Photo 16 - Devils Thumb - Concrete Foundation Erosion

It is also apparent that vegetation is starting to grow adjacent to the concrete footing. To prevent future damage to the concrete, the vegetation and soil should be removed and replaced with a weed barrier and free draining gravel.

After the inspection, the City mentioned a couple of other items that need attention. First is the rain guard that in circles the perimeter of the tank. For some reason the rain guard surrounding the tank was installed so that there is a trough around the structure. This holds water when it rains and has the potential to corrode the steel faster. The City mentioned that they thought this was installed upside down and that the water should have been allowed to freely flow off the rain guard. More research would be needed to determine if this should be re-installed in the opposite direction. The second issue is that the internal coating still contains lead. The exterior coating had been previously removed and re-coated with a non-lead based coating system, but the inside has not. This lead based coating should be removed as soon as practical as this presents a potential health hazard if the coating system fails.

Summary:

It is difficult to rate the whole structure by performing a quick inspection of the reservoir, but there are definitely components of the structure that need attention. The following list describes the known items that need attention and should be maintained on a regular basis.

- Rock pits surrounding the tank should be cleaned and re-coated on an annual basis.
- Finished Grade around the back side of the tank should be re-graded to allow proper drainage of the site.
- Rocks need to be removed from the roof.
- Further investigation into why the tank roof is dented and deformed is needed to identify if the possibility of the roof collapsing or failing in the near future exists.
- Concrete foundation needs to be protected or repaired.
- Vegetation next to the tank needs to be removed.
- Rain guard might need to be installed facing the opposite direction, further investigation is needed.
- Internal coating needs to be removed and re-coated because it contains lead.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 06481_06483x-BV16.pdf

Inspection Date: May 4th, 2010
Reservoir: Chautauqua Reservoir

The as-builts for Chautauqua Reservoir show that the reservoir plan is in the shape of a trapezoid. The base is approximately 250 feet with a top dimension of approximately 180 feet and edges with a length of approximately 260 feet each. The capacity is listed as 8.0 MG. The reservoir is covered with concrete double tees supported by concrete beams and columns. The double tees are covered with insulation and topped with asphalt and gravel. The perimeter of the reservoir sticks above the finished grade approximately 3 feet and the roof gradually slopes to multiple drains throughout the top deck.

Around the tank perimeter there is an access path and the grade is sloping away from the wall. The natural weeds and grasses have grown up to the concrete stem wall, but there were no major problems with the vegetation. There were only a couple of areas where the grasses and weeds were getting tall. Regardless, the area adjacent to the reservoir should be cleared of this vegetation and replaced with weed barrier and free draining rock.

The perimeter wall was in good condition. Only at a couple locations were there shrinkage cracks. A typical shrinkage crack can be seen in Photo 17. These cracks are not a serious problem, but should be "V" grooved and sealed to prevent further deterioration.

Photo 17 - Chautauqua - Typical Wall Shrinkage Crack

The worst exterior problem of the reservoir is the built up roof. It has failed and is past its service life. The asphalt is cracking and the insulation below the asphalt is holding water and is most likely deteriorated. Around the drains, the built up roofing was soft and one can tell that it is retaining water below the asphalt. A typical drain can be seen in Photo 18. It is apparent that the asphalt surface is deteriorated and needs to be replaced.

Photo 18 - Chautauqua - Typical Drain Condition

Other appurtenances that were looked at were the vent piping and the access hatches. Both were in working condition, but the coating on the vent piping has failed. Photo 19 shows a typical vent pipe with the condition of the coating. The existing coating should be removed and re-coated to prevent further erosion of the steel pipe.

Photo 19 - Chautauqua - Typical Roof Vent

Halfway through the inspection, I did get an opportunity to go into the main access hatch. The access is where the metal stair goes to the bottom of the reservoir. At the time of the inspection the water level was low and this gave me the opportunity to get a look at some of the concrete liner and the underside of the concrete double tees. It was apparent that the concrete liner was corroding and that the reservoir was leaking at the concrete liner joints. In some areas it looked as if in previous repairs, they tried to prevent the liner from moving by attaching metal plates across the joints. The plates that were visible looked in good condition, but it was apparent that the joints were leaking. Photo 20 shows the deteriorating concrete liner, areas where the joints are leaking, and how the concrete double tees sit on the exterior wall in this location.

Photo 20 - Chautauqua - Concrete Liner at Access Hatch

One item of major concern is the condition of the shear tabs of the double tees. I happened to look up at the joints of the double tees and noticed the shear tab that holds the double tees together was corroded and non functioning. This is one tab out of many, but it can be concluded that more tabs are in a similar condition. If this is the case, the roof diaphragm no longer functions in the manor it was designed. Any lateral loads will not be carried properly by the double tees to the shear walls and the external stability of the reservoir can be in jeopardy. Photo 21 shows the corroded concrete double tee shear tab that was in the reservoir access area. Further investigation into the condition of the roof shear tabs is necessary to determine the adequacy of the roof system.

Photo 21 - Chautauqua - Typical Roof Shear Tab

After the inspection of the reservoir, I briefly inspected the PRV. The PRV is located adjacent to the Reservoir and is mainly a cast-in-place concrete building. The concrete that was visible was in good condition and I saw no major problems with the structure.

Summary:

It is difficult to rate the whole structure by performing such a quick inspection of the reservoir, but there are definitely components of the structure that need attention. The following list describes the items that need attention and should be maintained on a regular basis.

- Perimeter wall shrinkage cracks should be “V” grooved and sealed to prevent future erosion.
- Built up roof system has failed and needs replacing. Suggest considering a separate roof system that isolates the roof from the concrete double tees.
- Roof vents need to be re-coated
- Further investigation of the internal concrete lining should be conducted to determine the condition and remaining service life. The leaking joints can lead to problems along the perimeter of the structure including settlement issues and possible contamination of the reservoir.
- Further investigation of the double tee shear tabs is needed to determine if the roof can perform as originally designed. New tabs might be needed, or the entire roof might need to be replaced.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 00131.pdf
- 00132.pdf
- 00135.pdf
- 03042.pdf
- 22213_22219-Chautauqua Res Improv.pdf

Inspection Date: May 4th, 2010
Reservoir: Booton Reservoir

The as-builts for Booton Reservoir show that the reservoir is actually a tank within a tank. The external tank is 173 foot in diameter and the internal tank is 68 feet in diameter with a capacity of 0.6 MG. Both tanks are pre-stressed concrete tanks that are completely below grade. At the time of the inspection, access into the above grade hatch was not possible so the only aspect of the reservoir that was inspected was the PRV vault. The PRV vault is located down the hillside from the reservoir and is cast-in-place concrete. The condition of the PRV was in good shape and no further comments are necessary.

Summary:

- The reservoir was not accessible for inspections therefore the condition of the buried tanks are unknown. These tanks were constructed within the last 20 years and the City staff has indicated that they have had no problems, so it is assumed that the tanks are in good condition. Regular inspections should be performed to verify the tanks are performing as designed.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 28200_28214-NoTerminalWaterTank.pdf

Inspection Date: May 4th, 2010
Reservoir: Gunbarrel Reservoir

The as-builts for Gunbarrel Reservoir show that the reservoir is an above ground steel tank with a plan diameter of 130 feet and a capacity of 2 MG. The tank is approximately 20 feet tall with a roof that overhangs the side walls by 4 feet. Below the overhang is a partial soffit that goes from the tank wall to the midpoint of the overhang. Surrounding the tank and the adjacent land is a security fence. This fence and regular maintenance seems to have kept the tank in great condition. For being built in the 70's, the tank visually looks in good condition.

The inspection started at the access ladder and went counter clockwise around the tank. The exterior surface of the tank was in good condition with only a few minor surface problems. As I walked around the tank, it was apparent that there was a little more damage on the West side of the tank. Considering it was really windy at the time of the Inspection, it can be concluded that the wind might have a tendency to blow rocks against the tank. All rock pits were relatively small with only small amounts of corrosion starting to occur. A typical rock pit can be seen in Photo 22. It is recommended to clean these pits and re-coat on an annual basis.

Photo 22 - Gunbarrel - Typical Rock Pit

As I was inspecting the exterior surface, I was also inspecting the concrete slab-on-grade with thickened edge. The foundation slab looked in good condition and there were only a few locations where the vegetation was growing over the slab and next to the tank wall. This vegetation should be cut back on a regular basis. I would ultimately recommend removing the soil and vegetation next to the slab and replacing with weed barrier and free draining rock. There was no evidence of the finished grade being too high or low and it appeared that the surface water was draining away from the tank. An example of where the vegetation was growing over the slab can be seen in Photo 23.

Photo 23 - Gunbarrel - Example of Vegetation Overgrowth

Another area of concern is at the soffit. It is apparent that birds are nesting in between the soffit and the roof overhang. Photo 24 illustrates a typical area of the soffit where there are bird nests and bird excrement down the exterior surface. This is not an ideal condition for the coating system and can overtime break down the coating. It is recommended to remove the nests in the fall, clean the surface, recoat where necessary, and then install wire mess between the soffit and roof overhang.

Photo 24 - Gunbarrel - Typical Soffit Condition

Other than those items listed, the tank exterior was in good condition. Due to the short inspection timeframe, I did not get an opportunity to inspect the roof or the inside of the tank. After inspecting the tank, the City did mention that the inside of the tank needed to be re-coated. This should be put on a long term maintenance schedule.

One oddity of the reservoir is that there is an external box with what looks like a corrosion protection system. The City did not know what it was and if it was working. More research should be conducted to fully understand the function of the box and if it is working. If this is integral to the protection of the tank, it would be good to know how it works and if it's working. This might need to be replaced and maintained on a regular basis.

Summary:

It is difficult to rate the whole structure by performing such a quick inspection of the reservoir, but there are definitely components of the structure that need attention. The following list describes the items that need attention and should be maintained on a regular basis.

- Rock pits should be cleaned and re-coated on an annual basis
- Vegetation should be kept from growing over the slab-on-grade and ultimately the adjacent soil should be removed and replaced with weed barrier and free draining rock
- The bird nests and excrement should be removed from behind the soffit and along the tank. After cleaning the area, bird screens or wire mesh should be installed between the soffit and the roof overhang to keep birds from nesting behind the soffit.
- Investigate the purpose of the external box that might contain a corrosion protection device.

References:

The following electronic files were provided to MWH by the City and were used as references for the following inspection

- 4457-4469 Gunbarrel Tank- General layout & details .pdf
- 06470_06472_B&V_Docs_Gunbarrel_Tank.pdf

This concludes the partial inspection of the City of Boulder's Finished Water Reservoirs. Additional information can be obtained from MWH by request.

Appendix F:

Checklist for Condition Assessment of Existing Pipelines

CHECKLIST FOR CONDITION ASSESSMENT AND SERVICE LIFE PREDICTION OF EXISTING PIPELINES

This checklist is intended as a guide to some of the main factors to be considered in undertaking pipeline condition assessment and remaining service lifetime prediction. Procedures and responsibilities may vary according to the Client and the scope of MWH's services. The following general stages are proposed:

1) **Stage 1 – Criteria for Selecting Condition Assessment** – Collate and analyse available information describing the pipeline, surrounding environment and failure history

2) **Stage 2 –Field Condition Assessment** – Walk-through of pipeline route, noting any features that may influence pipeline condition and/or indicate pipeline failure. Perform visual inspections and Non Destructive testing (NDT) – Expose the pipe in a number of sample holes and conduct soil assessment, coupons extraction and/or NDT for condition assessment.

3) **Stage 3 –Analysis of Condition Assessment Data** – Conduct appropriate tests on extracted soil samples and coupons to assist understanding of pipe condition and provide input into remaining service life prediction. Use information from stages 1) to 2) together with the appropriate failure criterion for the pipeline to predict remaining service life at inspection locations. Perform Non-Destructive (NDT) testing using modern technologies to define pipe condition and remaining pipe wall thickness on selected pipelines and at selected locations. Perform detailed structural analysis and remaining life assessment. Quantify variation in measured condition and use probabilistic methods to estimate expected remaining lifetime along the length of the pipeline

4) **Stage 4 – Preparation of Cost Intervention, Rehabilitation and Replacement Program** – Using the information developed in Stages 1 through 3 define the replacement costs and timing for pipeline replacement. Prepare the Cost Asset Management Report.

5) **Stage 5 – Develop Pipe Condition Report and Implementation Plan** – Using the Cost Implementation Management report and expand it to define the implementation timing to be used in sustaining and repairing or replacing the piping system.

For further information and guidance please contact:

Ed Barnhurst– Principal Pipeline/Conveyance Engineer, MWH USA., or

Sandra Rolfe-Dickinson – Knowledge Leader Pipeline Engineering, MWH UK Ltd.

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
1	**Stage 1 - Criteria for Selecting Condition Assessment**		
1.1	Source any as-built information from the Client. This should include if possible as-built drawings, relevant specifications.	**2**	
1.2	Establish the installation year and class of the pipeline. Source the pipe standards and manufacturers literature relevant to the appropriate date.	**1**	
1.3	Gather any historical failure information or repair information from client. Information should include (if available): • Failure year • Failure location along the pipe route • Failure position around pipe circumference (i.e. 12 o'clock; 3 o'clock; 6 o'clock etc.) • Pipeline element affected (i.e. pipe, joint, valve etc.) • Failure mode (i.e. external/internal corrosion, longitudinal fracture, circumferential fracture, section removal)	**2**	
1.4	Gather information on any relevant earlier condition assessment studies, such as CCTV surveys or any lab work carried out following failure.	**2**	
1.5	Identify any coatings, linings and protection systems in place along the pipeline. Establish when these protection systems were installed and (for cathodic protection), maintained.	**2**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
1.6	Gather information on historical repairs/replacement/rehabilitation work along the length of the pipeline. Identify pipe/lining material and installation year for repair/replacement/rehabilitation	**2**	
1.7	Source historical maps showing the area in which the pipeline is constructed. If available, maps predating pipe construction should also be obtained. Identify areas of potential localised external surface degradation including: • Old railway routes (often associated with coal/ash/clinker contamination) • Mining works • Refuse tips / dumps • Areas associated with storage of petrol/oil	**2**	
1.8	Undertake geological desk study to establish boundaries between different soil types along the pipeline. If available refer to local geotechnical/corrosion` expertise to: • Identify regions where soil environments may cause external corrosion and/or degradation • Identify presence of any landslips, sinkholes or other geological features that may indicate unusual loading or voiding around the pipeline	**2**	
1.9	Identify internal operating regime for pipeline: • Estimate working pressure/surge pressure along pipeline • Gather data describing the chemistry of internal water/wastewater/industrial trade waste • Identify locations where air pockets may exist along the pipe (primarily wastewater, i.e. drain down)	**1**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
2	**Stage 2 – Field Condition Assessment**		
2.1	Walk the route of the pipeline, looking for anything that could influence its condition or indicate failure. Take photographs or video with commentary where possible	**2**	
2.2	For steel pipes, locate overhead power lines / DC current rail systems / other nearby pipelines with cathodic protection which could induce stray current corrosion	**2**	
2.3	Locate known areas of refuse dumps/tips /landfill which could accelerate microbial corrosion (cement-based/metallic pipelines)	**2**	
2.4	Locate areas of petrol /oil storage, which could lead to swelling and softening of thermoplastics pipelines	**2**	
2.5	Locate pipeline road crossings with excessive traffic loading	**2**	
2.6	Record areas where adjacent civil works are in progress, which could lead to third party damage to or ground movement around existing pipeline	**2**	
2.7	Locate areas where odour problems are evident or have been previously reported (may indicate H2S generation and sulfuric acid attack in wastewater pipes)	**2**	
2.8	Identify areas of greenery or waterlogged ground along the pipeline route in otherwise dry, barren areas. This may indicate leakage or exfiltration	**2**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3	**Stage 3 - Analysis of Condition Assessment Data**		
3.1	Following on from the desk study and the initial field study, sufficient information should be available to determine the location of the trial holes. These should take account of: • Significant geological differences at pipe level that are relevant to pipe degradation and failure • Any pipe size / class / material changes along the route	**G**	
3.2	Sample holes should be dug to expose a short length of pipeline around its full circumference. These holes must be adequately supported and dewatered, have a safe means of entry/egress, and allow access to both sides of the pipeline. A minimum of 12-inch clearance must also be available beneath the pipeline.	**1**	
3.3	If possible, obtain soil samples at pipe 12 o-clock; 3 o-clock; 6 o-clock and 9 o-clock positions adjacent to the pipe. Samples shall completely fill airtight containers with no air space. Each container should be labelled clearly for future reference to the trial hole location	**1**	
3.4	If required, Non-destructive testing should also be conducted when pipe is exposed. The external surface of the pipe shall be cleaned and pipe wall thickness measurements conducted. The following test methods are recommended:	**G**	
3.5	**NDT TESTING METHODS**		

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.5.1	NDT for **Metallic** pipes: • Ultrasonic thickness gauge in each square of a 100 mm x 100 mm grids marked on the exposed pipe surface • Electromagnetic-based technique to detect reductions in wall thickness from corrosion (i.e. Broad Band E-M, Magnetic Flux Leakage)	**1**	
3.5.2	NDT for **Cement-based** pipes: • Surface Penetrating Radar to detect erosion and loss of wall thickness (Asbestos Cement) and position of reinforcement (Reinforced Concrete)	**2**	
3.5.3	NDT for **Plastic** pipes: • No commercially available NDT relevant to plastic pipe failure	**G**	
3.6	After soil extraction and NDT, extract pipe coupon for subsequent laboratory analysis. Either: • A full circular section approximately 500 mm (20 inch) in length, which is made good with make-up pieces and flexible couplings Or • Pipe coupon from the top of the pipe taken by under pressure coring. Coupons shall be sufficient size to permit tensile testing	**2 (Metallic)** **1 (Cement-based)**	
3.7	Following trial holes, laboratory testing will be conducted on soil samples. Soil tests will depend on the pipe material.	**1**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.8	**LABORATORY WORK - SOILS TESTS**		
3.8.a	Soil tests for **Metallic** pipes: • Moisture content • Liquid limit • Plastic limit • Sieving and hydrometry • pH • Resistivity • Sulfates • Redox Potential • Chlorides	**G**	
3.8.b	Soil tests for **Cement-based** pipes: • Moisture content • Liquid limit • Plastic limit • Sieving and hydrometry • pH • Sulfates • Redox Potential • Chlorides (for Reinforced concrete pipes)	**G**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.8.c	Soil tests for **Plastic** pipes: • Hydrocarbon contamination (petrol, diesel, oil)	G	
3.9	**LABORATORY WORK - COUPON TESTING**		
3.9.1	Following trial holes, laboratory testing will be conducted on coupon samples. Tests will depend on the pipe material.	1	
3.9.2	Coupon/ring section tests for **Metallic** pipes: • Grit blasting/sand blasting/chemical etching to remove corrosion product • Scanning Electron Microscopy to identify graphite structure and verify pipe material and manufacturing type • Measurement of internal/external corrosion pit depth • Measurement of residual tensile strength (Cast Iron pipes) pH profile for internal lining (Cement Mortar Lined pipes)	G	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.9.3	Coupon/ring section tests for **Cement-based** pipes: • Residual wall thickness from core samples • Phenolphthalein indicator to locate depth and position of pH change from degradation • Through-thickness measurement of residual pH • Through-thickness measurement of residual calcium content • Scanning Electron Microscopy to identify sulphate attack and localised cracking • Measurement of residual tensile strength of pipe wall • Concrete cover to steel reinforcement (Reinforced Concrete pipes) Compressive strength of core samples	**G**	
3.9.4	Models for **Ductile Iron** pipes • Estimate rate of corrosion pitting and wall thickness reduction [= (original - current remaining wall)/age] Yielding under internal pressure • Estimate rate of increase in applied hoop stress from internal pressure due to wall thickness reduction • Calculate time when applied stress exceeds material yield strength Rupture under combined pressure and deflection loads • Calculate time when wall thickness has decreased sufficiently such that applied external loads exceed load bearing capacity Pitting corrosion through pipe wall • Calculate time when pitting corrosion exceeds pipe wall thickness	G	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.9.5	Coupon/ring section tests for **Plastic** pipes: • Microscopic fracture surface examination to identify origins and size of crack initiation site (i.e. point load, inherent defect, thermal/UV degradation) • Microscopic fracture surface examination to establish mode of crack growth and fracture (i.e. fatigue, impact etc.) • Differential Scanning Calorimetry thermal analysis to assess levels of fusion and material quality (PVC pipes) • Material Fracture toughness testing (i.e. C-Ring test) (PVC pipes) • Material slow crack growth rate testing (i.e. Single Edge Notch Bend test) (PVC pipes) Craze formation and separation testing (i.e. Circumferential Deep Notch Tensile test) (Polyethylene pipes)	G	
3.10	**Predict Remaining Service Life**		
3.10.1	Based on results from trial holes, NDT and lab tests, remaining service lifetime is estimated for the pipelines at the trial hole location	1	
3.10.2	Quantify internal pressure and external loading conditions along pipeline route based on site visit and available data from client,	1	
3.10.3	Depending on pipe material, establish appropriate failure model to predict service lifetime	1	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.10.4	**DETAILED STRUCTURAL ANALYSIS AND REMAINING LIFE ASSESSMENT ALONG PIPELINE**		
3.10.4.a	Models for **Steel** pipes: • Estimate rate of corrosion pitting and wall thickness reduction [= (original - current remaining wall)/age] Yielding under internal pressure: • Estimate rate of increase in applied hoop stress from internal pressure due to wall thickness reduction • Calculate time when applied stress exceeds material yield strength Buckling under external loads and/or vacuum pressure: • Calculate time when buckling occurs under external loads and/or vacuum pressures Pitting corrosion through pipe wall: • Calculate time when pitting corrosion exceeds pipe wall thickness	G	
3.10.4.b	Model for **Asbestos Cement** pipes • Input measured residual strength and estimated loading conditions into failure criterion for brittle pipes under combined internal pressure and external loading • Estimate rate of loss of strength for pipe sample [= (original - measured residual strength)/age] Calculate time when strength decreases sufficiently such that failure criterion is satisfied.	G	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.10.4.c	Model for **Reinforced Concrete** pipes • Estimate rate of loss of concrete cover to reinforcement [= (original – current cover)/age] • Estimate rate of loss of concrete compressive strength [= (original – current compressive strength)/age] • Use measured cover to reinforcement and concrete compressive strength to calculate pipe crushing strength Failure predicted to occur when pipe crushing strength falls below applied external loads	G	
3.10.4.d	Model for **PVC** pipes • Estimate defect sizes for pipeline based on previous fracture surface examination • Calculate applied Stress Intensity Factors for defect in pipe wall under combined pressure and external loading conditions • Calculate crack growth rate under in-service loading conditions Failure predicted when crack length is such that applied Stress Intensity Factor exceeds material fracture toughness	G	
3.10.4.e	Model for **Polyethylene** pipes • Estimate defect sizes for pipeline based on previous fracture surface examination • Calculate applied craze stress for defect in pipe wall under combined pressure and external loading conditions • Calculate rate of decrease in material craze strength Failure predicted when craze strength decreases sufficiently to fall below the applied craze stress	G	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.10.5	**EXTRAPOLATING REMAINING LIFE ALONG PIPELINE LENGTH**		
3.10.5.a	Uncertainty estimation and probabilistic analysis are now used to extrapolate predicted lifetimes from sample hole locations to the remaining length of the pipeline.	**2**	
3.10.5.b	Identify zones along the pipeline that can be considered to be exposed to a uniform environment.	**2**	
3.210.5.c	Uniform zones for **Metallic** and **Cement-based** pipes: • Boundaries between different soil types along pipeline • Areas of potential air pockets along pipeline (wastewater pipes) Uniform zones for **Plastic** pipes: • Pipe lengths of different installation era • Areas of hydrocarbon-contaminated soil along pipeline	**G**	
3.10.5.d	Quantify random variation in model parameters Within each zone, by fitting to an appropriate probability distribution. Uncertain model parameters may include: • Corrosion rate (**Metallic** pipes) • Rate of strength loss (**Cement-based** pipes) • Rate of loss of concrete cover (**Reinforced concrete** pipes) • Pipe wall defect size (**Plastic** pipes) Possible probability distributions that may be applicable include 2-parameter Weibull and Log-Normal.	**G**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
3.10.5.e	Having obtained probability distribution for model variables, use Monte Carlo simulation of appropriate failure model to estimate expected remaining lifetime and standard deviation along the length of pipeline. Use material specific failure models described above.	**G**	
4	**Stage 4 - Preparation of Cost Intervention, Rehabilitation and Replacement Program**		
4.1	Develop pipe replacement cost data, based on unit costs including pipe, installation and restoration work.	1	
4.2	Apply the unit cost data to the replacement sections of pipe to get a cost per pipe segment.	1	
4.3	Prepare a total estimate of restoration cost for the pipelines.	1	
4.4	Prepare a list for the highest priority intervention (first tier),	**G**	
4.5	Define the best rehabilitation/replacement methods for each of those first tier pipelines.	**G**	
4.6	Develop an approach to the rehabilitation/replacement of all system elements (lower tier pipes) based on remaining life.	**G**	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
4.7	Prepare an implementation plan defining work and timing to be performed along with cash flow requirements.	G	
5.0	**Stage 5 - Develop Pipe Condition Report and Implementation Plan**		
5.1	Client report to include: • Executive Summary • Introduction and background • Description of all data obtained from desk study in Stage 1 • Description of all data gathered from field study in Stage 2 • Details of sample hole selection, soil sampling, coupon sampling and NDT conducted as part of Stage 3 • Results from soil/coupon laboratory tests in Stage 3. • Assumptions, details and results from structural analysis and remaining life prediction in Stage 3. • Assumptions, details and results from probability analysis and extrapolation in section 3 • Conclusions and recommendations	1	

Item	Activity	Priority 1 – Essential 2 – Desirable G – Guidance information	Complete (Y/N) Date
5.2	Report must include a clear statement that the remaining service lifetime analysis provides **estimates** of lifetime only. A suggested statement to include in both Executive Summary and Conclusions is: **"Please note that this analysis is based on an assessment of pipe condition obtained at a small discrete number of trial samples along the pipeline. As widely reported in the literature, it is to be expected that degradation rates and hence condition will vary significantly along the pipeline length. As such, remaining service lifetimes produced in this study should be treated as estimates only"**	**1**	

Appendix G:

Asset Management Update for BRWTF and Stranded Facilities

MWH®

BUILDING A BETTER WORLD

MEMORANDUM

TO:	*Memo to File*	DATE:	*July 7, 2011*
FROM:	*MWH*	REFERENCE:	*1008566 - WUMP*
SUBJECT:	*Asset Management Update for BRWTF and Stranded Facilities*		

1.0 Introduction

As part of the City of Boulder's 2010 Water Utility Master Plan, MWH performed an asset management update for the City. The objective of this task was to help the City better estimate the overall renewal and replacement Capital Improvement Program (CIP) and maintenance budgets.

In this effort, MWH worked with the City via workshops, desktop analysis, and field observations to evaluate, refine, and update the condition scores and replacement cost estimates of facility assets at the Boulder Reservoir (63rd Street) Water Treatment Facility (BRWTF) and stranded facilities. The stranded facilities considered in this analysis included:

- 101 Pearl and Sunshine PRV facilities
- Sunshine, Orodell, Maxwell and Kohler hydroelectric facilities
- Gunbarrel, Maxwell, Booton, Devils Thumb, Kohler, and Chautauqua reservoirs

Primary activities included:

- **Asset Data Review and Gap Filling:** The City's asset data for the facilities mentioned above were reviewed and analyzed for completeness for condition-based planning purposes. Analyses of the asset base included completeness and distributions of key parameters such as asset use, size, material, age, and condition. Data gaps were addressed using City and MWH staff knowledge, as well as professional judgment.

- **Asset Condition Scoring:** Condition scores were developed with City staff for each asset through workshops, desktop analysis, and field observation using industry best practices.

- **Renewal Cost Forecasting and Budget Scenario Analysis:** Long term (50-year) cost forecasts were developed for the City's facility assets. The results of these long-term forecasts enable the City to determine budget levels needed for the long-term renewal and replacement of its assets.

Key potential benefits to the City from this effort include the following:

- Having a consistent, high level estimate of the current condition and potential long-term reinvestment needs associated with its BRWTF and stranded facilities.
- A documented outline of a clear, defensible, and repeatable methodology for assessing asset condition, and enabling condition-based prioritization and financial forecasting across the City's infrastructure asset base.
- The initial condition scores, unit costs, and forecasts developed as part of this effort provide the foundation for future analyses and ongoing refinements of the City's financial needs as additional information is collected, and/or as management priorities change over time.
- Early awareness of potential gaps between current asset renewal budgets and expected long-term financial needs to adequately manage the condition and probable failure of assets will enable the City to develop sound long-term financial strategies to address potential budget shortfalls.

This proactive and comprehensive understanding of the City's condition profile will allow the City to address its current and expected future asset needs through careful planning and management of its inspection, maintenance, and asset repair and replacement activities.

Finding highlights from this analysis include:

- Data for the BRWTF were more complete than for the stranded assets. However, further review of project and facility documents helped to fill gaps. In a few instances, some gaps in original cost and installation date remain; however, the renewal forecast workbooks have been structured to allow this information to be provided by the City at a later date and most related updates to occur automatically.
- The condition scores for BRWTF assets were generally good. However, the condition of some dams and treated water reservoir tank roofs, piping, and valve vaults was generally worse.

As part of the scope of this effort to be consistent with the Pilot, this asset management effort is built off of the output format, condition fractions, and cost factors developed during the Pilot. It took an additional step to develop a more robust analysis tool for the City utilize for consequence-based asset analysis for capital improvements planning into the future, which will serve as an important foundation for a more strategic risk based analysis down the road.

Conclusions and Recommendations are included at the end of this memorandum in Section 5.0.

2.0 Methodology

The condition scoring and renewal forecasting for the BRWTF and stranded assets are outlined below. They are critical elements of effective asset maintenance and renewal planning. This project did not aim to explore the important risk (including consequence of failure) elements of each asset, although this is recommended in the near future. However, condition scores were created and updated for these assets. It will be important for the City to evolve to a risk based approach to best enhance their asset management to build justification of asset renewal priorities and related decisions and strategies.

The overall approach for developing condition scores and renewal forecasts is illustrated in **Figure 1** below:

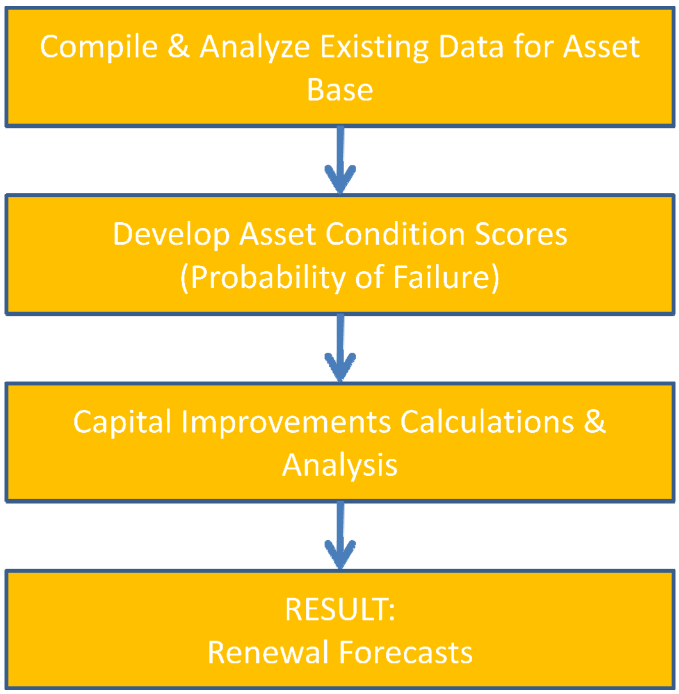


Figure 1. Overall Approach to Condition Scoring and Subsequent Renewal Forecasting

These steps involve the following:

- **Compile & Analyze Existing Asset Data:** Available asset data were compiled from the City's existing databases. Where necessary, data gaps were filled with estimated values based on discussions with City staff and analysis of related readily available information. Spreadsheets capturing this information were updated and enhanced for condition scoring and renewal forecasting purposes.
- **Develop Asset Condition (Probability of Failure) Scores:** Asset condition or probability of failure (POF) scores, based on available information and workforce knowledge, were assigned to each individual asset. An industry standard scale of 1 through 5 was used, with "1" representing very good condition, and "5" representing very poor condition (See Table 1 below).
- **Capital Improvements Calculations & Analysis:** The asset data were utilized to generate the asset renewal forecasts and create a foundation for the analysis of capital improvement needs.

- **Develop Inspection and Renewal Forecasts:** Useful lives were carried forward based on the probability of failure and are used to forecast the annual cost of renewal of assets.

Probability of failure scores for the City's assets at these facilities were estimated in accordance with industry best practices outlined in the International Infrastructure Management Manual (IIMM). Information related to asset condition, including use, age, material, existing condition scoring information, and existing City staff knowledge was utilized in making this condition assessment. The data gathering and analysis was performed offsite, as well as in interactive workshops with City staff.

Figure 2 shows the probability of failure scoring process applied in this project. Information was sought, provided, captured, and evaluated from staff knowledge, available data and records, and asset attributes to develop the initial probability of failure score for the City's linear assets.

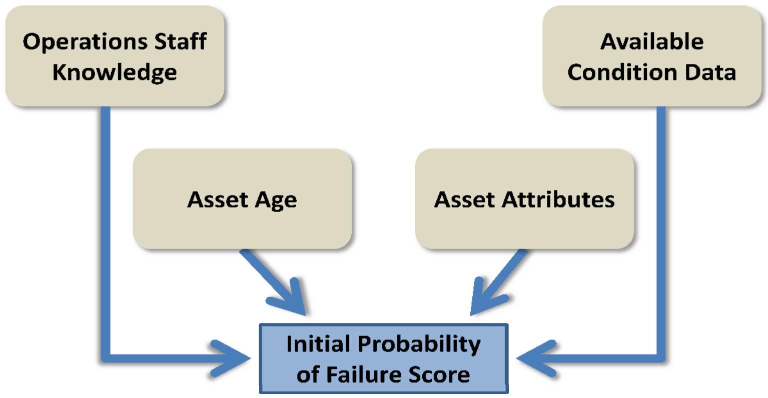


Figure 2. Summary of Probability of Failure Scoring Process

Table 1 presents the condition scoring system used in the condition analysis of assets to aid in the development of the probability of failure score. This rating system is an industry standard for asset management and comes from the International Infrastructure Management Manual.

Table 1: Asset Condition/Probability of Failure Scoring Descriptions

Condition Score	Scoring Definition	Renewal Required
1	**Very Good.** Sound physical condition. Asset likely to perform adequately without major work for 25 years or more for structures and for 10 years or more for mechanical and electrical assets.	0%
2	**Good.** Acceptable physical condition. Minimal short-term failure risk, but potential for deterioration in medium- to long-term (10 years plus for structures and 5 to 10 years for mechanical and electrical assets). Only minor work required, if any.	10%
3	**Fair.** Significant deterioration evident for structures and deterioration beginning to be reflected in performance and higher attendance for maintenance for mechanical and electrical assets. Failure unlikely within next 2 years, but further deterioration likely and major replacement likely within 10 years for structures and within 5 years for mechanical and electrical assets. Minor components or isolated sections of the asset need replacement or repair now, but asset still functions safely at adequate level of service. Work required, but asset is still serviceable.	20%
4	**Poor.** Failure likely in short-term. Likely need to replace most, or all, or asset within 2 years. No immediate risk to health or safety, but work required within 2 years to ensure asset remains safe. Substantial work required in short-term, asset barely serviceable.	40%
5	**Very Poor.** Failed or near failure. Immediate need to replace most, or all, of asset. Component effective life exceeded and excessive maintenance costs incurred. A high risk of breakdown with serious impact on performance. Health and safety hazards exist which present a possible risk to public safety, or asset cannot be serviced/operated without risk to personnel. Major work or replacement required urgently.	90%
Source:	*Adapted from the International Infrastructure Management Manual, Version 3.0, 2006*	

Beyond a condition analysis of assets to determine their probability of failure, risk scoring is an important next step of enhancing asset management at the City. Risk-based planning determines budgets needs based on current versus planned target risk levels for the asset base. Priorities for investment renewals are based on risk levels, and success can be measured by the risks managed or reduced at the end of the year. Risk-based planning drives the strategy implemented for each asset. In light of limited resources, a more proactive strategy (e.g., condition assessment, predictive maintenance, or routine maintenance) could be implemented for higher risk assets, while a “run to failure” strategy may be most appropriate for lower risk assets. This strategy allows for staff and financial resources to be directed most cost-effectively.

As can be seen from Figure 3, the probability of failure scoring of assets is an important component of the risk score. Additionally, the consequence of failure is the second component to develop risk scores. Consequence was not analyzed as part of this project, but it is important for the City to consider performing such an analysis to strive for an enhanced asset renewal forecast that is risk-based to attain the benefits of having risk perspectives described above. By combining the product of these two components, a risk score can be generated for the City’s assets.

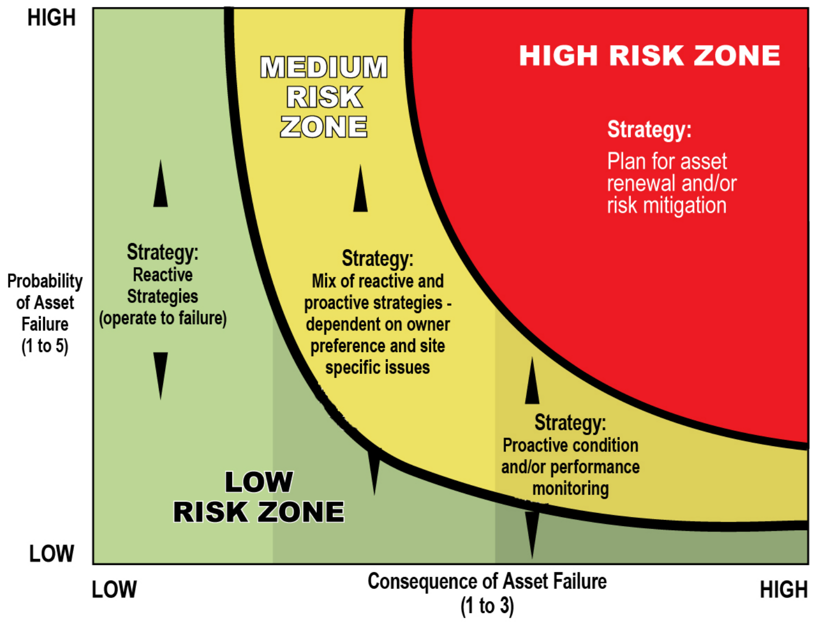


Figure 3: Risk-Based Strategies for Various Asset Risk Levels

When analyzing the assets for consequence of failure, the general approach starts with a screening for the economic impacts of an asset failure (looking at repair cost factors based on size, depth, and traffic issues) to arrive at an initial consequence of failure score (on a scale of 1 to 3) at the systems level. Scores for the City's assets are assigned to develop a relative ranking based on the economic, social, and/or environmental (triple bottom line) impacts.

It is noteworthy that City staff may want to revisit the condition/probability of failure scores developed during this project on a regular basis, particularly for special facilities and key customers which are likely to change over time. This will help the City keep its Renewal Forecast updated and as accurate as possible for the condition basis.

As part of the condition scoring process, City and MWH staff performed field investigations to develop or confirm some of the workshop- and desktop-based condition analyses. MWH used structural and hydroelectrical discipline engineers to perform these field inspections for the hydroelectric facilities and the storage reservoirs. Also as part of these inspections, engineering information provided by the City was reviewed and a brief summary of findings and condition were noted. The approach to these field observations are further detailed in Section 5.2 of this Master Plan document.

3.0 Data Analysis

Facility asset data was collected and analyzed for the BRWTF and the stranded facilities. This section provides an overview of these efforts.

3.1 Source Collection

Existing spreadsheets (e.g., Microsoft Excel workbooks) containing asset data for the BRWTF and stranded facilities were examined for completeness and relevancy. These initial files included:

- "BRWTP – 2008.xls"
- "Hydroelectric Facilities – 2008.xls"
- "Treated Water Storage Tanks - 2008_Data updated 2010.xls"

Data gaps were filled from facility document references, City staff and MWH knowledge, and field observation. General examples of documents consulted include:

- Facility reports
- Facility drawings
- Facility data spreadsheets and updates

A few specific examples include:

- "BRWTP_Rec_dwgs.pdf"
- "Water Storage Tanks_Hydro_PRV_Stations_2010R01.xls"
- "1985-1995-Orodell Hydro As-Built Drawings.pdf"
- "Hydro Facility Information.pdf"
- "Storage Tank Capacity Graphs.xls"
- "Kohler Roof Inspection Report 2007.pdf"

Key data of each type of facility (BRWTF, Hydroelectric, and Treated Water Reservoir Storage Tanks) were summarized on an output tab in each asset management workbook in a format based on the City's existing and preferred asset management format of the Betasso Water Treatment Facility (BWTF) asset management pilot project.

3.2 Asset Management Workbook Initial Preparation

Initial facility data spreadsheets to be used in the asset management probability of failure and renewal forecasting analyses were provided to MWH by the City to examine and identify pertinent gap filling needs after consulting existing facility documentation. Several updated versions were provided by the City to roll-into these spreadsheets and the analysis. When MWH reviewed and analyzed these spreadsheets, the following observations were made:

- Data gaps existed, and MWH worked with City staff as necessary to fill them.
- Some manual breakouts of data and other manipulation were needed to tailor the functionality of the workbooks to the application of probability of failure and renewal forecasting analyses.
- BRWTF data was more complete and updated than the stranded facilities. The stranded facilities required significant gap filling.
- Significant overlap of line items in the hydroelectric workbook existed; line item assets needed to be distinguished from other "19XX Improvements" projects to make sure they were broken out from the improvement line items to eliminate overlap in

probability of failure scoring and renewal forecasting analysis. This was done by eliminating improvement line items from the analysis.
- Condition scores of the stranded facilities developed during workshop analyses with City staff were verified during field observations with engineers of specialized disciplines.

Facility data workbooks of the BRWTF and stranded facility assets were adapted into new spreadsheet files for the purposes of probability of failure scoring and renewal forecasting. MWH prepared the initial workbooks and several subsequent revisions for review, comment, and revision by City staff. Several assumptions exist for the probability of failure scoring and renewal forecasting analyses. These include:

- Assets considered in these analyses include those with any of the following characteristics:
  - One year or greater expected useful life
  - Greater than $5000 expected replacement value
  - Are key to safety
  - Need significant routine inspection or maintenance
  - Are key to regulatory monitoring
- Facility data and information, including costs, provided by the City is assumed to be correct and up-to-date.
- Simple and Complex costs are calculated using the existing 2008 cost factor basis.
- The 2010 Condition Rating takes the place of the 2008 Condition Rating.
- Stranded facilities and their assets were scored as a two, unless knowledge or observation justified a different score.
- The methodology and appearance of the renewal forecast data was to be as similar as possible, excluding improvements viewed as necessary or preferred by the City, to the BWTF asset management pilot project workbook ("Betasso WTP - 2009 12-8-09.xls") and report ("Betasso_WTP_AM_Pilot_Summary_Draft_Aug09.pdf").
- Probable costs were based on AACE International (Association for the Advancement of Cost Engineering) guidelines for a Class 4 estimate.

3.3 Final Asset Management Workbooks

In order to facilitate consistency between the asset management workbook output/results and the City's financial and budgeting processes, the final asset management workbooks were prepared by City staff. The output from the finalized workbooks are presented in the following sections. However, workbook revisions and adaptations made by City staff to obtain the necessary consistency were not reviewed in detail by MWH. The filenames of the present versions of these workbooks are:

- Boulder Reservoir Treatment Facility – 2010
- Betasso Treatment Facility – 2010 (previously prepared by Carollo Engineers outside of the master plan project; updated for consistency with master plan financial and budgeting process)
- Treated Water Hydroelectric Facilities - 2010
- Treated Water Pump Stations - 2010
- Treated Water Storage Tanks – 2010
- Treated Water Transmission Pipes – 2010

4.0 Results

50-year repair and renewal forecasts were prepared for the BRWTF, hydroelectric and PRV facilities, and treated water reservoirs. The results of these forecasts are presented below.

4.1 BRWTF

Repair and renewal costs were estimated using the methodology described in Section 2. Figures 4 presents the results, reflecting a forecasted 50-year investment need of $61M, or $1.2M annually for the Boulder Reservoir Water Treatment Plant.

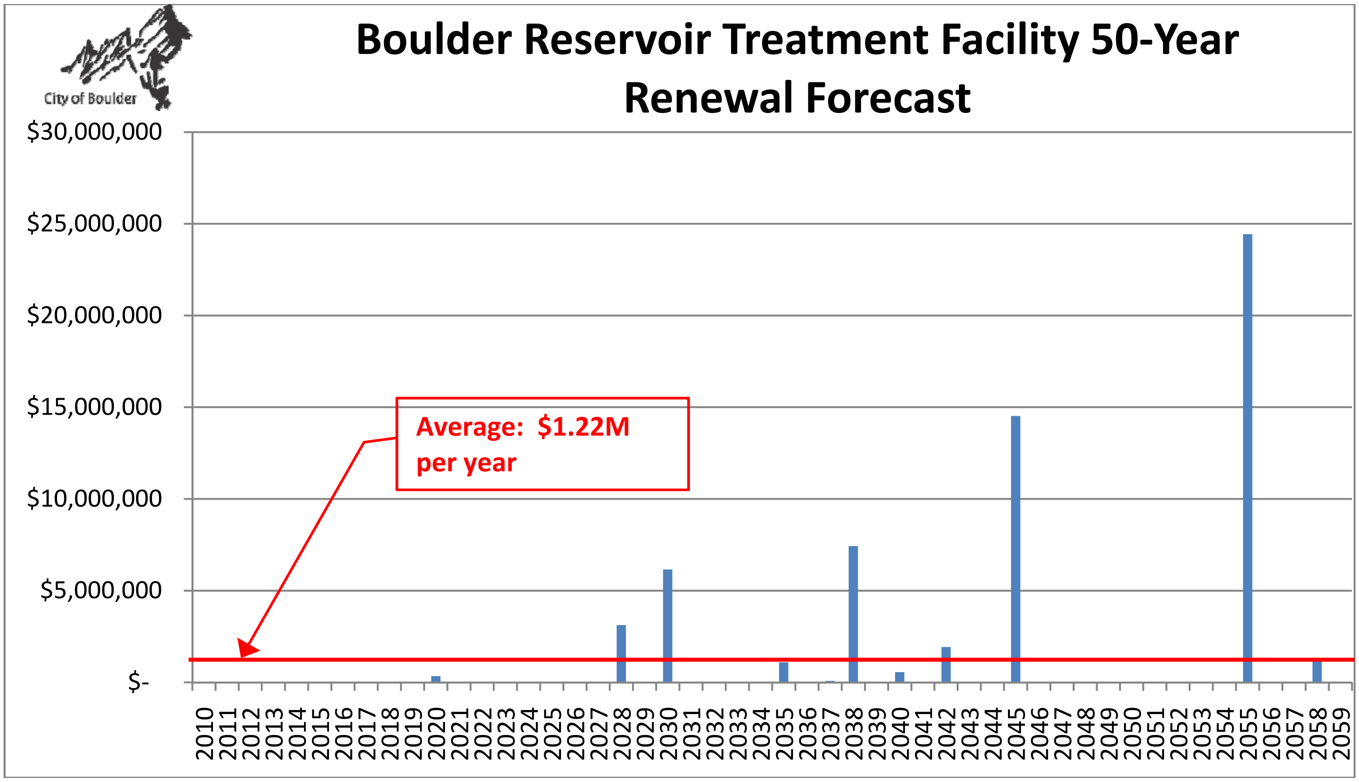


Figure 4: BRWTF 50-Year Renewal Forecast

4.2 BWTF

Figure 5 presents the results for the Betasso Water Treatment Facility, reflecting a forecasted 50-year investment need of $69.5M, or $1.39M annually.

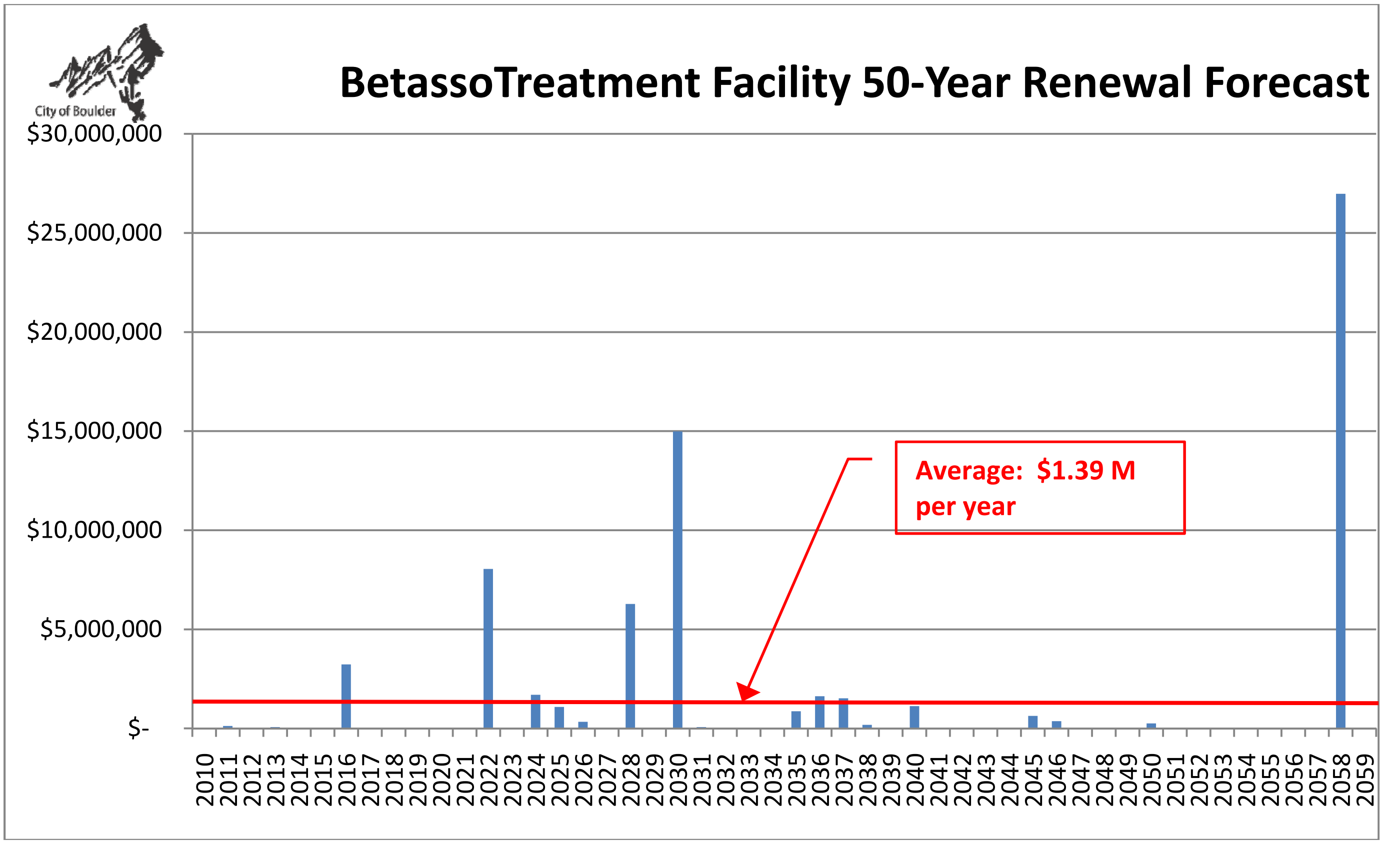


Figure 5: BRWTF 50-Year Renewal Forecast

4.3 Hydroelectric and PRV Facilities

Figure 6 presents renewal estimates for hydroelectric and PRV facilities. These estimates total to about $12M over 50 years, or approximately a $0.25M average annual expenditure.

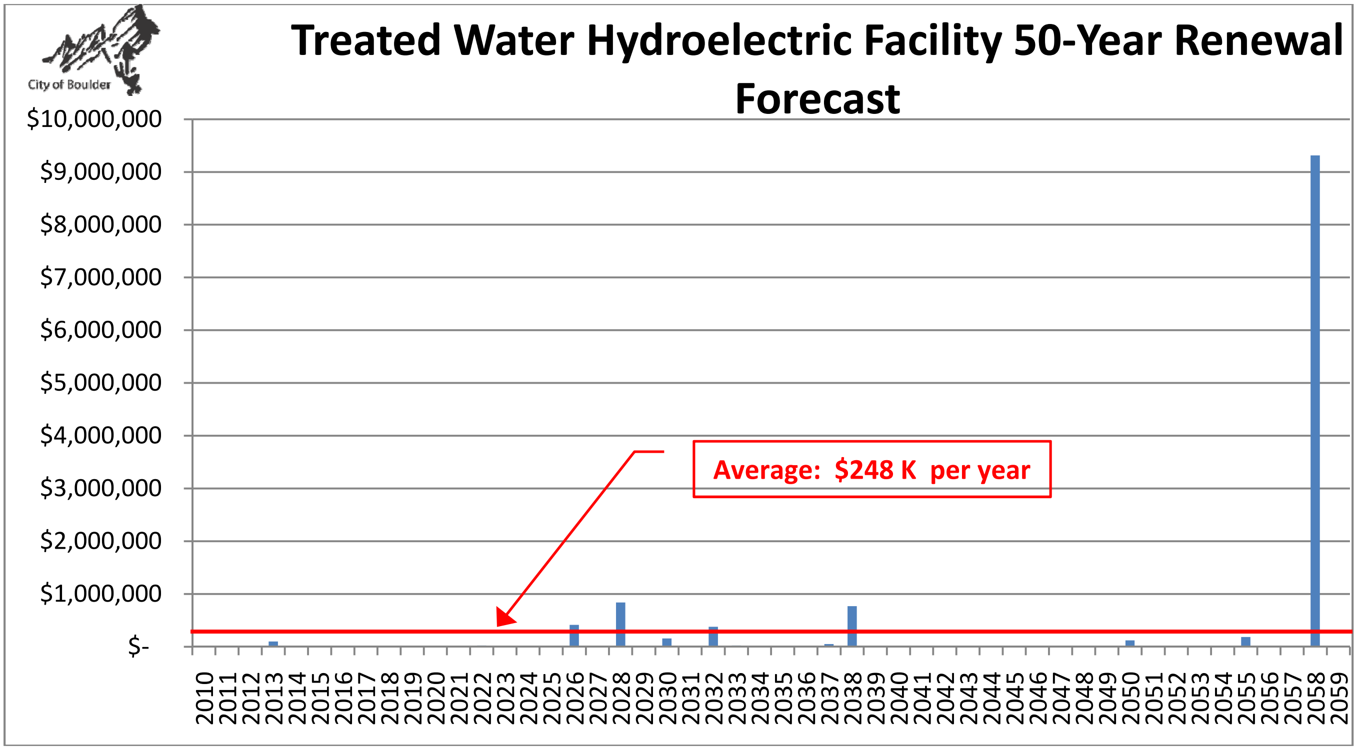


Figure 6: Hydroelectric and PRV Facilities 50-Year Renewal Forecast

4.4 Pump Station Facilities

Figure 7 presents renewal estimates for pump station facilities. These estimates total to about $3.5M over 50 years, or approximately a $0.07M average annual expenditure.

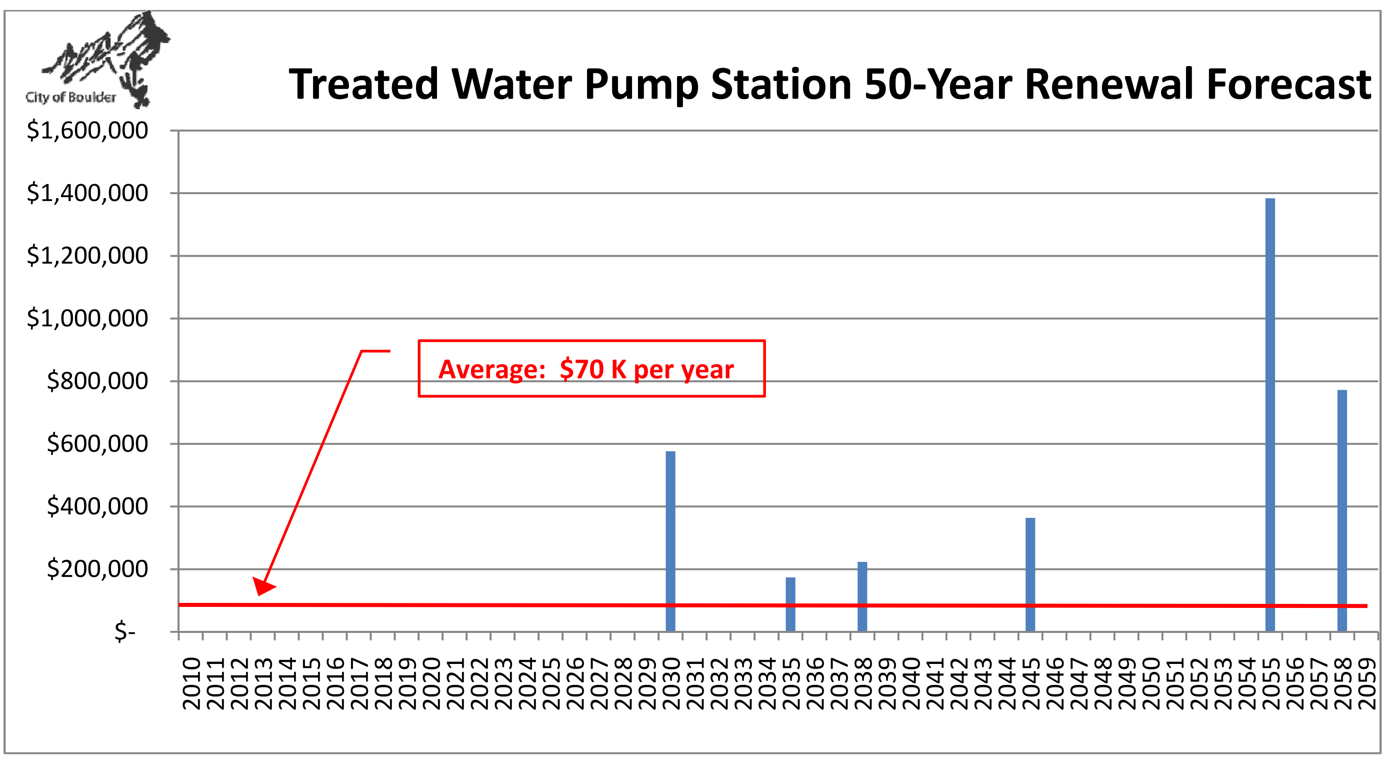


Figure 7: Treated Water Pump Station 50-Year Renewal Forecast

4.5 Treated Water Storage Facilities

Figure 8 presents repair and replacement estimates for the various treated water storage facilities. As shown in this figure, average repair and renewal costs for treated water storage facilities are estimated at $0.79M per year, or about $39M over 50 years.

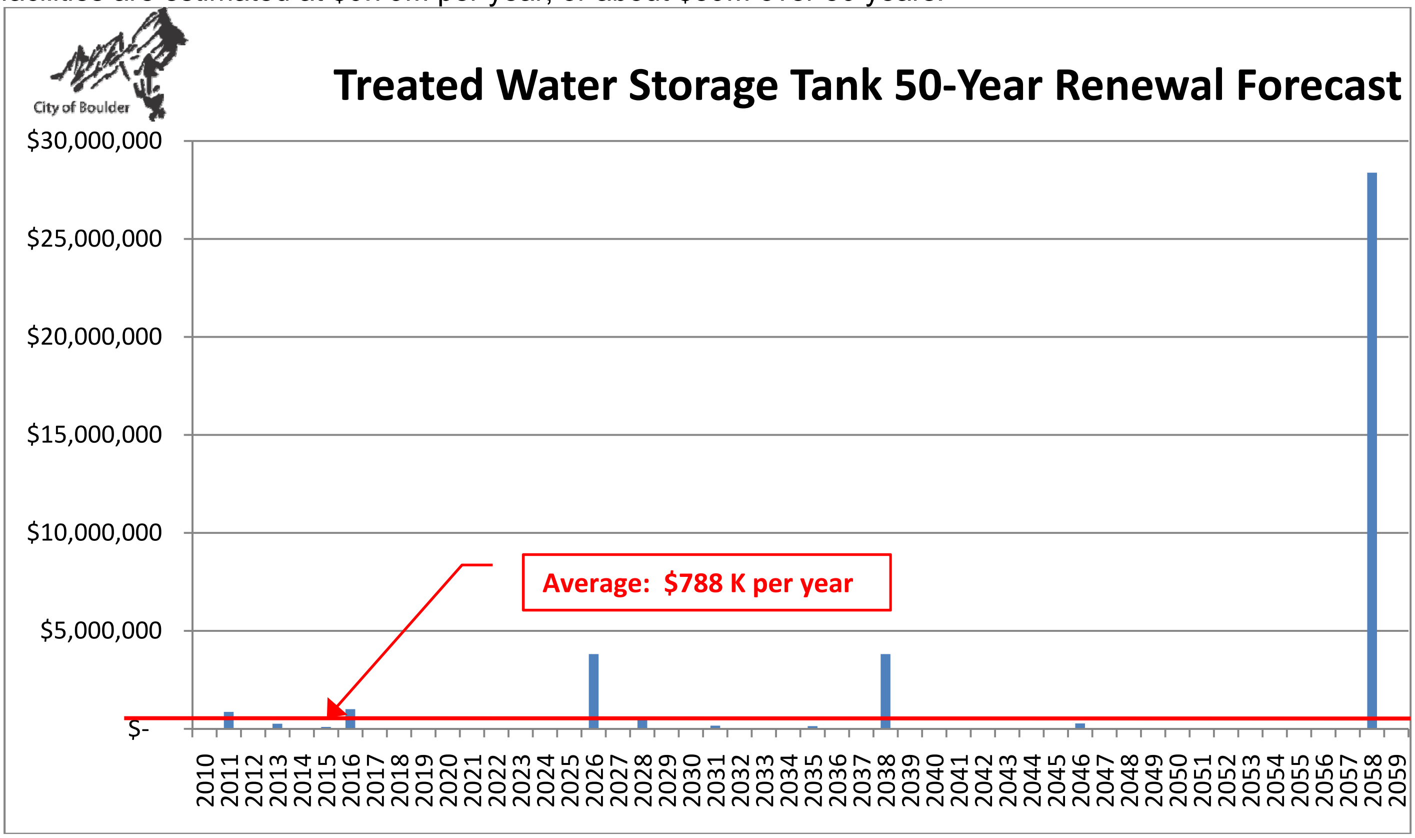
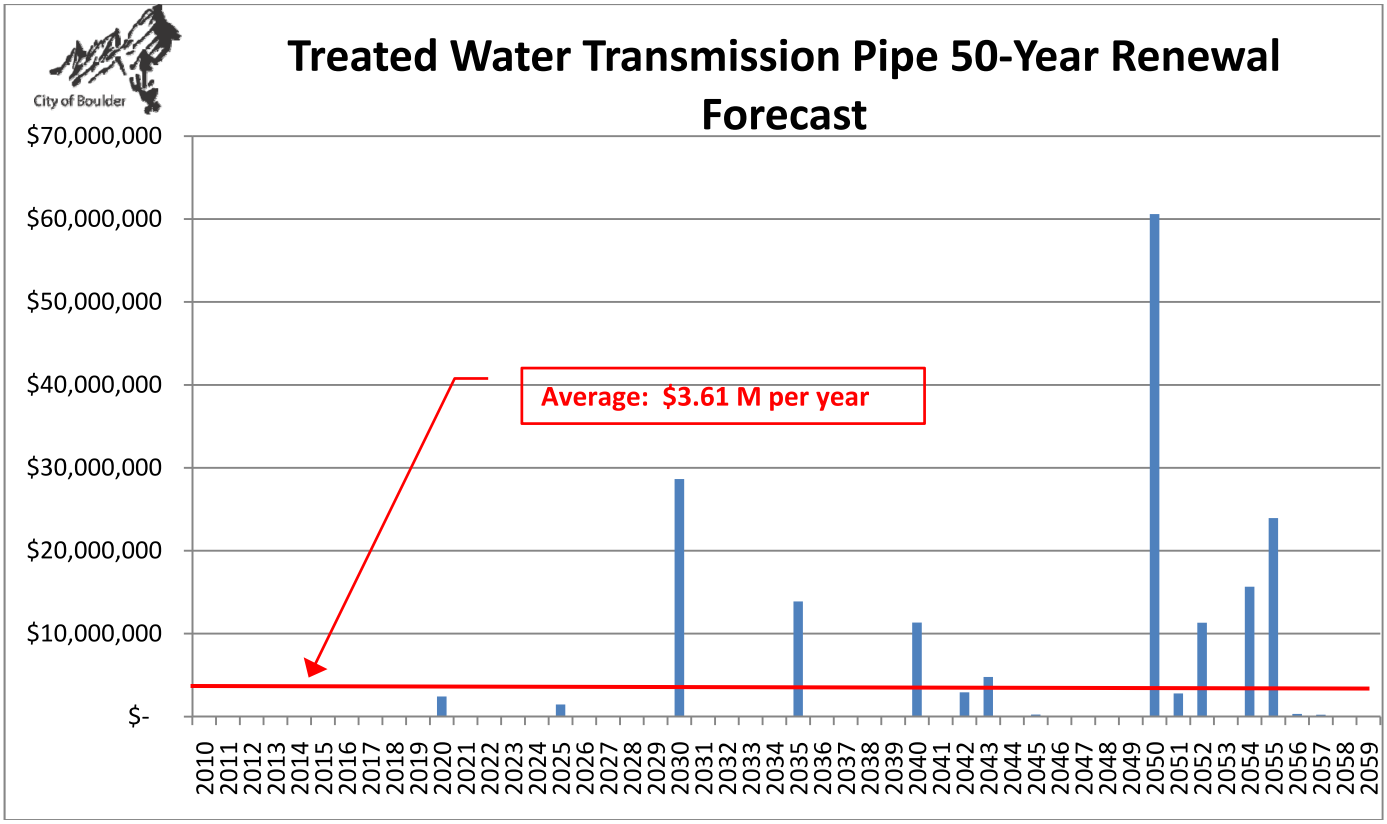


Figure 8: Water Storage 50-Year Renewal Forecast

4.6 Treated Water Transmission Lines

Figure 9 presents repair and replacement estimates for the various treated water storage facilities. As shown in this figure, average repair and renewal costs for treated water transmission lines are estimated at $3.61M per year, or about $181M over 50 years.



4.7 Overall Results

Based on the analysis performed on the presently available data provided, approximately $7.31M per year or $365M over 50 years should be budgeted to ensure the sustainable repair and renewal of the BRWTF and stranded facilities:

Table 4: Summary of Renewal Needs

Asset Group	Forecasted Need ($M/50yr.)	Forecasted Need ($M/yr.)
BRWTF	61	1.2
BWTF	69.5	1.39
Hydroelectric/PRV	12	0.25
Pump Stations	3.5	0.07
Storage Reservoirs	39	0.79
Transmission Lines	181	3.61
Totals	**365**	**7.31**

Projected costs well above the annual averages occur in the following years for the facilities as indicated below.

BRWTF

- **2030:** DAF mechanical, piping, and I&C and electrical renewal at $6.2M.

- **2038:** Filter Building and High Service Pump Station renewal and Administration Building I&C renewal totaling approximately $7.4M.

- **2045:** $14.5M in renewal needs are expected in 2045, mostly for the DAF building including $4.8M for DAF equipment, $2.1M for I&C, and $3.4M for MCCs and panels.

- **2055:** $24.4M predominantly for Filter Building filters 3 and 4 renewal.

BWTF

- **2022:** $8M in renewal needs are expected in 2022, $4.8M for filter media replacement, $1.7 M for residuals handling, and $2.7M in miscellaneous piping, valves, and vault renewal.

- **2028:** $6.2M in renewal needs are expected in 2028 with $3.4M for preliminary treatment sludge collectors and $1.2M for diesel generator replacement.

- **2030:** Approximately $15M in renewal needs are expected in 2045, with $4.7M for the DAF pumping system, $7.7M for Finished Water Reservoir No. 2, and $1.3M for the filter surface wash water system.

- **2058:** Approximately $27M the majority of which is for renewal of Finished Water Reservoir No. 1.

Hydroelectric/PRV Facilities

- **2058:** Approximately $9.3M with $7.5M allocated for renewal of the Sunshine Hydro facility.

Treated Water Storage Tanks

- **2058:** Approximately $28.3M largely for the replacement/renewal of the Devils Thumb Reservoir.

Transmission Lines

- **2030:** $28.6M in renewal needs are expected in 2030, $7.8M for Pressure Zone 1 pipeline renewal/replacement, $13.8 M for Pressure Zone 2 pipeline renewal/replacement, and $7.1M for Pressure Zone No. 3 pipeline renewal/replacement.

- **2035:** $13.9M in renewal needs are expected in 2035, $4.7 M for Pressure Zone 2 pipeline renewal/replacement, and $9.2M for Pressure Zone No. 3 pipeline renewal/replacement.

- **2040:** $11.3M in renewal needs are expected in 2040, $4.8M for Pressure Zone 1 pipeline renewal/replacement, $5.4 M for Pressure Zone 2 pipeline renewal/replacement, and $1.2M for Pressure Zone No. 3 pipeline renewal/replacement.

- **2050:** $60.6M in renewal needs are expected in 2050, $6M for Pressure Zone 1 pipeline renewal/replacement, $17.8 M for Pressure Zone 2 pipeline renewal/replacement, and $36.7M for Pressure Zone No. 3 pipeline renewal/replacement.

- **2054:** $15.7M in renewal needs are expected in 2054 all for Pressure Zone No. 3 pipeline renewal/replacement..

- **2055:** $23.9M in renewal needs are expected in 2055 all for Pressure Zone 2 pipeline renewal/replacement.

4.8 Valuation Analysis

The City calculates asset value using an accounting or straight-line approach:

Asset Value = Estimated Replacement Cost (new) – Depreciation

Here, depreciation is calculated in a straight-line fashion based on the age and expected useful life for the asset. For example, a 5-year-old blower with a replacement cost of $20,000 and an expected useful life of 10 years would be valued at $10,000:

Present Approach:

*(Replacement Cost – (% of life consumed)*Replacement Cost = Current Asset Value*

$20,000 - (5years/10years)$20,000 = $10,000*

This is the methodology built into both the Betasso WTP asset management pilot project and the three asset management workbooks (BRWTF, hydroelectric, tanks) developed as part of this Master Plan. In the future, the City may want to consider a more condition-based valuation methodology that takes the condition scores developed in this Master Plan into account and let that influence the expected useful life or the shape of the deterioration curve to make it more reflective of reality rather than a straight-line depreciation.

For example, the blower described above may still have a condition score of 2 (good ,or assumed 10% useful life consumed) after five years. The resulting valuation would take this condition into account when calculating the asset value and expected useful life:

Recommend Approach:

*Replacement Cost – (condition score fraction)*Replacement Cost = Current Asset Value*

$20,000 – (10%)$20,000 = $18,000*

Present Approach:

Contrast this with a blower that is poorly maintained, and has a condition score or 5 (very poor, or assumed 90% useful life consumed):

$20,000 – (90%)$20,000 = $2,000*

Thus, condition scores can be used to better understand the current value of the City's assets.

5.0 Conclusions and Recommendations

With this project, the City has taken important first steps in enhancing its approach to asset management for the BRWTF and stranded facilities. Several of these achievements pertaining to these facilities are listed below:

- Gap filling and reconciliation of the City's asset dataset, including updating of cost factors, the breakout detail and analysis of grouped improvements (i.e., "19XX Improvements") and breakout of valves from piping and yard piping from other sitework, refinement of the Hydro/PRV useful lives, and completion of asset original and/or replacement costs. This will help to add further refinement the forecasts.
- Assigning initial consequence of failure scores -- an important first step to being able to develop risk scores and develop a risk-based renewal forecast that is more strategic.
- Developing long term (50-year) renewal forecasts.
- Constructing asset management workbooks for three facility categories.

Based on this analysis of the BRWTF and stranded facilities, potential near-term enhancements to the City's existing asset management approach to consider include:

- Migrating asset data into one **database** driven application for more robust asset management capabilities.
- Establishing a **data framework** to have a clear asset hierarchy and asset registry.
- Incorporating the **consequence of failure** analysis to enhance the condition-based analysis of this task to strive for an enhanced, **risk-based asset renewal forecast**.
- Establishing **business processes** to enable and support ongoing enhanced asset management, regular updating of condition scores, and an overall asset management strategy.
- Develop an ongoing, **programmatic approach to asset management** to drive asset strategy throughout the organization and realize benefits associated with more defensible renewal budgets and utility performance. A quality asset management program will have both planning and implementation components, build on existing efforts, staff knowledge, and tools, and reach across water, wastewater, stormwater and flood management vertical (i.e., facilities) and horizontal (i.e., pipes) assets.

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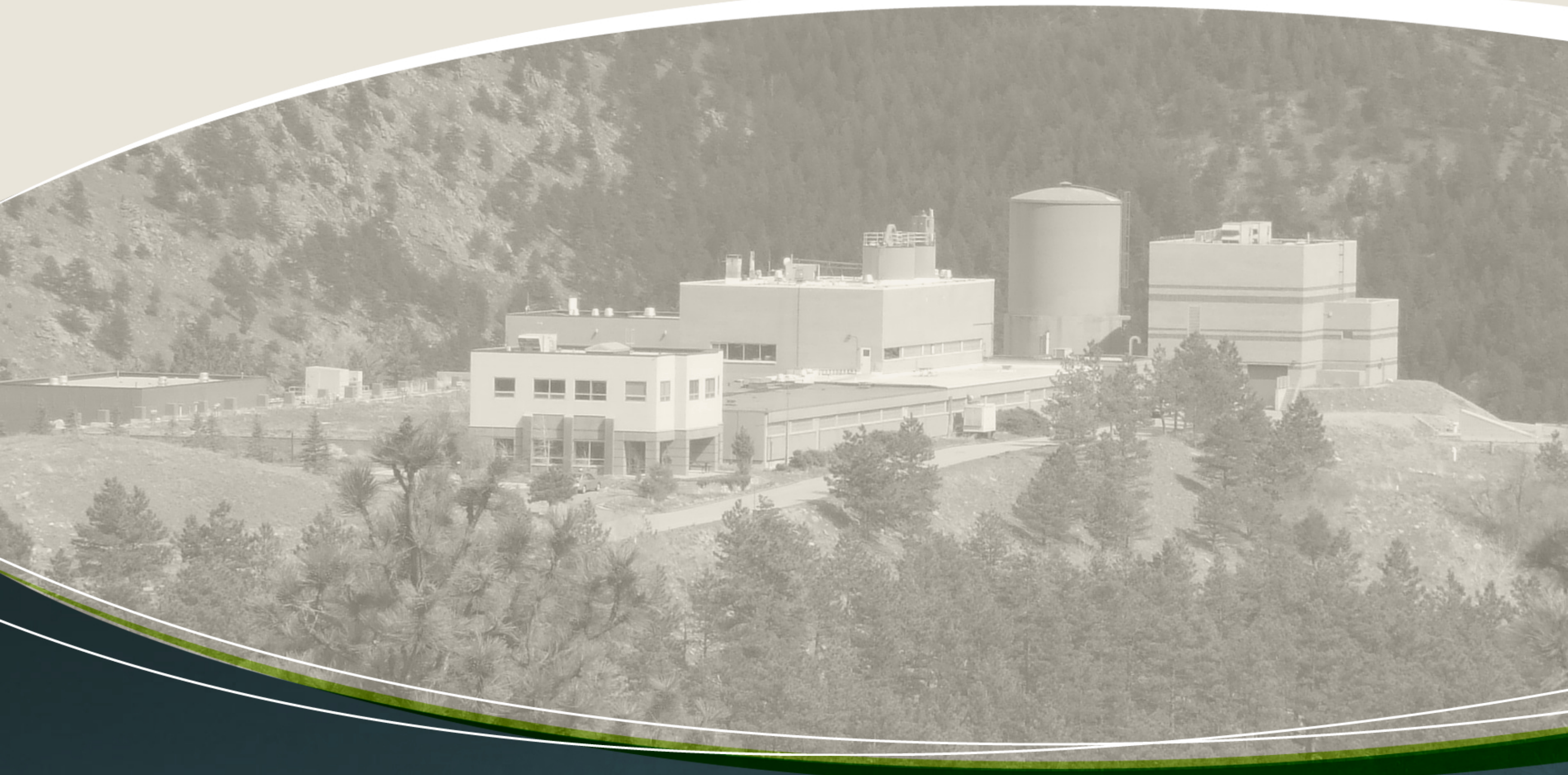

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