C I T Y O F B O U L D E R
WATER RESOURCES ADVISORY BOARD
INFORMATION ITEM

MEETING DATE: July 15, 2013

AGENDA TITLE: Informational Item – Overview of Water Treatment Operations

PRESENTERS:
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EXECUTIVE SUMMARY

In January 2013, staff provided the Water Resources Advisory Board with an overview of water supply and demand management with a focus on evaluating 2012 operations (January 2013 WRAB Information Item). This information item is intended to supplement the water supply and demand management information by providing a more in-depth look at the water treatment processes and challenges at the city's two water treatment facilities.

The City of Boulder (city) operates two water treatment facilities, the Betasso Water Treatment Facility (BWTF) and the Boulder Reservoir Water Treatment Facility at 63rd Street (BRWTF). The BWTF functions as the city's primary treatment facility with the BRWTF serving to optimize management of the city's water rights portfolio, meet peak demands, and provide reliability. Both facilities use conventional treatment processes with the key difference being that the BWTF clarification process relies on sedimentation while the BRWTF uses flotation.

Treatment processes are evaluated on an ongoing basis to maintain regulatory compliance and deliver a high quality product to customers. The city adds fluoride to its treated water in accordance with a 1969 ballot initiative. The BWTF is a key focus in the upcoming Utilities Capital Improvement Program (CIP), including preliminary design of an improvement project in 2014.

This item is intended to provide WRAB with an overview of water treatment operations as context for future WRAB agenda items. No formal action by the WRAB is requested at this time.

BACKGROUND

In October 2011, the city developed a consolidated Water Utility Master Plan (WUMP) that addresses source water, water treatment, and the distribution system. The WUMP incorporates an evaluation of the treated water system condition and recommendations for the next 20-year planning period (WUMP Vol. 5).

Water Treatment Facilities and Operations

The city's BWTF was built in 1964, and the BRWTF was built in 1971. Both facilities have had upgrades and improvements over the years. Table 1provides treatment capacity and raw water sources for each facility.

Table 1. Water Treatment Facility Capacity and Water Source

	BWTF	BRWTF
Treatment capacity	40 million gallons per day (MGD)	16 MGD
Water sources (WUMP, Vol. 4)	- North Boulder Creek system through Lakewood Reservoir (7,200 acre-feet) - Barker Reservoir (11,700 acre-feet)	- Boulder Reservoir (8,500 acre-feet) - Boulder Feeder Canal, which delivers Colorado-Big Thompson (C-BT) water to Boulder Reservoir from Carter Lake

Supplying safe drinking water is a year-round process that relies on the operation of both water treatment facilities. Over the last ten years, the amount of water treated, from both WTFs, has ranged from a high of 6,653 million gallons to a low of 5,363 million gallons. Since 2005 (the last major process change to the BRWTF), annual water treatment production has generally been about 70% from the BWTF and 30% from the BRWTF. This distribution has varied in recent years based on constraints on system resources (Table 2).

Table 2. Recent Water Production

Year	Total Production, MG	BWTF/BRWTF Production, % of Total
2011	6,079	79% / 21%
2012	6,459	63% / 37%
2013 (Jan-Jun*)	2,598	62% / 38%

*BRWTF increased production, in first half of 2013, when snowpack was limited and there was concern about adequate spring snowfall.

Source Selection. The city makes water source decisions on a daily basis, and water supply operation were described in the January 2013 WRAB Information Item. The city has high quality water sources, but each water source can have different physical and chemical characteristics at certain times of the year or in different years. After determining daily quantity and source for each facility, the next step is treating and delivering the water to the distribution system. Generally, the BWTF water sources from Lakewood and Barker Reservoirs provide cold, low alkalinity water that are fairly consistent and comparable quality that results in consistent water treatment and finished water. Seasonally, particularly during direct flows in the spring, the organic loadings in the North Boulder Creek system create color that can be problematic to remove at the BWTF. During periods of high color or when adding to water storage in the upper watershed, increasing the amount of water treated at BRWTF helps meet the system demands. During winter, treatment challenges include treating the very cold, low alkalinity water with a coagulant that does not consume alkalinity, and settling solids after treatment at low temperatures.

The BRWTF uses two water sources, Boulder Reservoir and the Boulder Feeder Canal (canal). Generally, the canal operates from May 1st until October 31st and can have limited shutdowns or low flows based on flow management and maintenance. The BRWTF treats Boulder Reservoir water when the canal is offline. Using Boulder Reservoir requires pumping water to the treatment facility, which adds to water treatment costs. The quality of canal water from Carter Lake is similar to the BWTF water sources (e.g., cooler, low dissolved solids). When Northern Water performs algae/weed mitigation or other maintenance operations that can impact water quality, or when canal flows are low, the city does not divert from the canal. Due to the underlying geology, Boulder Reservoir can have higher total dissolved solids than the other water sources, which is also affected by flows through the reservoir. In the summer, Boulder Reservoir water quality is susceptible to taste and odor occurrences from the algal growth and elevated temperature.

Water Treatment Processes

Both water treatment facilities have conventional treatment processes (i.e., coagulation, flocculation, clarification, filtration, disinfection) with fluoride addition and stabilization for corrosion control (Figure 1). A primary difference between the two WTFs is clarification by sedimentation at BWTF and by flotation at BRWTF. The BWTF uses older conventional treatment technology, because it was last expanded in 1976. The city selected a newer form of clarification when the BRWTF was expanded in 2004. Clarification options for BWTF will be evaluated in the upcoming CIP.

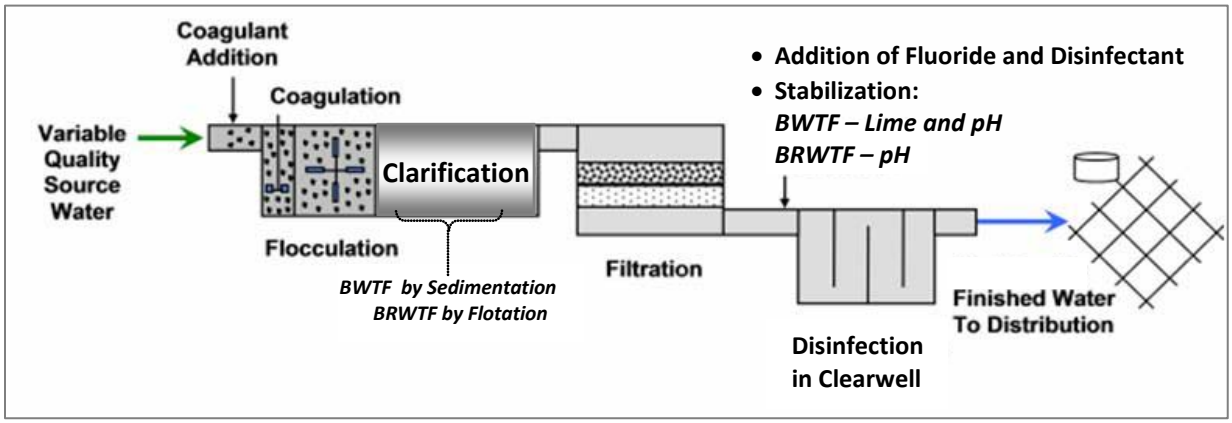

Figure 1. Water Treatment Process

Treatment Chemicals. Table 3 summarizes chemical use at each treatment facility.

Arsenic. In recent months, the WRAB discussed the city's wastewater treatment facility and evaluations related to compliance with the effluent discharge permit limit for arsenic (total) of 0.023 μg/L as a chronic, 30-day average. These discussions included questions related to arsenic concentrations in the source and treated drinking water. The following information summarizes the city's arsenic study, which included monthly monitoring for six months in 2011 (Attachment A).

The city monitored arsenic concentrations at eight locations representing the source water for both WTFs. Results showed arsenic concentrations in the source water exceed the 0.02 μg/L chronic water quality standard. Total arsenic ranged from 0.058 to 0.194 μg/L in the BWTF source water and from 0.187 to 1.050 μg/L in the BRWTF source water.

Table 3. Water Treatment Process Chemicals

Chemical	Purpose	Pros / Cons	Years in Use
BWTF			
Alum *Full scale Ferric trial in early 1990s*	Primary Coagulant	Pros – commonly used, low cost	1963 – Current
		Cons – reduces alkalinity, sludge production	
Sumaclear 820B	Coagulant / Flocculant Aid	Pros - Little pH and alkalinity effect, less sludge produced	1997– Current
		Cons- high cost compared with alum	
Lime	Corrosion Control stabilization	Pros – add alkalinity as Calcium carbonate	1963-1993 (add alkalinity) 1993 – Current (Stabilization)
		Cons – Lime feeders periodically problematic, calcium carbonate deposits at dosing point in the combined filter effluent, raises pH above target stabilization	
Carbon dioxide *Gas and/or Carbonic acid generated from Carbon dioxide*	pH control: pre-pH suppression; post-lime pH stabilization	Pros – does not reduce alkalinity while reducing pH	1993 - Current
		Cons - Decreased pretreatment pH may cause aggressive water that can shorten equipment life	
Peak Polymer *Slightly cationic polymer*	Coagulant for Pretreatment	Pros – works well in DAF pretreatment of recycled water	2000 - Current
	Dewatering for Sludge	Cons – feed system can be problematic, current feed system not effective for sludge dewatering	
BRWTF			
Alum	Coagulant	Pros – commonly used, low cost	1971 – 2001 2005 - 2011
		Cons – sludge production, increased pH adjustment for stabilization	
Ferric Chloride Ferric Sulfate	Primary Coagulant	Pros – good coagulant for sedimentation	2001 – 2004
		Cons – very aggressive to internal pipes and fittings	
Sumaclear 820B or 803B	Coagulant / Flocculant Aid	Pros - Minimal effect on pH and alkalinity, less and more manageable sludge	1996 - 2007 Floc aid 2007 – Current Coagulant
		Cons- high cost compared with alum, no advantage to mix with Alum in DAF process, not always as effective as Alum for TOC removal	
Peak Polymer *Slightly cationic polymer*	Coagulant / Flocculant Aid	Pros – works well to remove small particles not removed with primary coagulant (e.g. silt)	2005 - Current
		Cons – feed system can be problematic	
Carbon dioxide *Carbonic acid generated from Carbon dioxide*	Pre pH control	Pros – does not reduce alkalinity while stabilizing pH in source water to optimize coagulation	2010 - Current
		Cons – initial problems feeding at low flows now addressed with equipment modifications	
Sodium hydroxide *(caustic soda)*	Post pH control for stabilization	Pros – very effective for pH control	1996 - Current
		Cons – feed system can be problematic	
Both Facilities			
Hydrofluorosilicic acid	Fluoridation	Pros – safer to feed and store than dry chemical	1971 – 2002 Dry chemical 2002 – Current Wet chemical
		Cons – Higher trace level contaminants than dry chemical (e.g. arsenic)	
Sodium hypochlorite *(bleach)*	Disinfection / Oxidation	Pros – safer for community and employees than gas, does not require routine hazmat training for employees	1971 – 2001 Gas 2001 - Current Bleach
		Cons – concentration of free chlorine not as stable as gas	

Arsenic monitoring through the water treatment process indicate a 42% decrease in total arsenic at the BWTF and 62% decrease at the BRWTF, prior to fluoridation. Samples collected post-treatment, and after fluoride addition, showed an increase in arsenic on average (0.294 μg/L in the BWTF finished water and 0.372 μg/L in the BRWTF finished water). The average arsenic concentration in the BRWTF finished water was less than the incoming source water. For comparison, the arsenic maximum contaminant level (MCL) for drinking water is 10 μg/L. Table 4 summarized the 2011 arsenic monitoring results.

Table 4. 2011 Total Arsenic Monitoring Results

Sample Location	Total Arsenic, μg/L		
	Minimum	Maximum	Average
BWTF			
Source water	0.058	0.194	0.113
Combined filter effluent (pre fluoridation, post treatment)	0.047	0.083	0.066
Finished water (post fluoridation, post treatment)	0.214	0.400	0.294
BRWTF			
Boulder Reservoir – Canal or Basin – Combined Influent	0.187	1.050	0.640
Combined filter effluent (pre fluoridation, post treatment)	0.127	0.375	0.245
Finished water (post fluoridation, post treatment)	0.239	0.413	0.372
75th Street WWTF			
Influent	0.532	0.730	0.618
Final effluent	0.362	0.454	0.402
Boulder Creek			
Boulder Creek above City of Boulder (site BC-CAN)	0.259	0.542	0.422
Boulder Creek at Dry Creek - end of chronic mixing zone below 75th Street WWTF (site BC-aDC)	0.456	1.070	0.660
Total arsenic concentrations in all Boulder Creek samples collected above the 75th Street WWTF exceeded the 0.02 μg/L water quality standard by at least one order of magnitude.			

The city has performed some literature review on the removal of arsenic with alum and iron salts. Generally, the iron-based coagulants appear to be more effective than aluminum coagulants, and pH and arsenic speciation factor into the effectiveness. One consideration is that studies that have evaluated arsenic removal included concentrations that are one to two orders of magnitude higher than concentrations in the city's source water, in Boulder Creek, and the water quality standard.

Fluoride. In 1969, Boulder voters approved the addition of fluoride to the city's drinking water to reduce tooth decay. The ballot language stated that the city would introduce fluoride into the water supply to maintain a concentration of "*. . . approximately one part of fluoride to one million parts of water*." The fluoridation of drinking water was endorsed by various health organizations, such as the United States Public Health Service, American Public Health Association, American Dental Association, American Medical Association and various local civic groups and organizations. Since 1969, the city has added fluoride to its drinking water that meets

the recommendations of the various health organizations as well as the requirements of the approved ballot language. The city currently adds fluoride to maintain a concentration of approximately 0.9 parts per million (ppm or milligram per liter), as recommended by the Colorado Department of Public Health and Environment (CDPHE). The city also complies with the Environmental Protection Agency (EPA) fluoride MCL of 4 ppm.

In 2006, voters initiated a local ballot measure to eliminate fluoridation of drinking water, but the measure narrowly failed by a margin of 48.2 percent to 51.8 percent. As part of the ballot language, trace contaminants, including arsenic and lead, were identified as a concern since some fluoride products contain trace (low) levels of some metals. The city's fluoridation process, at both water treatment facilities, consists of adding hydrofluorosilicic acid, which is a liquid fluoride-based chemical. Each batch of hydrofluorosilicic acid is analyzed by the manufacturer for various trace level contaminants and a Certificate of Analysis is provided with every batch. Typically, arsenic is measured at detectable levels but lead is not.

After the 2006 ballot initiative to stop the addition of fluoride, the city evaluated options, other than adding hydrofluorosilicic acid, to fluoridate drinking water. The evaluation included a comparison of five fluoride options, including hydrofluorosilicic acid, looking a capital costs, operation and maintenance costs and the quality of fluoride with respect to trace contaminants. The results of the evaluation were presented to WRAB in 2007 (Attachment B). In summary, the addition of hydrofluorosilicic acid is the most cost effective method of fluoridation but other fluoride products contain fewer trace level contaminants and/or contain contaminants at lower concentrations.

In January 2011, the U.S. Department of Health and Human Services (HHS) and EPA, jointly announced important steps to ensure that people benefit from tooth decay prevention while at the same time avoid potential effects from too much fluoride. While the HHS provides a recommended "optimal level" for fluoridation, the HHS is not the regulatory agency for drinking water standards. The EPA regulates the MCL for fluoride in drinking water. The HHS proposed that the optimal fluoride level be reset to 0.7 ppm, which is lower than the current recommended optimal range of 0.7 to 1.2 ppm. While the HHS was expected to issue final guidance on the optimal level of fluoride in spring or summer 2011, a final recommendation has not been released to date.

The EPA has also announced that it will initiate a review of the current fluoride MCL to determine whether it should be revised. Currently, the maximum amount of fluoride in drinking water is not to exceed 4 ppm. The EPA also has a non-enforceable secondary MCL of 2 ppm. This means that drinking water should not exceed 2 ppm of fluoride, but regulatory enforcement doesn't occur until the MCL is exceeded. The schedule for the EPA review of fluoride regulatory levels is not known at this time.

If the final guidance from the HHS is that 0.7 parts per million of fluoride is an optimal level, and the CDPHE supports the recommendation, the city would consider reducing the amount of fluoride added to Boulder's drinking water to maintain a concentration of 0.7 ppm. This approach is consistent with the legislative intent of the 1969 ballot measure

Treatment Challenges. The following is an overview of operation and treatment challenges at each water treatment facility.

BWTF – The primary operation or treatment challenges include managing residuals, specifically excessive water needed to move sludge and inadequate storage, and the limitations of the aging conventional process equipment. The city initiated a detailed study of the residuals issue this year, and the BWTF CIP project is discussed in the subsequent analysis section. The challenges below are considered a priority in the upcoming CIP.

- Entire facility – Conventional process equipment (i.e. flocculation/sedimentation, filters) has not had a major upgrade since 1976 and is periodically limiting treatment capacity. Portions of the facility are nearing or have passed the AWWA standards for replacement and are operating below optimal levels.
- Coagulation – Flash mixer is ineffective at dispersing the applied chemicals.
- Flocculation / Sedimentation – Flocculation/sedimentation is periodically a process limiting issue. The existing design results in poor clarification during various scenarios and reduces filter run times. In addition, cleaning sludge from the basins requires high volumes of water that magnifies the residuals problem.
- Filtration – Spring run-off causes strain on the filters, requiring frequent filter backwashes. Media in all filters is 19 years old (AWWA standard for media replacement is 15 – 20 years), other than replenishment of lost anthracite media. Also see Attachment C.

  Residuals – Processes upstream require excessive water to move sludge to drying beds/lagoons, and the water/solids separation in storage areas is inadequate, requiring contracted removal of dilute residuals. Residuals are currently the primary process limiting issue at the BWTF.

  Taste and odor issues while cleaning sedimentation basins – During routine maintenance cleaning, a portion of flow is recycled to the head of the treatment process and can be managed by preoxidation with chlorine at the head of the facility. However, this can also contribute to increased disinfection byproducts so must be monitored for compliance with the disinfectant/disinfection byproducts regulation.

BRWTF

- Power outages – The BRWTF is at the end an Excel Energy line and only has one leg of power to the plant. Evaluation of relays and breakers is underway to reduce the number of power outages
- Faulty valves – Filter backwash and effluent valves do not always function properly. When the facility is required to shutdown while treating the Boulder Feeder Canal, the influent valve cannot be seated completely and a substantial amount of water leaks by causing significant issues with water in the backwash recovery tank that must be managed. This can be a process limiting factor during shutdown.
- Taste and odor issues while treating Boulder Reservoir – The Reservoir can be prone to taste and odor from algae growth during late summer months. Also, higher total dissolved solids in Boulder Reservoir can contribute to taste differences within the

distribution system. Normal operating procedures call for using the Boulder Feeder Canal during summer months but that is not always possible.

- High Service Pumps – Cavitation in the pumps is causing abnormal wear and requires more frequent rehabilitation. A 2012 study recommended a combination of operating procedures and new equipment for mitigation.
- Frequent flow changes – The BWTF is not as responsive in fluctuating flow, and the ability to adjust flows at the BRWTF provide valuable system flexibility, but frequent shutdown and startup procedures can introduce risk to equipment and water quality.
- Prairie dogs – Population has encroached too close to facility.
- Capacity rating confirmation – This facility is rated at maximum capacity of 20 MGD but delivery of this flow to the distribution system has not been fully tested..

Partnership for Safe Water

Both facilities applied for and received the Partnership for Safe Water Phase III Director's Award of Recognition in 2011 and 2012. The Partnership for Safe Water is a national volunteer initiative developed by the EPA, AWWA, and other organizations representing water suppliers striving to provide their communities with drinking water quality that surpasses the required federal standards. The city's water treatment facilities were each presented the award for successfully completing the Self-Assessment and Peer Review phase of the Partnership program, a phase which represents an extensive self evaluation of each facility and a commitment of all treatment plant employees to ensure public safety by routinely producing safe and palatable drinking water. The information from the self evaluation will help guide decisions in the upcoming BWTF CIP.

ANALYSIS

Continual maintenance and improvements to the water treatment facilities is evaluated and prioritized in the WUMP and implemented through the annual operations budget and CIP. The primary capital improvement project for water treatment infrastructure includes improvements to the BWTF. Preliminary design for the BWTF capital improvement project will begin in early 2014. Construction is scheduled to begin in 2016 and extend through 2017.

Proposed BWTF Capital Improvement Issues and Guiding Principles

- Establish a reliable, year round firm capacity at the facility
- Maintain and improve treated water quality
- Maximize use of existing facilities through rehabilitation and optimization where possible
- Replace assets at the end of their useful life
- Change and/or optimize the current treatment process
- Address problems identified in the Water Utility Master Plan
- Maintain a gravity system where possible
- Economically optimize effective and timely residuals handling
- Evaluate and plan for future regulations
- Optimize chemical storage, mixing and use

- Meet future water needs and reliability criteria
- Ensure room for future expansion

System Demands and Projections
The peak day demand has been declining gradually over the past two decades from a mid 40 MGD peak to a low 30 MGD peak (Figure 2). In 2035, the peak day demand is projected to be 49.3 MGD, based on an annual demand of 21,250 acre-feet and a conservative peaking factor of 2.6 (WUMP Volume 2). If current trends hold, and the peaking factor remains near 2, the peak day demand could be as low as 36 MGD in 2035 with current water conservation measures. A firm capacity of 40 MGD at the BWTF and 16 MGD at the BRWTF will be able to meet 2035 peak day demand in either scenario, which is consistent with the Water Conservation Futures Study update.

Potential BWTF Treatment Capacity
Deciding on and achieving a year-round firm capacity at the BWTF is one of the main goals of the upcoming CIP. The hydraulic capacity is 47.7 MGD, but some unit processes limit the actual treatment capacity especially during certain times of the year. During increased organic loading that creates color in the spring, the capacity is closer to 27 MGD, and during the rest of the year flows over 30 MGD render the existing pre-treatment process less and less effective.

Considering the facility's potential hydraulic capacity, one limiting factor that is outside the possible CIP scope is the raw water conveyance capacity to the plant of 47.7 MGD. A logical, achievable goal is a firm capacity between 40 MGD and 47.7 MGD, even during the challenging seasonal treatment periods.

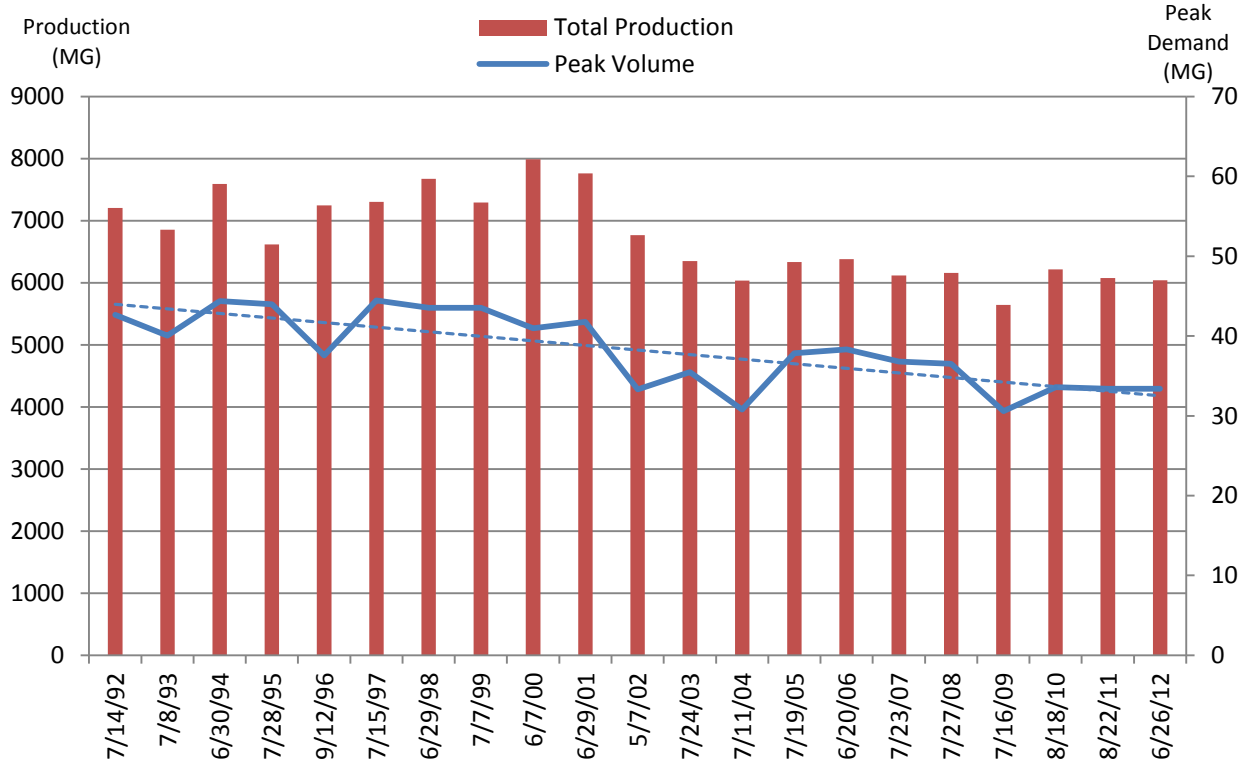

Figure 2. City of Boulder Water Treatment Annual Production, Peak Demand and Date

BWTF Evaluation
The recent WUMP provided an opportunity to evaluate operational problems at the facility and update the asset management analysis. Some of the items identified by staff are listed below. The complete list is available in the WUMP, Volume 5.

- 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.
- Facility operations staff has managed through the challenges by shifting water production to the BRWTF when needed.

Two studies were initiated to evaluate a couple of the major problems listed above. In 2012, Malcolm Pirnie/ARCADIS began working on the capacity issues encountered during spring runoff when color is high (Attachment C). Staff is currently working with the consultant to follow through on the 2012 report recommendations. Brown and Caldwell was recently selected to work on a Residuals Handling and Pilot study (Attachment D). The results and recommendations from these two studies will be used to help inform and develop the overall scope of the upcoming CIP project at the BWTF.

Preliminary Cost Estimate
The preliminary cost estimate of $17.5M in the 6-year CIP was developed from the asset management analysis and Consolidated Recommended Improvements Projects list for the BWTF from the WUMP. Asset management analysis estimates a cost of about $2.5M for items at the end of their useful life such as valves, motor control centers, backup generators and flocculation drives. The projects listed in the WUMP, Vol 5 and Vol. 6 total about $15M and are shown below. Projects and costs will evolve as the project scope and direction are determined. The goal is to enlist a design consultant in early 2014 and refine a scope and budget for next year's budget process.

NEXT STEPS

The schedule for the BWTF planning and improvements over the next year include completing the two studies in progress and selection of the Capital Improvement Project design consultant, along with refinement of the scope and cost.

- Spring Runoff Optimization Study - Late Summer 2013
- Preliminary Residuals Study (recommendations for pilot project) - Late 2013
- Selection of BWTF Capital Improvement Project design consultant - Late 2013
- Revised cost estimate and WRAB check in on preliminary design direction - Late Spring 2014
- Final Residuals Study Report - Fall 2014

ATTACHMENTS

A - 75th Street WWTF Evaluation Plan for Arsenic, Cyanide and Hex Chromium.
B – WRAB Agenda Item, May 21, 2007 - Evaluation of Water Treatment Fluoridation Chemicals
C – Malcolm Pirnie/ARCADIS BWTF Spring Runoff Plant Optimization Study
D - Brown and Caldwell BWTF Residuals Project Scope

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City of Boulder 75th Street Wastewater Treatment Facility Colorado Discharge Permit System Facility Evaluation Plan for Arsenic, Cyanide and Hexavalent Chromium

Purpose and Background

The City of Boulder (city) 75th Street wastewater treatment facility (WWTF), under Colorado Discharge Permit System (CDPS) permit No. CO-0024147, is required to submit a Facility Evaluation Plan (Plan) by December 1, 2011 to address compliance with arsenic (total recoverable), cyanide (WAD) and hexavalent chromium (dissolved) effluent limits. The Plan requirements are defined in the CDPS permit under the permit compliance schedule section as follows (compliance schedule code #43699):

> *Submit a report that identifies sources of Total Recoverable Arsenic, Cyanide and Hexavalent Chromium to the wastewater treatment facility and identifies strategies to control these sources or treatment alternatives such that compliance with the final limitations may be attained.*

Table 1 shows the 75th Street WWTF final effluent limitations for arsenic, cyanide and hexavalent chromium as defined in the CDPS permit effective May 1, 2011. The 75th Street WWTF effluent limitations are based on the following water quality standards.

- Arsenic (total recoverable)
  - 0.02 ug/L (chronic)
- Cyanide (free)
  - 5 ug/L (acute)
- Hexavalent chromium (dissolved)
  - 16 ug/L (acute)
  - 11 ug/L (chronic)

Table 1 – 75th Street Final Effluent Limitations for Arsenic, Cyanide and Hexavalent Chromium (Tier with flow > 20 MGD up to 25 MGD)

Effluent Parameter	30-Day Average	Daily Maximum
As, TR (µg/l) Until 5/31/13	Report	NA
As, TR (µg/l) Beginning 6/1/13	0.023	NA
CN, WAD (µg/l) Until 5/31/13	NA	30
CN, WAD (µg/l) Beginning 6/1/13	NA	5.4
Cr+6, Dis (µg/l) Until 5/31/13	Report	Report
Cr+6, Dis (µg/l) Beginning 6/1/13	12	17

This report documents the activities conducted by the city to comply with the December 1, 2011 compliance schedule requirements, including study results and recommendations, and is considered the Plan.

Arsenic, Cyanide and Hexavalent Chromium Study Plan

The city developed a Study Plan (Attachment A) to evaluate possible sources of arsenic, cyanide and heaxavalent chromium and to track each constituent through the water system and wastewater system. Data can also be used to evaluate possible control strategies and support regulatory options for compliance. Areas of focus for monitoring include: raw water (untreated source water); water treatment facility (WTF) processes; treated water distribution system; wastewater collection system and industrial discharges; WWTF influent and treated effluent; and, Boulder Creek above and below the 75th Street WWTF.

Monitoring Areas of Focus

A description of each area of focus for monitoring is provided below.

Raw Water. The city receives raw water from two separate sources. One source is the Boulder Creek watershed which supplies raw water to the city's Betasso WTF through Barker Reservoir and Lakewood Reservoir. Barker Reservoir is fed by the Middle Boulder Creek watershed and Lakewood Reservoir is primarily fed from Silver Lake, which is located in the city-owned Silver Lake watershed, through the Silver Lake pipeline. Lakewood Reservoir can also receive water directly from North Boulder Creek and Como Creek. The other source of raw water is Boulder Reservoir and the Boulder Feeder Canal which supply raw water to the Boulder Reservoir WTF. The Boulder Feeder Canal is the primary source of water to Boulder Reservoir and is fed by Carter

Lake which receives water from the western slope. There are also four small tributaries which feed into Boulder Reservoir directly.

> ***Monitoring Purpose:*** *The purpose of monitoring raw water is to evaluate natural or human induced (historic mining, point sources, etc.) sources of arsenic, cyanide and hexavalent chromium and to characterize water quality prior to treatment at the city's WTFs. A total of 18 sample locations were used for both sources of water, including individual streams and reservoirs and combined influent to both WTFs.*

Water Treatment Facilities. The city operates two WTFs, the Betasso WTF and Boulder Reservoir WTF, with a majority of the city's potable water treated at the Betasso WTF on an annual basis. The treatment process at both WTFs consists of: pre-disinfection; coagulation; sedimentation; filtration; post-disinfection; corrosion control; and, fluoridation. Fluoride has been added to the city's water treatment process since 1969 when City of Boulder voters approved adding fluoride to drinking water. The city uses hydrofluorosilicic acid at both WTFs to increase the amount of fluoride in drinking water with a goal of 0.9 milligrams per liter (mg/L) of fluoride in the final treated water.

> ***Monitoring Purpose:*** *The purpose of monitoring water treatment facilities is to evaluate the fate of arsenic, cyanide and hexavalent chromium through the treatment process and to evaluate the potential impacts from the addition of hydrofluorosilicic acid, which is used to fluoridate treated water. A total of four sample locations were used to evaluate the effects of water treatment and the process of fluoridation. Two samples of hydrofluorosilicic acid were also collected, one from each WTF hydrofluorosilicic acid source.*

Treated Water Distribution System. The city operates and maintains approximately 475 miles of treated water distribution system piping which feeds potable water from the city's two WTF to City of Boulder water customers.

> ***Monitoring Purpose:*** *The purpose of monitoring treated water in the distribution system is to evaluate the fate of arsenic and hexavalent chromium in the distribution system focusing on high water age sites. A total of two sample locations were used to evaluate the distribution system. Cyanide was not monitored in the distribution system.*

Wastewater Collection System and Industrial Discharges. The city's wastewater collection system collects raw wastewater from residential, commercial and industrial sources. The city's Industrial Pretreatment (IPT) Program regulates (by permit) 12

industries that are considered significant industrial users (SIUs). The types of industries regulated under the IPT Program include metal finishing operations, pharmaceutical manufacturing, food production, higher education, and research and development.

> ***Monitoring Purpose:*** *The purpose of monitoring the wastewater collection system and industrial dischargers is to evaluate potential contributions of arsenic, hexavalent chromium and cyanide from regulated industries and characterize wastewater in the collection system. Discharge samples from six industries and IPT Program permitted facilities were collected. Samples at three wastewater collection system locations in industrial areas and two collection system sample locations from residential areas were also collected. These monitoring locations are also used to characterize sanitary sewer contributions for local limits evaluations.*

75th Street Wastewater Treatment Facility. The city operates the 75th Street WWTF which has a rated capacity of 25 million gallon per day (mgd). The 75th Street WWTF was upgraded in 2008 to increase the rated capacity and change the treatment process from a trickling filter / solids contact treatment process to an activated sludge treatment process to meet future regulatory requirements. Discharges from the 75th Street WWTF are regulated by Colorado Discharge Permit System permit (No. CO-0024147) for the protection of water quality standards in Boulder Creek, Segment 9. The city's ITP Program also implements local limits to regulate discharges to the WWTF from local industries.

> ***Monitoring Purpose:*** *The purpose of monitoring at the WWTF is to evaluate arsenic, hexavalent chromium and cyanide concentrations coming into the WWTF (influent) and concentrations in the final treated effluent. Samples were collected at one influent and one effluent location.*

Boulder Creek. The city implements a comprehensive water quality monitoring program on Boulder Creek. Water quality is monitored at multiple locations, including locations upstream and downstream of the 75th Street WWTF. Monitoring results have multiple uses including determining compliance with water quality standards and sources of pollution.

> ***Monitoring Purpose.*** *The purpose of monitoring for arsenic in Boulder Creek is to evaluate concentrations of total arsenic upstream of the 75th Street WWTF and downstream of the WWTF. Two locations upstream of the WWTF and three locations downstream of the WWTF were sampled. Cyanide and hexavalent chromium were not sampled.*

Study Plan Implementation

As outlined in the Study Plan, monitoring was implemented for a six month period from May 2011 through October 2011, with data collected once per month, for a total of six sampling events. Although the city has a full service analytical laboratory, the laboratory does not have the capability to analyze cyanide or hexavalent chromium, or achieve a low enough practical quantitation limit (PQL) or method detection limit (MDL) for total arsenic. The city conducted extensive research to identify laboratories that could meet the objectives of the Study Plan and comply with the requirements of the 75th Street CDPS permit and compliance schedule. The following analytical laboratories were used to analyze samples collected under the Study Plan.

- Applied Speciation (Bothell, WA): Arsenic (total)
  - PQL = 0.097 ug/L
  - MDL = 0.01 ug/L

- AccuTest (Wheat Ridge, CO): Hexavalent chromium (dissolved)
  - PQL = 10 ug/L
  - MDL = 5 ug/L

- AccuTest (Wheat Ridge, CO): Cyanide (weak acid dissociable)
  - PQL = 5 ug/L
  - MDL = 3 ug/L

- Montgomery Watson Harza (Monrovia, CA): Hexavalent chromium (dissolved)
  - MRL = 0.02 ug/L (note: this is a method and MRL specific for drinking water analysis)

Analytical Results and Source Characterization

Analytical results for each sampling event and each sample site is presented in Attachment B. Table 2 provides a summary of the data by site.

Table 2 Summary of Arsenic, Cyanide and Hexavalent Chromium Results

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
Betasso WTF Raw Water Sources									
Middle Boulder Creek just above Barker Reservoir and above Beaver Creek confluence	0.059/0.222	0.118	0.182	NS	NS	NS	NS	NS	NS
Town of Nederland WWTF effluent	0.694/0.909	0.822	0.907	NS	NS	NS	NS	NS	NS
Beaver Creek at Middle Boulder Creek just above Barker Reservoir	0.133/0.398	0.229	0.292	NS	NS	NS	NS	NS	NS
Barker Reservoir - composite sample within epilimnion	0.090/0.141	0.108	0.127	NS	NS	NS	NS	NS	NS
Barker Reservoir – composite sample at reservoir bottom	0.179/0.701	0.399	0.586	NS	NS	NS	NS	NS	NS
Como Creek at Lakewood pipeline (prior to	0.074/0.222	0.140	0.191	NS	NS	NS	NS	NS	NS

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
Lakewood Reservoir)									
North Boulder Creek at Lakewood pipeline	0.052/0.197	0.116	0.163	NS	NS	NS	NS	NS	NS
Silver Lake Pipeline at Lakewood Reservoir	0.057/0.165	0.091	0.124	NS	NS	NS	NS	NS	NS
Boulder Reservoir WTF Raw Water Sources									
Boulder Reservoir - 0.5 meters off bottom	0.590/3.660	1.299	2.023	NS	NS	NS	NS	NS	NS
Boulder Reservoir – composite sample within epilimnion	0.488/0.972	0.701	0.925	NS	NS	NS	NS	NS	NS
Unknown ditch to Boulder Reservoir	3.730/3.840	3.785	3.824	NS	NS	NS	NS	NS	NS
Little Dry Creek (tributary)	0.875/1.170	0.996	1.112	NS	NS	NS	NS	NS	NS
Dry Creek (tributary)	1.000/2.610	1.747	2.453	NS	NS	NS	NS	NS	NS
Farmers Ditch (irrigation ditch draining to reservoir)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Betasso WTF Raw Water Intake									
Lakewood Reservoir	0.058/0.169	0.095	0.128	NS	NS	NS	NS	NS	NS

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
raw water tap in the operations laboratory									
Barker Reservoir raw water tap in the Betasso WTF operations laboratory	0.095/0.194	0.128	0.152	NS	NS	NS	NS	NS	NS
Betasso WTF combined raw water	0.071/0.163	0.113	0.147	<5.0/3.0	0.60	1.2	0.029/0.04	0.035	0.038
Boulder Reservoir WTF Raw Water Intake									
Boulder Reservoir raw water	0.928/0.990	0.959	0.981	NS	NS	NS	NS	NS	NS
Boulder Feeder Canal raw water	0.198/0.280	0.237	0.266	NS	NS	NS	NS	NS	NS
Boulder Reservoir – Canal or Basin – Combined Influent	0.187/1.050	0.640	1.012	<5.0/3.0	0.60	1.2	<0.02 – 0.039	0.021	0.037
Betasso WTF Finished Water									
Fluoride additive	59,000[C]			NS	NS	NS	NS	NS	NS
Combined filter effluent (pre fluoridation and post	0.047/0.083	0.066	0.083	NS	NS	NS	NS	NS	NS

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
treatment)									
Betasso finished water (post fluoridation and post treatment)	0.214/0.400	0.294	0.349	NS	NS	NS	0.31/0.35	0.34	0.34
Boulder Reservoir WTF Finished Water									
Fluoride additive	46,250[C]			NS	NS	NS	NS	NS	NS
Combined filter effluent (pre fluoridation and post treatment)	0.127/0.375	0.245	0.344	NS	NS	NS	NS	NS	NS
Boulder Reservoir finished water (post fluoridation and post treatment)	0.239/0.413	0.372	0.431	NS	NS	NS	<0.02/0.047	0.032	0.039
Distribution system – high water age sites									
Distribution system representing Betasso WTF	0.211/0.393	0.322	0.385	NS	NS	NS	0.28/0.39	0.34	0.38
Distribution system representing Boulder Reservoir WTF	0.223/0.472	0.381	0.452	NS	NS	NS	0.027/0.09	0.046	0.063
Industrial Facilities									
Industry discharges (6 regulated	0.391/3.090	0.806	0.860	<3/7	3.2	3.0	<5/46[B]	4.7	4.2

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
industries/ permitted facilities)									
Collection system – industrial area	NS	NS	NS	<3/<3	0	0	<5/21[B]	14	26.2
Collection system – residential area	0.567/0.812	0.690	0.775	<3/3[B]	1.5	2.55	<5/34[B]	17	28.9
75th Street WWTF									
Influent	0.532/0.730	0.618	0.663	<3/3	1	3	<5/5	0.83	1.2
Final effluent	0.362/0.454	0.402	0.427	<3/4	1	2.8	<4/<5	0	0
Boulder Creek									
Boulder Creek above City of Boulder (site BC-CAN)	0.259/0.542	0.422	0.529	NS	NS	NS	NS	NS	NS
Boulder Creek – below City of Boulder and upstream of 75th Street WWTF (site BC-61)	0.425/1.010	0.600	0.739	NS	NS	NS	NS	NS	NS
Boulder Creek at Dry Creek - end of chronic mixing zone below 75th Street WWTF (site BC-	0.456/1.070	0.660	0.844	NS	NS	NS	NS	NS	NS

Sample Location	**Arsenic (Total), ug/L**			**Cyanide (WAD), ug/L**			**Hexavalent Chromium (Dissolved), ug/L**		
	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]	Min/Max	Avg[A]	85th %tile[A]
aDC)									
Boulder Creek at107th Street - 4.5 miles below 75th Street WWTF (site BC-107)	0.576/1.350	0.970	1.170	NS	NS	NS	NS	NS	NS
Boulder Creek below the Coal Creek confluence - (beginning of Segment 10 8.5 miles below 75th Street WWTF (site BC-bCC)	0.641/3.650	1.600	2.444	NS	NS	NS	NS	NS	NS

[A] Values below the PQL (<) were considered a zero value in calculating average and 85th percentile values, consistent with metals data calculations in the CDPS permit.
[B] Maximum value is a "J" qualified value (above MDL but below RL) based on diluted sample due to matrix interference.
[C] Single sample from May 2011 hydrofluorosilicic acid (fluoride additive) shipment for Betasso WTF and March 2011 hydrofluorosilicic acid shipment for Boulder Reservoir WTF.
NS = Not sampled

Below is a summary of monitoring results by parameter for each area of focus.

Total Arsenic

Raw Water. Raw water total arsenic samples were collected at eight locations with a total of 32 samples collected. Results from the 32 samples show total arsenic concentrations above the 0.02 ug/L total arsenic water quality standard at all Betasso WTF and Boulder Reservoir WTF raw water sample locations Betasso WTF raw water

source concentrations ranged from 0.052 ug/L to 0.701 ug/L, with an 85th percentile concentration range of 0.127 ug/L to 0.586 ug/L, with the highest concentrations typically found in Barker Reservoir and Beaver Creek just upstream of Barker Reservoir. The Town of Nederland WWTF, which is a lagoon treatment system, discharges to Barker Reservoir and WWTF effluent concentrations ranged from 0.694 ug/L to 0.909 ug/L.

Total arsenic concentrations in the Boulder Reservoir WTF raw water sources are typically higher than Betasso WTF raw water sources ranging from 0.590 ug/L to 4.840 ug/L. The Unknown Ditch tributary to Boulder Reservoir had the highest measured concentrations ranging from 3.730 ug/L to 3.840 ug/L, but the Unknown Ditch provides a very small portion of water to Boulder Reservoir (0.2% in 2010). The Unknown Ditch collects agricultural irrigation runoff originating from Farmer's Ditch, which runs from Boulder Creek to Boulder Reservoir. The Unknown Ditch flows intermittently during the irrigation season or during major storm events.

For all raw water sample locations total arsenic is assumed to be coming from natural sources, primarily local soils and geology. No significant point or non-point sources of total arsenic were identified beyond the Town of Nederland WWTF effluent.

Water Treatment Facilities. Total arsenic samples were collected at two locations (18 samples) within the Betasso WTF and Boulder Reservoir WTF: 1) post-treatment and pre-fluoridation; and, 2) post-treatment and post-fluoridation. Batches of hydrofluorosilicic acid (fluoride additive) for each WTF were also analyzed (two samples) for total arsenic concentrations by the manufacturer.

Betasso WTF combined influent (raw water from one or more sources prior to treatment) total arsenic concentrations averaged 0.113 ug/L with post-treatment concentrations being lower with a 0.066 ug/L average. The results indicate an approximate 42 percent decrease in total arsenic through the treatment process. Samples collected post-treatment and after the addition of hydrofluorosilicic acid showed an increase in total arsenic with a 0.294 ug/L average. The city's goal is to achieve an average fluoride concentration 0.9 mg/L (i.e. 900 ug/L) in treated water from the Betasso WTF.

Boulder Reservoir WTF combined influent (raw water from either Boulder Reservoir or Boulder Feeder Canal water) concentrations averaged 0.640 ug/L with post-treatment concentrations being lower with an average of 0.245 ug/L. The results indicate an approximate 62 percent decrease in total arsenic through the treatment process. Samples collected post-treatment and after the addition of hydrofluorosilicic acid showed an increase in total arsenic with a 0.336 ug/L average.

Concentrations of total arsenic in the batches of hydrofluorosilicic acid (two samples total – one from each WTF) were 59,000 ug/L for hydrofluorosilicic acid used at the Betasso WTF and 46,250 ug/L for hydrofluorosilicic acid used at the Boulder Reservoir WTF. The city's goal is to achieve an average 0.9 mg/L fluoride concentration in treated water from the Boulder Reservoir WTF.

Treated Water Distribution System. Total arsenic samples were collected at two locations (10 samples) within the distribution system, with one location representative of treated water from the Betasso WTF and one location representative of treated water from the Boulder Reservoir WTF. Both sample sites are considered to be located in high water age areas in the distribution system. Total arsenic in the distribution system representative of water from the Betasso WTF had an average concentration of 0.211 ug/L, which is similar to the finished water concentration of 0.294 ug/L from the Betasso WTF. Total arsenic in the distribution system representative of water from the Boulder Reservoir WTF had an average of 0.381 ug/L, which is similar to the finished water concentration of 0.372 ug/L from the Boulder Reservoir WTF. Distribution system results indicate that total arsenic concentrations do not increase in the distribution system.

Wastewater Collection System and Industrial Discharges. Total arsenic samples were collected from six facilities (six samples) permitted by the city's IPT Program and from two locations (two samples) within the city's collection system representative of domestic waste. Hexavalent chromium concentrations from the six regulated facilities ranged from 0.391 ug/L to 3.090 ug/L, with an average concentration of 0.806 ug/L. The maximum concentration of 3.090 was from a pharmaceutical manufacturing facility with an average daily flow rate of 23,000 gallons per day, which is approximately 0.15 percent of the average daily flow to the 75th Street WWTF. Average daily flow from the six facilities sampled is approximately five percent of the daily flow to the 75th Street WWTF. Total arsenic concentrations in the collection system representative of domestic waste ranged from 0.567 ug/L to 0.812 ug/L, with an average of 0.775 ug/L.

75th Street Wastewater Treatment Facility. Twenty total arsenic samples were collected from the 75th Street WWTF influent and final effluent. Influent concentrations ranged from 0.532 ug/L to 0.730 ug/L, with an average of 0.618 ug/L. Final effluent concentrations ranged from 0.362 to 0.454 ug/Lwith an average of 0.402 ug/L. The average total arsenic removal rate through the WWTF is approximately 35 percent. The proposed total arsenic effluent limit for the 75th Street WWTF, effective June 2013, is 0.023 ug/L, or approximately 17 times lower than the average final effluent concentration.

Boulder Creek. Total arsenic samples were collected from two locations above the 75th Street WWTF. The most upstream location (site BC-Can) is located at the base of Boulder Canyon on the western edge of the City of Boulder just prior to the City of Boulder urban area (approximately eight miles above the 75th Street WWTF). Total arsenic concentrations (5 samples) at this site ranged from 0.259 ug/L to 0.542 ug/L, with an average concentration of 0.422 ug/L and an 85th percentile concentration of 0.529 ug/L. Samples (5 samples) were also collected in Boulder Creek approximately 1.5 mile above the 75th Street WWTF at the eastern edge of the City of Boulder urbanized area (site BC-61). Total arsenic concentrations ranged from 0.425 ug/L to 1.010 ug/L, with an average concentration of 0.600 ug/L and an 85th percentile concentration of 0.739 ug/L. This location is considered background for the 75th Street WWTF.

Total arsenic samples were also collected from three locations below the 75th Street WWTF. The first location (site BC-aDC) is approximately 1.7 miles below the 75th Street WWTF at the end of the chronic mixing zone. Total arsenic concentrations (5 samples) ranged from 0.456 ug/L to 1.070 ug/L, with an average concentration of 0.660 ug/L and an 85th percentile concentration of 0.844 ug/L. The second location (site BC-107) is located approximately 4.5 miles below the 75th Street WWTF and total arsenic concentrations (5 samples) ranged from 0.576 ug/L to 1.350 ug/L, with an average concentration of 0.970 ug/L and an 85th percentile concentration of 1.170 ug/L. The most downstream location (site BC-bCC) is located approximately 8.5 miles below the 75th Street WWTF and total arsenic concentrations (5 samples) ranged from 0.641 ug/L to 3.650 ug/L, with an average concentration of 1.600 ug/L and an 85th percentile concentration of 2.444 ug/L.

Total arsenic concentrations in all samples collected exceeded the 0.02 ug/L water quality standard by at least one order of magnitude, even at sample sites upstream of the 75th Street WWTF. Based on a preliminary comparison of total arsenic concentrations above the 75th Street WWTF (site BC-61) and below the 75th Street WWTF at the end of the chronic missing zone (site BC-aDC), total arsenic concentrations do not appear to be affected by the 75th WWTF discharge. The average and 85th percentile concentration above the WWTF (site BC-61) is 0.600 ug/L and 0.739 ug/L, respectively, while the average concentration below the WWTF (site (BC-aDC) is 0.660 ug/L and the 85th percentile concentration is 0.844 ug/L.

Cyanide (WAD)

Raw Water. Cyanide samples were collected at one location (10 samples) in the Betasso WTF raw water influent and Boulder Reservoir WTF raw water influent (prior to

treatment) with samples representative of the raw water source being used at the time of the sampling. Raw water cyanide concentrations at both the Betasso WTF and Boulder Reservoir WTF ranged from less than 5.0 ug/L to 3.0 ug/L (equal to the MLD). All sample results were below the proposed 75th Street effluent limit of 5.4 ug/L and below the cyanide water quality standard of 5.0 ug/L.

Wastewater Collection System and Industrial Discharges. Cyanide samples were collected from nine facilities (nine samples) permitted by the city's IPT Program, two locations (two samples) within the collection system representative of domestic waste and three locations in the collection system representative of industrial and commercial waste. Cyanide concentrations from permitted facilities ranged from less than 3.0 ug/L to 7.0 ug/L, with an average of 3.2 ug/L. The 7.0 ug/L cyanide concentration is from a pharmaceutical manufacturing facility with an average daily flow rate of 23,000 gallons per day, or 0.15 percent of the daily 75th Street WWTF influent flow rate. None of the sample facilities are regulated for cyanide.

Cyanide concentrations from the collection system representative of domestic waste ranged from less than 3.0 ug/L to 3.0 ug/L, with an average concentration of 1.0 ug/L. Concentrations from the collection system representative of industrial and commercial waste were all less than 3.0 ug/L. All collection system cyanide concentrations were below the 5.0 ug/L cyanide water quality standard.

75th Street Wastewater Treatment Facility. Three cyanide samples were collected from the 75th Street WWTF influent and three sample from the final effluent. Influent concentrations ranged from less than 3.0 ug/L to 3.0 ug/L (MDL), with an average concentration of 1.0 ug/L. Final effluent concentrations ranged from less than 3.0 ug/L to 4.0 ug/L, with an average of 1.0 ug/L. All final effluent cyanide concentrations are below the proposed cyanide effluent limit of 5.4 ug/L effective June 2013.

Hexavalent Chromium

Water Treatment Facilities. Hexavalent chromium samples were collected at one location (10 samples) within the Betasso WTF and Boulder Reservoir WTF post treatment and post fluoridation. Betasso WTF combined influent (raw water from one or more sources prior to treatment) hexavalent chromium concentrations averaged 0.035 ug/L with the post treatment average concentration approximately equal at 0.034 ug/L. Boulder Reservoir WTF combined influent (raw water from either Boulder Reservoir or Boulder Feeder Canal) concentrations averaged 0.021 ug/L with the post treatment concentration average slightly higher at 0.032 ug/L. No known sources of hexavalent

chromium are in the WTF treatment process and the small increase in concentration is within the variability of the analytical method.

Treated Water Distribution System. Hexavalent chromium samples were collected at two locations (10 samples) within the distribution system, with one location representative of treated water from the Betasso WTF and one location representative of treated water from the Boulder Reservoir WTF. Both sample sites are considered to be located in high water age areas in the distribution system. Hexavalent chromium in the distribution system representative of water from the Betasso WTF had an average concentration of 0.340 ug/L, which is equal to the finished water concentration of 0.340 ug/L from the Betasso WTF. Hexavalent chromium in the distribution system representative of water from the Boulder Reservoir WTF had an average of 0.046 ug/L, which is similar to the finished water concentration of 0.032 ug/L from the Boulder Reservoir WTF. Distribution system results indicate that hexavalent chromium concentrations do not increase in the distribution system.

Wastewater Collection System and Industrial Discharges. Hexavalent chromium samples were collected from nine facilities (nine samples) permitted by the city's IPT Program, two locations (two samples) within the collection system representative of domestic waste and three locations (three samples) within the collection system representative of industrial and commercial waste. Sources of hexavalent chromium can be difficult to identify due to the ability of total chromium to oxidize and convert to hexavalent chromium in the environment. Due to the matrix of industrial discharge and sanitary sewer collection system samples matrix interferences occurred with some samples and required those samples be diluted, which increased the MDL and RL. These samples tended to show higher concentrations of hexavalent chromium.

Concentrations of hexavalent chromium samples collected from the six regulated facilities ranged from less than 5 ug/L to 46 ug/L, with an average of 17 ug/L. The 46 ug/L concentration is from a government research facility at a flow rate of 61,000 gallons per day, or 0.4 percent of the daily 75th Street WWTF influent flow rate. Concentrations of hexavalent chromium in the sanitary collection system representative of industrial and commercial waste ranged from less than 5 ug/L to 21 ug/L, with an average of 14 ug/L. Concentrations from the collection system representative of domestic waste ranged from less than 5 ug/L to 34 ug/L, with an average of 17 ug/L.

Of the 23 hexavalent chromium samples collected from regulated facilities and the collection system, only four of the samples showed concentrations above the 17 ug/L acute water quality standard. Based on the low flow rate of the six sample facilities the overall contribution is small (less than 6 percent) and the load is not considered to be

significant. None of the sampled facilities are currently regulated for hexavalent chromium.

75th Street Wastewater Treatment Facility75th Street Wastewater Treatment Facility. Six 75th Street WWTF influent and 27 hexavalent chromium final effluent samples were collected. Hexavalent chromium concentrations ranged from less than 5.0 ug/L to 5.0 ug/L (MDL), with an average concentration of 0.83 ug/L. All final effluent concentrations were than the MDL range of 4.0 ug/L and 5.0 ug/L. All final effluent hexavalent chromium concentrations were below the proposed 17 ug/L daily maximum hexavalent chromium effluent limit and 12 ug/l 30 day average effluent limit.

Conclusions and Next Steps

No sources of hexavalent chromium and cyanide were identified based on comprehensive sampling from May through October 2011. Based on 75th Street WWTF final effluent hexavalent chromium concentrations the city anticipates being able to comply with the proposed 17 ug/L daily maximum effluent limit and the 12 ug/L 30 day average effluent limit. The city also expects to meet the proposed cyanide daily maximum effluent limit of 5.4 ug/L based on WWTF final effluent data.

Background concentrations of total arsenic in the city's raw water sources exceed the 0.02 ug/L water quality standard by one to two orders of magnitude. Concentrations of total arsenic above the city's 75th Street WWTF also exceed the standard by an order of magnitude, and the discharge from the city's 75th Street WWTF does not appear to have an impact on Boulder Creek below the WWTF. 75th Street WWTF final effluent total arsenic concentrations do exceed the proposed total arsenic effluent limit of 0.023 ug/L by an order of magnitude.

The city will continue to evaluate arsenic, cyanide and hexavalent chromium water quality data and evaluate potential treatment options in preparation for the next compliance schedule progress report due to the Division by June 1, 2012. While technologies such as chemical precipitation, adsorption, ion exchange, and reverse osmosis may be available to remove heavy metals from wastewater, the city is not aware of any municipal wastewater facilities that employ such technologies for removal of arsenic, specifically to such low levels. The city will also evaluate regulatory options to address the inability of the 75th Street WWTF to meet the proposed total arsenic effluent limit.

Arsenic Temporary Modification

Based on total arsenic study results, ambient (background) arsenic concentrations in the city's raw water sources and Boulder Creek above the city's 75th Street WWTF exceed the total arsenic water quality standard by an order of magnitude. The city is considering requesting a Temporary Modification for total arsenic to be applied to Segment 9 of Boulder Creek, which is the receiving water for the city's 75th Street WWTF. It is the city's opinion that available data support a temporary modification and meet the *Conditions Justifying a Temporary Modification* as outlined in Regulation #31 (Basic Standards) under Section 31.7(3)(a) and (b). Section 31.7(3) reads as follows:

(a) Conditions Justifying a Temporary Modification

The Commission may grant a temporary modification if:

(i) an existing permitted discharge has a demonstrated or predicted water quality-based effluent limit compliance problem, and

(ii) one of the following is shown to exist:

(A) there is significant uncertainty regarding the water quality standard necessary to protect current and/or future uses.

(B) there is significant uncertainty regarding the extent to which existing quality is the result of natural or irreversible human-induced conditions.

(C) there is significant uncertainty regarding the timing of implementing attainable source controls or treatment (this subsection C is repealed effective 1/1/2013).

(b) Adequate Supporting Information

Adequate supporting information must be submitted including a justification for the interim narrative or numeric value, wherever possible raw data describing effluent and ambient quality, a plan for eliminating the need for the temporary modification, and a justification for the proposed expiration date.

Based on the Colorado Water Quality Control Commission (Commission) Rule Making Hearing (RMH) schedule, the next Temporary Modification RMH is schedule for December 10, 2012. The following schedule would be implemented to meet the December 10, 2012 RMH schedule.

- Notify the Commission of the total arsenic Temporary Modification proposal by June 1, 2012.
- Submit Statement of Basis and Purpose language for the total arsenic Temporary Modification by July 15, 2012.
- Commission Notice approved August 13, 2012.
- Temporary Modification RMH on December 10, 2012.

Under the Temporary Modification, the city would work with the Division to identify additional studies and regulatory options to address natural background concentrations of total arsenic.

C I T Y O F B O U L D E R
WATER RESOURCES ADVISORY BOARD
AGENDA ITEM

MEETING DATE: May 21, 2007

AGENDA TITLE: Evaluation of Water Treatment Fluoridation Chemicals

PRESENTER/S:
Robert E. Williams – Director of Public Work for Utilities
Randy Crittenden – Water Treatment Coordinator
Suzanne Givler – Process Optimization Specialist

EXECUTIVE SUMMARY:

This report is a staff evaluation of available fluoride-containing water treatment additives. Currently City of Boulder water is fluoridated using fluorosilicic acid. Sodium silicofluoride is a dry fluoride-containing water treatment additive that has fewer contaminants than fluorosilicic acid. Both products meet all regulations.

Sodium silicofluoride can be purchased as 50-pound bags or as 2,000- or 2,500-pound supersacks. The cost to convert the City of Boulder feed system to a dry feed system that can feed sodium silicofluoride is estimated to be:

Total Operation and Maintenance Cost for Each Fluoride Chemical		
Chemical	**Capital Cost, including forklift training and respirator program**	**O&M Cost: Chemical, Labor, Forklift Training, Respirator Training**
Fluorosilicic Acid	$38,750 for tank replacement + unknown extras + piping, unknown date	$68,600 (chemical cost only)
Sodium Fluoride Bag System	$847,100	$107,000
Sodium Silicofluoride Bag System	$847,100	$63,400 ($5,200 chemical savings over FSA)
Sodium Fluoride Supersack System	$1,049,100	$102,100
Sodium Silicofluoride Supersack System	$1,049,100	$60,000 ($8,600 chemical savings over FSA)

STAFF RECOMMENDATION:
None at this time.

COUNCIL FILTER IMPACTS:
None at this time.

OTHER IMPACTS:
None at this time.

BOARD AND COMMISSION FEEDBACK:
No action requested at this time.

PUBLIC FEEDBACK:
None at this time.

ANALYSIS:
None at this time.

MATRIX OF OPTIONS:
Please see attached report.

ATTACHMENTS:
City of Boulder Water Treatment Fluoride Additive Evaluation and Appendices

City of Boulder Water Treatment Fluoride Additive Evaluation

May 2007

Staff:
Ned Williams, Director of Public Works for Utilities
Randy Crittenden, Water Treatment Coordinator
Suzanne Givler, Process Optimization Specialist

Fluoride Additive Evaluation
May 2007

INTRODUCTION

The City of Boulder has added fluoride to municipal drinking water since voters approved fluoride addition in 1969. From 1969 until the 1990s, the chemical used for fluoride addition was sodium silicofluoride, a dry crystalline chemical supplied in 50-pound bags. Brown and Caldwell Consultants stated in the 1990 City of Boulder Treated Water Master Plan, Phase I:

> The existing fluoride feed system requires bags of fluoride to be manually emptied into a hopper. This is a very labor intensive practice, and the employee responsible for handling the bags may be exposed to excessive fluoride dust. Also, ventilation in the bag feed room is inadequate for dust control.
>
> It is recommended that the existing fluoride feed system be replaced with a system utilizing a bulk storage system with automatic feed.

In 1993 improvements were completed to the Betasso Water Treatment Plant that allowed for bulk storage and feeding of fluorosilicic acid, a liquid fluoride chemical. These improvements were completed for the Boulder Reservoir Water Treatment Plant (a.k.a. 63rd Street Water Treatment Plant) in 1998.

In 2007, City staff reviewed current fluoridation practices and researched advantages and disadvantages of switching to another fluoridation chemical.

REGULATIONS

The Colorado Department of Public Health and Environment, *Design Criteria for Potable Water Systems*, requires that "any chemical additives or materials that come in contact with the water will be certified under the ANSI standard 60 or 61, respectively." The American National Standards Institute (ANSI) accredits the National Sanitation Foundation (NSF) to develop American National Standards.

NSF/ANSI Standard 60 covers chemicals which are used to treat drinking water, and NSF/ANSI Standard 61 covers devices, components, and materials which come into contact with drinking water.

For contaminants regulated by the EPA, the NSF/ANSI Standard 60 sets a single product allowable concentration not to exceed ten percent of the Maximum Contaminant Level (MCL). The single product allowable concentration is the concentration of the contaminant present at the tap in any consumer's home. Thus, any fluoridation chemicals meeting NSF/ANSI Standard 60 will never add greater than one-tenth of the MCL of any contaminant to finished water.

There are three fluoride-containing water treatment additives that are approved for use under the NSF/ANSI Standard 60: Drinking Water Treatment Chemicals. These are fluorosilicic acid,

sodium silicofluoride, and sodium fluoride. Pure fluoride ion solutions are not available. Fluorine is the most reactive of all the elements and elemental fluoride is never found by itself in nature.

The City of Boulder further specifies that that the fluorosilicic acid supplied must conform to AWWA Standard B703-00. AWWA has been developing standards since 1908 that are used throughout the world. Although conformance to AWWA standards is not mandatory, they are industry standards that many utilities and regulatory agencies choose to enforce.

The Colorado Department of Public Health and Environment (CDPHE) sets the Maximum Contaminant Level (MCL) and the Maximum Contaminant Level Goal (MCLG) for fluoride in drinking water at 4.0 mg/L. The EPA defines an MCL as "the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards." The EPA defines an MCLG as "the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals."

The CDPHE sets the Secondary Maximum Contaminant Level (SMCL) for fluoride at 2.0 mg/L. SMCLs are not enforceable and are intended as guidelines for chemicals that primarily affect the aesthetic qualities of drinking water. When the fluoride level exceeds the SMCL, public notification is required.

CHEMICALS

Fluorosilicic Acid (aka Fluosilicic Acid or Hydrofluorosilicic Acid or FSA):

According to "Water Fluoridation and the Environment: Current Perspective in the United States," published in the October, 2004 *International Journal of Occupational and Environmental Health*, roughly 59% of communities fluoridating their water supply use fluorosilicic acid and about 63% of citizens drinking fluoridated water are drinking water treated with fluorosilicic acid. Kip Duchon, Fluoridation Engineer at the Center for Disease Control, reported in 2006 that, currently, closer to 77% of the fluoride market is for fluorosilicic acid.

The AWWA standard for fluorosilicic acid is standard B703-00. AWWA Standard B703-00 does not specify a maximum allowable heavy metal concentration for fluorosilicic acid.

The City of Boulder feeds fluorosilicic acid provided by Lucier Chemical Industries (LCI) in Jacksonville Beach, Florida (see Appendix A for a list of other Front Range communities feeding fluorosilicic acid. See Appendix B for a picture of the fluorosilicic acid feed system at Betasso Water Treatment Plant). LCI's Product Data Sheet states that their fluorosilicic acid heavy metals concentration (as Lead) will never exceed 200 mg/L.

Certificates of Analysis provided with product deliveries in 2006 and 2007 show the following concentrations of arsenic and lead:

Date of Analysis	Date of Delivery	Arsenic Concentration (mg/L)	Lead Concentration (mg/L)
5/22/06	6/7/06 – Betasso	20.75	<1 (undetectable)
6/9/06	6/26/06 – 63rd	26.00	<1 (undetectable)
7/3/06	7/27/06 – Betasso	30.75	<1 (undetectable)
1/31/07	2/13/07 – Betasso	45.50	<1 (undetectable)
4/2/07	4/24/07 – Betasso	In analysis	12.7

An arsenic concentration of 45.5 mg/L can result in a maximum estimated finished water arsenic addition of 0.18 µg/L (see Appendix C for calculations). The maximum contaminant level for arsenic specified by the EPA is 10 µg/L. A lead concentration of 12.7 mg/L can result in a maximum estimated finished water lead addition of 0.05 µg/L (see Appendix C for calculations). The action level for lead specified by the EPA is 15 µg/L.

In September 2005, the Colorado Department of Public Health and Environment published "A Message from the Prevention Services Division to Public Water Systems that Fluoridate" which states:

> On September 1, 2005, the Colorado Department of Public Health and Environment (CDPHE), Prevention Services Division, Oral Health Unit notified all Community Public Water Systems (PWS) in the State that fluoridate the public drinking water they produce that there may be a potential disruption to their fluoride supply, and provided recommendations to maximize their current supplies. The Centers for Disease Control and Prevention (CDC) has identified that there is a disruption to the fluoride products market, resulting in the potential for shortages. A major producer of hydrofluorosilicic acid, U.S. Agrichemicals, is withdrawing from the market, and remaining producers do not have sufficient fluoride recovery capacity to replace the lost production.

In 2007, Kip Duchon (CDC) reported that the shortage was temporary, and other producers are now filling the need for fluorosilicic acid.

The City of Boulder's cost for fluorosilicic acid has changed as follows:

Year	Cost per ton	% Increase per ton	Annual cost	% Increase in annual cost	# of deliveries per year
2005	$268.00		$29,162		4 (Bet), 1 (63rd)
2006	$391.00	45.9%	$39,094	34.1%	2 (Bet), 1 (63rd)
2007	$500.00	27.9%			2 (Bet) to date

In 2006 and before, fluorosilicic acid deliveries arrived approximately four to ten days after they were ordered by city staff. In 2007 city staff was notified by LCI that this could increase to 21 days.

The City's fluorosilicic acid tanks have an expected life of 20 years and the piping has an expected life of 10 years. The tank and piping at Betasso Water Treatment Plant is 14 years old and the tank and piping at Boulder Reservoir Water Treatment Plant is 9 years old. The City of Fort Collins also feeds fluorosilicic acid and has a similar feed system. They replaced their tank at 14 years and their feed piping at less than 10 years. Estimated costs for tank replacement are $21,250 for the Betasso tank and $17,500 for the Boulder Reservoir tank. These costs are for the tank only and not for any additional parts such as nozzles, ladders, etc. It is unclear whether these costs include assembly of the tank onsite.

Sodium Silicofluoride (aka Sodium Fluorosilicate):

According to the October, 2004 article from the *International Journal of Occupational and Environmental Health*, roughly 16.3% of communities fluoridating their water supply use sodium silicofluoride and about 28.2% of citizens drinking fluoridated water are drinking water treated with sodium silicofluoride. Kip Duchon (CDC) reported in 2006 that, currently, 15% of the fluoride market is for sodium silicofluoride.

The AWWA standard for sodium silicofluoride is standard B702-99. This standard requires that sodium silicofluoride have a heavy metal concentration of less than 500 mg/L.

Sodium silicofluoride is used by several Front Range communities (see Appendix A for a list of communities). Denver Water, who uses sodium silicofluoride at two of their three plants, forwarded to City staff two analyses performed on their product that showed the concentration of the three heavy metals of interest to all be below detection limits of the method used:

Date of Analysis	Arsenic Concentration (mg/L)	Lead Concentration (mg/L)	Method Used
7/4/03	<1	<1	ICP
9/19/06	<2	<2	ICP-OES

An arsenic concentration of 2 mg/L can result in a maximum estimated finished water arsenic addition of 0.003 µg/L (see Appendix C for calculations). The maximum contaminant level for arsenic specified by the EPA is 10 µg/L. A lead concentration of 2 mg/L can result in a maximum estimated finished water lead addition of 0.003 µg/L (see Appendix C for calculations). The action level for lead specified by the EPA is 15 µg/L.

Kip Duchon (CDC) reported in 2007 that when U.S. Agrichemicals withdrew from the market in 2005, about half of U.S. sodium silicofluoride supplies began to be imported from a producer in China. This resulted in longer lead times when ordering sodium silicofluoride but not a big cost increase.

Staff at Denver Water reported that the cost of their chemical increased 5% from 2006 to 2007, and the lead time required when placing an order increased from 3-4 weeks in 2006 to 8-12 weeks in 2007. Denver Water feeds sodium silicofluoride in bulk. The City of Longmont uses sodium silicofluoride 50-pound bags. They reported that the cost of their chemical did not increase much between 2006 and 2007, but the lead time required when placing an order had

gone from approximately one week to approximately four weeks. A sales representative at a major sodium silicofluoride producer, KC Industries, reported that base cost per ton went from $560 in 2006 to $616 in 2007, a 10% increase. He further reported that cost per ton would increase at least $40 per ton as of July 1, 2007 due to increasing costs of raw material, such as fluorosilicic acid, and energy.

Sodium in drinking water:

Addition of sodium silicofluoride would add up to approximately 0.37 mg/L of sodium to the finished water (see Appendix C for calculations).

Sodium data for Betasso and the Reservoir Water Treatment Plants is as follows:

Betasso Water Treatment Plant

Sample Location	Date	Sodium (mg/L)	Source
Betasso Finished Water *	5/9/06	3.8	18 cfs Lakewood 9 cfs Barker
Betasso Filter Flume	11/29/05	1.5	6 cfs Lakewood 5 cfs Barker

* Sample location changed

63rd Street Water Treatment Plant

Sample Location	Date	Sodium (mg/L)
63rd Boulder Reservoir Basin	1/2/07	6.0
63rd Boulder Reservoir Basin	12/4/06	5.9
63rd Boulder Reservoir Basin	11/21/06	5.8
63rd Boulder Reservoir Basin	6/5/06	6.8
63rd Boulder Reservoir Basin	4/4/06	10.6
63rd Boulder Reservoir Basin	3/6/06	9.6
63rd Boulder Reservoir Basin	1/31/06	9.9
63rd Boulder Feeder Canal	10/2/06	5.8
63rd Boulder Feeder Canal	9/5/06	2.4
63rd Boulder Feeder Canal	8/21/06	2.5
63rd Boulder Feeder Canal	10/3/05	3.2
63rd Finished Water	5/9/06	18 (Basin source)
63rd Finished Water	11/29/05	14.8 (Basin source)

The EPA has set a sodium Drinking Water Equivalent Level (DWEL) of 20 mg/L. This DWEL is defined in the EPA's *Contaminant Candidate List Regulatory Determination Support Document for Sodium* (2003) as "a non-enforceable guidance level considered protective against non-carcinogenic adverse health effects and is based on an American Heart Association recommendation issued in 1965." However, EPA states on their *Sodium in Drinking Water* webpage (http://www.epa.gov/safewater/contaminants/unregulated/sodium.html), "EPA believes this guidance level for sodium needs updating, and is probably low. If a health benchmark for

drinking water were established using current information and current drinking water health assessment procedures, it would likely be higher."

EPA does not regulate sodium with a National Primary Drinking Water Regulation. In the *Contaminant Candidate List Regulatory Determination Support Document for Sodium* it is stated that this is because the EPA has found that regulation "may not present a meaningful opportunity for health risk reduction for persons served by public water systems." This document further states, regarding hypertension and sodium regulation:

> "The weight of evidence favors the conclusion that high sodium intakes can have an adverse effect on blood pressure, especially for sodium-hypertensives. Hypertension affects almost 50 million people in the United States, and along with factors such as body weight, alcohol intake, and cholesterol, is a risk factor for heart disease. However, hypertension is influenced more by lifestyle, behavior, and other nutrient intake than by sodium intake.
>
> "Sodium is known to occur in public water systems and in a few cases at levels of public health concern, particularly for salt-sensitive hypertensives. However, at these same concentrations, taste is generally affected and would likely lead consumers to decrease consumption. In addition, when compared with other intake routes, sodium from drinking water has a minor impact. For these reasons, regulation of sodium is unlikely to present a meaningful opportunity for health risk reduction for persons served by public water systems. However, EPA may choose to issue a non-enforceable Drinking Water Advisory, based on current health effects, taste effects, and occurrence data, to provide guidance to communities that may be exposed to elevated concentrations of sodium chloride or other sodium salts in their drinking water. In addition, under EPA-required sodium monitoring, test results must be reported to State and local public health authorities, who may advise sensitive populations of any risk they may face."

The State of Colorado requires annual monitoring for sodium. However, there is no Maximum Contaminant Level, Secondary Contaminant Level, Treatment Technology, or Action Level for sodium specified by the State.

Sodium fluoride:

According to the October, 2004 article from the *International Journal of Occupational and Environmental Health*, roughly 24.9% of communities fluoridating their water supply use sodium fluoride and about 9.2% of citizens drinking fluoridated water are drinking water treated with sodium fluoride. Kip Duchon (CDC) reported in 2006 that, currently, 8% of the fluoride market is for sodium silicofluoride.

The AWWA standard for sodium fluoride is standard B701-99. This standard requires that sodium fluoride have a heavy metal concentration of less than 400 mg/L.

Thatcher Chemical, a company that supplies sodium fluoride, informed City staff that the manufacturer (in China) reported typical heavy metal concentrations in the sodium fluoride of 50 mg/L lead and 40 mg/L arsenic. City staff was unable to obtain any analyses of sodium fluoride showing actual heavy metals concentrations.

The Town of Hayden in Colorado in northwest Colorado uses sodium fluoride. They reported that the cost of their chemical did not increase between 2006 and 2007. Also, the lead time required to place an order did not increase. Their orders are relatively small, at approximately 20 bags per order.

Sodium fluoride is more expensive than the other dry form, sodium silicofluoride (see Appendix A for estimated chemical costs).

Pharmaceutical grade:

Sodium fluoride is also available in ACS/Reagent (American Chemical Society) and USP (U.S. Pharmaceutical) grades. ACS/Reagent grade chemicals are generally intended for laboratory and other analytical applications. USP grade chemicals are suitable for food, drug, or medicinal use and also may be used for most laboratory purposes. NSF grade chemicals are specifically intended for use in drinking water and thus specify that any contaminant regulated by the EPA be specifically tested for and meet certain criteria.

Sodium fluoride meeting ACS specifications must have a heavy metals (as Pb) concentration of less than 30 mg/L. Sodium fluoride meeting USP specifications also must have a heavy metals (as Pb) concentration of less than 30 mg/L. USP-grade sodium fluoride is a powder. The AWWA standard for sodium fluoride specifies that a coarse crystalline grade be used. Using the USP-grade powder could potentially create more dust, which is a hazard to water treatment plant operators. It is the understanding of City staff that there are no communities feeding ACS- or USP-grade sodium fluoride.

It is unclear whether ACS- or USP-grade sodium fluoride could be purchased in the quantities required in order to be used as the fluoride source by the City of Boulder.

It is possible that the Colorado Department of Public Health and the Environment would approve feeding ACS- or USP-grade sodium fluoride even though these grades do not meet NSF/ANSI certification. Kip Duchon (CDC) reported in 2007 that “the biggest concern and motivation for NSF certification was to ensure maintenance of the product quality during chemical delivery, for it has been documented that the overwhelming amount of impurities occur as a function of transport and distribution. USP provides no protection during distribution and transportation. My opinion is that USP provides much less protection for the consumer.” He further reported that, of the three grades of sodium fluoride available (NSF, USP, and ACS), “Each is slightly different, but they result in a comparable level of impurities.”

Sodium in drinking water:

Addition of sodium fluoride would add up to approximately 1.1 mg/L of sodium to the finished water (see Appendix C for calculations). (See further discussion about sodium above)

SODIUM SILICOFLUORIDE SELECTED FOR FUTHER CONSIDERATION

Sodium silicofluoride is the least expensive of the fluoridation chemicals used in water treatment and it is used by several municipalities along the Front Range. Thus, City staff selected sodium silicofluoride for further consideration.

PRICING FOR CONVERSION TO SODIUM SILICOFLUORIDE

Black and Veatch developed a cost estimate for converting the existing fluorosilicic acid feed systems to dry chemical feed systems (see Appendix D for Black and Veatch's full report). Sodium silicofluoride may be purchased as 50-pound bags or as 2500-pound or 1-ton supersacks (see Appendix B for a picture of a bag feed system and a supersack feed system).

Black and Veatch determined that the existing chlorine scrubber room at Betasso Water Treatment Plant could be used to house the feed equipment and two pallets of fluoride. An additional storage building would be needed to house additional pallets. Black and Veatch determined that the existing chlorine scrubber room at the Boulder Reservoir Water Treatment Plant is sufficient to house the feed equipment and all pallets.

Bag Feed System

Costs provided by Black and Veatch for addition of a dry fluoride bag feed system include the cost for renovation of the scrubber rooms; new feed equipment including a dry feeder, storage hopper, solution tank, two pumps, piping, electrical, and instrumentation; storage racks for dry fluoride pallets; elevated feed platforms; and a new building at Betasso Water Treatment Plant. Costs were estimated as:

Item	**Cost**
Betasso Water Treatment Plant: Renovation of Scrubber Room	$155,800
Betasso Water Treatment Plant: New Storage Building	$92,000
Reservoir Water Treatment Plant: Renovation of Scrubber Room	$149,500
Contingency (40%)	$159,000
General requirements (10%)	$56,000
TOTAL	**$613,000**

In addition, the City of Boulder would need to purchase two forklifts for moving and lifting pallets. Final project capital costs estimated by Black and Veatch were:

Total Capital Cost for Conversion to Dry Chemical Bag Feed System	
Betasso Water Treatment Plant Construction Cost	$382,000
63rd Street Water Treatment Plant Construction Cost	$231,000
Two Owner Purchased Forklifts	$53,000
Engineering Costs (design, bid, construction administration, inspection)	$133,000
TOTAL	**$799,000**

Black and Veatch estimated 2007 fluoride chemical costs as:

Chemical	**2007 Estimated Chemical Cost**
Fluorosilicic Acid	$68,600
Sodium Fluoride	$75,200
Sodium Silicofluoride	$33,100

Black and Veatch estimated increased operation and maintenance costs of a dry fluoride bag feed system due to operators manually loading bags of fluoride into the storage hoppers as:

Chemical	**Number of 50-Lb. Bags**	**O&M**
Sodium Fluoride	2300/year	$4,900/year
Sodium Silicofluoride	1730/year	$3,350/year

Final operation and maintenance costs estimated by Black and Veatch compared to operation and maintenance costs for the current fluorosilicic acid feed system were calculated as:

Annual Operation and Maintenance Cost for Each Chemical			
Chemical	Chemical Cost	O&M Cost	Annual Cost
Fluorosilicic Acid (FSA)	$68,600	$0	$68,600
Sodium Fluoride bag system	$75,200	$4,900	$80,100
Sodium Silicofluoride bag system	$33,100	$3,350	$36,450 ($32,150 savings over FSA)

Supersack System

Kip Duchon (CDC) recommended to City staff that the supersack system be considered to minimize handling and labor issues if the City decides to switch to sodium silicofluoride.

Costs provided by Black and Veatch for addition of a dry fluoride supersack system include the cost for renovation of the scrubber rooms; new feed equipment including a dry feeder, solution tank, superstructure, two pumps, piping, electrical, and instrumentation; storage racks for dry fluoride pallets; and a new building at Betasso Water Treatment Plant. Costs were estimated as:

Item	**Cost**
Betasso Water Treatment Plant: Renovation of Scrubber Room	$208,750
Betasso Water Treatment Plant: New Storage Building	$92,000
Reservoir Water Treatment Plant: Renovation of Scrubber Room	$206,250
Contingency (40%)	$203,000
General requirements (10%)	$71,000
TOTAL	**$781,000**

As for the bag feed system, the City of Boulder would need to purchase two forklifts for moving and lifting pallets. Final project capital costs estimated by Black and Veatch were:

Total Capital Cost for Conversion to Dry Chemical Supersack Feed System	
Betasso Water Treatment Plant Construction Cost	$463,000
63rd Street Water Treatment Plant Construction Cost	$318,000
Two Owner Purchased Forklifts	$53,000
Engineering Costs (design, bid, construction administration, inspection)	$167,000
TOTAL	**$1,001,000**

Final operation and maintenance costs estimated by Black and Veatch compared to operation and maintenance costs for the current fluorosilicic acid feed system were calculated as:

Annual Operation and Maintenance Cost for Each Chemical			
Chemical	Chemical Cost	O&M Cost	Annual Cost
Fluorosilicic Acid	$68,600	$0	$68,600
Sodium Fluoride supersack system	$75,200	$0	$75,200
Sodium Silicofluoride supersack system	$33,100	$0	$33,100 ($35,500 savings over FSA)

Black and Veatch indicated in their report that sodium fluoride supersack systems are somewhat rare and thus the chemical cost used in the above table may be incorrect.

Forklift Training

A forklift will be required at each plant for unloading pallets from the truck at deliveries, moving the pallets to a storage area, and then moving them when they are ready to be used. For a bag system, the pallets are lifted onto a platform from which operators can empty bags into the dry feed hopper. For a supersack system, the supersacks are lifted from the pallets onto the dry feeders.

OSHA requires that operators attend a training class that will certify them to operate the forklifts. There are two types of classes. Individual operator training costs $85.00 per student and is a half-day class. Alternatively, one person can be trained to train others for $795.00 for a full-day class.

Forklift training costs were determined for 17 employees: 13 operators and 4 maintenance staff. It was assumed that training would be done onsite at one of the plants on two different days, so that only 10 employees (6 night operators and 4 day operators) would have to come in at a time that is not during their regular shift. The following tables summarize the cost estimates:

Initial forklift training costs			
	Training costs	Overtime costs	Total costs
Individual operator training costs: 17 operators	$1145	$1440 (10 operators, 4 hours each)	$2585
Train the trainer: 1 operator	$795	$1728 (1 operator, 8 hours, plus 10 operators, 4 hours each)	$2523

Forklift training would be required for any new operators. Assuming that a new operator would have to travel to the forklift dealership for training at a time that is not during their regular shift, the cost would be approximately $373 for training costs and salary. In 2005, there was one new operator hire and one internal transfer to operations. In 2006, again there was one new operator hire and one internal transfer to operations. This is an average of two new operators per year, for a total estimated ongoing forklift training cost of $746 per year.

Respirator program

Material Safety Data Sheets for sodium silicofluoride specify that respirators should be worn when handling the chemical.

Poms & Associates Insurance Brokers, Inc., a company that has worked regularly with the City of Boulder in the area of risk assessment and safety training, listed the steps for implementation of a respirator program as:

1. Workplace assessment. This includes air sampling at both plants.
2. Respirator selection for specific chemicals in use.
3. Medical evaluations of affected staff. The minimum requirement for the first year of a respirator program is a pulmonary function and fit test for approximately $150 per person. However Poms & Associates recommends a full pulmonary physical and a fit test in the first year for employee health and safety.
4. Staff training – recognizing hazards, respirator use and maintenance.
5. Annual fit testing, as well as fit testing for new employees or chemicals. The minimum requirement for subsequent years is a fit test for approximately $50 per person. However Poms & Associates recommends a full pulmonary physical in addition to a fit test each year for employee health and safety.

Costs were determined for 21 employees: 13 operators, 2 backup operators, 4 maintenance staff, and 2 supervisors. The following tables summarize the cost estimates:

Estimated startup costs:

Air sampling at both plants	$6000
Poms & Associates providing the City with respirator program paperwork, and a Poms & Associates consultant working onsite to act as a technical advisor, overseeing monitoring, coordinating vendors and quotes, assisting with medical requirements setup, and conducting initial training: 40 hours total	$4800
Pulmonary physicals for 21 employees: $300 per person	$6300
Fit tests for 21 employees: $50 per person	$1050
Respirators: 11 full face ($300 each) and 10 positive air flow ($500 each) for bearded staff members	$8300
Respirator cartridges ($30-40/set) and disposal	$6000
Long length rubber gloves for cutting bags: 10 sets (5 per plant)	$160
Lightweight Rubber-Coated Cloth Aprons for cutting bags: 10 (5 per plant)	$115
Tyvek Cleanroom Garments for covering clothing during maintenance: 50 garments (25 per plant)	$1000
TOTAL	**$33,725**

Annual operation and maintenance costs:

Annual pulmonary physicals and fit tests for 21 employees	$7350
Program review and refresher training: 40 hours onsite by Poms & Associates consultant	$4800
Respirator cartridges ($30-40/set) and disposal	$6000
Long length rubber gloves for cutting bags: 10 sets (5 per plant)	$160
Lightweight Rubber-Coated Cloth Aprons for cutting bags: 10 (5 per plant)	$115
Tyvek Cleanroom Garments for covering clothing during maintenance: 50 garments (25 per plant)	$1000
Time of an internal program administrator	Unknown
TOTAL	**$19,425**

Poms & Associates further recommended that an additional 15% be added to final cost estimates for contingencies, plus an additional 20% for unknown and unforeseeable issues. This gives final estimated costs of:

Estimated startup costs:	**$45,500**
Annual operation and maintenance costs:	**$26,200**

Grants

The Colorado State Fluoridation Program administers federal funds known as Preventative Block Funds. In 2007, the State is expecting to receive $10,000 - $15,000 for this use. The general purpose of these funds is to encourage new plants to install fluoridation. However, State staff said that if the City of Boulder switches to a new fluoride chemical and applies for these funds, the application will be considered based on availability of funding at the time.

The Colorado Department of Local Affairs administers Community Development and Community Services Block Grants. However, these grants are intended for projects that primarily benefit low/moderate income persons and may not be applicable to the City of Boulder.

CONCLUSIONS

City staff researched available fluoridation chemicals and their costs in order to determine if a different chemical may result in higher water quality. City staff focused on sodium silicofluoride because of its low cost, common use in the Front Range area, and low heavy metals contamination. Estimated costs for each chemical are:

Total Operation and Maintenance Cost for Each Fluoride Chemical		
Chemical	**Capital Cost, including forklift training and respirator program**	**O&M Cost: Chemical, Labor, Forklift Training, Respirator Training**
Fluorosilicic Acid	$38,750 tank cost + extras + piping, unknown date	$68,600
Sodium Fluoride Bag System	$847,100	$107,000
Sodium Silicofluoride Bag System	$847,100	$63,400 ($5,200 savings)
Sodium Fluoride Supersack System	$1,049,100	$102,100
Sodium Silicofluoride Supersack System	$1,049,100	$60,000 ($8,600 savings)

Appendices

Appendix A	Fluoride Chemical Comparison
Appendix B	Fluoride Feed System Pictures
Appendix C	Fluoride Concentration Calculations
Appendix D	Black and Veatch's City of Boulder Dry Fluoride Feasibility Study

City of Boulder Water Treatment
Fluoride Chemical Comparison

	Sodium silicofluoride	**Sodium fluoride**		**Fluorosilicic Acid**
Grade	*NSF-certified*	*NSF-certified*	*Pharmaceutical grade*	*NSF-certified*
Chemical form (specified by AWWA standard, where applicable)	Granular. Available in 50-pound bags and 2000-pound or 2500-pound supersacks	Coarse crystalline. Available in 50-pound bags	Powder. Available in sizes up to 250-pounds	Liquid. Available in bulk
Location of manufacture (source: Kip Duchon, CDC Fluoridation Engineer, 2007)	90% domestically produced (predominantly by Mosaic Co.), 5% imported from Mexico, 5% imported from Canada	100% imported from Asia, mostly from China	100% imported from Asia, mostly from China	50% domestically produced. 50% imported from China
Heavy metals contamination levels: AWWA standard	< 500 ppm as Pb	< 400 ppm as Pb	NA	Does not specify
Typical contamination levels	Typical 2 ppm as Pb. LCI/Denver analyses 2003, 2006: As, Cd, Pb undetectable	Typical As < 40 ppm. Typical Cd < 20 ppm. Typical Pb < 50 ppm. No actual analyses data	From manufacturer: Max heavy metals 30 ppm as lead	LCI: < 200 ppm as Pb. Actual LCI 2006-2007 analyses: 20.75 ppm < As < 45.5 ppm; Pb < 1 ppm; Cr = 50 ppm
Meets ANSI-NSF 60?	Yes	Yes	No	Yes
Meets State standards?	Yes	Yes	No	Yes
Aproximate % Fluoride Ion	59	44	44	19
Liquid / Slurry pH	3.5 - 4.0	7.0	7.0	1.0 - 1.2
Estimated annual amount of chemical required for City of Boulder (2006 chemical usage)	37,700 kg (avg 4.5 bags per day total)	50,500 kg (avg 6.1 bags per day total)	50,500 kg (avg 1.2 bags per day total)	119,700 kg
Estimated annual chemical cost for City of Boulder (2006 chemical usage, 2007 cost)	$31,800	$72,300	$1,053,800	$66,000
Front Range communities that use this product	Denver (Foothills, Moffat), Longmont, Lafayette, Louisville, Fort Collins, Greeley, Loveland, Brighton, Arvada, Broomfield, Superior	None along the Front Range. Hayden (northwest Colorado) is the closest known community.	None	Boulder, Fort Collins, Denver (Marston), Aurora, Arvada
Personal Protection Equipment Required.	Ventilation, respirator, gloves, goggles, dust impervious protective suit.	Ventilation, respirator, gloves, safety glasses/face shield, boots, coveralls	Ventilation, respirator, gloves, safety glasses/face shield, boots, coveralls	Ventilation or breathing protection. Gloves, glasses/face shield, overalls, boots.
Respirator training required?	Yes	Yes	Yes	Only maintenance personnel

City of Boulder Water Treatment
Fluoride Feed System Pictures

Current feed system: Fluorosilicic Acid (Betasso pictured)

City of Boulder Water Treatment
Fluoride Feed System Pictures

Example dry chemical bag system (Longmont's sodium silicofluoride feed system pictured)

City of Boulder Water Treatment
Fluoride Feed System Pictures

Dry chemical supersack system (activated carbon feed system pictured with 2000 or 2500 pound supersacks. Courtesy of Black & Veatch).
Note that each plant would only require one feeder.

City of Boulder Water Treatment
Fluoride Concentration Calculations

Attachment B

	Boulder Reservoir Water Treatment Plant @ 63rd St.												
	Date	Fluoride - mg/l		Total Fl Added (mg/L)	FSA			Sodium Silicofluoride			Sodium Fluoride		
		Raw	Finished		mL FSA per L treated water	As ug/L[1]	Lead ug/L[2]	ml Na2SiF6 per L treated water	As or Pb ug/L[3]	Sodium Added (mg/L)	ml NaF per L treated water	As ug/L[4]	Sodium Added (mg/L)
	1/1/2004	0.28	0.99	0.71	0.0031	0.140	0.0391	0.0010	0.0019	0.2865	0.0013	0.052	0.8595
	2/1/2004	0.23	0.91	0.68	0.0029	0.134	0.0374	0.0009	0.0019	0.2744	0.0012	0.050	0.8232
	7/8/2004	0.24	0.92	0.68	0.0029	0.134	0.0374	0.0009	0.0019	0.2744	0.0012	0.050	0.8232
	8/2/2004	0.29	0.88	0.59	0.0026	0.116	0.0325	0.0008	0.0016	0.2381	0.0011	0.043	0.7142
	9/1/2004	0.38	1.04	0.66	0.0029	0.130	0.0363	0.0009	0.0018	0.2663	0.0012	0.048	0.7989
	4/1/2005	0.27	0.95	0.68	0.0029	0.133	0.0372	0.0009	0.0018	0.2730	0.0012	0.049	0.8191
MIN	**7/4/2005**	**0.33**	**0.87**	**0.54**	**0.0023**	**0.105**	**0.0294**	**0.0007**	**0.0015**	**0.2159**	**0.0010**	**0.039**	**0.6476**
	10/2/2005	0.17	0.88	0.71	0.0031	0.139	0.0388	0.0010	0.0019	0.2845	0.0013	0.052	0.8534
	11/1/2005	0.22	0.83	0.61	0.0026	0.119	0.0333	0.0008	0.0016	0.2441	0.0011	0.044	0.7324
	12/1/2005	0.22	0.96	0.74	0.0032	0.146	0.0407	0.0010	0.0020	0.2986	0.0014	0.054	0.8958
	1/11/2006	0.27	0.92	0.65	0.0028	0.127	0.0355	0.0009	0.0018	0.2603	0.0012	0.047	0.7808
	2/2/2006	0.24	0.91	0.67	0.0029	0.132	0.0369	0.0009	0.0018	0.2704	0.0012	0.049	0.8111
	3/1/2006	0.29	1.01	0.72	0.0031	0.142	0.0396	0.0010	0.0020	0.2905	0.0013	0.053	0.8716
	4/1/2006	0.29	0.91	0.62	0.0027	0.121	0.0338	0.0008	0.0017	0.2482	0.0011	0.045	0.7445
	5/1/2006	0.31	0.95	0.64	0.0028	0.126	0.0352	0.0009	0.0017	0.2582	0.0012	0.047	0.7747
	6/1/2006	0.25	0.86	0.61	0.0026	0.119	0.0333	0.0008	0.0016	0.2441	0.0011	0.044	0.7324
	7/3/2006	0.22	0.89	0.67	0.0029	0.131	0.0366	0.0009	0.0018	0.2683	0.0012	0.049	0.8050
MAX	**8/1/2006**	**0.16**	**0.94**	**0.78**	**0.0034**	**0.154**	**0.0429**	**0.0011**	**0.0021**	**0.3147**	**0.0014**	**0.057**	**0.9442**
	9/1/2006	0.21	0.94	0.73	0.0032	0.144	0.0402	0.0010	0.0020	0.2946	0.0013	0.053	0.8837
MAX	**10/2/2006**	**0.20**	**0.98**	**0.78**	**0.0034**	**0.154**	**0.0429**	**0.0011**	**0.0021**	**0.3147**	**0.0014**	**0.057**	**0.9442**
	11/1/2006	0.23	0.89	0.66	0.0029	0.130	0.0363	0.0009	0.0018	0.2663	0.0012	0.048	0.7989
	12/1/2006	0.21	0.83	0.62	0.0027	0.122	0.0341	0.0008	0.0017	0.2502	0.0011	0.045	0.7505
	1/2/2007	0.30	0.98	0.68	0.0029	0.134	0.0374	0.0009	0.0019	0.2744	0.0012	0.050	0.8232

City of Boulder Water Treatment
Fluoride Concentration Calculations

Attachment B

	Betasso Water Treatment Plant												
	Date	Fluoride - mg/l		Total Fl Added (mg/L)	FSA			Sodium Silicofluoride			Sodium Fluoride		
		Raw	Finished		mL FSA per L treated water	As ug/L[1]	Lead ug/L[2]	ml Na2SiF6 per L treated water	As ug/L[3]	SODIUM ADDED (mg/L)	ml NaF per L treated water	As ug/L[4]	Sodium Added (mg/L)
	1/1/2004	0.13	0.95	0.82	0.0036	0.162	0.0451	0.0011	0.0022	0.3309	0.0015	0.060	0.9926
	4/1/2004	0.11	0.87	0.76	0.0033	0.150	0.0418	0.0010	0.0021	0.3067	0.0014	0.056	0.9200
	5/1/2004	0.09	0.95	0.86	0.0037	0.170	0.0473	0.0012	0.0023	0.3470	0.0016	0.063	1.0411
	6/1/2004	0.12	0.91	0.79	0.0034	0.156	0.0435	0.0011	0.0022	0.3188	0.0014	0.058	0.9563
	7/1/2004	0.08	0.88	0.80	0.0035	0.158	0.0440	0.0011	0.0022	0.3228	0.0015	0.058	0.9684
MIN	11/1/2004	0.19	0.90	0.71	0.0031	0.140	0.0391	0.0010	0.0019	0.2865	0.0013	0.052	0.8595
	1/1/2005	0.10	0.87	0.77	0.0033	0.152	0.0424	0.0010	0.0021	0.3107	0.0014	0.056	0.9321
	6/1/2005	0.10	0.99	0.89	0.0038	0.175	0.0487	0.0012	0.0024	0.3571	0.0016	0.065	1.0713
	8/1/2005	0.11	0.96	0.85	0.0037	0.168	0.0468	0.0012	0.0023	0.3430	0.0016	0.062	1.0289
	9/1/2005	0.10	0.84	0.74	0.0032	0.146	0.0407	0.0010	0.0020	0.2986	0.0014	0.054	0.8958
	12/3/2005	0.11	0.90	0.79	0.0034	0.156	0.0435	0.0011	0.0022	0.3188	0.0014	0.058	0.9563
MAX	1/1/2006	0.07	0.98	0.91	0.0039	0.179	0.0501	0.0012	0.0025	0.3672	0.0017	0.066	1.1016
	4/2/2006	0.12	0.91	0.79	0.0034	0.156	0.0435	0.0011	0.0022	0.3188	0.0014	0.058	0.9563
MIN	5/2/2006	0.09	0.80	0.71	0.0031	0.140	0.0391	0.0010	0.0019	0.2865	0.0013	0.052	0.8595
	6/1/2006	0.08	0.89	0.81	0.0035	0.159	0.0443	0.0011	0.0022	0.3248	0.0015	0.059	0.9745
	8/1/2006	0.07	0.84	0.77	0.0033	0.151	0.0421	0.0010	0.0021	0.3087	0.0014	0.056	0.9261
	9/1/2006	0.11	0.85	0.74	0.0032	0.146	0.0407	0.0010	0.0020	0.2986	0.0014	0.054	0.8958
	11/1/2006	0.08	0.87	0.79	0.0034	0.156	0.0435	0.0011	0.0022	0.3188	0.0014	0.058	0.9563
	12/1/2006	0.13	0.82	0.69	0.0030	0.136	0.0380	0.0009	0.0019	0.2784	0.0013	0.050	0.8353
	1/1/2007	0.09	0.86	0.77	0.0033	0.152	0.0424	0.0010	0.0021	0.3107	0.0014	0.056	0.9321

1 - Using 45.5 ppm arsenic concentration in fluorosilic acid - from COB 1-07 certificate of analysis - WORST CASE
2 - Using 12.7 ppm lead concentration in fluorosilicic acid - from COB 4-07 certificate of analysis - WORST CASE
3 - From City of Denver's analysis September 2006: As < 2 ppm and Pb < 2 ppm
4 - From typical As concentration provided by Thatcher Company: As < 40 ppm, Pb < 50 ppm

Arsenic MCL = 10 ug/L
Arsenic MCLG = 0 ug/L
Lead Action Level (no MCL) = 0.015 mg/L = 15 ug/L
Lead MCLG = 0 ug/L

mL FSA added per liter of treated water =

= dose / dens / %fluoride ion =

$$= \frac{\text{mg F-}}{\text{L treated water}} * \frac{\text{mg H2SiF6}}{\text{mg F-}} * \frac{\text{mg HFS}}{\text{mg H2SiF6}} * \frac{\text{mL HFS}}{\text{1234 mg HFS}} = \frac{\text{mL HFS}}{\text{L treated water}}$$

ug As added per liter of treated water =

$$= \frac{\text{mL HFS}}{\text{L treated water}} * \frac{\text{mg As}}{\text{L HFS}} * \frac{\text{1L}}{\text{1000 mL}} * \frac{\text{1000 ug}}{\text{1 mg}} = \frac{\text{ug As}}{\text{L treated water}}$$

City of Boulder
Dry Fluoride Feasibility Study

Black & Veatch Corporation
Centennial, Colorado
Project No. 144922.230
May 2007

DRAFT

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Appendix A Detailed Cost Estimates

City of Boulder
Dry Fluoride Feasibility Study

1.0 Introduction and Purpose

The City of Boulder (the City) currently fluoridates finished water at its Betasso and Boulder Reservoir Water Treatment Plants (WTPs) using fluorosilicic acid. Flurorosilicic acid is delivered to the WTPs in liquid form and is fed neat (as delivered, undiluted) into the finished water. Due to increasing concerns in regards to the addition of trace contaminants contained within water treatment chemicals, the City is considering alternative forms of fluoride that have lower trace contaminant levels. These alternative forms include sodium fluorosilicate and sodium fluoride, both of which are dry (powder/granular) chemicals. Generally, sodium fluoride has the lowest level of trace contaminants, while fluorosilicic acid has the highest. However, this can be manufacturer specific, especially when dealing with the dry forms. The main contaminants within fluoride type chemicals are heavy metals, such as lead, cadmium, chromium, and arsenic. It is important to note that the City's current fluoridation program does not exceed any water treatment regulations in regards to heavy metal contaminant levels.

The purpose of this study is to determine whether existing space at both the Betasso and Boulder Reservoir WTPs can be utilized to store and feed dry fluoride or if new buildings would need to be constructed. Two dry fluoride systems were considered. The first type of system utilizes 50-pound bags that are manually loaded into a hopper that is connected to the dry feeder and solution tank. The second system uses 2,000- or 2,500-pound "supersacks" that are directly hooked into the dry feeder (see Figure 1). This type of system requires a fairly large superstructure that encapsulates the hoisting mechanisms, dry feeder, and solution tank.

Once the determination was made as to the location of the new dry chemical feed and storage areas, feasibility level floor plans and cost estimates were prepared. Lastly, an operation and maintenance (O&M) cost comparison between all three chemicals was completed.

Figure 1 – "Supersack" Dry Chemical Feeders

2.0 Preliminary Investigations and Alternative Selection

Each of the WTPs has an existing chlorine scrubber room available for use as the new dry fluoride feed and storage areas if the space permits it. The City no longer uses gaseous chlorine; therefore, there is no need for the existing scrubbers. A site visit and review of these available rooms at both the WTPs was conducted on April 2, 2007. The site visit included reviewing the most up-to-date drawings and comparing them to the current layout of the scrubber rooms. Potential for forklift access into each of the rooms from outside and the turning radius required inside the room was also investigated since the dry fluoride will be delivered and stored on pallets (fifty, 50-pound bags or one "supersack" per pallet). Height of the ceilings in each room was also considered for the "supersack" type feeders, since these can be as tall as 15 to 17 feet. The City completed preliminary feed calculations and determined that a truckload consisting of 17 pallets could be split between the two plants. This amount of dry fluoride would be sufficient to provide at least a one month supply of dry fluoride at the maximum feed rate and maximum WTP flow rates as determined by the City.

After the review, the determination was made that the scrubber room at the Betasso WTP was only large enough to house the feed equipment and two or three pallets of fluoride (a standard pallet is 40 inches by 48 inches). An additional 20-foot by 20-foot storage building to house the remainder of the pallets will need to be constructed. The Boulder Reservoir WTP scrubber room is sufficient in size to house both the feed equipment and store eight pallets.

3.0 Selected Alternatives

Feasibility level configurations for the dry chemical fluoride feed facilities are described in the following sections.

3.1 Betasso WTP Layout and Construction Cost Estimate

The scrubber room at the Betasso WTP is approximately 17.5 feet by 20.0 feet and has access from the outside of the building that is at grade with stair landings inside the building. The basic layouts for renovations of this room are shown on Figure 2 for the 50-pound bag system and Figure 3 for the "supersack" system. The main components and design considerations of these layouts include the following:

- Add additional support under the existing stairway landings in order to accommodate the forklift and pallet loads.

- Install a new concrete operating floor to the extents shown on Figures 2 and 3.

- Set the new feed equipment in the "pit" at Elevation 6410.67 feet. The feed equipment would include a dry feeder, solution tank, storage hopper (for the 50-pound bag manually loaded system only), superstructure (for the "supersack" system only), and two feed pumps (one duty, one standby).

- Install a two-tier, single-bay steel storage rack to house two pallets of dry fluoride. This would help to eliminate the need to continuously bring in pallets from the storage building, especially in the event of bad weather. A forklift would be used to transfer dry chemical pallets from the storage rack to the feeding platform or to locate the "supersacks" under the hoist. The installation of this small storage rack would not hinder the forklift turning radius in order to load a pallet onto the feeding platform.

- **50-Pound Bag Manual Loaded System Only.** Install a steel or aluminum feeding platform large enough to accommodate one pallet of dry fluoride. Note that this elevated platform is needed because the estimated height of the feed hopper is expected to be approximately 9 feet above the floor elevation.

In addition to renovation of the existing chlorine scrubber room, a small storage building will need to be constructed to accommodate any additional pallets of fluoride. This building would not need to be any larger than 20 feet by 20 feet and would need to match the existing architecture at the WTP.

Estimated construction costs for the manually fed and "supersack" type systems are $382,000 and $463,000, respectively. Detailed cost estimates are included in Appendix A, Tables A-1 and A-2. An industry standard 40 percent contingency is included at this feasibility level.

3.2 Boulder Reservoir WTP Layout and Cost Estimate

The scrubber room at the Boulder Reservoir WTP is approximately 18.5 feet by 28.5 feet. Current access from outside into the scrubber room is by stairs that access a door approximately 2 feet above the outside grade. The basic layouts for renovations of this room are shown on Figures 2 and 3. The main components and design considerations of this layout include the following:

- Demolition of the existing stairs and walkway inside of the scrubber room. The new operating floor would be at the current lowest level (Elevation 5165.50 feet) of this room.

- Install a new concrete landing and stairs to the extents shown on Figures 2 and 3.

- Set the new feed equipment at an Elevation 5165.50 feet. The feed equipment would include a dry feeder, solution tank, storage hopper (for the 50-pound bag manually loaded system only), superstructure (for the "supersack" system only), and two feed pumps (one duty, one standby).

- Install a two-tier, three-bay steel storage rack to house six pallets of dry fluoride. Two additional pallets could be stored in front of the storage rack.

- Demolition of outside stairway and landing, lower existing threshold, and install new door.

- **50-Pound Bag Manual Loaded System Only.** Install a steel or aluminum feeding platform large enough to accommodate one pallet of dry fluoride. Note that this elevated platform is needed because the estimated height of the feed hopper is expected to be approximately 9 feet above the "pit" elevation.

Estimated construction costs for the manually fed and "supersack" type systems are $231,000 and $318,000, respectively. Detailed cost estimates are included in Appendix A, Tables A-3 and A-4. An industry standard 40 percent contingency is included at this feasibility level.

3.3 Operation and Maintenance Costs

The main O&M costs associated with any chemical feed system are the cost of the chemical themselves. The City provided Black & Veatch Corporation (Black & Veatch) with fluorosilicic acid usage information that indicated there was a 4 percent increase in usage from 2005 to 2006. Using this increase, along with cost data that the City also supplied, the yearly costs of using each of the chemicals was calculated for anticipated 2007 usage (see Table 1).

Table 1

Year 2007 Estimated Fluoride Chemical Costs

Chemical	2007 Chemical Cost ($)
Fluorosilicic Acid	68,600
Sodium Fluoride	75,200
Sodium Fluorosilicate	33,100

In addition to the chemical costs, the only anticipated difference between liquid fluoride and dry fluoride feed costs would be that of the WTP operators having to manually load bags of fluoride into the storage hoppers for the 50-pound bag manually fed type system. Using the same usage information provided by the City, a labor cost associated with this activity was calculated. These costs were calculated at $4,900 per year and $3,350 per year for sodium fluoride and sodium fluorosilicate, respectively. The difference in the costs is attributed to the fact that sodium fluoride contains a lesser amount of fluoride ion per pound; therefore, more pounds of chemical per year will be utilized.

4.0 Summary

Table 2 summarizes the capital costs that would be required to convert the City's current liquid fluoride feed and storage systems to that of dry fluoride feed and storage. Table 3 summarizes the anticipated O&M cost differential of using sodium fluoride or sodium fluorosilicate versus fluorosilicic acid.

Table 2

Summary of Capital Costs for Conversion to Dry Fluoride

System	Capital Cost ($)
50-Pound Bag Manually Loaded System	
Betasso WTP Construction Cost	382,000
Boulder Reservoir WTP Construction Cost	231,000
Owner-Purchased Forklifts (2)	53,000
Engineering Costs [1]	133,000
Total Project Cost	**799,000**
"Supersack" System	
Betasso WTP Construction Cost	463,000
Boulder Reservoir WTP Construction Cost	318,000
Owner-Purchased Forklifts (2)	53,000
Engineering Costs [1]	167,000
Total Project Dost	**1,001,000**

[1] Includes design, bid phase services, construction administration, and inspection.

Table 3

Annual Operation and Maintenance Cost Differential for Dry Fluoride Use Compared to Fluorosilicic Acid

Chemical	Annual Cost Differential [1] ($)
50-Pound Bag Manually Loaded System	
Sodium Fluoride	11,500
Sodium Fluorosilicate	(32,150)
"Supersack" System	
Sodium Fluoride	6,600
Sodium Fluorosilicate	(35,500)

[1] Annual cost differential was calculated using the values in Table 1 and Section 3.3.

It is important to realize that the O&M costs can vary widely due to unpredictable market values and supply of chemicals. A case in point is that one of the suppliers of sodium fluorosilicate (KC Industries) informed Black & Veatch that there is currently a shortage of fluorosilicic acid in the United States, and that many WTP authorities have been getting emergency shipments of dry fluoride to supplement their liquid fluoride feed operations. This has resulted in price increases for the dry chemicals.

Lastly, discussions with suppliers indicate that it is somewhat rare to have sodium fluoride delivered in "supersacks". This also could lead to a fairly substantial variability in the cost of this chemical.

APPENDIX A

DETAILED COST ESTIMATES

Table A-1

Betasso WTP Dry Fluoride Storage and Feed Construction Costs
(50-Pound Bag Manually Loaded System)

Item	Quantity	Unit	Unit Cost ($)	Total Cost ($)
RENOVATION OF EXISTING SCRUBBER ROOM				
Additional Steel Structural Support for Existing Landings	1	Lump Sum	1,500.00	$1,500.00
Demo of Existing Scrubber System (including Chemical Disposal)	1	Lump Sum	30,000.00	$30,000.00
Concrete	20	Cubic Yard	550.00	$11,000.00
Loading Platform (includes Grating and Framing)	40	Cubic Yard	120.00	$4,800.00
Handrail	30	Linear Feet	50.00	$1,500.00
Pallet Storage Racks	1	Lump Sum	3,000.00	$3,000.00
Door (6' x 8')	1	Lump Sum	3,500.00	$3,500.00
Connections and Piping to Existing Feed System	1	Lump Sum	1,500.00	$1,500.00
Electrical	1	Lump Sum	10,000.00	$10,000.00
Instrumentation	1	Lump Sum	13,000.00	$13,000.00
Dry Feed System	1	Each	76,000.00	$76,000.00
NEW STORAGE BUILDING				
Structure	400	Square Feet	180.00	$72,000.00
Electrical and Heating, Ventilating, and Air Conditioning	400	Square Feet	50.00	$20,000.00
SUBTOTAL				**$247,800.00**
CONTINGENCY (40%)				$99,000.00
ROUNDED CONSTRUCTION SUBTOTAL				**$347,000.00**
GENERAL REQUIREMENTS				$35,000.00
CONSTRUCTION TOTAL				**$382,000.00**

Table A-2

Betasso WTP Dry Fluoride Storage and Feed Construction Costs ("Supersack" System)

Item	Quantity	Unit	Unit Cost ($)	Total Cost ($)
RENOVATION OF EXISTING SCRUBBER ROOM				
Additional Steel Structural Support for Existing Landings	1	Lump Sum	1,500.00	1,500.00
Demo of Existing Scrubber System (including Chemical Disposal)	1	Lump Sum	30,000.00	30,000.00
Concrete	10	Cubic Yard	550.00	5,500.00
Handrail	15	Linear Feet	50.00	750.00
Pallet Storage Racks	1	Lump Sum	3,000.00	3,000.00
Door (6' x 8')	1	Lump Sum	3,500.00	3,500.00
Connections and Piping to Existing Feed System	1	Lump Sum	1,500.00	1,500.00
Electrical	1	Lump Sum	10,000.00	10,000.00
Instrumentation	1	Lump Sum	13,000.00	13,000.00
Dry Feed System	1	Each	140,000.00	140,000.00
NEW STORAGE BUILDING				
Structure	400	Square Feet	180.00	72,000.00
Electrical and Heating, Ventilating, and Air Conditioning	400	Linear Feet	50.00	20,000.00
SUBTOTAL				**300,750.00**
CONTINGENCY (40%)				120,000.00
ROUNDED CONSTRUCTION SUBTOTAL				**421,000.00**
GENERAL REQUIREMENTS				42,000.00
CONSTRUCTION TOTAL				**463,000.00**

Table A-3

Boulder Reservoir WTP Dry Fluoride Storage and Feed Construction Costs
(50-Pound Bag Manually Loaded System)

Item	Quantity	Unit	Unit Cost ($)	Total Cost ($)
RENOVATION OF EXISTING SCRUBBER ROOM				
Demo Existing Concrete Walkway and Stairs	1	Lump Sum	1,000.00	1,000.00
Demo of Existing Scrubber System (including Chemical Disposal)	1	Lump Sum	30,000.00	30,000.00
Concrete	5	Cubic Yard	550.00	2,750
Loading Platform (includes Framing and Grating)	35	Linear Feet	150.00	5,250.00
Handrail	40	Linear Feet	50.00	2,000.00
Pallet Storage Racks	1	Lump Sum	7,500.00	7,500.00
Door (6' x 8')	1	Lump Sum	3,500.00	3,500.00
Connections and Piping to Existing Feed System	1	Lump Sum	1,500.00	1,500.00
Electrical	1	Lump Sum	10,000.00	10,000.00
Instrumentation	1	Lump Sum	13,000.00	13,000.00
Dry Feed System	1	Each	73,000.00	73,000.00
SUBTOTAL				**149,500.00**
CONTINGENCY (40%)				60,000.00
ROUNDED CONSTRUCTION SUBTOTAL				**210,000.00**
GENERAL REQUIREMENTS (10%)				21,000.00
CONSTRUCTION TOTAL				**231,000.00**

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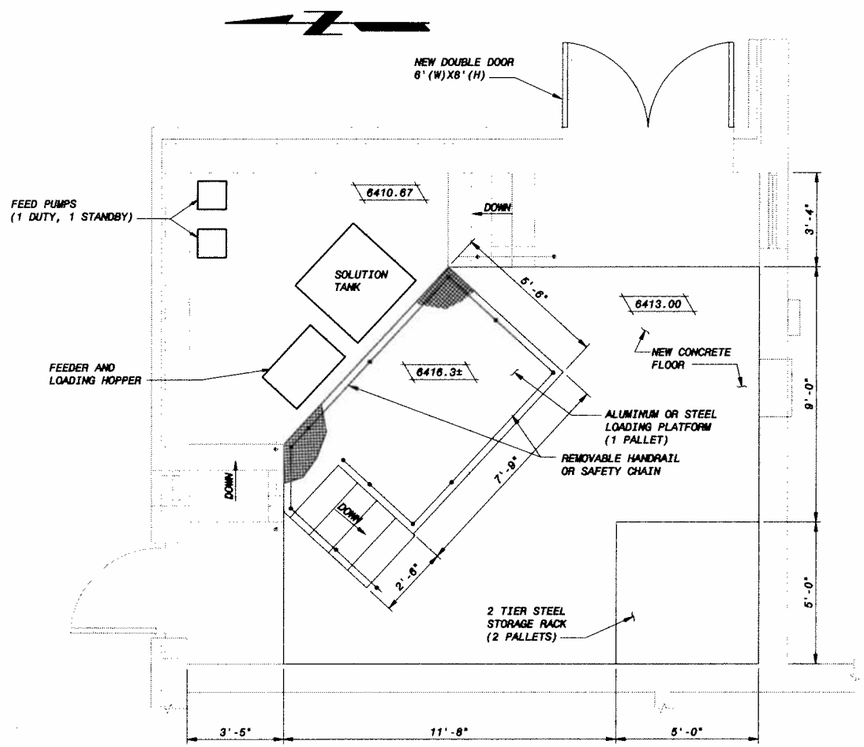
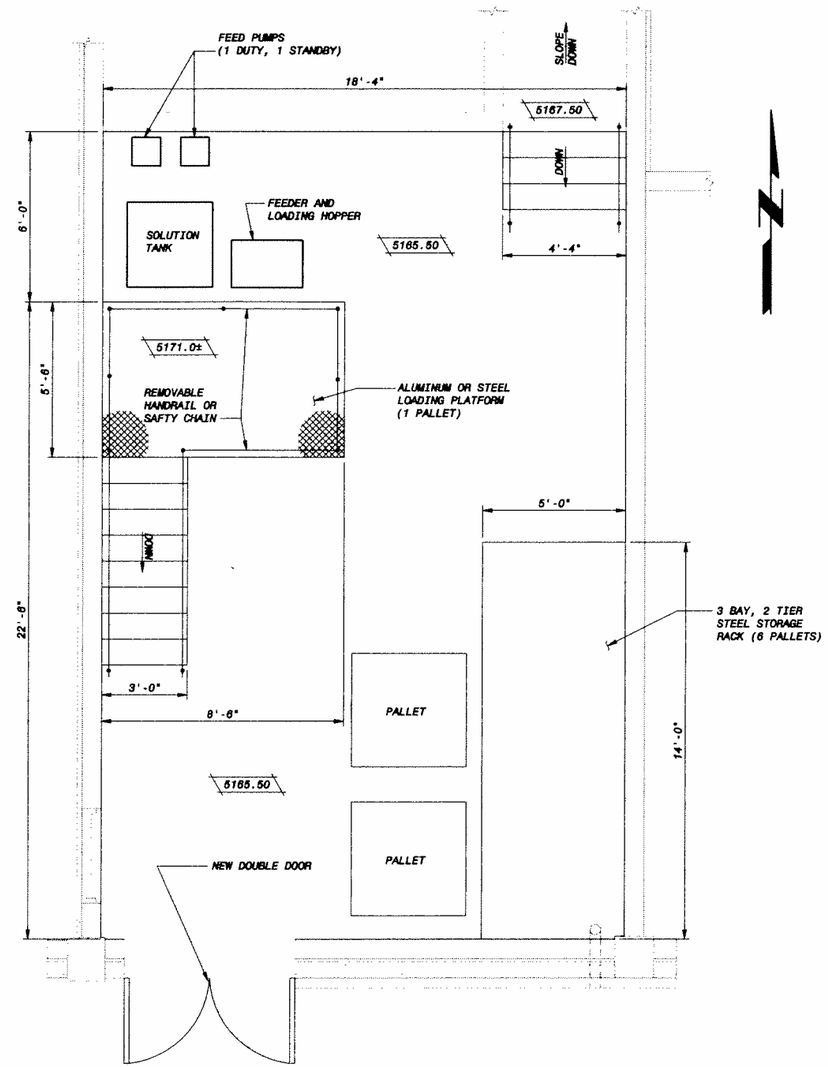
Table A-4

Boulder Reservoir WTP Dry Fluoride Storage and Feed Construction Costs ("Supersack" System)

Item	Quantity	Unit	Unit Cost ($)	Total Cost ($)
RENOVATION OF EXISTING SCRUBBER ROOM				
Demo Existing Concrete Walkway and Stairs	1	Lump Sum	1,000.00	1,000.00
Demo of Existing Scrubber System (including Chemical Disposal)	1	Lump Sum	30,000.00	30,000.00
Concrete	5	Cubic Yard	550.00	2,750
Pallet Storage Racks	1	Lump Sum	7,500.00	7,500.00
Door (6' x 8')	1	Lump Sum	3,500.00	3,500.00
Connections and Piping to Existing Feed System	1	Lump Sum	1,500.00	1,500.00
Electrical	1	Lump Sum	10,000.00	10,000.00
Instrumentation	1	Lump Sum	13,000.00	13,000.00
Dry Feed System	1	Each	137,000.00	137,000.00
SUBTOTAL				**206,250.00**
CONTINGENCY (40%)				83,000.00
ROUNDED CONSTRUCTION SUBTOTAL				**289,000.00**
GENERAL REQUIREMENTS (10%)				29,000.00
CONSTRUCTION TOTAL				**318,000.00**



BETASSO WTP
RENOVATION OF EXIST SCRUBBER ROOM
3/8" = 1'-0"



BOULDER RESERVIOR WTP
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3/8" = 1'-0"

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XREF4:
XREF5:
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BLACK & VEATCH
Black & Veatch Corporation
Centennial, Colorado

CITY OF BOULDER, COLORADO
DRY FLUORIDE FEASIBILITY STUDY

RENOVATION OF EXISTING
SCRUBBER ROOMS FOR
MANUALLY LOADED DRY FLUORIDE SYSTEM

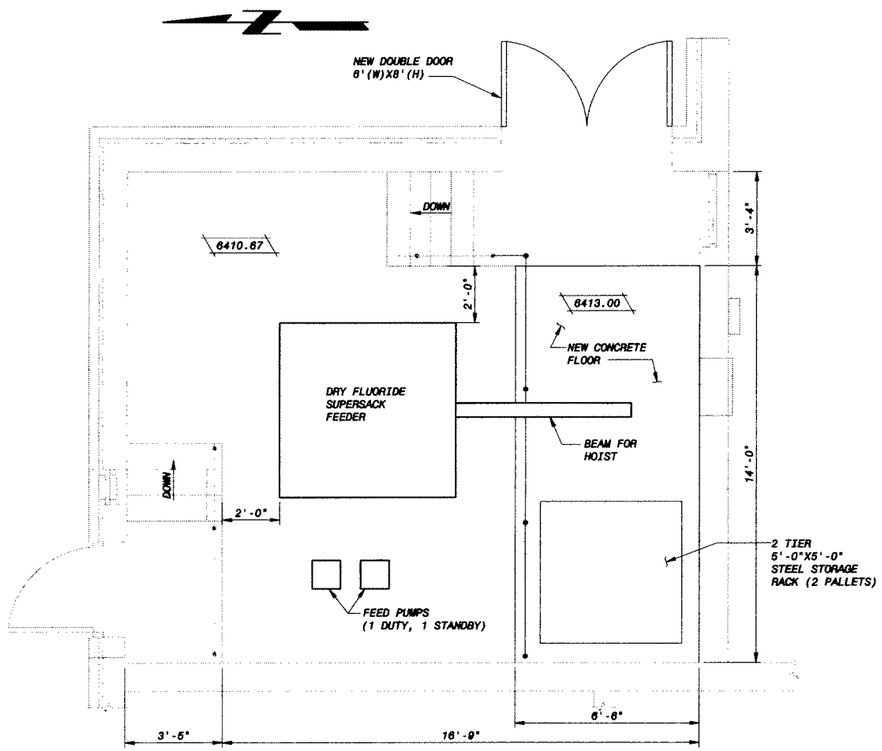
DESIGNED:
DETAILED:
CHECKED:
APPROVED:
DATE:

0 1/2 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO FULL SCALE

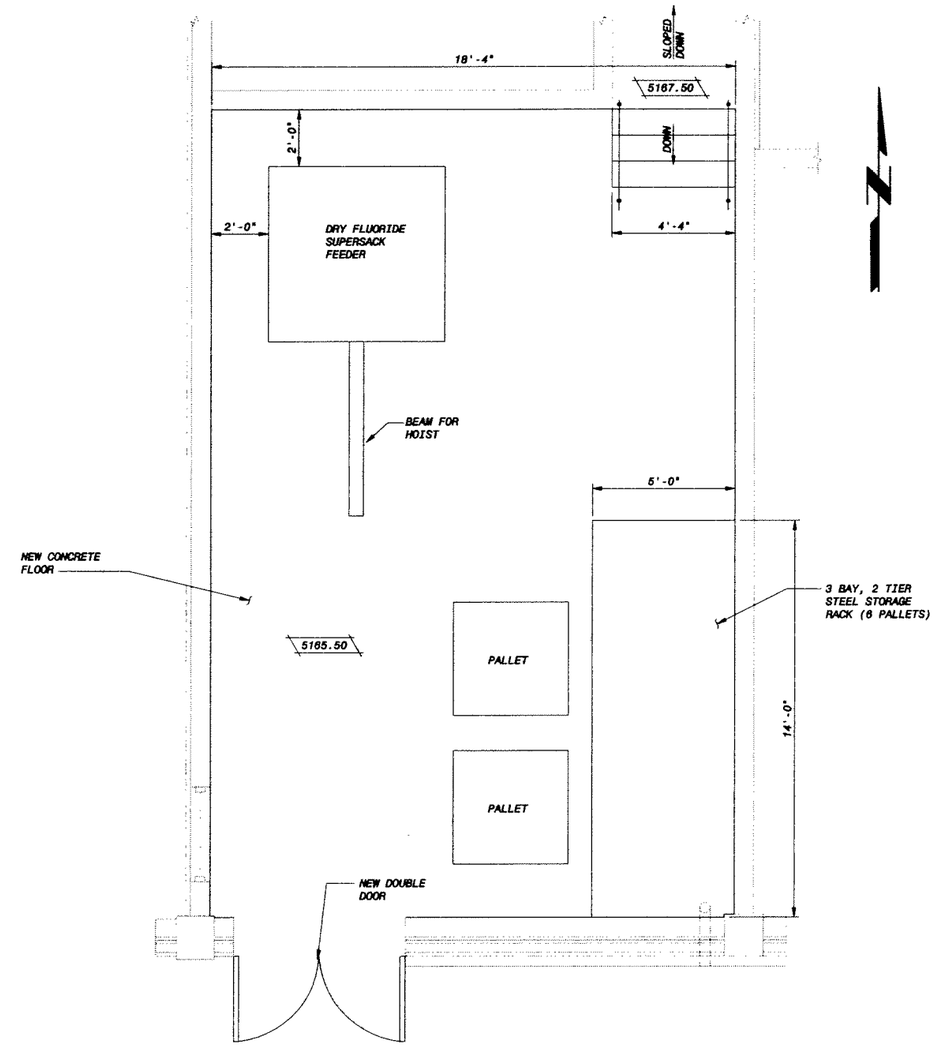
PROJECT NO.
144922

FIGURE 2

FD6000
D6075



BETASSO WTP
RENOVATION OF EXIST SCRUBBER ROOM
3/8" = 1'-0"



BOULDER RESERVOIR WTP
RENOVATION OF EXIST SCRUBBER ROOM
3/8" = 1'-0"

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PLOTTED: XREF4:
USER: JTR06820 DWG VER: XREF5:

BLACK & VEATCH
Black & Veatch Corporation
Centennial, Colorado

CITY OF BOULDER, COLORADO
DRY FLUORIDE FEASIBILITY STUDY

RENOVATION OF EXISTING
SCRUBBER ROOMS FOR
SUPERSACK DRY FLUORIDE SYSTEM

DESIGNED:
DETAILED:
CHECKED:
APPROVED:
DATE:

0 1/2 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO FULL SCALE

PROJECT NO.
144922

FIGURE 3

FD06000
D80175

Attachment C

City of Boulder

Prepared for: City of Boulder

REPORT

2012 Betasso Spring Runoff Plant Optimization

Betasso Water Treatment Plant

AUGUST 2012

Report Prepared By:

MALCOLM PIRNIE | ARCADIS

The Water Division of ARCADIS

Attachment C

The Water Division of ARCADIS

Imagine the result

City of Boulder

Betasso Spring Runoff

Executive Summary

August 20, 2012

City of Boulder

Betasso Spring Runoff Optimization

Prepared for:
City of Boulder

Prepared by:
ARCADIS U.S., Inc.
100 Fillmore Street
Suite 200
Denver
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Tel 303 316 6500
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Our Ref.:
05311000.0001

Date:
August 20, 2012

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Appendices

A Testing Matrix

B PAC Study

C Filter Inspection Results

Acronyms and Abbreviations

C.U.	Color Units
CU-Boulder	University of Colorado – Boulder
gal	Gallons
in	Inch
L/d	Length (mm)/Diameter (mm)
mgd	Million Gallons per Day
mg/L	mg/L
mm	millimeter
NTU	Nephelometric Turbidity Units
PAC	Powdered Activated Carbon
Pirnie/ARCADIS	Malcolm Pirnie, the Water Division of ARCADIS
RPM	Revolution per Minute
sf	Square Foot
UFRV	Unit Filter Run Volume

1. Introduction

The City of Boulder contracted with Malcolm Pirnie, The Water Division of ARCADIS (Pirnie/ARCADIS) to assist in the investigation of methods to improve the filter productivity during high color events. This challenge, treatment during high color events, was acknowledged during recent planning activities conducted at Betasso. This project's focus is to further understand the issue and identify possible solutions.

The plant's rated production capacity is about 40 mgd. To treat the high color spring runoff events, the plant production is significantly less, approximately 27 mgd, because turbidity breakthrough occurs. The City would like to bring the rated production capacity during the spring runoff events into alignment with the production capacity the rest of the year.

Although the Betasso plant has several raw water source options, the primary sources are as follows:

- Lakewood Reservoir
- Barker Reservoir
- Blend of Lakewood and Barker.

These challenge events occur typically during the snow melt and elevated river flows from April – June (spring runoff), and result in significantly lower unit filter run volumes (UFRV) on the order of 50% of the typical value. UFRV is a "normalized" metric for filter efficiency which is a measure of the gallons of water filtered through one square foot of the filter during a filter run. Generally speaking, the UFRV at a plant should be consistent among filters regardless of the time of year. This is not the case for the Betasso filters which exhibit significant fluctuations.

The Betasso plant has a stringent filtered water turbidity goal of 0.1 NTU. During these events, turbidity breakthrough in filter effluent occurs much earlier than other times of the year. Additionally, it has been identified that Filters 1 – 4 are impacted more than Filters 5 – 8. Figure 1 shows the impact on UFRV during 2011 Spring Runoff in Filter 1 as compared to Filter 8. The figure shows that as the color increases, UFRV decreases dramatically. This effect is most severe in Filter 1 but also evident in Filter 8.

Although color is a key indicator of the presence of organic matter, during the challenge period, turbidity and color have almost identical patterns (Figure 2). Turbidity could be an indicator of organic or inorganic compounds. As such, assessment of both color and turbidity were investigated. The City's goal during the 2012 runoff event is to use the opportunity to better understand and narrow the reasons for the phenomenon and develop solutions that the City will build into their Capital Improvement Program.

Pirnie/ARCADIS worked closely with the Betasso water treatment plant staff to provide technical guidance and oversight on the development and execution of the City's proposed testing plan. Pirnie/ARCADIS provided:

- Prioritized Spring 2012 testing matrix
- Testing guidelines and best practices
- Negotiation of scope of work with CU Boulder for powdered activated carbon (PAC) testing
- Support and on-call services during testing execution (performed by City staff)
- Historical data review
- Testing data review
- Summary of testing results

City of Boulder staff provided:

- Execution of testing plan
- Procurement of equipment and chemicals
- Raw testing results
- Historical data

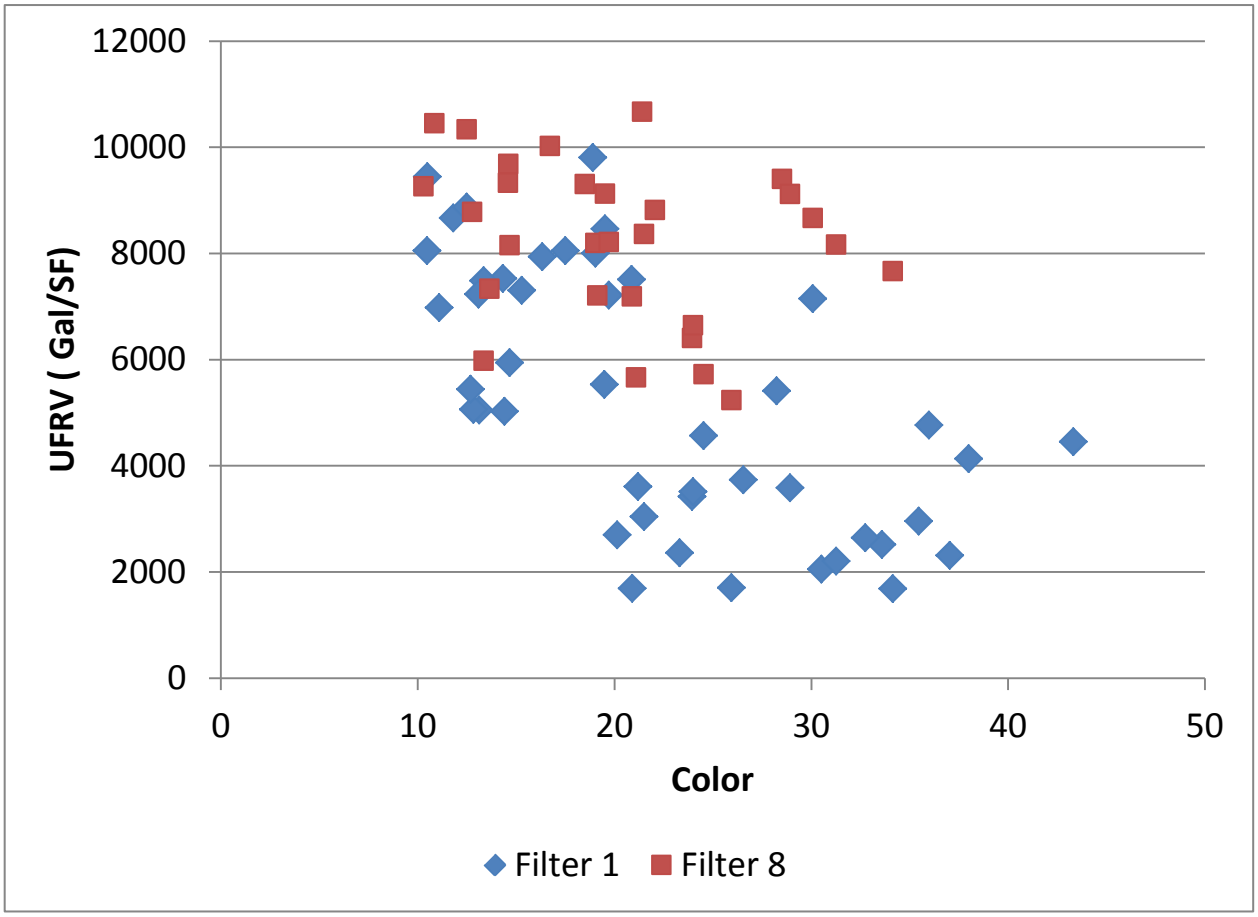


Figure 1 Impact on UFRV During 2011 Spring Runoff

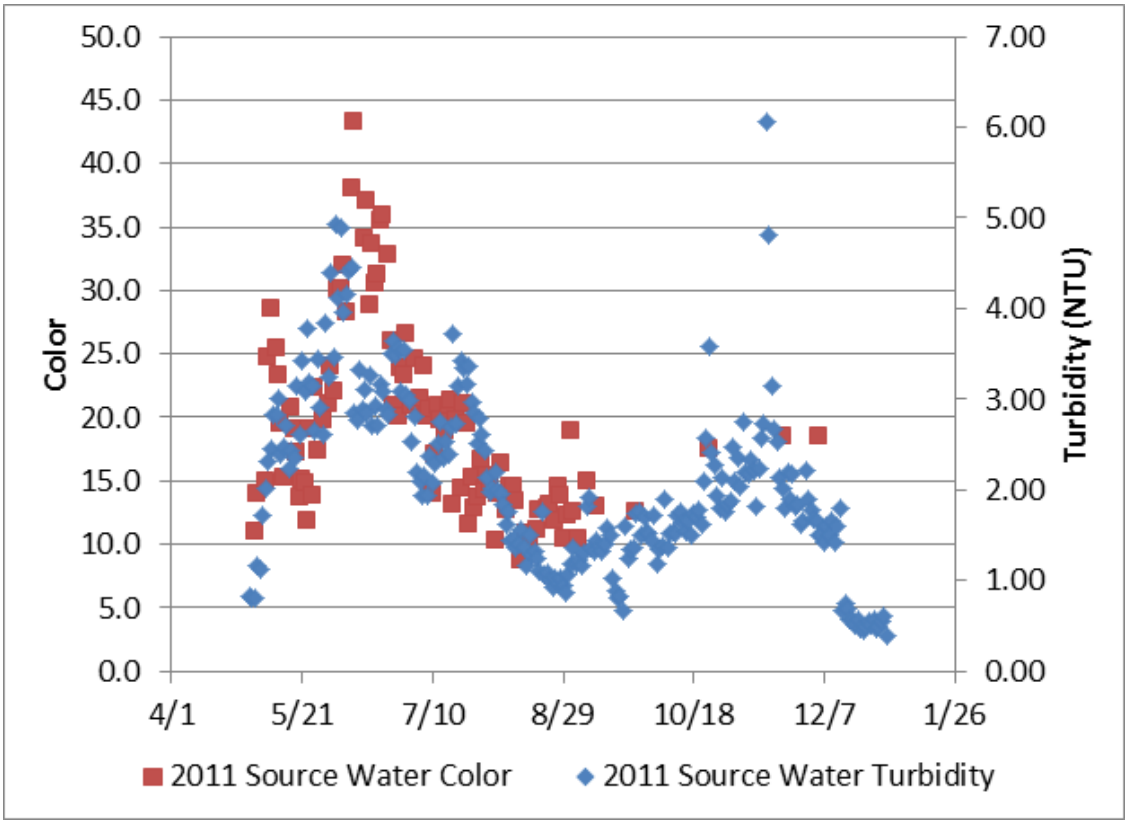


Figure 2 Turbidity and Color Correlation

A summary of key meetings conducted and deliverables is shown in Table 1.

Table 1 Betasso Spring Runoff Optimization Meetings and Deliverables

Kickoff Meeting	April 3, 2012
Kickoff Meeting Minutes	April 6, 2012
Project Meeting: Powdered Activated Carbon Testing Meeting (held at CU Boulder)	April 11, 2012 (meeting minutes issued the same day)
Project Meeting – Review Bench Testing Planning	April 19, 2012 (meeting minutes issued the same day)
Project Meeting – Support Jar Testing Efforts	May 3, 2012 (meeting minutes issued the same day)
PAC Treatment Scope of Work – Issued by Dr. Scott Summers, CU Boulder	May 4, 2012
Project Meeting – Review data and discuss next steps	May 18, 2012
Project Meeting – PowerPoint update of all testing and data analysis results to date to full team	May 30, 2012
Project Meeting – Discuss Executive Summary outline and final tasks to wrap-up the spring testing program	June 13, 2012
Project Report	July 9, 2012

2. Testing Matrix

At the onset of the project, a meeting was conducted to discuss the full spectrum of testing options (Appendix A), and make decisions regarding recommendations for this Spring Optimization event. Decisions were based on testing that was anticipated to have the greatest impact on UFRV, equipment availability and staffing. Table 2 below presents final testing matrix executed by the City and CU Boulder.

Table 2 2012 Betasso Water Treatment Plant Spring Runoff Testing

Testing/Evaluation	Purpose	Notes
Preoxidation with potassium permanganate (KMnO4)	Evaluate the impact of preoxidation with KMnO4 on color and organics	Bench test
Preoxidation with chlorine dioxide (ClO2)	Evaluate the impact of preoxidation with ClO2 on color and organics	Bench test
Powdered Activated Carbon	Evaluate the impact of three different PACs on color and organics	Bench testing conducted at CU Boulder
Tapered vs Non-Tapered flocculation	Evaluate the impact of tapered flocculation on the turbidity leaving Basin 4	Full-scale plant evaluation
Filter #2 Inspection	In depth filter evaluation to identify strengths and weaknesses of current filter performance that may impact turbidity removal. Filter 2 is a historically poor performing filter.	Full-scale plant evaluation
Filter #8 Inspection	In depth filter evaluation to identify strengths and weaknesses of current filter performance that may impact turbidity removal. Filter 8 is a historically good performing filter.	Full-scale plant evaluation
Flocculent Aid Polymer	Evaluate the impact of creating a more settleable and filterable flocc using various polymers.	Bench test. Brief test was completed with one polymer. Recommend this testing be continued this summer.

In addition to these efforts, analyses of existing operating plant data were conducted during the course of the evaluation. These include:

- Detailed analysis of UFRV during 2011 challenge period
- Review historic water quality pertinent to the UFRV issue including:
  - UFRV
  - Raw and finished water color
  - Raw total organic carbon (TOC)
  - Filtered water chlorine residual
  - Raw settled and filtered water turbidity
  - UV 254 data was requested but it is not currently analyzed

- Requested collection of chlorine residual in filter effluent and associated UFRV for that filter
- Review of particle count data
    - All filters
    - Filter 2, 2008 vs 2011
- Basin turbidity versus UFRV

2.1 Non-Traditional Spring Runoff

Although spring runoff conditions vary from year to year, the 2012 spring runoff was particularly atypical due to a variety of reasons. Snowpack measurements on May 1, 2012, in the City's Silver Lake Watershed averaged about 50 percent of what is typical for this time of year. As a result, peak spring streamflow levels were lower than average. Water from North Boulder Creek and Como Creek was diverted to Lakewood Reservoir to boost storage in the Silver Lake Watershed.

Over the past few years, the City had avoided using water from these sources as they can be more difficult to treat. The Como Creek and North Boulder Creek source waters are more impacted by runoff and stormwater events than the Silver Lake pipeline source. The TOC, turbidity, and color levels in the Como Creek and North Boulder Creek sources are typically higher than the Silver Lake pipeline source, and the operators often experience an increase in coagulant demand when switching to the Como Creek and North Boulder Creek sources. Additionally, the Barker source was not available for treatment until mid May due to the turbine replacement at the hydroelectric plant and the reservoir improvement work at Kossler Reservoir.

Certain raw water quality parameters differed from the previous year. In 2011, color peaked in June for both sources. In 2012, color peaked in April for Lakewood, and it is unknown when Barker color peaked, as it was offline in April.

3. Testing Results and Discussion

The following section presents testing results and discusses the key findings.

3.1 Pre-Treatment

3.1.1 Preoxidation results – ClO2 vs. KMnO4

Eight preoxidation tests were conducted in late April and May, 2012 by City of Boulder staff. Four tests were conducted with KMnO4 and four with ClO2. Each test consisted of several jars with varying doses of the preoxidant and a jar with no preoxidant to

serve as the baseline. A description of the testing and results is presented in Tables 3 and 4.

In reviewing the City's data from the preoxidation testing, it is difficult to make strong recommendations for implementation of a preoxidant based on the results. The existing coagulation scheme worked as well as the preoxidation in most cases in removing color. In some cases the color was removed to 1 to 2 C.U.s, in other cases it was still as high as 14 to 17 C.U.s.

It should be noted that a review of historical plant data does indicate color as high as 10 C.U. in the finished water during challenge conditions. Although 10 C.U. is below the EPA's secondary maximum contaminant level (SMCL) goal of 15 C.U., the color may be a colloidal particle that could be registered as turbidity, hence leading to the shorter filter runs. The addition of a preoxidant did not provide a significant increase in color or turbidity removal over the coagulants alone in this testing – however, it was an atypical spring runoff. It is recommended that these tests be repeated on a pilot scale where additional data can be collected over a longer period of time.

Table 3 Preoxidation Bench Testing Overview

Preoxidant	Dose	Contact Time (minutes)	Source Blend (%Lakewood/%Barker)	Coagulant Scheme (mg/L Alum/mg/L Sumaclear)
KMnO4	0.1, 0,2 and 0.3 mg/L	1 min 15 min	60/40 and 40/60	12/7
ClO2	0.6 mg/L 1.2 mg/L	30 sec 1 min	60/40 and 40/60 100% Lakewood 100% Barker	12/7

Table 4 Preoxidation Bench Testing Results

Test	Source Blends and Color	Test Conditions: Pre-oxidant dose, Contact time, Coagulation chemicals	Results
KMnO4 (4//30/12)	40%/60% Lkwd/Barker ~ 20 C.U.	0.0, 0.1,0,2 and 0.3 mg/L KMnO4 1 min contact time Alum and Sumaclear	All jars, including the jar with no preoxidant removed the color Jar 4 with 0.3 mg/L KMnO4 indicated overdose of KMnO4 as measured by soluble Mn
KMnO4 (5/3/12)	60/40 Lkwd/Barker ~22 C.U.	0, 0.1 and 0.2 mg/L KMnO4 1 min and 15 min contact time Alum and Sumaclear	No discernible difference between preoxidant contact time Measurable color after preoxidation and coagulation ranging from 15 – 20 C.U. Best jar was jar with coagulation only, no preoxidation (color – 11 C.U.)
ClO2 (5/3/12)	60/40 Lkwd/Barker ~22 C.U.	0, 0.6 and 1.2 mg/L 1 min Alum and Sumaclear	Moderate to poor color removal Final color in coagulation only jar was 14 C.U. Did not perform as well as previous tests. Color in jars with ClO2 and coag was 11 and 17 C.U. Settled water turbidity all similar.
ClO2 (5/8/12)	60/40 and 40/60 Lkwd/Barker 20 C.U. and 17 C.U	0, 0.6 and 1.2 mg/L ClO2 30 seconds Alum and Sumaclear	All of the jars with the 40/60 blend of Lkwd/Barker had same resulting color after treatment, 14 C.U. The color in the source for this blend was 17 C.U. Best jar was 60/40 blend and 1.2 mg/L ClO2 – resulting color was 9 C.U. All jars had similar turbidity results

3.1.2 Effectiveness of Powdered Activated Carbon (PAC)

PAC testing was conducted at CU Boulder under the direction of Dr. Scott Summers. A bench-scale jar testing apparatus was used to simulate the full-scale conventional treatment process. Jar tests were run to simulate rapid mix (250 rpm for 1 min) and flocculation (75 rpm for 60 min).

3.1.2.1 Materials and Reagents

Three types of PAC were used at this study; bituminous (Calgon WPH), lignite (Norit HDB), and wood (Norit CASP). The PAC doses were 5, 15, and 30 mg/L – the doses found to be most representative of water plant operational practices. The coagulants Sumaclear and Alum were dosed at 7 mg/L and 12 mg/L, respectively, representing typical Betasso coagulant doses for this time of year and consistent with the preoxidation jar testing. Variables are shown in Table 5.

Table 5 Raw Water Quality and Operational Conditions

Variables	Range
TOC concentration	3.7 mg/L
Color	20 Pt-Co
UV_{254}	0.104 1/cm
Alkalinity	14 mg/L as CaCO3
Turbidity	3.6 NTU
pH	7.08
PAC type	Lignite, bituminous and wood
PAC dose	0, 5, 15 and 30 mg/L
Contact times	10 min, 30 min, and 60 min
Coagulant-Polymer dose	Sumaclear (7 mg/L) and alum (12 mg/L)

3.1.2.2 Impact of Coagulation Alone on Color Removal

Coagulation with Sumaclear (7 mg/L) and alum (12 mg/L) was very effective for the control of color with > 90% removal. It also removed 60% of the TOC and 80% of the UVA.

3.1.2.3 Impact of PAC Type

All of the PACs preformed in a very similar manner; there was not one PAC type that did best under all conditions. After 60min at a dose of 30 mg/L of PAC **without** coagulant, they all removed about ~70% of the color, ~20% of TOC and UVA and 75% of MIB. As shown in the figures in Appendix B color removal was already at >90%, so PAC addition could not yield a small improvement. When combined **with** the coagulant, PAC yielded a 0.3 to 0.5 mg/L additional TOC removal (about 15% more) and a 0.006 /cm additional UVA removal (about 6% more).

3.1.2.4 Impact of PAC Dose and Kinetics

Increasing the dose from 5 to 15 mg/L and to 30 mg/L **without** coagulant, increased the removal for all parameters. Less of a dose impact was found when dosed with the coagulant. In general the kinetics are very fast with most of the removal occurring in the first 10 min. The complete report including tables and graphs can be found in the report developed by Dr. Scott Summers and Kyle Shimabuku in Appendix B.

3.2 Flocculation & Sedimentation Evaluation

The Betasso plant has four Basins, each which contain three stage flocculation and conventional sedimentation. These processes are an important barrier for particulate removal and their performance can greatly impact the performance of the filters. During our 2012 challenge period, we investigated:

1. The impact that the Basin performance has on UFRV.
2. The impact of tapered vs non-tapered flocculation

3.2.1 Impact that Basin Performance has on UFRV

During the Spring 2011 challenge period, the turbidity values leaving the sedimentation basins to the filters increased, corresponding with the decrease in filter UFRV (Figure 3). This is not surprising since settleability is strongly correlated with filterability. The following paragraphs describe the full-scale plant evaluation conducted to investigate possible improvements in settled water turbidity.

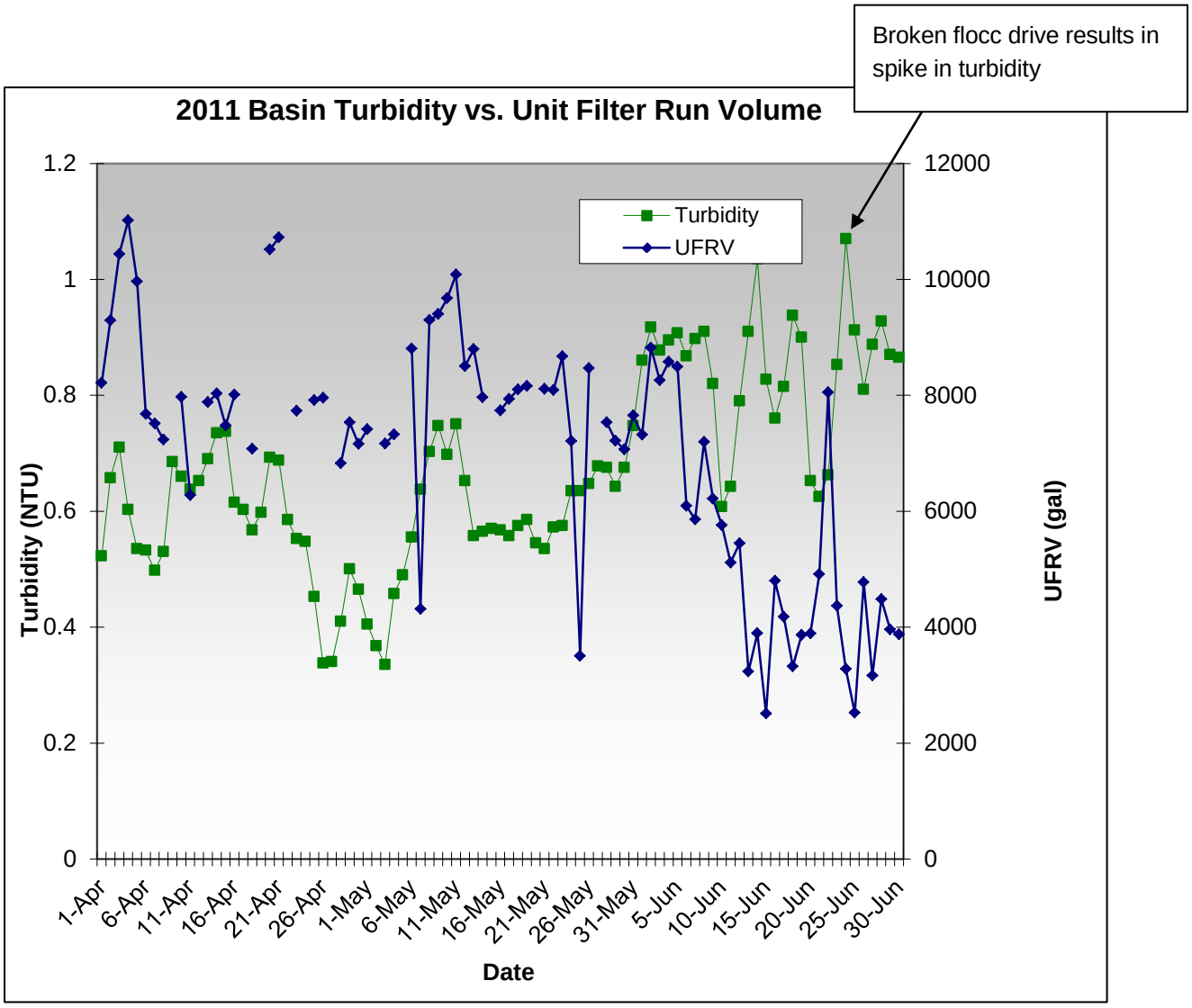


Figure 3 2011 Basin Turbidity vs. Unit Filter Run Volume

3.2.2 Impact of Tapered Flocculation vs. Non-Tapered Flocculation

Historically, flocculation has been operated with all flocculators running at the same rotations per minute (RPM). It was discovered however that in Basin 4, the motor was geared differently, and thus tapered mixing was occurring. On April 19th, Basin 4 was adjusted so that there was non-tapered flocculation (the same imparted energy in all three stages of Basin 4), and on May 3rd, it was returned to its previous tapered flocculation settings. Results of this testing are shown below in Figure 4.

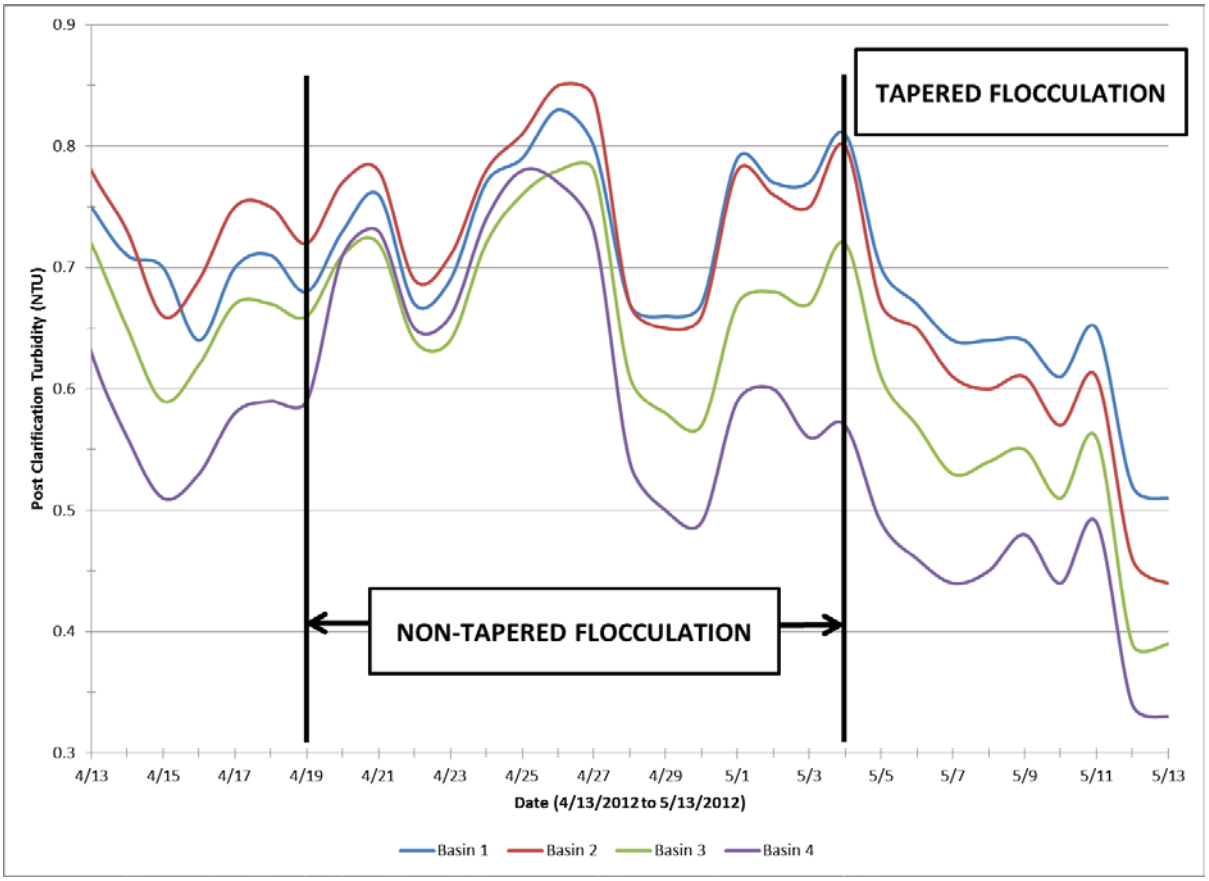


Figure 4 Impact of Tapered Flocculation vs Non-Tapered Flocculation

When the initial adjustment to create non-tapered flocculation is made to Basin 4, a clear increase in turbidity is observed. Ultimately, prior to the adjustment back to tapered flocculation the Basin 4 turbidity improves and this seems to continue once tapered flocculation is resumed. These data suggest that operating in tapered flocculation could have a positive impact and increase the UFRV during challenge conditions. It is recommended that the flocculation drives be repaired so that tapered flocculation can be consistently practiced or lower the Basin effluent turbidity. This is

important because the treatment performance of the basins does impact the filter UFRV (refer to Figure 3). Removing these particles more effectively will require not only the recommended modifications to the basin flocculation drives but it is also recommended that the coagulation chemistry be revisited to confirm that the current strategy is appropriate for this challenge condition and that settleability is maximized.

3.3 Filtration

3.3.1 Impact of Cl2 feed location on filter run performance

Each of the four plant sedimentation basins has independent chlorine feeder systems that deliver chlorine to its effluent. This also serves as the pre-filtration chlorine feed point. During this evaluation, it was brought to our attention that only the chlorine feeder on Basin 4 was working. Upon investigation, this also results in prefiltration chlorination in only the filters seeing water from Basin 4 which are typically the highest numbered filter(s) in operation (Figure 5).

Figure 5 May 3 Filter Effluent Chlorine Residual Results – Pink color indicates a chlorine residual; Filter 1: 0.03 mg/L; Filter 4: 0.03 mg/L; Filter 6: 0.40 mg/L.

It is well documented that the introduction of a preoxidant prior to filtration can enhance particle attachment efficiency. It reduces particle stability which makes the particle more filterable. Based on the fact that the highest numbered filters consistently have

the highest UFRV, it is possible that part of the explanation is the presence of chlorine residual in the feed water to the filters.

To highlight the impact that chlorine may be having on UFRV an evaluation of the 2011 UFRV data was done (Table 6). The UFRV data was aggregated and sorted by filter using the following conditions:

- High flow, high color
- High flow, low color
- Low flow, high color
- Low flow, low color

Where:

- High flow = > 20 MGD
- Low flow =<20 MGD
- High color = > 20 C.U.
- Low color = < 20 C.U.

Historical data indicated that UFRV's in the 8000-10,000 range are possible at the Betasso plant. Since some filters are able to achieve this performance, all filters should be able to regardless of the source water quality. Using this information, a system was established, during challenge periods described above, to identify how each individual filter performed. UFRVs that were greater than 8000 gal/sf are colored green to indicated good performance. Average UFRVs lower than 5000 gal/sf are colored red to indicated very poor performance. UFRV's between 5000 and 8000 gal/sf are colored yellow. This analysis supports the theory that prechlorination may be having a positive impact on filterability. Additional observations include:

- High flow high color is the most challenging condition
- Filters 1-5 all show indications of weakness in terms of the UFRV
- Filter 4 is weakest performing filter
- **Filters 6-8 best performing filters – these are the filters most likely to receive prechlorinated water**

Table 6 Impact of Flow and Color on Filter Run Performance on UFRV (g/sf)

	High Flow/High Color 6/9-7/8	High Flow/Low Color 7/24-9/4	Low Flow/High Color 5/26-6/9	Low Flow/Low Color 5/1-5/26 & 9/4-12/31
Filter 1 (g/sf)	3012	7331	5976	8666
Filter 2 (g/sf)	3178	5428	6081	8518
Filter 3 (g/sf)	3553	7162	No Data	8290
Filter 4 (g/sf)	2946	4826	6068	6163
Filter 5 (g/sf)	4858	7466	7483	8279
Filter 6 (g/sf)	6033	9049	8635	8711
Filter 7 (g/sf)	7519	8917	8971	8952
Filter 8 (g/sf)	7408	9109	9225	8708
Total Average (g/sf)	4813	7411	7491	8286

3.3.2 Filter Inspection of Filters 2 and 8

Inspections of Filters 2 and 8 were conducted to evaluate the media condition, media size and backwash efficiency. General observations include the media condition appeared good and no mudballs were observed. A sieve analysis is currently being conducted by an outside lab. This information will be forwarded when available.

Backwash efficiency was evaluated by conducting flocc retention analyses pre and post backwash, measuring filter expansion during backwash and collecting turbidity samples at the overflow weir during backwash. In general, the investigation indicated that the filters are getting clean – potentially over clean - during backwash. The results of the tests as well as the industry guidelines are described below in Table 7. The full set of data from the filter evaluation can be found in Appendix C.

One of the goals in conducting this evaluation was to understand if the filters were getting sufficiently cleaned or overcleaned, during the backwash cycle. Based on the results, it is possible that, since the filter backwash turbidity at the end of backwash is less than 1 NTU, the backwash procedure could be relaxed. Also, since the filters are getting cleaned, and during challenge periods the filter run is terminated based on turbidity and not headloss **it is highly recommended that a filter aid polymer be investigated to address turbidity breakthrough.** This should be evaluated on the pilot scale, so appropriate cleaning can also be evaluated. Currently the plant filter headloss gauges are not working. These must be operational prior to full scale filter aid polymer application.

Table 7 Results from Inspections of Filter 2 and Filter 8

Test	Goal	Filter 2	Filter 8
Flocc Retention Analysis	30 – 60 NTU	37 NTU	25 NTU
Filter Expansion	20 – 30% depending on plant and operating conditions	20%	20%
Filter Backwash Turbidity (at end of backwash cycle)	10 NTU	<1 NTU	< 1 NTU

3.3.3 Impact of Filter Media Configuration on Turbidity Removal

Filter designers use a ratio called "L/d" as one of the criteria to ensure an appropriate media configuration is selected that will result in good particulate removal. The L/d Ratio is the calculation of:

Media depth (L), mm / diameter (d)

Where L is the media depth in mm

d = the media effective size in mm

Using previous sieve analysis data from the 2009 inspection of Filter 2, as well as data collected during the 2012 Spring Optimization, an L/d Ratio was calculated (Table 8). The results indicated an L/d of about 914 in 2009. Soon after this evaluation, the media was supplemented with additional anthracite. The resulting L/d for the filter based on media collected this spring is 992. Adding media definitely improved the L/d however, an L/d of 1100 to 1200 is the minimum for this filter configuration based on water treatment plant filter design criteria. As such, it is recommended that higher L/d ratios, 1200 – 1700, be evaluated as part of pilot testing in Spring 2013.

Table 8 L/d Ratio for Filter 2 Based on 2009 and 2012 Data

Filter 2 Media in 2009

Media	Effective Size	Uniformity Coefficient	d_{90}	d_{60}	d_{10}	L	L/d
Anthracite	1.17	1.38	1.99	1.62	1.17	14	304
Sand	0.5	1.3	0.8	0.65	0.5	12	610
							914

Filter 2 Media in 2012

Media	Effective Size	Uniformity Coefficient	d_{85}	d_{60}	d_{10}	L	L/d
Anthracite	1.07	1.4	1.8	1.48	1.07	18	427
Sand	0.54	1.3	0.8	0.68	0.54	12	564
							992

4. Conclusions

The primary places where improvements can be made at Betasso to improve filter performance during the spring challenge period are:

1. Chemical treatment during coagulation
2. Physical performance during settling and filtering
3. Improve chlorination before filtration

In order of prioritization, it is recommended that:

1. Repair Basin chlorinators

   As discussed earlier the chlorination of the post sedimentation stream/filter feed water stream has impact on the filtration efficiency. The chlorine feed system includes on line chlorine residual analyzers, rate of flow control of the chlorine dose, effective metering of the flow rate and a chlorine injection system to evenly distribute the chlorine over the flow cross section. It may include a chlorine concentration feedback loop to confirm and maintain the target chlorine concentration. A review of the chlorine storage and feed

systems at the Betasso WTP should be completed to identify any issues and needed improvements.

2. Improve flocculation and sedimentation by fixing flocculator drives to improve basin performance

   Improvement and economy in flocculation can be achieved by tapering the velocity gradient from a G value of 40 to 60 s^{-1} in the first stage down to a G value of 15 to 25 s^{-1} in the third stage. The higher G value in the first stage enhances the production of high-density flocs and a minimum G value is needed in the last stage to prevent settling of flocs in the basin. In general good flocculation occurs when the G x t (where t is in minutes) is as low as 30,000 to as high as 200,000. For Betasso WTP a 'Flocculator Energy Gradients (Basins 3 and 4)' has been prepared by others. It identifies the Paddle RPM, the G and the Gxt for various flow/production rates. This should be used as a guide in establishing and operating the flocculators once the VFD's are operational.

3. Explore modifying filter L/d ratio

   This was discussed in Section 3.3.3

4. Evaluate addition of filter aid polymer

   Filter aid polymer may be a good interim strategy for improving filter run length. Polymer can create a "seal" with extra stickiness that captures particles in a filter. Drawbacks of using polymer include over feed, which results in filter blinding and development of mudballs. Investigation indicated that good backwashing is occurring therefore, with proper attention, mudballs should not form. Additionally, this should be considered a seasonal strategy, hence the polymer would only be used during the spring runoff. This will minimize issues that plant's experience when they use polymer continuously.

5. Address filter headloss gauge operability

   These gauges will be critical if filter aid polymer is adopted. Polymer may increase headloss so a careful balance between filter effluent turbidity and headloss increase must be struck.

6. Conduct additional investigation on chemical coagulation during 2013 spring runoff. Identify a firm sedimentation basin turbidity goal as a key metric for this testing. This should include limited bench scale testing, and focus

predominately on the pilot scale. Pretreatment oxidation or PAC addition may be part of this overall plan.

Continue this spring's optimization efforts. Recommend moving from bench scale to pilot scale to fully investigate the impact of changes on the entire process train.

Recommended next steps, beyond the repair of Basin chlorinators and flocc drives, include both bench and pilot testing. These efforts are described below.

4.1 Bench Testing

Bench testing for settleability of flocc under different pretreatment coagulation scenarios is recommended. This testing could begin this summer in order to develop a method and approach and then continue next spring in conjunction with pilot testing.

4.2 Pilot Testing

To date, several individual processes have been evaluated but the combination of processes has not. In order to assess the optimized arrangement of processes and design criteria that should be targeted during upgrades, it is recommended that pilot plant testing be conducted next spring, 2013. Conducting pilot testing in 2013 would allow for design during 2014 and construction to begin in 2015.

It may be possible to utilize the existing pilot from the 63th St. Water Treatment Plant. It consists of rapid mix (via static mixer), three stage flocculation and plate sedimentation. Two filter columns have already been moved from the 63rd St. Plant to Betasso. This pilot would need to be further evaluated, but this could be a very cost effective approach to accomplish testing. It is also possible that CU Boulder may have students that could operate and manage the data at a very reasonable rate. Two additional filter columns will be available in September, 2012 that would bring the total number of pilot columns to four. Piloting would allow for confirmation of the following:

1. Preoxidation or PAC recommendation
2. Evaluation of different coagulation scheme during the challenge period – focus on particle settleability
3. Impact of plates in sedimentation – identification of surface overflow rate
4. Effectiveness of filter aid polymer addition during challenge conditions
5. Evaluation of different media configurations for removal of particulates

5. Project Schedule

A simple timeline has been prepared to show the recommended schedule for additional planning activities that will allow the City to stay on track for 2015 construction at Betasso.

	2012		2013				2014				2015			
Activity	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Bench Testing														
Pilot Testing Planning														
Pilot Testing Execution														
Scope of Work for Betasso Design Services														
Selection of Consultant														
Design Services														
Construction														

Figure 6 Project Schedule

Appendix A

Testing Matrix

Test	Variable	Description	Analytes	Schedule
1A. Preoxidation – ClO_2	Dose	Doses: 0.6, 1.0 and 1.4 mg/L	Raw and Settled: Turbidity pH Alkalinity Temperature Color Manganese (total and soluble) UV-254 Total Organic Carbon	Week of 4/16
	Source water blend (two blends)	Blend: 60% Lakewood; 40% Barker		
	Contact Time	Contact time: 0.5 minutes and 1.0 minutes		
1B. Preoxidation – $KMnO_4$	Dose	Conduct demand test to minimize soluble Mn (< 0.02 mg/L after reaction). Start by bracketing using dose of 0.1, 0.2 and 0.3 mg/L $KMnO_4$.	Raw and Settled: Turbidity pH Alkalinity Temperature Color Manganese (total and soluble) UV-254 Total Organic Carbon	Week of 4/16
	Source water blend (two blends)	Blend: 60% Lakewood; 40% Barker		
	Contact Time	Contact time: 1 minute and 15 minutes		
2. Powdered Activated Carbon	Dose	Doses: 0, 10, 20, 30 mg/L	Raw and Settled: Turbidity pH Alkalinity Temperature Color UV-254 Total Organic Carbon	Week of 4/23
	Type	Bituminous Lignite Wood		
	Contact Time	Time: 10, 20 and 30 minutes		
	With and Without Coagulant	7 mg/L Sumaclear 12 mg/L Alum		
3. Flocculation Aid	Dose	TBD	Raw and Settled: Turbidity pH Alkalinity Temperature Color Manganese (total and soluble) UV-254 Total Organic Carbon	Week of 5/3
	Type	TBD		
	Location	TBD		
4A. Filter Aid Polymer (This test will be conducted using the pilot filter columns)	Dose	This testing was not conducted. Recommend for Summer 2012 using pilot filter columns.		
	Type			
4B. Media Configuration (This test will be conducted using the pilot filter columns)	L/d	This testing was not conducted. Recommend for Summer 2012 using pilot filter columns.		

Test	Variable	Description	Analytes	Schedule
5. Flocculation Velocity Gradient	1. Document RPM of all 4 basin flocculators. 2. Set Basin 4 flocculators at consistent RPM, document turbidity for one week. 3. Use existing information to determine velocity gradient using RPM. 4. Modify Basin 4 RPM to tapered flocculation, allow to stabilize and document turbidity for one week.			Week of 4/9
6. Coagulation Chemistry				

Appendix B

PAC Study

Study Report to MPI (6-12-12)
Evaluation of PAC for the Betasso Water Treatment Plant
City of Boulder

Kyle Shimabuku and R. Scott Summers

Project Objective

The objective of this study was to evaluate the impact of powdered activated carbon (PAC) type, dose and kinetics on removing color, total organic carbon (TOC) UV absorbance (UVA) and 2-methylisoborneol (MIB) from the Betasso Water Treatment Plant source water.

Approach

Bench-Scale Apparatus

A bench-scale jar testing apparatus was used to simulate the full-scale conventional treatment process. A modified jar (2 L) with limited headspace was used in all experiments to minimize the loss of volatile MIB. Jar tests were run to simulate rapid mix (250 rpm for 1 min) and flocculation (75 rpm for 60 min).

Materials and Reagents

Three types of PAC were used at this study; bituminous (Calgon WPH), lignite (Norit HDB), and wood (Norit CASP). The PAC doses were 5, 15, and 30 mg/L. The coagulants Sumaclear and Alum were dosed at 7 mg/L and 12 mg/L, respectively. Variables and range of MIB experiments are below Table 1. The water was spiked with ^{14}C-labeled MIB at a concentration of approximately 100 ng/L.

Table 1. Raw water quality and operational conditions

Variables	Range
TOC concentration	3.7 mg/L
Color	20 Pt-Co
UV_{254}	0.104 1/cm
MIB target concentration	100 ng/L
PAC type	Lignite, bituminous and wood
PAC dose	0, 5, 15 and 30 mg/L
Contact times	10 min, 30 min, and 60 min
Coagulant-Polymer dose	Sumaclear (7 mg/L) and alum (12 mg/L)

Measurements

^{14}C-labeled MIB was analyzed by Packard TRI-CARB 2300TR liquid scintillation analyzer. NOM was characterized as TOC or DOC concentration using SIEVERS 800 TOC instrument and UVA using HACH DR4000 Spectrophotometer.

Experimental approach

Raw water was collected from the Lakewood Reservoir (collected at the Betasso Water Treatment Plant) and Barker Reservoir (collected directly from the reservoir) on May 14th 2012, in a fashion to capture spring runoff conditions. The water used for jar tests was a blend of 60% Lakewood Reservoir water and 40% Barker Reservoir water. The raw water was spiked with MIB at 100 ng/L.

The jar tests began with a rapid mixing speed of 250 rpm followed by the addition of PAC and/ or the coagulant and then mixed for 1 min. The mixing speed was then reduced to 75 rpm for 60 min to simulate flocculation. Samples were taken after 10 min, 30 min and 60 min. The procedure was followed for all three PAC types and all three PAC doses. The above matrix was completed with and without coagulant. In addition to this matrix, one jar was dosed without PAC and underwent coagulation only. The lignite PAC test at a dose of 15 mg/L was run in duplicate.

Results and Discussion

All results are contained in the following tables and figures. Tables 1, 2 and 3 show the impact of PAC type, dose and kinetics on the removal of color, TOC, UVA and MIB.

Impact of coagulation alone on removal

Coagulation with Sumaclear (7 mg/L) and alum (12 mg/L) was very effective for the control of color with > 90% removal. It also removed 60% of the TOC and 80% of the UVA. The impact on MIB was not measured, but from prior work it is known not to be effective for MIB control.

Impact of PAC type

All of the PACs preformed in a very similar manner; there was not one PAC type that did best under all conditions. After 60min at a dose of 30 mg/L of PAC **without** coagulant, they all removed about ~70% of the color, ~20% of TOC and UVA and 75% of MIB. As shown in the figures color removal was already at >90%, so PAC addition could not yield a measureable improvement. When combined **with** the coagulant, PAC yielded a 0.3 to 0.5 mg/L additional TOC removal (about 15% more) and a 0.006 /cm additional UVA removal (about 6% more).

Impact of PAC dose and kinetics

Increasing the dose from 5 to 15 mg/L and to 30 mg/L **without** coagulant, increased the removal for all parameters., but was most effective for MIB control. Less of a dose impact was found when dosed with the coagulant. In general the kinetics are very fast with most of the removal occurring in the first 10 min. This can be most easily seen in the figures.

Table 1. Results at 10 min

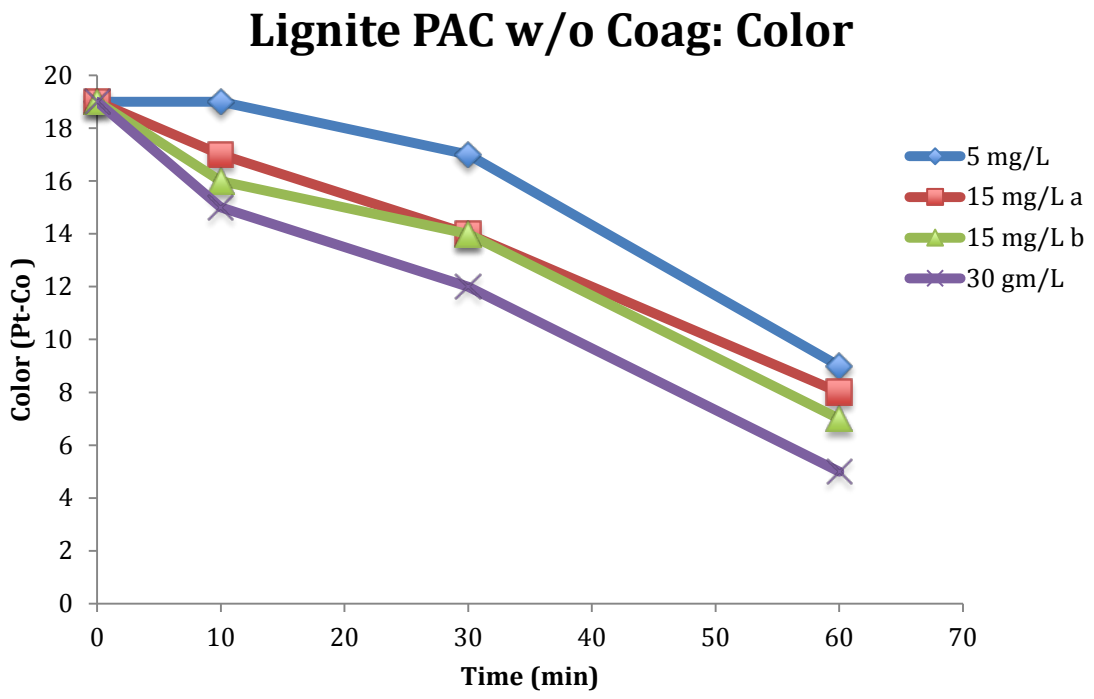
10 min	Color (Pt-Co)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	19	2	20	1	20	1
5	19	2	15	0	10	0
15	17	2	10	1	10	1
30	15	2	8	0	8	1
	TOC (mg/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	3.32	1.29	3.1	1.17	3.4	1.23
5	3.85	1.36	2.93	1.23	3.4	1.74
15	3.35	1.15	2.9	1.22	3.3	1.53
30	3.07	1.09	2.85	1.15	3.19	1.32
	UVA (/cm)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	.101	0.019	0.102	0.019	.104	0.021
5	.102	0.026	0.095	0.024	.100	0.030
15	.098	0.021	0.097	0.019	.098	0.020
30	.091	0.018	.095	0.017	.093	0.016
	MIB (ng/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	92	n/a	110	n/a	95	n/a
5	83	n/a	90	n/a	85	n/a
15	72	n/a	80	n/a	59	n/a
30	50	n/a	76	n/a	41	n/a

Table 2. Results at 30 min

30 min	Color (Pt-Co)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	19	1	20	0	20	1
5	17	1	8	0	10	0
15	14	1	8	0	10	1
30	12	0	6	0	10	1
	TOC (mg/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	3.32	1.30	3.1	1.19	3.4	1.17
5	3.32	1.34	2.94	1.31	3.14	1.28
15	3.12	1.26	2.87	1.07	3.03	1.17
30	3.03	1.08	2.75	0.92	2.95	0.88
	UVA (/cm)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	.101	.019	.104	0.021	.104	0.019
5	.098	.020	.100	0.021	.097	0.020
15	.097	.016	.098	0.018	.094	0.016
30	.089	.014	.093	0.016	.088	0.012
	MIB (ng/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	92	n/a	110	n/a	95	n/a
5	80	n/a	75	n/a	78	n/a
15	60	n/a	59	n/a	44	n/a
30	36	n/a	56	n/a	24	n/a

60 min	Color (Pt-Co)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	19	1	20	0	20	0
5	9	1	14	0	8	0
15	8	0	7	0	9	0
30	5	0	6	0	7	0
	TOC (mg/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	3.54	1.31	3.1	1.39	3.1	1.21
5	3.39	1.32	3.1	0.99	3.1	1.30
15	3.20	1.23	2.84	1.07	2.97	1.17
30	2.89	0.90	2.67	0.91	2.99	0.89
	UVA (/cm)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	1.01	.019	1.02	.021	1.03	.020
5	.1	.018	.091	.014	.089	.019
15	.097	.017	.087	.017	.085	.016
30	.088	.014	.085	.014	.083	.014
	MIB (ng/L)					
	Lignite PAC		Bituminous PAC		Wood PAC	
PAC dose (mg/L)	w/o coag	with coag	w/o coag	with coag	w/o coag	with coag
0	94	n/a	110	n/a	95	n/a
5	80	n/a	76	n/a	71	n/a
15	54	n/a	56	n/a	39	n/a
30	30	n/a	25	n/a	18	n/a

Color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Color (Pt-Co)
Time (min)
0
2
4
6
8
10
12
14
16
18
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10
20
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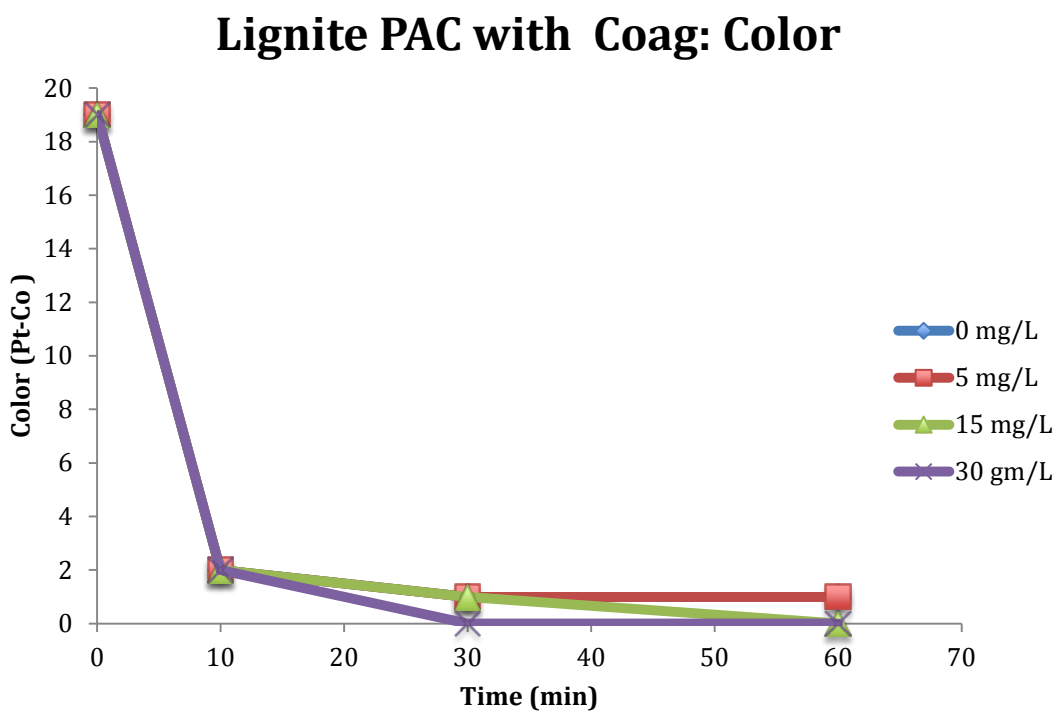
40
50
60
70
5 mg/L
15 mg/L a
15 mg/L b
30 gm/L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Color (Pt-Co)
Time (min)
0
2
4
6
8
10
12
14
16
18
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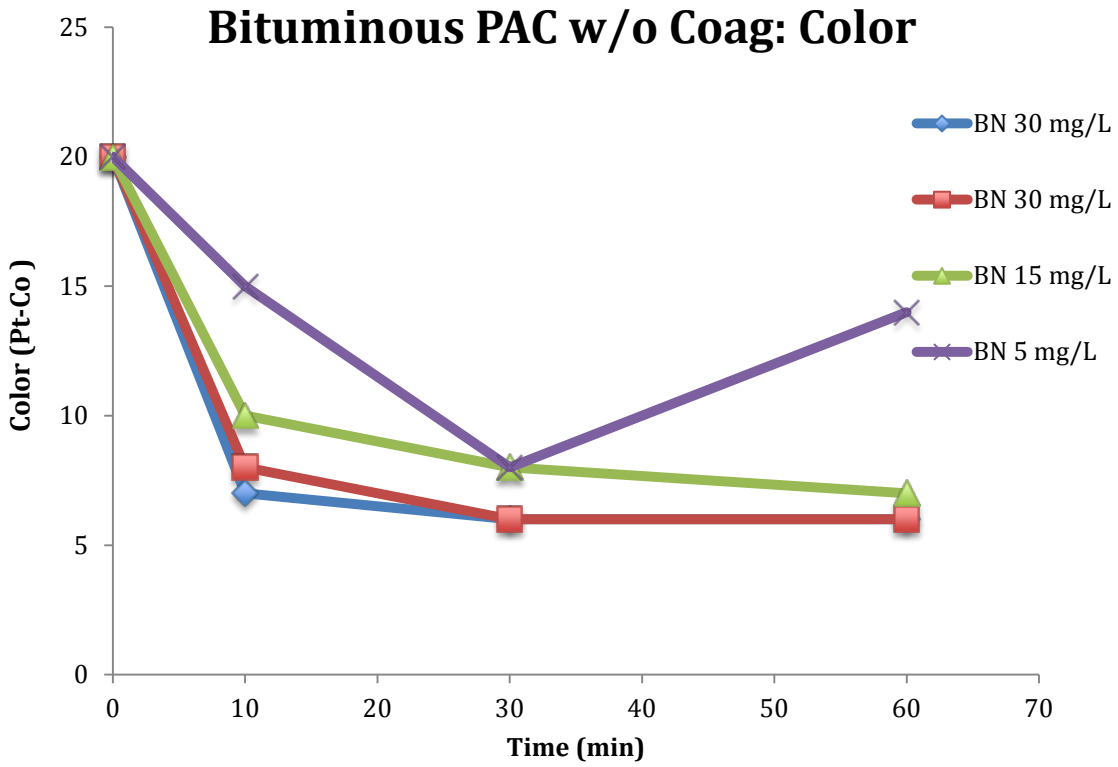
20
30
40
50
60
70
0 mg/L
5 mg/L
15 mg/L
30 gm/L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Color (Pt-Co)
Time (min)
BN 30 mg/L
BN 30 mg/L
BN 15 mg/L
BN 5 mg/L
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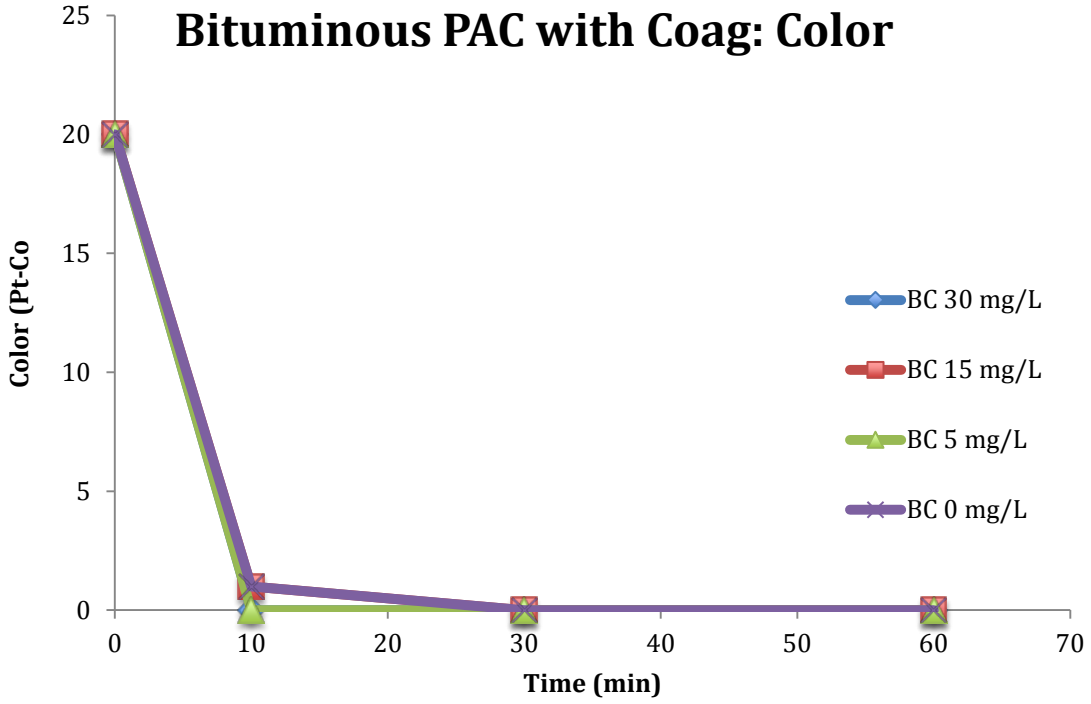
5
10
15
20
25
0
10
20
30
40
50
60
70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Color (Pt-Co
Time (min)
BC 30 mg/L
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BC 5 mg/L
BC 0 mg/L
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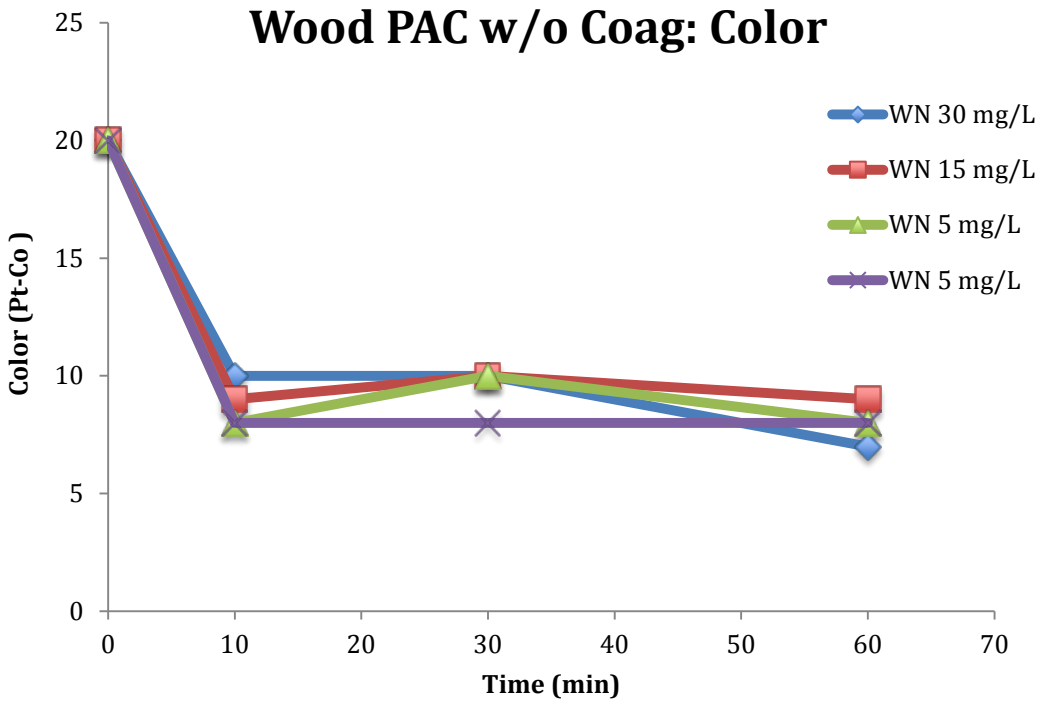
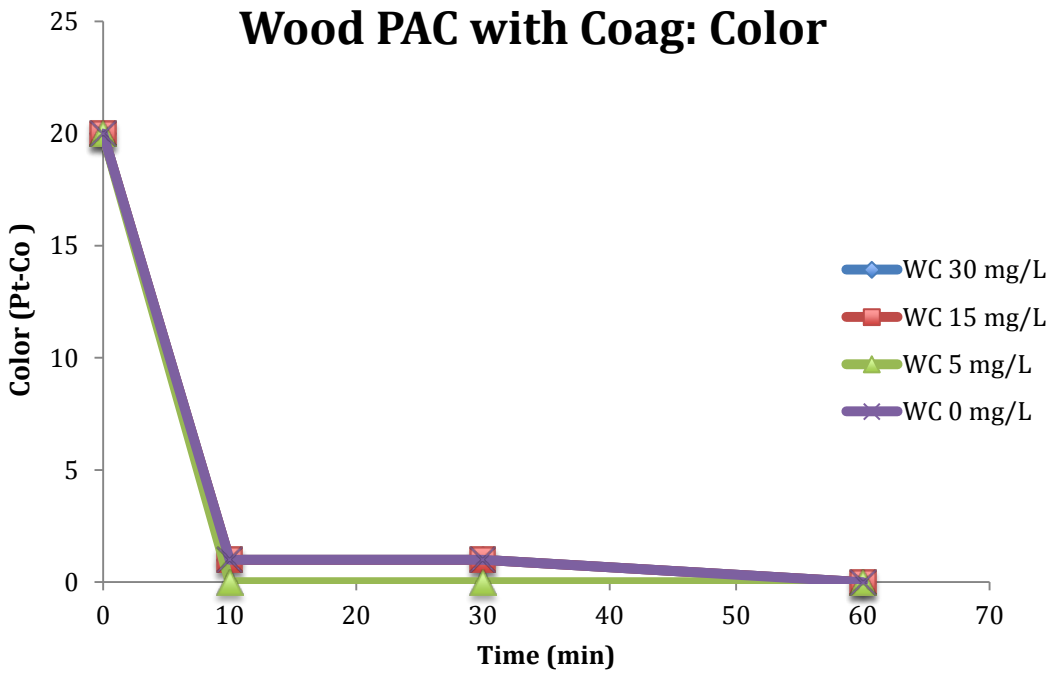
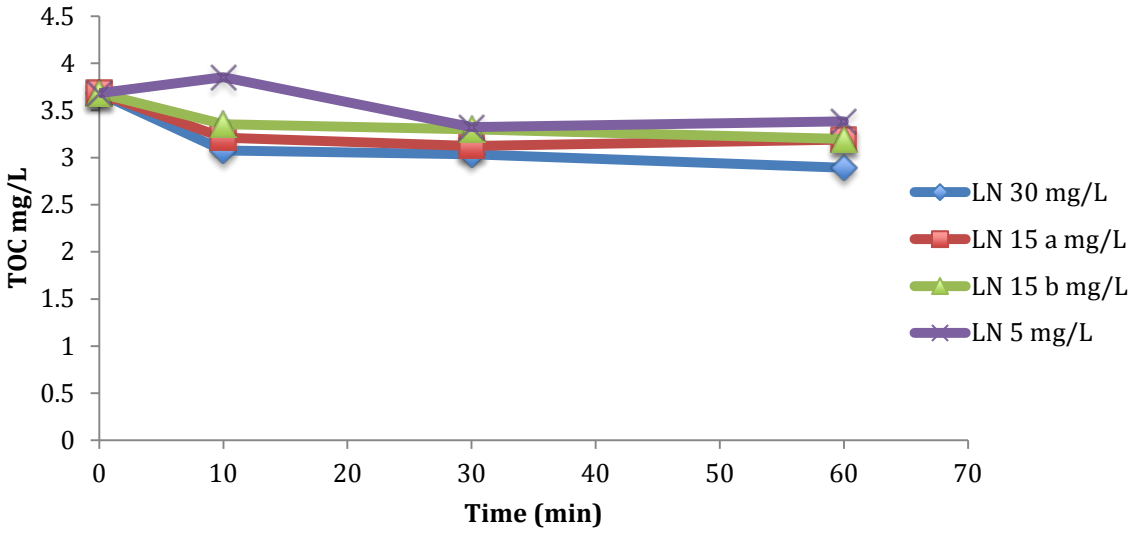
10
15
20
25
0
10
20
30
40
50
60
70


Wood PAC w/o Coag: Color
Color (Pt-Co)
Time (min)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
WN 30 mg/L
WN 15 mg/L
WN 5 mg/L
WN 5 mg/L

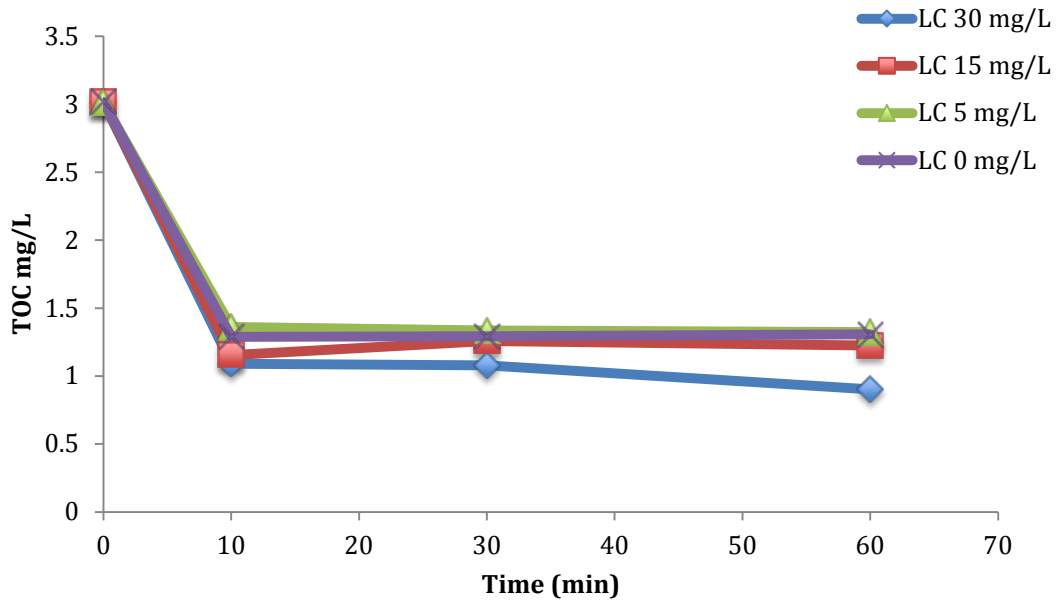

Wood PAC with Coag: Color
Color (Pt-Co)
Time (min)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
WC 30 mg/L
WC 15 mg/L
WC 5 mg/L
WC 0 mg/L

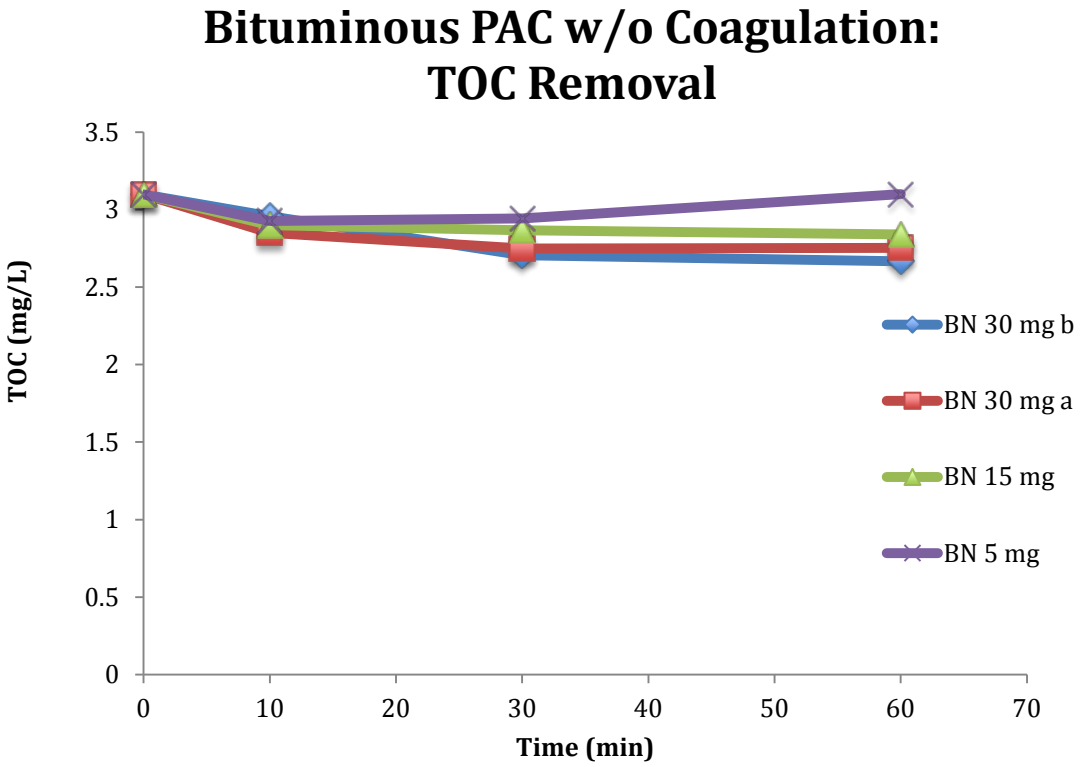
TOC

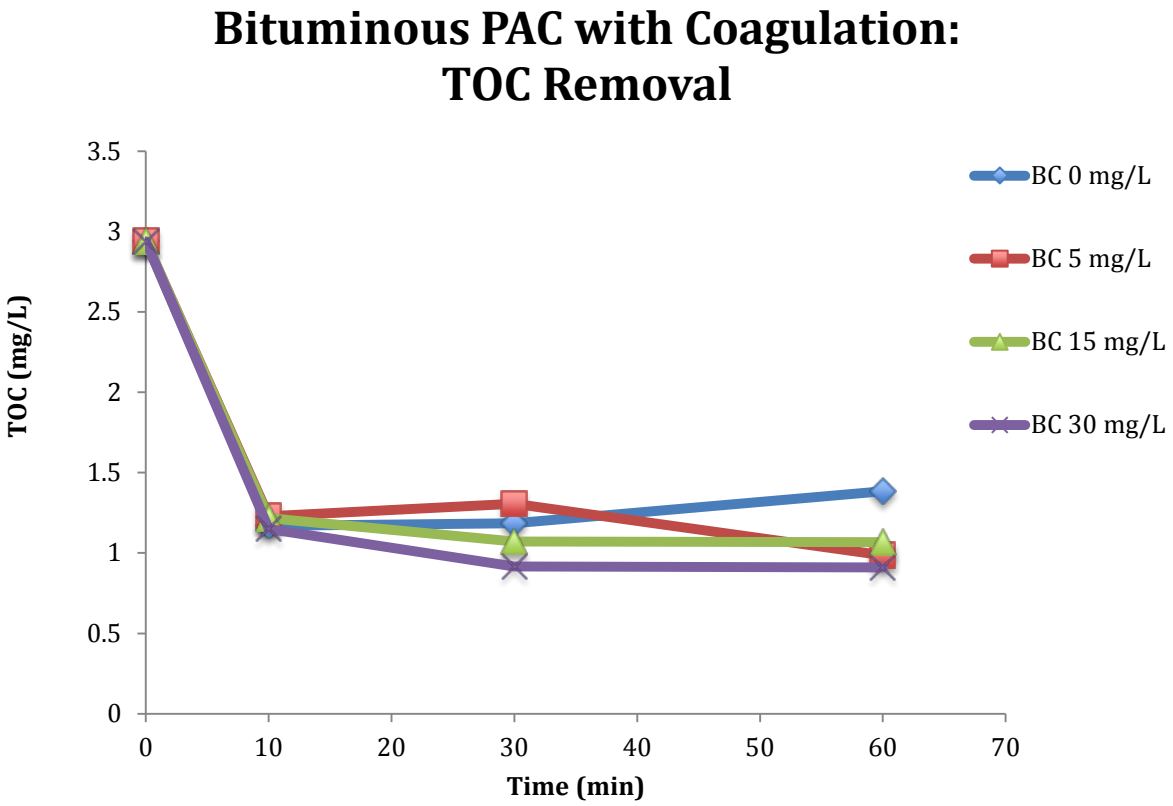
Lignite PAC w/o Coagulation: TOC Removal

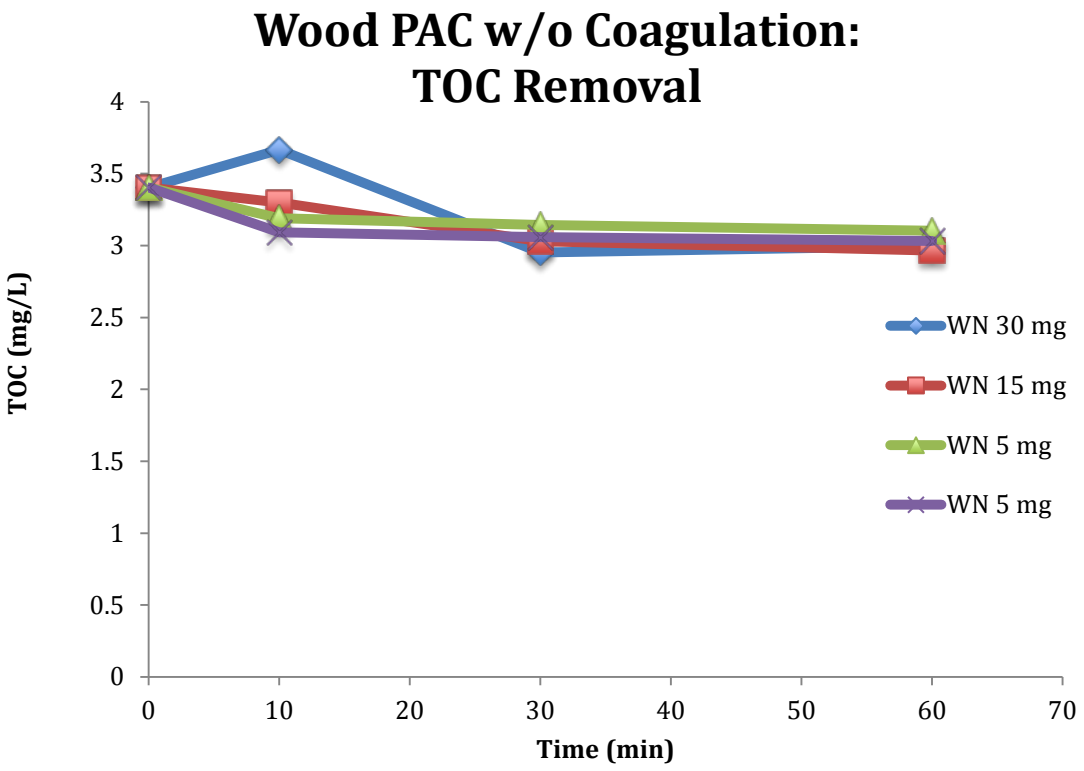


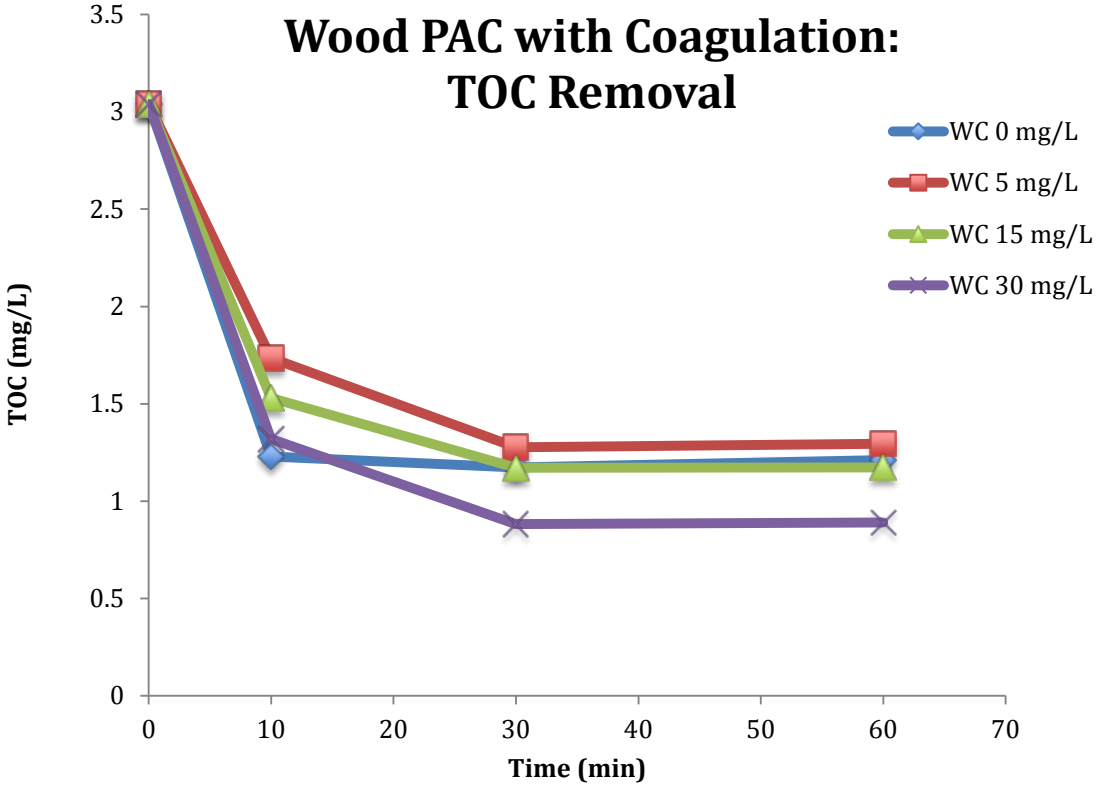
Lignite PAC with Coagulation: TOC Removal



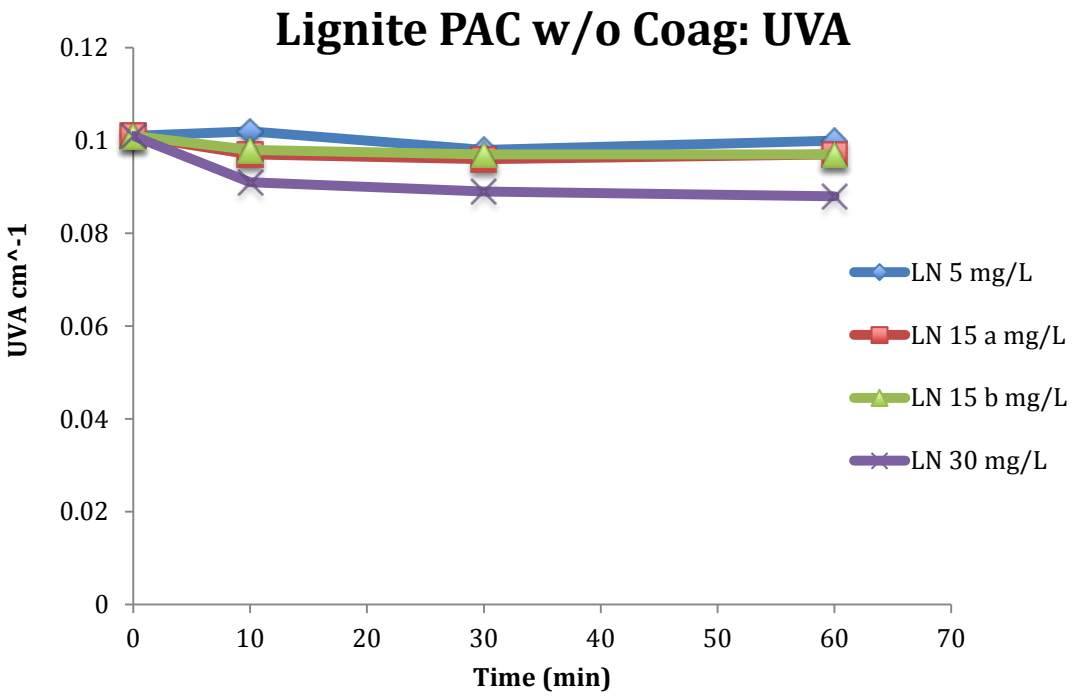

Bituminous PAC w/o Coagulation:
TOC Removal
TOC (mg/L)
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
Time (min)
BN 30 mg b
BN 30 mg a
BN 15 mg
BN 5 mg

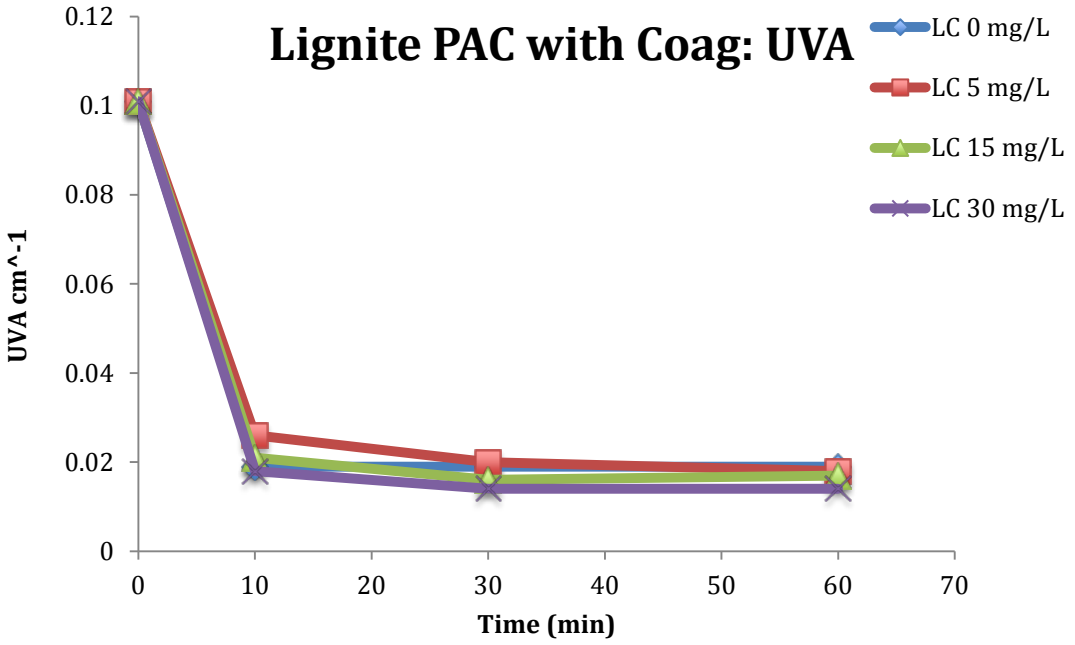

Bituminous PAC with Coagulation:
TOC Removal
TOC (mg/L)
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
Time (min)
BC 0 mg/L
BC 5 mg/L
BC 15 mg/L
BC 30 mg/L

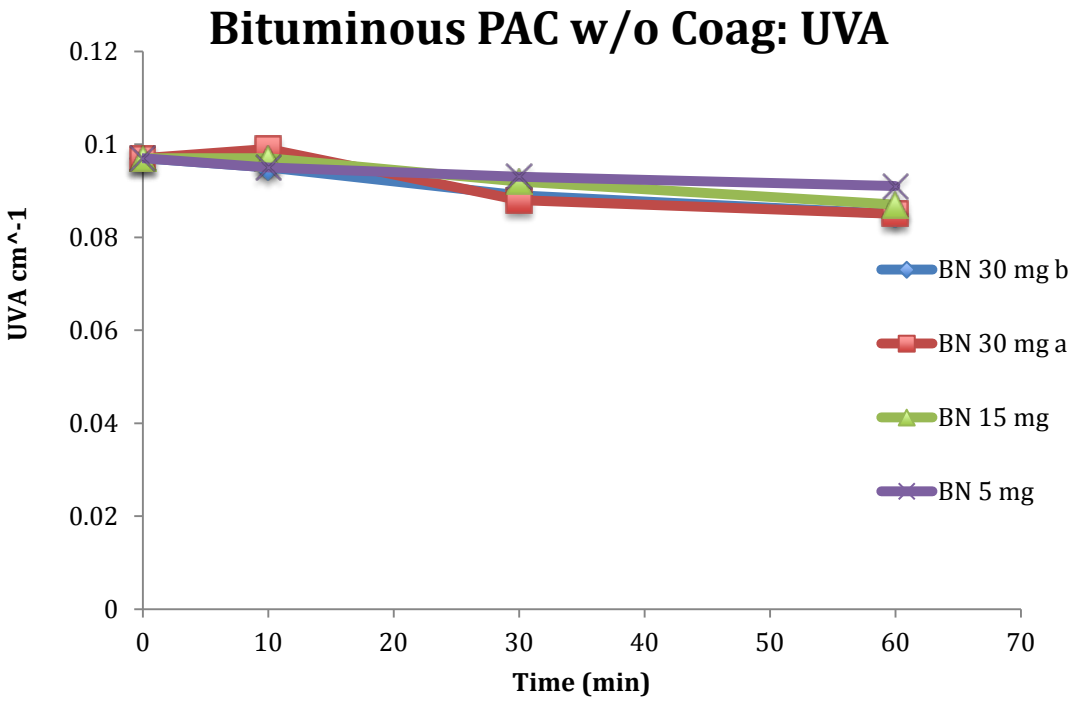

Wood PAC w/o Coagulation:
TOC Removal
TOC (mg/L)
Time (min)
WN 30 mg
WN 15 mg
WN 5 mg
WN 5 mg
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70

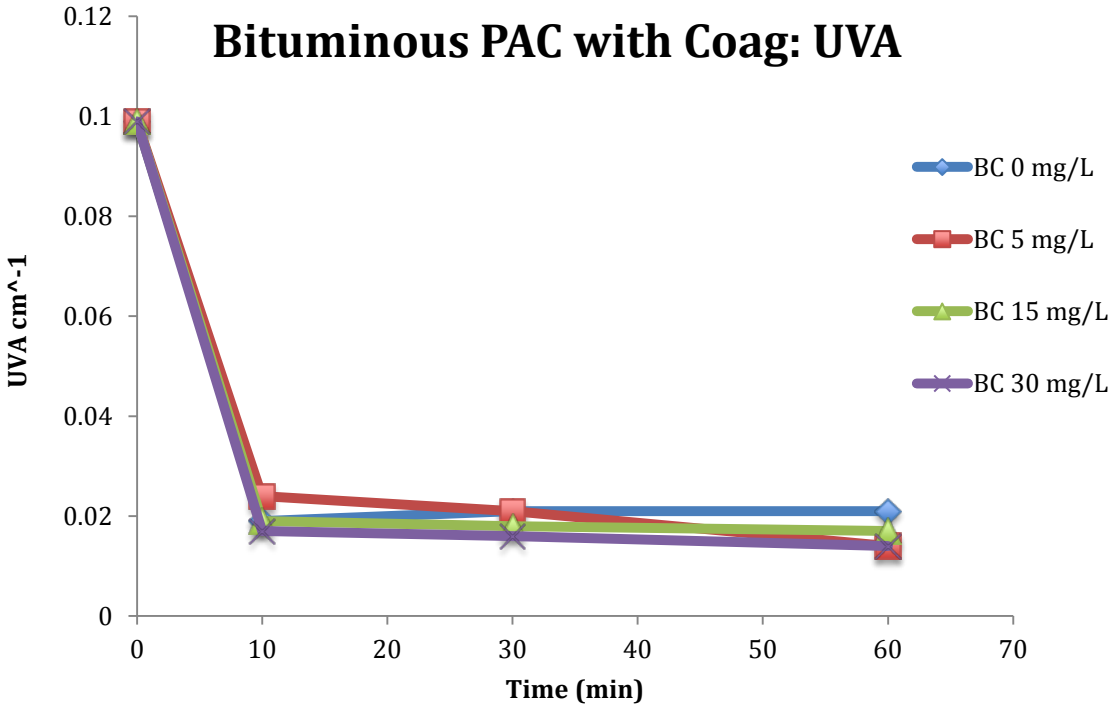

Wood PAC with Coagulation:
TOC Removal
TOC (mg/L)
Time (min)
WC 0 mg/L
WC 5 mg/L
WC 15 mg/L
WC 30 mg/L
0
0.5
1
1.5
2
2.5
3
3.5
0
10
20
30
40
50
60
70

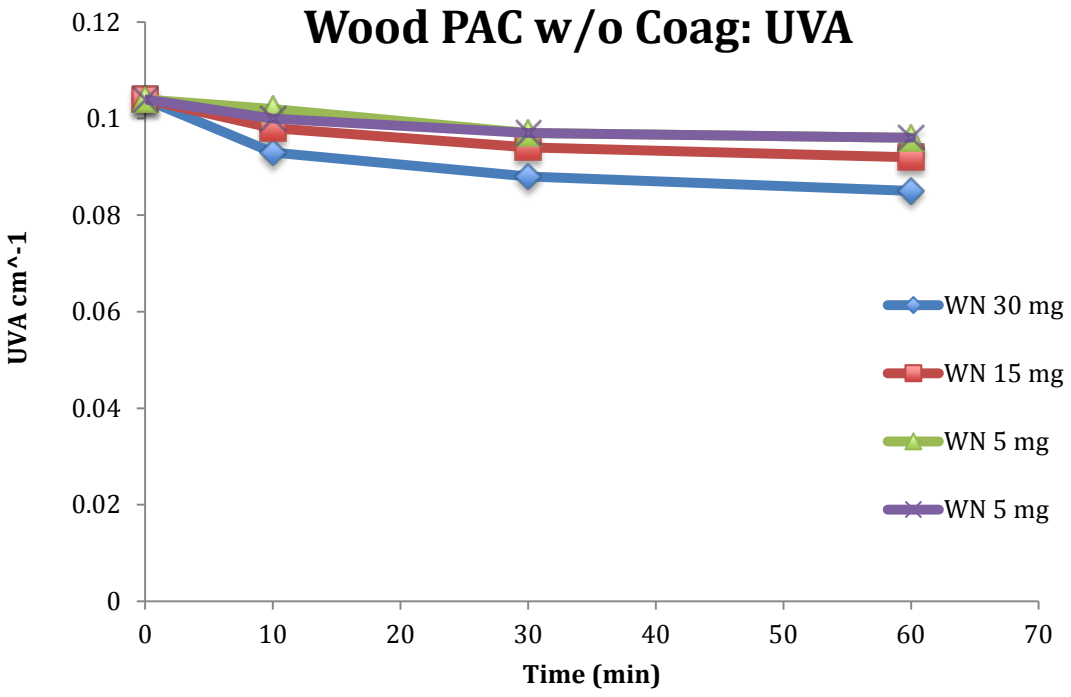
UVA

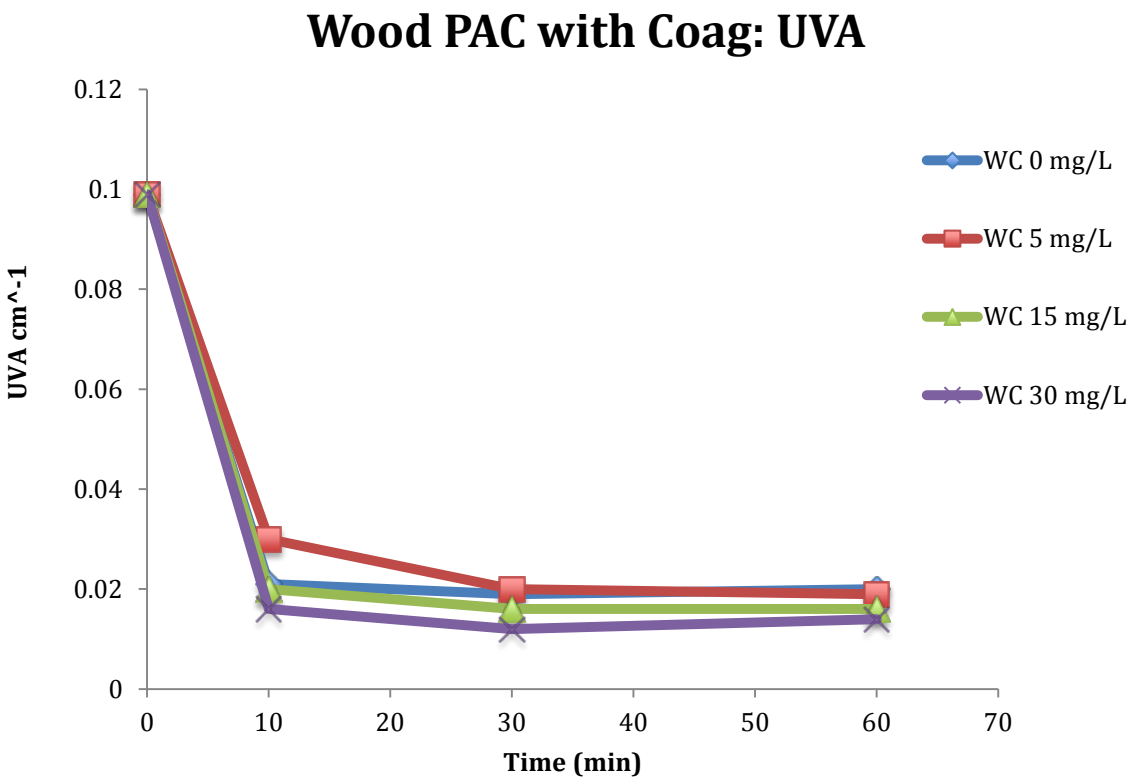

Lignite PAC w/o Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
LN 5 mg/L
LN 15 a mg/L
LN 15 b mg/L
LN 30 mg/L


Lignite PAC with Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
LC 0 mg/L
LC 5 mg/L
LC 15 mg/L
LC 30 mg/L

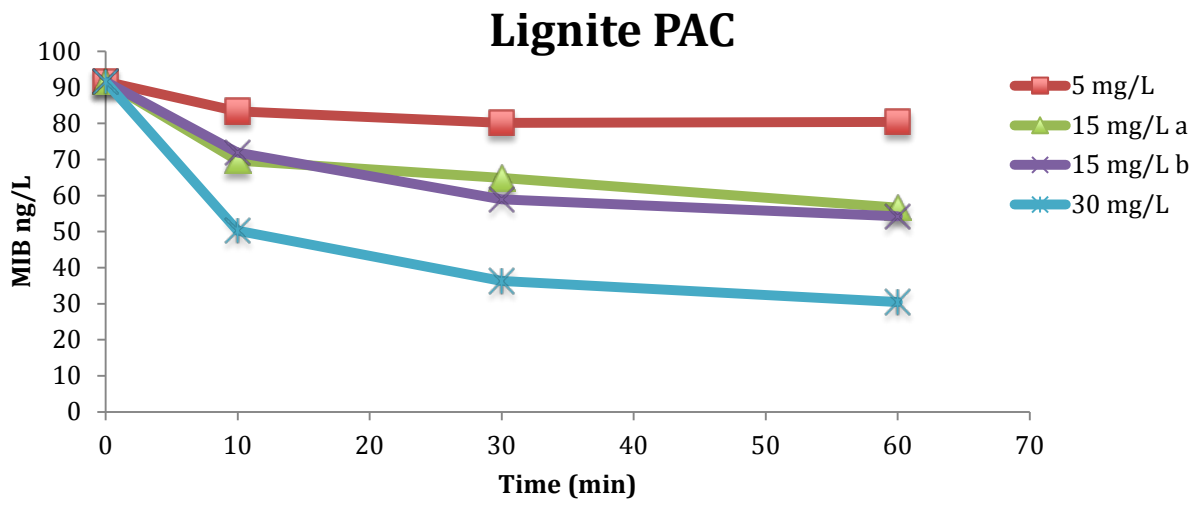

Bituminous PAC w/o Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
BN 30 mg b
BN 30 mg a
BN 15 mg
BN 5 mg

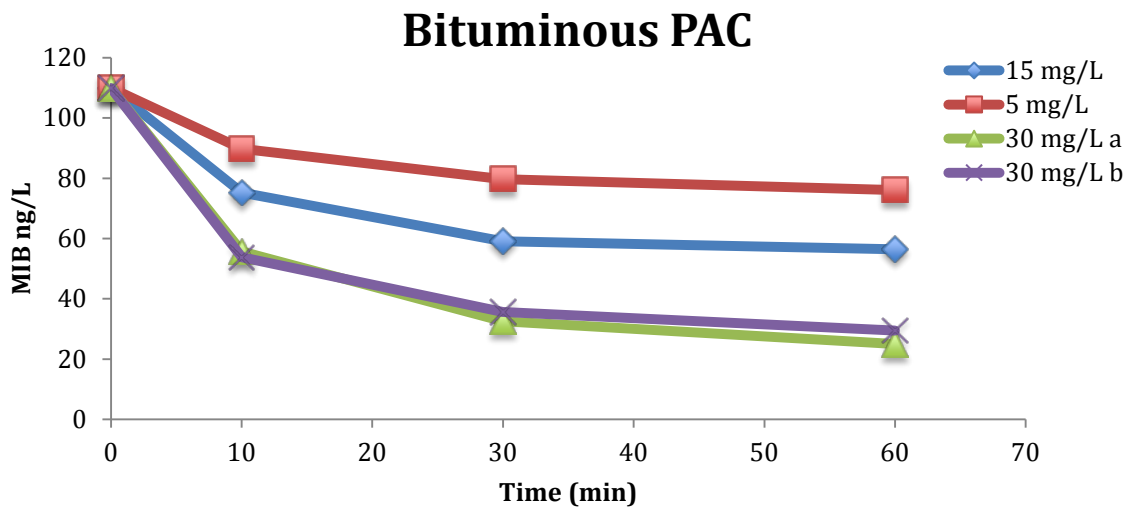

Bituminous PAC with Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
BC 0 mg/L
BC 5 mg/L
BC 15 mg/L
BC 30 mg/L

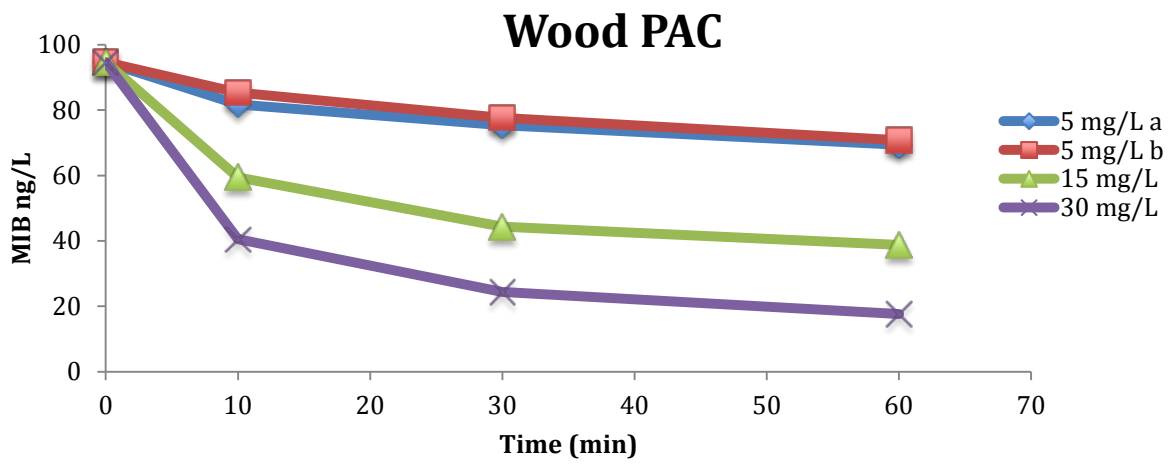

Wood PAC w/o Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
WN 30 mg
WN 15 mg
WN 5 mg
WN 5 mg


Wood PAC with Coag: UVA
UVA cm^-1
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
Time (min)
WC 0 mg/L
WC 5 mg/L
WC 15 mg/L
WC 30 mg/L

MIB without Coagulation



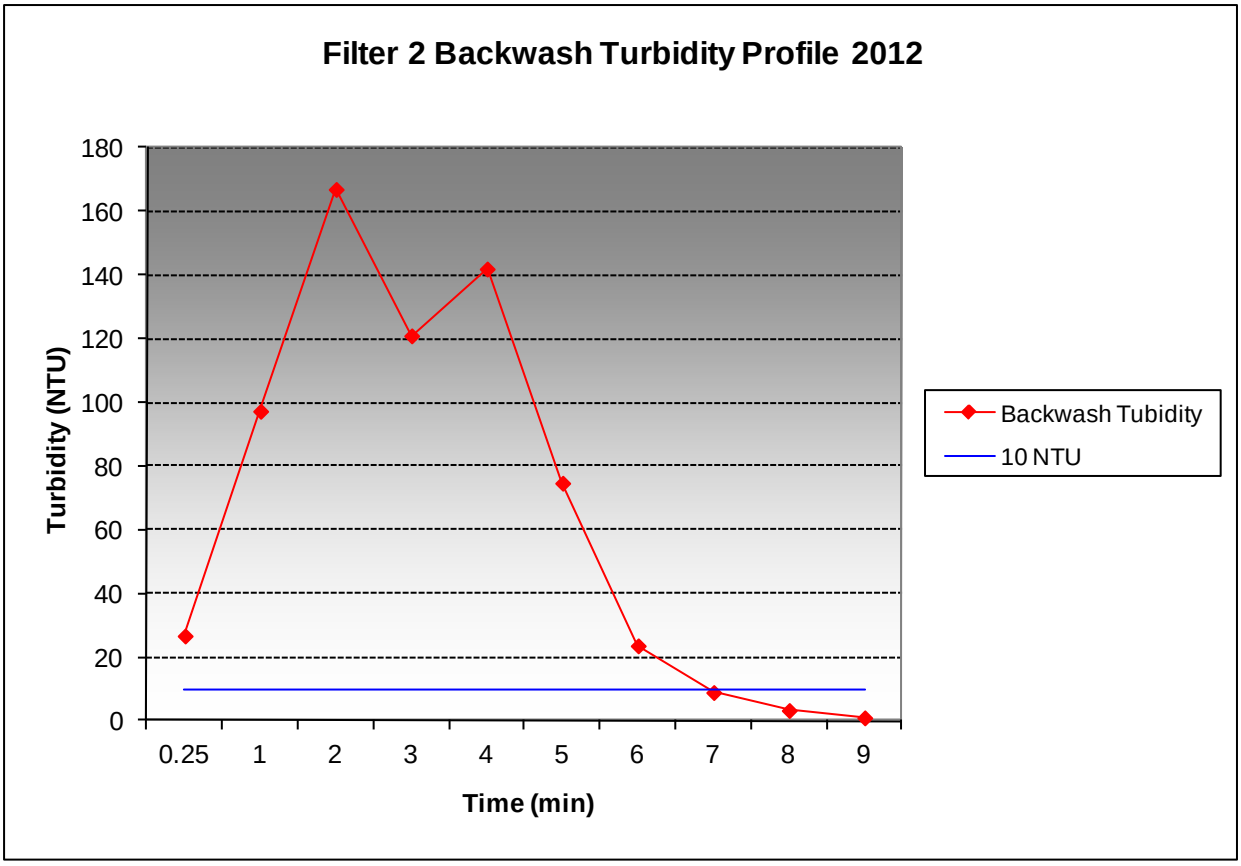


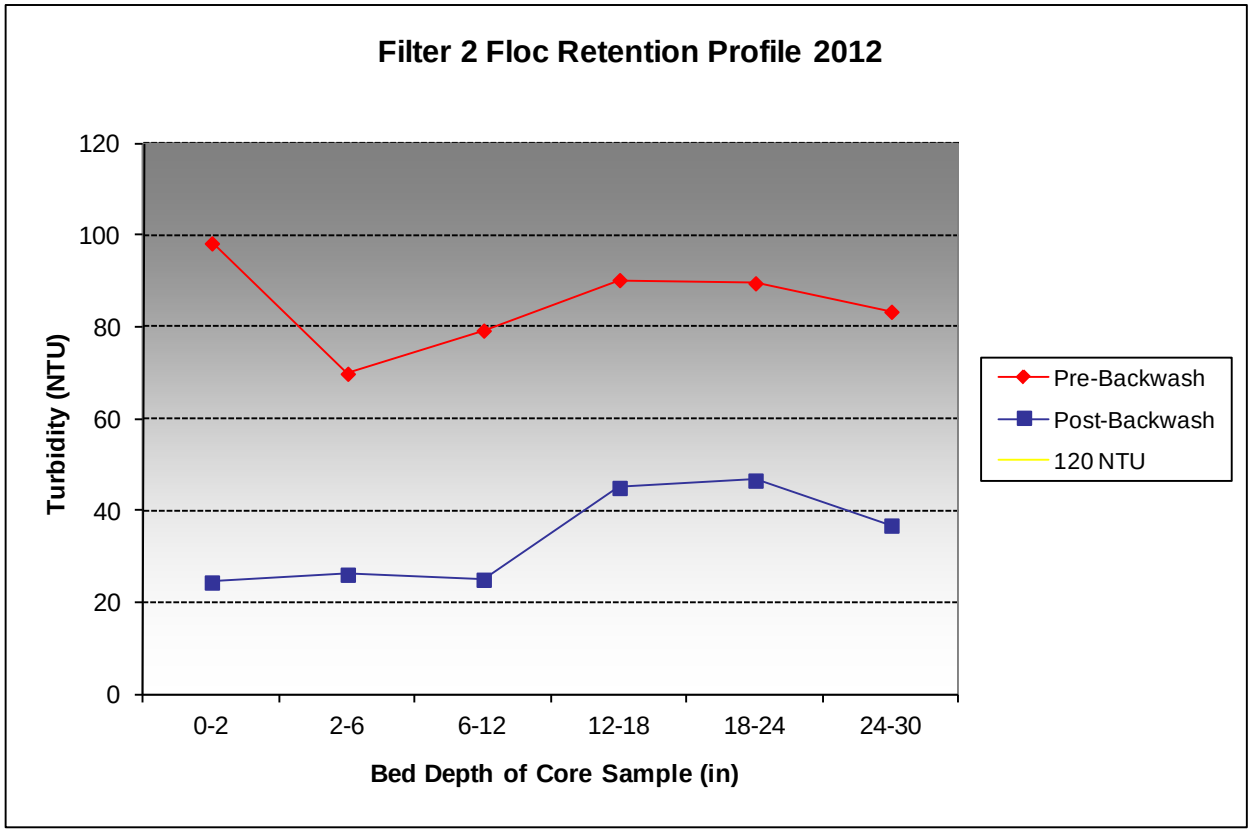


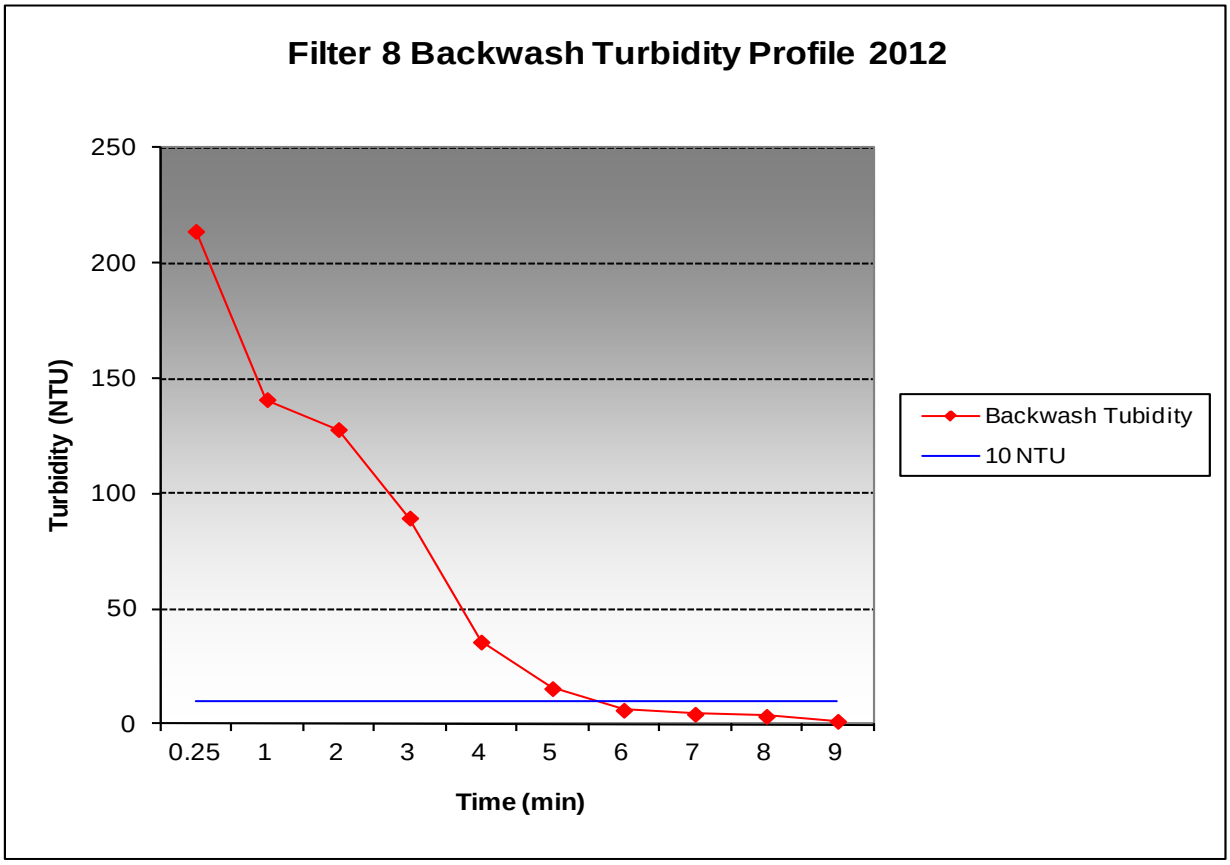
Appendix C

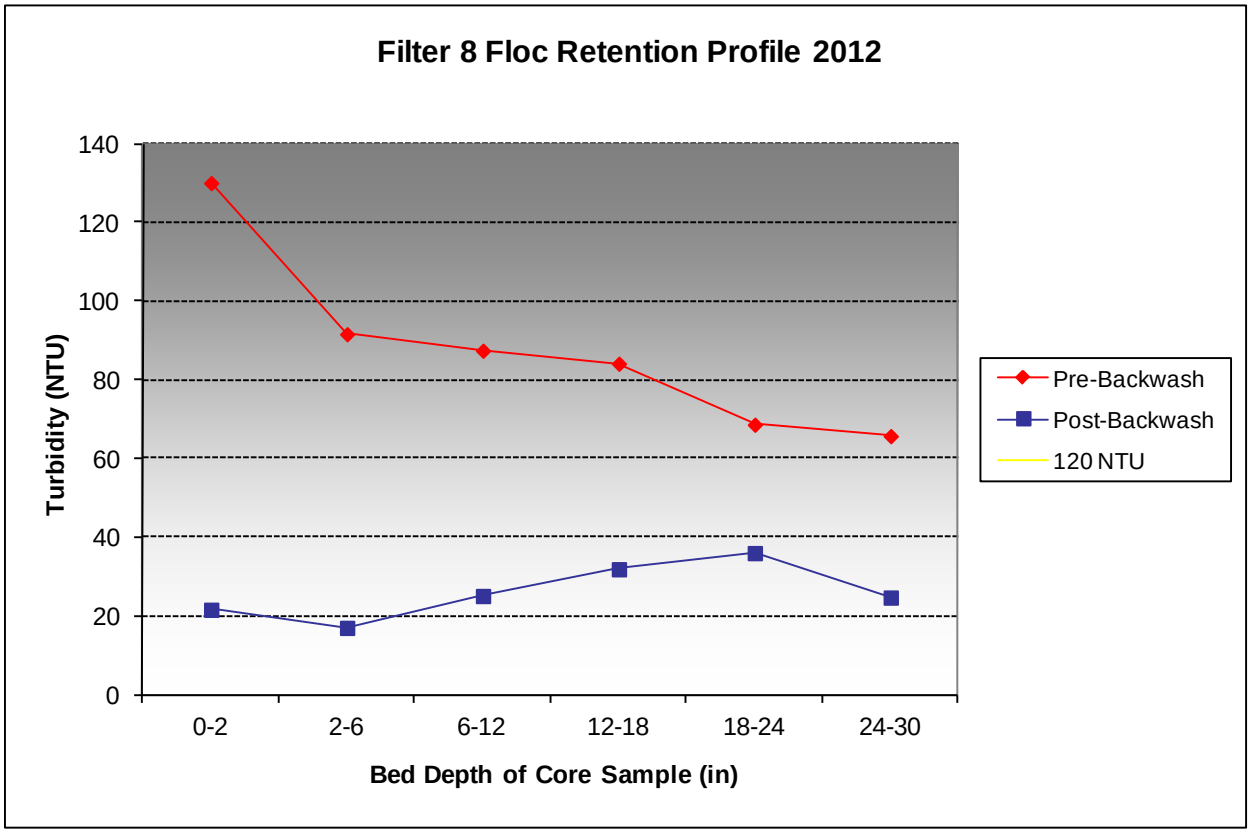
Filter Inspection Results

Filter Inspection Results Spring 2012 – Filters 2 and 8






Filter 8 Backwash Turbidity Profile 2012
Turbidity (NTU)
250
200
150
100
50
0
0.25
1
2
3
4
5
6
7
8
9
Time (min)
Backwash Tubidity
10 NTU


Filter 8 Floc Retention Profile 2012
Turbidity (NTU)
140
120
100
80
60
40
20
0
0-2
2-6
6-12
12-18
18-24
24-30
Bed Depth of Core Sample (in)
Pre-Backwash
Post-Backwash
120 NTU

Attachment C

Report Prepared By:

MALCOLM PIRNIE | ARCADIS

The Water Division of ARCADIS

100 Fillmore Street, Suite 200, Denver, CO 80206

Exhibit A

Scope of Work

Project Overview:

The City of Boulder's Betasso Water Treatment Facility (WTF) is currently limited by its residuals handling capacity. The existing lagoons and drying beds do not have sufficient capacity to dewater residuals produced through current operation of the WTF. Brown and Caldwell (BC) has been retained to investigate alternatives to thicken and dewater residuals in an effort to remove this bottleneck from WTF operation.

In order to address this issue, BC will identify areas within the existing process that may be optimized to minimize residuals production, as well as identify, evaluate and recommend alternatives for residuals thickening and dewatering. Maximizing the use of existing facilities will be a priority of the study to minimize capital investment where practical.

Project Objectives

The following specific project objectives have been identified:

- Identify areas for further optimization of residuals streams.
- Identify thickening and dewatering alternatives to address residuals handling capacity at the WTF.
- Screen alternatives to short list technologies for pilot testing.
- Conduct pilot testing of screened alternatives.
- Evaluate piloted alternatives and provide final recommendations and design criteria for full-scale implementation.

Owner Responsibility

The City shall provide to BC all available relevant information to aid in the evaluation. This includes but is not limited to:

- Previous studies.
- As-built drawings.
- Operational data.
- Provide review comments within agreed upon schedules.

Project Assumptions

The following assumptions were made in the development of this Scope of Work:

- The City will provide all consumable materials for pilot testing, including polymer, coagulant, electricity and water.
- The City will conduct all laboratory analyses in support of this project.
- The City will provide payment for all application and review fees.
- BC will submit an electronic copy of all draft deliverables to the City's project manager. The City's project manager will distribute draft deliverables to the appropriate City staff and collect all City

review comments into a single review package. BC will incorporate comments from the review package into the final deliverable. Each deliverable is assumed to have a single review between draft and final versions.

- A single revision will be made to each deliverable between draft and final submittals.
- City will furnish equipment for temporary piping, electricity, and other ancillary equipment where available.
- All deliverables will be delivered in PDF format only, with the exception of the final report. Up to 5 hard copies of the final report will be delivered to the City upon the City's request.
- Direct costs for pilot facilities associated with this project have been estimated based on anticipated rental fees and construction costs at the time of the proposal. Costs may change depending on the technologies chosen for piloting. BC will alert the City of any anticipated increase in piloting costs as soon as practical.

Phase 000 – Finalize Scope of Work

Objective: To work with City staff to finalize scope of work and engineering fee.

Activities:

001 Scoping Workshop. BC will hold a meeting with City staff to discuss items identified during the proposal process, and reach consensus on a final scope of work.

002 Prepare Scope of Work. BC will prepare a final scope of work and engineering fee for City review.

Deliverables:

1. Scope of Work
2. Engineering fee

Assumptions:

1. Compensation for this phase has been limited to $2,500, as stated in the request for proposals, dated February 22, 2013.

Phase 050 – Project Management and QA/QC

Objective: To provide management, direction, coordination and control of all BC work associated with the preparation and maintenance of the project contract schedule, budget, technical quality, and monthly invoices. BC will also provide internal coordination, and technical reviews for all deliverables.

Activities:

051 General project administration including project setup, staffing, budget control, update of the Project Information Manual and related project administration tasks will be provided.

052 Technical Workshops and Meetings. BC will develop, facilitate and summarize each workshop identified within this Exhibit A. Materials submitted for review by the City will be delivered no later than 5 working days prior to the workshop, unless otherwise approved by the City's Project Manager. BC shall prepare a draft agenda for review by the City 5 working days prior to the workshop. This agenda will be distributed electronically to workshop participants after City review. BC will prepare meeting minutes that will be delivered to the City within 5 working days following

the workshop. The City will collect and compile comments from their staff into a single review copy of the materials being discussed and transmit that copy to BC within 10 working days following the workshop.

053 Progress Reports. BC will prepare monthly progress reports to be submitted with the invoices for the work and reviewed at regular progress meetings. The progress reports will describe the work completed in the last monthly period and compare earned value to billings. The progress reports will include an updated schedule and trend register. It is anticipated that this project will be invoiced under a separate account number. These reports will be supported by a monthly meeting between the City's and BC's Project Manager to review progress, status and additional specific issues related to completing the project.

054 Progress Trend Log. BC will maintain a Project Trend Log to document requested changes and their impacts to schedule and budget as they occur. The City's Project Manager will be requested to review and accept or reject the impacts of pending changes in a timely manner to allow work to proceed with minimal delay.

Deliverables:

1. Project Plan
2. Meeting agendas and minutes
3. Monthly invoices and status reports

Assumptions:

1. Compensation for this task is based on a 15-month project duration

Phase 100 – Collect and Review City Data

Objective: To review existing reports and process data to fully characterize current residuals production. In addition, this phase will compare current operation of the WTF to industry best practices to identify potential areas for future optimization.

Activities:

101 Review existing reports including:

- Recent Betasso WTF Studies
- As-Built Drawings
- Operations Data
- Permit Specifications

102 Compare current operation to industry standard, or 'textbook', operational values to identify areas for optimization.

103 Prepare a technical memorandum recommending areas for further investigation of liquid-stream process optimization.

104 Conduct process optimization workshop to discuss results of operations data analysis and recommended optimization alternatives.

Deliverables:

1. Technical Memorandum recommending future process optimization studies.

2. Workshop agendas and minutes.

Assumptions:

1. BC will provide recommendations for further process optimization study.

Phase 200 – Alternatives Identification and Screening

Objective: To identify alternatives for solids thickening and dewatering, establish screening criteria, conduct desktop and bench-scale screening, and provide recommendations for pilot testing of equipment

Activities:

201 Conduct a workshop to identify thickening and dewatering alternatives and establish screening criteria.

202 Perform desktop and bench-scale screening.

203 Prepare technical memorandum identifying alternatives, screening criteria, and screening process, and provide recommendations for pilot testing.

204 Conduct a workshop to discuss preliminary evaluation results and finalize piloting recommendations.

Deliverables:

1. Workshop agendas and minutes.
2. Technical Memorandum summarizing alternatives screening.

Assumptions:

1. Up to four thickening alternatives will be evaluated.
2. Up to eight dewatering alternatives will be identified.

Phase 300 – Pilot Testing

Objective: Develop a pilot testing plan and conduct pilot testing of thickening and dewatering equipment identified in Phase 200.

Activities:

301 CDPHE coordination of piloting activities.

302 Develop a pilot testing plan, including:

- Field work health and safety plan
- Contact information for key personnel
- Description of objectives, goals and schedule
- Description of pilot testing process and operations
- Site plan(s) showing location of pilot testing facilities
- Sampling plan and procedures

303 Coordinate with equipment suppliers to schedule and execute pilot testing.

304 Oversee and conduct up to three pilot tests.

305 Compile and analyze pilot testing results.

306 Prepare technical memorandum on pilot testing results.

Deliverables:

1. Pilot testing plan.
2. Technical memorandum summarizing piloting results.

Assumptions:

1. Pilot testing will be conducted for up to a total of three thickening or dewatering technologies.

Phase 400 – Final Alternatives Evaluation

Objective: To review the work completed to date, establish evaluation criteria, perform a final evaluation of alternatives, and provide a recommendation for full-scale implementation.

Activities:

401 Conduct a workshop to review pilot testing results and establish evaluation criteria.

402 Prepare technical memorandum summarizing piloted alternatives, evaluation criteria, and evaluation process, and provide recommendations for full-scale implementation.

403 Conduct a workshop to discuss final evaluation results and confirm recommendations for full-scale implementation.

404 Finalize technical memorandum, including:

- Establishing design criteria for thickening/dewatering equipment
- Developing a process flow diagram showing integration into the existing facilities
- Confirming system hydraulics to determine if additional pumping is required

Deliverables:

1. Workshop agendas and minutes.
2. Technical Memorandum summarizing recommendations for full-scale implementation.

Phase 500 – Final Report

Objective: To prepare a final report summarizing the findings of the project.

Activities:

501 Prepare draft report for City review.

502 Incorporate City's review comments into a single submittal.

Deliverables:

1. Draft report.
2. Final report

Assumptions:

1. The final report will be a compilation of the previous TM's developed as part of this project, with an executive summary of the results.

Attachment 2 - Engineering Fee Proposal

Boulder, City of (CO) -- Betasso Water Treatment Plant

Phase	Phase Description	Hill, Charles G	Eichenberger, James M	Levinson, Kristen M	O'Connell, Sean D	Rogers, Stephen E	Bratby, John R	Wong, Joseph M	Comstock, Kelly K	Rosco, Douglas T	Bucasas, Rhonda R	Senior Designer	Engineer II	Total Labor Hours	Total Labor Effort	Reproduction	Airfare	Lodging and Food	Other Travel	Equipment	Total ODCs	Total Expense Effort	Total Effort
		Project Manager	Project Engineer	Project Analyst	Project Delivery Officer	Operations Specialist	Process Specialist	QA/QC	QA/QC	Safety	Accounting	CAD	Design Engineer										
		$221.00	$144.00	$85.00	$195.00	$178.00	$221.00	$211.00	$221.00	$160.00	$85.00	$124.00	$109.00										
010	**Finalize Scope of Work**	3	4	0	3	0	3	0	0	0	0	0	0	**13**	**2,500**	0	0	0	0	0	**0**	**0**	**2,500**
****	Default Task	3	4	0	3	0	3	0	0	0	0	0	0	**13**	2,500	0	0	0	0	0	**0**	**0**	**2,500**
050	**Project Management**	9	70	17	8	0	0	0	0	1	8	0	0	**113**	**15,914**	0	0	0	500	0	**500**	**500**	**16,414**
051	Project Controls and Repo	8	60	16	8	0	0	0	0	0	8	0	0	**100**	14,008	0	0	0	0	0	**0**	**0**	**14,008**
052	Project Plan	1	4	0	0	0	0	0	0	0	0	0	0	**5**	797	0	0	0	0	0	**0**	**0**	**797**
053	Health and Safety Plan	0	2	0	0	0	0	0	0	1	0	0	0	**3**	448	0	0	0	0	0	**0**	**0**	**448**
054	Project Closeout	0	4	1	0	0	0	0	0	0	0	0	0	**5**	661	0	0	0	500	0	**500**	**500**	**1,161**
100	**Collect and Review City I**	20	108	0	0	16	116	2	2	0	0	8	40	**312**	**54,672**	0	250	500	100	0	**850**	**850**	**55,522**
101	Background Information R	4	16	0	0	0	40	0	0	0	0	0	0	**60**	12,028	0	0	0	0	0	**0**	**0**	**12,028**
102	Evaluate Existing Facilities	8	40	0	0	8	60	0	0	0	0	0	40	**156**	26,572	0	0	0	0	0	**0**	**0**	**26,572**
103	Existing Facilities TM	4	40	0	0	8	12	2	2	0	0	8	0	**76**	12,576	0	0	0	100	0	**100**	**100**	**12,676**
104	Existing Facilities Worksho	4	12	0	0	0	4	0	0	0	0	0	0	**20**	3,496	0	250	500	0	0	**750**	**750**	**4,246**
200	**Identify and Screen Alter**	24	88	0	0	8	32	2	2	0	0	8	16	**180**	**30,072**	0	500	1,000	200	0	**1,700**	**1,700**	**31,772**
201	Alternatives Workshop	4	12	0	0	0	4	0	0	0	0	0	0	**20**	3,496	0	250	500	100	0	**850**	**850**	**4,346**
202	Alternatives Screening TM	16	64	0	0	8	24	2	2	0	0	8	16	**140**	23,080	0	0	0	0	0	**0**	**0**	**23,080**
203	Screening Workshop	4	12	0	0	0	4	0	0	0	0	0	0	**20**	3,496	0	250	500	100	0	**850**	**850**	**4,346**
300	**Pilot Testing**	24	192	0	0	24	44	4	4	0	0	20	0	**312**	**51,156**	0	0	0	1,100	20,000	**21,100**	**21,100**	**72,256**
301	Coordination with CDPHE	8	24	0	0	0	0	0	0	0	0	0	0	**32**	5,224	0	0	0	100	0	**100**	**100**	**5,324**
302	Pilot Plan	4	32	0	0	8	16	2	2	0	0	16	0	**80**	13,300	0	0	0	0	0	**0**	**0**	**13,300**
303	Pilot Testing	8	100	0	0	8	16	0	0	0	0	0	0	**132**	21,128	0	0	0	1,000	20,000	**21,000**	**21,000**	**42,128**
304	Pilot Summary TM	4	36	0	0	8	12	2	2	0	0	4	0	**68**	11,504	0	0	0	0	0	**0**	**0**	**11,504**
400	**Final Alternatives Evalua**	12	52	0	0	8	20	2	2	0	0	8	16	**120**	**19,584**	0	250	500	200	0	**950**	**950**	**20,534**
401	Alternatives Workshop	4	12	0	0	0	4	0	0	0	0	0	0	**20**	3,496	0	250	500	100	0	**850**	**850**	**4,346**
402	Final Alternatives TM	4	32	0	0	8	12	2	2	0	0	8	16	**84**	13,168	0	0	0	0	0	**0**	**0**	**13,168**
403	Final Workshop	4	8	0	0	0	4	0	0	0	0	0	0	**16**	2,920	0	0	0	100	0	**100**	**100**	**3,020**
500	**Final Report**	16	28	0	0	2	4	14	14	0	0	16	16	**110**	**18,584**	500	0	0	0	0	**500**	**500**	**19,084**
501	Draft Report	8	16	0	0	2	4	12	12	0	0	16	16	**86**	14,224	0	0	0	0	0	**0**	**0**	**14,224**
502	Final Report	8	12	0	0	0	0	2	2	0	0	0	0	**24**	4,360	500	0	0	0	0	**500**	**500**	**4,860**
	GRAND TOTAL	**108**	**542**	**17**	**11**	**58**	**219**	**24**	**24**	**1**	**8**	**60**	**88**	**1,160**	**192,482**	**500**	**1,000**	**2,000**	**2,100**	**20,000**	**25,600**	**25,600**	**218,082**

Hours and Dollars are rounded to nearest whole number. To display decimals, change the format of the cells.