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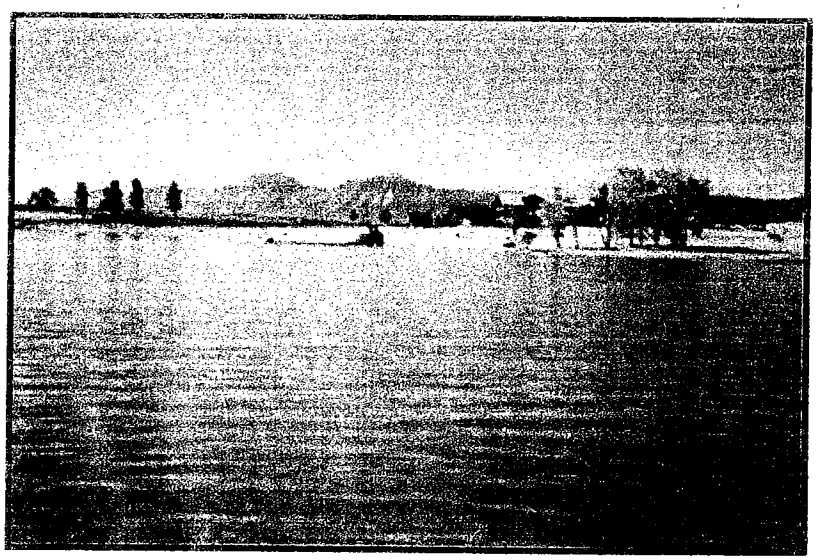

City of Boulder

Predesign Report for Near-Term Improvements for the Boulder Reservoir Water Treatment Plant

June 20, 2003

MWH

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Executive Summary

The Boulder Reservoir Water Treatment Plant (BRWTP) is located east of the City of Boulder, Colorado at 63rd and the Diagonal Highway. It was built in 1971 with a nominal treatment capacity of 8 million gallons per day (mgd). Until 1996, the BRWTP had primarily been used as a peaking plant to meet summer water demands. During 1996, it became necessary to operate the facility on a year-round basis to maximize use of the City's raw water resources.

The importance of the BRWTP greatly increased last summer when drought conditions restricted raw water availability for the Betasso WTP. Designed for 8 mgd, BRWTP was treating 12 mgd in Summer 2002. In addition, one of BRWTP's raw water sources, Boulder Reservoir, was held at abnormally high levels during Summer 2002 for drought-related water management purposes, which caused adverse changes in water quality at the BRWTP intake.

In September 2002, the City issued an industrial wastewater discharge permit to BRWTP restricting the daily maximum ferric (iron) coagulant that may be discharged to the sanitary sewer. Alternative residuals (sludge) disposal options were required to maintain BRWTP's treatment capacity at its 8-mgd rated capacity.

Several deficiencies at the BRWTP had previously been identified in the City's *Treated Waster Master Plan* (Integra Engineering, 2000) (*Master Plan*). In particular the plant's pretreatment processes (rapid mix/flocculation/sedimentation) limited the BRWTP capacity to less than 8.5 mgd.

The City hired McGuire Environmental Consultants, Inc. (MEC), to conduct an *Assessment of the Boulder Reservoir Water Treatment Plant* (2001) (*Assessment)*. The *Assessment* agreed with the *Master Plan* regarding deficiencies in the pretreatment processes, as well as the following:

- *Giardia* inactivation insufficient to comply with Environmental Protection Agency's (EPA's) Interim Enhanced Surface Water Treatment Rule (IESWTR) at low water levels in the treated water reservoir,
- Recommendation for investigation into advanced treatment processes such as ultraviolet (UV) disinfection, ozonation or membrane filtration, and
- Recommendation for investigation into source water quality management alternatives.

The City hired MWH in July 2002 to evaluate near-term and long-term improvements to BRWTP. At that time, anticipated near-term projects included raw water conveyance, pretreatment, disinfection, residuals, instrumentation (flow meter) and supervisory control and data acquisition (SCADA) improvements. Potential long-term improvements included UV disinfection, ozonation, membrane filtration, pre-sedimentation, spent filter backwash options, emergency/redundant power, alkalinity adjustment and protozoan removal/inactivation. Integra Engineering and MEC were retained as subconsultants to assist in performing these evaluations.

The City piloted dissolved air flotation (DAF) during November-December 2002 with three of the leading manufacturers (Parkson, Leopold, Ondeo) of this particular technology. Leopold's report was submitted in January 2003 and Parkson's in February 2003. Ondeo did not submit a report.

From July 2002 through April 2003, the City and MWH, with Integra Engineering and MEC, conducted a series of workshops and developed several technical memoranda. The memoranda are included as supplemental material in the Appendix to this Predesign Report.

The distinction between near- and long-term improvements blurred over the course of the project, and a new category, "Mid-Term Improvements," was added. The preliminary construction costs for Near-Term, Mid-Term and Long-Term capital improvements at BRWTP are provided in Table ES-1. Near-term improvements will include the following:

- New DAF Pretreatment
- Clearwell Baffling
- Increased High Service Pumping Capacity
- New Residuals Lagoons
- Instrumentation and Control (I&C) Improvements
- New Pilot Facility
- New Online Floc Monitoring Improvements

These order-of-magnitude cost estimates are based on construction in the first quarter of 2003 and were prepared without the benefit of detailed design drawings. An estimate of this type is expected to have an accuracy range of plus 50 to minus 30 percent. The final project cost will depend on the actual labor and material costs, competitive market conditions, final project scope, bid date and other variable factors. As a result, final project costs will vary from the estimates presented herein. Based on these factors, project feasibility and funding needs must be carefully reviewed prior to making specific financial decisions to ensure proper project evaluation and adequate funding. A budget estimate that would be expected to more closely estimate the actual cost will be prepared during the final design phase of each project.

Near-term improvements at BRWTP could possibly increase the annual operation and maintenance (O&M) costs at the plant. From piloting results, it appears that the DAF process may require fewer chemicals than the existing pretreatment process. At 10 mgd average flow rate, the reduction in annual chemical costs could be $33,000. The annual increase in manpower and power due to DAF would be approximately $27,000. The net impact on total O&M at BRWTP from DAF pretreatment would be relatively minor. Many variable factors (raw water quality, chemical costs, useful life of equipment, unscheduled equipment failures and reactive maintenance costs, etc.) could also impact O&M costs for pretreatment.

Table ES-1. BRWTP Capital Improvement Costs

CIP Item	Description	Overall Cost	Near-Term Horizon (2003-4)	Mid-Term Horizon (2005-6)	Long-Term Horizon	Notes
Chlorine Dioxide for Preoxidation		**$200,000**		**$200,000**		Costs are for storage and piping only. Assumes that generators and analyzer equipment are leased as part of chlorite procurement package.
Residuals		**$4,164,000**	**$1,006,000**	**$3,158,000**		
Near-Term Project	Residuals lagoons	$1,006,000	$1,006,000	done		**Near-Term Project** - lagoons for approx. one-third of residuals production at 10 MGD average annual flow rate. Long-Term Project - lagoons and/or accelerated dewatering system for all residuals production at 10 MGD average annual flow rate. 4 lagoons in near term cost closer to 1.5 million
Long-Term Project	Residuals lagoons and potential advanced dewatering system	$3,037,000		$3,037,000	- ? - if production exceeds 10 MGD average.	
Lagoon Decant Return to BRWTP	Pump station and return piping	$121,000		$121,000		
Control System		**$565,000**	**$155,000**	**$400,000**	**$10,000**	
Flow Tubes		$20,000	$20,000			
PLC Integration		$300,000		$300,000		
Automated Backwash		$50,000		$50,000		
Filter Instrumentation		$15,000		$15,000		
SCADA Reconfiguration		$20,000		$20,000		
Enhanced Process Trending		$15,000		$15,000		
Automated Chemical Dosing Implementation		$20,000	$20,000			Equipment in place. Assumes only reprogramming and loop tuning.
SCADA Expansion		$35,000	$25,000		$10,000	Near-term portion includes new HMI in pretreatment building.
Relocate Base Totalizers		$15,000	$15,000			Assumes minimum of 10 points ($1,500 per point) integrated
Feeder Canal Monitoring Implementation		$75,000	$75,000			Remote raw water turbidity monitoring station and telemetry to BRWTP
Staff Training		$0	N/A			Staff training currently underway
Graphics/Reporting Study		$0	N/A			Currently underway?
Reservoir Contact Time		**$2,607,000**	**$72,000**	**$0**	**$2,535,000**	
Clearwell Baffling	Install flexible membrane curtain in existing clearwell	$72,000	$72,000			
New Reservoir		$2,535,000			$2,535,000	
Raw Water Conveyance		**$127,000**		**$127,000**		Install new raw water pump
DAF Pretreatment		**$4,067,000**	**$2,810,000**	**$0**	**$1,257,000**	
Near-Term Project	Demo existing flocculating clarifier and install two DAF units, flash mix and yard piping modifications	$2,810,000	$2,810,000			Each unit will have a minimum capacity of 8 mgd. Nominal plant capacity will be 16 mgd; firm capacity will be 8 mgd.
Long-Term Project	Install one additional DAF unit	$1,257,000			$1,257,000	Nominal plant capacity will be 20 - 24 mgd; firm capacity will be 16 mgd.

Table ES-1. BRWTP Capital Improvement Costs

CIP Item	Description	Overall Cost	Near-Term Horizon (2003-4)	Mid-Term Horizon (2005-6)	Long-Term Horizon	Notes
Waste Washwater Treatment		**$829,000**	**$0**	**$829,000**	**$0**	
Sludge Collection		$0	N/A			Given the cost of sludge collection, utilize waste washwater treatment
Separate Wastewater Treatment	Stand-alone structure with gravity plate settler units	$829,000		$829,000		Potentially, lower cost of approx. $200,000 for first phase of treatment installation, assuming placement of package plate settling unit in existing pretreatment area.
Presedimentation		**$1,376,000**	**$0**	**$1,376,000**	**$0**	
Convert remainder of pretreatment basin to conventional settling presedimentation unit		$1,076,000		$1,076,000		Utilizes remaining space in pretreatment area after allowing for three DAF treatment trains. Includes baffle curtains, launders and sludge collection equipment.
Install plate settlers in conventional presedimentation unit		$300,000		$300,000		Incorporate plate settlers into presedimentation unit to improve treatment efficiency.
High Service Pump *		**$200,000**	**$200,000**			Install new high service pump
Long Term Improvements		**$3,486,000**	**$0**	**$225,000**	**$3,261,000**	Not cumulative of all potential long-term improvements options. Includes ph adjustment, UV disinfection and emergency power.
UV		$2,145,000			$2,145,000	Most probable project for long-term control of *Cryptosporidium*. Would not be warranted if membrane filtration replaces granular media filtration at plant.
Emergency Power		$400,000			$400,000	
Membranes		$8,995,000			$8,995,000	Warranted if plant hydraulics ulitmately limit capacity of granular media filters.
GAC	Replace anthracite with GAC caps in existing granular media filters	$250,000			$250,000	Potential T&O control approach
pH Adjustment System	Leased CO2 feed system	$225,000		$225,000		Used for reducing pH below upper range of target values. Additive alternative item for near-term project.
Pilot Facility		**$50,000**	**$50,000**			Purchase used pilot facility from DAF manufacturer as part of BRWTP equipment procurement
On-Line Floc Monitoring		**$35,000**	**$35,000**			
TOTAL COST		**$17,706,000**	**$4,328,000**	**$6,315,000**	**~ $12,000,000****	

*Funded out of distribution.
**Not additive. Some of the Long-Term Improvements are mutually exclusive.

The O&M cost for residuals disposal at BRWTP is speculative. There are currently no residuals hauling costs at BRWTP because all residuals are sewered. (Sewering of BRWTP residuals was recommended by *City of Boulder Colorado Sludge Disposal Option Study* (Richard P. Arber Associates, 1990) and successfully piloted in 1991.) There are certain process advantages at 75th Street Wastewater Treatment Plant (WWTP) associated with ferric residuals from BRWTP including less hydrogen sulfide in the digester gas, less struvite formation in the anaerobic digester complex, enhanced settling in the gravity thickener, less odors in the finished biosolids, and higher iron content in the biosolids.

Potential downsides to discharge to the 75th Street WWTP include higher solids loadings, higher hydraulic loadings, inhibition of biological processes (phosphorus binding or biofilm "coating") and settling, and corrosion of aluminum gates and concrete. In February 2001, experimentation with alternative operation of the BRWTP sedimentation process resulted in a large quantity of concentrated ferric chloride being discharged to the sewer and extensive biofilm coating. In September 2002, the City issued an industrial wastewater discharge permit to BRWTP restricting the daily maximum ferric coagulant that may be discharged to the sanitary sewer.

4 lagoons built to handle 10 MGD

The Near-Term Improvements Project will provide for new residuals lagoons at BRWTP. However, this will not provide sufficient capacity to completely eliminate sewering to 75th Street. A portion of the water plant residuals will continue to be discharged to 75th Street until additional drying lagoons are constructed. The proportions of residuals to be discharged to these two locations is unknown. Assuming that 25 percent of the BRWTP residuals are hauled offsite (at 8 mgd capacity), the annual cost would be about $27,300 (52 20-cubic-yard loads at $525 per load).

Other O&M costs will be minimal. The O&M associated with clearwell baffling is negligible, while I&C improvements should reduce the annual O&M. The O&M cost associated with high service pumping is principally a function of the total volume of water treated at BRWTP. The pilot facility and on-line floc monitoring installation would require some additional O&M depending upon usage.

Project Description

This project is titled, "Near-Term Improvements Project" and consists of the following work at the Boulder Reservoir WTP:

- Demolition of existing flocculator/clarifier mechanism, launders, supports, reaction basin baffle and concrete supports, mixing chamber, sluice gates, and vertical wall below mixing chamber;
- New concrete slab over entire flocculator/clarifier floor, concrete walls between each of the three DAF trains and between DAF and presedimentation, concrete flow splitter, and concrete flocculation inlet channel;
- New buried raw water distribution pipe to flash mixing and flow splitter, including buried cross and diversion valves adjacent to existing Manhole Number 2 (Pumping Station control valve), new flow meter vault, and new overflows;
- New pumped jet diffusion flash mixing, two-stage flocculation process, dissolved air flotation (DAF) tanks (two trains), and electrical/controls room;
- ~~New residuals lagoons~~ including concrete perimeter walls; lagoon lining; cellular confinement system and underdrains; decant/filtrate vaults and integral pump station (provisions for future pump); yard piping; and access ramps;
- New coated fabric curtains and 90-degree bend inside the existing clearwell;
- Control system improvements, including new flow measurement, implementation of automated chemical feed, SCADA expansion, and relocation of base;
- Two new high service pumps;
- New pilot facility; and
- New on-line floc monitoring equipment.

Project Requirements

Project-specific requirements are described below.

Contracts

The DAF equipment will be preprocured. The City will select DAF equipment with a competitive preprocurement process. The agreed upon equipment costs will be included on the bid sheet in the subsequent bid documents as prenegotiated costs.

The project will be designed around the pre-selected pretreatment equipment. At this time advertisement is scheduled for late autumn 2003, as a single construction contract.

Datum

All elevations are United States Geological Survey (USGS) datum. Existing drawings are based on USGS datum. Add 5,000 feet to existing Black & Veatch drawing elevations to obtain USGS elevations.

Codes

Facilities will be designed to comply with the following codes as currently adopted, as applicable:

- Uniform Building Code (UBC), 2000;
- Uniform Plumbing Code;
- Uniform Mechanical Code;
- Uniform Fire Code;
- National Electrical Code;
- Americans with Disabilities Act (ADA).

Equipment Redundancy

Chemical feed to both stages of flash mixing will be provided so that the plant may operate in single-stage mode upon pump or nozzle failure in the other stage. Although, each flocculation and flotation train in the first phase will be designed to treat 8 mgd, excess capacity may exist seasonally. Hydraulic capacity through each train may be more than 8 mgd.

Soils/Foundations

At this time, only minor geotechnical investigations are expected to be required for this project. A boring will be required if a new electrical/control room is constructed adjacent to the flocculator/clarifier.

Process Design

Pretreatment

The existing pretreatment process at BRWTP consists of two-stage (hydraulic/mechanical) flash mixing with ferric sulfate, cationic coagulant (Nalco 8102), and MIOX feed; an integrated flocculation/clarification process (Walker Process, 1970); and a settled water contact (reaction) basin.

As part of this project, the existing flash mixing process will be abandoned and all other existing pretreatment equipment demolished. Existing chemical feed lines will be extended to the new flash mixing process.

One new DAF pretreatment stage will be located in the reaction basin. Two others will be located in the adjacent flocculation/sedimentation basin. Provisions will be made to for future installation of either conventional (unaided) presedimentation or high-rate lamella-plate settling in the unused portion of the flocculation/sedimentation basin. Presedimentation provisions include a valve and blind flange on the new raw water influent prior to flash mixing, a piping extension and a blind flange on the existing flocculation/sedimentation influent piping for future presedimentation connection, and a blind flange on existing sludge piping for future presedimentation sludge. No channels will be provided within the future presedimentation basin under the Near-Term Improvements Project. The new wall between the third DAF train and future presedimentation will be designed for a higher water level in presedimentation.

Either Parkson Corporation (Parkson) or F.B. Leopold Company (Leopold) will manufacture the DAF equipment, pending evaluation of preprocurement submittals.

DAF piping (including air) will be PVC or CPVC. Air saturation tanks, valves, fasteners, etc., will be stainless steel. Air compressors will be reciprocating-type (same as Betasso WTP), and float pumps (if required) will be progressive cavity (same as Betasso WTP). The bottom of the flocculation and DAF flotation tanks will be sloped to drain. Fixed ladders will be installed into each process tank or stage. Access will be provided around each process tank or stage. On-line Hach turbidimeters ("Optiquant") will be installed on raw water and DAF effluent.

Process design criteria are as follows:

- Raw Water Flow Metering. The existing influent flow tube will be abandoned, and a new magnetic flow meter will be installed in a new concrete meter vault in the yard. Flow range of meter = 5 to 20 mgd.
- Flash mixing. Two-stage, with pumped jet diffisuion at principal mixing location. Gt = 400 to 1600 sec/sec at principal mixing location. Flow range through plant = 5 to 20 mgd. Ferric sulfate, polymer, and MIOX feed lines will be extended to both stages of flash mixing. Application points will be situated as far as possible from one another. Provisions will be made for installing an in-line floc monitor and a streaming current detector for coagulant control, and a

spare chemical feed point will be provided for future acid/carbon dioxide addition.

- Flow Splitter. Sharp-crested weirs dividing 5 to 20 mgd into 2.5- to 10-mgd flow rates to each of three flocculation influent channels. A connection for portable pump hook-up and sand pumping will be provided.
- Flocculation. Two-stage, variable speed, vertical-shaft flocculators, with direct flow through horizontal tanks and baffle wall. G = 120-30 s^{-1} tapered; T = 20 minutes at 8 mgd per train. Number of mixers = four per stage. Flocculation influent channels will be covered for access. Provisions will be made to decant or allow floating sludge to pass through to flotation tanks.
- Flotation tanks. Surface loading rate = 4.2 gpm/ft^2 at 8 mgd per train. Depth will be maximized to minimize bubble carryover. Float removal will be mechanical. Water level on float beach will be maintained as constant as practicable. Knockout wall will be constructed in DAF Train Number 2 effluent channel to connect DAF Train Number 3.

Residuals

Two existing sludge lagoons were constructed in 1970, approximately 500 feet northwest of the Administration Building. Originally each lagoon could hold about 400,000 gallons of residuals at a depth of 5 feet. At some point in time, both lagoons were enlarged to hold about 700,000 gallons each, each with different shapes and depths. The west lagoon is a rectangular shape; the east lagoon is spoon-shaped and somewhat shallower than the west. For the last several years, the lagoons have been used only irregularly and both contain trees and prairie dogs.

As part of this project, the existing lagoons will be replaced. New lagoons with concrete walls, liners, paved access ramps, cellular confinement systems, perforated underdrain piping, decant/filtrate/pumping structure(s), and influent, decant/filtrate piping will be constructed. Provisions will be made for future pumped return of decant and filtrate. However, no decant/filtrate pumps will be provided as part of this project. Decant/filtrate will discharge to 75th Street WWTP by gravity. No electrical (lighting) or I&C will be provided under this project.

Assuming that 75th Street WWTP will accept two-thirds of the BRWTP residuals for sewering, refurbishing the existing ponds will provide about five months of dewatering for the remaining one-third in each bed at a 10 mgd average daily flow. If 75th Street refuses to accept BRWTP residuals in the future, another six lagoons of similar size would be required.

Clearwell Baffling

Coated fabric curtains will be suspended between the cast-in-place concrete columns and nearby walls to create serpentine flow through the existing clearwell. A 42-inch diameter, 90-degree bend will be installed on the clearwell inlet to direct incoming flow away from the first curtain baffle. The existing 4-foot by 2-foot washdown opening between the two sides of the clearwell will be plugged with a removable fiberglass panel.

High Service Pumps

The existing high service pumps (four, 4-mgd nominal capacity each) are constant speed, horizontal-split-case pumps. They were provided with electrically actuated, adjustable-speed discharge throttling valves in order to minimize pressure surges during startup and shutdown. A single 30-inch diameter check valve with a 3-inch diameter bypass gate valve prevents backflow through the high service pumps upon power outages, as well as cushioning check valve closure.

High service pumping at BRWTP was evaluated in February 2003 using the City's H_2ONet model. The results were presented in a report entitled *Zone 1 Distribution System Analysis* (Integra Engineering). The report suggested that during the peak hour demand scenario (20 mgd BRWTP, 40 mgd Betasso), the four existing pumps will achieve 17.4 mgd with the Gunbarrel Tank full. The report recommended adding two pumps (Phase 3) that are similar to the existing pumps to achieve a flow of 19.8 mgd. The design point for each of the two pumps was determined to be 2,800 gpm at 270 feet total head (low and average demand) or 2,300 gpm at 290 feet total head (peak hour demand). A 300-horsepower motor was recommended.

The net positive suction head requirement (NPSHR) of the proposed high service pumps at the design point is 18.5 feet. SCADA data from the existing BRWTP high service pumps suggest that the discharge pressure may be as low as 250 feet, at which point the NPSH requirement would be 21 feet. The barometric pressure at the BRWTP site is 28 feet, which would allow about 7 feet of head loss due to friction in the 400-foot suction line from the reservoir, assuming an 8-foot water depth in the reservoir (zero suction lift).

Variable frequency drives (VFDs) for the high service pumps have been discussed as a potential long-term improvement at BRWTP. Because the City's utility billing at BRWTP is based on the maximum power usage in a sliding 15-minute window with a 12-month ratchet, the only way that VFDs could be proven cost-effective is if the high service pump(s) with VFDs were never operated at full speed during a given year. As mentioned in Supplemental Memorandum 5, *Long-term Improvements*, in the Appendix, VFDs might also be justified because the electrically actuated, adjustable-speed discharge throttling valves mentioned above are inoperative or because Gunbarrel Reservoir is significantly undersized. (The *Zone 1 Distribution System Analysis* investigated Zone 1 storage and determined that Gunbarrel Reservoir provided about half the required storage (2 million gallons (MG) out of a theoretical 3.9 MG) at peak day demand.) VFDs for new or existing high service pumps was not mentioned in the *Zone 1 Distribution System Analysis* and are not currently in the scope of improvements at BRWTP.

A Hand-Off-Auto switch will be provided at each pump. The discharge valves will be furnished with Open-Close-Remote switches. In the Auto or Remote modes, the device will be controlled by the remote terminal unit (RTU).

Renovation of Existing Floc/Clarifier Building

- Structural. The existing floor slab and foundation will be used to support the new DAF walls. The existing floc/clarifier floor will be leveled.

- Mechanical. Heating in the existing Floc/Clarifier Building is provided by hydronic unit heaters. Each hot water unit heater is controlled by a thermostat. Ventilation in the existing Floc/Clarifier Building is provided by three cabinet fans. Each fan is furnished with a Hand-Off-Auto switch. In the Auto position, each cabinet fan is controlled by its respective thermostat.
- The new electrical room will be independently heated and cooled. It will be furnished with a new air-conditioning system and electric unit heater.
- Electrical. All electrical equipment in the existing Floc/Clarifier Building is fed from Power Control Panel 1 (PC-1) in the Administration Building. New electrical loads for DAF recirculation pumps and compressors exceed the capacity of this system. New electrical service will be installed the building and a new motor control center (MCC) installed in a new electrical room.

Computer Control System Modifications

- Flow Tubes. The existing raw water influent flow tube will be abandoned as part of the Near-Term Improvements Project. A new magnetic meter will be installed in the new yard piping. The effluent flow tube will be supplemented with an insertion magnetic meter in the filtered water line.
- Automated Chemical Dossing Implementation. This item includes installation of a new raw water meter, installation of a pressure sustaining valve in the backwash supply line and installation of three new panel-mounted loop controllers.
- SCADA Expansion. This item includes installation of a new human/machine interface (HMI) in the DAF Building. It will include one new workstation which will be located in the new electrical room. Fiber optic cabling will be installed to the workstation.
- Relocate Base Totalizers. The production totalizers are currently not calculated within the SCADA HMI system. Moving these calculations to the PLC would make them more accurate and reliable. MWH will reconfigure up to 10 plant flow meters to output their flow readings to certain PLCs. These PLCs will be reprogrammed.

Safety Considerations, Standards, QA/QC

- All new equipment (lights, fixed ladders, stairs, grating, etc.) will comply with the codes and regulations listed above, and state and federal Occupational Safety & Health Administration (OSHA) regulations as applicable. There are no hazardous chemical concerns for the Near-Term Improvements Project. The City of Boulder Fire Department will be contacted regarding specific Fire Code requirements for the renovated Floc/Clarifier Building. Fire protection may be required for the new electrical room.
- Design standards for the Near-Term Improvements Project will include the following:
  - MWH's Lotus Notes-based, updated Design Quality Procedures (DQB) databases including the Civil, Architectural, Structural, Mechanical/HVAC,

Electrical, Instrumentation, Drawings (CAD Standards and QC procedures) and Specifications (Masters) databases;

- MWH's internal website-based knowledge centers (KNet Americas Global Knowledge Center) including the CAD, Architectural, Structural, Mechanical, Electrical, Instrumentation and Water Treatment knowledge bases; water treatment discussion forums; technical memos; technical transfer notes; tools and lessons learned;
- American Water Works Association (AWWA) Manuals and Standards as applicable, and
- Design textbooks including *Integrated Design and Operation of Water Treatment Facilities, Second Edition* (Kawamura, 2000) and *Water Quality & Treatment, Fifth Edition* (American Water Works Association, 1999).

- Quality Assurance/Quality Control (QA/QC) procedures will follow the following model:
  - MWH Americas Municipal Lotus Notes-based QA/QC program including project initiation, project notebook, project roles/responsibilities, budget-schedule-progress, project reviews, checking and certification, files and document control.

List of Drawings and Specifications, Final Design Schedule

A list of drawings and specifications for the Near-Term Improvements Projects is included in Appendix A. The final design schedule is included in Appendix B.

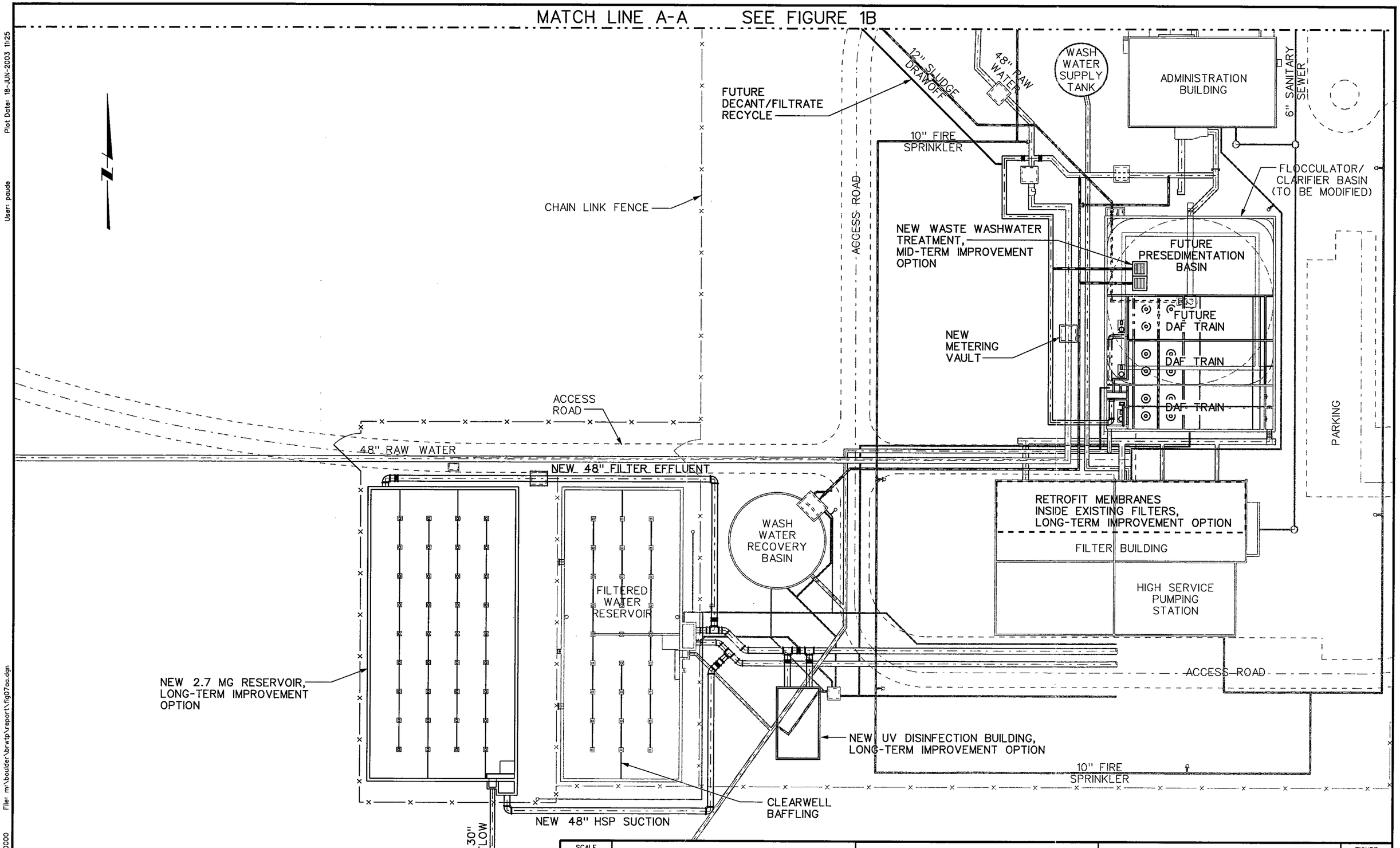
Mid-Term and Long-Term Improvements, Site Plans, and Plant Hydraulics

The above near-term improvements, as well as mid-term and long-term improvements alternatives, are depicted in the following site plans (Figures 1A and 1B). A hydraulic profile following construction of the near- and mid-term improvements is included in Figure 2.

The capital improvements plan shown in the Executive Summary (Table ES-1) include costs for the following Mid-Term and Long-Term Improvements:

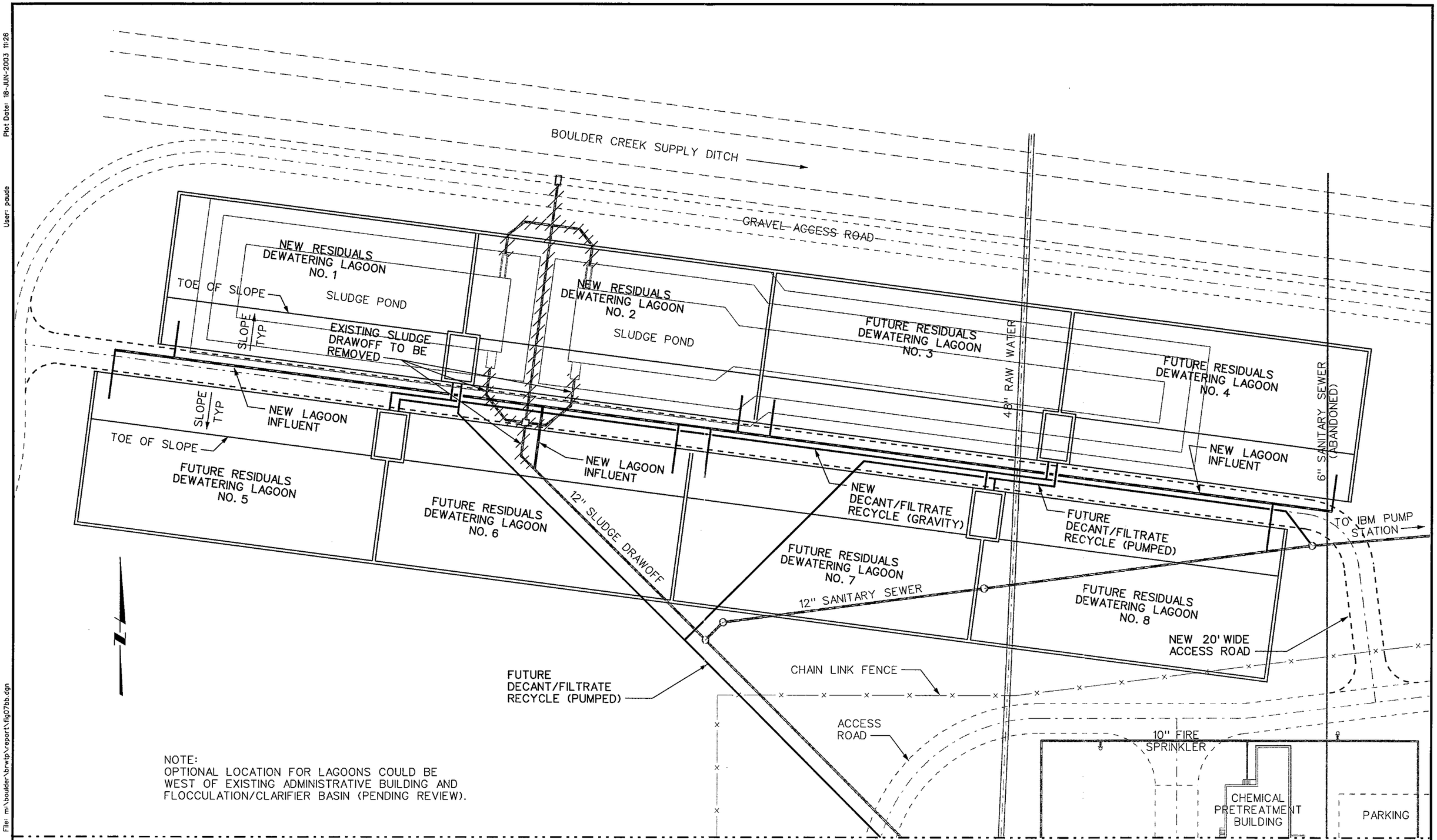
- Mid-Term
  - Chlorine dioxide,
  - Additional residuals lagoons,
  - Decant/filtrate pumps and return piping,
  - PLC integration,
  - Automated backwash,
  - Filter instrumentation,
  - SCADA reconfiguration,
  - Enhanced process trending,
  - New raw water pump,
  - Waste washwater treatment,
  - Presedimentation, and
  - pH adjustment system.
- Long-Term
  - SCADA expansion,
  - New reservoir,
  - New pretreatment train,
  - UV disinfection,
  - Emergency power,
  - Membranes, and
  - GAC caps in existing granular media filters.

The Long-Term Improvements list can not be firmly established at this time. The final combination of Long-Term Improvements at BRWTP will be determined to a large extent by the City's internal water quality goals; future regulatory requirements (microbial "toolbox" options) for *Cryptosporidium* removal/inactivation under the proposed Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR); and feasibility of developing alternative sources of raw water (*i.e.*, full containment from Carter Lake). There are other issues (such as Calgon's UV patent) that could change in the future and effect the feasibility of the Long-Term Improvements. Some of the Long-Term Improvements are mutually exclusive—that is, construction of a new UV disinfection facility would make construction of a new reservoir unnecessary solely for *Giardia* inactivation. It is recommended that these issues be periodically reviewed so that pilot testing of UV or membranes, if required, can be conducted in a timely manner.



SCALE				FIGURE
1" = 60'	MWH MONTGOMERY WATSON HARZA — Denver Colorado	CITY OF BOULDER, COLORADO BOULDER RESERVOIR WATER TREATMENT PLANT IMPROVEMENTS	SITE PLAN ALL IMPROVEMENTS 1 OF 2	1A

Plot Date: 18-JUN-2003 11:25
User: paude
File: m:\boulder\brwtp\report\fig07aa.dgn
Job No: 0000000

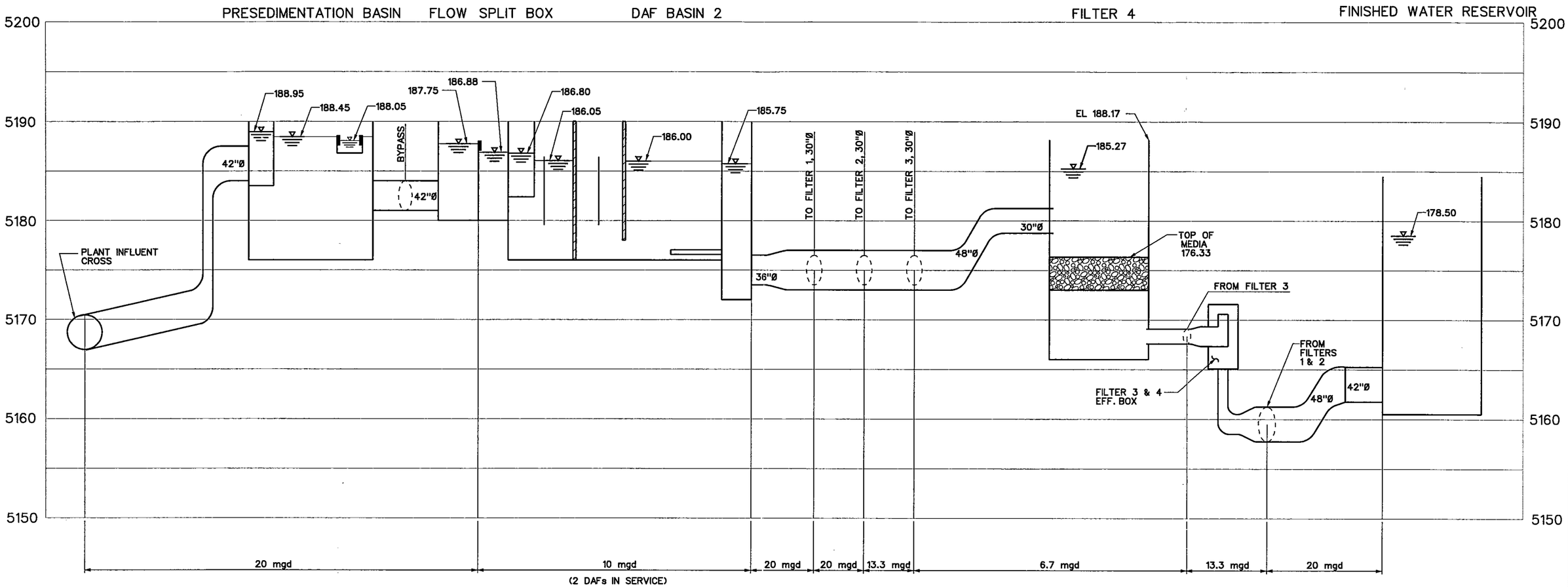


NOTE:
OPTIONAL LOCATION FOR LAGOONS COULD BE WEST OF EXISTING ADMINISTRATIVE BUILDING AND FLOCCULATION/CLARIFIER BASIN (PENDING REVIEW).

MATCH LINE A-A SEE FIGURE 1A

SCALE				FIGURE
1" = 60'	MWH MONTGOMERY WATSON HARZA Denver Colorado	CITY OF BOULDER, COLORADO BOULDER RESERVOIR WATER TREATMENT PLANT IMPROVEMENTS	SITE PLAN ALL IMPROVEMENTS 2 OF 2	1B

Job No: 0000000 File: m:\boulder\brwtp\report\fig07bb.dgn User: paude Plot Date: 18-JUN-2003 11:26



SCALE				FIGURE
.	MWH Denver Colorado	CITY OF BOULDER, COLORADO BOULDER RESERVOIR WATER TREATMENT PLANT IMPROVEMENTS	HYDRAULIC PROFILE FOR DISSOLVED AIR FLOTATION WITH PRESEDIMENTATION	2

Plot Date: 18-JUN-2003 11:27
User: paude
Job No: 0000000 File: m:\boulder\brwtp\report\ms04-fig2.dgn

Appendix A – List of Drawings

Sheet Count	Discipline	Sheet Number	Description
1	General	G-1	Cover sheet and vicinity map
2	General	G-2	List of drawings and design criteria
3	General	G-3	Process flow sheet
4	General	G-4	Hydraulic profile
5	General	G-5	General abbreviations
6	General	G-6	Pipe schedule
7	General	G-7	General symbols
Total 7 Sheets General			
8	Civil	C-1	Standard details 1
9	Civil	C-2	Standard details 2
10	Civil	C-3	Site plan
11	Civil	C-4	Yard piping and demo plan
12	Civil	C-5	Yard piping plan
13	Civil	C-6	Plant overflow system modifications
14	Civil	C-7	Yard piping profiles
15	Civil	C-8	Residuals lagoons grading plan
16	Civil	C-9	Residuals lagoons mechanical/structural foundation plan
17	Civil	C-10	Residuals lagoons mechanical/structural sections/details
Total 10 Sheets Civil			
18	Structural	S-1	Standard details 1
19	Structural	S-2	Standard details 2
20	Structural	S-3	Standard details 3
21	Structural	S-4	Standard details 4
22	Structural	S-D-1	Demolition of existing floc-clarifier - foundation plan
23	Structural	S-D-2	Demolition of existing floc-clarifier - floor plan
24	Structural	S-D-3	Demolition of existing floc-clarifier - sections/details 1
25	Structural	S-D-4	Demolition of existing floc-clarifier - sections/details 2
26	Structural	S-CB-1	New clarification building access - loading dock/rollup door plan, sections, and details
27	Structural	S-CB-2	New clarification building access - miscellaneous
28	Structural	S-CB-3	Clarification building - key plan
29	Structural	S-CB-4	Clarification building - gallery foundation and floor plan
30	Structural	S-CB-5	Clarification building - gallery sections and details
31	Structural	S-CB-6	Clarification building - floc basin foundation/floor plan
32	Structural	S-CB-7	Clarification building - floc basin sections and details
33	Structural	S-CB-8	Clarification building - DAF basin foundation/floor plan
34	Structural	S-CB-9	Clarification building - DAF basin sections and details
35	Structural	S-CB-10	Clarification building - electrical/controls room floor/roof plan
36	Structural	S-CB-11	Clarification building - electrical/controls room sections and details
37	Structural	S-CW-1	Finished water clearwell - baffling plan
38	Structural	S-CW-2	Finished water clearwell - baffling sections and details
39	Structural	S-MV-1	Yard meter vault and civil structures - plan, sections, and details
40	Structural	S-MV-2	Yard meter vault and civil structures - miscellaneous
Total 23 Sheets Structural			
41	HVAC	H-1	Clarification building electrical/controls room - HVAC 1
42	HVAC	H-2	Clarification building electrical/controls room - HVAC 2
43	HVAC	H-3	Clarification building electrical/controls room - HVAC 3
Total 3 Sheets HVAC			
44	Mechanical	M-1	Standard details 1 and equipment and valve lists
45	Mechanical	M-2	Standard details 2
46	Mechanical	M-3	Standard details 3
47	Mechanical	M-CB-1	Clarification building - demolition plan and temporary facilities
48	Mechanical	M-CB-2	Clarification building - demolition sections and temporary facilities

Sheet Count	Discipline	Sheet Number	Description
49	Mechanical	M-CB-4	Clarification building - plan
50	Mechanical	M-CB-5	Clarification building - gallery partial plan
51	Mechanical	M-CB-6	Clarification building - gallery elevation plans
52	Mechanical	M-CB-7	Clarification building - gallery sections
53	Mechanical	M-CB-8	Clarification building - gallery sections
54	Mechanical	M-CB-9	Clarification building - floc basin partial plan
55	Mechanical	M-CB-10	Clarification building - floc basin elevation plans
56	Mechanical	M-CB-11	Clarification building - floc basin sections/details
57	Mechanical	M-CB-12	Clarification building - floc basin sections/details
58	Mechanical	M-CB-13	Clarification building - DAF basin partial plan
59	Mechanical	M-CB-14	Clarification building - DAF basin elevation plans
60	Mechanical	M-CB-15	Clarification building - DAF basin sections/details
61	Mechanical	M-CB-16	Clarification building - DAF basin sections/details
62	Mechanical	M-PS-1	High service PS - general plan
63	Mechanical	M-PS-2	High service PS - new pump plans
64	Mechanical	M-PS-3	High service PS - sections/details
65	Mechanical	M-PS-4	High service PS - new pressure-sustaining valve installation
66	Mechanical	M-MV-1	Meter vault mechanical plans/sections/details
Total 23 Sheets Mechanical			
67	Electrical	GE-1	General electrical 1
68	Electrical	GE-2	General electrical 2
69	Electrical	GE-3	General electrical 3
70	Electrical	GE-4	General electrical 4
71	Electrical	GE-5	Medium voltage single-line
72	Electrical	GE-6	Medium voltage single-line
73	Electrical	GE-7	Electrical site plan
74	Electrical	GE-8	Lighting fixture and panelboard schedules
75	Electrical	GE-9	Ductbank schedule
76	Electrical	E-PS-1	High service pump plan
77	Electrical	E-PS-2	High service pump schematic
78	Electrical	E-PS-3	High service pump conduit and wire
79	Electrical	E-CB-1	DAF single-line diagram
80	Electrical	E-CB-2	DAF single-line diagram
81	Electrical	E-CB-3	Clarification building - demolition plan
82	Electrical	E-CB-4	Clarification building - MCC elevation
83	Electrical	E-CB-5	Clarification building - lighting plan
84	Electrical	E-CB-6	Clarification building - lighting plan
85	Electrical	E-CB-7	Clarification building - electrical plan
86	Electrical	E-CB-8	Clarification building - electrical plan
87	Electrical	E-CB-9	Clarification building - schematics
88	Electrical	E-CB-10	Clarification building - schematics
89	Electrical	E-CB-11	Clarification building - schematics
90	Electrical	E-CB-12	Clarification building - conduit developments
91	Electrical	E-CB-13	Clarification building - conduit developments
92	Electrical	E-CB-14	Clarification building - conduit schedules
93	Electrical	E-CB-15	Clarification building - conduit schedules
Total 27 Sheets Electrical			
94	I&C	I-1	Instrumentation symbols and abbreviations - 1
95	I&C	I-2	Instrumentation symbols and abbreviations - 2
96	I&C	I-3	SCADA architecture
97	I&C	I-4	Loop controller interconnections
98	I&C	I-5	Clarification Bldg. panel layout
99	I&C	I-6	High Service PS panel layout
100	I&C	I-7	Misc panel layout
101	I&C	I-8	PLC elementaries - 1

Sheet Count	Discipline	Sheet Number	Description
102	I&C	I-9	PLC elementaries - 2
103	I&C	I-10	PLC elementaries - 3
104	I&C	I-11	Instrumentation and I/O lists
105	I&C	I-12	Location plans - 1
106	I&C	I-13	Location plans - 2
107	I&C	I-14	Installation details - 1
108	I&C	I-15	Installation details - 2
109	I&C	PID-1	P&ID - residuals lagoons
110	I&C	PID-2	P&ID - raw water flow measurement
111	I&C	PID-3	P&ID - flash mix system and flow split
112	I&C	PID-4	P&ID - flocculation basin 1
113	I&C	PID-5	P&ID - DAF basin 1
114	I&C	PID-6	P&ID - flocculation basin 2
115	I&C	PID-7	P&ID - DAF basin 2
116	I&C	PID-8	P&ID - DAF recirculation system 1
117	I&C	PID-9	P&ID - DAF recirculation system 2
118	I&C	PID-10	P&ID - DAF float/sludge pumping
119	I&C	PID-11	P&ID - DAF pilot facility connections
120	I&C	PID-12	P&ID - new high service pumps
121	I&C	PID-13	P&ID - filtered water metering and chemical addition
Total 28 Sheets I&C			
Total 121 Sheets			

Appendix B – Preliminary List of Specifications

Specification Number	Specification Title
00030	Notice Inviting Bids
00100	Instructions to Bidders
00300	Bid Forms
00500	Agreement
00610	Performance Bond
00620	Payment Bond
00700	General Conditions
00800	Supplementary General Conditions
01010	Summary of Work
01025	Measurement and Payment
01070	Abbreviations of Institutions
01090	Reference Standards
01300	Contractor Submittals
01301	Schedule of Values
01311	CPM Construction Schedule
01312	Construction Sequencing
01400	Quality Control
01505	Mobilization
01510	Temporary Utilities
01520	Security
01530	Protection of Existing Facilities
01532	Site Condition Surveys
01550	Site Access and Storage
01560	Temporary Environmental Controls
01580	Project Sign
01590	Field Offices, Equipment, and Services
01600	Products, Materials, Equipment and Substitutions
01640	Demolition and Reconstruction
01650	Testing and Disinfection of Concrete and Steel Potable Water
01655	Gravity Pipeline Testing
01656	Pressure Pipe Testing and Disinfection
01660	Equipment Testing and Plant Startup
01700	Project Closeout
02100	Site Preparation
02160	Excavation Support Systems
02200	Earthwork
02268	Erosion Control Barrier
02274	Geotextiles
02490	Precast Concrete Manholes and Vaults
02565	Ductile Iron Pipe (AWWA C51, Modified)
02570	Steel Pipe, Specials, and Fittings
02571	Steel Pipe, Mortar Lined and Enamel/Tape Coated
02572	Steel Pipe Fabricated Specials
02597	Poly Vinyl Chloride Pressure Pipe, Rubber Joints
02620	Hydraulic Structure Testing and Disinfection
02643	Water Pipeline Testing and Disinfection
02831	Chain Link Fences and Gates
02930	Seeding and Sodding
03100	Concrete Formwork
03150	Concrete Formliners
03200	Reinforcement Steel
03290	Joints in Concrete

Specification Number	Specification Title
03300	Cast-in-Place Concrete
03315	Grout
03320	Concrete Floor Topping
05140	Structural Aluminum
05300	Metal Decking
05550	Miscellaneous Metalwork
05521	Aluminum Railings
07100	Waterproofing
07101	Moisture Protection
07105	Dampproofing
07920	Sealants and Caulking
08365	Roll-up Doors
08710	Finish Hardware
09900	Architectural Paint Finishes
10400	Identifying Devices
10520	Fire Protection Specialties
10900	Miscellaneous Specialties
11000	Equipment General Provisions
11100	Pumps, General
11106A	Large Horizontal Split Case Pumps
11137	Horizontal Non-Clog Pumps
11144	Progressing Cavity Pumps
11200	Mixers and Flocculators, General
11203	Pumped Mixers
11210	Vertical Shaft Flocculator Units
11510	Compressors, Base-Mounted, Reciprocating
11553	Dissolved Air Flotation Thickeners
11900	Miscellaneous Equipment
14600	Hoists and Cranes, General
14605	Electric Monorail Systems
15000	Piping, General
15005	Piping Identification
15006	Pipe Supports
15037	Copper Water Tube
15060	Poly Vinyl Chloride Pressure Pipe
15075	Meters, General
15081	Magnetic Flow Meters
15082	Venturi Meters
15089	Ultrasonic Flow Meters (Field-Mounted)
15150	Fire Sprinkler Systems
15151	Wet Pipe Sprinkler System
15155	Halogen Fire Extinguishing Systems
15183	Gauges
15200	Valves, General
15201	Valve and Gate Actuators
15202	Butterfly Valves
15203	Check Valves
15204	Ball Valves
15207	Plug Valves
15230	Telescoping Valves
15230	Miscellaneous Valves
15500	Heating, Ventilating, and Air Conditioning
15550	Electric Heating System
15560	Air Conditioning System
15570	Fans, Blowers, and Ventilators

Specification Number	Specification Title
16050	Electrical Work, General
16110	Electrical Raceway Systems
16111	Underground Raceway Systems
16120	Wires and Cables
16140	Wiring Devices
16300	Medium Voltage Distribution
16362	Medium Voltage Transformer and Switchgear
16455	Variable Frequency Drive Units
16460	Electric Motors
16480	Low Voltage Motor Control Centers
16481	Solid-State Reduced Voltage Starters
16482	Medium Voltage Motor Control
16483	Medium Voltage Solid State Motor Starters
16485	Local Control Stations and Miscellaneous Electrical Devices
16500	Lighting
16950	Electrical Tests
17100	Process Control and Instrumentation Systems
17106	Level Measuring Systems
17200	Control Panels
17201	Control Panel Instrumentation
17510	PLC-Based Control Systems Hardware
17520	PLC-Based Control Systems Software
17801	Multimode Fiber Optic Cable

Appendix C – Final Design Schedule

Final design for the BRWTP Near-Term Improvements project will be conducted over a five-month period beginning June 9, 2003 and finishing by October 24, 2003. Project printing and bidding is planned for over a four-week period between October 27 and November 21, 2003. A listing of key milestone dates is summarized below. A detailed project schedule will be prepared as part of the Project Management Plan.

Listing of Key Milestones

Project Milestone	Scheduled Date
Begin Final Design	June 9, 2003
50 Percent Submittal	August 8, 2003
Receive Review Comments (50%)	August 15, 2003
90 Percent Submittal	October 10, 2003
Receive Review Comments (90%)	October 17, 2003
Final Design Complete	October 24, 2003
Print Documents	October 27 – November 3, 2003
Bid Period	November 3 – November 21, 2003
Bid Date	November 21, 2003
Contract Award	November 26, 2003

Attachment A-1 – Hydraulic Profiles – Task A9

MEMORANDUM

MWH

integra engineering

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dave Butler

Date: April 7, 2003

Reference: Boulder Reservoir WTP--Preliminary Design for Near-term Improvements

Subject: **Hydraulic Profile – Task A9**

Purpose

The purpose of this Technical Memorandum is to present the results of analysis of the hydraulics of process flow through the City of Boulder's Boulder Reservoir Water Treatment Plant (BRWTP) following construction of the third dissolved air flotation (DAF) train and expansion of the plant capacity to 20 mgd. This analysis will verify the feasibility of the proposed plant modifications and identify any limitations associated with operation of the BRWTP at a future peak flow rate of 20 mgd.

Background

The City of Boulder is in the process of planning for expansion of the BRWTP to a capacity of 20 mgd. As part of that planning effort several conceptual options for treatment were considered. The preferred option at this time is conversion of the existing flocculator/clarifier and reaction basin into dissolved air flotation (DAF) units. Only about half of the flocculator/clarifier is required for DAF. The remainder of the existing sedimentation basin would become a presedimentation basin. The presedimentation basin may be bypassed with low-turbidity raw water. During high turbidity periods, raw water could be diverted through the presedimentation basin where heavy solids could be removed by gravity prior to flash mixing. A separate technical memorandum (*Raw Water Conveyance – Task A8*) presented the results of a hydraulic analysis of the existing raw water conveyance systems. The firm capacity of the existing Boulder Reservoir Raw Water Pumping Station is about 14 mgd at low reservoir level. The addition of a fourth raw water pump would enable the Boulder Reservoir Raw Water Pumping Station to deliver a firm capacity between 18.6 and 21 mgd to the upgraded plant. The raw water pipeline from the Boulder Feeder Canal can deliver up to 35 mgd. The evaluation presented herein was undertaken to determine whether sufficient hydraulic capacity would be available after the proposed process modifications to convey 20 mgd through the plant.

Hydraulic Analysis

Proposed Facilities

The conceptual design for expansion of the BRWTP includes modification of the prefiltration processes. Filtration, finished water storage, conveyance piping, and high service pumping to the distribution system would remain unchanged.

The major proposed facility modifications include:

- Installation of three separate trains of flocculation equipment and dissolved aeration process equipment in a portion of the existing sedimentation basin.
- Conversion of the remainder of the sedimentation basin into a presedimentation basin.
- Installation of new piping to bypass the existing influent flume. The proposed piping would create two flow paths. One path would be through the DAF process, bypassing the presedimentation stage, and the second would be through the presedimentation stage ahead of the DAF process.

Hydraulic Model

The proposed process train along the critical flow path was modeled using Excel spreadsheet software. The hydraulic characteristics of the proposed facilities were developed based on the layout of DAF alternative presented in the March 3, 2003, technical memorandum entitled *Pretreatment*. The hydraulic characteristics of unmodified facilities at BRWTP were determined from as-built information for the existing plant. The following key features were included in the model:

- Flow enters the future presedimentation basin via the existing basin influent pipe and new influent channel with submerged orifices.
- Flow exits from the presedimentation basin over V-notch weirs along both sides of an effluent launder.
- Flow is divided equally among the operating DAF units by sharp crested weirs in a new splitter structure.
- Flow enters the flocculation zone of the DAF units through submerged orifices in the influent channels.
- Flow exits from the DAF units via perforated or slotted effluent collection piping.

Although two flow paths exist upstream of the splitter structure, passing through the presedimentation process results in additional head loss (by observation) making this the critical hydraulic flow path. This flow path was modeled and is shown on Figure 1.

Results

Hydraulic calculations were performed based on the following operational assumptions:

- 20 mgd peak design flow through the plant.
- Three DAF units with one out of service, resulting in 10 mgd flow per DAF train.
- Four filters with one off line for backwashing, resulting in a flow of 6.67 mgd per operating filter.
- Maximum water level of 5178.5 feet in the filtered water reservoir corresponding to an operating depth of 18 feet.
- An allowance of five feet for head loss due to solids accumulation through the filter media.

The flow rates through the various elements of each flow path at the 20 mgd peak flow rate are shown on Figure 1. This figure also shows the free water surface elevations in each process unit making up the process train under peak flow conditions. The results indicate that the proposed facility will be able to pass the 20 mgd design flow without modifying the existing basins or constructing new filters.

The indicated operating mode would provide roughly four feet of freeboard at some of the existing basin walls along the DAF units and about 1.5 feet of freeboard in the presedimentation basin. The indicated water surface elevation in the presedimentation basin influent channel is only one foot below the top of the existing basin walls. However, this influent channel would not need to be added as part of the Near-Term Improvements Project, and the four sides of the future presedimentation influent channel could be set higher than the basin walls when constructed.

Attachment A-2 – Evaluation of Alternatives for Sludge Handling and Management

MEMORANDUM

MWH

integra engineering

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dave Butler

Date: March 24, 2003

Reference: Boulder Reservoir WTP-- Preliminary Design for Near-term Improvements

Subject: **Evaluation of Alternatives for Sludge Handling and Management – Task A2**

Purpose

The purpose of this Technical Memorandum is to present the results of an evaluation of options for handling and management of residuals from the prefiltration treatment processes at the City of Boulder's Boulder Reservoir Water Treatment Plant (BRWTP). The results of this analysis will be used in evaluating treatment process alternatives for expanding the BRWTP treatment capacity.

Background

The BRWTP was constructed in 1971 as a seasonal peaking plant designed to treat water conveyed by the Colorado-Big Thompson (C-BT) transmountain diversion project from the western slope of Colorado. Originally, water was diverted to the BRWTP from the Boulder Feeder Canal (BFC) a short distance above Boulder Reservoir. As a result, the plant could only operate during the summer months when water was running in the canal. In the early 1980s a pump station was constructed to draw water from Boulder Reservoir and deliver it to the BRWTP, enabling the plant to operate all year. However, the plant was not operated year round until 1996 when 24-hour per day operation during peak demand months (May-Oct), and 12-hour per day operation during off peak months (Nov-Apr) was instituted. In 2001, year round 24-hour per day operation was started to optimize the use of the City's water resources.

The BRWTP was designed to treat an average of 8 mgd with a peak "hydraulic overload capacity" of 12 mgd. The plant is typically operated in the range of 5 to 8.5 mgd but is commonly run at up to 11.5 mgd. Planning is currently underway for expanding the BRWTP to have the capability for year round operation at a capacity of 20 mgd. As a result, total residuals will increase.

The existing BRWTP uses a conventional water treatment process that includes coagulation, flocculation, sedimentation, granular media filtration, and disinfection by chlorination (MIOX). Contaminants removed from the raw water settle out along with the process chemicals in the

single sedimentation basin or are trapped on the filters. The residuals are removed from the sedimentation basin by gravity and from the filters by backwashing. Currently, the sedimentation basin residuals are discharged directly to the City's sewer system. Filter backwash water is impounded and recycled to the beginning of the treatment process. This evaluation anticipates that filter backwash water will continue to be handled separately in the future, and, therefore consideration is given only to options for managing residuals from the prefiltration processes.

Sludge Disposal Issues

Originally, residuals discharged from the sedimentation basin to two sludge drying lagoons located in the northwest corner of the site. After drying, the solids were hauled to the Marshall Landfill for disposal. With the plant operating only during the summer months, this arrangement worked acceptably until disposal to the landfill was stopped due to regulatory constraints. After a brief period of stockpiling dewatered sludge on site, sludge from the sedimentation basin was directed to the sanitary sewer for removal at the wastewater treatment plant and codisposal, along with the WWTP sludge, by land application. Sewering of BRWTP residuals was recommended by the *City of Boulder Colorado Sludge Disposal Option Study* (Richard P. Arber Associates, 1990) and successfully piloted in 1991. The primary coagulant at BRWTP was also changed from alum to ferric chloride to reduce the volume of residuals discharged to the wastewater treatment processes.

This arrangement worked satisfactorily as long as the water treatment plant sludge volume did not exceed the capacity of the WWTP processes to assimilate it. In February 2001, experimentation with alternative operation of the BRWTP sedimentation process resulted in a large quantity of concentrated ferric chloride sludge being discharged to the sewer. As the sludge passed through the WWTP it disrupted the biological treatment process, particularly the trickling filters, resulting in an extended period of discharge of poor quality effluent. Following this incident, the capacity of the WWTP processes to assimilate WTP sludge was reconsidered and a discharge permit limiting the discharge of ferric coagulant to 1,210 pounds per day was issued to the BRWTP. Numerical limitations were also listed in the permit for pH and inductively coupled plasma (ICP) metals. However although no pH or ICP-metal data was collected during dissolved air flotation (DAF) piloting, the permitted metal limitations would not be expected to constrain treatment capacity at BRWTP.

Although WWTP staff determined that the presence of iron in process sludges is beneficial because it helps reduce sulfides, particularly hydrogen sulfide, and struvite formation in sludge stabilization processes, the concern remains that the presence of excess iron could inhibit biological processes resulting in inadequate treatment. Biological inhibition at other WWTPs has been attributed to the precipitation of phosphorus with the ferric sludge in the primary treatment stage, thereby reducing the phosphorus concentration in the wastewater reaching subsequent biological processes to extremely low levels. With a vital nutrient unavailable, the biomass activity declines and process performance is diminished. If inadequate phosphorus was found to be a problem, experience at other facilities indicates that it could be mitigated by adding a small amount (1 mg/l) phosphoric acid to the WWTP influent. Hence, the ability of the WWTP biological processes to operate properly with residual iron present would not necessarily be the limiting factor governing discharge of WTP sludge to the sewer system.

Biofilm coating from BRWTP residuals has also been suggested as an inhibitory effect. It is obvious that uncontrolled dumping of BRWTP residuals must be avoided at all times. However at this point in time, the precise mechanism for performance problems at 75th Street WWTP due to *controlled* residuals discharges has not been identified.

WWTP staff is also concerned with complying with the limitation on dissolved iron in the plant effluent. The 75th Street WWTP operates in accordance with a wastewater discharge permit issued by the State of Colorado. The February 1, 2003, permit includes a limit on dissolved iron in the effluent discharged to Boulder Creek of 349 micrograms/liter (parts per billion), 30-day average, beginning January 1, 2006. Since the iron compounds associated with water treatment sludges are insoluble, it is not clear to what extent they would affect the concentration of dissolved iron in the WWTP effluent. Further study would be needed to determine the amount of WTP sludge that could be accepted by the WWTP without violating the dissolved iron discharge limit.

Regardless of the basis, the BRWTP is currently permitted to discharge a maximum of 1,210 pounds per day of ferric coagulant to the sanitary sewer. Based on this limit, the BRWTP could treat about 4.8 mgd when feeding 30 mg/l of ferric sulfate (dry weight basis). Consequently, unless the permitted limit for ferric coagulant is significantly raised, the BRWTP will need to change primary coagulants or find an alternative means of sludge disposal to replace the current practice of sewering residuals in order to operate for sustained periods at the proposed 20 mgd rate. Although changing primary coagulants will satisfy the current permit requirements, there is no guarantee that WWTP inhibition would be eliminated.

Process Issues

The planning process for expansion of the BRWTP includes consideration of alternative prefiltration treatment processes. Final consideration is being given to modifying the existing sedimentation basin to improve performance, and to replacement of the existing sedimentation process with dissolved air flotation (DAF). DAF sludge concentration is typically in the range of 2 to 4 percent solids while sedimentation basin sludge normally has a solids concentration of 0.5 to 1.0 percent. Thus the choice of water treatment process will determine the volume and character of sludge to be handled, which will, in turn, influence the size and configuration of solids treatment facilities.

Process chemicals also have a direct impact on sludge quantities and dewatering characteristics, and, at this time, neither the mix of chemicals nor their dosages are established. This is due in part to ongoing efforts to optimize performance of the existing process by experimenting with various types and combinations of coagulants and flocculent aids. For example, after running for a number of years with ferric chloride as the primary coagulant, a change was recently made to ferric sulfate. Although initial jar testing with polyaluminum chloride (Sumaclear) produced inconclusive results, the plant is currently feeding 24 mg/L ferric sulfate and 14 mg/L Sumaclear. The actual mix of process chemicals and resultant residuals production associated with DAF is not clearly defined at this time.

Residuals Management Issues

Management of the treatment process residuals from the expanded plant must be considered as part of the capacity expansion planning effort. This evaluation considers conceptual options configured and sized based on reasonable assumptions related to projecting sludge quantities and characteristics to demonstrate the general scope and feasibility of available options. Final design would necessarily require refinement of residuals production estimates with better definition of both treatment process and plant operating scenarios.

Residuals Production

Estimates of residuals quantities are necessary for determining the size and operating costs of potential management programs. Typically, estimates of residuals quantities are based on historic operating data or anticipated operation of proposed processes derived from pilot testing results or experience with similar facilities. However this is not practical in this case. Consequently, estimates were made based on reasonable assumptions of loadings and sludge production rates using the following equations:

Dry ferric sulfate sludge, lb/day =
(8.34 Q)(bT + 0.8(ferric sulfate dose, mg/l as $Fe_2(SO_4)_3$) + 0.5 (PACl dose, mg/l))

Q = flow, mgd
T = influent turbidity, NTU
b = ratio of suspended solids to turbidity mg/l/NTU
PACl = Polyaluminum chloride (Sumaclear 820B)

The factor *bT* is used to estimate suspended solids concentration from raw water turbidity. Because there is a wide range in the ratio of TSS to turbidity the coefficient *b* must be estimated for each application. Recent studies for local facilities have used ratios of 1.5 to 2.0 TSS/turbidity. For this evaluation, a value of 1.5 mg/l TSS per NTU was chosen for *b* to provide conservative estimates.

The BRWTP draws water from the Boulder Feeder Canal part of the year and from Boulder Reservoir the remainder of the year. Raw water turbidity varies between the two sources, which would affect the amount of sludge produced. However, future annual water production patterns are not defined at present making it impractical to estimate volumes treated from each source. Based on recent plant operating data, influent raw water turbidity averages about 13.5 NTU for water drawn from both sources over the course of a year. Applying *b* of 1.5 to a *T* of 13.5 results in an estimate for average influent TSS, *bT*, of 20 mg/l. This approach is consistent with development of conceptual residuals management options with various other critical factors not well defined.

Residuals estimates were made for two general treatment process configurations: continued use of the existing flocculation/sedimentation process with modifications to enhance performance, and replacement of the existing process with dissolved air flotation.

- **Improved flocculation/sedimentation process:**
  - Winter 2003 process chemical feed of 45 mg/l ferric sulfate and 7 mg/l Sumaclear 820B, both measured on a liquid weight basis, is estimated to produce 316 lb dry solids / MG treated. Spring 2003 chemical feed of 24 mg/L ferric sulfate and 14 mg/L Sumaclear 820B is estimated to produce 385 lb dry solids/MG treated.

- **Dissolved air flotation process:**
  - 15 mg/l ferric sulfate, and 15 mg/l Sumaclear 820B polyaluminum chloride, dry weight basis, is estimated to produce 329 lb dry solids / MG treated.

Based on the foregoing projections, it was assumed that an average of about 320 lb of dry solids would be produced for each million gallons of treated water produced. However, the volume of sludge to be handled would differ significantly between the two processes because of the widely different solids content of the residuals produced. Settled sludge from the sedimentation basin will typically have between 0.5 and 1.0 percent solids concentration resulting in a range of sludge volume from 3,800 to 7,700 gallons per million gallons of treated water produced. Float sludge from a DAF typically has a solids concentration of 2 to 4 percent. The resulting range in discharge may be up to 2,550 gallons of sludge per million gallons of water treated.

Solids Handling Options

From an operational standpoint, the simplest method of disposing of process residuals from the BRWTP is discharge to the sanitary sewer as is the current practice. However, discharge of DAF process sludge to the sewer may not be practical because of its high solids content which could inhibit gravity flow. Thus, depending on the characteristics of the actual sludge produced by the selected process, discharge to the sanitary sewer may be physically possible only for the renovated sedimentation basin process. In addition, continued discharge to the sewer is not considered a viable long-term option unless the current 1,210 pounds per day limit on the discharge of ferric coagulant is increased substantially. For example, feeding 30 mg/l of ferric sulfate to a 10 mgd flow would result in a discharge of about 2,500 pounds per day of ferric coagulant—twice the daily maximum allowed. Although this appears to be a significant violation, the real capacity of the WWTP to assimilate iron is not presently known. Therefore, the first step in managing residuals from the expanded BRWTP would be a thorough evaluation of the WWTP process capacity to accept sludge from the WTP. This evaluation would include a definitive determination of the cause of process limitations and potential operational changes, such as addition of phosphoric acid that could increase the capacity of the WWTP to accept sludge. Once the true capacity of the WWTP to accept WTP sludge has been established, the practicality of adapting WTP operation, particularly process chemicals, to keep residuals quantities and characteristics within the capabilities of the WWTP can be assessed. If it is determined that WTP process operations and chemical selection cannot reduce residuals production to within the WWTP capacity range discharge to the sanitary sewer would need to be discontinued. Should this be necessary, two general concepts for managing residuals were considered:

- Hauling liquid sludge to off-site disposal.
- Dewatering the sludge prior to hauling to off-site disposal.

Consideration of combining water residuals and wastewater biosolids, post-treatment, is beyond the scope of this technical memorandum. Since the City of Boulder is currently in the process of planning for future sludge treatment and disposal facilities for the 75th Street WWTP, that planning process should extend to the integrated management of water and wastewater residuals. Pending the outcome of that study, hauling and off-site disposal of water plant residuals by an independent contract operator was assumed for establishing order of magnitude annual operating costs for this evaluation.

Hauling liquid sludge to off-site disposal

Under this option, liquid sludge would be hauled off site by tank trucks and disposed of by land application. Current local practice involves hauling sludge in 5,000 gallon tank trucks owned and operated by a contract hauler with disposal by land application on land owned or accessible to the contractor by an agreement with the owner. These operations are conducted in accordance with state regulations and the contract operator assumes the liability for proper disposal. The current cost for hauling and disposal of liquid sludge by this method is 4 cents per gallon.

Sedimentation Basin Process. Sludge from the sedimentation basin would have a concentration in the 0.5 to 1.0 percent solids range. With the plant operating at 10 mgd, as much as 75,000 gallons of sludge could be produced in a day requiring 15, 5,000 gallon tank truck trips to haul the sludge away. In addition to the large number of truck trips, the hauling and disposal cost based on gallons of sludge transported would be high. Thickening the sedimentation basin sludge to a concentration of 4 to 6 percent solids would reduce the volume of sludge to be disposed of by about 90 percent. Consequently, a holding basin to permit the sludge to thicken prior to hauling would be included in this option.

The low concentration of solids in the sludge would allow it to drain by gravity from the sedimentation basin to a concrete holding basin located northwest of the Administration Building, near the original sludge drying beds. The basin would be sized to hold 30 days of sludge at four percent solids concentration to provide time for the sludge to concentrate and reduce the cleaning frequency. At the design-operating rate of 10 mgd with 320 pounds of sludge produced per million gallons treated, 96,000 dry pounds of sludge would be produced monthly. At a concentration of four percent solids the required storage volume would be 290,000 gallons. Setting the storage volume as 2/3 of the basin volume to accommodate decanting, results in a total basin volume of 430,000 gallons. With an 8-foot operating depth the basin would be approximately 60 feet by 120 feet. The basin would be divided into two cells 60 feet square to permit one to be cleaned while the other is in service.

The supernatant water would be decanted from above the settled sludge by telescoping valves or adjustable weirs. The decanted water would be pumped back to the plant influent at a controlled rate by variable speed centrifugal pumps. A separate pumping system would provide for removal of sludge from the basins and loading onto tanker trucks using 300 gpm positive displacement pumps.

Basin cleaning would occur about every two weeks and would involve hauling approximately 133,000 gallons of sludge. This would require about 27 truck trips, which would be spread over

five days if an average of 5 truckloads per day could be maintained. Total annual truck trips would be 690 and the annual cost for hauling and disposal would be $138,000 at a cost of four cents per gallon.

DAF Process. Sludge produced by the DAF process is typically in the 2 to 4 percent solids range and could be loaded directly onto trucks for hauling to disposal. However, the DAF process would operate around the clock, 7 days per week, while hauling and land application typically are done only during the day, 5 days per week. Further, variations in process flow and solids content of the float sludge must be anticipated. Consequently, a sludge holding tank would be included to provide operational flexibility by absorbing the differences between sludge production and truck hauling of sludge to disposal. For purposes of this evaluation, a 430,000 gallon tank identical to the sedimentation basin holding tank on the previous page was assumed. This volume would provide over 15 days of storage at 10 mgd water production with float sludge at two percent solids concentration.

Depending on the final design arrangement, it may be possible to discharge float sludge to the holding tank by gravity and provide pumps for truck loading. However, for purposes of this evaluation, it will be assumed that separate pumps will be provided for transferring float to the holding tank and for loading the tanker trucks.

At four percent solids concentration, approximately 67,000 gallons of sludge would be produced weekly. Assuming sludge would be hauled five days per week about 14 truck loads per week would be required, an average of over 2 per day. The total annual truck trips, 690 and annual disposal cost, $138,000 would be the same as for the sedimentation basin process.

An estimate of the present worth for construction and operation of a liquid sludge hauling facility assuming a 20 year life and 5 percent interest rate is presented in **Table 1**.

Table 1 – Present Worth of Liquid Sludge Hauling

	Treatment Process	
Item	**Sedimentation Basin**	**DAF**
Holding Tank	$217,000	$217,000
Pumping Facilities	$135,000	$90,000
Site Improvements and Yard Piping	$45,000	$45,000
Electrical and Instrumentation	$20,000	$15,000
Mechanical	$10,000	$5,000
Subtotal	$427,000	$372,000
Contingency @30%	$128,000	$112,000
Capital Cost	$555,000	$484,000
Annual Disposal Cost	$138,000	$138,000
Present Worth of Disposal Cost	$1,462,000	$1,462,000
Total Present Worth	**$2,017,000**	**$1,946,000**

Dewatering Prior to Hauling to Off-site Disposal

Dewatering can be accomplished either by mechanical or non-mechanical means. Non-mechanical systems employ some form of drying bed to impound the sludge and provide for removal of excess water by a combination of gravity separation and evaporation. Typically, when sufficient land is available, non-mechanical methods are preferred because of their simplicity and ease of operation. Only non-mechanical dewatering is considered herein.

Drying Beds. Sand drying beds remove excess water by a combination of drainage through a permeable sand layer that makes up the bottom of the bed, decanting of supernatant, and evaporation. Deeper beds for multiple applications are typically termed "lagoons." The City's Betasso WTP has sludge lagoons with permeable cellular confinement systems. For cost-estimating purposes, it was assumed that the beds at BRWTP would be similar to those at Betasso.

In operation, sludge would be added to a bed and would concentrate by gravity separation to five to six percent solids. Supernatant would be drawn off by telescoping valves, and the collected drainage conveyed by gravity to 75th Street WWTP. Provisions will be made to install pumps in the future for recycling to the head of the plant. After the initial drainage the bed would be left to further dewater by evaporation until the desired solids concentration was attained. The length of time required to attain final concentration depends on the net evaporation available and the initial bed loading. A lower initial loading will shorten the cycle time of an individual bed but will increase the total bed area required since less sludge can be applied per unit area.

For this evaluation, a drying bed complex of 8 beds sized for 6.5 weeks of sludge production, each, and a 10-month cycle time was assumed. Because the future annual operating pattern of the BRWTP is not known, beds were sized to accommodate the projected sludge production from the 10 mgd design flow any month of the year. Bed area was estimated based on monthly net evaporation rates from long range climate statistics summarized in **Table 2**. Due to past negative experience with polymer conditioning at the Betasso plant, sludge dewatering characteristics without polymer conditioning were assumed.

Table 2 – Monthly Climate Data

Month	Precipitation (inches)	Evaporation[1] (inches)	Net Evaporation Inches
January	0.39	0.84	0.45
February	0.39	0.76	0.37
March	1.15	1.34	0.19
April	1.7	2.52	0.82
May	2.34	4.37	2.03
June	1.87	5.88	4.01
July	1.11	6.55	5.44
August	1.19	6.55	5.36
September	1.34	5.29	3.95
October	0.85	3.44	2.59
November	0.7	1.68	0.98
December	0.58	0.92	0.34
Annual Total	**13.61**	**40.14**	**26.53**

[1]Measured at Chatfield Reservoir.

Operation of the BRWTP at 10 mgd with 320 pounds of sludge produced per million gallons treated would generate 3,200 pounds per day of sludge. Assuming that a solids concentration of four percent can be attained by decanting, a volume of approximately 58,000 cubic feet would be generated each 6.5 weeks. Applied to a bed at a depth of 36 inches results in an area of 20,000 square feet per bed, and an annual bed loading rate of about 7.3 pounds per square foot. The drying bed complex would include 8 beds 100 feet by 200 feet for a total bed area of 160,000 square feet. Two of the eight lagoons exist, albeit unlined and in disrepair.

Each bed would be filled over the course of 6.5 weeks and simultaneously decanted. Water would also be removed by evaporation while the bed fills. After the bed was full it would continue to dewater by evaporation for the next ten months and then would be cleaned. A full year of drying would remove a net 26 inches of water by evaporation, resulting in a final solids concentration of about 15 percent. At this level of dryness a full bed would hold about 575 cubic yards of sludge which would be removed by a rubber tired loader and loaded onto dump trucks for hauling to off site disposal. Typical rates charged by contract haulers for hauling and disposal of dewatered sludge are $7.00 per wet ton plus $400 per 20 cubic yard load. Assuming an 18 percent solids concentration, each 20 cubic yard load would cost about $525. At the projected rate of sludge production about 230, 20-cubic-yard loads would be generated per year resulting in an annual sludge disposal cost of approximately $101,000.

Location of the drying beds in the open area northwest of the Administration Building would permit sludge to be conveyed to them via the existing 12-inch gravity line that fed the plant's original sludge drying beds. For purposes of this evaluation it was assumed that the low concentration sedimentation basin sludge would flow by gravity while the four to six percent concentration sludge from a DAF process would need to be pumped to the beds.

Excess water removed by decanting would be conveyed to a pumping station for return to the head of the plant. The sedimentation basin process would produce up to 77,000 gallons of sludge at 0.5 percent solids concentration. Decanting to five percent solids would generate about 69,000 gallons of water per day. Solids discharged from a DAF process at two percent solids concentration would produce about 19,000 gallons per day and decanting to five percent solids would remove approximately 11,500 gallons per day. A pumping station consisting of a concrete vault built adjacent to the drying bed complex, with two submersible, variable speed pumps having a range of 10 to 100 gpm would provide for equalized return of decant water.

Table 3 – Present Worth of Drying Beds

	Treatment Process	
Item	**Sedimentation Basin**	**DAF**
Drying Beds	$3,000,000	$3,000,000
Pumping/Decant Facilities	$30,000	$50,000
Site Improvements and Yard Piping	$45,000	$45,000
Electrical and Instrumentation	$10,000	$15,000
Subtotal	$3,085,000	$3,110,000
Contingency @30%	$925,000	$933,000
Capital Cost	$4,010,000	$4,043,000
Annual Disposal Cost	$101,000	$101,000
Present Worth of Disposal Cost	$1,070,000	$1,070,000
Total Present Worth	**$5,080,000**	**$5,113,000**

Evaluation of Options

The estimated cost to implement the options considered in this evaluation are summarized in **Table 4**. It should be noted that sludge disposal costs represent only the cost of hauling and disposal by a contract operator and do not include plant staff time or other operating costs.

Table 4 – Summary of Costs for Residuals Management Options

Option	Capital Cost	Rank	Annual Disposal Cost	Rank	20-Year Present Worth	Rank
Liquid Sludge Hauling						
Sedimentation Basin	$555,000	2	$138,000	2	$2,017,000	2
DAF	$484,000	1	$138,000	2	$1,946,000	1
Drying Beds						
Sedimentation Basin	$3,085,000	3	$101,000	1	$5,080,000	3
DAF	$3,110,000	4	$101,000	1	$5,113,000	4

This assessment shows that there would be only a limited cost impact associated with the selection of prefiltration treatment process. The following observations can also be made.

- **Liquid Sludge Hauling**
  - Lowest capital cost and present worth
  - Easiest to operate
  - Least amount of additional staff time
  - Highest number of truck trips averaging 2 per day, 365 days a year

- **Drying Beds**
  - Highest capital cost resulting in highest present worth
  - Simple to operate
  - Requires staff time for cleaning beds and replacing sand
  - Average of 4.4 truck trips per week at 10 mgd

Conclusions

Continuing to discharge sludge to the sewer would be the best option. However this is not expected to be a long-term option. Based on the results of this evaluation, liquid sludge hauling would be the least costly to implement, the simplest to operate and would have the least effect on plant staffing. However the additional truck traffic is considered to be untenable.

Therefore it is recommended that the existing sludge ponds be refurbished as part of the near-term improvements at BRWTP. New drying beds should be phased in to allow for the flexibility of eliminating discharge to 75th Street WWTP in the future.

Attachment A-3 – Costs of Near-Term Improvements

MEMORANDUM

MWH

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dan Wetstein

Date: March 10, 2003

Reference: Boulder Reservoir WTP - Preliminary Design for Near-term Improvements

Subject: **Costs of Near-Term Improvements**

Purpose

This Technical Memorandum (TM) summarizes costs for identified potential near-term improvements at Boulder Reservoir WTP (BRWTP).

Background

From July 2002 through April 2003, the City conducted a series of meetings and workshops on the following topics:

- July 24, 2002: Pretreatment options, residuals management, disinfection improvements, backwash system modifications
- September 23, 2002: Pretreatment facilities, residuals management, MIOX system evaluation, raw water conveyance
- January 16, 2003: Pretreatment facilities
- February 3, 2003: Pretreatment facilities, residuals management, disinfection improvements/preoxidation
- February 20, 2003: Pretreatment facilities, long-term improvements (multiple barriers, LT2ESWTR, membranes, ozone, UV, backwash water management)
- April 3, 2003 (partial group): Residuals management

The following draft technical memoranda have also been submitted:

- Chlorine Dioxide for Preoxidation (November 5, 2002)
- Control Systems Improvements Report No. 1 (February 3, 2003)
- Reservoir Contact Time Improvements (February 24, 2003)
- Raw Water Conveyance—Task A8 (February 3, 2003)
- Pretreatment (March 3, 2003)
- Long-term Improvements (March 6, 2003)
- Disinfection Process Improvements for the BRWTP (March 12, 2003)

- Evaluation of Alternatives for Sludge Handling and Management—Task A2 (March 24, 2003)

As a result of the above workshops and TMs, five near-term improvements were initially identified for potential implementation:

- First phase of DAF pretreatment (two, 8-mgd trains),
- Residuals management improvements,
- Clearwell baffling,
- Waste washwater treatment, and
- Conventional (unassisted) presedimentation.

The last two items above were reclassified as mid-term and long-term improvements, respectively, and the following improvements were reclassified as near-term:

- Control systems improvements,
- High service pumping,
- Pilot facility, and
- On-line floc monitoring.

The last two items were deleted from the near-term final design scope. Estimated costs of the remaining near-term improvements for final design are provided below.

First Phase of DAF Pretreatment

General

The following assumptions have been used in developing the conceptual design for costing DAF pretreatment at BRWTP:

- Firm capacity of the facilities will be 16 mgd (three trains of 8 mgd). Two of the three trains will be constructed under the current project;
- Two-stage pumped jet diffusion flash mixing will be provided (no backup pumps or injection nozzles);
- Two-stage flocculation will be provided ($T_D = 20$ minutes at 8 mgd, each train);
- Surface loading rate of DAF flotation tanks = 3.5 gpm/ft^2 at 8 mgd, each train;
- Flocculation and flotation processes will be dedicated; *i.e.,* no intermediate connection between the two processes;
- Pending review of existing geotechnical reports, we are assuming that no insurmountable structural difficulties will be encountered to preclude modifications to the existing flocculator/clarifier.

Observations and Conclusions

There are unknowns regarding the bearing capacity of the soil and piers beneath the existing flocculator/clarifier. Preliminary review of the previous geotechnical investigations at the BRWTP site suggest that uplift was the controlling condition for the flocculator/clarifier piers.

Each flocculation and flotation train in the first phase should be designed to hydraulically accommodate and treat 10 mgd (to the extent possible).

Residuals Management Improvements

General

The following assumptions have been used in developing the conceptual design of residuals management improvements at BRWTP:

- Approach based on upgrading existing lagoons to both manage and store excess solids over amount sent to WWTP, and provide emergency solids location when WWTP unable to accept BRWTP solids;
- The existing lagoon bypass/decant to Boulder Creek Supply Ditch will be abandoned;
- The dimensions of the existing sludge ponds are as follows: west pond = 55 feet by 185 feet; east pond = 25 to 55 feet by 410 feet (spoon-shaped). Ponds will be refurbished to provide dimensions of approximately 100 feet by 200 feet by 5 feet (depth). This volume provides approximately 2.5 months storage of 4 percent DAF float at 10 mgd. To provide for 10.5 months cycle time at 10 mgd, the WWTP would have to accept 75 percent of the residuals from BRWTP.
- Refurbishing costs include tree removal, demolition, excavation, and earthwork--sand, stone--plus liner, paved access ramps, cellular confinement system, and $20,000 allowance for new access road and fencing;
- The 12-inch sludge drawoff line from flocculator/clarifier slopes continuously to the original sludge ponds and can be reused;
- New lagoons will be lined;
- New decant/filtrate structure will be provided;
- Decant/filtrate vault will be designed for future pump and discharge piping to recycle decant/filtrate upstream of flash mixing. Decant/filtrate will initially be discharged by gravity to 75th Street WWTP;
- Concrete walls, access ramps and cellular confinement systems similar to Betasso will be provided;
- No electrical (lighting) or I&C to lagoons.

Observations and Conclusions

Additional lagoons would be required if BRWTP is operated above approximately 7.5 mgd for significant periods of time, because the industrial discharge permit effectively limits the plant's sewering capacity to about 5 mgd. Prairie dog relocation costs were not included in the construction costs. Polymer conditioning might improve decanting performance and reduce dewatering time at modest additional cost. Decant/filtrate recycling could be provided by adding a pump and approximately 900 feet of 4-inch piping.

Clearwell Baffling

General

The following assumptions have been used in developing the conceptual design of clearwell baffling at BRWTP:

- Coated fabric curtains will be supported between columns in the existing clearwell to create longitudinal baffling and serpentine flow;
- A 42-inch diameter, 90-degree bend will be provided to direct incoming flow parallel to, and away from, curtain baffles.

Observations and Conclusions

EPA's 0.5-log *Giardia* inactivation requirement could be met at 20 mgd, if the proposed baffle curtains increase the clearwell's T_{10}/T ratio to 0.7 ("superior" classification) and the clearwell water level was always maintained higher than 7 feet. Due to net positive suction head (NPSH) limitations at the high service pumps, the clearwell is typically maintained above 7 feet to minimize cavitation.

Plant down time will be required to install baffling in the existing clearwell. Consideration might be given to installing valves and valve vaults on the existing filtered water and high service pump suction piping at that time, since another plant outage would be required in the future for this work. These valves would be required should a second clearwell be constructed and would increase the cost of this work by approximately $130,000.

Control Systems Improvements

General

The Control Systems Improvements Report (Report) cited above identified twelve potential improvement items and prioritized them from high to low. Four of the eight "high" items and one of the three "medium" items were classified as near-term improvements:

- Flow tubes,
- Automated chemical dosing,
- SCADA reconfiguration,
- Relocate base totalizers, and
- Feeder canal monitoring.

Observations and Conclusions

Flow tubes. The Report recommended replacement of both the raw water and the finished water flow tubes. The raw water meter must be replaced as a result of the new DAF pretreatment facilities described above. This work consists of replacement of the finished water flow tube.

Automated chemical dosing. The hardware required for automated chemical dosing has been previously installed. This work consists of reprogramming and loop tuning.

SCADA reconfiguration. This item includes installation of a new human/machine interface (HMI) in the DAF Building. It will include one new workstation which will be located in a sealed, environmentally controlled space and fiber optic cabling. The City is replacing the two existing SCADA servers at BRWTP. All units will be upgraded to iFIX 3.0 and reconfigured so that all servers can be combined with a hot redundant standby.

Relocate base totalizers. The production totalizers are currently calculated within the SCADA HMI system and is susceptible to occasional system outages. Moving these calculations to the PLC will make them more accurate and reliable. This work consists of reconfiguring up to ten plant flow meters to output their flow readings to certain PLCs and reprogramming those PLCs.

Feeder canal monitoring. A remote monitoring station will be installed under this task. The station will enclosed and will monitor Boulder Feeder Canal flow and turbidity. Data will be transmitted to BRWTP via telemetry.

High Service Pumping

General

High service pumping at BRWTP was evaluated in February 2003 using the City's H2Onet model. The results were presented in a report entitled *Zone 1 Distribution System Analysis* (*Analysis*) (Integra Engineering). The report recommended adding two pumps similar to the existing pumps to achieve a flow of 19.8 mgd (all pumps in service/Gunbarrel Tank full). The design points for each of the two pumps were determined to be 2,800 gpm at 270 feet total head (low and average demand) and 2,300 gpm at 290 feet total head (peak hour demand). A 300-horsepower motor was recommended. This work will be designed as part of the Near-Term Improvements Project.

Observations and Conclusions

The *Analysis* estimated the capital costs for adding two new pumps and all associated piping and appurtenances at $200,000. Although not stated in the *Analysis*, this cost (plus the fact that variable frequency drives (VFDs) were recommended for Cherryvale and Iris Pump Stations but not BRWTP) suggests that the assumed BRWTP motors were constant speed. The $200,000 cost estimate was inserted into the table below; however it is not known whether it was intended to include necessary electrical improvements.

Costs of Near-Term Improvements

Alternative	Cost	Installation Factor	Total Cost
DAF (FIRST PHASE)			
Construction Costs			
Civil	$200,000	Included	$200,000
Yard Piping	$50,000	Included	$50,000
Flash Mix	$50,000	Included	$50,000
Flocculation	$350,000	Included	$350,000
DAF	$1,000,000	Included	$1,000,000
Electrical/I&C	$330,000	included	$330,000
Subtotal			**$1,980,000**
General Conditions, Overhead and Profit (9%)			$180,000
Contingencies and Allowances (30%)			$650,000
Construction Subtotal			**$2,810,000**
RESIDUALS MANAGEMENT IMPROVEMENTS			
Construction Costs			
Civil[1]	$375,000	Included	$375,000
Yard Piping[2]	$140,000	Included	$140,000
Concrete walls	$150,000	Included	$150,000
Outlet/pumping structure[3]	$45,000	Included	$45,000
Subtotal			**$710,000**
General Conditions, Overhead and Profit (9%)			$64,000
Contingencies and Allowances (30%)			$232,000
Construction Subtotal			**$1,006,000**
CLEARWELL BAFFLING			
Construction Costs			
42-inch 90° Bend	$3,000	67%	$5,000
Baffle curtains	$30,000	50%	$45,000
Subtotal			**$50,000**
General Conditions, Overhead and Profit (9%)			$5,000
Contingencies and Allowances (30%)			$17,000
Construction Subtotal			**$72,000**
CONTROL SYSTEMS IMPROVEMENTS			
Construction Costs			
Flow tube	$20,000	Included	$20,000
Automated chemical dosing	$20,000	Included	$20,000
SCADA expansion	$25,000	Included	$25,000
Relocate base totalizers	$15,000	Included	$15,000
Feeder canal monitoring	$75,000	Included	$75,000
Subtotal			**$155,000**
General Conditions, Overhead and Profit (9%)			Included
Contingencies and Allowances (30%)			Included
Construction Subtotal			**$155,000**
HIGH SERVICE PUMPING			
Construction Costs			
High service pumps (2), piping and appurtenances[4]	$200,000	Included	$200,000
Subtotal			**$200,000**
General Conditions, Overhead and Profit (9%)			Included
Contingencies and Allowances (30%)			Included
Construction Subtotal			**$200,000**

Notes:
[1]Civil includes tree removal, demolition, excavation, and earthwork–sand, stone--plus liner, paved access ramps, cellular confinement system, and $20,000 allowance for new access road and fencing. No imported fill, dewatering, or off-site hauling.
[2]Yard piping assumes 4,500 lineal feet of 6-inch underdrain piping and fittings and 900 lineal feet of 6-inch decant/filtrate piping.
[3]Outlet structure includes decanting (telescoping valves), draining, and overflow protection for both cells and integral (future) decant/filtrate pumping station. Also miscellaneous metals (handrail, grating).
[4]Cost is taken from *Zone 1 Distribution Analysis* (Integra Engineering, February 2003).

The total cost of the near-term improvements would be $4,243,000.

Attachment A-4 – Disinfection Process Improvements for the BRWTP

McGuire Environmental Consultants, Inc.

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MEMORANDUM

TO: Annie Noble, Boulder Water Department
Dan Wetstein, MWH

FROM: Michelle M. Frey, PhD
McGuire Environmental Consultants, Inc.

DATE: March 12, 2003

SUBJECT: Disinfection Process Improvements for the BRWTP

The Boulder Reservoir Water Treatment Plant (BRWTP) is currently configured to apply free chlorine to the raw water, filter influent, filter effluent, and finished water supplies. The use of chlorine has been associated with several performance objectives of the plant, namely:

- Improved coagulation and filtration performance
- Taste and odor control
- Manganese control
- Primary disinfection for the inactivation of pathogens
- Residual (secondary) disinfection to maintain a residual in the distribution system

These uses of chlorine can be generalized as (1) preoxidation treatment for coagulation/filtration performance, taste and odor, and manganese control, (2) primary disinfection, and (3) residual disinfection. Important water quality concerns have been identified for each of these general areas of oxidation/disinfection performance. Each of these concerns will be identified and addressed in this Technical Memorandum (TM). Further the conclusions of the analyses described in this TM will be the development of an appropriate, well-integrated strategy for oxidant and disinfectant applications at the BRWTP.

Preoxidation Treatment

The use of free chlorine as a preoxidant at the Boulder Reservoir WTP is intended to address several water quality management concerns for the City; namely, stabilization of oxidant demand conditions, mitigation of microbiota blooms in plant processes, maintenance of filtration performance, and provision of a safety margin for pathogen control. The consequences of

preoxidation include the increased formation of disinfection by-products, and issues associated with providing adequate oxidant dosages if chlorine use is continued for this purpose.

An important question for the City is whether the current chlorine-based oxidation strategy is optimal for the BRWTP. The use of the MIOX-generated free chlorine as the preoxidant of choice has, in the past, led to limitations in oxidant delivery capacity which has placed the treatment process at risk of providing insufficient free chlorine for both primary and secondary disinfection purposes. The high demand water that can be delivered to the plant at time can create excessive burdens on the current MIOX system. Whether a more powerful oxidant could serve as an alternative and relieve the capacity requirements of the MIOX system is an important consideration.

The chlorine operational data for the BRWTP from 1999-2001 was reviewed and used to develop Figure 1, which shows the preoxidation performance of the plant. These calculations were made by computing the difference between the chlorine dose applied to the raw water and the chlorine residual measured after the clearwell. Preoxidation by free chlorine consumes on average 90 percent of the total chlorine demand in the BRWTP supply. Therefore, the post-chlorination process remains stable, experiencing very little demand fluctuation over time (Figure 1). While the benefit of having consistent chlorine demand post-filtration is important, the preoxidation operation includes certain inefficiencies in demand management. By routinely using a preoxidant, the maximum demand of the water will be exerted and consume the oxidant through the course of treatment. If the application point were moved to downstream of the flocculation or clarification processes, for example, lower demand conditions would exist and would provide the benefit of minimizing the chemical use requirement of the system.

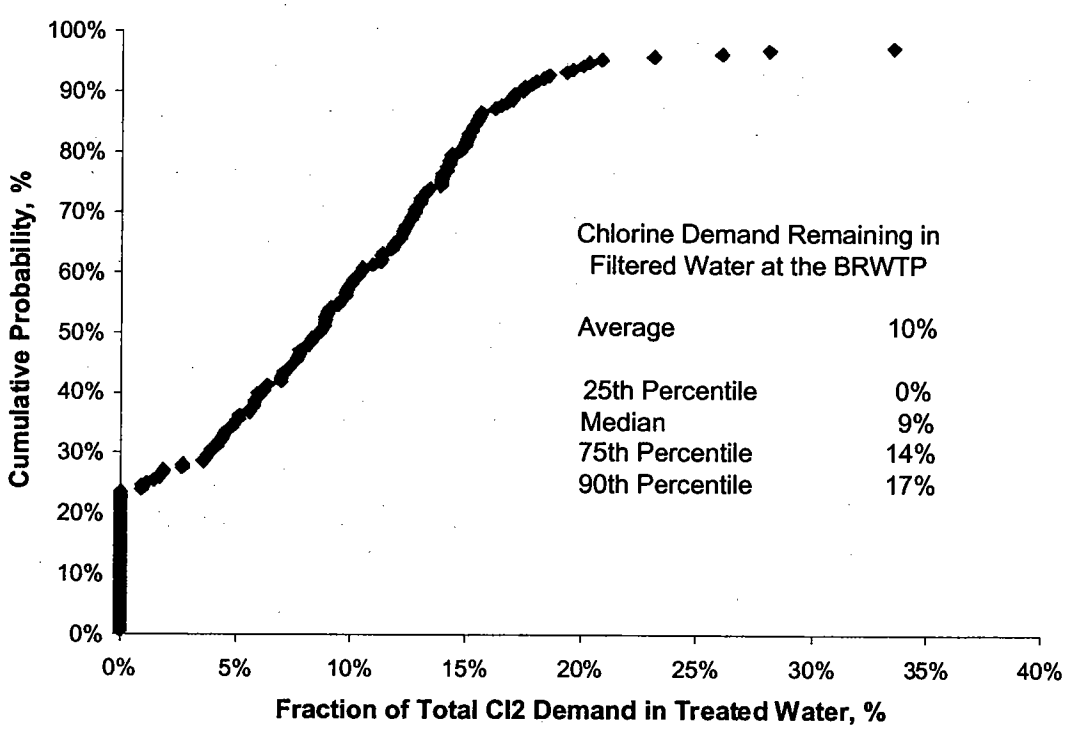


Figure 1. Fraction of total chlorine demand at the BRWTP remaining in the filtered water after prechlorination

Exceptions in water quality conditions do occur where high preoxidant demands can be found in the BRWTP source waters (Figure 2). At this point, it is not possible to say with certainly whether these oxidant demand excursions reflect water quality changes or some difficulty with control or monitoring of the existing oxidant feed system. If the excursions were due to water quality changes, having the ability to apply a preoxidant at the head of the plant would provide flexibility for addressing unusual events, or even performing shock disinfection of the pretreatment processes, if necessary. Handling excursion events in preoxidant demand, however, cannot be fully addressed until further investigative study is performed to determine the source of the excursions. City staff reported that during the summer of 2002, the BRWTP suffered a prolonged and unusually high oxidant demand period. While biological activity was suspected, sampling to determine whether a bloom existed within the plant was not performed. The susceptibility of the BRWTP to such events means that: (1) resources should be mobilized to investigate the source of the demand excursion conditions, and (2) optimization of preoxidation processes is dependent upon developing an effective excursion control strategy.

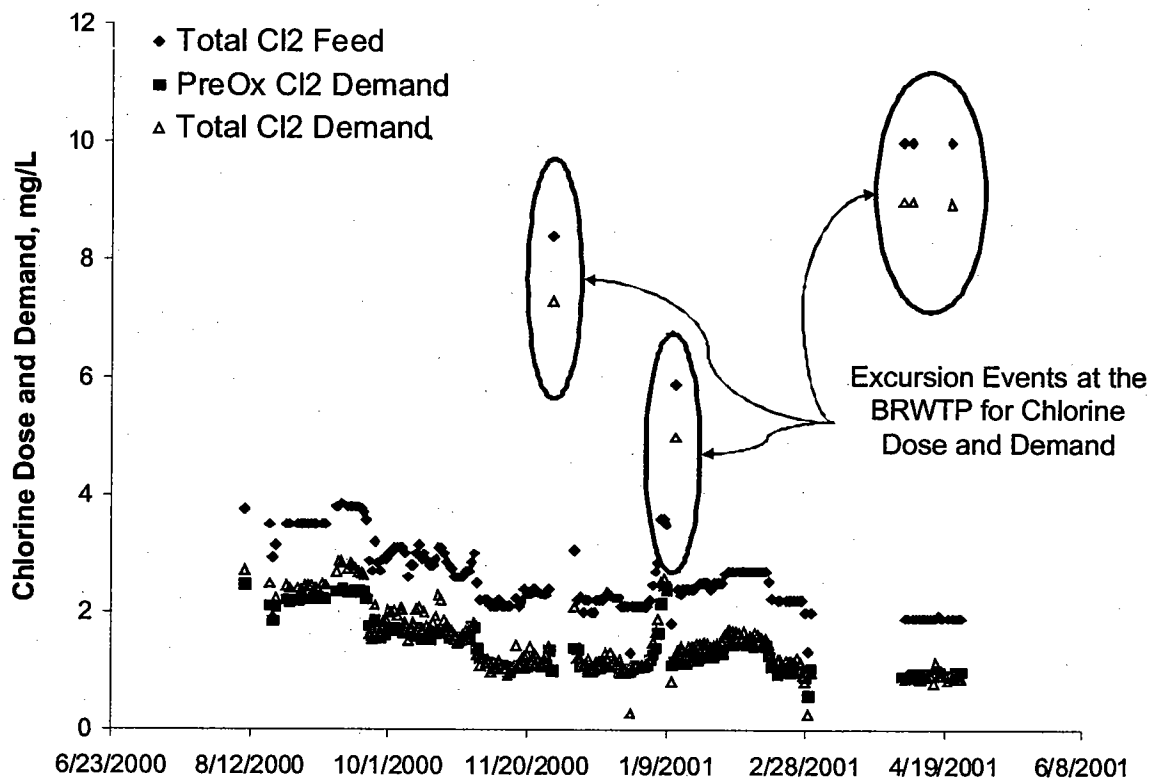


Figure 2. Excursions in chlorine demand and response do occur at the BRWTP

The preoxidation strategy for the BRWTP should consider alternative oxidants to free chlorine for a number of reasons:

- The delivery limitations of the current MIOX system for free chlorine can create unreliable performance for oxidation at the plant,

- The anticipated benefits of MIOX have not been realized, so that the oxidation efficiency is only equivalent to that of free chlorine,
- If treatment of BR water year-round is considered, manganese oxidation capacity could become important and free chlorine is a poor oxidant for manganese at the coagulation pH conditions experienced at the BRWTP,
- The presence of free chlorine in the raw water serves to promote DBP formation which is in direct conflict with the City's water quality goals,
- Free chlorine is a taste and odor promoter, and can mask the origin of taste and odor (T&O) events,
- Chlorine is a slower algicide than other preoxidants and its ability to control biological blooms in the plant was rendered suspect due to the summer event in 2002.
- Finally, a recently completed study by the University of Colorado found that pre-chlorination did not benefit particle control treatment processes through the plant. However, the use of free chlorine as a preoxidant was found to significantly contribute to higher DBP levels in the treated water supply.

The alternative oxidants available to the City include free bromine, chlorine dioxide, ozone, and potassium permanganate. Table 1 presents the theoretical dose requirements for each of these oxidants to meet the chlorine demand exerted at the BRWTP. Demand requirements for the alternative oxidants were computed using historical chlorine demand data and comparing those to the relative oxidizing power of the alternatives (first column in Table 1). There are important caveats to the relative estimates of dose requirements in Table 1; namely, that these are order-of-magnitude estimates that do not account for either the selectivity or relative decomposition rates of the various oxidants. To determine the actual demand exerted on each oxidant, bench or flow-through testing should be performed. The results of the University of Colorado study on preoxidation will provide necessary information for actual dose requirements.

While the Table 1 estimates are theoretical in nature, they demonstrate the potential viability of alternative oxidants as:

- Free bromine should not be considered, even though it is an effective oxidant for many of the BRWTP needs, as it is highly reactive with NOM and can lead to excessive formation of brominated DBPs. This would only increase the DBP concerns of the City.
- While the use of ozone has a very low dose requirement, the cost for ozone at the BRWTP has not as yet been justified, especially when the chlorine dioxide dose requirements are only marginally higher and the capital costs are significantly lower.
- The application of potassium permanganate must be approached with caution as the loss of control can lead to unacceptably high manganese release in the finished water and potentially, the production of "pink" water.

The value for preoxidation, especially if operated only occasionally, would be best realized by the application of chlorine dioxide. While this system does produce chlorite as a byproduct of concern, chlorite management is feasible at the BRWTP. Further, if the City did consider the use

of chloramines as a final disinfectant for DBP control, the presence of low levels of chlorite in the treated water actually serves as a benefit in nitrification control.

Table 1.
Theoretical Dose Equivalents Among Alternative Preoxidants

Oxidants	G^o (Kj/Mol)	Molecular Weight (mg/mMol)	Range of Dose Required, mg/L	Average Dose Required, mg/L	Byproducts Produced
Free Chlorine	6.90	70	0.6 – 2.5	1.4	THM, HAA, TOX
Free Bromine	3.93	180	2.3 – 9.9	5.6	THM-Br, HAA-Br, TOX-Br
Potassium Permanganate					MnOx
Chlorine Dioxide	117.6	67	0.03 – 0.14	0.08	Chlorite, Chlorate
Ozone	163.2	48	0.02 – 0.07	0.04	Aldehydes, Ketones

An important issue regarding chlorine dioxide use is manganese control by preoxidation. If the worst-case water from Boulder Reservoir were to enter the BRWTP, chlorine dioxide would be effective in oxidizing the manganese, but would generate very high levels of chlorite in the treated water because of the demands exerted by the presence of solids, TOC, manganese, and other constituents. However, reservoir management techniques can mitigate the need for manganese treatment at the plant. In-situ aeration techniques are proven methods of manganese control and could help form the basis of an effective overall strategy for manganese control that considers both reservoir management and treatment-based approaches.

Upon post-chlorination, the chlorite can react to form both chlorate and chlorine dioxide. Thus, the City would have to carefully monitor its finished water for chlorite and chlorine dioxide and would assume the full burden of the Stage 1 Disinfectants and Disinfection Byproducts Rule (D/DBPR) for chlorine dioxide systems. These chlorite/chlorine dioxide monitoring requirements would be in addition to the existing DBP monitoring requirements under the Rule.

Recommended Preoxidation Strategy

For the BRWTP future operations and improvements, the following preoxidation strategy is recommended:

- Eliminate routine pre-chlorination at the rapid mix location, but maintain the ability to feed free chlorine (i.e., MIOX or liquid sodium hypochlorite) at that location for emergency use.
- Apply free chlorine to the influent of the filters routinely. A 1 mg/L applied dose under normal conditions should be adequate for maintaining filter operations. Additional free chlorine should be applied after the filters and prior to the clearwell to achieve the targeted finished water residual leaving the plant.
- Investigate the application of chlorine dioxide on an "as needed" basis at the flash mix location.
    - Bench testing for chlorine dioxide demand and decay when applied to the raw water

- Include in bench testing the fate of chlorine dioxide, chlorite and chlorate

- Monitor chlorine demand across the filters in order to inform BRWTP of potential excursions in oxidant demand and to effectively manage chlorine residual through the clearwell for primary disinfection. This is important because the existing clearwell does not allow the City to meet its 30-min. contact time requirement under all conditions and will not allow the City to consistently meet C•t if that requirement is adopted by the State. Low chlorine concentrations entering the clearwell will further compromise disinfection efficiency.
- Institute routine and robust investigations of oxidant demand excursions.
  - Biological parameters should include algae, coliforms, HPC
  - General water chemistry parameters should include pH, DO, alkalinity, turbidity, color, iron/manganese

Primary Disinfection

The primary disinfection process is designed to effectively inactivate pathogens of concern from the drinking water supply prior to consumption by any customers. The US Environmental Protection Agency has passed treatment technique regulations that specify the degree of inactivation required for conventional surface water plants such as the BRWTP. The Interim Enhanced Surface Water Treatment Rule (IESWTR) requires conventional surface water plants to achieve a minimum of 0.5-log *Giardia* inactivation and 2.0-log virus inactivation by the primary disinfection process.

The Colorado Department of Public Health and the Environment (CDPHE), the state agency with primacy for the implementation of drinking water regulations, has taken a different approach to determining the adequacy of inactivation than that suggested by EPA in their guidance document. Namely, the CDPHE requirements are for plants to have 30-minutes of ***effective*** contact time post-filtration when using free chlorine. Effective, in this case, means the expected time in which 10 percent of the flow has passed through the storage reservoir or clearwell. Given the current configuration of the BRWTP clearwell, the theoretical contact time available post-filtration was calculated at 10 percent of the theoretical detention time. (The City is advised to conduct a tracer test to determine the actual clearwell detention time.) While the City is in full compliance with the IESWTR as implemented by CDPHE, the current configuration of the clearwell often does not meet the minimum standards of the CDPHE as the operational level available in the clearwell reaches a minimum condition of "half full" daily and the flow rate conditions often exceed 5 mgd (Figure 3).

Improvements to the clearwell are necessary to achieve the minimum required effective contact time for CDPHE regulations. Baffling improvements are possible to extend the effective contact time. When sufficient baffling is installed to achieve a 0.5 or higher ratio between the T_{10} and the theoretical detention time of the clearwell, over 30 minutes of effective contact time would be achieved under all flow conditions, while maintaining half the reservoir volume for the high service pumps. However, there are some limitations to a baffling-only approach to clearwell improvements:

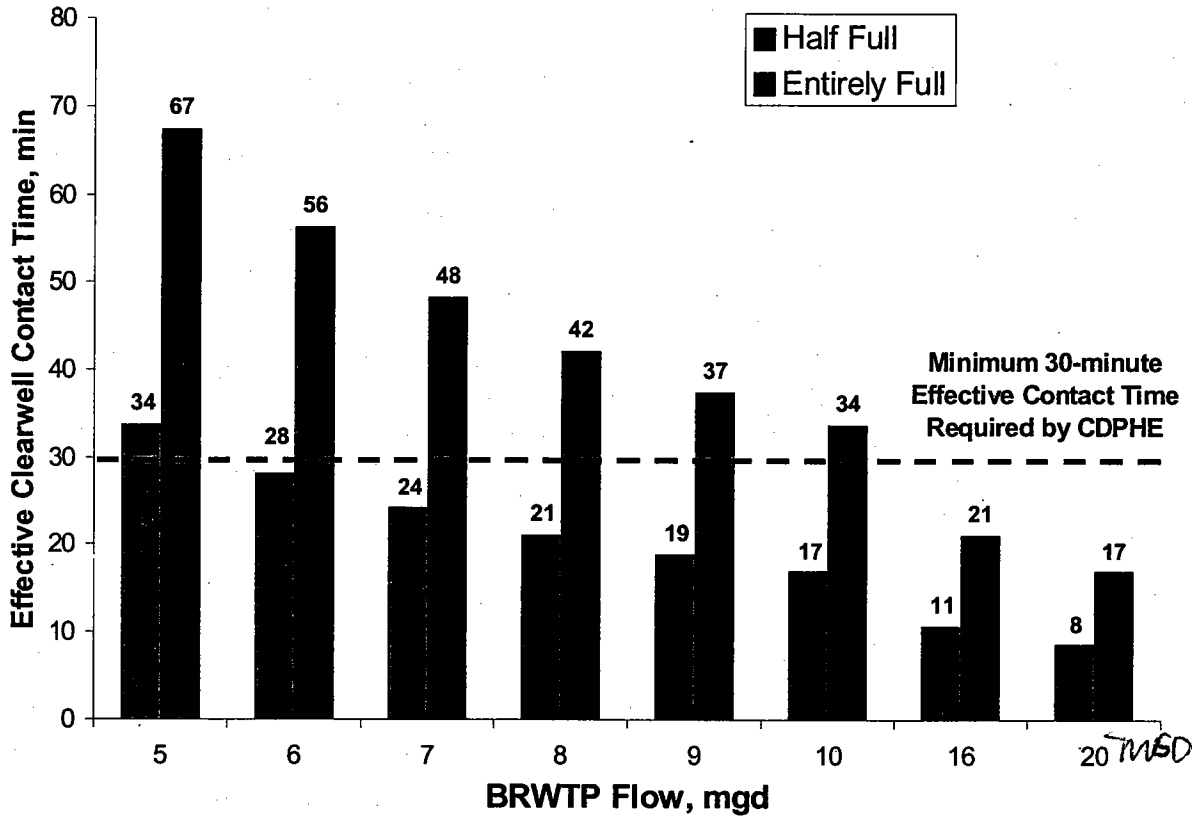


Figure 3. Current clearwell effective contact time (minutes) depends on the operational level of the clearwell and the flow rate of the BRWTP

- The wet-well requirements of the high service pumps when operating at 20 mgd are likely to be greater than that required currently at the plant. This means that more than half of the clearwell would need to be reserved for distribution system demand management.
- Once the clearwell tracer test is done, decisions can be made regarding the need for baffling to minimize short-circuiting. Unfortunately, it is very difficult to baffle a clearwell while it is in service so planning for a second clearwell may need to be initiated. Even if the clearwell was baffled, it may not be possible to maintain adequate clearwell levels to satisfy both disinfection and system demand needs.
- Reliability of disinfection performance, especially as the City moves toward its overall disinfection performance goals for inactivation of *Giardia* and viruses, is compromised by having the primary disinfection process and the distribution system demand response functions within the same basin.

Based on the City's water quality goals, primary disinfection performance of the BRWTP is to be considered per the EPA approach of measuring inactivation; namely, using the relationship between the product of disinfectant residual concentration ("C") and the effective contact time ("t") with the logs of inactivation achieved. The minimum *Giardia* inactivation level for

conventional plants like the BRWTP is 0.5-log per EPA guidance. Inactivation levels above this minimum threshold is the goal for near-term performance of the BRWTP while, in the future, the City would like to achieve 1.5-log *Giardia* inactivation. For this future condition, the measure of achieving the goal is to always meet at least 95 percent of the targeted level, or to always achieve 1.425-log_*Giardia* inactivation. (This condition was defined by the City as part of its goal-setting process.) Based on the historical operating data for the BRWTP, the current operation does not continuously meet the 0.5-log *Giardia* inactivation goal (Figure 4). Further, the current operation only achieves the 1.5-log *Giardia* inactivation target 7 percent of the time. Under future conditions, with increased production at the BRWTP, the frequency of inactivation performance < 0.5-log increases from 35 percent of the time to 75 percent. Improvements to the clearwell are necessary to mitigate this poor performance.

Baffling improvements to the clearwell increase the available contact time and therefore, also increase the effective inactivation level of *Giardia*. Under current operational conditions, baffling could be very effective in assuring continuous achievement of 0.5-log *Giardia* reduction (Figure 5). The ability to achieve a baffling factor above 0.5 reliably can be difficult. With the expected pH fluctuations, the minimum chlorine residual leaving the clearwell at a baffling factor of 0.5 would be 1.0 mg/L. However, if lower chlorine residuals are targeted in the future for the finished water or, if with the elimination of prechlorination, greater variability is found in clearwell effluent chlorine residual levels, completely addressing the inactivation requirements for *Giardia* through the current clearwell will be difficult. If the full capacity of the clearwell was available for disinfection, a reasonable degree of baffling would provide both a high degree of reliability and robustness for the primary disinfection process.

As shown in Figure 5, if the clearwell must continue to be operated based on distribution system demands (routinely operated at half-full capacity), then with baffling alone, primary disinfection performance of 1.5-log inactivation cannot be met.

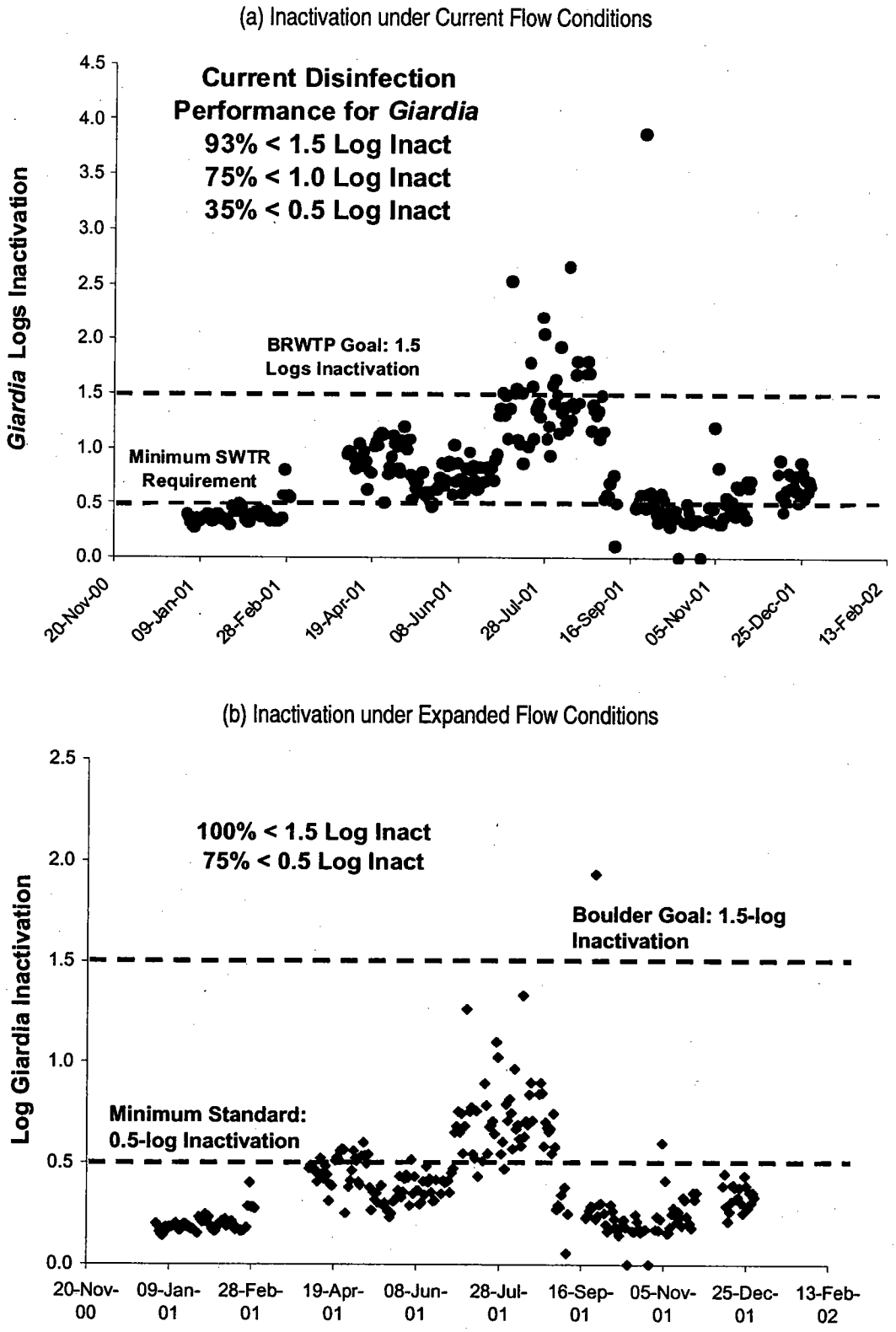


Figure 4. Primary disinfection process performance for *Giardia* inactivation at the BRWTP under (a) current flow conditions and (b) under expanded flow conditions

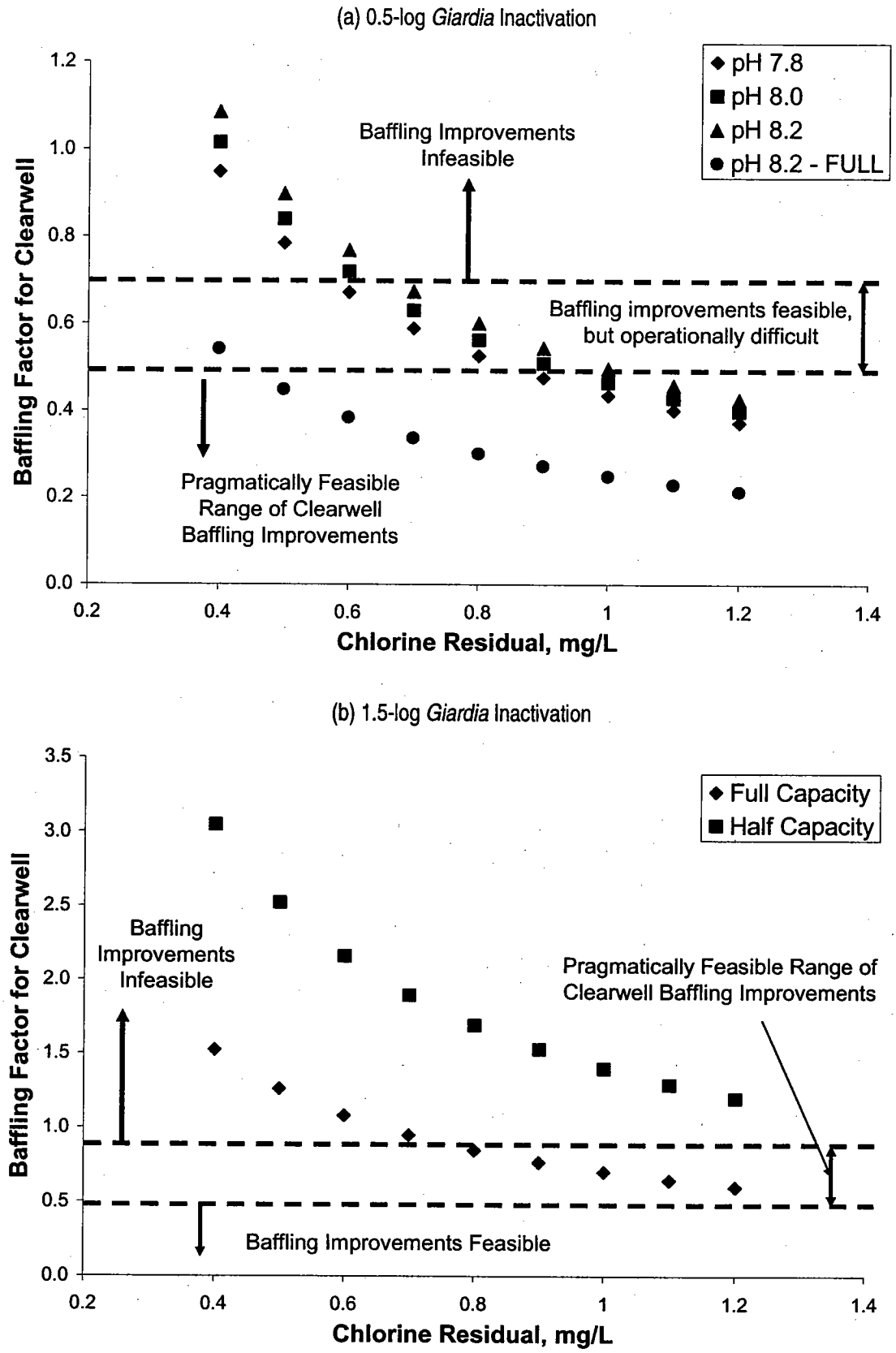


Figure 5. Relationship between pH, chlorine residual, and baffling factors to achieve targeted *Giardia* inactivation at design capacity for the BRWTP

Recommendations for Primary Disinfection

- Baffling the clearwell is a priority to maximize its utility as a disinfection contact chamber and high service pumping station forebay. After this task is completed, decisions regarding addition of a second clearwell should be made. Addition of a second clearwell should be based on plant capacity and the continued use of the clearwell for primary disinfection.
- Baffling alone cannot guarantee that the BRWTP will meet the minimum SWTR requirements 100 percent of the time (0.5-log *Giardia* inactivation). Operation of plant storage for high service pumps and distribution system demand is also a critical requirement for the BRWTP and the storage necessary for this function should be separated from the clearwell used for disinfection.
- Maintaining a consistent residual chlorine level leaving the clearwell will require more active operational oversight and management with the elimination of pre-chlorination. For the near-term, maintaining a minimum residual leaving the clearwell should be near 1.0 mg/L. In the future, with expansion of the clearwell, some reduction of the chlorine residual leaving the clearwell may be possible, provided that low chlorine residual areas in the system are addressed by addition of chlorine booster stations..
- The ability to "trim-up" free chlorine before the distribution system should be added.
- Using Carter Lake or Boulder Reservoir water year-round under alternative source water management options, while reducing pathogen load, will extend the operational period of low temperature water. This will stress the disinfection process in terms of effective contact time for a given inactivation level of *Giardia* as it is temperature sensitive. Consequently, it may be appropriate to reconsider the inactivation performance measures for the public health protection goals in order to recognize the trade-off with the higher quality water.

Residual Disinfection

Maintaining an effective disinfectant residual in the distribution system is an important requirement for the City. The SWTR requires that 95 percent of all monthly samples collected from distribution system sampling locations have detectable levels of disinfectant residual concentrations. The City has defined explicit measures for chlorine residual levels in the distribution system:

- Finished water leaving the plant free chlorine levels of 1.1 ± 0.1 mg/L in 95 percent of the on-line samples;
- Minimum free chlorine residual at all times and at all locations in the distribution system of 0.2 mg/L
- Range of free chlorine residual levels at 95 percent of the distribution system locations of 0.5 ± 0.1 mg/L.

The BRWTP achieves consistent finished water free chlorine residuals where only 5 percent of the daily values are below 1.0 mg/L and 13 percent are above 1.1 mg/L (Figure 6). While this performance is still below the goal measures, it represents a good degree of consistency in performance. The expectation for future operations is greater inconsistency in the finished water chlorine levels due to the elimination of prechlorination. With the ability to "trim-up" the free chlorine at the end of the clearwell, consistency of free chlorine residual can be achieved if not improved.

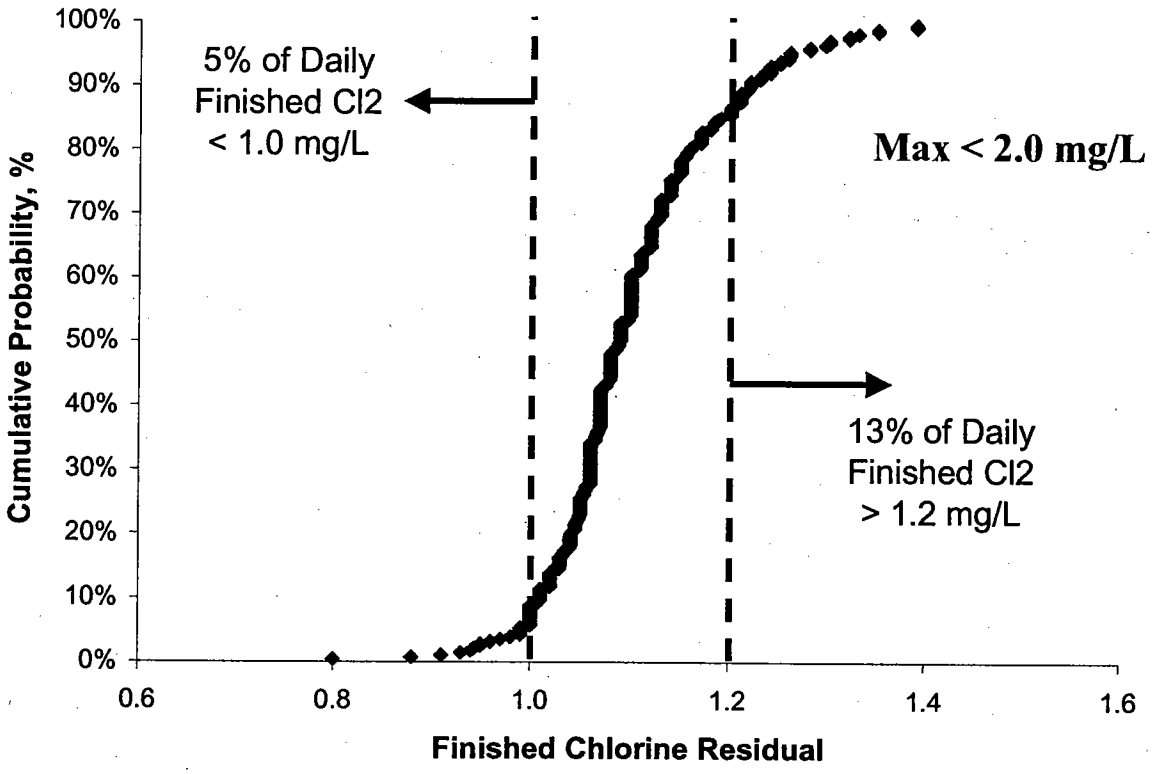


Figure 6. Free chlorine residual in the finished water leaving the BRWTP

The chlorine residual in the distribution system is well maintained at most locations (Figure 7). However, a few locations do experience routine chlorine residual maintenance problems, especially in warmer water conditions. The "problem" sites have dictated the residual requirements for the treated water so that the minimum disinfectant residual goal can be obtained. With the improvements to the BRWTP, additional improvements in the distribution system and its operation will be necessary to handle the added capacity being distributed. The residual requirements of the distribution system should also be revisited. It is likely that adding chlorine boosting capabilities in areas that experience notoriously low chlorine residual levels will be important under any circumstance.

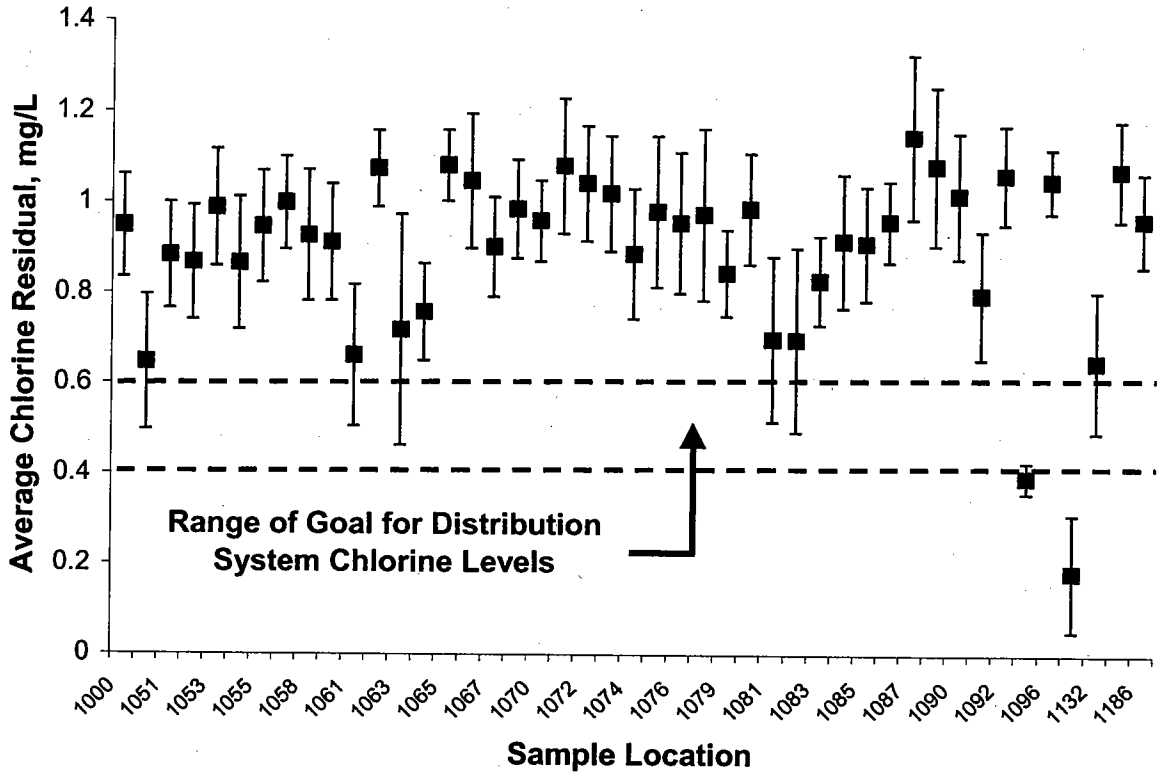


Figure 7. Free chlorine residual levels at distribution system sampling locations

Recommendations for Residual Disinfection

- The ability to "trim-up" the finished water chlorine should be implemented, if not already available. This includes the necessary monitoring and control systems to enhance consistency in the chlorine residual leaving the plant. A similar capability would be beneficial for the Betasso WTP, if not already available.
- The City needs to develop a management plan for those sites in distribution system experiencing significant chlorine residual loss before any further changes in finished water chlorine levels can be implemented at the plant. The management plan needs to address the operational solutions potentially available with distribution system modifications as well as the possibility of installing booster chlorination facilities.

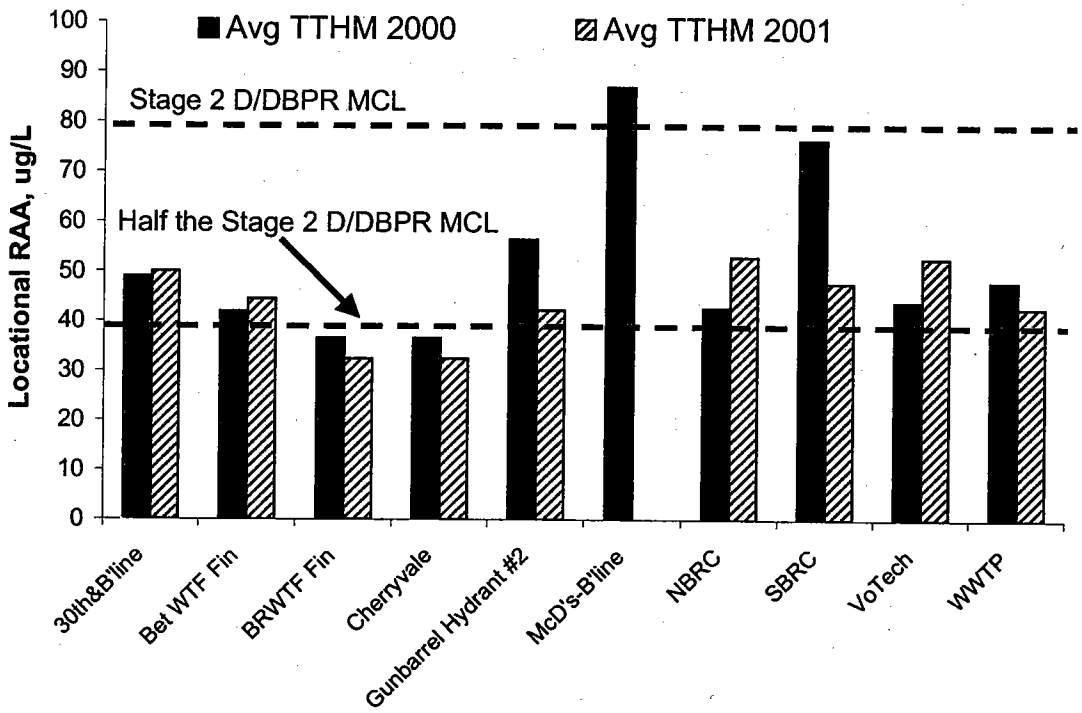
Disinfection Byproduct Control

The final aspect of disinfection treatment is the control of byproducts. The City has established the goal of meeting 40/30 µg/L for TTHM/HAA5 as locational running annual average values at all distribution system locations. As shown in Figure 8, many of the sites currently sampled either meet this goal or are near the 40/30 levels. With the elimination of pre-chlorination, improvements in the DBP control can be expected. The difficulty will be the Stage 2 Disinfectants and Disinfection Byproducts Rule (D/DBPR) requirement for the selection of new

compliance monitoring sites on the basis of expecting high levels of either TTHM or HAA5. The DBP levels found at one of the sites was significantly higher than other locations. This site indicates a vulnerability to excessive TTHM and HAA5 levels in the distribution system.

Elimination of pre-chlorination should benefit the City by reducing DBP levels. At this time, no further action is necessary for DBP control except to continue to monitor levels in the distribution system following changes in pretreatment and pre-chlorination.

(a) TTHM LRAA Values



(b) HAA5 LRAA Values

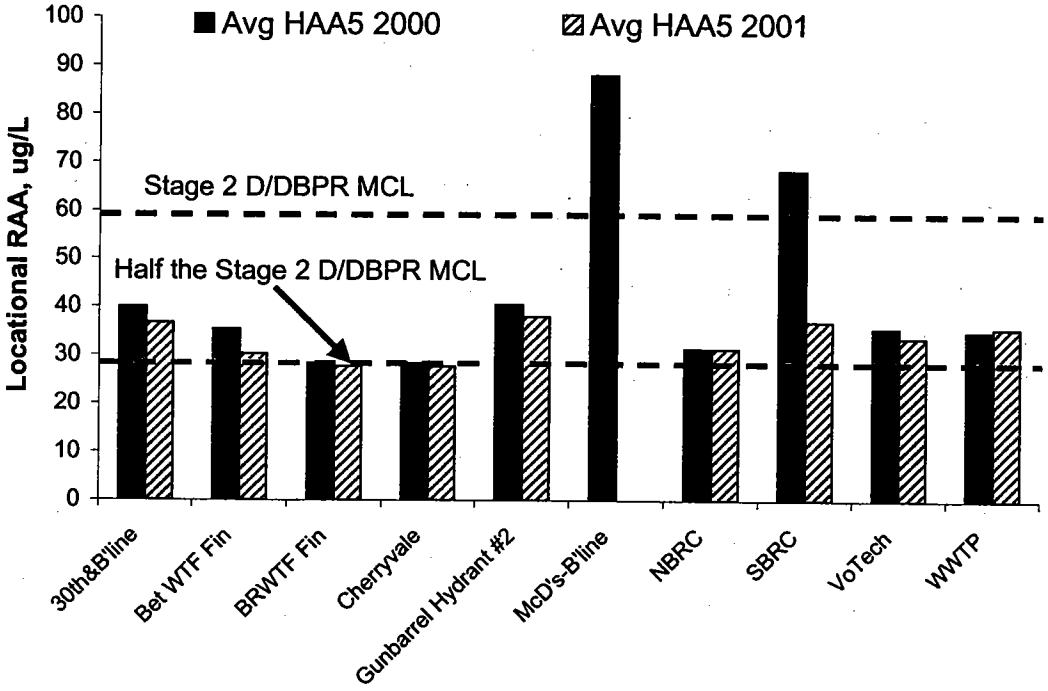


Figure 8. Locational running annual average levels for TTHMs and HAA5

Attachment A-5 – Long-Term Improvements

MEMORANDUM

MWH

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dan Wetstein

Date: March 6, 2003

Reference: Boulder Reservoir WTP - Preliminary Design for Near-term Improvements

Subject: **Long-term Improvements**

Purpose

This Technical Memorandum (TM) analyzes potential long-term improvements (ozone, backwash water management, ultraviolet (UV) disinfection, emergency/redundant power, and membranes) at Boulder Reservoir WTP (BRWTP). The principal driver for analyzing ozone, UV, and membranes is the need for additional *Cryptosporidium* removal/inactivation required to meet the City's internal water quality goals and quite possibly the proposed Long-term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

Background

From February through May 2002, the City conducted a series of workshops, facilitated by McGuire Environmental Consultants, Inc. (MEC), to identify and prioritize possible long-term improvements for BRWTP. Approximately eighteen different problems were identified and ranked as either a "fatal flaw," "prudent," or a "goal gap," in descending order of importance. The "fatal flaw" improvements (flash mixing/flocculation/sedimentation, sludge management, *Giardia* inactivation, flow metering, SCADA/I&C, and raw water conveyance) became near-term improvements. All other issues were categorized as long-term improvements.

This prioritization was modified several times since May 2002. Among the major changes, preoxidation (once rated only "prudent") was first upgraded to a near-term improvement, then downgraded to long-term. Security of the treatment plant and filter-to-waste were deleted from this predesign effort. The remaining long-term issues are listed below:

- Multiple Barriers. This subtask is intended to evaluate the need for additional processes (pretreatment pond, sand trap, membranes) and/or source protection. Source protection (source water planning) was evaluated by Black & Veatch (*Source Water Planning, Phase I* draft, January 2003). New pretreatment basins and the accumulation of sediments ("sand") in the raw water pipeline have

previously been discussed as near-term improvements under the TM's entitled "Pretreatment" and "Raw Water Conveyance." As a result, this subtask currently deals exclusively with membranes.

- Backwash Water Management. This subtask will evaluate treatment of spent filter backwash versus discharging it to the 75th Street WWTP.
- LT2ESWTR, Stage II D/DBR Regulations, Protozoa. LT2ESWTR will include a "microbial toolbox" of options to control *Cryptosporidium*, including watershed control, alternative sources, pretreatment, improved treatment, improved disinfection, etc. Alternative sources were discussed in the *Source Water Planning, Phase I report* cited above; pretreatment was discussed in the "Pretreatment" TM; and chlorine dioxide was discussed in the "Chlorine Dioxide" TM. Membranes have (somewhat arbitrarily) been placed in the "Multiple Barrier" subtask, while ozone and UV (also somewhat arbitrarily) have been included under this subtask.
- Emergency/Redundant Power. This subtask was originally intended to "Review costs and assumptions in previous studies for plant-wide standby power, peak shaving, dual-powered high service pumps, and variable frequency drives for the high service pumps." Unfortunately there were no previous studies on these issues. This subtask will consist of a brief discussion regarding each of these issues and observations or recommendations for future study.
- Alkalinity Adjustment. This subtask will evaluate the need and options for adjusting the treated water final alkalinity to meet Lead and Copper Rule goals.

This technical memorandum will conceptually design and estimate the present worth of membranes, ozone, and UV disinfection, spent filter backwash recycle pretreatment, and spent filter backwash sewering at BRWTP. It will also briefly discuss the issues surrounding standby power, peak shaving, dual-powered high service pumps, variable frequency drives for the high service pumps, alkalinity adjustment, and protozoa, in that order.

Membranes

Membrane technology is evolving rapidly, and there are many manufacturers, configurations, and types of membranes generally used in water treatment applications today. At the current time, we feel the most appropriate membrane configuration for this application would be the low-pressure, submerged, microfiltration (MF) or ultrafiltration (UF) type. As such, we have focused our conceptual design on two experienced manufacturers producing this type of membrane system. They include:

- Zenon ZeeWeed 1000
- USFilter Memcor CMF-S

Both manufacturers report greater than 5-log removal of *Cryptosporidium*. Retrofitting the existing filters or reaction basin to house membranes appears feasible and economical at BRWTP and will be assumed for cost estimating purposes.

General

Other assumptions made in developing the conceptual design of membranes at BRWTP:

- Membrane cassettes would be retrofitted inside the existing filters, and the existing filter gallery would be retrofitted with ancillary membrane equipment.
- System capacity = 16 mgd (firm) or 20 mgd (total).
- Membrane influent water quality (post-pretreatment) would meet the following criteria:
  - Turbidity < 2 ntu
  - pH (maximum) = 7
  - Alkalinity = 75 mg/L
  - Hardness = 150 mg/L
  - TOC < 5 mg/L
  - Color < 5 TCU
- Volume available for membranes in existing filter basins assumes eight tanks, each with dimensions of 15 feet x 30 feet x 13 feet deep.

Site layout of this option is presented in **Figure 1**, and present worth costs are included in **Table 1** at the end of this TM.

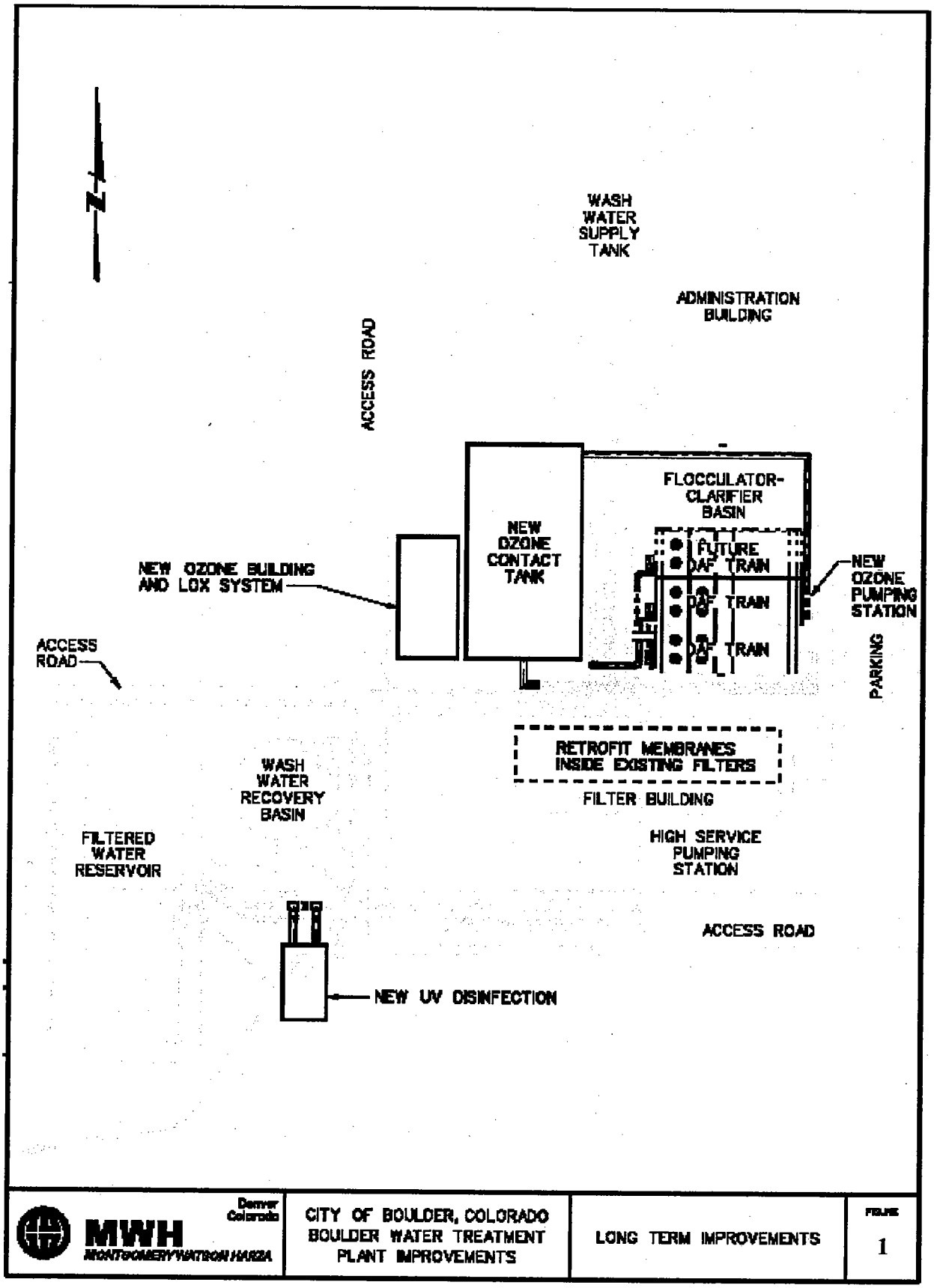
Observations and Conclusions

Membranes provide an effective physical barrier capable of meeting the City's long-term water quality objectives for pathogens. While both skid-mounted and submerged low-pressure membrane configurations are applicable, the submerged MF/UF membranes are the most cost-effective approach for the BRWTP.

Manufacturer's estimates of total membrane capacity available within the existing filter structure range from 40-65 mgd, depending on influent water quality. Piloting would be required to confirm pretreatment, membrane configuration/geometry, driving force, and fouling assumptions. The modular nature of membranes also makes them an attractive option for phasing.

Ozone Disinfection

As noted in the "Reservoir Contact Time Improvements" memo, the City's stated water quality goal for *Cryptosporidium* removal and inactivation is 5 logs. Because the conventional treatment process at BRWTP is assumed to be credited with 3-logs of removal under LT2ESWTR, ozonation is conceptually designed to provide 2-logs inactivation. The conceptual design for an ozone system capable of 2-log *Cryptosporidium* inactivation is summarized below, along with the associated present worth costs.


N
WASH WATER SUPPLY TANK
ADMINISTRATION BUILDING
ACCESS ROAD
FLOCCULATOR-CLARIFIER BASIN
NEW OZONE CONTACT TANK
FUTURE DAF TRAIN
DAF TRAIN
DAF TRAIN
NEW OZONE BUILDING AND LOX SYSTEM
NEW OZONE PUMPING STATION
ACCESS ROAD
PARKING
RETROFIT MEMBRANES INSIDE EXISTING FILTERS
FILTER BUILDING
WASH WATER RECOVERY BASIN
FILTERED WATER RESERVOIR
HIGH SERVICE PUMPING STATION
ACCESS ROAD
NEW UV DISINFECTION
MWH
Denver Colorado
MONTGOMERY WATSON HARZA
CITY OF BOULDER, COLORADO
BOULDER WATER TREATMENT PLANT IMPROVEMENTS
LONG TERM IMPROVEMENTS
FIGURE
1

General

The following assumptions have been used in developing the conceptual design of ozone at BRWTP:

- Ozone would be added between pretreatment and filtration.
- In the absence of plant-specific ozone demand and decay rates for BRWTP's settled water, the following characteristics were assumed:
  - pH = 6 (pH adjustment required)
  - Alkalinity = 75 mg/L
  - TOC = 5 mg/L
  - $t_{10}/t_{hydraulic}$ (contactor) = 0.6
  - Initial ozone demand = 1.2 mg/L
- *Ct* = 26.8 (2-logs) for water temperature of 3° C
- System capacity = 16 mgd (firm) or 20 mgd (total); minimum flow = 5 mgd; 20-year average flow = 10 mgd.
- System would use liquid oxygen (LOX) as the oxygen source.
- Two ozone generators provided, each capable of a 7:1 turndown ratio.
- Two ozone contactors provided in one structure; gallery provided between contactors to house ozone-destruct equipment.
- Costs associated with chemical addition not included.

Summary

Conceptual ozone system design summary:

- Ozone building with LOX facilities (approximate footprint of 35 feet x 75 feet) to accommodate:
  - Two, 680 lb/day generators at 10 percent ozone concentration
  - LOX storage tank and vaporizers
  - Average ozone dose of 4 mg/L (at 10 mgd)
  - Firm ozone generation capacity (equivalent plant flow) = 16 mgd (one generator off line)
- Ozone contact tank structure (approximate footprint of 50 feet x 110 feet) to accommodate:
  - Two, 10-cell over/under-type ozone contact tanks (21-foot side water depth)
  - Ozone destruct and other miscellaneous equipment
  - To provide an average hydraulic residence time per tank of 23 minutes (@ 12 mgd)
  - Firm contact tank capacity (equivalent plant flow) = 16 mgd (meeting 2-log *Cryptosporidium Ct* with one tank offline)

Site layout of this option is presented in **Figure 1** above, and present worth costs are included in **Table 1** at the end of this TM.

Observations and Conclusions

Ozone is one of the strongest chemical oxidants/disinfectants used in water treatment today. Ozone is generally more effective than chlorine dioxide or chlorine for *Cryptosporidium* inactivation, many taste-and-odor compounds, and perhaps for improving filtration efficiency. It does not produce halogenated DBPs except in bromide-rich waters where it reacts to produce bromate. The bromide concentrations in BRWTP's raw water are unknown. Ozone generation is fairly straightforward. Based on the assumptions made in this TM, it is possible that the annual O&M costs for ozone would be comparable to chlorine dioxide or UV.

Ozone also has significant disadvantages. It can form bromate under certain conditions, which is regulated under the D/DBP Rule and would trigger relatively aggressive regulatory requirements. Because it converts TOC to assimilable organic matter (AOM), it would be recommended that the existing filters at BRWTP be converted to biologically active filtration. This would almost certainly require a new filter-to-waste system and (perhaps) new underdrains for air scour. Chlorine (MIOX or sodium hypochlorite) would still be required to maintain a disinfectant residual. Like chlorine dioxide, ozone must be generated on site with associated concerns regarding safety, operations, and maintenance.

UV Disinfection

General

Disinfection by UV light is accomplished by disrupting the deoxyribonucleic acid (DNA) of cells, which prevents the microbe from reproducing, thus rendering it non-infectious. There over 2,000 UV disinfection systems treating drinking water in Europe and over 1,000 in the United States, primarily treating small flows. There are over eleven systems worldwide treating over 10 mgd.

Similar to chemical disinfectants, UV has dose-response curves for differing microbes including bacteria, virus, protozoa, yeast, algae, and fungi. The term "UV dose" is the product of UV intensity expressed as milliwatts per square centimeter (mW/cm^2) and exposure time expressed in seconds. EPA included UV disinfection among its Microbial Toolbox options for inactivation of *Cryptosporidium* and has issued a *UV Guidance Manual* (draft, October 2002). MWH has recently designed a 16-mgd UV facility for Weber Basin Water Conservancy District (Utah) and this analysis assumes that the BRWTP UV facility would be similar.

The following assumptions have been used in developing the conceptual design of UV disinfection at BRWTP:

- The UV system would utilize two closed reactors of approximately 20 mgd capacity, each, to treat filtered water with a minimum dosage of 40 mJ/cm^2;
- Low-pressure, high-intensity, continuous wave lamps;
- Minimum UV transmittance of 90 percent;
- Minimum 2-logs inactivation of *Cryptosporidium;*
- Minimum water temperature of 3° C;

- UV manufacturer would supply acid cleaning system, UV sensors, ballasts, and power distribution enclosures;
- Maximum headloss across a reactor (flange to flange) including inlet and outlet distribution plates shall not exceed 10 inches water column at 20 mgd;
- No pump station would be required;
- Each reactor would provide 40 mJ/cm^2 down to 5 mgd;
- No pilot testing costs;
- No licensing fees.

Site layout of this option is presented in **Figure 1** above, and present worth costs are included in **Table 1** at the end of this TM.

Observations and Conclusions

UV disinfection has definite advantages at BRWTP including its relatively low cost and its efficacy against *Cryptosporidium*. Construction costs are comparable to adding a new 2.7-million gallon clearwell for *Giardia* inactivation, which would no longer be required for *Ct*.

There are several unknown UV issues that must be resolved prior to implementation. These include (a) existing hydraulic constraints at BRWTP, (b) electrical/standby power concerns, (c) O&M costs and patent issues, and (d) actual goals for *Cryptosporidium* removal/inactivation. For example, only 6.25 feet of head is available between the clearwell overflow and the filter overflow at BRWTP, suggesting that the clearwell could never be operated full (20-foot depth) and provide adequate filter run lengths with high flows and cold water. (The "Reservoir Contact Time" TM assumed that the maximum clearwell level was 18 feet--8.25 feet of total head for filtration, of which 5 feet might be available for clogging of the filter bed at 20 mgd, 3° C water.) The hydraulic head requirements for UV (reactor plus associated piping, valves, and fittings) would be a minimum of 2-3 feet, which either reduces the head available for filtration or lowers the maximum 'effective' clearwell operating level to at no more than 15-16 feet.

Calgon Carbon Corporation obtained a US patent entitled *Method for Preventing Replication in Cryptosporidium parvum using Ultraviolet Light* on October 20, 2000, and brought a civil suit against the Town of Ontario, New York (and the superintendent of Ontario Water Utilities Department) for patent infringement in August 2001. Calgon's licensing fee is usually given as $0.015 per 1,000 gallons of water treated by UV. At 10 mgd, the City would pay $55,000 a year in royalties for BRWTP. The total present worth of UV disinfection would become $4,000,000.

Spent Filter Backwash Recycle Pretreatment

General

Filter backwash is a concern in water treatment plants because they can contain high concentrations of pathogens, including *Cryptosporidium* oocysts, and can degrade the treatment process by causing a chemical imbalance, hydraulic surge, or turbidity spike. Spent filter backwash at BRWTP is currently equalized and recycled, untreated, upstream of primary coagulant addition.

Filter backwash at BRWTP is equalized by a 370,000-gallon, covered, circular wash water recovery basin. This volume accommodates about two backwashes. The recovery tank was not designed to settle floc and inflow mixes the tank during each backwash, which causes turbidity spikes at the rapid mix. Three identical 2-mgd (each) vertical turbine pumps with variable frequency drives recycle the spent filter backwash either (a) upstream of the flash mix facility or (b) to the sanitary sewer to 75th Street WWTP.

Conventional design criteria suggest that the recycling rate at most water treatment plants should be maintained at less than 10 percent. At these rates, most conventional water treatment plants should be able to tolerate the associated chemical imbalances, hydraulic surges, and turbidity spikes. Recirculation of preformed floc has been shown to actually improve flocculation and sedimentation due to the seeding effect of turbidity in spent filter backwash at low blending ratios. Depending upon the turndown of the wash water recycling pumps, the blending ratio at BRWTP may be too high. Even at a 20-mgd buildout flow rate at BRWTP, only one of the three recycling pumps should ever be run at a time. Pump capacity and control may be a problem, in addition to the absence of treatment.

The volume of the wash water recovery tank is primarily dependent upon the frequency of backwashing—*i.e.*, the efficiency of the BRWTP pretreatment processes. Because the near-term pretreatment improvements will reduce filter influent turbidity below existing, the existing recovery tank volume may be adequate for future equalization. Particularly during periods when the raw water has algae, filter backwashing frequency may be extended (compared to the existing operational conditions) and the influent blending ratio reduced.

Treatment of filter backwash is not required by the Filter Backwash Recycling Rule. The rationale for treating spent filter backwash at BRWTP must therefore rest upon two propositions. Either (a) the pump capacity/control issue cannot be solved by programming; or (b) BRWTP is run at rates beyond its capacity and certain high concentrations of constituents in spent filter backwash (*Cryptosporidium*, manganese, iron, aluminum, disinfection byproducts, organic carbon, *Giardia*, particles) threaten BRWTP performance and must be removed even at low blending ratios. Using similar rationale at Betasso, DAF was installed for treatment of filter backwash.

At BRWTP, lamella-plate settlers are proposed for cost-estimating and conceptual design purposes for both long-term presedimentation and long-term spent filter backwash pretreatment. The following assumptions have been used in developing the conceptual design of spent filter backwash recycle pretreatment at BRWTP:

- Type of treatment process = lamella plates;
- Capacity = 2 mgd;
- Flash mixing by in-line static mixer;
- Three-stage flocculation. T_D = 30 minutes at 2 mgd;
- Surface loading rate = 0.2 gpm/ft^2 (horizontal projected area) at 2 mgd;
- Nonionic polymer dose = 0.03-0.3 mg/L;
- Construction costs are for retrofitting existing flocculator/clarifier. Because both presedimentation and spent filter backwash pretreatment could be accommodated

within the portion of the flocculator-clarifier not used for DAF, lamella plate costs include both processes

Present worth costs are included in **Table 1** at the end of this TM.

Observations and Conclusions

Pretreatment improvements should increase the plant's ability to handle higher flows, turbidity spikes, as well as provide more protection against higher concentration of *Cryptosporidium*, manganese, iron, aluminum, disinfection byproducts, organic carbon, *Giardia*, particles, etc., in the spent filter backwash. Maximizing the volume of the existing wash water recovery basin that is used, maximizing turndown of the spent filter backwash recycling pumps, and minimizing the blending ratio at BRWTP will help control spiking of high-concentration returns to the flash mixing facility, as well.

The cost of installing a new recycle pretreatment facility could be deferred until the proposed pretreatment improvements are made and the existing recycling operation is optimized. Because conventional presedimentation within the existing flocculator/clarifier is only a short-term, temporary process, lamella plates may have to be installed following the near-term improvements project. At that time, the incremental costs of providing flocculation and polymer feed for recycle pretreatment become relatively insignificant.

Spent Filter Backwash Sewering

General

The quality of the spent filter backwash depends on the raw water quality and pretreatment unit processes. No data was collected during DAF piloting regarding future spent filter backwash quality. However for a conventional purification plant using alum, the typical properties of the waste are

Turbidity: 150-250 ntu
BOD: 2 to 10 mg/L

- COD: 30-150 mg/L
- pH: 6.7 to 7.5
- TDS: 0.01 to 0.05%

BRWTP is required to monitor flow, pH, BOD, TSS under their existing industrial wastewater discharge permit; however pH is the only parameter (of these) that has limitations—less than 5.5 or more than 10.5 for more than five minutes. Although the permit lists daily maximum metals limits and although metals can be concentrated in spent filter backwash, most of the permitted metal concentrations are 100 to 500 times higher than raw water. The chances of an exceedance from spent filter backwash for these metals would be very small. There are some constituents (arsenic, cadmium, molybdenum, and perhaps nickel) that are permitted at less than 100 times raw and pose a bit more concern. Nonetheless, it seems extremely unlikely that sewering spent filter backwash would violate the industrial discharge permit or cause any other problems at 75th Street WWTP from a hydraulic or solids loading perspective.

The proportion of waste to the amount of water treated is usually about 2 percent during the warm months and 3 percent during the cold. The maximum equalized spent filter backwash rate (20 mgd, warm months) could therefore be estimated at about 400,000 gpd (278 gpm) or two backwashes (48-hour filter runs). (The assumed 2-mgd pumping capacity, per pump, at BRWTP provides a 500% factor of safety.)

Piping from BRWTP to the IBM Lift Station could restrict the flow to approximately 480,000 gpd (333 gpm). One section of this 12-inch diameter pipe is shown as "flat/uphill," and another section is indicated as having a full-pipe capacity of 0.48 mgd. Randy Earley's (City of Boulder's) June 4, 2002, memo estimated that the sanitary sewer could carry 0.36 mgd *under gravity flow conditions without surcharging*. Under the rules-of-thumb mentioned above and near-perfect equalization, the piping capacities should be adequate.

Observations and Conclusions

At this point, the principle constraints to spent filter backwash sewering appear to be (a) solving the pump capacity/control and operational protocol problems mentioned above and (b) water rights. It is possible that the City loses "dominion and control" of the spent filter backwash once it is discharged to the sewer. The 10,000 to 15,000 acre-feet wasted per year may be lost and unavailable for lease or exchange. On the other hand, the City may get the credit back by discharging an additional 10,000 to 15,000 acre-feet at 75th Street. Carol Ellinghouse should be contacted regarding the net effect on water rights.

No present worth analysis was performed for this option. Construction costs appear minimal; O&M costs would be no different than at present (spent backwash must be pumped regardless); and water rights costs are unknown. Given the recent drought and renewed emphasis regarding water rights, the burden of proof would seem to favor any option *except* discharge.

Standby Power

A 200-kW engine-generator was installed at BRWTP in 1997 to replace the original 125-volt dc battery system that powered switchgear breaker controls, high service pump and BFC control valves, wash water bleed valve, and other vital control equipment. The engine-generator was also sized to maintain power for ventilating Group H-7 chemical storage spaces during power outages per Code. Gaseous chlorine was subsequently replaced by MIOX, rendering many of the 1997 engine-generator loads obsolete. Two uninterruptible power supplies (UPSs) were also installed to maintain file servers, computers, and telephone system.

During predesign for the 1997 project, Black & Veatch investigated whether to increase the size of the engine-generator to 1,500 kW to provide capacity to power two 4-mgd high service pumps or to construct a dual power supply to BRWTP by bringing a new 1.25-mile-long service from the Gunbarrel Substation (Appendix A). At that time (1995), the capital costs were similar--$400,000. Due to the following facts—(a) the City had two water plants; (b) Betasso had standby power capable of operating 50% of the plant capacity (about 20 mgd); (c) the high reliability record of single power feed to BRWTP; and (d) the fact that BRWTP was unable to supply water to the entire City, it was recommended that both options be deferred until "...water production

from (BRWTP) becomes essential for significant periods of time." At that time, construction of a second utility source and main transformer were recommended.

It is likely that the capital costs are still similar and that the rationale for deferment is still valid. However, the drought has revealed the importance of water production from BRWTP. It is recommended that the issue of standby power be revisited and discussed internally by the City before proceeding with Xcel Energy and predesign of both options.

Peak Shaving

The four basic treatment plant operational modes used to achieve peak shaving are (a) load shedding, (b) reduction of the peak utility demand, (c) paralleling with utility, and (d) prime power cogeneration. At BRWTP, only "reduction of the peak utility demand" has been considered in the past and has been taken to mean "running one (or more) of the high service pumps with an engine-generator." BRWTP has four, 3-mgd high service pumps.

Xcel's demand charge at BRWTP is based on the maximum power usage in a 15-minute period. The utility billing for power usage is based on a monthly basis and uses a 12-month "ratchet." This means that the peak demand in any one month carries over for the next 12 months. In the 1995 Black & Veatch memo cited above, Mr. Larry Poehler of Xcel (then Public Service) reviewed BRWTP's kW demand record and concluded that "...power for the facility can be purchased at a lower cost than it can be generated onsite and that peak shaving for this facility would not be economical."

In order for MWH to review this conclusion, it would be necessary to determine the percentage of time that a third high service pump has been, or will be, operated at BRWTP. This number could probably be deduced from finished water flow data at BRWTP, if available. There may be also be noise and air pollution/emissions issues to resolve if the generator runs for an extended period. It is recommended that the issue of peak shaving be discussed internally by the City at the same time as standby power (above) before contacting the City's Planning Department, analyzing finished water flow data, and revisiting the peak-shaving issue with Xcel Energy.

Dual-powered High Service Pumps

Similar to the standby power/peak shaving issues above, McLaughlin Water Engineers (McLaughlin) prepared a cost estimate in 1998 for conversion of one of the four high service pumps at BRWTP to natural gas. Although this estimate has not been located, Randy Earley's cover memorandum (Appendix B) indicated that the cost was prohibitive. For whatever reasons, the conversion was never done.

MWH has used dual powered pumps (albeit usually electric/diesel in series) and could revisit McLaughlin's 1998 cost estimate. However as with the issue of peak shaving above, the City's Planning Department, finished water flow data, and Xcel Energy must be involved in the early stages to fully assess the idea's practicality.

Variable Frequency Drives for the High Service Pumps

The existing high service pumps (four, 4-mgd nominal capacity) are constant speed, horizontal split-case pumps. They were provided with electrically-actuated, adjustable-speed discharge throttling valves in order to minimize pressure surges during startup and shutdown. A single 30-inch diameter check valve with 3-inch diameter bypass gate valve prevents backflow through the pumps, as well as cushioning check valve closure.

The system-head curves of the high service pumps and the range of operating pressures is believed to limit the turndown to about 10%. Additional information is required to confirm this assumption.

The BRWTP high service pumps pump serve Zone 1, which contains the 2 million gallon Gunbarrel Reservoir. Additional information is required to determine whether variable-frequency drives can be justified because the controlled startup and shutdown systems are inoperative, because Gunbarrel Reservoir does not provide sufficient storage for Zone 1 demand fluctuations, or both.

Alkalinity Adjustment

The City's public health protection measures for lead and copper are founded in water chemistry management. The two principal operational goals are:

- Finished water pH of 7.8 ± 0.2
- Finished water alkalinity ≥ 40 mg/L $CaCO_3$

Historical operating experience indicates that the pH goal is met approximately 60 percent of the time. Thirty-three percent of the time, the finished water is below the lower end (pH 7.6) of the goal operating range and 6 percent of the time, it is above the upper end (pH 8.0) of the range. Similarly, the finished water alkalinity falls below the operational goal on a frequent seasonal basis.

Accordingly, it is recommended that supplemental pH adjustment facilities be installed as part of the long-term improvements for the BRWTP. A chemical storage and metering system for caustic soda (NaOH) will both add alkalinity and increase pH. The requirement for lowering the pH is less obvious, with high pH excursions occuring only 6 percent of the time. For lowering the pH a carbon dioxide (CO_2) gas storage and feed system will be appropriate and cost effective.

Present Worth Analyses

Costs for the long-term improvements discussed above are presented in the table below.

Conceptual Design for Long-Term Improvements –Present Worth

Alternative		Cost	Installation Factor	Total Cost
MEMBRANES				
Construction Costs				
Membrane System Equipment		$4,480,000	Included	$4,480,000
Membrane System installation in Existing Structure[1]		$810,000	Included	$810,000
Electrical/I&C		$1,058,000	included	$1,058,000
	Subtotal			$6,348,000
Contingencies (20%)				$571,000
Overhead and profit (10%)				$2,076,000
	Construction Subtotal			$8,995,000
Operation and Maintenance Costs				
Total Annual O&M costs[2]				$256,000
	O&M Subtotal			$256,000
	Present Worth, O&M[3]			$2,707,000
	Total Present Worth			**$11,702,000**
OZONE DISINFECTION SYSTEM				
Construction Costs				
Ozone Contact Tank Structure		$1,968,000	Included	$1,968,000
Ozone System Equipment		$1,400,000	50%	$2,100,000
Ozone Building and Piping		$525,000	Included	$525,000
Ozone Pumping Station		$165,000	40%	$231,000
Electrical/I&C		$965,000	Included	$965,000
	Subtotal			$5,789,000
Contingencies (30%)				$1,737,000
Overhead and profit (10%)				$753,000
	Construction Subtotal			$8,279,000
Operation and Maintenance Costs				
Manpower[4]				$56,000
LOX[5]				$43,000
Power[6]				$38,000
	O&M Subtotal			$137,000
	Present Worth, O&M[7]			$1,451,000
	Total Present Worth			**$9,730,000**
UV DISINFECTION				
Construction Costs				
Civil[8]		$160,000	Included	$160,000
Yard piping		$150,000	Included	$150,000
UV Disinfection Facility		$1,070,000	Included	$1,070,000
Electrical/I&C[9]		$135,000	Included	$135,000
	Subtotal			$1,515,000
Contingencies (20%)				$450,000
Overhead and profit (10%)				$180,000
	Construction Subtotal			$2,145,000
Operation and Maintenance Costs				
Manpower[10]				$69,000
Chemicals				$10,000
Power[11]				$40,000
	O&M Subtotal			$119,000
	Present Worth, O&M[8]			$1,261,000
	Total Present Worth			**$3,406,000**

Conceptual Design for Long-Term Improvements –Present Worth

Alternative	Cost	Installation Factor	Total Cost
SPENT FILTER BACKWASH RECYCLE PRETREATMENT – LAMELLA-PLATE SETTLERS			
Construction Costs			
Piping	$48,000	Included	$48,000
Concrete	$75,000	Included	$75,000
Mixer/Flocculation	$150,000	Included	$150,000
Plates (SFB recycle plates only)	$250,000	Included	$250,000
Electrical/I&C	$105,000	Included	$105,000
Subtotal			$628,000
Contingencies (20%)			$126,000
Overhead and profit (10%)			$75,000
Construction Subtotal			$829,000
Operation and Maintenance Costs			
Manpower[13]			$15,000
Chemicals			$5,000
Power[14]			$4,000
O&M Subtotal			$24,000
Present Worth, O&M[15]			$254,000
Total Present Worth			**$1,083,000**

Notes:
[1]Based on 1-year construction period (270 workdays) for a $3,000/day construction crew.
[2]Power, chemicals, labor, and membrane replacement costs.
[3]Series Present-worth Factor (P/A, 7%, 20)=10.5940.
[4]Assumes 2 hrs/day average for operations and maintenance manpower at $85/hour.
[5]From PCI-Wedeco, based on $70/ton.
[6]From PCI-Wedeco, based on two generators operating to meet 20-mgd production at 10% concentration ($0.07/kW-hr).
[7]Series Present-worth Factor (P/A, 7%, 20)=10.5940.
[8]Civil cost assumes no imported embankment fill, no dewatering, no off-site hauling, no retaining walls, and no landscaping.
[9]Electrical does not include cost of new switchgear and new high-voltage power feeders from new main switchgear.
[10]Operation and maintenance of equipment; monitoring; cleaning, instrumentation, lamp replacement (total labor=$85/hr).
[11]$0.07/kW-hr.
[12]Series Present-worth Factor (P/A, 7%, 20)=10.5940.
[13]Operation and maintenance of equipment; monitoring; cleaning, instrumentation, flow control (total labor=$85/hr).
[14]$0.07/kW-hr.
[15]Series Present-worth Factor (P/A, 7%, 20)=10.5940.

Attachment A-6 – Pretreatment

MEMORANDUM

MWH

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dan Wetstein

Date: March 3, 2003

Reference: Boulder Reservoir WTP - Preliminary Design for Near-term Improvements

Subject: **Pretreatment**

Purpose

This Technical Memorandum (TM) summarizes DAF piloting results and evaluates pretreatment options at Boulder Reservoir WTP (BRWTP).

Historical Overview of Existing Operations and Process

The BRWTP was constructed in 1970 and consisted of coagulation, flocculation/sedimentation, a settled water contact basin (normally off line), filtration, disinfection, a filtered water reservoir, and high service pumping. The original design capacity was 8 mgd, and the plant is currently operated at 10-12 mgd.

The original plant was designed for single-stage hydraulic flash mixing using activated silica and alum. Soda ash could be applied to the settled water contact basin if necessary for alkalinity. Activated silica feed was abandoned shortly after the plant began operation, and soda ash was abandoned in 1997. A second-stage mechanical flash mixer was added downstream of the flume at that time as well. All pretreatment chemicals are currently added to the second stage. A coagulant polymer feed system and a caustic soda feed system were also installed in 1997. Although caustic soda was installed primarily to reduce copper solubility at BRWTP, it also adds alkalinity. The City recently (2002) began using ferric sulfate as the principal coagulant chemical at BRWTP. Polyaluminum chloride (Sumaclear 820B), cationic flocculent aids (Nalco 7199), or cationic coagulant aids (Nalco 8102) have occasionally been fed full-scale in conjunction with ferric coagulants.

The flocculation/sedimentation process consisted of a center feed, radial flow, 115-foot diameter, Type UC (*UniMix*) clarifier manufactured by Walker Process. The circular unit was installed in a square tank with corner sweeps. Water depth varies between 12.5 and 17 feet. The *UniMix* clarifier was designed for flocculation and clarification in a single tank. Two constant-speed, vertical-shaft mixers were installed in the 150,000-gallon flocculation zone, providing a *mean*

velocity gradient (*G*) value of perhaps 50 sec^{-1} at 6° C and a floc time of 27 minutes at 8 mgd. The resultant *Gt* of 8 x 10^4 at 8 mgd is theoretically reasonable. However the flocculation portions of the *UniMix* design were deficient in many other respects including number of stages, mixer tip speed, blade area/tank area percentage, and the blade diameter /equivalent tank diameter ratio. It also does not meet the Colorado Department of Public Health and Environment's (CDPHE's) 1997 *Design Criteria for Potable Water Systems* (*Design Criteria*) which requires a minimum three-stage tapered agitation process.

The surface loading rate of the *UniMix* at BRWTP is 0.54 gpm/ft^2 and the detention time is 3 hours at 8 mgd. BRWTP was originally designed as a hot-weather peaking plant and the criteria reflects this approach. The clarifier outlet consists of a single, square, cantilevered, double-sided V-notch-weir launder.

The existing pretreatment process at BRWTP has been evaluated on two previous occasions. The 1990 *Treated Water Master Plan* (Brown and Caldwell, 1990) recommended mechanical rapid mixing, recoating the flocculator/clarifier, installation of a bypass and new drain system, evaluation of plant hydraulics, and a flocculator/clarifier cover. With the exception of the bypass, all of these 1990-era recommendations have been made. Field hydraulic surveys were conducted in 1991 and revealed that at 12 mgd, the flocculator/clarifier V-notch weirs were overtopped and that a weir plate across the inlet end of the hydraulic jump caused the flume structure to overflow. The flocculator/clarifier launders and weirs were replaced in 1993, removing one of these restrictions.

The 2000 *Treated Water Master Plan* (Integra Engineering, 2000) recommended removal or bypassing the hydraulic flash mixer; construction of a new two-stage rapid mixing chamber (with Water Champs) closer to the clarifier; tube settlers; and relocation of the existing clarifier launders (to provide a uniform upward flow pattern through the tubes). The rationale for moving the rapid mixing chamber closer to the clarifier is unknown, and no flocculation improvements were identified. It is somewhat questionable whether tube settlers would have overcome the *UniMix's* inherent short-circuiting problems or have been reliably implementable. The bottleneck refers to the weir plate across the inlet end of the hydraulic jump, and all of the pretreatment options evaluated herein assume that the bottleneck (and existing flume structure) will be abandoned and bypassed. Several other sedimentation tank designs (solids contact, sludge blanket, ballasted flocculation) were not carried forward for evaluation herein following a July 2002 workshop.

Review of Existing Data/Pretreatment Goals

Raw water quality data have been previously presented in several recent technical memoranda and presentations and will not be repeated herein. In general, both surface sources occasionally have total organic carbon (TOC) concentrations greater than 4 mg/L, alkalinities less than 60 mg/L, and specific ultraviolet light absorbance (SUVA) less than 3 L/mg C-m^{-1}. The City has established a goal of 45 percent removal of TOC and the existing plant has 'shown greater than 45 percent removal of TOC during the summer months' (*Leopold Dissolved Air Flotation Pilot Report*, November 2002). However this performance is often difficult to sustain with colder, low-SUVA raw water which may not be amenable to enhanced coagulation. Recent pilot testing of dissolved air flotation (DAF) indicated that pH adjustment (acid addition) and alkalinity

supplementation would be necessary to reach this target with low-temperature Boulder Reservoir water.

The City has established turbidity goals for sedimentation of <1 ntu 90 percent of the time and <5 ntu at all times. Both surface water sources are subject to turbidity spikes (>200 ntu) due to high winds, heavy rains, or spent filter backwash return. Data from McGuire Environmental Consultants' *Prioritization Workshop* indicates that the City's settled water turbidity targets (<1 ntu, 90 percent; <5 ntu 100 percent) were exceeded 84 percent and 4 percent of the time, respectively, in 2000-2001. Given the shortcomings of flash mixing and *UniMix* mentioned above, the changes in coagulant chemistry, plus natural and manmade turbidity spikes, this result is not surprising.

The City has adopted the national secondary standards for iron (Fe) and manganese (Mn), which are occasionally exceeded in the raw water from Boulder Reservoir (BR). Although preoxidation is discussed elsewhere, the flotation/sedimentation options for pretreatment should remove a significant fraction of the Fe and Mn precipitates formed during preoxidation. Recent pilot testing of manganese removal with DAF indicated that the process removed virtually all of the particulate manganese.

Although the TOC/alkalinity goals cannot be consistently met year-round without additional chemical feed systems, it is apparent that pretreatment improvements could be made to meet the City's turbidity goals. These options are described below.

Pretreatment Options

General. The following assumptions have been used in developing pretreatment options:

- Firm capacity of the pretreatment facilities following all phases of construction will be 16 mgd. "Firm capacity" is defined as follows: Sufficient number of units will be provided such that with the largest unit out of service, the remaining units will have a capacity of 16 mgd. Short-term loss of a single flocculator will not require the entire flocculation train to be removed from service.
- Minimum flow = 5 mgd; average flow (20-year) = 10 mgd.
- For the present worth comparisons, a presedimentation process was included in all options. For the DAF and center-feed clarifier alternatives, the presedimentation process was assumed to be high-rate sedimentation using plates with polymer feed. For the lamella-plate settler option, it was assumed that the existing flocculator-clarifier could be successfully reused for presedimentation. (The DAF option was subsequently modified to include conventional presedimentation within a portion of the flocculator-clarifier.)
- Residuals, existing chemical feed systems, and standby power are not discussed. It was assumed that existing chemical feed piping could be extended to new flash mixing facilities under each option and that residuals would be conveyed by gravity to the existing 12-inch sludge line inside the flocculator-clarifier or underground to a point northwest of the Administration Building.
- No redundant raw water control valve(s) or meters will be installed for flow control.

- The existing influent flow tube vault will be abandoned under all options. A new mag meter will be installed.
- No backup pumps or injection nozzles for flash mixing will be provided. The plant will operate with single-stage flash mixing during outages of this equipment.
- Flocculation trains and sedimentation/flotation processes are paired; *i.e.*, there is no intermediate connection between the two processes.
- Geotechnical conditions for all new construction will be similar to existing.
- No insurmountable structural difficulties will be encountered to preclude modifications to the existing flocculator/clarifier.
- No hydraulic improvements to existing facilities are required to accommodate the pretreatment options. New plant overflows would be required for either center-feed or lamella-plate sedimentation.
- Provisions will be made for future connection of BRWTP to the Southern Water Supply Project, pH adjustment (acid feed), supplemental alkalinity, and membranes, but not additional pretreatment.

Option 1 – Center-feed Clarifiers. This option was carried forward from the July 2002 workshop and represents an extension of the existing pretreatment process. The following design parameters were used:

- Pumped jet diffusion flash mix (two-stage). Gt = 400 to 1,600 sec/sec, each stage.
- Three-stage flocculation (three trains). T_D = 40 minutes at 5° C.
- Sedimentation (three circular clarifiers). Surface loading rate = 0.54 gpm/ft^2.

Site layout of this option is presented in **Figure 1**. For costing purposes, it was assumed that the flash mix and flocculation process would be housed in block-and-brick structures similar to existing, and the clarifiers would be housed in subdued, low profile architectural domes.

Option 2 –Lamella-plate Settlers. The following design parameters were used:

- Pumped jet diffusion flash mix (two-stage). Gt = 400 to 1,600 sec/sec, each stage.
- Three-stage flocculation (three trains). T_D = 40 minutes at 5° C.
- Lamella plate settlers (three trains). Surface loading rate = 0.30 gpm/ft^2 (based on horizontal projected area)

Site layout of this option is presented in **Figure 2**. It was assumed that all processes would be housed in block-and-brick structures. The plate settlers would be stainless steel, either cable-operated (ClariTrac-type) or reciprocating wedge (Parkson SuperScrapers) submerged sludge collectors would be provided.

Option 3 – DAF. The following design parameters were used:

- Pumped jet diffusion flash mix (two-stage). Gt = 400 to 1,600 sec/sec, each stage.
- Two-stage flocculation (three trains). T_D = 24 minutes at 20 mgd.
- Flotation tanks (three trains). Surface loading rate = 3.5 gpm/ft^2

Site layout of this option is presented in **Figure 3**. Redundant recirculation systems (saturator tanks, pumps) would be provided, all sized to handle the entire plant flow. All processes would be housed within the existing flocculator/clarifier basin and reaction basin.

DAF was piloted during November-December 2002 by F.B. Leopold Company (Leopold), Ondeo Degremont (Ondeo), and Parkson Corporation (Parkson). Pilot testing was mandatory for selection. Following pilot testing, each manufacturer was to prepare a cost proposal. To date, no proposals have been received. However, Leopold and Parkson have submitted reports and the City has prepared a memorandum entitled *DAF Piloting Observations and Design Issues* (*DAF Observations*). Based on these documents, the following comments could be made:

- *DAF Observations* suggested that the DAF units encountered few problems up to a raw turbidity of 50 ntu, but higher turbidity waters required large amounts of coagulant to maintain performance. Leopold's report claimed DAF effluent turbidities of "...less than 1.0 ntu with raw water turbidities up to 200 ntu", and Leopold apparently never fed more than about 35 mg/L ferric sulfate, not a particularly large dosage. There was relatively little data with raw water turbidities between perhaps 25 and 150 ntu to substantiate either interpretation. It might be more accurately stated that adding polymer enabled the DAF pilots to maintain DAF effluent turbidities of less than 2.0 ntu with raw water turbidities up to 200 ntu, which did not definitively impact filter effluent turbidities or particle counts.
- A large portion of both Leopold's and Parkson's pilot studies was devoted to optimizing the coagulation chemistry. Leopold's best results were achieved with ferric sulfate at a pH between 5.5 and 6.0, followed in order of performance by Sumaclear with ferric sulfate and Sumaclear alone. Parkson was directed not to pilot ferric coagulants alone and conducted most of its piloting with alum, Sumaclear, or some combination. Parkson's best results were achieved with 40-50 mg/L of alum.
- As noted by others, the DAF process works better with high-energy mixing and shorter mixing periods. Leopold's piloting was primarily done at *G*-values of 100 sec^{-1} in the first stage, 30-90 sec^{-1} in the second stage, and 24 minutes total flocculation time for a *Gt* of 1.15×10^5 at 6° C; perhaps twice the energy input needed for conventional sedimentation. Most piloting was run at loading rates of 4-4.4 gpm/ft^2 and 11 percent recycle. Parkson's pilot was primarily done at *Gt*'s of about 4.8×10^4, about half of Leopold's.
- DAF performed very well with color and particulate manganese removal.
- *DAF Observations* suggests that the current practice of recycling untreated filter backwash at excessive return rates upset the coagulant process when using alum during periods of high raw water turbidity. These pump-backs of spent filter backwash had less of an effect with ferric and almost no effect during normal turbidity periods.

Present Worth

Costs for the three options are presented in the table below.

Preliminary Design for Near-term Improvements – Pretreatment Options Present Worth

Alternative		Cost	Installation Factor	Total Cost
OPTION 1 – CENTER-FEED CLARIFIERS				
Construction Costs				
Civil[1]		$300,000	Included	$300,000
Yard piping		$150,000	Included	$150,000
Presedimentation		$1,255,000	Included	$1,255,000
Flash mix		$150,000	Included	$150,000
Flocculation		$1,000,000	Included	$1,000,000
Clarifiers		$3,000,000	Included	$3,000,000
Electrical/I&C		$1,171,000	included	$1,171,000
	Subtotal			**$7,026,000**
Contingencies (20%)				**$2,297,000**
Overhead and profit (10%)				**$632,000**
	Construction Subtotal			**$9,955,000**
Operation and Maintenance Costs				
Manpower[5]				$33,000
Chemicals[6]				$450,000
Power[7]				$10,000
	O&M Subtotal			**$493,000**
	Present Worth, O&M[8]			**$5,223,000**
	Total Present Worth			**$15,178,000**
OPTION 2 – LAMELLA PLATE SETTLERS				
Construction Costs				
Civil[1]		$180,000	Included	$180,000
Yard piping		$100,000	Included	$100,000
Presedimentation		$70,000	Included	$70,000
Flash mix		$150,000	Included	$150,000
Flocculation		$1,000,000	Included	$1,000,000
High-Rate Sedimentation		$2,200,000	Included	$2,200,000
Electrical/I&C		$740,000	included	$740,000
	Subtotal			**$4,440,000**
Contingencies (20%)				**$1,452,000**
Overhead and profit (10%)				**$400,000**
	Construction Subtotal			**$6,292,000**
Operation and Maintenance Costs				
Manpower[5]				$33,000
Chemicals[6]				$450,000
Power[7]				$10,000
	O&M Subtotal			**$493,000**
	Present Worth, O&M[8]			**$5,223,000**
	Total Present Worth			**$11,515,000**
OPTION 3 – DAF				
Construction Costs				
Civil[1]		$200,000	Included	$200,000
Yard piping		$100,000	Included	$100,000
Presedimentation		$1,255,000	Included	$1,255,000
Flash mix		$50,000	Included	$50,000
Flocculation		$500,000	Included	$500,000
DAF		$1,500,000	Included	$1,500,000
Electrical/I&C		$721,000	included	$721,000
	Subtotal			**$4,326,000**
Contingencies (20%)				**$1,415,000**
Overhead and profit (10%)				**$389,000**
	Construction Subtotal			**$6,130,000**

Preliminary Design for Near-term Improvements – Pretreatment Options Present Worth

Alternative	Cost	Installation Factor	Total Cost
Operation and Maintenance Costs			
Manpower[5]			$105,000
Chemicals[6]			$365,000
Power[7]			$35,000
O&M Subtotal			**$505,000**
Present Worth, O&M[8]			**$5,350,000**
Total Present Worth			**$11,480,000**

Notes:
[1]Civil cost assumes no imported embankment fill, no dewatering, no off-site hauling, no retaining walls, and no landscaping.
[2]Operation and maintenance of equipment; monitoring; cleaning, instrumentation, flow control (total labor=$30/hr)
[3]Ferric sulfate at $0.08/lb (delivered), Sumaclear at $0.45/lb (delivered). Dosage 45 mg/L ferric (dry weight)/7 mg/L Sumaclear. Assumed dosage is 15 mg/L ferric (dry weight) and 15 mg/L Sumaclear.
[4]$0.07/kW-hr.
[5]Series Present-worth Factor (P/A, 7%, 20)=10.5940.

Nonmonetary Evaluation

A non-economic evaluation scoring matrix was distributed to each of the addresses of this TM before Option 2-Lamella-plate Settlers was added to the evaluation. Responses for the other two options were received from City staff, summarized, and presented during a February 3, 2003, workshop. The results are summarized in the following table.

Non-Economic Evaluation Scoring Summary

Evaluation Criteria	Average Weight Factor	Averaged Weighted Scores: DAF	Averaged Weighted Scores: Upgrade Existing
Compatibility with future changes	3.9	15.7	11.2
Reliability	5.0	17.8	17.2
Constructability	2.9	12.4	5.9
Safety	3.6	12.7	12.2
Security	3.0	9.9	8.8
Operational complexity	4.2	10.8	17.0
Impact on plant hydraulics	3.0	7.4	8.1
Aesthetics	2.2	7.4	5.8
Water quality/performance	4.9	17.3	11.3
Planning process	4.0	2.4	1.8
Average Total Score		**114**	**99**

Note:
Averages based on a total of nine participants.

The following observations regarding the nonmonetary evaluation could be made:

- Based on this set of nonmonetary criteria and weighting, the highest point total (and most desirable option) was DAF, which scored higher than center-feed clarifiers in 8 of the 10 categories—notably higher in "water quality/performance," "compatibility with future changes," and "constructability." There is perhaps some overlap between "water quality/performance" and "compatibility with future changes," which represents some double accounting for this factor. Water quality/performance was also one of the most important nonmonetary factors to all respondents, and DAF clearly rated higher in this category.

- Center-feed clarifiers scored better than DAF in "operational complexity" and "impact on plant hydraulics." Differences in operational and maintenance complexity were also accounted for in the present worth analyses (which represents some double accounting for this factor), and plant hydraulics have not yet been performed. It is presumed that all three options are hydraulically similar and that none would seriously impact plant hydraulics.
- There was rather consistent agreement among the respondents regarding the weighting factors to be assigned to the categories with two exceptions, "security" and "aesthetics." In the end neither category proved statistically important.

Recommendations

Based on the monetary and nonmonetary comparisons above, the following conclusions can be made:

- Expanding BRWTP pretreatment to 16-mgd firm capacity with center-feed clarifiers would cost significantly more, about $3,750,000 in today's dollars, than either of the other two options. The 20-year present worth value of center-feed clarifiers would be about 30 percent more than either of the other two options. Center-feed clarifiers are the least process-stable, least robust of the three options selected for this evaluation. For these reasons, Option 1-Center-feed Clarifiers is not recommended as a long-term expansion option at BRWTP. It should be noted that the major advantage of center-feed clarifiers is associated with their sheer size. The large surface areas and detention times would dampen flow surges, minimize level changes due to flow variations, and provide additional pre-filtration *CT* credit. These potential advantages are discussed below.

  Flow surges using BFC raw water were formerly associated with backwashing BRWTP when the process contained only two filters, as well as from flow adjustments due to sudden turbidity spikes. The backwashing problem was alleviated in 1997 by the addition of two filters. The turbidity spikes from the BFC could be mitigated by a combination of better online instrumentation (flow meter and streaming current detector), automated chemical dosing, improved flocculation, and spent filter backwash mixing. Remote monitoring of the BFC and a new presedimentation process would also provide early warning of turbidity spikes and remove a portion of the spike.

  Flow surges using BR water could be mitigated by installing variable frequency drives on the raw water pumps.

  The specific reasons for preoxidizing using free chlorine at BRWTP have never been manifestly clear, and moving the point of initial chlorination downstream has been recommended since at least the 1990 *Treated Water Master Plan* cited above. Therefore obtaining additional *CT* credit for disinfection is not a primary rationale for center-feed clarifiers.

- The major advantage of Option 2-Lamella-plate Settlers appears to be the fact that, under the assumptions made above, the existing flocculator-clarifier could be reused for presedimentation. However, the surface loading rate at 20 mgd would be 1.1 gpm/ft^2, twice the 0.5 gpm/ft^2 assumed for presedimentation under Options 1 and 3 and almost four times the 0.3 gpm/ft^2 assumed for settling typical floc at BRWTP. Thus the performances and construction cost comparisons among options would not be considered strictly identical. The existing flocculator/clarifier would not perform to the same levels as a custom-designed plate settling unit. However, it is a highly cost-effective approach.

  Because plates were not included in the present non-economic evaluation scoring matrix, it is not known where they would rank with center-feed clarifiers and DAF in terms of City staff preferences. For purposes herein, MWH has assumed that DAF at BRWTP will require three times as much O&M as plates. The total operating costs remain comparable among options due to the fact that chemicals are several times as expensive as labor, and sedimentation at BRWTP currently requires more chemicals than did the DAF pilot.

- Advantages of DAF include the following: (a) it provides better water quality and was determined to be more compatible with future changes than center-feed clarifiers; (b) it removes algae better than plates or center-feed clarifiers; (c) it requires a shorter flocculation period than plates or center-feed clarifiers; (d) it typically produces a thicker sludge than plates or center-feed clarifiers; (e) it is the least expensive alternative, from both a capital-cost and a present-worth point of view; (f) it was piloted at BRWTP by all of the leading DAF manufacturers; and (g) DAF might be installed in the existing flocculator-clarifier building. Based on limited data, it is possible that DAF may also remove color and manganese better than plates or center-feed clarifiers, allow BRWTP to achieve 3.5-log removal of particles, and lower raw water turbidity from 200 ntu to less than 2 ntu with polymer addition.

- There are several questions and possible drawbacks with DAF that should be noted. DAF has more equipment (recirculation systems) to operate and maintain than plates or center-feed clarifiers. Therefore, more operator attention may be required and staffing may become an issue at some point in the future.

  There may be minor regulatory issues with DAF. CDPHE's *Design Criteria* does not mention DAF, and certain aspects of DAF flocculation are different than flocculation for gravity sedimentation. Although DAF was approved for treating spent filter backwash at Betasso, the extent of CDPHE's review and approval process for DAF pretreatment are currently unknown. MWH has contacted CDPHE regarding this project, and no major difficulties are anticipated with the review and approval process. CDPHE suggests that an informal kick-off meeting be scheduled to begin that process.

  Structural issues surrounding new DAF loads to the existing flocculator-clarifier piles and slab may become prohibitively expensive or insurmountable. It appears that, because the footprint would be smaller and because the equipment would be

no more costly, DAF would be less expensive than plates even if a new building were required to house it.

Pending structural design, DAF (**Figure 3**) is recommended for pretreatment at BRWTP.

Phasing and Procurement

The City's limited budget precludes immediate construction of the entire $6.2 million project shown in **Figure 3**. It is therefore recommended that civil and yard piping work, flash mix, and two of the three DAF trains be constructed under this project and that presedimentation and the third DAF train be deferred pending future budgeting. The cost of this near-term work would be approximately $3,000,000. At a 10-minute flocculation time and 5-gpm/ft^2 surface loading rate in the float tank, each DAF train could treat 12 mgd, giving the BRWTP a total (interim) installed capacity of 24 mgd and a firm (interim) capacity of 12 mgd for pretreatment. Scale-up from piloting is always subject for discussion; however there are limited data to suggest that DAF could meet the City's settled water turbidity goals at these loadings with proper coagulant addition and warmer BFC water, even with 150 ntu raw water turbidity spikes.

It is recommended that the City proceed with structural design of the settled water contact (reaction) basin and flocculator-clarifier modifications in order to (a) determine feasibility of loading the existing foundation with new walls and DAF equipment and (b) prepare drawings to accompany the City's procurement bid package. It is recommended that the procurement package be given to Leopold and Parkson. It is also recommended that consideration also be given to procuring the flocculators.

The DAF equipment bid package should consider adding the DAF design features listed in *DAF Observations*:

- PVC or CPVC piping
- Stainless steel fasteners
- Cone-shaped bottom with drains on floc basins (may impact structural design)
- Bottom of DAF basin sloped to drain (no impact on procurement)
- Air lines to be approved PVC
- All valves to be stainless steel
- Fixed ladders in all chambers (not procured)
- Catwalks (walkways) on all equipment (not procured)
- Air saturator tanks to be stainless steel
- Reciprocating air compressors to match Betasso WTP
- Sludge pumps to match Betasso WTP equipment (not procured)
- Sludge trough in the floc basins to decant floating sludge accumulation
- Hach-style turbidimeters on raw water and DAF effluent (not procured)
- Constant level on the beach
- Maximum practical depth for the DAF chamber to minimize bubble carryover

MWH will obtain more feedback from the City regarding the cone-shaped bottoms on floc basins and discuss ideas regarding controlling level on the beach. The cone-shaped flocculation basins may become problematic from a structural point of view or, even a flocculation-time point of

view. It may be possible to allow floating sludge to pass through the floc basins to the float tank, and sludge pumps may not be needed if hydraulically or mechanically assisted hydraulic float removal is employed.

It is recommended that an informal kick-off meeting be scheduled with CDPHE in the near future and that structural drawings and DAF (perhaps also flocculator) specifications be prepared for procurement of at least two trains of pretreatment, with the third train bid as an additive alternate.

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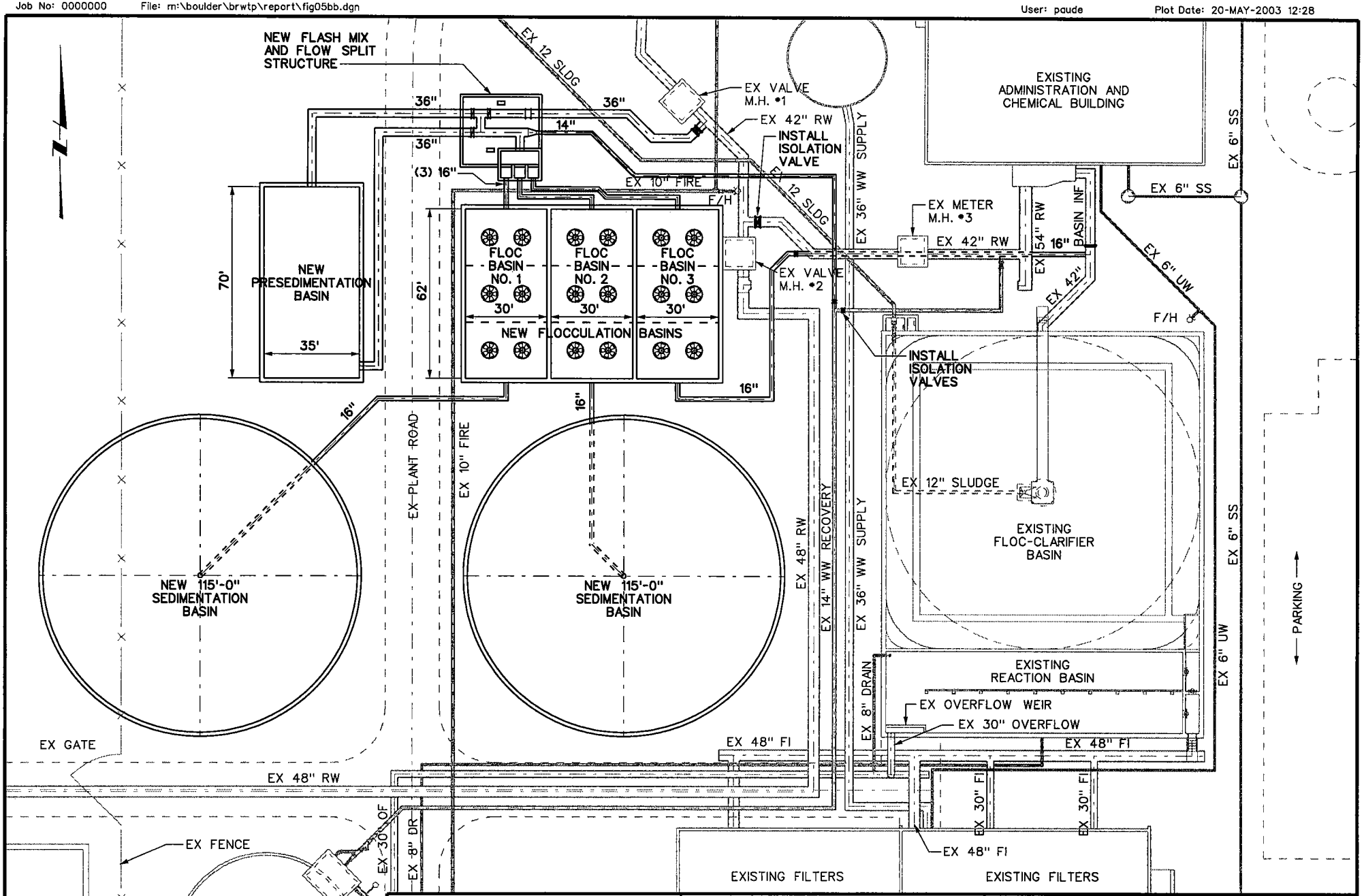

Denver Colorado

MWH
MONTGOMERY WATSON HARZA

CITY OF BOULDER, COLORADO
BOULDER RESERVOIR
WATER TREATMENT
PLANT IMPROVEMENTS

OPTION 1
UPGRADE EXISTING
PRE-TREATMENT
(WITH PRE-SED)

FIGURE
1

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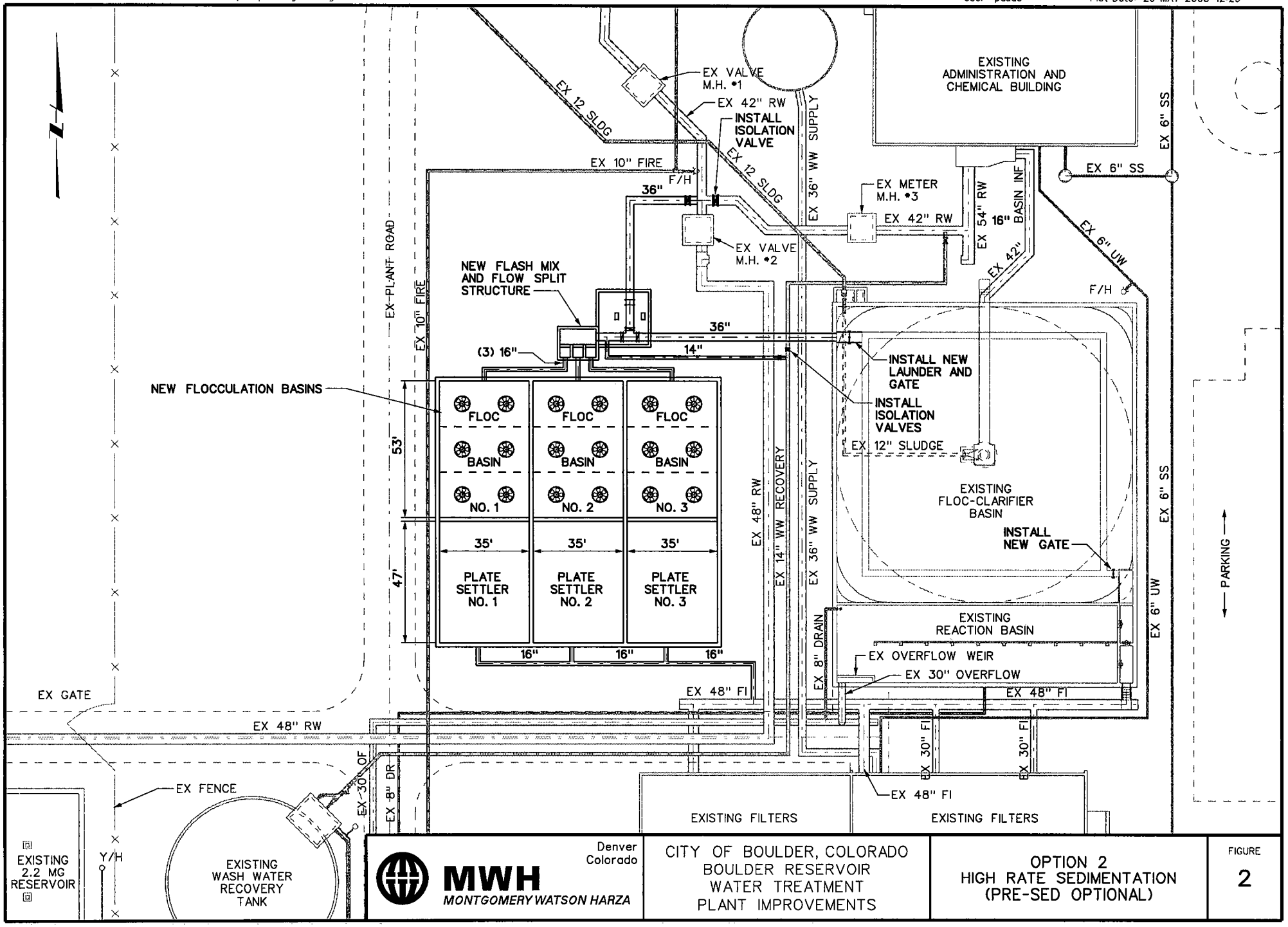

Denver Colorado

MWH
MONTGOMERY WATSON HARZA

CITY OF BOULDER, COLORADO
BOULDER RESERVOIR
WATER TREATMENT
PLANT IMPROVEMENTS

OPTION 2
HIGH RATE SEDIMENTATION
(PRE-SED OPTIONAL)

FIGURE
2

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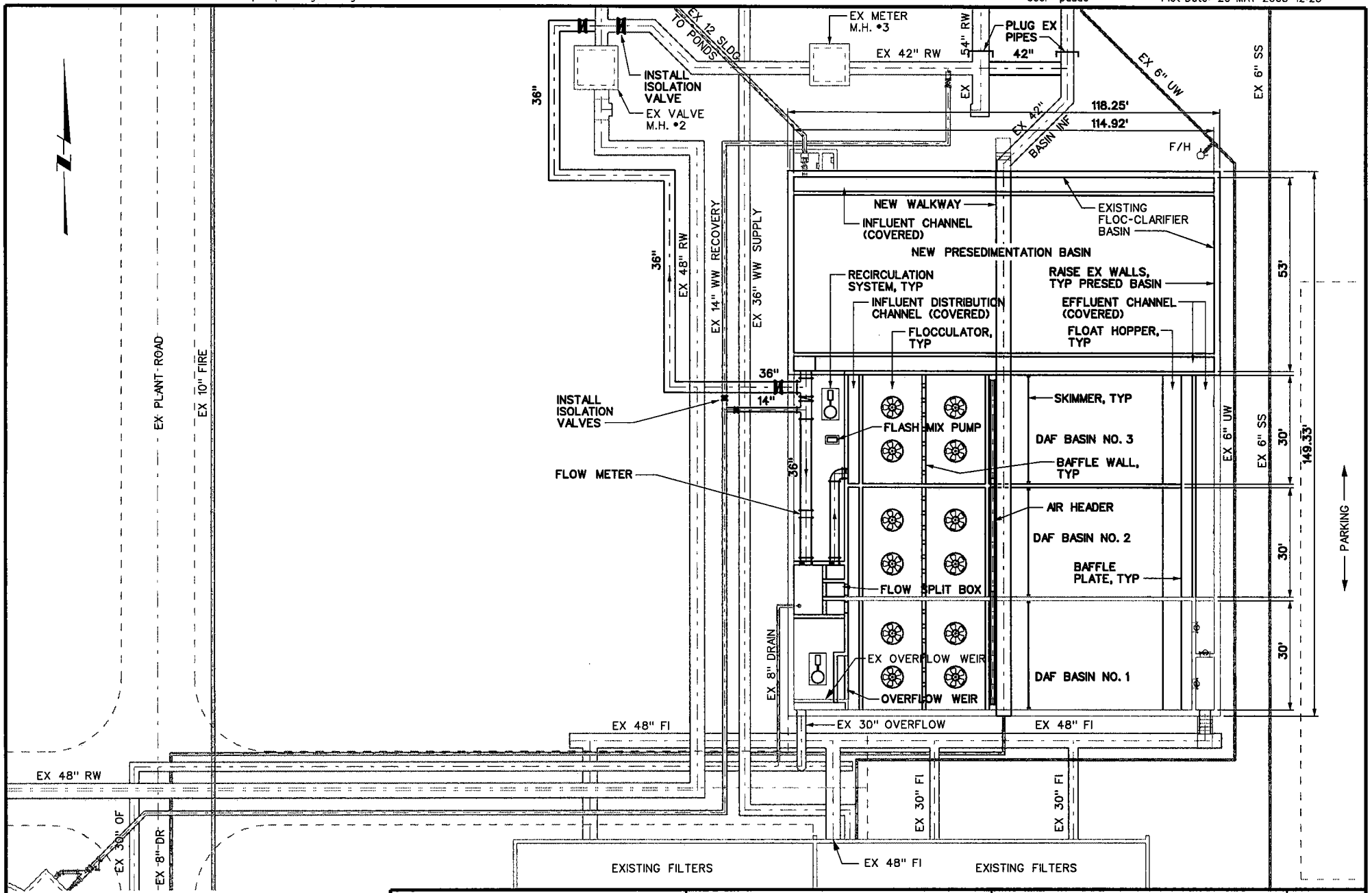

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CITY OF BOULDER, COLORADO
BOULDER RESERVOIR
WATER TREATMENT
PLANT IMPROVEMENTS

OPTION 3
DISSOLVED AIR FLOTATION
(WITH PRE-SED)

FIGURE
3

Attachment A-7 – Raw Water Conveyance – Task A8

MEMORANDUM

MWH

integra engineering

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Bob Bolton

Date: January 25, 2003

Reference: Boulder Reservoir WTP--Preliminary Design for Near-term Improvements

Subject: **Raw Water Conveyance – Task A8**

Purpose

The purpose of this Technical Memorandum is to present the results of an analysis of the capacities of the raw water delivery systems for the City of Boulder's Boulder Reservoir Water Treatment Plant (BRWTP). The results of this analysis will be used in planning for expansion of the BRWTP treatment capacity to 20 mgd.

Background

Boulder Reservoir was constructed to store water diverted from the western slope of Colorado by the Colorado-Big Thompson and Windy Gap transmountain diversion projects. The BRWTP was constructed in 1971 to treat water from this source to meet peak demands during the high water use summer season. Water is conveyed to Boulder Reservoir from Carter Lake west of Loveland by the Boulder Feeder Canal (BFC). Initially, water was delivered to the plant by gravity from a diversion point on the BFC and the plant could be operated only during the months when water was running in the canal, generally April through October. In the early 1980s a pump station was constructed to deliver water to the plant from Boulder Reservoir, which provided for year round operation. The City of Boulder is in the process of planning for expansion of the BRWTP to a capacity of 20 mgd. As part of that planning effort it is necessary to determine whether any improvements to the raw water conveyance systems will be required to provide a firm 20 mgd raw water supply from both the Boulder Reservoir Raw Water Pump Station and the Boulder Feeder Canal gravity system. To determine the need for and scope of improvements required to meet the proposed 20 mgd treatment capacity, this investigation included collecting and reviewing drawings and other available information on the existing facilities and hydraulic modeling of both existing raw water supply systems.

Existing Facilities

Raw water can be conveyed to the BRWTP by gravity from the Boulder Feeder Canal or by pumping from Boulder Reservoir. Figure 1 presents a schematic overview of the BRWTP raw water delivery system. As can be seen, the two systems interconnect at a point near the plant and

a single pipe extends to the inlet flume structure on the south side of the Administration Building. With existing instrumentation and controls, this interconnection precludes operating by gravity and pumping at the same time.

The common section of pipeline extends approximately 110 feet from the point of interconnection as 42-inch size and increases to 54-inch size immediately before terminating at the flume structure. The common pipeline section also includes a 30-inch venturi-type flow meter that was originally intended to measure plant influent flow and provide for automatic control of flow rate by adjusting motor operated butterfly valves in each supply line upstream from the interconnection point. However, the flow meter is not currently used because plant operating staff considered it to be inaccurate and installed a weir plate in the flume box to measure plant flow. This arrangement causes the flume structure to overflow at flow rates greater than about 12 mgd.

Water is diverted from the Boulder Feeder Canal into the gravity system by an intake structure at the canal and conveyed to the plant via approximately 5,560 feet of 42-inch pipe. The intake structure includes a coarse trash rack and a 48-inch square sluice gate.

Water is conveyed from Boulder Reservoir to the Raw Water Pumping Station (RWPS) via an intake structure and approximately 330 feet of 48-inch pipe. Immediately before entering the pump station suction piping, water passes through a 30-inch automatic self-cleaning strainer. The pumping station contains three vertical turbine pumps of two different sizes installed in a "can" type arrangement. Pump data are shown in **Table 1**.

Table 1 – Raw Water Pump Data

Pump No.	Motor Horsepower	Design Flow, mgd	Design Head, ft
1	25	4	28
2	50	8	29
3	50	8	29

The pumps discharge into a 48-inch main approximately 1,360 feet in length that connects to the 42-inch gravity line from the BFC upstream from the flume structure as described above. The pumps run at a constant speed, and, since the venturi-type flow meter is not in use, the flow rate is controlled by selecting the combination of large and small pumps to run, and by manually adjusting the 36-inch motor operated butterfly valve located in a vault a short distance upstream from the point of connection of the pumped main to the gravity line.

Gravity System Hydraulic Analysis

System operating parameters and basic assumptions used in modeling the gravity feed system are shown in **Table 2**. In general, conservative values were used. Losses associated with the intake structure include the 48-inch-square sluice gate and a flared entrance to the 42-inch pipe. Because the range of operating levels in the canal is not known, the elevation of the canal invert was used as the minimum water surface elevation for purposes of this evaluation. Similarly, since the flume structure may be modified as part of the plant expansion to improve the flash mixing operation, the elevation of the top of the flume structure was used as the water surface

elevation of the point of discharge to eliminate uncertainties in the future operating water surface level.

Table 2 – Gravity Feed System Operating Parameters

Parameter	Value	Comments
WSEL[1] at canal intake structure	5208.3	Canal invert
WSEL at pipeline discharge	5192.5	Operating floor at flume structure
Available head, ft H_2O	15.8	–
Pipe Hazen-Williams roughness coefficient, "C"	120	Corresponds to a Manning's "n" of 0.012

[1]WSEL = water surface elevation

Table 3 shows the calculated hydraulic head required to deliver various flow rates from the canal to the BRWTP. Based on these results, the available head of 15.8 feet would be capable of delivering nearly 35 mgd to the plant. With approximately 5.6 feet of head theoretically required to convey 20 mgd to the plant from the canal, 10 feet of excess head is available, indicating that the existing system should be capable of conveying the desired plant flow without modification. It should be noted that, although this analysis does not include an allowance for losses through the trash rack (clean condition), it does assume a minimum possible water surface at the canal and a maximum possible water surface at the discharge point, and is therefore conservative.

Table 3– System Head Requirements

Flow, mgd	Head Required, ft H_2O
0	0.0
5	0.4
10	1.6
15	3.3
20	5.6
25	8.5
30	12.0
35	15.9

Pumped System Hydraulic Analysis

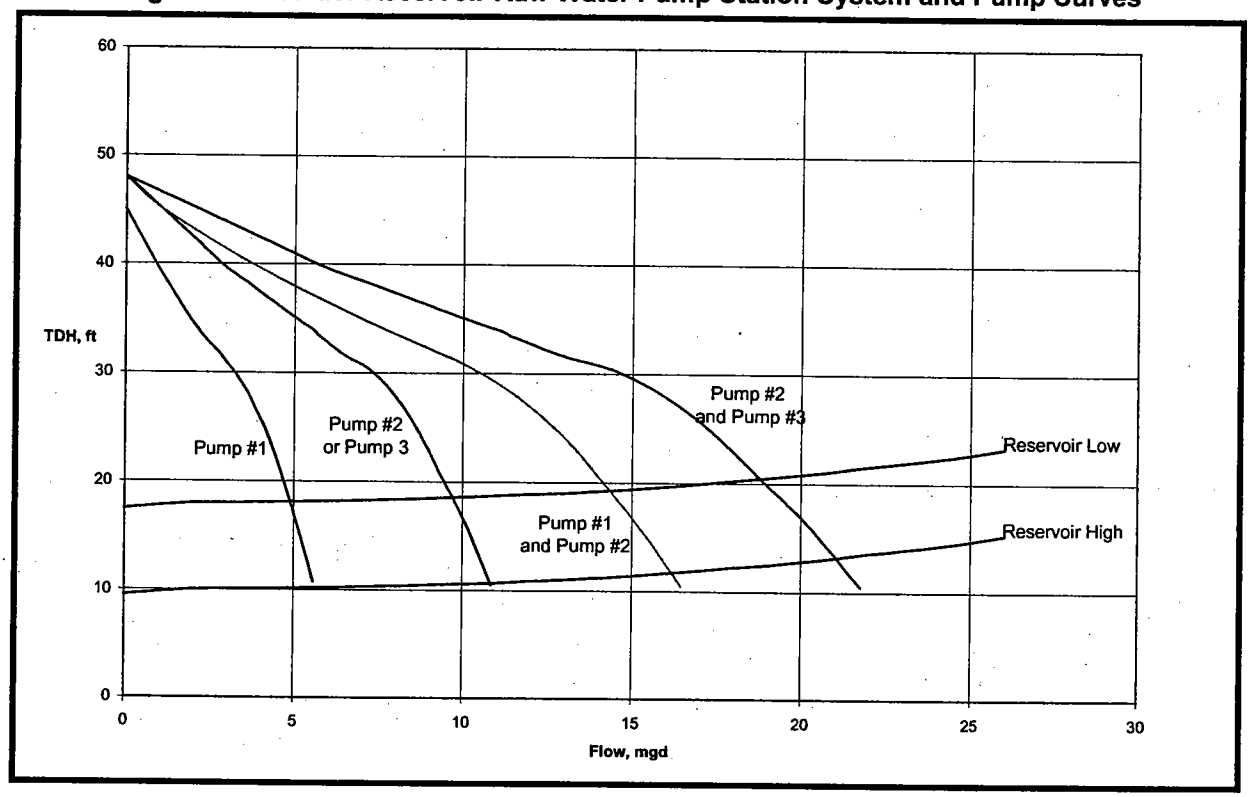
System operating parameters and basic assumptions used in modeling the pumped raw water supply system are shown in **Table 4**. As with the gravity system analysis, conservative values were used. Losses associated with the suction side of the pumping system include the intake structure entrance loss, various fitting losses, and losses associated with the RWPS suction side strainer. The system was modeled with the flow control valve wide open to establish the maximum possible flow with the existing equipment.

Table 4 – Raw Water Pumping System Operating Parameters

Parameter	Value	Comments
Maximum reservoir WSEL at intake structure	5183.0	Information provided by City of Boulder
Minimum reservoir WSEL at intake structure	5175.0	Information provided by City of Boulder
WSEL at pipeline discharge	5192.5	Operating floor at flume structure
Maximum system static head, ft	17.5	–
Minimum system static head, ft	9.5	–
Pipe Hazen-Williams roughness coefficient, "C" used	110	–

Figure 1 shows the system-head curves for the pumped raw water system with the reservoir at maximum and minimum levels. Performance curves for the existing pumps have been superimposed on the system-head curves to establish the existing pumping capacity. The pump curves shown have been modified to account for in-station losses. As can be seen, the maximum theoretical flow possible with the two large pumps running in parallel varies between 18.7 and 21.0 mgd depending on the reservoir water surface elevation. With one large pump off-line and the small pump running in parallel with the remaining large pump, maximum possible flows vary between 14.3 and 16.2 mgd depending on the reservoir water surface elevation. Therefore the firm capacity of the pump station is approximately 15 mgd at this time.

Figure 1 – Boulder Reservoir Raw Water Pump Station System and Pump Curves



Required Improvements

Gravity System

The results of this analysis indicate that the theoretical capacity of the gravity system is 35 mgd. Thus, the Boulder Feeder Canal gravity system is capable of providing 20 mgd to the BRWTP without modification. However, these results are based on the pipeline being in good condition without deterioration or accumulation of sediments that would restrict flow, an assumption that has not been verified. The pipeline is more than a mile long and has no manholes or other means of access except at either end. As a result, past attempts to inspect the pipeline, either by physical entry or closed circuit television, have been unsuccessful. A complete inspection of the pipeline would require creating a number of access openings at approximately 500 foot intervals from where the pipe could be entered and inspected, and cleaning and repairs could be carried out as

needed. Before a project of this scope is undertaken, assessing the condition of the pipeline by indirect means should be attempted.

If sediments have accumulated in the pipeline it is likely that the bulk of the material has settled in the low points along the line. As a result the general condition of the pipeline could be initially evaluated by opening the blow off valve at the low point of the line under the Boulder Creek Supply Canal. If the water released was observed to be clean it could be concluded that sediment accumulation is not a significant problem. The observance of considerable sediments in the blow off stream would indicate the potential need to clean the pipeline.

After the initial assessment of the presence of accumulated sediments is made by opening the blow off, the overall condition of the pipeline could be further verified by measuring the pressure drop in the pipeline at various flow rates. Close agreement of actual head loss with the theoretical would indicate that the pipeline was in good condition, free from serious deterioration or capacity restricting sediment buildup. Large divergence of operating head loss from calculated estimates would indicate that physical inspection would be needed to identify the cause. For flow rates up to 12 mgd, field tests could be accomplished by passing water through the plant in the normal fashion and making simultaneous measurements of the water surface elevations at the canal diversion structure and the flume to determine the actual head loss at each flow rate. To test flow rates above 12 mgd, the raw water pump station could be used. By inserting a temporary plug in the inlet line at the flume structure and opening the gravity line control valve, flow could be pumped backward through the gravity line to the BFC. Noting the pump discharge pressure at a given flow rate would allow the hydraulic losses in the pipeline to be estimated.

If the hydraulic tests indicate that further inspection is needed, access openings would need to be made to permit entry into the pipeline. The first access openings should be located immediately downstream from the siphons under the Bypass and Boulder Creek Supply canals. This will permit inspection and remediation in the low points of the line, which are the most probable problem areas, before moving on to inspect the remainder of the pipeline. After any cleaning or repairs at these points, retesting of hydraulic losses in the pipeline would be conducted before moving to other inspection sites.

Pumped System

The existing raw water pump station can, with both large pumps in service, deliver the required 20 mgd to the plant. However, the firm capacity of the pump station is approximately 15 mgd with one large pump out of service. To increase the pumped system firm capacity to 20 mgd an additional large pump will need to be provided. As the pump station was designed with space and piping connections for two additional pumps, and the 20 mgd (13,900 gpm) design peak flow rate is well within the design range of the existing strainer, this capacity upgrade can be accomplished without major modification to the pump station. A budget level estimate of the cost for providing an additional large pump is shown in **Table 5**. This estimate assumes that the existing electric power supply to the pump station has sufficient capacity for the additional pump. It also assumes that the new pump would be constant speed, although the City may want to consider installing variable frequency drives to provide more precise flow control and better energy efficiency than throttling with a control valve.

Table 5 – New Raw Water Pump Budgeting Cost

Item	Material Cost	Installation Cost	Total Cost
Pump and motor	$40,000	$16,000	$56,000
18-inch butterfly valve	$5,500	$1,500	$7,000
2-inch air/vacuum valve	$1,200	$500	$1,700
Miscellaneous Piping	$10,000	$5,000	$15,000
Electrical (15%)			$8,500
Subtotal			**$88,200**
Contingency (25 %)			$22,000
Subtotal with Contingency			$110,200
Contractor overhead and profit (15%)			$16,500
Total Project			**$126,700**

Flow Measurement

Plant flow is currently measured by a weir plate installed across the inlet end of the Parshall flume in the flume structure. This arrangement causes the flume structure to overflow at flow rates above about 12 mgd. Obviously, this condition will need to be eliminated for the plant to operate at 20 mgd. As part of the plant expansion currently being planned it is anticipated that the flume structure will be modified to improve the flash mix operation. Along with this process improvement, rehabilitation or replacement of the existing 30-inch venturi flow meter would restore accurate flow measurement and eliminate the hydraulic restriction created by the weir.

References

The following project drawings and information were used to establish pumping system and gravity flow operating parameters:

Boulder Reservoir Auxiliary Outlet, R.J. Tipton and Associates, Inc. and Phillips-Cater-Osborn, Inc. Drawings, 1062-19, 1062-20, 1062-21, 1092-22 and 1062-23, February 1954.

Boulder, Colorado, Boulder Reservoir Water Treatment Plant Raw Water Pumping Station, Contract 39, Black and Veatch Consulting Engineers, Denver CO – Kansas City, MO, 1981.

Boulder, Colorado, Water Works Improvements, Water Treatment Plant, Contract 19, Black and Veatch Consulting Engineers, Denver CO – Kansas City, MO, January, 1969.

Certified pump curves for existing raw water pumps. Aurora Pump Corp., 1982.

Manufacturer's information on raw water pump station strainer. S.P. Kinney Engineers, Inc., 1982.

Attachment A-8 – Reservoir Contact Time Improvements

MEMORANDUM

MWH

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Dan Wetstein

Date: January 10, 2003

Reference: Boulder Reservoir WTP--Preliminary Design for Near-term Improvements

Subject: **Reservoir Contact Time Improvements**

Purpose

This Technical Memorandum (TM) summarizes disinfection improvement options at Boulder Reservoir WTP (BRWTP), makes recommendations regarding improvements needed to increase post-treatment contact time for *Giardia* control. This TM does not evaluate the use of ozone or ultraviolet (UV) disinfection, both of which are considered to be long-term improvements and will be evaluated later in the current project.

Historical Overview of Existing Operations

The BRWTP has two surface water supplies—the Boulder Feeder Canal (BFC) and Boulder Reservoir (BR), both of which are operated by Northern Colorado Water Conservancy District (Northern). Water quality varies between the two raw water sources. The BFC consists of a 21-mile-long unlined, unfenced channel subject to microbial contamination for its entire length. The BR is a relatively shallow reservoir used for boating, fishing, swimming, and other recreational activities. Both raw water sources collect runoff from animal farms and grazing, waterfowl droppings, as well as windborne contamination. Source Water Quality Planning is currently being undertaken at BRWTP that will further define sources of microbial contamination.

The BRWTP was constructed in 1970 and consists of coagulation, flocculation/sedimentation, a settled water contact basin (normally off line), filtration, disinfection, a filtered water reservoir, and high service pumping. The plant was designed as a peaking facility capable of treating 8 mgd with a 'hydraulic overload capacity' of 12 mgd. Gaseous chlorine was originally fed at three locations in the process train – rapid mix, settled water contact basin, and post-filtration. Chlorine was replaced by a multiple – or mixed-oxidant (MIOX) disinfectant in 2001, which is currently fed to the same feed points. Assuming a MIOX concentration of 0.35 percent free chlorine, the dosages are estimated to be 1.9, 1.0, and 0.4 mg/L, respectively.

Historically the plant's operational strategy has been to provide contact time for disinfection using the 2.2-million-gallon concrete filtered water reservoir and post-filtration piping. The

original design called for a 4.8-million-gallon clearwell, but it was downsized to reduce costs. Provisions were made in the original clearwell to facilitate future expansion to the west. The existing clearwell's inlet and outlet are adjacent to each other at the mid-point of the reservoir's length. The inlet and outlet are unbaffled and separated by a dividing wall. The reservoir was not designed as a chlorine contact chamber and performs poorly as a hydraulic contactor. (**Figure 1**). No disinfection profiling or tracer studies have been performed at BRWTP to quantify clearwell short-circuiting or identify disinfection deficiencies through the plant.

The City has established water quality goals of 4-log *Giardia*, 5-log viruses, and 5-log *Cryptosporidium* removal and inactivation in order to achieve "...an additional order of magnitude factor of safety for waterborne disease than that required as the minimum in Federal standards on average" (*Integration of Quality and Quantity Goals* (*Goals*) workshop, February 2002). Conventional treatment provided at BRWTP is assumed to remove 2.5-log *Giardia*, 2-log viruses, and 2-log *Cryptosporidium*. The respective differences (1.5-log *Giardia*, 3-log viruses, 3-log *Cryptosporidium*) must therefore be obtained through either inactivation or a combination of microbial toolbox options under the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2WSTR). The *Goals* workshop concluded that the BRWTP was capable of achieving 5-log virus removal, but neither of the other two disinfection goals. Achieving 5-log *Cryptosporidium* inactivation is impossible using MIOX (or sodium hypochlorite), and therefore *Cryptosporidium* control will be addressed in more detail in a subsequent technical memorandum. This memorandum will focus primarily upon measures necessary for the BRWTP to achieve enhanced disinfection for *Giardia*.

Goal Conventional Currently
Giardia 4.0 2.5
Viruses 5.0 2.0 ok
Crypto 5.0 2.0

Review of Existing Data

Raw Water Quality

Selected raw water quality data are presented below. Most of the BR values were obtained from the South Dam Bottom (SDB) sampling location, which approximates the water quality at the BRWTP intake structure. The raw water values in the table were based on approximately 35 grab samples from the BFC location and 82 grab samples from the SDB location taken between 1992 and 2000.

Water Quality Parameter	Boulder Feeder Canal	Boulder Reservoir
Maximum alkalinity, mg/L	50	100
Average Giardia, cysts/L1	0.49	<0.001
Average Cryptosporidium, oocysts/L1	0.16	0.01
Minimum dissolved oxygen, mg/L	8	0.1
Maximum hardness, mg/L	60	225
Maximum dissolved iron, mg/L	0.05	0.1
Maximum dissolved manganese, mg/L	0.01	1.0
Average pH	8	7.9
Minimum temperature, oC	8.1	3
Maximum TOC, mg/L	4.9	5.3
Maximum UV254 absorption/cm	0.127	0.115
SUVA, L/mg-m (approximate)2	2.6	2.1
Maximum turbidity, ntu	15	30

Notes:
[1]McGuire Environmental Consultants (MEC), Inc., *Assessment of the Boulder Reservoir Water Treatment Plant* (unpublished draft material, 2001).
[2]Assumes that (a) DOC is 0.9 × TOC and (b) UV254 and TOC were measured from same sample.

Raw water data would suggest that BFC water may be slightly warmer than BR water and may occasionally have higher pH. There is also some evidence to suggest that BR removes a portion of the encysted parasites. As a practical matter, these differences in raw water characteristics are probably not significant enough to impact the design of contact time for disinfection. (No raw water data regarding bromide or ammonia has been found; albeit this data would be useful for estimating TTHM formation.)

Hydraulic Characterization

Methodology Used To Calculate *CT*. There are at least four principal methods of estimating *CT*, the residual concentration and contact time necessary to inactivate microorganisms. These include (a) Colorado Department of Public Health and Environment's (CDPHE) 30-minute *T*/0.2-mg/L (free chlorine) *C* approach; (b) the United States Environmental Protection Agency's effluent method; (c) Coffey and Gramith's log-integration method; or (d) some variation of the Integrated Disinfection Design Framework (IDDF) method. Although the BRWTP undoubtedly complies with CDPHE's *CT* method at many full clearwell/low plant flow combinations, this methodology achieves no better than 0.5-log *Giardia* inactivation under EPA's approach with relatively low pH/high temperature water. For purposes of this technical memorandum, EPA's effluent method will be used to model disinfection because it is more conservative than either the log-integration or IDDF method, and it would be acceptable to the State of Colorado without site-specific testing.

The following table summarizes the *CT* and UV dose values for *Giardia*, viruses, and *Cryptosporidium* when applying each of the disinfectants individually under laboratory conditions. The shaded columns in the table represent the *CT* or UV dose values needed to meet the City's goals for public health protection. Field verification of the UV and ozone values would likely be required prior to design.

CT/UV Dose Values for Log Removals and Disinfection Alternatives

	1.5 Logs1 Inactivation			3 Logs2 Inactivation		
Disinfectant	**Giardia**	**Viruses**	**Crypto**	**Giardia**	**Viruses**	**Crypto**
Free Chlorine3	128 (43)	5 (5)	Ineffective	256 (171)	7 (5)	Ineffective
UV4	0.7 (N/A5)	74.9 (30.4)6	6.1 (1.8)	N/A5 (3.3)	142 (97.7) 6	16.7 (10)
Chlorine Dioxide7	17 (6)	6.6 (6.6)	636 (212)	33 (22)	20 (6.6)	1273 (849)
Ozone7	1.12 (0.37)	0.69 (0.69)	20.1 (6.7)	2.23 (1.49)	1.04 (0.69)	40.1 (26.8)

[1]EPA requirement (0.5 log) in parentheses.
[2]EPA requirement (2 logs) in parentheses.
[3]Temperature=3oC; pH=8; C=1.0 mg/L
[4]Units=milliJoules/square centimeter
[5]N/A=insufficient data
[6]Predicted 90% inactivation of adenovirus
[7]Assumes initial disinfectant residual is not measured

From these *CT*/UV dose values, the following observations could be made:

- In all probability, either ozone or UV could satisfy all of the City's disinfection goals for *Giardia* and *Cryptosporidium*.
- Neither chlorine nor chlorine dioxide alone would be capable of controlling *Cryptosporidium*. Although synergism with respect to *Cryptosporidium* control has been observed in the laboratory using chlorine dioxide followed by free

chlorine, quantifying full-scale effects (potentially 2-3 logs *Cryptosporidium* inactivation) at BRWTP would require a site specific inactivation study, as well as CDPHE approval.

- The City's *Giardia* inactivation goals can be met with any of the four alternative disinfectants. Disinfection profiling at BRWTP would likely demonstrate that the plant's current MIOX dosing may satisfy the City's 1.5-log *Giardia* inactivation goal at the plant's design flow rate (8 mgd), particularly if the settled water contact basin (T=60 minutes at 8 mgd, average baffling) were placed on line for additional T.

Ozone or UV technologies are known to be expensive, operator-intensive, and relatively complex. As a result, additional *Cryptosporidium* control may have to be accomplished vis-à-vis membranes or some other combination of toolbox options.

If full-scale trial of chlorine dioxide at BRWTP proves unsuccessful, the City must consider either improvements to the filtered water reservoir or conducting a disinfection profile to quantify deficiencies in *Giardia* inactivation using free chlorine at 20 mgd. Even if adequate theoretical *Giardia* inactivation could be demonstrated through profiling, it would not preclude future operational or process changes that could reduce *CT*. Therefore, clearwell improvements will be evaluated in order to define a fail-safe approach to *Giardia* inactivation with free chlorine.

Assumed T_{10}/T Ratio of the Clearwell. Baffling classifications for clearwells were defined in EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems using Surface Water Sources* (1990) and have been incorporated in one form or another in numerous publications, including CDPHE's *Design Criteria for Potable Water Systems* (1997). These classifications (from CDPHE's *Design Criteria*) are as follows:

- Unbaffled (mixed flow). No baffling, agitated basin, very low length to width ratio, and high inlet and outlet flow velocities receives an actual to theoretical (A/T) credit of 0.1.
- Poor. Single or multiple unbaffled inlets and outlets with no intra-basin baffles receives and A/T credit of 0.3.
- Average. Baffled inlet or outlet with some intra-basin baffles receives and A/T credit of 0.5
- Superior. Perforated inlet baffle, serpentine or perforated intra-basin baffles and outlet weirs or perforated launders has an A/T of 0.7.
- Perfect (plug flow). Very high length to width ratio, perforated inlet, outlet, and intra-basin baffles receives and A/T of 1.0.

Although the BRWTP has a transverse baffle between the inlet and outlet to prevent straight-through flow, there is a significant volume of dead space at both ends of the clearwell. For purposes herein, it is assumed that the maximum T_{10}/T of the existing BRWTP clearwell would be approximately 0.3 at 20 mgd.

Water Level in the Clearwell. Clearwells can be designed to serve as many as four distinct functions: (1) to meet water peak demands, (2) to provide a sufficient volume of water for plant operations, (3) to provide adequate chlorine contact time, and (4) to store water for firefighting. The City's most recent *Treated Water Master Plan* (2001) concluded that, "With typical diurnal demand variations a 48-hour simulation under peak day conditions indicated that the existing storage capacity is adequate (in Zone 1)." (Zone 1 is supplied by BRWTP's high service pumps.) Although adequacy of storage in Zone 1 was apparently an issue in Boulder prior to the *Treated Water Master Plan* (hence the quotation), for purposes of this analysis it is assumed that no water volume at BRWTP is dedicated to emergency or equalization purposes. Similarly, filter washing at BRWTP is provided by a separate backwash storage tank, and it is assumed that no water volume for plant operations is furnished by the clearwell. Hence the entire clearwell volume is assumed to be available for chlorine contact.

Results of Hydraulic Characterization and *CT* Table. Given the *CT* values for *Giardia* inactivation (at 1.0 mg/L) and assumed T_{10}/T ratio above, the following observations could be made:

- With no modifications and 80 percent full (16-foot water depth), the existing clearwell theoretically complies with EPA's 0.5-log inactivation criterion for *Giardia* at 20 mgd with 3°C, pH 8 water from BR. Thus as previously established, at 20 mgd, the lack of baffling in the existing clearwell severely limits its functionality with respect of meeting EPA's *Giardia* inactivation criterion under some raw water conditions. The existing clearwell is incapabale of meeting the City's 1.5-log *Giardia* inactivation requirement under any realistic raw water conditions.
- Assuming that modifications were made to the clearwell to create a serpentine flow pattern and achieve a T_{10}/T ratio of 0.7, EPA's 0.5-log *Giardia* requirement could be achieved at 20 mgd and 7 feet of water depth. These modifications are shown in **Figure 2**. However, the City's 1.5-log *Giardia* requirement would still limit the ultimate BRWTP capacity to 16.9 mgd with a full (18-foot depth) clearwell and worst-case BR water. As a result, maintaining the plant's historical operating strategy of using post-filtration contact time and free chlorine (MIOX) for *Giardia* inactivation will require additional clearwell volume. Although provisions were made in 1970 to add a second clearwell in series, a parallel clearwell is strongly recommended in order to provide operational and construction flexibility. At 20 mgd, the second clearwell should be sized for 2.7 million gallons of storage at the maximum 18-foot water level, and the clearwell must be baffled to achieve a T_{10}/T ratio of 0.7. This arrangement is shown on **Figure 3**. Existing 48-inch-diameter filter effluent (reservoir influent) piping and 42-inch-diameter high service pump (reservoir effluent) suction piping appear to have been sized for a future expansion to at least 20 mgd. The velocity in the pump suction piping would be 3.2 ft/sec at 20 mgd.

Construction of the new clearwell would allow the BRWTP to remain in service while baffling curtains are installed in the existing clearwell. A new clearwell would also provide more Zone 1 storage and the ability to clean either clearwell in the future while the plant remains on line.

Present Worth

Costs for improvements needed to construct a 2.7-million-gallon buried clearwell are presented in the table on the next page. It is assumed that an aboveground reservoir at the BRWTP site would be untenable to the City's Planning Department or Development Review process for aesthetic reasons.

Alternative	Cost	Installation Factor	Total Cost
2.7 Million Gallon Buried Concrete Reservoir			
Construction Costs			
Sitework[1]	$200,000	Included	$200,000
Concrete[2]	$1,200,000	Included	$1,200,000
Piping and valves[3]	$300,000	50%	$450,000
Baffle curtains[4]	$60,000	Included	$60,000
Miscellaneous metals and specialties[5]	$100,000	Included	$100,000
Electrical/I&C[6]	$30,000	40%	$42,000
Subtotal			$2,052,000
Contingencies (20%)			$205,000
Overhead and profit (10%)			$225,000
Construction Subtotal			$2,482,000
Operation and Maintenance Costs			
Manpower[7]			$5,000
O&M Subtotal			$5,000
Present Worth, O&M[8]			$53,000
Total Present Worth			**$2,535,000**

Notes:
[1]Sitework cost assumes no imported embankment fill, no dewatering, no off-site hauling, no retaining walls, and no landscaping. Includes gravel road replacement.
[2]Concrete includes piles and twin tee roof.
[3]Piping includes vent, drainage, washdown hydrants, 48-inch influent, 48-inch HSP suction, and 36-inch overflow piping. No stormwater piping.
[4]Baffles for both reservoirs. Coated fabric.
[5]Waterproofing, access ladders, hatches, grating, handrail, fencing, gates, security.
[6]Flowmeter, manhole, level transmitter, I/O to SCADA
[7]Cleaning, instrumentation, flow control.
[8]Series Present-worth Factor (P/A, 7%, 20)=10.5940.

Recommendations

Construction of a new clearwell possesses both advantages and disadvantages. The advantages include:

- Improves *CT* credit for *Giardia* inactivation, particularly important with free chlorine (MIOX or sodium hypochlorite). A new clearwell would eliminate any regulatory need for pre-filtration *CT* credit.
- Would likely allow the first point of disinfection to be moved downstream, reducing TTHM/HAA formation with free chlorine
- Meets City's 20-mgd public health goals for *Giardia* while eliminating the need for chlorine dioxide solely for *Giardia* inactivation
- Increases storage volume in Zone 1
- Simplifies overall plant operations with respect to *Giardia*

- Minimizes annual operation and maintenance costs compared with chlorine dioxide
- Provides redundancy and flexibility for future cleaning and maintenance in both clearwells

The disadvantages of constructing a new clearwell include:

- Construction cost
- Need for a new clearwell slightly diminished should chlorine dioxide, ozone, or membranes ever be provided at BRWTP, any of which is capable of *Giardia* inactivation with no additional clearwell capacity

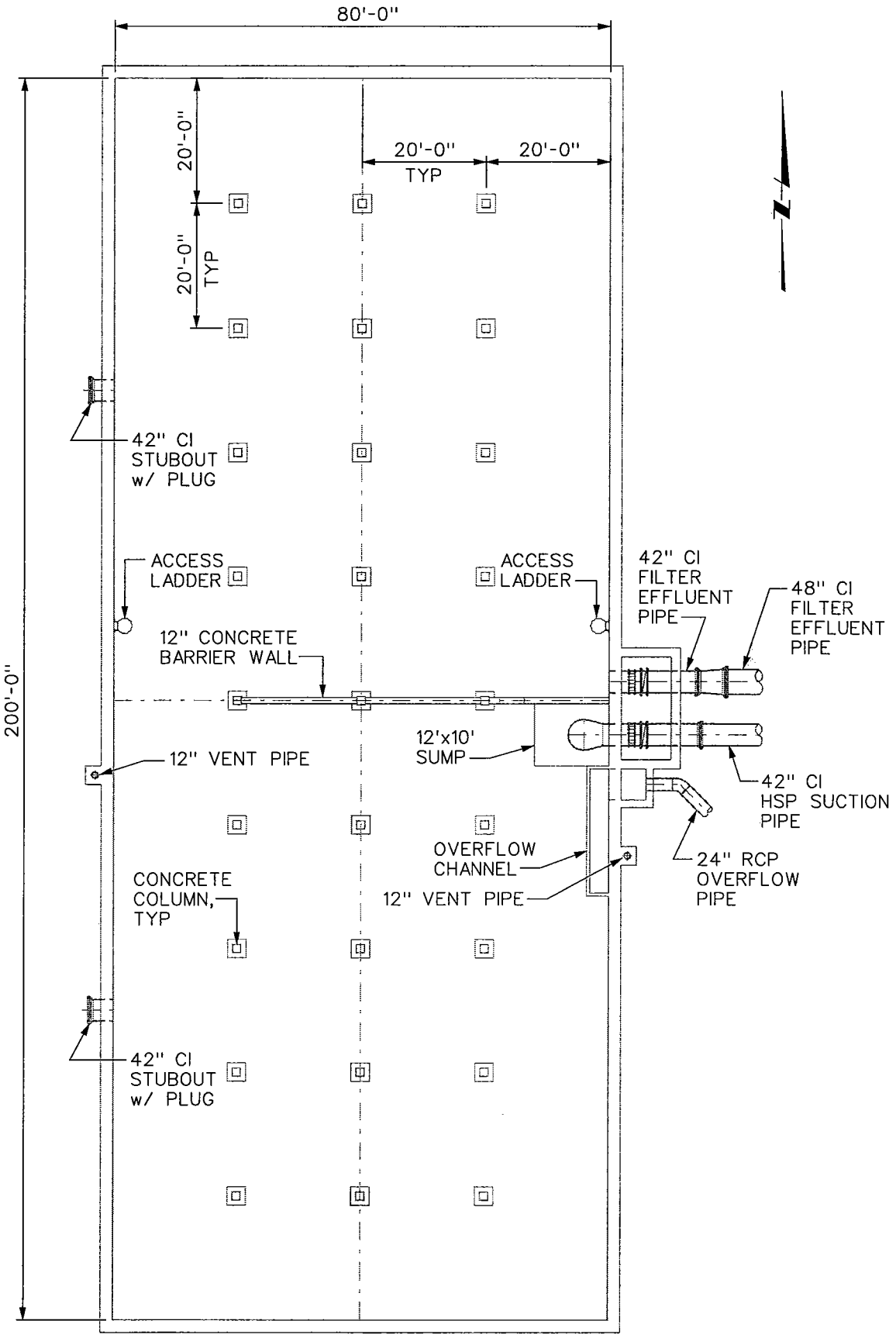
As presented in a previous technical memorandum regarding preoxidation, the 20-year present worth cost of chlorine dioxide ranged from $1,500,000-$1,900,000 with annual O&M costs ranging from $110,000-$140,000 per year. This compares to $2,500,000 for a new clearwell and negligible O&M. These two options are not directly comparable, however. Chlorine dioxide is more effective than MIOX (or sodium hypochlorite) for *Giardia* and *Cryptosporidium* inactivation and generates essentially no TTHM/HAA byproducts. The worst-case *CT* for 1.5-log *Giardia* inactivation with chlorine dioxide is only 17 mg min/L—a target that can be readily met at 20 mgd through BRWTP with no improvements to the existing clearwell (assuming that BR iron and manganese concentrations are negligible or reduced). Neither MIOX nor chlorine dioxide is particularly effective against *Cryptosporidium*. The worst-case 0.5-log *CT* for *Cryptosporidium* inactivation with chlorine dioxide at BRWTP is 212 mg min/L.

As discussed in the preoxidation technical memorandum, many of the reasons for feeding chlorine dioxide as a preoxidant—taste and odor control, controlling biological growth in the floc/clarifier and filters, iron and manganese reduction, color, etc.—are not quantifiable. Although in many respects chlorine dioxide would be expected to outperform free chlorine as a preoxidant, nothing in the data seems to suggest that free chlorine has been inadequate.

The advantages associated with construction of a new clearwell at the BRWTP include simplified plant operation (compared with chlorine dioxide) with minimal O&M. Although chlorine dioxide generators and associate chemical storage/feed facilities could be installed at a fraction of the cost of a new clearwell, the operational and maintenance complexities associated with chlorine dioxide generation would be considerably greater than those associated with additional filtered water storage. Regulatory and testing requirements would be considerably reduced by adding a new clearwell, and plant reliability and safety would be markedly increased compared with chlorine dioxide. A new clearwell would be consistent with current operator experience, knowledge, and skills. If desired, the existing MIOX system could be replaced by a sodium hypochlorite feed system, further reducing O&M costs, particularly those associated with electrical usage.

Pending detailed analyses of ozone, membranes, and other microbial toolbox options for *Cryptosporidium* control in the forthcoming Long-Term Improvements memorandum, baffling of the existing clearwell (**Figure 2**) and construction of a new clearwell (**Figure 3**) would be recommended for future *Giardia* inactivation at BRWTP.

Phasing. Plant downtime could be minimized by several weeks by constructing a new clearwell immediately. However down time is required in any case to tie in the existing filtered water and high service pump suction piping. The City's limited budget also precludes immediate clearwell construction. It is therefore recommended that the existing clearwell be baffled under this project, and new clearwell construction be deferred pending future budgeting. The cost of baffling the existing clearwell and installing valves and valve vaults on the existing filtered water and high service pump suction piping would be approximately $200,000. The cost of baffling the existing clearwell only would be approximately $72,000. As stated above, this would allow the BRWTP to achieve EPA's 0.5-log *Giardia* requirement at 20 mgd and 7 feet of water depth. Using the City's 1.5-log *Giardia* inactivation goal, baffling would limit the ultimate BRWTP capacity to 16.9 mgd with a full (18-foot depth) clearwell and worst-case BR water. Nevertheless, this appears to be a reasonable near-term objective that is achievable at relatively low cost.



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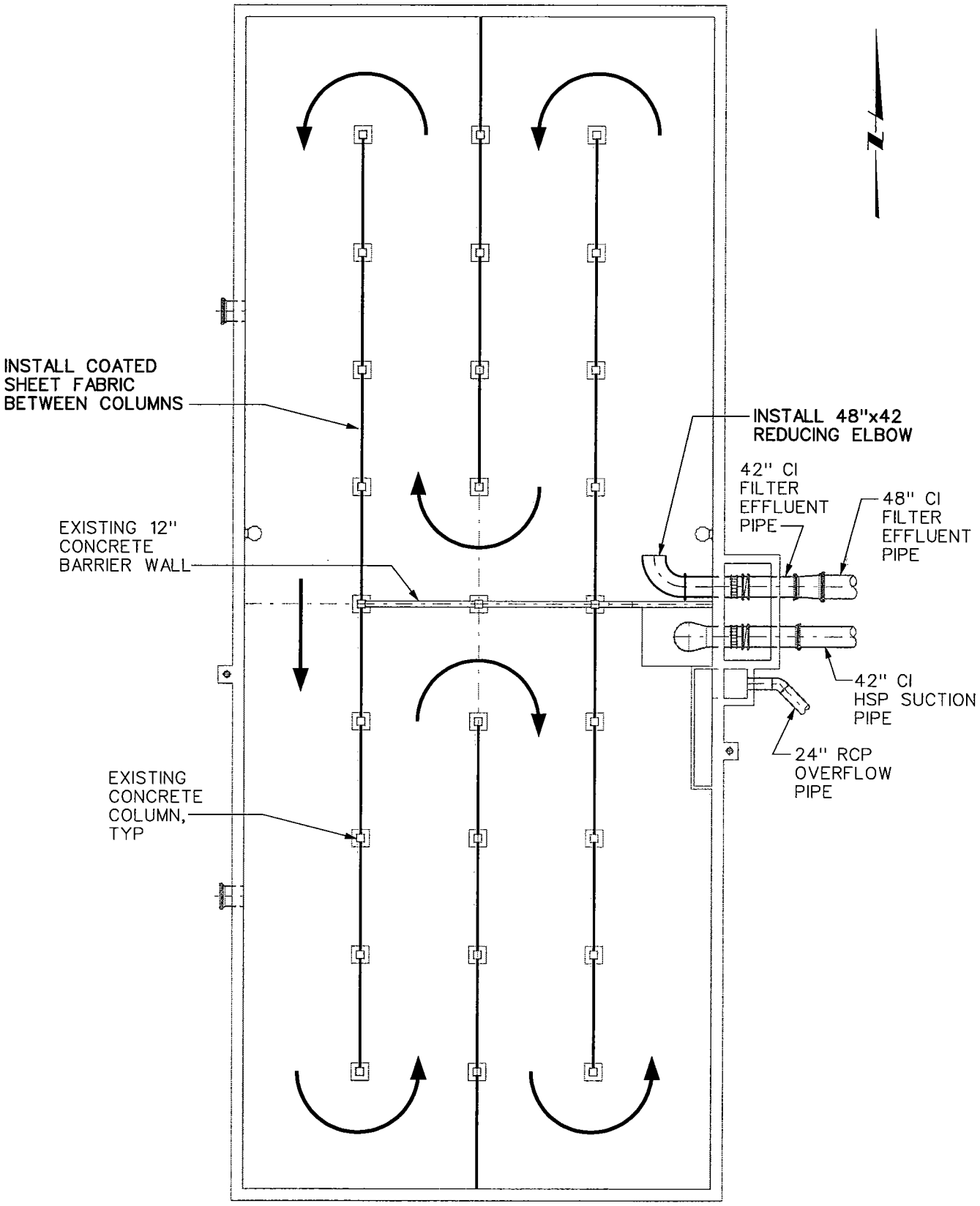

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Denver Colorado MWH MONTGOMERY WATSON HARZA	CITY OF BOULDER, COLORADO BOULDER RESERVOIR WATER TREATMENT PLANT IMPROVEMENTS	EXISTING 2.2 MG RESERVOIR BAFFLING MODIFICATIONS SECTIONAL PLAN AT EL 5177.0	FIGURE 2

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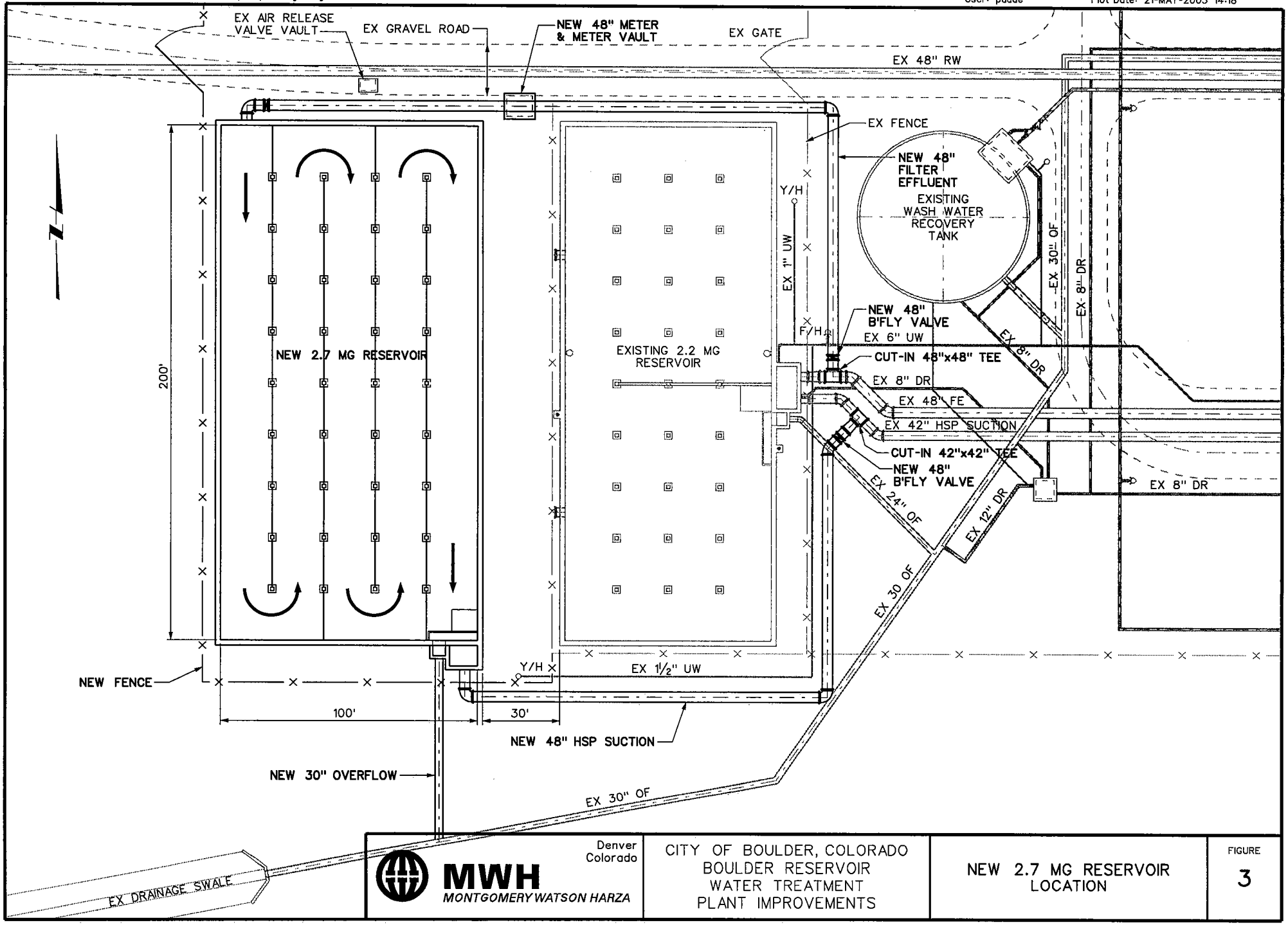


Denver Colorado

MWH
MONTGOMERY WATSON HARZA

CITY OF BOULDER, COLORADO
BOULDER RESERVOIR
WATER TREATMENT
PLANT IMPROVEMENTS

NEW 2.7 MG RESERVOIR
LOCATION

FIGURE
3

Attachment A-9 – Control Systems Improvements Report No. 1

MEMORANDUM

MWH

To: Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck

From: Sang Nguyen

Date: January 28, 2003

Reference: Boulder Reservoir WTP--Preliminary Design for Near-term Improvements

Subject: **Control System Improvements Report No. 1**

Purpose

This memorandum is based on several discussions with the City's Boulder Reservoir WTP maintenance and operations personnel. The intent is to compile a list of instrumentation and control related issues for the City's evaluation. MWH has also included opinions on the state of the system and benefits of enhancements.

Each item has an associated priority assignment. This evaluation is based on comments from City personnel as well independent evaluation from MWH.

The costs associated with each item are independent of each other. Therefore there was no attempt to take advantage of economies of scale. It is difficult at this stage of the project to determine the scope of each task. The estimates noted here are for budgetary purposes only.

Improvement Options

Facility Raw Water Influent and Effluent Flow Tubes

Priority: High
Estimated Cost: $20,000
Issue: The venturi flow tubes, installed with the original construction of the facility are oversized and may have outlived their design service lives. The original design was sized for an ultimate capacity of 30 MGD. The plant occasionally operates at less than 5 MGD. Operating at the lower flow threshold of the meter reading is problematic due to loss of accuracy. Typically, instruments operate most accurately in the range of 40% to 60% of span. Considering the vintage of the equipment, spare parts, calibration and expertise with the equipment have been difficult to procure. The inaccuracy of these instruments has been troublesome in normalizing and reporting of plant flow data. MWH recommends replacement of these meters.

PLC System Status and Improvements

Priority: High
Estimated Cost: $300,000
Issue: As shown in **Figure 1**, the facility is currently monitored and controlled by three limited functionality industrial controllers. The Motorola MOSCAD programmable remote terminal units (RTUs) were installed in the mid-1990s. Motorola and its family of industrial controllers are well known for their features and functions in remote terminal unit applications. In centralized operations, the MOSCAD product line lacks the process and functionality demands of a plant-based controller. Traditional control functions such as proportional-integral-derivative (PID) are not available in the MOSCAD. The PID instruction is the standard control algorithm of the controls industry. Currently, a Honeywell single loop controller is used to control the operation of the filter effluent valves. This controller is not connected to the SCADA system, thus enhanced monitoring and tuning is only available at the local control station. This system has evolved in a piecemeal fashion over the life of the facility and suffers from a lack of overall integration. As a result, training and support for staff have been limited.

Communications from the MOSCAD RTUs to the SCADA system is limited by the protocol and the architecture of the MOSCAD RTU. The MOSCAD communicates to its companion PLC or SCADA system via a MODBUS protocol. This protocol is master-slave, ASCII based and is normally carried on two wires at 19.2 Kbaud. Master-slave communication is a standard where only the master system (SCADA) could initiate data requests, then the target slave would respond in kind. If a slave system (PLC) communicates out of context, the data is ignored by all systems. Again, in remote applications where the demand for data is limited, this protocol works well. However in a plant-wide installation, this limitation of speed and functionality is unacceptable. To exacerbate the data throughput problem, the control system is structured in a "star" architecture with the use of Digi-Boards. The Digi-Boards allow the concentration of communication paths from up to 8 PLCs to a single connection to the central SCADA node serially. In a serial communication system, only one PLC may be addressed at a time, thus reducing the overall throughput of the system.

As noted earlier, Motorola and its family of industrial controllers are well known for their features and functions in remote terminal unit applications. The City has numerous remote installations at collection and distribution sites. There are immediate uses of the MOSCAD PLCs should they become available (see Item 10).

MWH recommends a design effort to evaluate the overall cost and scope of upgrading the existing system. This will be a relatively costly item due to hardware and software changes and high potential for operational impact.

Automate Filter Backwash Operations

Priority: High
Estimated Cost: $50,000
Issue: Current filter backwash operation is executed manually and requires a high level of operator attention. Although the SCADA system was recently upgraded, filter backwashing has

not been automated. Backwashing a filter is a labor-intensive and operator-specific process that, for good reasons, has been automated in most water plants in Europe and North America.

The control system could be configured to include two modes of backwash operation: "SEMI-AUTO "and "FULL-AUTO". In SEMI-AUTO mode, the Operator would manually initiate a backwash request and the control system would automatically cycle the filter equipment based on preset backwash sequences. In FULL-AUTO mode, the control system would initiate backwash based on either of the following parameters: filter run-time, high discharge turbidity or high filter differential pressure.

Filter Instrumentation

Priority: High
Estimated Cost: $15,000
Issue: The filter effluent valves have a discretely controlled operators, which are not traditionally supportive of analog control schemes. The valve operator opens and closes based on two digital output signals working exclusively. This operator works well in applications where the process requires fully opened or closed valves. In a level (or any analog) control scheme, where precise valve position is mandatory, the controller is forced to maintain the process by means of pulsing the valve open or close. Inherent in this control scheme. Hysteresis is the difference reading (or dynamics) depending on direction of measurement (or control). Hysteresis is caused by mechanical friction, magnetic effects, elastic deformation or thermal effects. Hysteresis will cause resonance in the control of a process. MWH recommends upgrading inlet valve operator to a servo-type with analog control of the valve position and integrating the filter effluent valve control algorithm into the PLC.

To support the FULL-AUTO mode of filter backwashing, the filter loss-of-head sensor and transmitter needs to be re-implemented. The primary function of this signal is to establish the need to manually or automatically initiate a filter backwash. Due to unavailability of the automated backwash system, the instruments have been reclaimed for other use. MWH recommends reinstallation of these instruments for all filters.

To support the FULL-AUTO mode of filter backwashing, the filter effluent turbidity sensors and transmitters need to be calibrated. The primary function of these signals is to establish the need manually to or automatically initiate a filter backwash. It is suspected that due to non-use, the instruments may have been neglected. MWH recommends these instruments and all other turbidity instruments throughout the facility be placed on a more frequent calibration schedule.

SCADA Reconfiguration

Priority: Medium
Estimated Cost: $20,000
Issue: Currently the system consists of two separate Intellution FIX32 Version 6.15 SCADA servers, each having its own database. These servers do not have any built-in or configured redundancy. This version was originally deployed in 1995, and Intellution has no plans to extend its development beyond the current Version 7. Instead, Intellution has transitioned its human machine interface (HMI) product into a more Windows-based form. Intellution is now promoting

its iFIX Dynamics product line. This product has all the features of the Legacy System plus many state-of-the-art features. Among the notable enhancements are the embedded redundancy feature and the use of MS VBA (open scripting tool) as the application enhance platform. The integration of IT and industrial software standards has allowed the iFIX Dynamics to remain as the front-runner of the HMI market.

The City maintains the SCADA licenses on an annual basis and as long as this is kept current, all future upgrades will be available. The City is planning to upgrade the server computers during first quarter of 2003. With the latest version of the SCADA software coupled with ever-faster computers, there are advantages in combining the servers and configuring a hot redundant standby (not available with master-slave communications). Even with the MOSCAD RTUs, the second computer could be setup as a "warm" standby. The advantage of reconfiguration is having a backup available, whereas the plant currently has no backup. MWH recommends reconfiguration of the SCADA servers.

Enhanced Process Trending

Priority: Medium
Estimated Cost: $15,000 (software and installation)
Issue: Plant Operations would like to obtain a process trending system to supplement the HMI system. The current system is antiquated and does not provide the functionality available in most trending-only applications. Key deficiencies of the current system are highlighted below:

1. Inability to view real-time and historical data from the same application.
2. Inability to dynamically add or remove pens.
3. No data analysis tools.
4. Inability to export information to an analysis tool such as MS Excel.

With the City's plan on migration from the FIX32 to the Dynamics HMI, chances of integrating third party trending packages are greatly improved. Due to Dynamics use of MS VBA many of today's third party trending applications, which are based on VB, will integrate readily with Dynamics. Although Dynamics has a trending package, it is not as thoroughly developed and user friendly as those that are specifically written for that purpose.

Automate Chemical Dosing and Process Controls Tuning

Priority: High
Estimated Cost: $5,000 (study only)
Issue: Plant Operations reports that most or all chemical dosing systems are manually operated. It is unclear whether manual operation is due to lack of confidence in the feedback measurement for equipment problems. However manual chemical feed is inefficient and requires frequent attention to be effective. MWH recommends evaluation of the individual systems and preparation of an implementation plan with associated costs.

SCADA Expansion with View, Only Clients

Priority: Low
Estimated Cost: $10,000 (5 user licenses, PC not included)
Issue: Staff has expressed interest in having a direct 'view' of the SCADA system. The graphic stations will be limited to views only (no controls). Intellution offers a Terminal Server application that converts the Dynamics HMI graphic screen without any user intervention. The Terminal Server application serves the graphics to the clients via an Internet browser. The advantage of the Terminal Server is its ability to rebroadcast the HMI graphics with live data from the SCADA system. MWH recommends deploying the Terminal Server for use with view only clients.

Relocate SCADA Based Totalizers to PLC

Priority: High
Estimated Cost: $1500 per point
Issue: The production totalizers are currently calculated within the SCADA HMI system. Because the HMI runs on a NT-based computer, it is susceptible to occasional system outages. These system cycles could be caused by a number of factors including power blips or software upgrades. Moving these calculations to the PLC would make them more accurate and reliable. Because the PLCs are developed for the industrial environment, they have an outstanding uptime record as well as resistance to software-based viruses. MWH recommends evaluating the functionality of the totalizers and relocating them to their respective PLCs.

Monitor the Feeder Canal

Priority: Medium
Estimated Cost: $5,000 (study only)
Issue: The Boulder Feeder Canal has historically provided the major portion of the plant's water. There is no monitoring of water quality upstream of the plant's inlet. Often, surges in turbidity would not be recognized until they reached the plant. Once the upset makes its way to the plant, it is too late to take any preemptive actions.

Plant Operations would like to add a monitoring station within Dobb's WWTP facility due to Dobb's cooperation in providing power. The monitoring facility would include a housing structure with a Motorola remote terminal unit (RTU). This site would be provided with equipment to measure flow and turbidity. Communications to this facility would be similar to other collection or distribution sites throughout the city. MWH recommends evaluation of the of this scheme and preparation of an implementation plan with associated costs.

Staff Training

Priority: High
Estimated Cost: $6,000 (through local certified system trainers)
Issue: With the upgrade of the HMI software, the technology transition will be significant. The latest Dynamics HMI software is based on MS VBA and demands full understanding of the MS networking to properly configure the system. Although Intellution has attempted to provide tools to facilitate the configuration task, nothing is ever foolproof. Therefore it is critical that plant

maintenance be exposed to the system. With plant staff being able to execute more of the day-to-day modification and troubleshooting, the City could begin minimizing reliance on third-party suppliers.

MWH recommends evaluating the training requirements for plant staff and preparation of an implementation plan with associated costs

WTP Process Graphics/Reporting via City's Intranet

Priority: High
Estimated Cost: $20,000 (study only)
Issue: The City currently has a production historian that is marginal in terms of its functionality, robustness and reliability. The City needs to evaluate the data requirement of production, the ongoing demands of data from its constituents and its ability to deliver data to personnel need it the most. Described below are the three data "historians" that the City has as its disposal. Clearly the most reliable and effective approach to preserving and serving the data is to implement a system that is based on the Oracle data and its ability to deliver data to the City's intranet.

ChemLog

ChemLog is the City's custom-built WTP production data report system, which is in use at both WTP plants. The system's creator is no longer employed with the city. ChemLog is difficult to maintain and data extraction is limited due to 'report' style of the data structure. ChemLog does not provide the user with a friendly lookup reference to the data element or its intended purpose. Over time, the lack of documentation has led to degradation of system knowledge. ChemLog stores data in a per day format, which stores data in elements of the particular day where the actual data time is implied. This method of data archive is difficult to manage due to the need to frequently 'normalize' the data. Typically, time-series (chronological) data is stored as events occur or in time periods that captured data. This method ensures that the data is time-stamped with the collection time versus the implied time method.

ChemLog was written in MS Access '97. Since the author is no longer employed with the City, enhancements, modifications and upgrades (to the current version MS Access) are not possible. Over time, the City will outgrow this system and will need to migrate to a more robust and user-friendly form.

ChemLog database currently resides on a backup network drive, with the user interface located in the control room. This architecture has resolved the file backup issue; however should the plant lose connection to the network drive, the operator interface is not operational. During the period of outage, data could not be entered and reports could not be requested from the system.

Tribal Lab Management System

The City has experimented with a third-party lab management system with Tribal Software's Laboratory Data Management Software. This is software is designed for complete proprietary laboratory management. It has features that are specific to the day-to-day operations of a lab. This software is far more extensive than what the City really needs. Further customized application and the ability to perform ad-hoc data extraction are not possible, due to the proprietary nature of

the software application. Because the system is based on an MS Access database, it has similar limitations as the ChemLog application.

Oracle Collecting and Archiving WTP Process Data

Late in 2002, the City started the process of centralizing the production data to the central Oracle database. In doing so, plant operation has been liberated from the task of 'sneaker-netting' the local historian's archives to CD-ROM. The system takes advantage of the SCADA system's ability to collect and send data to the Oracle database. Within the IT environment, the day-to-day process of backups, data preservation, and data availability are performed by the most qualified personnel.

With the data now centrally located, it would be possible to provide intranet-based ad-hoc data extraction queries, process data graphic presentation and generate standardized reports. The advantage of creating these applications for the intranet is to make the information available to anyone at no charge.

MWH recommends evaluating the City's requirement for accessing the WTP production data via the intranet and prepare an implementation plan with associated costs.

Summary of Recommendations

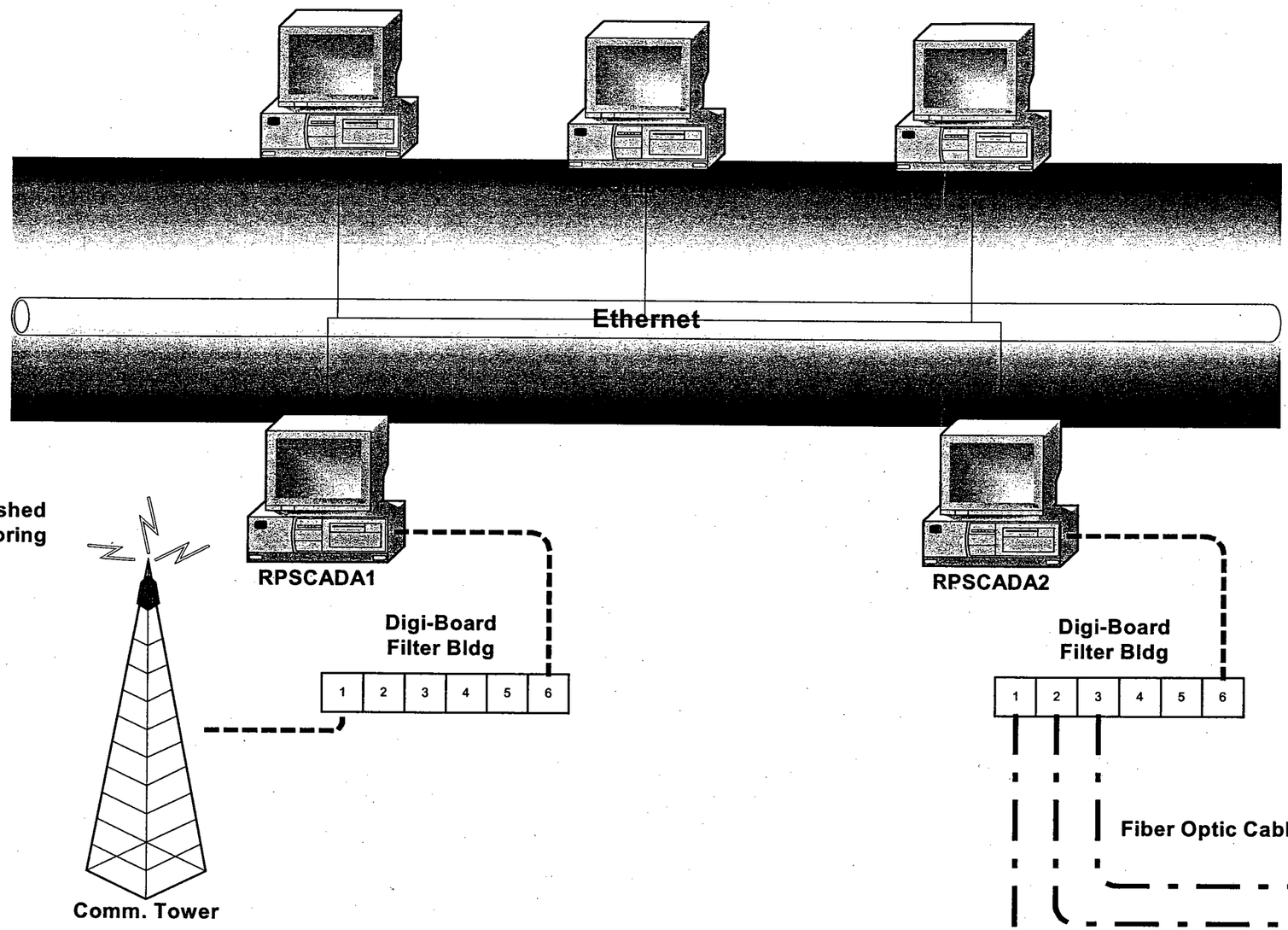
The following table summarizes the improvements and the estimated costs for each improvement.

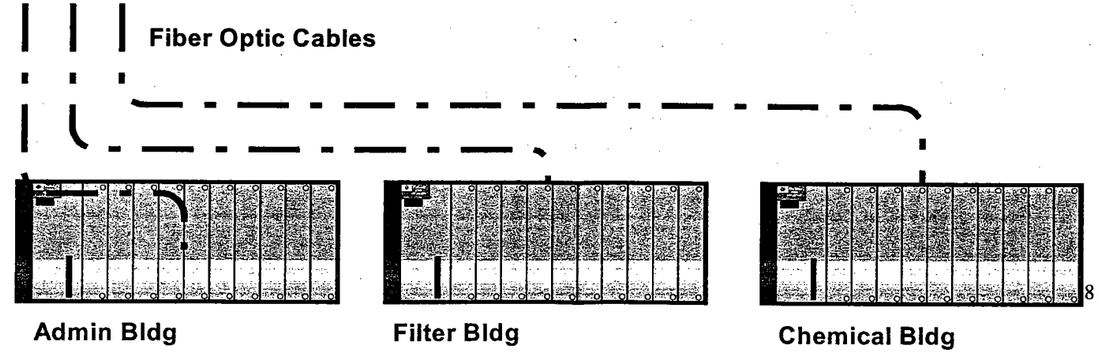
Improvements			
Item	Description	Prioritization	Estimated Costs
1	Facility Raw Water Influent and Effluent Flow Tubes	High	$20,000
2	PLC System Status and Improvements	High	$300,000
3	Automate Filter Backwash Operations	High	$50,000
4	Filter Instrumentation	High	$15,000
5	SCADA Reconfiguration	Medium	$20,000
6	Enhanced Process Trending	Medium	$15,000
7	Automate Chemical Dosing and Process Controls Tuning	High	$5,000
8	SCADA Expansion with View Only iClients	Low	$10,000
9	Relocate SCADA Based Totalizers to PLC (per point)	High	$1,500
10	Monitor the Feeder Canal	Medium	$5,000
11	Staff Training	High	$6,000
12	WTP Process Graphics/Reporting	High	$20,000

cc: File 1700506
B. Nelson
B. Mishra

CITY OF BOULDER -- BOULDER RESERVOIR WTP IMPROVEMENTS

EXISTING PLANT CONTROL SYSTEM ARCHITECTURE





Attachment A-10 – Chlorine Dioxide for Preoxidation

MEMORANDUM

MWH
MONTGOMERY WATSON HARZA

To:	**Anne Noble, Randy Crittenden, Terry Reichenberger, Bob Luna, Brad Segal, Chester Phillips, Dave Shuchter, Craig Sheard, Tom Marano, Steve Houck**	Date:	**November 5, 2002**
From:	**Dan Wetstein**	Reference:	**Boulder Reservoir WTP--Preliminary Design for Near-Term Improvements**
Subject:	**Chlorine Dioxide for Preoxidation**		

Purpose

This Technical Memorandum (TM) summarizes historical preoxidant operations at Boulder Reservoir WTP (BRWTP), reviews the existing data, and makes recommendations regarding a new chlorine dioxide (ClO_2) system. This TM does not evaluate the use of chlorine dioxide versus other alternatives for disinfection.

Historical Overview of Existing Operations

The City of Boulder has two water treatment plants. Betasso WTP, the larger of the two plants, is capable of delivering water to Boulder's entire service area by gravity. The BRWTP is currently capable of pumping into two of the City's three pressure zones representing approximately 65 percent of the City's service area. As a result, power costs to deliver finished water from BRWTP are higher than at Betasso. The City's water rights occasionally impact decision-making concerning the volume of treated water supplied via Northern's C-BT Project.

The BRWTP has two surface water supplies—the Boulder Feeder Canal (BFC) and Boulder Reservoir (BR), both of which are operated by Northern Colorado Water Conservancy District (Northern). The City owns the BR. Raw water must be pumped from BR to the treatment plant. The BFC is a 21-mile-long unlined channel, which Northern typically operates from May to October each year. The BR is used for drinking water, irrigation and recreation. Although the majority of water in BR is supplied by the BFC, water quality varies between the two raw water sources. The chemical content of BR varies from winter to summer depending upon the amount of inflow from the natural drainage area and from Northern's Colorado-Big Thompson (C-BT) Project. Two tributary creeks to BR have a high mineral concentration, especially sulfates. The original plan was to divert the tributary creeks around BR in winter.

The BRWTP was constructed in 1970 and consists of coagulation, flocculation/sedimentation, a settled water contact basin (normally off line), filtration, disinfection, high service pumping, and treated water storage. The plant was designed as a peaking facility capable of treating 8 mgd

with a 'hydraulic overload capacity' of 12 mgd. Historically BRWTP has seldom been operated after Northern terminates operation of the BFC each fall. The filtration and disinfection processes at BRWTP have always been covered, and the flocculation/sedimentation, settled water contact basin, and spent backwash equalization basin were covered in 1993.

Using BFC water, the plant feeds about 20 mg/L (liquid weight) of ferric chloride and 0.2 mg/L (liquid weight) Nalco 7199 (medium charge cationic flocculent). With BR water, the ferric chloride dosage is estimated to be approximately 50 percent higher.

Provisions were made at the original BRWTP for feeding activated silica, alum or ferric, powdered activated carbon, soda ash, chlorine, ammonia, potassium permanganate, and sodium hexametaphosphate. Chlorine or potassium permanganate could be fed to the main hydraulic jump for preoxidation; and chlorine could be fed to the settled water contact basin for taste and odor control or iron and manganese reduction. Activated carbon could also be fed to the main hydraulic jump or the settled water contact basin primarily to control taste and odor. The original design envisioned a two-stage strategy for taste and odor. If chlorine was used at the head of the plant, activated carbon could be used in the contact basin and vice versa.

The activated silica, ammonia, potassium permanganate, activated carbon, and sodium hexametaphosphate feed systems were never used and have been demolished for several years. Gaseous chlorine was replaced by a multiple- or mixed-oxidant (MIOX) disinfectant in 2001. MIOX is fed at three points in the treatment plant (rapid mix, settled water, post-filtration). MIOX, ferric chloride, and cationic flocculent are fed simultaneously to the mechanical stage of the two-stage hydraulic/mechanical rapid mix facility. The present MIOX dosages are difficult to quantify due to the fact that the concentration strength can vary based on amperage and only the post-filtration feed point is continuously monitored for chlorine residual. However assuming a MIOX concentration of 0.35 percent free available chlorine (FAC), the chlorine dosages would be about 1.9, 1.0, and 0.4 mg/L, respectively. A chlorine residual of 1.0-1.2 mg/L is maintained in the finished water entering the distribution system. At a flow rate of 12.5 mgd through BRWTP and the above dosages, the MIOX system experiences problems meeting total plant demands.

The City's *Treated Water Master Plan* (1990) identified elevated trihalomethane (THM) levels as a problem from both Boulder water plants and recommended bench-scale testing to evaluate moving the point of initial disinfectant application, followed by plant-scale testing of chlorine dioxide for preoxidation. This project will implement plant-scale application of chlorine dioxide on a temporary basis. The installation could become permanent depending upon its performance during trial conditions.

Review of Existing Data

Rationale for Preoxidation. Due to the fact that the BRWTP has fed a preoxidant for many years for taste and odor control, to control biological growth in the floc/clarifier and filters, and iron and manganese reduction (and to a lesser degree for color and to aid coagulation/filtration) a review of existing data was conducted in an attempt to broadly explore the rationale for preoxidant demand. No data or operational experience is available regarding preoxidant uses such as color, biological growth control, or the effectiveness of MIOX as an aid to coagulation or filtration. These preoxidant functions are not discussed further. It should be noted that due to its cost, photosensitivity, and off-gassing potential during rapid mix or from open channels and basins, chlorine dioxide is typically not fed solely to control biological growth in most treatment

plants. Although the major unit processes at BRWTP are covered, the potential for microbial growth in the absence of a residual is difficult to predict. It is assumed that the capability of utilizing the existing MIOX (or a new liquid bleach) system for periodic shock treatment of the pretreatment basin(s) will be maintained.

A review of the data regarding the remaining rationales for preoxidation was somewhat inconclusive. Although this does not affect the recommendations of the City's *Treated Water Master Plan* cited above, it simply means that the rationale for switching preoxidants is based on the following facts: (1) the present MIOX installation experienced several design and start-up problems, not all of which have been conclusively resolved; (2) there are questions surrounding the MIOX system's O&M costs and performance including its solution strength and production capability; (3) MIOX speciation (FAC, ozone, chlorine dioxide, hydrogen peroxide) purportedly contained in MIOX is in fact FAC-only; (4) the advantages asserted by the MIOX manufacturer (better *Cryptosporidium* inactivation, lower DBP formation, more persistent and stable chlorine residual in the distribution system, elimination of taste and odor, lower doses) are unproven (or unproveable); and (5) chlorine dioxide is undoubtedly superior with respect to *Giardia* and *Cryptosporidium* inactivation than MIOX, especially at the moderately elevated pH levels occasionally found in BFC. As mentioned, the preoxidation data is somewhat inconclusive but is presented and discussed below.

Raw Water Quality. Selected raw water quality data are presented below. Most of the BR values were obtained from the South Dam Bottom (SDB) sampling location, which approximates the water quality at the BRWTP intake structure. The raw water values in the table were based on approximately 35 grab samples from the BFC location and 82 grab samples from the SDB location taken between 1992 and 2000.

Water Quality Parameter	Boulder Feeder Canal	Boulder Reservoir
Maximum alkalinity, mg/L	50	100
Maximum chlorophyll a, counts/mL[1]	5.7	2
Average Giardia, cysts/L[2]	0.49	<0.001
Average Cryptosporidium, oocysts/L[2]	0.16	0.01
Minimum dissolved oxygen, mg/L	8	0.1
Maximum hardness, mg/L	60	225
Maximum dissolved iron, mg/L	0.05	0.1
Maximum dissolved manganese, mg/L	0.01	1.0
Average pH	8	7.9
Minimum temperature, oC	8.1	3
Maximum TOC, mg/L	4.9	5.3
Maximum UV254 absorption/cm	0.127	0.115
SUVA, L/mg-m (approximate)[3]	2.6	2.1
Maximum turbidity, ntu	15	30

[1]Primarily *Chlorella*. Units/parameter agreement questionable.
[2]McGuire Environmental Consultants (MEC), Inc., Assessment of the Boulder Reservoir Water Treatment Plant (unpublished draft material, 2001).
[3]Assumes that (a) DOC is 0.9 x TOC and (b) UV254 and TOC were measured from same sample.

TTHM/HAA5 Control. One of chlorine dioxide's most definitive advantages with respect to MIOX (other than its disinfection capabilities) is due to the fact the chlorine dioxide does not form trihalomethanes or haloacetic acids. The City's present TTHM/HAA5 goals are 40 µg/L TTHM and 30 µg/L HAA5 locational running annual average (LRAA). Data from the City's *Prioritization Workshop* (MEC unpublished draft material, 2002) suggests that while the BRWTP finished water met the 40/30 LRAA goals, almost none of the compliance monitoring

sites in the distribution system did. TTHM/HAA5 formation in the distribution system should be dynamically modeled using the City's H_2ONET model, which might identify operational modifications (pump cycling, storage tank operation, etc.) to reduce the water age and affect TTHM/HAA5 formation in the distribution system.

Despite the relatively low SUVA values estimated above, anecdotal evidence indicates that enhanced coagulation at the BRWTP meets the DBP precursor (TOC) removal requirement with BFC water using 20 mg/L (liquid weight) of ferric chloride solution. Limited data also indicates that BR South Dam Bottom (SDB) sampling location may have a lower specific ultraviolet absorbance (SUVA) than BFC. As a result, TOC removal via enhanced coagulation may be more difficult with BR water than with BFC water. This may affect TTHM/HAA5 control as currently practiced. However, although the advantages associated with switching from MIOX to chlorine dioxide preoxidant with respect to precursor removal are well established, current TTHM/HAA5 formation at BRWTP would appear to be rather minimal at least with respect to BFC water. More important factors of concern might include TTHM/HAA5s from Betasso and reactions within the distribution system itself.

Iron and Manganese Control. Stoichiometrically, 2.45 mg ClO_2/mg Mn and 1.21 mg ClO_2/mg Fe are required to oxidize manganese and iron. The iron and manganese values in the table above suggest that iron and manganese concentrations in BR could require a theoretical dosage as high as 2.6 mg/L chlorine dioxide to completely oxidize combined Mn/Fe. In reality, reduction of the Mn concentration to perhaps 0.02 mg/L should eliminate customer complaints from manganese. However because 50-70 percent of the chlorine dioxide consumed by oxidation reactions is converted to chlorite, a 2 mg/L chlorine dioxide dose (maximum) could produce chlorite ion (ClO_2^-) level beyond the current maximum contaminant level (MCL) of 1 mg/L. Obviously no chlorine dioxide residual will be available for *CT* credit when the raw water has high concentrations of reduced Mn/Fe. (For unknown reasons, perhaps ferrous contamination or side reactions, ferric salts have also been observed to oxidize minor amounts (perhaps 10-15 percent) of the chlorite ion in water treatment.) An oxidant-demand study of BRWTP raw water has not been performed, which would help determine a ClO_2 dosage (as well as potential *CT* credits for disinfection).

Limited data suggests that manganese levels in BR may be unacceptably high only in summer and may be associated with low (near-zero) dissolved oxygen concentrations in the lowest zone of the reservoir. Wintertime (post-turnover) iron and manganese levels at SDB may be less than the National Secondary Drinking Water Regulations (NSDWR) guidelines (and City's goals) of 0.3 mg/L and 0.05 mg/L, respectively. The effect of physical forces (water mixing, sedimentation patterns, wind speed and direction, water level changes) on the manganese cycle in BR are unknown. Reservoir control strategies (mixing, aeration) for manganese are not investigated herein.

Limited profiling of BR at SDB also suggests that there may be less-than-objectionable levels of dissolved manganese in the top zone (5 meters) of the reservoir. The highest water level during the winter is 6 meters above the roof of the intake structure, which has eight 2 ft by 4 ft vertical openings and one 4.42 ft by 4.42 ft horizontal opening in the roof. Changing the approach flow to the intake structure from combined horizontal/vertical to downward only by plugging the vertical intake structure openings could reduce dissolved manganese levels to the BRWTP. A 6-foot diameter, 2-foot high concrete manhole ring could be placed on top of the roof to raise the the drawoff level into the higher dissolved oxygen layer. It is likely that under most

pumping/current combinations, low-manganese water from the 5-meter zone will be drawn into the intake. The intake velocity would become 1.6 ft/sec at 20 mgd, which may be low enough to minimize the impact on raw water pumping.

Raw water data suggests that iron and manganese control in BFC water may seldom be required to meet the City's (and NSDWR's) goals of 0.3 mg/L total iron and 0.05 mg/L total manganese. In that regard, if Northern could operate the BFC until after the fall turnover in BR, chemical costs for manganese removal might be minimized.

Taste and Odor Control/Algae. Little chlorophyll *a* (and no phytoplankton count) data are available from the SDB and BFC sampling locations. Although monthly phytoplankton counts in BR have been performed since 1993, samples were collected from the surface of the reservoir and contain floating species that may not be representative of BR raw water. Many organisms commonly associated with either taste and odor (*Oscillatoria*, *Cryptomonas*, *Dinobryon*, *Eudorina*, *Tabellaria*, *Synedra*, *Asterionella*) or filter clogging (*Tabellaria*, *Synedra*, *Asterionella*, *Stephanodiscus*) were not overly abundant in the monthly counts mentioned above. Thus the specific relationships and linkages among phytoplankton dynamics, taste and odor, and filter clogging remain largely unknown.

There is no data regarding methylisoborneol (MIB), geosmin, *Actinomycetes*, hydrogen sulfide, or other odor-producing compounds; nor have flavor profile analyses been conducted to characterize and identify sources of specific odors. Customer complaint history regarding non-chlorine-related taste and odor from BRWTP have not been provided or reviewed. It is not known whether taste and odor problems originate in the distribution system or raw water source. As a result, it is difficult to identify MIOX's specific taste and odor deficiencies or predict the improvement from chlorine dioxide with respect to particular taste-and-odor-causing species or compounds. Experience has shown that chlorine dioxide works well against a wide variety of algae and other odor-producing compounds at many other plants, and nothing suggests that BRWTP is unique in that respect.

For several years, Northern has applied copper sulfate to the BFC as an algaecide on a weekly basis. The application method, dose and effectiveness of this practice are unknown. Although algal dynamics in BFC and BR may be impacted somewhat by Northern's aquatic plant control practices, these practices are not under the City's control and are not considered a viable control measure for BRWTP algae.

Dissolved air flotation (DAF) is being considered for pretreatment for this project, and one of DAF's notable advantages with respect to conventional sedimentation is its effectiveness on low-density solids such as algae.

Data Review Summary. The historic bases for preoxidation at BRWTP (taste and odor control, biological growth control, and iron and manganese reduction) are difficult to quantify from the data reviewed, which is likely more a problem with the data not the process. It can be said that high levels of reduced iron and manganese from the deepest part of BR prior to turnover are well defined. However during most of this seasonal occurrence, manganese-free water from BFC is available. Minor intake modifications might also help control manganese from BR. In the absence of an oxidant-demand study of wintertime BR raw water and considering historically low wintertime levels of dissolved iron and manganese at SDB, temporary plant-scale chlorine dioxide testing during the winter may not represent the worst case.

The fact the chlorine dioxide does not form trihalomethanes or haloacetic acids, and MIOX does, is a major benefit and will afford a level of comfort and additional insurance at BRWTP in terms of meeting the City's goals of 40 μg/L TTHM and 30 μg/L HAA5, LRAA. In years past, BRWTP has produced relatively high levels of TTHMs as a result of using gaseous chlorine for preoxidation. It appears that split-feeding of MIOX has minimized this problem, at least through the BRWTP distribution system entry point. (Although rarely practiced in the United States, the capability of feeding chlorine dioxide as a postdisinfectant at both plants is at least an intriguing concept.)

Although *CT* credits for disinfection are unknown at this point in time, chlorine dioxide is clearly superior with respect to *Giardia* and *Cryptosporidium* inactivation than MIOX alone. Switching to chlorine dioxide would likely enable the City to achieve its public health goals for *Giardia* without baffling modifications in the existing clearwell with BFC and low-Mn/Fe BR raw water.

Chlorine Dioxide Equipment Manufacturers

Chlorine dioxide can be generated in several ways, among which are the following:

- Acid-chlorite.
- Aqueous chlorine-chlorite.
- Recycled aqueous chlorine.
- Two-chemical using chlorine gas and solid sodium chlorite.
- Electrochemical.
- Two-chemical using chlorine gas and sodium chlorite.
- Three-chemical using sodium hypochlorite, sodium chlorite, and acid.
- Three-chemical using sodium chlorate, hydrogen peroxide, and acid.

This technical memorandum eliminates acid-chlorite, aqueous chlorine-chlorite, recycled aqueous chlorine, two-chemical using chlorine gas and solid sodium chlorite, electrochemical, and two-chemical using chlorine gas and sodium chlorite systems from consideration due to the fact that they utilize chlorine gas, costs, production limits, excess chlorine byproducts, safety, or a combination of the above. Only the final two generator types above are considered feasible for BRWTP. It is assumed that only automatic (as opposed to batch) systems will be considered.

<u>Three-chemical using sodium hypochlorite, sodium chlorite, and hydrochloric acid</u>. Also referred to as "chlorite ion-based," or "hypochlorite/hydrochloric-acid-based" systems, major manufacturers of three-chemical generators of this type include Vulcan Performance Chemicals (Vulcan);); Sabre Oxidation Technologies, Inc. (Sabre); PureLine Treatment Systems (PureLine); and International Dioxcide, Inc. (IDI). This list is not exclusive. Most of North America's sodium chlorite is manufactured by Vulcan in Wichita, Kansas.

All the above systems are vacuum driven with no metering pumps and, as a result, shut down automatically upon loss of motive force (water) to the eductor, can be flow-paced, and are provided with multiple alarms to ensure that any out-of-range condition is communicated promptly. All manufacturers offer a variety of lease/purchase/service-contract options. Full-service programs are those where the costs of the generator and associated equipment are covered under a supply contract for the sodium chlorite that extends for typically 2-3 years. The City of Arvada currently has a Vulcan three-chemical system.

There are many minor differences amongst the various generators. The IDI generator mixes the precursors at the same time, which requires the pH be maintained in the range of about 2.5 to 3.0 ("low-pH"). Excess chlorine may therefore be produced, particularly in alkaline waters, to lower the pH to this level.

It is clear that minimizing excess chlorine, chlorite ion, chlorate ion, hydrogen peroxide, perchlorate ion, and other impurities are major concerns in municipal drinking water applications. Although differences in generation technology amongst the above manufacturers might determine the composition and purity of their respective generator's effluents, to our knowledge no side-by-side comparisons have been conducted to confirm the various manufacturers' claims regarding conversion efficiency, purity, yield, and byproducts.

Three-chemical using sodium chlorate, hydrogen peroxide, and acid. Also referred to as "chlorate ion (ClO_3^-)-based," or "acid/peroxide/chlorate"systems, this method has long been the method of choice for producing large quantities of ClO_2 for the pulp and paper industries. Currently, the only generator of this type for municipal drinking water applications is Akzo Nobel/Eka Chemicals' (Eka) Single Vessel Process (SVP)-Pure system, which is distributed in Colorado by PureLine. It is referred to herein as a "three-chemical" system, however two of its chemicals (hydrogen peroxide and sodium chlorate) are blended to form a proprietary compound, "Purate," which is warehoused in Pueblo.

Like the chlorite-ion-based systems above, SVP-Pure is vacuum driven and shuts down automatically upon loss of motive force (water) to the eductor, can be flow-paced, and is provided with multiple alarms to ensure that any out-of-range condition is communicated promptly. Unlike the chlorite ion-based systems, SVP-Pure pumps the precursors to the eductor with metering pumps. SVP-Pure can be flow-paced. Eka offers a variety of lease/purchase/full-service-contract options. The City of Lafayette currently has an SVP-Pure system.

Advantages claimed for the chlorate-based system include chemical costs (both lower handling and lower cost per lb of ClO_2) and non-volatile (no off-gassing) precursors.

Disadvantages of the chlorate-based system include the fact that, although non-volatile, 78% sulfuric acid can cause severe tissue destruction from relatively short exposure. Dr. Gilbert Gordon's article entitled *Is All Chlorine Dioxide Created Equal?* (Journal AWWA, April 2001) is attached and raises potential disadvantages with chlorate ion-based systems including perchlorate ion byproducts and hydrogen peroxide pass-through. The objectivity of these observations may be compromised somewhat by the fact that the article's cited perchlorate ion data was provided by a competitor (Sterling Pump Chemicals).

Present Worth

Costs for chlorine dioxide generators are presented in the table on the next page. For purposes of this analysis, it was assumed that the City would purchase the chlorine dioxide equipment, as well as a service contract, from the manufacturer. It was also assumed that the chemical storage tanks would be installed indoors to minimize off-gassing and freeze protection. Pending detailed structural design, it was assumed that chemical storage would be located in the former chlorine storage room and that the floor slab will likely require reinforcement or replacement.

Alternative	Cost	Installation Factor	Total Cost
THREE-CHEMICAL (SODIUM HYPOCHLORITE, SODIUM CHLORITE, AND HYDROCHLORIC ACID)			
Construction Costs			
Sitework and demolition[1]	$15,000	Included	$15,000
Concrete[2]	$40,000	Included	$40,000
Equipment			
Generators/online analyzer[3]	*$151,000*	*30%*	*$196,300*
Storage tanks/piping[4]	*$30,000*	*30%*	*$39,000*
Electrical/I&C	$20,000	30%	$26,000
Subtotal			$316,300
Contingencies (20%)			$63,260
Overhead and profit (10%)			$31,630
Construction Subtotal			$411,190
Operation and Maintenance Costs			
Manpower[5]			$38,000
Chemicals[6]			$101,300
Power[7]			$500
O&M Subtotal			$139,800
Present Worth, O&M[8]			$1,481,041
Total Present Worth of Alternative A			**$1,892,231**
THREE-CHEMICAL (SODIUM CHLORATE, HYDROGEN PEROXIDE, SULFURIC ACID)			
Construction Costs			
Sitework and demolition[1]	$15,000	Included	$15,000
Concrete[2]	$40,000	Included	$40,000
Equipment			
Generators/online analyzer[3]	*$112,000*	*30%*	*$145,600*
Storage tanks/piping[4]	*$20,000*	*30%*	*$26,000*
Electrical/I&C	$20,000	30%	$26,000
Subtotal			$252,600
Contingencies (20%)			$50,520
Overhead and profit (10%)			$25,260
Construction Subtotal			$328,380
Operation and Maintenance Costs			
Manpower[5]			$36,500
Chemicals[6]			$70,500
Power[7]			$2,500
O&M Subtotal			$109,500
Present Worth, O&M[8]			$1,160,000
Total Present Worth of Alternative B			**$1,488,380**

Notes:
[1]Demolition includes existing chlorine room floor.
[2]Concrete includes new floor in existing chlorine room, secondary containment.
[3]Two 200 lb/day generators, online ClO_2 analyzer, PLC.
[4]Three 6,000 gallon tanks for Alternative A; two 6,000 gallon tanks for Alternative B, plus associated interior piping.
[5]Operation and maintenance of equipment; monitoring, testing and reporting (total labor=$30/hr).
[6]25%NaClO2 at $0.60/liquid lb, 10%NaOCl at $0.15/liquid lb, 15%HCl at $0.22/liquid lb, Purate at $0.63/liquid lb, 78%$H_2SO_4$ at $0.12/liquid lb.
[7]$0.07/kW-hr, water usage=10 gpm for Alternative A; 30 gpm for Alternative B (plus two 1hp pumps).
[8]Series Present-worth Factor (P/A,7%,20)=10.5940.

Recommendation

Long-term. The present worth analysis above seems to bear out the fact that the chlorate ion-based system (SVP-Pure) may be less expensive than the chlorite ion-based systems—perhaps 20 percent. Because chemical costs represent the overwhelming majority of present worth costs for both designs, and because chemical costs will vary widely depending upon global market conditions, local availability, freight, the City's method of equipment procurement and scope of manufacturer services, it is somewhat difficult to accurately predict O&M. Complicating the

O&M issue further is the fact that the principal chemical in each system (sodium chlorite or Purate) is presently proprietary, either in fact or in effect.

However it can be said that compared with the current MIOX system, chlorine dioxide possesses both advantages and disadvantages. The advantages of chlorine dioxide were mentioned above and include:

- Efficacy against protozoa (improved *CT* credits for disinfection--in the absence of Mn or Fe, and possible synergistic *Cryptosporidium* effects using a chlorine or monochloramine secondary)
- Less pH dependency
- TTHM/HAA reduction
- Three-chemical system using sodium hypochlorite, sodium chlorite, and hydrochloric acid would allow MIOX system to be abandoned.
- Less power consumption

The disadvantages of chlorine dioxide include:

- Cost of precursors
- Safety
- Need for more complicated analysis methods and more skilled operators
- Regulatory (monitoring) requirements
- Additional chemical storage
- Uncertainties regarding chlorite and chlorate concentrations in the distribution system (See Helene Baribeaus's attached article entitled *Chlorite and Chlorate Ion Variability* (Journal AWWA, July 2002).

The regulatory requirements associated with chlorine dioxide are aggressive. The maximum contaminant level goal (MCLG) and MCL for chlorite are 0.8 and 1.0 mg/L, respectively. Daily chlorite sampling at the entrance to the distribution system is required, and any exceedance will trigger additional distribution system sampling. Monthly three-sample sets for chlorite in the distribution system are required for at least the first year using ion chromatography. Distribution system sampling may be reduced to quarterly, pending future exceedances. The maximum residual disinfectant level goal and maximum residual disinfectant level for ClO_2 are both 0.8 mg/L. Daily chlorine dioxide samples at the entrance to the distribution system are required, and any exceedance will trigger additional distribution system sampling.

The complexities associated with chlorine dioxide generation (process adjustments for variations in precursor chemical quality, maximizing generator yield and performance, optimizing alternate ClO_2 application points, distribution system variables, as well as required laboratory analyses), together with the City's staffing restraints, cast considerable doubts regarding the acceptance and implementation of new technology at BRWTP. Although service programs and adequate training for operators and lab analysts are available, this assistance may not be enough.

However, based largely on the City's unsuccessful experiences with MIOX at BRWTP and the successful use of sodium hypochlorite as a postdisinfectant at Betasso, it is recommended that a three-chemical system using sodium hypochlorite, sodium chlorite, and hydrochloric acid be piloted at BRWTP. Although the 20-year present worth of the three-chemical system using

sodium chlorate and Purate above would suggest that the chlorate ion-based design is perhaps 20 percent less expensive to operate and maintain, replacement of MIOX with sodium hypochlorite will make both Boulder water treatment plants comparable with respect to postdisinfectant chemical feed--an operational advantage with respect to shared staffing at the City. Although the chlorate ion-based system has fewer storage tanks, lower chemical handling costs, and may have lower annual chemical costs per pound of ClO_2, those advantages are mitigated somewhat by the fact that a chlorite ion-based system allows replacement of the existing MIOX system with sodium hypochlorite. Although somewhat difficult to quantify at BRWTP (power supply to MIOX not being metered separately), the annual costs for MIOX (salt, electricity, water, labor) are undoubtedly higher than they would be for bulk delivery of sodium hypochlorite. The off-gassing from chlorite ion-based precursors can be contained and treated per Code. The hazards associated with handling 78% sulfuric acid are generally recognized to be greater than those associated with 15% hydrochloric acid. (Although sulfuric acid could also be used to prepare activated silica, there are other reacting chemicals.)

Chlorine dioxide will almost certainly enable the City to meet its *Giardia* inactivation goals at 20 mgd using BFC or low Mn/Fe BR water without clearwell modifications. This assumption should be verified through profiling following preliminary design of the pretreatment facilities. In addition, full-scale synergism of chlorine dioxide followed by free chlorine may provide *Cryptosporidium* inactivation, one possible method of obtaining Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) credit, subject to CDPHE's approval.

Assuming that the piloting/evaluation phase proves encouraging, it is recommended that the City negotiate lease (or loan) terms for chlorine dioxide equipment, service contract terms and conditions, as well as a sole-source chemical purchase contract with the selected manufacturer.

Chlorine dioxide feed points should be installed upstream of the rapid mix, downstream of the rapid mix, downstream of the hydraulic mixer at the settled water contact basin, filter effluent pipe to the finished water storage reservoir, and high service pump discharge line to distribution (for future piloting). These applications points may be in different locations than presently, depending upon the final configuration of pretreatment facilities at BRWTP. Modeling future TTHM formation through BRWTP is made more difficult due to the possible changes in *CT*.

Changing the approach flow to the intake structure from combined horizontal/vertical to downward only by plugging the vertical openings, as well as placing a concrete manhole ring to raise the drawoff elevation into high-dissolved-oxygen/low-manganese water should be considered regardless of pre-oxidant. This work could be performed by divers for about $10,000. By lowering the pre-oxidant demand for iron and manganese control, the same level of protozoan inactivation can be achieved with no increase in dosage.

<u>Short-term</u>. Both Vulcan and PureLine have offered to provide free equipment for the City's short-term evaluation (assuming that the City agrees to purchase the precursor chemicals from them, as required) and a limited scope of services. Although PureLine markets different types of chlorine dioxide generators, their current offer extends to only Eka's SVP-Pure (chlorate ion-based) system. Both Eka's SVP-Pure and IDI's OXYCHLOR III trial units would be automatically flow-paced. Vulcan would provide monthly site visits for 90 days; PureLine would visit on 'regular intervals.' IDI has also offered to lease a manual unit for $500 per month; however they have offered to perform three chlorite/chlorate analyses per month and provide an indefinite number of monthly site visits. Theoretically the City could accept any or all of the

offers and do a side-by-side comparison. However, as discussed above, the specifics of the particular situation at BRWTP seem to favor a three-chemical system using sodium hypochlorite, sodium chlorite, and hydrochloric acid. Vulcan has more experience and more U.S. installations than either PureLine or IDI, which is a bonus. Similar to the long-term chlorine dioxide installations discussed above, terms and conditions of the short-term trial equipment agreement are negotiable.

Attachments:
Is All Chlorine Dioxide Created Equal? (Journal AWWA, April 2001)
Chlorite and Chlorate Ion Variability (Journal AWWA, July 2002)