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Memorandum

To: *Darrell Zimbelman, Public Works Department, Berthoud, CO*

From: *Chris Schulz, CDM*

Date: *October 15, 2009*

Subject: *Technical Memorandum: Berthoud Water Treatment Plant Assessment for Taste and Odor Control*

Purpose

The purpose of this technical memorandum (TM) is to present the results of a site visit to the Berthoud Water Treatment Plant (WTP) on September 10, 2009, together with CDM's observations, conclusions and recommendations with respect to the plant's current capability to control seasonal taste and odor events in the raw water supply (Berthoud Reservoir) and our recommendations for process upgrades to improve taste and odor related treatment performance. As outlined in the scope of work for this assignment, this TM addresses the following four questions:

- As designed, constructed, and operated is the Berthoud Water Treatment Plant capable of producing high quality, safe, reliable, and drinkable water as designed, constructed, and operated? The Town is particularly interested in comments and recommendations related to the plant's ability to minimize taste and odor issues in the water leaving the plant.

- Are there actions that the Public Works Department can take that will have an immediate impact on the elimination of taste and odor problems in the water leaving the Water Treatment Plant?

- Are there longer term infrastructure modifications or operating procedures that could be implemented to eliminated or at least minimize the potential for the production of water with taste and odor problems?

- If the response to question # 3 is positive, what steps should be implemented to develop a design for Water Treatment Plant modifications or additions that will address the identified deficiencies.

This TM completes the contractual obligations outlined in the engineering consulting agreement between the Town of Berthoud and CDM dated August 24, 2009.

Sources of Information

A site visit to the Berthoud WTP was held on September 10, 2009 for Chris Schulz of CDM to meet with the interim Public Works Director (Darrell Zimbelman) and plant operating staff to get updated on the plant process train and operating history, followed by a tour of the plant. The following documents were provided at the site visit and in subsequent correspondence between CDM and plant staff to support the engineering assessment presented herein.

- Comprehensive Performance Evaluation (CPE) report for the Berthoud WTP, prepared by Sear-Brown and dated May 6-8, 2002
- Construction drawings for the Berthoud WTP expansion, prepared by McLaughlin Water Engineers and dated October 1996.
- Monitoring schedule for the Berthoud WTP to meet requirements of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), prepared by the Colorado Department of Health and Environment (CDPHE) and dated December 2008.
- Monthly CDPHE reports on finished water quality data (turbidity, chlorine residual, fluoride residual, disinfection by-products and total organic carbon) for selected months over the period 2006 to 2008.
- Vendor product literature and equipment specifications for the powdered activated carbon (PAC) volumetric feeder for the Berthoud WTP, manufactured by Tecweigh.
- Results of full-scale testing of PAC doses and impacts on filter performance, prepared by Ed Simpson and transmitted to CDM by email attachment on September 21, 2009.

In addition, CDM contacted the equipment vendor for the Tecweigh PAC feeder and a specialty laboratory (Engineering Performance Solutions) with expertise in conducting carbon performance testing for taste and odor removal. The results of these discussions are included in this TM.

Existing Water Quality and Treatment Performance

Historical Taste and Odor Events

The Town of Berthoud has experienced severe taste and odor events and related customer complaints for several years which are attributable to algae growth in Berthoud Reservoir, primarily during the summer months. The off taste and odors are typically described by the Town's customers as "earthy-musty". The two most prevalent compounds associated with earthy-musty taste and odors in water are 2-Methylisoborneol (MIB) and Geosmin, which are metabolic by-products of blue-green algae growth. These compounds do not affect human health but can be detected by human senses at part per trillion (ppt) levels. While PAC can work well to remove these compounds, it is difficult to predict the PAC dose required for a particular water supply due to competitive adsorption demands by total organic carbon (TOC) and other constituents in water. No information has been collected to date by the Town to correlate historical PAC doses with MIB/Geosmin removal rates during taste and odor events. Accordingly, a taste and odor treatability study is recommended to support design recommendations for improving treatment performance with respect to taste and odor control, as discussed later.

Process Train Description

The Berthoud WTP was originally constructed in 1933 and has undergone several process upgrades since then, with a major plant expansion designed in 1996 and completed in 2000, which doubled the plant's rated capacity from 2 to 4 mgd. The average daily water production at the plant is currently 1 mgd with a peak production rate of 3 mgd. The plant operates intermittently for several hours each day to meet system demand. The SCADA system provides automatic start-up and shut-down of the plant based on operating water levels in the finished water clearwell and 3-mg storage tank.

The plant includes two process trains—Train A (commissioned in 1933) and Train B (commissioned in 1996), each rated at 2 mgd. The unit processes for each train are similar (except as noted below) and include:

- One rapid mix chamber (common to Trains A and B)
- One two-stage, vertical-shaft flocculation basin
- One clariflocculation basin (the flocculator drives are not used since they do not promote good flocculation)
- One post-clarification PAC contactor (for Train B only)
- Two multi-media filters, the filter media include 24 inches of anthracite over 6 inches of sand and 10 inches of support gravel.

Except for PAC addition, which is applied in the PAC contactor for Train B only, the treatment chemicals for both trains are the same and include:

- Potassium permanganate for preoxidation, applied in the raw water pipeline
- Cationic polymer (NALCO Ultrion 8157) for coagulation applied at the rapid mix chamber
- Sodium hypochlorite for preoxidation and post-disinfection applied at the rapid mix chamber and upstream of the finished water clearwell

- Fluoride for dental hygiene protection, applied upstream of the filtered water clearwell.

In 2008, two reservoir recirculation units (manufactured by Solar Bee) were installed in Berthoud Reservoir and the banks were relined with riprap. According to the plant superintendent, these upgrades have significantly reduced algal blooms in the reservoir and mitigated (but not eliminated) seasonal taste and odor problems in the finished water supply.

PAC Storage and Feed System

The existing PAC storage and feed system for Train B is located at the southwest quadrant of the Filter Building. It includes a volumetric feeder/hopper unit and solution/mixing tank supplied by Tecweigh, and a PAC contact chamber with a theoretical contact time of 16 and 32 minutes at design and average flows of 2 and 1 mgd, respectively. The new filter building is designed to be expanded to 4 mgd by adding two additional filter cells (replacing the older existing filters for Train A). Under this expansion scenario, clarified flows from Train A would be transferred to the PAC contact chamber to provide PAC addition for both plant trains, effectively cutting the available PAC contact time in half.

Based on a review of design information for the existing PAC system, and discussions with plant staff and the equipment vendor ((Techna-Flo of Englewood, CO), several design and operational deficiencies were noted which diminish the capability of this system to provide effective taste and odor control for the Berthoud WTP, as noted below.

- **PAC Feed Dose Accuracy**. The Tecweigh feeder has a volumetric feed capacity of 2 to 14 pounds per hour, assuming a PAC bulk density of 21 pounds per cubic foot, according to the specification sheet for the unit. However, the system at the Berthoud WTP typically operates at feed rates ranging from 0.15 to 0.4 pounds per hour, corresponding to feeder settings of 110 to 180, which is below the manufacturer's recommended operating range of 400 to 700. This is done in order to avoid head loss build-up on the downstream filters. Given the large discrepancy between manufacturer's data and plant operating records, it is recommended that the Tecweigh sales representative visit the plant to check on dose calibration of the feeder.

- **PAC Feed Capacity**. As stated above, the maximum feed capacity of the Tecweigh system is 14 pounds per hour, which corresponds to the following PAC design doses:

  - 10 mg/L at design flow of 4 mgd
  - 13.3 mg/L at historical maximum flow of 3 mgd
  - 40 mg/L at average design flow of 1 mgd

Typical PAC doses for MIB/Geosmin reduction range from 10 to 20 mg/L for moderate taste and odor events, but could be as high as 100 mg/L for severe taste and odor events. Accordingly, the feed system auger may need to be replaced with a larger unit, if laboratory testing indicates that higher PAC doses are required than can be fed by the existing 0.75-inch auger.

- **PAC Contact Time**. As discussed above the theoretical contact time of the PAC contact basin will be reduced to 8 minutes at design flow, if flows from Train A and B are treated. For effective PAC treatment, contact times of at least 30 minutes, and preferable 1-2 hours are recommended to allow the adsorptive capacity of the PAC to be more fully utilized. Furthermore, the contact basin does not include any internal baffling, so flow short-circuiting is likely occurring between the inlet and outlet piping, which significantly reduces the effective contact time for PAC adsorption.

- **Impacts on Filter Performance**. Full-scale testing of different PAC feed rates, performed recently by plant staff, indicates that filter run times are severely limited at higher PAC doses. PAC feed rates were gradually ramped up from 0.15 to 0.4 lbs/hr over a period of several days to determine impacts on filter run time. These rates equate to a PAC dose of 0.4 to 1.2 mg/L at a Train B flow of 1 mgd. At a PAC dose of 1.2 mg/L, filter run times were reduced to 18-20 hours, but increased to 26 to 30 hours, when the dose was slightly reduced. Conventional filters operating at filtration rates less than 4 gpm/sft (applicable to the Berthoud filters) should typically have run lengths 24 to 48 hours. Cleary, these test results indicate that PAC carryover to the filters negatively impacts head loss accumulation rates across the filter bed, resulting in shorter run times and more frequent backwashing requirements. Consequently, the existing post-clarification PAC feed system cannot be operated at the required dose range (10-20 mg/L) to deal with moderate taste and odor events, without significant adverse impacts to filter operations.

Taste and Odor Treatability Study

Due to the severity of past taste and odor events in the Berthoud water system, apparent ineffectiveness of PAC and preoxidation (using potassium permanganate and sodium hypochlorite) for controlling taste and odors, and lack of water quality data on taste and odor causing compounds, a treatability study is recommended to support development and costing of feasible design alternatives for effective taste and odor treatment at the Berthoud WTP. The main elements of the study are outlined below.

- **Reservoir Sampling Program**. Perform monthly sampling for MIB/Geosmin at the intake in Berthoud Reservoir for at least a two year period, beginning each year when sustained algae growth appears in the reservoir and continuing until MIB/Geosmin levels drop below 10 ng/L. The analytical results will be used to establish MIB/Geosmin trends in the reservoir for guiding both short-term (< one year) and long-term (2-3 years) taste and odor treatment design alternatives.

- **PAC Performance-Based Lab Testing**. Contract with a specialty laboratory to conduct performance-based jar testing to evaluate PAC doses for taste and odor control under the same treatment conditions as would occur at the Berthoud WTP. The testing procedure should be in accordance with ANSI-AWWA Standard B600 (Appendix B). The samples should be spiked with 100 ng/L of MIB and 100 ng/L of Geosmin to represent an extreme taste and odor condition in the reservoir. Consider three PAC media types (bituminous, wood and lignite based) and at least four PAC doses in the screening tests. The tests should only evaluate the proposed PAC application point in the rapid mix chamber (as discussed later) for a contact time through flocculation of 60 minutes. The test results will be used to select the best-performing, most cost-effective PAC media for the Berthoud WTP and develop PAC dose removal curves for MIB and Geosmin for each application point.

- **Ozone Demand/Decay Testing.** Perform laboratory testing to determine the ozone demand and decay characteristics of clarified water from the Berthoud WTP for a range of ozone doses and water quality conditions. These results will be used to select the ozone design dose for effective taste and odor control (MIB/Geosmin). In addition, the bromide ion and bromate concentrations should be analyzed before and after ozonation in laboratory testing to determine the bromate formation potential, which is a regulated ozone disinfection by-product.

Short-Term Process Improvements

The following short-term treatment process improvements should be considered to improve capability of the Berthoud WTP for treating taste and odors in Berthoud Reservoir by the summer of 2010 prior to implementation of long-term solutions, which may take up to three years for implementation.

- **Eliminate Continuous Prechlorination**. The Berthoud WTP applies sodium hypochlorite at the rapid mix chamber for preoxidation and to maintain a residual across the pretreatment basins and filters. It is recommended that continuous prechlorination be stopped since it provides no apparent benefit to the treatment process, and research has shown that it is ineffective for removing Geosmin/MIB related taste and odors. In addition, chlorine can temporarily mask musty/earthy odors and, in some cases, enhance them in the distribution system when the chlorine residual dissipates. Potassium permanganate should continue to be applied year-round as a preoxidant for improved coagulation and manganese reduction. However, its use should be avoided, if possible, during periods of PAC addition, since it will exert an oxidant demand on the PAC, resulting in higher PAC doses for controlling taste and odors. Capability for prechlorination should be retained to provide a periodic maintenance dose of chlorine to prevent biological growths in the pretreatment basins.

- **Convert to Biofiltration**. By stopping prechlorination, chlorine residuals will no longer be carried through filtration and consequently heterotrophic biological activity will increase over time across the filters, converting them to mature biological filtration processes within a 4-6 month period. Recent research has shown that biological filtration can be effective in achieving 40 to 50% reduction in MIB/Geosmin during warm water conditions. Moreover, biological filtration is an important treatment step in combination with ozonation, which may be recommended as a long-term taste and odor treatment solution for the Berthoud WTP. Ozonation is a very strong oxidant which breaks down organic matter into smaller biodegradable organic compounds which can be removed by biological filtration, thereby producing a biologically stable finished water and reducing the risk of biological regrowth in the distribution system.

- **Relocate PAC Application Point to Rapid Mix Chamber**. The PAC application point should be relocated to the rapid mix chamber to allow higher PAC doses (in the range of 10 to 20 mg/L) and longer contact times (1-2 hours through clarification), which are currently not possible at the current application point upstream of the Train B filters. The raw water application point will also allow both Trains A and B to be treated with PAC during seasonal taste and odor events. Selection of the optimal PAC type and dosage should be determined from special laboratory testing, as discussed earlier. Impacts on coagulant dosage, settled water turbidity and residuals should be determined through jar testing, possibly by the NALCO sales representative who has done previous jar testing work at the Berthoud WTP. The Tecweigh feed system can be relocated to the loading dock adjacent to the rapid mix chamber, until such time as long-term process improvements for taste and odor control are implemented at the plant. To reduce the level of effort associated with manual refilling of the PAC feed hopper using 50-lb bags—particularly at the higher PAC doses required for effective taste and odor removal—consider using 1,000-lb PAC "super-sacks" which can be offloaded and positioned above the hopper for gravity feed using a standard fork lift.

Long-Term Process Improvements

The need for long-term (up to three years out) and more capital-intensive process improvements for taste and odor control at the Berthoud WTP will be dictated by results of the treatability study, with confirmation from the first year of operation of short-term improvements in the summer of 2010. Three design alternatives should be considered for long-term improvements, as discussed below.

Alternative 1: Convert Anthracite-Sand Filters to Filter-Adsorbers

Under this alternative, the filter building for Train B would be expanded to include four filter cells, with the existing anthracite-sand filter media replaced with granular activated carbon (GAC). The older filters for Train A would be abandoned and yard piping would be modified to transfer clarified water from Train A to the 24-inch inlet piping to the new filter building. The automatic backwash sequence would be reprogrammed to provide lower backwash rates for effective media expansion and cleaning of the lighter GAC media, while avoiding media loss into the washwater troughs. The empty bed contact time (EBCT) for the GAC filter medium would be approximately 4.2 minutes at design flow (4 mgd), 5.6 minutes at historical maximum flow (3 mgd) and 16.8 minutes at average flow (1 mgd). These EBCTs are at the low end of the typical range for effective taste and odor control (7.5 to 10 minutes). If longer EBCTs were desired (to reduce GAC replacement frequency), the filter underdrains could be replaced with gravel-less underdrains to increase the GAC media depth to 26 inches, and increase the EBCTs by 50 percent.

It is not recommended to convert the older Train A filters to GAC filter-adsorbers because the filter structure is over 70-years old and the filter cells must be manually backwashed, which may increase the risk of GAC media loss.

Alternative 2: Install New Ozone System to Replace PAC Contactor

Ozone is the most powerful oxidant available in drinking water treatment and the most effective for oxidation of Geosmin and MIB compounds, achieving typical removal rates of 80-90 percent. Moreover, it does not form chlorinated disinfection by-products (trihalomethanes, haloacetic acids) which are regulated in drinking water. In conjunction with biological filtration, it can achieve higher reductions of total organic carbon than conventional treatment and produce biologically stable finished water. It can also be used intermittently, as needed, during taste and odor events, if its treatment role is limited to taste and odor control, to reduce annual operating cost of the system. However, year-round operation of the ozone system has been shown to provide multiple water quality benefits including improved filterability (lower turbidity and particle counts), reduced chlorinated DBPs in the distribution system, reduced chlorine demand for post-disinfection, and improved chlorine residual stability in the distribution system.

Based on the site visit and review of record drawings for the Berthoud WTP, it may be feasible to install the ozone system in the same space as the PAC contactor. The upper level of the contactor would be converted into an ozone generation room and the PAC contactor would be modified to include baffles and a gas-tight top slab. The ozone would be injected into the 24-inch inlet pipeline immediately upstream of the PAC contactor using a pumped sidestream injection system. Design issues to be addressed during preliminary design would include: sizing and space requirements of ozone system equipment components (liquid oxygen tank, ozone generator, offgas destruct unit, sidestream booster pump, and ozone injection piping), hydraulic gradeline impacts, contactor structural integrity, building mechanical requirements, and monitoring and control system.

Alternative 3: NCWCD Pipeline Extension to Bypass Berthoud Reservoir

One of the alternatives discussed during CDM's site visit to the Berthoud WTP was the possibility of the Town constructing a pipeline extension to the existing 18-inch raw water pipeline operated by the Northern Colorado Water Conservancy District (NCWD), which transfers flow from Carter Lake to Berthoud Reservoir. The pipeline extension would allow flows to be bypassed around Berthoud Reservoir directly to the Berthoud WTP, thereby eliminating the potential for taste and odors to develop in the raw water supply from algal blooms on the reservoir. Carter Lake is a deep reservoir and less subject to seasonal algal blooms. According to plant operating staff, the pipeline has a carrying capacity of 6 mgd and operates at a pressure of 50 psi at the proposed tie-in connection, which is sufficient to serve the Berthoud WTP without the need for a raw water storage reservoir or low lift pumping.

The pipeline connection project would involve a ½-mile pipe extension to the tie-in point and a new valve chamber owned and operated by the Town. A modulating control valve and venturi flow meter would be installed in the chamber. The valve would be controlled by the plant SCADA system to allow "on-demand" automatic and intermittent operation of the treatment plant to meet operating water levels in the clearwell and elevated storage tank, as discussed earlier.

The feasibility of this alternative will depend on the current contractual agreement between the Town of Berthoud and NCWCD for supplying raw water to Berthoud Reservoir, plus a detailed assessment of water quality characteristics of Carter Lake and the operating history of plants which treat water directly from that lake.

Recommended Implementation Plan

This assessment of the Berthoud WTP indicates that the existing plant does not have adequate treatment processes for effective taste and odor control. The existing post-clarification PAC system cannot operate at sufficient doses or contact times to achieve effective reductions in MIB/Geosmin concentrations, due to unacceptable filter plugging and head loss impacts on the downstream filters. The severity of algal blooms and MIB/Geosmin concentrations in Berthoud Reservoir have not been quantified to date so there is a lack of water quality data to support development of process design criteria and treatment process improvements for taste and odor control. To address these constraints, CDM recommends that the Town proceed immediately with the treatability study to fill water quality data gaps and implementation of short-term treatment plant improvements for improving the plant's capability to deal with taste and odor events by the summer of 2010.

In parallel with these activities, the Town should proceed with a predesign study to evaluate the three alternatives for long-term process improvements discussed above. This would be followed by detailed design, construction and start-up services for the recommended alternative. The recommended treatment improvements at the Berthoud WTP can be delivered using a traditional design-bid-build approach over a 2-3 year period or a fast-track design-build approach, which would cut the project schedule to 1-2 years. The design-build approach provides several compelling advantages for a project of this type:

- **Reduces the overall project schedule** for getting plant improvements online as soon as possible. This is a significant benefit given the Town's chronic history with taste and odor events in the water system. First, the competitive bid period between design and construction is eliminated completely. Secondly, the design often does not have to be taken to 100 percent completion. Since the end use of the design documents is not to prepare a bid package for a general contractor, but rather to develop the design sufficiently to allow for owner approval, satisfy construction permit requirements, and guide in-house and subcontractor construction efforts, typically, little is gained from developing design documents beyond 85 percent completion . Thirdly, it allows pre-construction and construction activities to overlap with the design phase. Some aspects of mobilization, materials procurement, and site development can begin while design is underway.

- **Provides single source responsibility**. In other words, the Town has the ability to contractually limit itself to one company (or team). In turn, that company assumes responsibility for completing the project in full, eliminating the designer-contractor conflicts common to conventional delivery. It also reduces the owner's administrative efforts, as they have one contract to manage as opposed to two or three.

- **Potential for construction cost savings**. Studies performed over the last 10 years have shown that design-build delivery reduces change orders and decreases project costs - while maintaining the same level of quality as conventional delivery. With design-build delivery, owners can often realize significant cost savings because of the shortened overall project schedule and reduced administrative burden (one entity, one contract).