Memorandum

Date: February 9, 2021

To: Town of Johnstown, CO

From: Burns & McDonnell
9785 Maroon Circle Suite 400
Centennial, CO 80112

Subject: Technical Memorandum – Jar Testing Results with Powdered Activated Carbon for Taste and Odor Control, Burns & McDonnell Project No. 130019

1. Introduction

This memorandum summarizes the results from jar testing that took place on January 4, 2021 and makes general taste and odor control recommendations based on the jar testing results. The purpose of this testing was to investigate powder activated carbon (PAC) dosages for optimal taste and odor removal. The goal of the testing was to identify potential improvements in current dosages and provide recommendations to the Town of Johnstown (Johnstown) for future improvements to the PAC system. If jar testing results show that PAC improvements are insufficient or not feasible, this memo will identify the next steps in developing a taste and odor control strategy.

2. Background

Johnstown has access to three primary raw water sources: Lonetree Reservoir, Johnstown Reservoir (Town Lake), and the Home Supply Ditch. Both reservoirs are subject to seasonal taste and odor issues, primarily caused by Geosmin and 2-methylisoborneol (MIB). While Geosmin and MIB concentrations are not regulated or harmful, they have a very strong, earthy taste and odor that is detectable by humans at very low levels (approximately 7 to 10 ng/L).

Geosmin and MIB concentrations are usually highest during late summer into early fall when reservoir levels are low. Both Lonetree and Johnstown Reservoirs are predominantly impacted by Geosmin. Table 1 summarizes approximately 9 years of Geosmin data for Lonetree and Johnstown Reservoirs. Figure 1 illustrates seasonal and yearly fluctuations in these concentrations. Analysis shows that of the two reservoirs, Lonetree tends to have slightly higher Geosmin concentrations.

Table 1: Historic Geosmin Concentrations

	Minimum	Average	Maximum	85^{th} Percentile	90^{th} Percentile	95^{th} Percentile
Lonetree Reservoir	1.51	129	985	188	330	365
Johnstown Reservoir	0.81	79	856	33.4	177	460

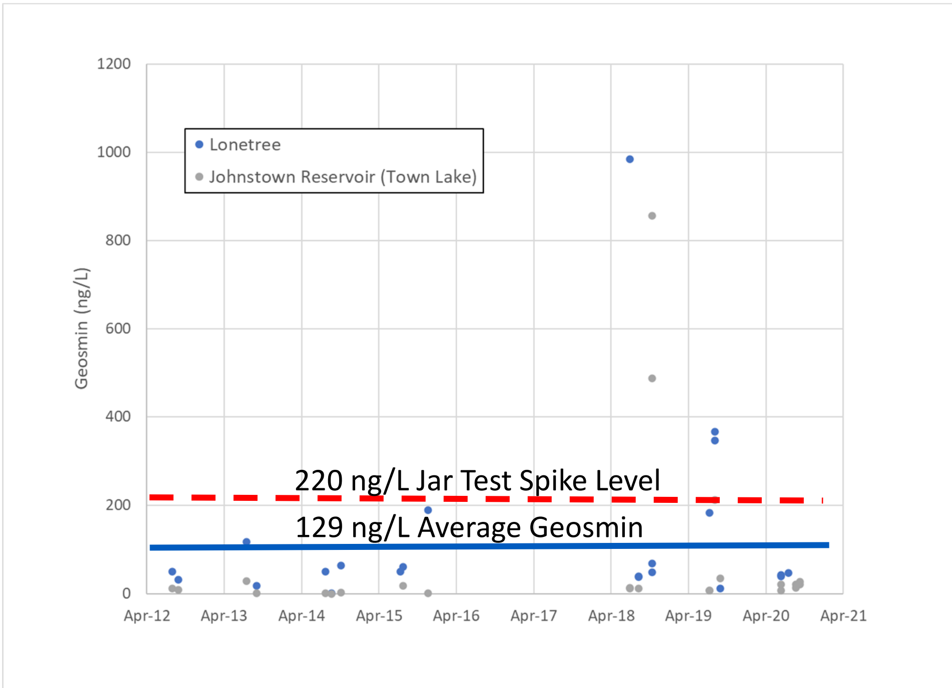

Figure 1: Historic Geosmin Concentrations

The current Johnstown WTP (3.1 mgd firm filtration capacity, 6.2 mgd total filtration capacity) processes include rapid mix, two-stage flocculation, dissolved air flotation (DAF), granular media filtration, and disinfection. PAC can be injected at the Lonetree Pump Station (PS) for pretreatment of raw water from Lonetree Reservoir and Home Supply Ditch. Currently, PAC dosing is limited to 1 to2 mg/L, due to equipment limitations and the manual labor required to add more than one or two 50 pound sacks of PAC per day. The existing system does not currently allow for adding more than one sack at a time, and the distance from the WTP limits the ability of operators to make frequent trips to the PS. The existing PAC system has a rated capacity of 150 pounds per day (lb/d). The PAC system was previously located at the Johnstown Reservoir PS but was relocated because the contact time was too limited and did not affect taste and odor levels at the WTP.

3. Comparison with Similar Systems

Johnstown data was compared with three similar municipalities in Colorado that also face taste and odor issues: The Town of Erie, the City of Thornton, and the City of Greeley. Each of these municipalities uses a different combination of technologies for seasonal taste and odor control.

3.1. Town of Erie

The Town of Erie (Erie), Colorado operates the Lynn R. Morgan Water Treatment Facility (16.65 mgd). The WTF processes include PAC injection, rapid mix, four-stage flocculation, sedimentation with inclined plate settlers, microfiltration membranes (submerged and pressure), granular activated carbon (GAC) contactors, solids handling, and disinfection. The PAC injection and GAC contactors are used for seasonal taste and odor control.

Erie utilizes four surface water sources for treatment and distribution: Raw Water Pump Station, Erie Lake, Northern Colorado Water Conservancy District (NCWCD), and Thomas Reservoir. All four raw water sources are conveyed to the facility by pipelines that combine in Vault B, which includes a PAC dosing point on the common feed. The GAC feed system operates downstream of the pressurized membrane system. The GAC system is utilized based on raw water TOC concentrations. Filtrate from the pressure membrane system is fed through the GAC system and blended with filtrate from the submerged membrane system.

Similar to Johnstown, Erie taste and odor issues are primarily caused by Geosmin. Raw water from Erie Lake presents the greatest treatment challenge for Erie, with an average value of approximately 400 ng/L and a maximum value of approximately 700 ng/L. However, Erie Lake is only used as a floating storage reservoir off the RWPS discharge pipes and is used periodically. Erie primarily utilizes water from the RWPS, which draws water from the Boulder Feeder Canal through diversion structure. The Boulder Feeder Canal averages below 10 ng/L Geosmin.

3.2. City of Thornton

The City of Thornton, CO (Thornton) recently completed construction on the new Thornton Treatment Plant (TTP, 20 mgd capacity). The TTP will treat water from three sources, Standley Lake, Thornton Water and East Gravel Lakes #4 (EGL4). Standley Lake water has few treatment challenges, with low pH being the primary concern as it could result in higher corrosion potential, and dissolved manganese concentrations varying over the course of a day. EGL4 water is challenging to treat due to organic material, higher mineral content, algal blooms, manganese, and taste and odor constituents. The TTP process design allows poor water quality EGL4 source to be treated separately prior to an ozone process. This ability to isolate EGL4 water for pre-treatment is expected to reduce chemical costs and allows operational flexibility.

TTP processes include iron and manganese oxidation, flash mixing, three-stage flocculation, lamella plate settlers, intermediate ozone, biological filtration, and disinfection. The combined use of ozone and biological filtration will be utilized to address taste and odor concerns that come with treating EGL4 water. A combination of jar testing, bench scale testing, and pilot testing was performed with both Standley Lake and ELG4 source waters to confirm and refine the individual treatment processes including pretreatment, ozone, and biological filtration.

Historic raw water quality from EGL4 indicated an average value of 4 ng/L and a maximum value of 80 ng/L for Geosmin. Design criteria for the facility assumed a maximum value of 300 ng/L.

3.3. City of Greeley

The City of Greeley, CO (Greeley) operates two water treatment plants, the Bellevue Water Treatment Plant (35 mgd) and the Boyd Lake Water Treatment Plant (38 mgd). The Boyd Lake WTP is a seasonal peaking plant that treats water from Boyd Lake and Lake Loveland. Boyd Lake has comparable water quality to Lonetree and Johnstown Reservoirs, as it is also filled with Big Thompson River water The Boyd Lake WTP has dealt with historic taste and odor issues, similar to Johnstown. Multiple technologies have been tested at the Boyd Lake WTP to control MIB and Geosmin including algaecide and DAF, but the WTP has continued to face taste and odor issues. Greeley is currently designing an ozone system to address their taste and odor issues.

4. Jar Testing Materials and Methods

At the time of testing, raw water was entirely sourced from Johnstown Reservoir. A week before jar testing, a raw water sample was taken from a sample tap on the WTP influent line to estimate a baseline concentration of Geosmin and MIB. This sample indicated that Geosmin and MIB concentrations were below detection limits.

To complete the jar testing, the raw water was spiked with Geosmin[1] to simulate estimated typical summer conditions in Lonetree Reservoir, approximately 200 ng/L. The raw water and spiked raw water were sent for analysis along with the jar testing samples. The raw water Geosmin concentration was still below detection limits at the time of jar testing. The spiked raw water Geosmin concentration was approximately 220 ng/L. The approximate human detection

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[1] The raw water was also spiked with MIB to simulate a typical estimated summer condition of 20 ng/L. However, all lab results had an MIB concentration below detection limits, indicating a potential bad ampule of MIB stock solution. This does not impact analysis or recommendations because in general Geosmin and MIB behave similarly and removals can be correlated. Additionally, Johnstown taste and odor issues are dominated by Geosmin.

threshold of Geosmin is 10 ng/L. This value was used to an establish a goal finished Geosmin concentration of 7 ng/L.

The jar tests used a Phipps & Bird jar tester. Each jar test followed the same protocol.
The jar test protocol simulated the hydraulic retention time (HRT) in the pipeline from Lonetree Reservoir to the WTP. The HRT was calculated based on 4.5 mgd , which was typical of average maximum day demand in 2020 when taste and odor issues were present. Each test lasted approximately 176 minutes with the jar tester mixers operating at 5 RPM to simulate the slow-mixing conditions in the pipeline. One test also included a sample representative of the HRT from Johnstown Reservoir to the WTP, which is approximately 12 minutes. After the pipeline simulation, Burns & McDonnell pulled water samples from each of the four jars.

ESML Analytical tested the samples for Geosmin and MIB. Johnstown provided total organic carbon (TOC) data, taken at the time of the jar testing, as well as historic data.

4.1. Chemical Additives

Jar testing was limited to PAC as the only type of chemical additive. PAC adsorbs constituents (e.g., TOC, taste & odors) located within the liquid process stream. Burns & McDonnell prepared stock solutions of PAC using Burns & McDonnell equipment as well as equipment provided by the Johnstown WTP lab. Jar testing was performed to determine the Geosmin removal rates for varying PAC doses. Burns & McDonnell evaluated three (3) types of PAC as adsorbents in this study: Norit Hydrodarco® 20BF, Calgon WPH800, and Calgon WPH1000. Johnstown WTP historically used Calgon WPH800, but recently switched to Calgon WPH1000.

5. Jar Testing Results

Figures 2 through 5 display the removal of Geosmin by varying PAC types and dosages.

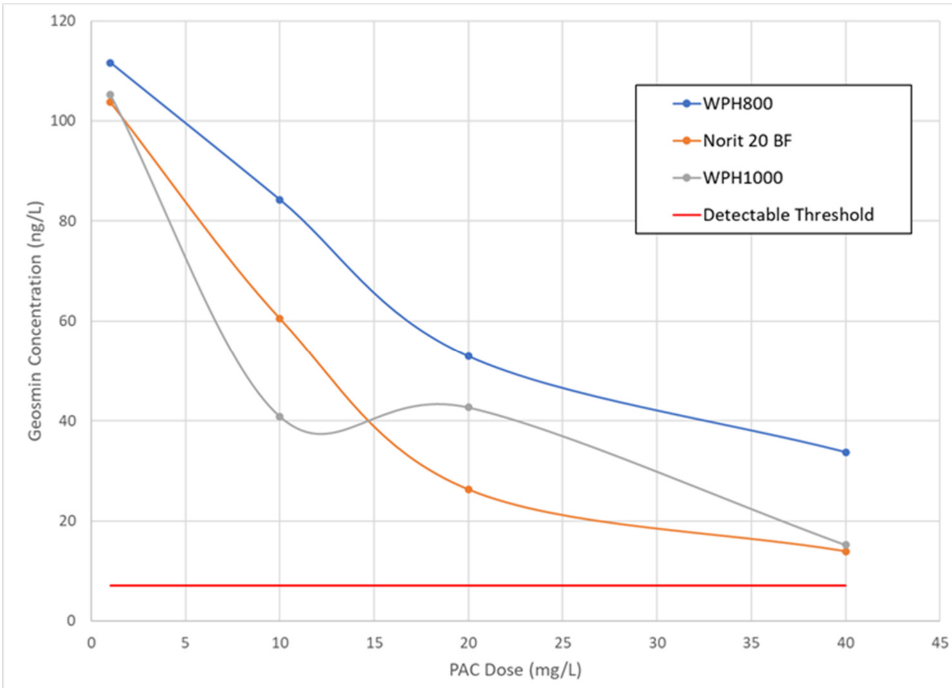

Figure 2: Final Geosmin Concentrations versus PAC Dose (mg/L)

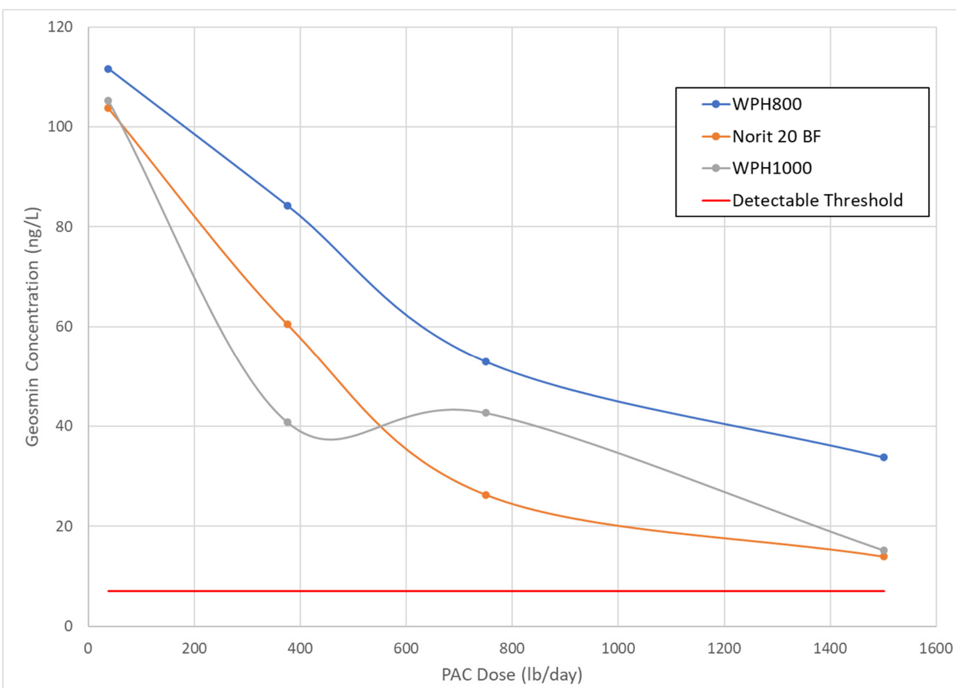

Figure 3: Final Geosmin Concentration versus PAC Dose (lb/d)

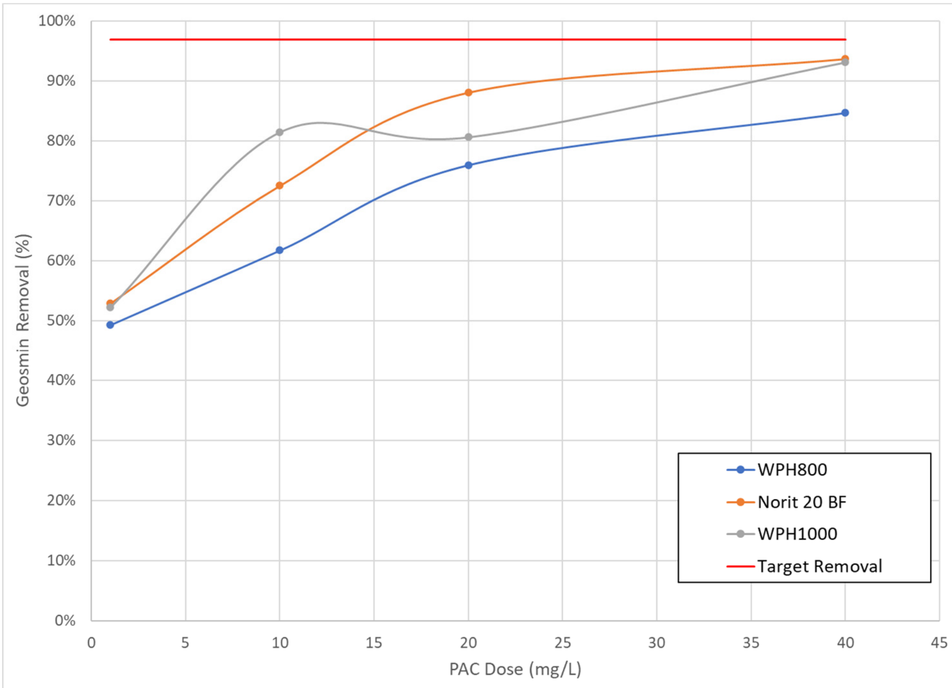

Figure 4: Percent Geosmin Removal versus PAC Dose (mg/L)

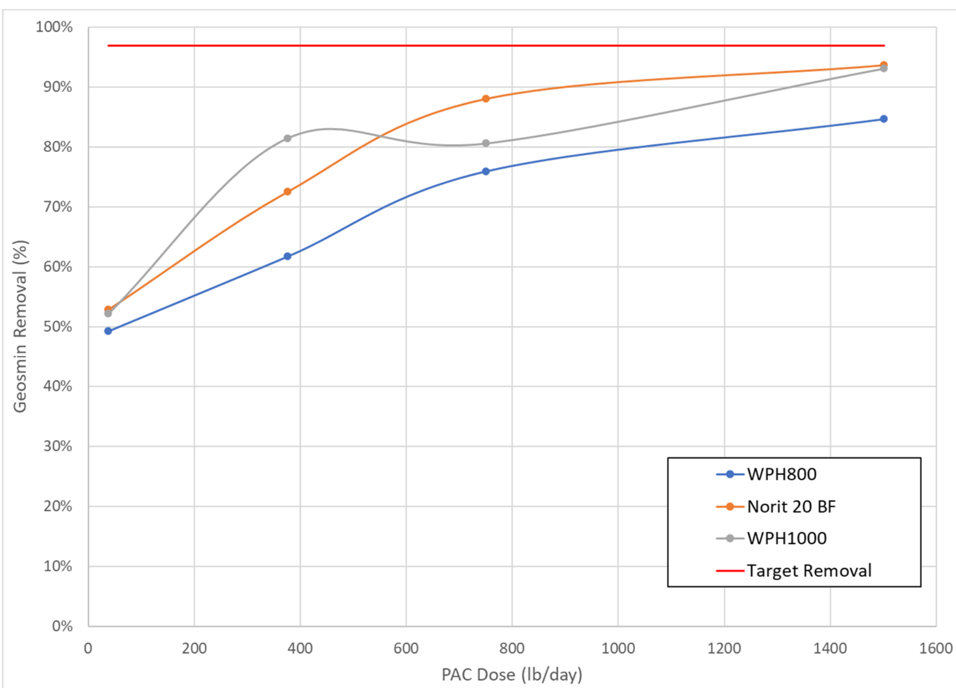

Figure 5: Percent Geosmin Removal versus PAC Dose (lb/d)

At all four doses tested, the previously used PAC, Calgon WPH800, proved to be the least effective. The newly employed PAC, Calgon WPH1000, demonstrated the best performance at all doses, except for at a dose of 20 mg/L. Norit Hydrodarco 20BF performed comparably to the Calgon WPH1000, particularly at the highest dose, and should be considered as an alternative. Both Calgon WPH1000 and Norit Hydrodarco 20BF demonstrated a maximum removal over 95%, while Calgon WPH800 demonstrated a maximum removal of approximately 85%. None of the PAC types tested were able to achieve the goal Geosmin concentration of 7 ng/L based on a starting concentration of 220 ng/L (96.8% removal).

The WTP currently doses approximately 1 to2 mg/L or one to two 50 pound sacks of PAC per day during peak taste and odor issues in the summer. At this dose in the jar tests, Geosmin was reduced approximately 50% to a level of 100 ng/L, which is consistent with the limited historic data provided by the town, as measured at the DAF inlet. At the doses of 10 and 20 mg/L, Geosmin removal was increased to approximately 60 to 80%. At the highest dose tested, 40 mg/L, Geosmin removal increased to almost 95% and almost met the detection threshold of 7 ng/L. However, this dose would mean a forty-fold increase in PAC consumption, which is not possible with current PAC system and staffing levels. High PAC doses are expected to have implications with the WTP operations, in particular on the DAF performance, shorten filter run times and increase the solids in the backwash pond. The high carbon load in the waste stream is also expected to have negative implications on the Central Wastewater Treatment Plant (WWTP), which is currently operating at its capacity.

5.1. HRT Impact

During the third jar test using WPH1000, a sample was also taken at approximately 12 minutes to simulate the HRT of the pipeline between Johnstown Reservoir and the WTP. Figure 6 compares the results of the two HRTs. At a dose of 10 mg/L WPH1000, the Johnstown Reservoir HRT only achieved a Geosmin concentration of approximately 85 ng/L. In comparison, the Lonetree HRT with same dose achieved a Geosmin concentration of approximately 40 ng/L. A sample was also taken from the 1 mg/L PAC dosed jar, but an error at the ESML lab resulted in the 10 mg/L sample being tested twice, resulting in the same Geosmin value for both jars.

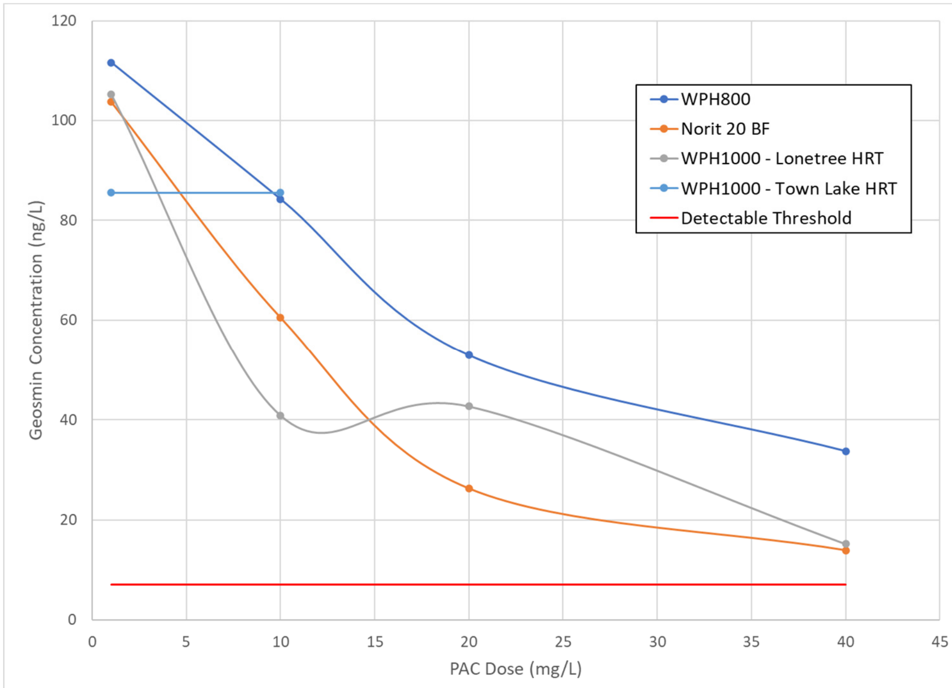

Figure 6: HRT Impact on Geosmin Removal

5.2. TOC Potential Impacts

Johnstown WTP staff provided TOC data for the week of testing as well as historic data (see Table 2 and Figure 7). The sample taken on January 7, 20201 had a TOC concentration of 4.3 mg/L, which is comparable to the average influent TOC. This is an important consideration because PAC may selectively remove TOC over Geosmin and MIB when TOC concentrations are high. TOC is typically highest in the summer when Geosmin and MIB are also highest. This means that the results of this jar testing are likely accurate for average conditions, but that lower Geosmin and MIB removal may be expected when TOC concentrations are higher.

Table 2: Historic TOC Data Summary (2016-2020)

	TOC (mg/L)
Minimum	2.6
Average	4.0
Maximum	5.3

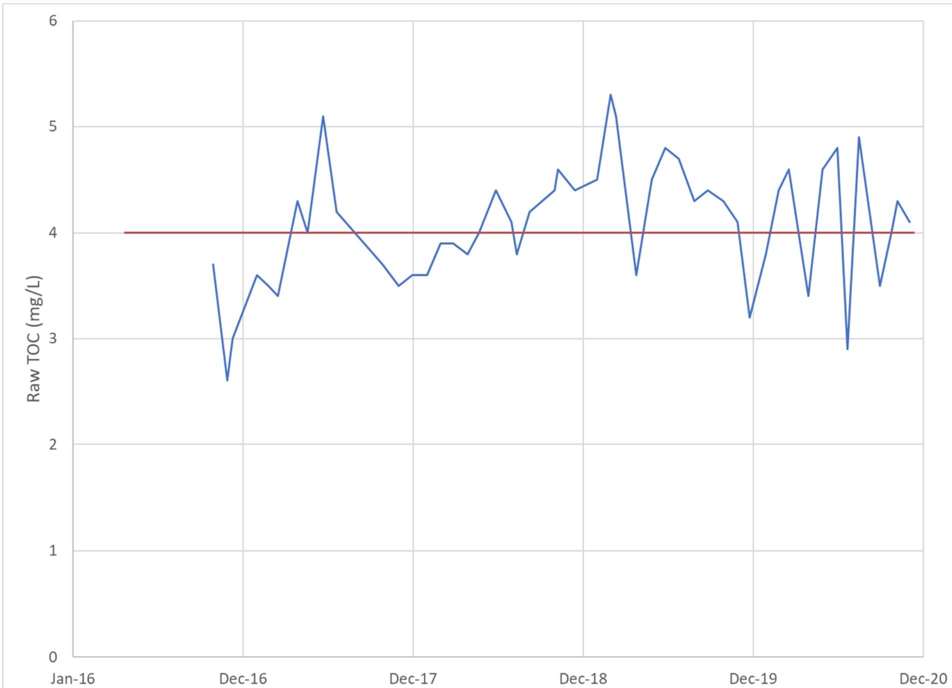

Figure 7: Historic TOC Trends

6. <u>Jar Testing Conclusions</u>

Jar testing confirmed that the new WPH1000 PAC is more effective than the previously used WPH800 PAC, particularly at higher doses. Results also showed the Norit Hydroarco 20BF PAC to perform comparably to the WPH1000. The WTP can use this information to make decisions about future PAC purchases.

Jar testing also confirmed that the HRT in the pipeline from the Johnstown Reservoir to the WTP provides insufficient contact time to remove Geosmin in comparison to the pipeline from Lonetree to the WTP.

The jar testing revealed limitations in the existing PAC dosing system. The current dose of 1 to 2 mg/L is insufficient to reduce Geosmin levels to below the detection threshold. A dose of 10 to 40 mg/L is required to achieve closer to the Geosmin concentrations desired but may not be feasible due to existing infrastructure and potential impacts to other processes in the WTP, including increased labor and solids loading.

7. Alternative Taste and Odor Removal Technologies

There are several operational approaches and treatment technologies for taste and odor control available to the town:

- Source Water Management
- Lake Management
- Powdered Activated Carbon
- Optimize DAF
- Granular Activated Carbon
- Oxidant
- Biologically Active Filtration

7.1. Source Water Management

The Johnstown water supply system is included in Figure 7 below. Lonetree Reservoir and Johnstown Reservoir are the town's primary water sources. However, to mitigate taste and odor issues, the town may consider the following source management alternatives:

- Strategically switch the blending ratio between Lonetree Reservoir and Johnstown Reservoir during taste and odor events
- Establish the ability to pump directly from the Home Supply Ditch to avoid high taste and odor compounds in the Lonetree Reservoir. Current piping configurations prevent direct access to the Home Supply Ditch when the Lonetree Reservoir is at a high operating level.
- Use the existing interconnections with the Little Thompson Water District, Central Weld County Water District, or the City of Greeley to replace or supplement the WTP production when taste and odor compounds are present.
- Investigate the feasibility of accessing the town's Chapman Reservoir water right to diversify raw water sources.

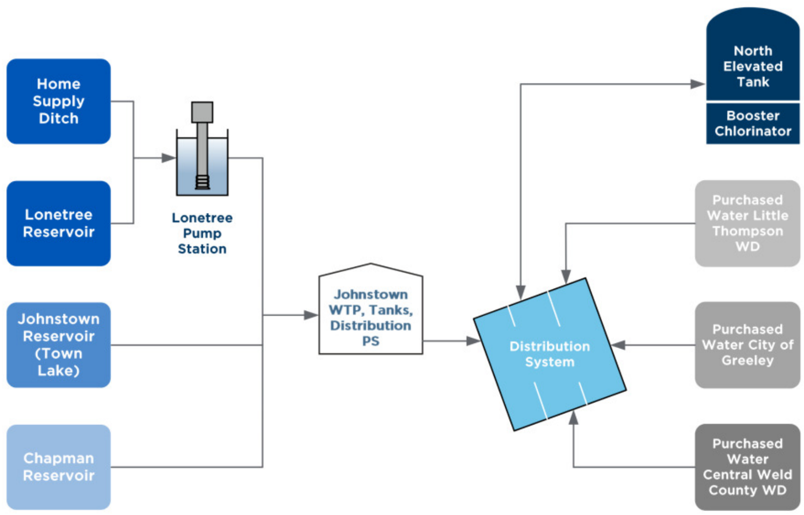

Figure 7: Johnstown Water Supply System

7.2. Lake Management

Lake management strategies for reducing taste and odor issues include level management, use of algaecide or ultrasonic buoys. The town does not have control over the operating levels in the Lonetree Reservoir. Algaecide will require care to prevent overdosing and risk to natural life. Ultrasonic buoys have the ability to reduce blue-green algae growth using with ultrasonic technology. The buoys are solar powered and low maintenance. Ultrasonic buoys are recommended as an easily implemented option ahead of the high taste and odor season of 2021. The application is suitable for the shallow depths in the Johnstown Reservoir. Deploying ultrasonic buoys in Lonetree Reservoir is more complex and may not be allowed by the reservoir manager.

7.3. Powder Activated Carbon

If the town desires to keep using PAC at a higher dose, this could be accomplished through changes to the existing system, a temporary system, or an entirely new system.

The existing system is only rated for 150 lbs/day with a hopper sized for 126 lbs. In order to increase the output, the town could either change the gear reducer to increase auger speed or change the existing auger and spout diameter to a larger size. However, these changes could only feasibly increase the output to 200 lbs/day. Jar testing indicated approximately 60% removal at this dose. It would be the lowest cost PAC expansion but would significantly increase the labor required to monitor the existing PAC system at its maximum capacity. Any increase to the PAC dose also will significantly increase solids loading on the WTP and increase the carbon load at the WWTP.

Multiple manufacturers such as Velodyne, Cabot Norit and SST have pre-fabricated, skid or container-mounted PAC systems. These systems come in different configurations, including indoor, outdoor, and container system options. A temporary PAC system could increase dose rates to over 1,600 lbs/day, which showed removals ups to 90%. The lead time on a temporary system could be anywhere from 4 weeks to over 6 months depending on the manufacturer and option selected. Lease costs are variable between $5,000 to $8,000/month in comparison to a purchase cost of approximately $200,000.

The town could also replace the entire existing PAC system. This would likely require adding a new a building at the Lonetree Reservoir. An approximately 45-foot by 10-foot footprint is available to either expand the existing concrete masonry unit building or add a new foundation for a pre-engineered metal building. A new system could increase the capacity to over 2,500 lbs/day, which demonstrated over 90% removal in jar testing. Lead time for the building would likely be approximately five months to account for permitting and approvals, while the equipment lead time is approximately six months. This option would likely cost between $300,000 to $700,000 for PAC equipment, an estimated building cost of $200,000 and related piping, valves, electrical and controls between $100,000 and $500,000.

7.4. Pretreatment Optimization

Two options to potentially increase T&O removal in pretreatment are optimizing the existing DAF or consider a saturated air flotation (SAF) conversion.

Optimizing the DAF process could potentially increase TOC, T&O, and algae removal. In order to optimize the DAF system, testing would need to occur to establish baseline removals. Increased removal could be achieved by adjusting chemical doses with alternative chemicals, such as the Cat-Floc 8108-Plus polymer the town intends to implement in early 2021.

A SAF conversion involves a change from dissolved to saturated air. SAF processes utilize a surfactant to create anionic bubbles that both attract and lift suspended compounds in the raw water. A conversion would require the addition of a foaming agent generator and emulsion mixer. The existing saturators, compressors, and recycle pumps would be abandoned or removed. SAF systems offer increased flow and solids loading capacities when compared with conventional DAF processes. While a DAF process typically runs at approximately 7 gpm/sf and floats 3% of solids, a SAF process may achieve over 20 gpm/sf and floats up to 6 to 8% of solids. The equipment for a SAF conversion would be approximately $500,000 and likely would involve CDPHE approval of the process change.

7.5. Granular Activated Carbon

There are many options for implementing GAC at the WTP. GAC absorbs T&O compounds through contactors, which can be installed as either pressure vessels or as media in the existing filters (GAC caps). If installed as pressure vessels, the process could be either before or after filtration. GAC involves frequent media replacements after the GAC has been consumed. In comparison to other alternatives, GAC has increased maintenance and is more expensive in terms of both capital and maintenance costs. GAC is anticipated to achieve between 40 to 70% Geosmin removal or higher, depending on the contact time, age of the GAC, solids loading rate, source of the carbon and pretreatment performance. GAC has slightly lower MIB removals than Geosmin removals. Costs and lead time will be highly dependent on configuration chosen.

7.6. Oxidation

Oxidation can be accomplished by using ozone, chlorine, potassium permanganate, or aeration. Chlorine, potassium permanganate and aeration are typically applied to oxidize other compounds in drinking water not related to taste and odor. Ozone is a strong oxidant that is effective at removing taste and odor compounds. An ozone system includes a liquid oxygen vessel (lease or purchase), ozone generators, reactors, and destructors. There is potential to reuse the existing clarifiers for the reactor, but the open basins must be refitted with tops to prevent the unwanted loss of ozone to the atmosphere. An ozone system would likely be the most expensive option for the town, for both capital and maintenance. Equipment costs for a fully redundant ozone system is approximately $2,700,000, plus costs for the associated structure, reactor vessel, piping, valves, electrical, controls and installation. Ozone is also the most complex to operate but would likely achieve the highest Geosmin removal (over 90%). An added benefit of ozone is that it is eligible for primary disinfection credits and will reduce the required water level to be maintained in the existing ground storage tanks to meet disinfection contact time. The town could also consider adding hydrogen peroxide for more advanced oxidation. One potential option would be pre-ozonate at the Lonetree PS, which would increase the reaction time. However, it is important to consider the potential to generate bromate, a harmful disinfection byproduct.

7.7. Biologically Active Filtration

Biologically active filtration (BAF) is another taste and odor control process that can achieve over 90% removal. BAF achieves T&O removal by biodegradation. Chemicals are added as a nutrient source, including pre-ozone or another carbon source, ammonium sulfate, and phosphoric acid. BAF could be implemented at the WTP by retrofitting the existing granular media filters. A recycle stream would be added to maintain the biology, and a deeper filter column may be required. The process would also require increased monitoring to manage the biological process through more complex chemical injection and monitoring systems. BAF is not applicable if the town converts to a membrane filtration based process.

8. Conclusions

Jar testing revealed that PAC is likely not a practical option to address the historic taste and odor issues related to Gesomin to below detection thresholds. A multi-phased approach is recommended to gain partial removals through several steps across the water sources and treatment processes. The town is interested in a temporary, leased equipment option to help with taste and odor control for the 2021 summer season while a longer term solution is implemented with the WTP expansion. The town should determine if a leased or purchased facility is suitable for the short term.

Longer term, the town should consider a multi-phase approach that incorporates reservoir management, and either a combination of PAC, DAF, and GAC technologies. Alternatively, the high effectiveness of ozone makes it suitable as a single-step process for taste and odor control.

Additional water quality testing, jar testing and potentially pilot testing is recommended for the optimization of the existing DAF system, an evaluation of a SAF conversion and additional investigation into potential GAC configurations for short-term relief in 2021.

BDP/mal