ABSTRACT

Groveland Community Services District (GCSD) owns and operates the water system serving the communities of Groveland, Big Oak Flat, and Pine Mountain Lake. The source of raw water is the Hetch Hetchy reservoir. Water is pumped from the Hetch Hetchy tunnel by the supply pumps located at the Big Creek Shaft and the Second Garrotte Shaft. Treatment facilities consisting of chlorine disinfection and lime addition for corrosion control are installed at each of these locations. The reaction of chlorine with the natural organic matter in the water results in the formation of disinfection byproducts (DBPs) including total trihalomethane (TTHM) and haloacetic acids (HAAs).

GCSD is planning to construct disinfection system improvements at two water treatment plants to comply with the DBP rules. Suggested improvements include short term chlorination, chloramination in the existing clear wells, and UV radiation. Onsite sampling was performed on November 25, 2003 at the Second Garrotte Shaft to evaluate the proposed disinfection modifications design criteria for conditions (such as raw water quality, travel time in the water distribution system) observed at the GCSD water system. The primary objectives of the testing program are listed below:

1. To document the decrease in DBP formation when chloramines are used instead of free chlorine.

2. DBP formation tends to increase as the disinfectant residual concentration and contact time increase. Testing was performed to quantify the effects of chloramines residual concentration and contact time (time in the distribution system) on DBP formation.

3. Pre-chlorination with free chlorine will be applied for a short period of time (for approximately 10 minutes) before ammonia is added to achieve four logs of virus inactivation. Testing was performed to quantify the amount of DBP formation as a result of chlorination for approximately 15 minutes.

4. It is suggested that the UV dosages used in water treatment (40 mJ/cm^2) would not cause significant levels of chloramines decay (if any). Testing was performed to determine the effect of UV radiation on chloramines decay.

SUMMARY OF TESTING RESULTS

Considerable amounts of TTHMs and HAA5 were observed with current disinfection practices at a water temperature of 10.4ºC. DBP formation was greatly reduced when monochloramines were used in lieu of free chlorine. Bromate and chlorite were not detected in any of the samples. A reduction of approximately 85 to 90 percent in DBP concentration was observed as a result of monochloramination after 15 minutes of chlorination. As expected the TTHM concentration was observed to increase with time, but even the highest TTHM value measured in this testing program (9.2 µg/L) was significantly lower than the future MCL for TTHM (80 µg/L). HAA5 was not detected

immediately after chloramination. HAA5 was observed to increase with time like TTHM, but even the highest HAA5 value measured (13 µg/L) was significantly lower than the future MCL for HAA5 (60 µg/L). The effect of UV radiation on chloramination was observed to be insignificant. Monochloramine destruction was observed to be only two percent with a UV dose of 40 mj/cm^2.

THREE STEPS TO COMPLY WITH THE DISINFECTANT/DISINFECTION BYPRODUCT RULES

By

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Groveland Community Services District (GCSD) is located in southern Tuolumne County in the central Sierra Nevada foothills serving the communities of Groveland, Big Oak Flat, and Pine Mountain Lake. GCSD currently serves less than 3,000 customers at an average daily water demand of approximately 0.5 million gallons per day (mgd). The source of raw water is the Hetch Hetchy reservoir. Because Hetch Hetchy water is relatively pristine and meets the EPA's Surface Water Treatment Rule (SWTR) criteria for filtration avoidance, the California Department of Health Services (DHS) approved a filtration avoidance waiver in 1993 for GCSD. However, the SWTR includes a provision that "*if an unfiltered system fails any of the avoidance criteria, that system must install filtration within 18 months, regardless of future compliance with avoidance criteria*." With the currently configured water treatment plants, the District will not be in compliance with recently adopted and proposed drinking water regulations.

DESCRIPTION OF EXISTING WATER SYSTEM

The GCSD water system consists of two supply pump stations with treatment facilities and clearwell storage, and five storage tanks serving 11 pressure zones. Water is pumped from the Hetch Hetchy tunnel by the supply pumps located at Big Creek and Second Garrotte. Total treated water storage capacity within GCSD is approximately 6,600,000 gallons including the two clearwells located at Big Creek shaft and Second Garrotte shaft. Each of the clearwells has a capacity of 2,000,000 gallons. The water stored in the clearwells is pumped to five other storage tanks in the distribution system by booster pumps located at the treatment facilities. Treatment consists of disinfection via chlorination and pH adjustment.

Chlorine, in the form of sodium hypochlorite, is injected at two separate points. Chlorine generated on site is added before the clearwells to achieve the required disinfection levels for the inactivation of giardia and viruses. A static mixer is used to diffuse the chlorine. Required disinfection levels are achieved based on chlorine residual concentrations (chlorine dosage is controlled based on a preset chlorine residual concentration) and the reaction time in the clearwell. Clearwells are baffled to minimize short circuiting. Additional chlorine is added just after the clearwells to prevent microbial re-growth and biofilm production in the distribution system. Chlorine residual levels are continuously monitored at the inlet, midpoint, and outlet of the clearwells.

Lime is added after the secondary chlorine injection point to increase the pH levels to 9.5-10 to provide corrosion control. A static mixer is used to mix lime with water, and pH levels are monitored continuously.

Turbidity levels are measured continuously using online turbidimeters to monitor compliance with the filtration avoidance criteria.

SUMMARY OF DBP ISSUES AND REGULATORY IMPACTS

As stated previously, GCSD currently uses chlorine for disinfection purposes. Chlorine has been the primary disinfectant used in drinking water treatment systems in the United States for more than 80 years. Chlorine reacts with naturally occurring organic matter in the water to form compounds such as chloroform and other trihalomethanes, haloacetic acids, halonitriles, haloaldehydes, and chlorophenols. These substances are called DBPs, and they have the potential to cause cancer in humans. The formation of these potential carcinogenic compounds have led the EPA to impose maximum contaminant levels (MCLs) for certain DBPs including total trihalomethanes (TTHM) and haloacetic acids (HAAs). Disinfectants and disinfection byproducts (D/DBP) rules are based on HAA5 concentration, which is the total concentration of five of the nine HAAs.

Based on the existing data available on TTHMs and HAA5, GCSD will not be in compliance with the pending and proposed D/DBP rules. The key requirements of the various pending and proposed regulations for GCSD are summarized in Table 1.

TABLE 1
SUMMARY OF KEY REGULATORY IMPACTS FOR GCSD CONSIDERING PENDING AND PROPOSED EPA RULES

		D/DBP MCLs			
		TTHMs		**HAA5s**	
Rule	**Compliance Date**	SRAA[a]	LRAA[b]	SRAA	LRAA
Stage 1 D/DBP	January 2004	80 µg/L	n/a	60 µg/L	n/a
Stage 2 D/DBP Phase 1	3 to 5 years after rule promulgation	80 µg/L	120 µg/L	60 µg/L	100 g/L
Stage 2 D/DBP Phase 2	8 ½ to 10 ½ years after rule promulgation	n/a	80 µg/L	n/a	60 µg/L
Long Term 2 Surface Water Treatment Rule	8.5 years after rule promulgation	Minimum of two disinfectants required[c]			

[a] System-wide running annual average
[b] Locational running annual average
[c] Complete inactivation requirement for each of the regulated pathogens (virus, giardia, cryptosporidium) should be achieved with one of the disinfection methods

PROPOSED WATER TREATMENT PLANT DISINFECTION MODIFICATIONS

Several short and long term measures were evaluated to mitigate the problems associated with DBPs. Short term measures are those that do not require a large capital expenditure that can be implemented in 2004, and will enable GCSD to comply with current regulations including the Stage 1 D/DBP Rule. Two short term solutions evaluated were: (1) operation of clearwells in batch mode with disinfection using chloramines, and (2) removal of DBP precursors (organics) with activated carbon. Treatment modifications including ozonation, filtration, and ultraviolet radiation, all in combination with chloramination were analyzed as long term measures to comply with the proposed D/DBP regulations.

Long term alternative involving short term chlorination, chloramination, and UV radiation was recommended for GCSD as a result of the evaluation study. Short term chlorination (for approximately 10 minutes) is proposed to achieve 4 log virus inactivation to comply with the proposed Long Term 2 Surface Water Treatment Rule (LT2). Chloramination and UV radiation will follow short term chlorination. Chloramination will take place in the existing clearwells and is included in the project to provide residual disinfection and to reduce the formation of DBPs by converting free chlorine to chloramines. UV is proposed to achieve the total required inactivation levels for Giardia and Cryptosporidium, and to comply with the two disinfectant requirement of the LT2 rule. UV will be implemented after the clearwells, because there is a considerable amount of sand in the raw water, and the sand would abrade the quartz sleeves of the UV lamps in a short time. Also, the existing plant layouts tend to favor the installation of UV facilities after the clearwells.

Identical disinfection modifications are proposed for both treatment plants. All of the disinfection steps at both plants are designed for a flow rate of approximately 2.1 mgd. Anticipated future average and maximum daily water demands at Big Creek and Second Garrotte are approximately 0.95 mgd and 2.1 mgd, respectively.

DBP TESTING PROGRAM

Onsite sampling was performed on November 25, 2003 at the Second Garrotte Shaft to evaluate the proposed disinfection modifications design criteria for conditions (such as raw water quality, travel time in the water distribution system) observed at the GCSD water system. The primary objectives of the testing program are listed below:

1. To document the decrease in DBP formation when chloramines are used instead of free chlorine.

2. DBP formation tends to increase as the disinfectant residual concentration and contact time increase. Testing was performed to quantify the effects of

chloramines residual concentration and contact time (time in the distribution system) on DBP formation.

3. Pre-chlorination with free chlorine will be applied for a short period of time before ammonia is added to achieve four logs of virus inactivation. The reaction time between the organics and chlorine would be approximately 7.0 minutes for the proposed disinfection modifications. Testing was performed to quantify the amount of DBP formation as a result of chlorination for approximately 15 minutes.

4. The effect of UV radiation on free chlorine and chloramines decay is not well understood. It is suggested that the UV dosages used in water treatment (40 mJ/cm^2) would not cause significant levels of chloramines decay (if any). Testing was performed to determine the effect of UV radiation on chloramines decay.

Specific methodology, analytical results, and conclusions from the DBP testing program are presented below.

Methodology

Higher DBP levels were measured previously at Second Garrotte Shaft compared to Big Creek Shaft between 1998 and 2002. Testing was therefore undertaken at Second Garrotte and samples were collected for laboratory analysis during the testing program. The methodology followed to achieve the program objectives is discussed below.

Existing Sampling Procedures at Big Creek and Second Garrotte

Free chlorine residual, pH, and turbidity are monitored continuously at both plants before and after the clear wells. These measurements were recorded when samples were collected.

DBP Formation with Current Disinfection Practices

Free chlorine (in the form of sodium hypochlorite) is currently applied before and after the clear wells. Two water samples (GCSDS1-1 and GCSDS1-2) of the chlorinated water after the clear well were collected for laboratory analysis to determine the amounts of DBPs formed with current disinfection practices. Free chlorine residual values were 3.15 mg/L and 1.67 mg/L (see Table 1) before and after the clear well respectively. Results of these tests are compared with the results of the tests conducted with chloramines (discussed later) to determine the decrease in DBP formation when chloramines are used in lieu of free chlorine. One of the samples (GCSDS1-1) was collected for analysis to determine the DBP concentrations immediately after the clear well. The other sample (GCSDS1-2) was collected to evaluate the DBP levels in the distribution system. Residence times as high as five days are observed in the distribution system under average day conditions. Therefore the sample collected to evaluate the DBP formation in the distribution system (GCSDS1-2) was maintained at room temperature for five days to simulate worst case conditions (highest recorded water temperature values were between 13ºC and 14ºC). The temperature of the sample was observed to be around 21ºC during five days of sample retention.

DBP Formation with Chloramination After 15 Minutes of Chlorination

Tests were performed to analyze the effects of residual monochloramine concentration and contact time on DBP formation.

Six water samples (GCSDS2-1 through GCSDS2-6) were collected before the clear well after the current chlorination point. Monochloramines are formed from the reaction of chlorine and ammonia. Appropriate amounts of aqueous ammonia were added to the collected chlorinated water samples (after approximately 15 minutes of chlorination) to obtain monochloramine concentrations similar to the values suggested in the proposed disinfection modifications. The theoretical chlorine to ammonia ratio (free chlorine as Cl_2 / NH_3-N) is five to form monochloramines. Chlorine to ammonia ratios from 3:1 to 6:1 were tested to select the ratio to form monochloramines. Ratios from 4:1 to 6:1 (free chlorine as Cl_2 / NH_3-N) resulted in essentially the same monochloramine concentration (for the same free chlorine residual concentration). A ratio of 3:1 resulted in approximately five percent more monochloramine concentration compared to higher chlorine to ammonia ratios. A chlorine to ammonia ratio of approximately 4 to 1 (chlorine to ammonia ratio in the suggested disinfection modifications) was then selected to produce monochloramine. A monochloramine concentration of 2.09 mg/L was obtained for the tests suggested to be conducted at a monochloramine concentration of 2 mg/L (GCSDS2-1, GCSDS2-3, GCSDS2-5, and GCSDS3-1). A monochloramine concentration of 2.61 mg/L was obtained for the tests suggested to be conducted at a monochloramine concentration of 2.5 mg/L (GCSDS2-2, GCSDS2-4, GCSDS2-6, GCSDS3-2, and GCSDS3-3). Two of the samples (GCSDS2-1 and GCSDS2-2) were collected to determine the DBP concentrations immediately after chloramination. Other samples (GCSDS2-3 through GCSDS2-6) were collected to evaluate the DBP levels in the distribution system. Samples GCSDS2-3 and GCSDS2-4 were retained for two days at a water temperature of approximately 21ºC. Samples GCSDS2-5 and GCSDS2-6 were retained for five days at a water temperature of approximately 21ºC. Monochloramine concentrations were also measured at the end of two and five days of sample retention.

Decay of Chloramines with UV radiation

Tests were performed to quantify the chloramine decay amount caused by UV radiation (if any). Three water samples were collected before the clear well after the current chlorination point. Appropriate amounts of aqueous ammonia were added to the collected chlorinated water samples (after approximately 15 minutes of chlorination) to form monochloramines as in the suggested disinfection modifications. The samples were packed in cool boxes with pre-frozen icepacks and were couriered to Trojan Technologies for UV application.

Results

The analytical results obtained in this testing program are discussed in this section and summarized in Table 2.

DBP Formation with Current Disinfection Practices

The total organic carbon (TOC) concentration was 15 mg/L for both chlorinated samples (GCSDS1-1 and GCSDS1-2) collected after the clear well. For the other samples collected, the TOC concentration is expected to be close to 15 mg/L because the collection period only extended over five hours. For reference, the TOC value of 15 mg/L is relatively high for GCSD considering the range for TOC concentrations was 1.3 mg/L - 10.2 mg/L between January 2002 and July 2003. Higher levels of DBPs are generally observed for high TOC concentrations. DBP rules are based on HAA5 concentration, which is the total concentration of five of the nine HAAs. TTHM and HAA5 concentrations were observed to be 49.2 µg/L and 43 µg/L, respectively with current disinfection practices. The temperature of the water after the clear well was observed to be 10.4ºC, which is approximately 3ºC - 4ºC lower than the highest temperature values observed during June and July. DBP levels would likely be higher during summer months because more DBPs are formed as the water temperature increases. This is demonstrated in the sampling program where the TTHM and HAA5 concentrations increased to 59.1µg/L and 90 µg/L, respectively, when sample (GCSDS1-2) was maintained at room temperature for five days. Bromate and chlorite were not detected in either of the samples collected with current disinfection practices.

DBP Formation with Chloramination After 15 Minutes of Chlorination

TTHM concentrations were observed to be 3.81 µg/L and 3.70 µg/L (after approximately 15 minutes of chlorination) for monochloramine concentrations of 2.09 and 2.61 mg/L, respectively. HAA5, bromate and chlorite were not detected at either of the monochloramine residual concentrations. TTHM concentrations were observed to increase to 7.8 µg/L and 9.2 µg/L after two days of retention at room temperature for monochloramine concentrations of 2.09 and 2.61 mg/L, respectively. TTHM concentrations were observed at 7.8 µg/L and 9.0 µg/L after five days of retention for monochloramine concentrations of 2.09 and 2.61 mg/L, respectively. HAA5 concentration was observed to increase to 13 µg/L after two and five days of retention at room temperature for a monochloramine concentration of 2.61 µg/L. Bromate and chlorite were not detected after five days of retention. Therefore, it can be concluded that significant DBP formation occurred within two days.

TABLE 2
GROVELAND COMMUNITY SERVICES DISTRICT
RESULTS OF DBP TESTING PROGRAM SAMPLING UNDERTAKEN NOVEMBER 25, 2003

		Target chlorine residual	Target chloramine residual	Sample retention	Observed chlorine residual		Ammonia addition	Monochloramine residual after ammonia addition		pH	Temperature at time of sampling		Temperature during sample retention		Turbidity	Parameters analyzed in laboratory	TOC	TTHM	HAA5[a]	Bromate	Chlorite
Sample ID	Sample Type	(mg/L)	(mg/L)	(days)	Before Clear Well (mg/L)	After Clear Well (mg/L)	mg/L	At time of sampling (mg/L)	After sample retention (mg/L)		ºF	ºC	ºF	ºC	NTU		mg/L	µg/L	µg/L	µg/L	mg/L
GCSDS1-1	After clear well, chlorinated	--	--	--	--	1.67	--	--	--	7.15	50.7	10.4	--	--	0.330	TOC,TTHM, HAA5,Bromate, Chlorite	15	50	43	ND	ND
GCSDS1-2	After clear well, chlorinated	--	--	5	--	1.67	--	--	--	7.15	50.7	10.4	69.8	21.0	0.330	TOC,TTHM, HAA5,Bromate, Chlorite	15	59.1	90	ND	ND
GCSDS2-1	Raw water, chlorinated for 15 minutes, ammonia added	2	2	--	2.2[b]	--	0.55	2.09	--	7.14	55.0	12.8	--	--	0.352	TTHM,HAA5, Bromate, Chlorite	--	3.81	ND	ND	ND
GCSDS2-2	Raw water, chlorinated for 15 minutes, ammonia added	2.5	2.5	--	2.65[b]	--	0.67	2.61	--	7.15	56.8	13.8	--	--	0.340	TTHM, HAA5, Bromate, Chlorite	--	3.70	ND	ND	ND
GCSDS2-3	Raw water, chlorinated for 15 minutes, ammonia added	2	2	2	2.2[b]	--	0.55	2.09	1.65	7.14	55.0	12.8	69.8	21.0	0.352	TTHM	--	7.8	--	--	--
GCSDS2-4	Raw water, chlorinated for 15 minutes, ammonia added	2.5	2.5	2	2.65[b]	--	0.67	2.61	2.04	7.15	56.8	13.8	69.4	20.8	0.340	TTHM, HAA5	--	9.2	13	--	--
GCSDS2-5	Raw water, chlorinated for 15 minutes, ammonia added	2	2	5	2.2[b]	--	0.55	2.09	1.23	7.14	55.0	12.8	69.8	21.0	0.352	TTHM	--	7.8	--	--	--
GCSDS2-6	Raw water, chlorinated for 15 minutes, ammonia added	2.5	2.5	5	2.65[b]	--	0.67	2.61	1.49	7.15	56.8	13.8	69.6	20.9	0.340	TTHM,HAA5, Bromate, Chlorite	--	9	13	ND	ND
GCSDS3-1	Raw water, chlorinated for 15 minutes, ammonia added, UV radiated	2	2	--	2.2[b]	--	0.55	2.09[c]	--	7.14	55.0	12.8	--	--	0.352	Chloramines	--	--	--	--	--
GCSDS3-2	Raw water, chlorinated for 15 minutes, ammonia added, UV radiated	2.5	2.5	--	2.65[b]	--	0.67	2.61[c]	--	7.15	56.8	13.8	--	--	0.340	Chloramines	--	--	--	--	--
GCSDS3-3	Raw water, chlorinated for 15 minutes, ammonia added, UV radiated	2.5	2.5	--	2.65[b]	--	0.67	2.61[c]	--	7.15	56.8	13.8	--	--	0.340	Chloramines	--	--	--	--	--

[a] HAA5 concentration was observed to be equal to HAAs for all of the samples.
[b] Free chlorine residual concentration before ammonia addition
[c] Chloramine concentration observed at time of sampling before the sample is exposed to UV radiation

As expected some decay in monochloramine concentration was observed with time. Monochloramine levels decreased by approximately 20 percent and 40 percent after two days and five days, respectively. A monochloramine concentration of 1.23 mg/L was still observed after five days for an initial monochloramine concentration of 2.09 mg/L.

Decay of Chloramines with UV radiation

Tests were performed to quantify the extent of chloramine decay caused by UV radiation. Several UV doses were exposed to the samples to determine the UV dose required for one log destruction of chloramines. The dose required for one log destruction of chloramines was observed to be 4,420 mj/cm^2. Therefore, a dose of 40 mj/cm^2 (UV dose in the suggested disinfection modifications) would result in 0.009 log or about 2 percent monochloramine destruction.

CONCLUSIONS

Following conclusions are withdrawn based on the results obtained from the DBP testing program:

1. Considerable amounts of TTHMs and HAA5 were observed with current disinfection practices at a water temperature of 10.4ºC. Higher DBP levels would be observed during summer months because DBP formation is enhanced as the water temperature increases.

2. DBP formation was greatly reduced when monochloramines were used in lieu of free chlorine. A reduction of approximately 85 to 90 percent in DBP concentration was observed as a result of monochloramination after 15 minutes of chlorination.

3. As expected the TTHM concentration was observed to increase with time, but even the highest TTHM value measured in this testing program (9.2 µg/L) was significantly lower than the future MCL for TTHM (80 µg/L). HAA5 was not detected immediately after chloramination. HAA5 was observed to increase with time like TTHM, but even the highest HAA5 value measured (13 µg/L) was significantly lower than the future MCL for HAA5 (60 µg/L).

4. The effect of UV radiation on chloramination was observed to be insignificant. Monochloramine destruction was observed to be only two percent with a UV dose of 40 mj/cm^2.

5. Based on the results of this testing program, the suggested disinfection modifications are expected to bring GCSD into compliance with the pending and proposed Disinfectants/DBP rules.

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