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 system consists of two supply pump stations with treatment facilities and clearwell storage, and five storage tanks serving 11 pressure zones. The source of raw water is the Hetch Hetchy reservoir. Water is pumped from the Hetch Hetchy tunnel by 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. Because the 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. 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*." One of the avoidance criterion relates to disinfection byproducts (DBPs), including total trihalomethane (TTHM) and haloacetic acids (HAAs). TTHMs and HAAs can be formed when water containing natural organic matter is chlorinated. Because GCSD uses free chlorine for disinfection, DBPs above the maximum contaminant level (MCL) have been recorded in the system.

This paper addresses the issues of disinfection byproducts formation and provides alternatives for both short and long term solutions. A summary of DBP issues including regulatory impacts is provided.

MEETING THE CHALLENGE OF DISINFECTION BYPRODUCT REGULATIONS – NOW AND IN THE FUTURE

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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.

The EPA proposed additional conditions for the two disinfectant requirement for unfiltered systems (LT2). Each of the two disinfectants must achieve by itself the total inactivation required for one of the three pathogens (3 log Giardia lamblia inactivation, 2 or 3 log Cryptosporidium inactivation, and 4 log virus inactivation). This additional condition is intended to increase the redundancy and reliability of the disinfection systems in unfiltered systems. Therefore, necessary provisions are considered in this project to ensure that each disinfectant will achieve the total inactivation requirement for one of the pathogens.

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
LT2	8.5 years after rule promulgation	Two disinfectants required			

[a] System-wide running annual average
[b] Locational running annual average

Existing Facilities Performance with Respect to D/DBP Regulations

Current D/DBP rules as defined under the SWTR include the following: 1) maintenance of a disinfectant residual in the distribution system; and, 2) removal and/or inactivation of a minimum of 3 log (99.9%) of giardia and 4 log (99.99%) of viruses. Current MCLs for TTHMs and HAA5 are 100 micrograms per liter (µg/L) and 60 µg/L, respectively (system wide running annual average values). The existing treatment facilities at GCSD are capable of producing water in compliance with the current D/DBP rule.

The Stage 1 D/DBP rule MCL value for TTHM will be reduced to 80 µg/L (system-wide running annual average value). Annual TTHM average value for four sampling locations was 83 µg/L in year 2000. Based on existing data available on TTHMs, the existing treatment facilities will be unable to produce water that would meet the requirements of Stage 1 D/DBP rule.

Compliance with each future DBP MCL will be also determined based on a running annual average calculated at each sample location in addition to system-wide running annual average values with the Stage 2 D/DBP rule. TTHM concentrations as high as 205 µg/L were observed in the GCSD distribution system (with an annual average value of 119 µg/L). GCSD will not be in compliance with the proposed Stage 2 D/DBP rule with their existing disinfection practices.

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) is proposed to provide increased protection against microbial pathogens in public water systems which use surface water sources. The proposed LT2 focuses on cryptosporidium, a protozoan pathogen that is widespread in surface waters. GCSD would be required to provide at least 3 log inactivation for cryptosporidium unless it is demonstrated through monitoring that the system's mean cryptosporidium concentration is less than or equal to 1 oocyst/100 L (2 log inactivation is required if cryptosporidium concentration is less than or equal to one oocyst/100 L). In addition, at least two different disinfection processes (for unfiltered systems) would be required to achieve the total inactivation requirement of 2 (or 3) log for cryptosporidium, 3 log for giardia, and 4 log for viruses. Cryptosporidium is highly resistant to inactivation by chlorination (required cryptosporidium inactivation levels can not be achieved with feasible detention times and typical chlorine dosages). LT2 requirements can not be met with the existing system, because chlorination is the only disinfection method currently employed.

EVALUATION OF DISINFECTION ALTERNATIVES

Short and long term measures that were evaluated to mitigate the problems associated with DBPs are discussed below.

Short Term Measures

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 and with the Stage 1 D/DBP Rule. Two short term solutions evaluated are: (1) operation of clearwells in batch mode with disinfection using chloramines, and (2) removal of DBP precursors (organics) with activated carbon.

Operation of Clearwells in Batch Mode with Disinfection Using Chloramines

By injecting chloramines at the inlet of the clearwell, it is possible to achieve the required detention times for GCSD's water system, if the following operational modifications are adopted to operate the clearwells in batch mode:

- Lock out the distribution system booster pumps during the time the clearwells are filling (For a period of time T1, see Table 2).
- Lock out both supply and distribution pumps for an adjustable time period after the clearwells are full (T2, see Table 2).
- Lock out the supply pumps and pump from the clearwells to the distribution system to satisfy maximum daily demand and emergency needs (T3, see Table 2).

One disadvantage of using the clearwells in batch mode is that the operational complexity of the treatment plants will increase. Additional reporting requirements may be imposed by DHS on the use of clearwells in batch mode. Each of these factors will increase the labor cost of operating the chloramination facilities. Probable capital cost of this alternative is $110,000. Operational and maintenance costs were estimated at $0.06 per thousand gallons of water treated.

Activated Carbon

Granular activated carbon was evaluated as a treatment method to reduce the organic precursors prior to chlorination. Carbon treatment can remove up to 60% of the organics. American Water Works Association literature indicates typical organic removal percentages from 40 percent to 50 percent.

Based on eight hours per day operation at 1,600 gpm (with influent organic carbon of 2.0 mg/L) and carbon replacement cost of $100,000, GAC treatment would cost $0.24 per thousand gallons. In addition, the total capital cost to install GAC equipments at both plants was estimated to be approximately $1,700,000. Due to the high capital and operating costs, GAC treatment was not recommended as a short term solution.

TABLE 2
SUGGESTED CYCLE TIMES FOR OPERATION OF CLEAR WELLS IN BATCH MODE WITH DISINFECTION USING CHLORAMINES (RESIDUAL CONCENTRATION 2-4 MG/L)

CT Treatment Segment	Cold Weather Period Second Garrotte	Cold Weather Period Big Creek	Warm Weather Period Second Garrotte	Warm Weather Period Big Creek
T1, hr	1	0.7	2.1	1.1
T2, hr	2.8	3.4	0.6	2.5
T3, hr	1	0.7	2.1	1.1

Long Term Measures

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. Each of these alternatives is discussed below.

Pathogen Inactivation with Ozone and Residual Disinfection Using Chloramines

Ozone, chemical symbol O_3, is an allotrope of oxygen. Ozone is an unstable gas, with a half-life of a few hours in air, and from approximately 30 to 120 minutes when dissolved in water, depending on the pH, water temperature, and other factors. Ozone has a pungent odor at low concentrations. This characteristic is considered a safety factor, because ozone leakage may be detected by smell before it reaches harmful exposure concentrations.

Ozone is created naturally by ultraviolet light reacting with air, or with high voltage electrical discharges during lightning storms. Ozone is a powerful oxidant, second only to fluorine, and is the most powerful oxidant used in water treatment plants. Ozone is manufactured for use in water treatment plants by exposing air or oxygen to a high voltage of 4,000 to 20,000 volts. Ozone is produced when oxygen (O_2) molecules are sufficiently excited by the electrical discharge to disassociate into atomic oxygen (O^-) and subsequently combine with an oxygen molecule to form an ozone (O_3) molecule.

The electric discharge method of ozone production utilizes electrodes spaced close together, with a non-conducting dielectric in the space between the electrodes, plus a discharge gap, which is a small space for passage of air or oxygen. Clean, dry air, or high purity oxygen flows through the space. The dielectric serves as a layer of insulation to prevent short-circuiting or arcing across the electrodes. When sufficient voltage is applied across the discharge gap, a uniform flow of electrons will pass across the gap where the gas is flowing. This flow of electrons, called a corona, bombards the oxygen molecules, splitting them into oxygen atoms, which combine with other oxygen molecules to form ozone. Heat is also generated, which must be controlled with a small flow of cooling water. The yield of the ozonator is a function of the voltage between the electrodes, the electrical frequency, and the properties of the dielectrics.

If air is used as the feed gas, it must be dried and cleaned to high standards prior to introduction into the ozone generator to prevent the formation of byproducts such as nitric acid, which could damage the generator. Much higher concentrations of ozone can be produced with the same electrical power input using oxygen as compared to air, which means that smaller, less expensive generators may be used to produce the required amount of ozone.

Ozone does not react with organic matter to form DBP's. Ozone typically reduces the level of DBP precursors by an average of 10 to 15 percent by oxidizing the organic matter that reacts with chlorine to form DBP's. With the use of ozone to meet inactivation requirements, followed by chloramination for residual disinfection, DBP's would be significantly lower at the clearwell outlet and in the distribution system. In addition, the chloramine demand of the ozonated water would be nearly zero, so a smaller amount of chloramine will be required for residual disinfection in the distribution system. Ozone is effective for inactivating all of the regulated pathogens at low detention times and concentrations. Probable capital and operating costs are $1,800,000 and $0.16/1,000 gallon (water treated), respectively.

Two Stage Filtration Using Powdered Activated Carbon

Two stage filtration using powdered activated carbon (PAC) to remove DBP precursors was also evaluated. Treatment plants employing this process for Big Creek and Second Garrotte would be significantly more costly to construct and to operate than other alternatives. Probable capital and operating costs were $4,000,000 and $0.90/1,000 gallon (water treated), respectively. Further, the residuals (waste) from this process would be problematical. Problems associated with DBPs may not be solved completely, because organic removal is not complete as in GAC treatment. Because of all these factors, this alternative was not recommended as a long term solution.

Short Term Chlorination and Ultraviolet Radiation for Pathogen Inactivation with Chloramination for Residual Disinfection

UV disinfection is very effective against cryptosporidium and giardia. Ultraviolet (UV) radiation system and short term chlorination to meet the pathogen inactivation requirements along with a chloramination system to provide residual disinfection was proposed as a long term solution.

Several ultraviolet (UV) radiation technologies are available as alternative water disinfection methods to meet the pathogen inactivation requirements. UV light is a physical rather than a chemical disinfecting agent. Radiation with a wavelength between 240 and 280 nm is able to penetrate into the cell wall of the microorganism, preventing the reproduction of the cells or causing the cells to die. The wavelength specified above can be achieved with low pressure mercury lamps. These lamps are capable of converting electrical energy to light that is emitted at a characteristic wavelength of 254 nm. The efficiency of conversion can be as high as 85 percent. Medium pressure mercury lamps are becoming more popular because of their increased disinfecting capacity across a broader spectrum of biocidal range. The application of UV radiation has become even more feasible as the high intensity UV lamps are becoming available (number of lamps required are less with high intensity lamps). A medium pressure high intensity UV radiation system was evaluated in this study.

UV disinfection is considered a safe disinfection method, as it does not involve the use of any chemicals. UV systems are also relatively easy to operate and maintain, and require less space. Probable capital and operating costs are $1,200,000 and $0.17/1,000 gallon (water treated), respectively. Because of these factors and District's desire to pursue a long term measure, this alternative was selected.

PROPOSED WATER TREATMENT PLANT DISINFECTION MODIFICATIONS

As noted earlier, an alternative with UV radiation, short term chlorination and chloramination was recommended for GCSD. Chlorination is proposed to achieve 4 log virus inactivation (with chlorination only) to meet the proposed LT2 requirement. Chloramination and UV radiation will follow short term chlorination. Chloramination will take place in the existing clearwells. 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.

Chlorination

Chlorination is included in the project to comply with the two disinfectant requirement of the LT2 rule. UV disinfection is effective for the inactivation of Giardia and Cryptosporidium but not as effective for viruses. Total required Giardia and Cryptosporidium inactivations will be achieved with UV while total required virus inactivation will be achieved with chlorination. Anticipated pathogen log inactivation levels after the proposed modifications are summarized in Table 3.

Free chlorine will be applied for a short period of time before ammonia is added to the water. The D/DBP rules require a minimum combination of disinfectant dose and contact time with the disinfectant to provide the required inactivation of pathogens. The product of these two variables (disinfectant dose and time) is expressed as CT, where C is the disinfectant concentration in mg/L and T is the contact time (in minutes). The CT requirement for 4 log virus inactivation with chlorine is 7.2, at the cold weather conditions at GCSD. For a flow rate of 2.1 mgd, a contact tank of approximately 15,000 gallons in volume would be required, assuming a baffling factor of 0.35 and a chlorine residual of 2.0 mg/L. The chlorine contact tank will be installed prior to the

TABLE 3

MINIMUM ANTICIPATED PATHOGEN LOG INACTIVATION LEVELS AFTER PROPOSED DISINFECTION MODIFICATIONS AT BIG CREEK SHAFT AND SECOND GARROTTE SHAFT

Disinfection Method	Cold Weather Period[a]			Warm Weather Period[b]		
	Virus	Giardia[c]	Cryptosporidium[d]	Virus	Giardia[c]	Cryptosporidium[d]
Chlorination[e]	4	0	0	5	0	0
Chloramination[f]	1	0.7	0	2	0.9	0
UV	0.5	3	3	0.5	3	3
Total	5.5	3.7	3	7.5	3.9	3

[a] Temperature = 7º C
[b] Temperature = 13º C
[c] Giardia inactivation by chlorination is assumed to be negligible for a CT value of 7.2.
[d] Cryptosporidum inactivation by chlorination and chloramination is assumed to be negligible.
[e] Chlorine concentration = 2.0 mg/L
[f] Chloramine concentration = 2.0 mg/L

clearwell, with chlorine injected at the inlet. The reaction time between the organics and chlorine would be approximately 10 minutes (sufficient for the required virus inactivation levels) but not long enough for the formation of DBPs. Ammonia will be injected at the contact tank outlet, from where the water will flow by gravity to the clearwell.

Chloramination

Chloramination is included in the project to provide residual disinfection and to reduce the formation of DBPs. Chloramines are formed from the reaction of chlorine and ammonia. The mixture that results from the reaction of chlorine and ammonia may contain different chloramines species including: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), or nitrogen trichloride (NCl_3). The distribution of chloramine species are primarily dependent on pH and controlled to a large extent by the chlorine to ammonia nitrogen (Cl_2: N) ratio. Temperature and contact time also play a role. At pH values between 6.5 and 8.5, monochloramine is the dominant form when the applied Cl_2 to N ratio is less than 5 by weight. Dichloramine exists when the applied Cl_2 to N ratio is between 5 and 7.6 by weight. Breakpoint reaction occurs as the applied Cl_2 to N ratio increases to 7.6, reducing the residual chlorine level to a minimum. Free chlorine and nitrogen trichloride become the dominant species, if the applied Cl_2 to N ratio is increased above 7.6.

Monochloramine is the preferred chloramine species for use in disinfecting drinking water because of taste and odor problems associated with dichloramine and nitrogen trichloride. To ensure that monochloramine is the dominant species and breakpoint is not reached, the common practice is to target a Cl_2 to N ratio in the range of 3 to 5, with a typical value of 3 to 4. It should also be noted that undesirable effects of nitrification and biofilm growth can occur at Cl_2 to N ratios below 3 (because of excess ammonia).

The normal dosage range for monochloramine is 1.0 - 3.0 mg/L. The MCL for monochloramine is 4 mg/L. Residual monochloramine in the distribution system is kept higher than 0.5 mg/L. A minimum monochloramine dosage of 2.0 mg/L is recommended to prevent nitrification in the distribution system. In addition, an applied Cl_2 to N ratio of 4 is proposed for the project.

For chloramination, aqueous ammonia (19 percent strength) will be added after the chlorine contact tanks, prior to the clearwells to minimize the formation of DPBs at each treatment plant. Ammonia will be stored in bulk in pressure rated tanks.

Ultraviolet Radiation

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. A flow through UV reactor system is proposed for GCSD because of the following properties:

1. Required disinfection targets are achieved with fewer UV lamps
2. UV dose is delivered efficiently and reliably because of good reactor hydraulics, eliminating potential short circuiting
3. Compact footprint
4. Reduced capital costs for new plants
5. Automatic, easy cleaning system

One UV reactor train with 3 units (in parallel), each 12 inches in diameter and 3 feet in length, will be installed after the clearwells at each treatment plant. UV design guidelines proposed by the National Water Research Institute (NWRI) are recommended. A UV system with a minimum of one reactor train with three units (two duty plus one standby) is required at both treatment plants per NWRI guidelines. UV system sizing is based on the assumption that an interruption of the treatment flow from 4 to 8 hours in a day (if required) satisfies NWRI guidelines.

UV facilities would be designed to deliver a minimum UV dose of 40 milli joule/cm^2 (mJ/cm^2) at maximum day flow. The minimum required design dose is based on the following conditions:

1. Minimum allowable water transmittance is 80 percent (if 12 month data are not available, a minimum transmittance value of 80 percent is required per NWRI guidelines).

2. UV dose is to be achieved with two units in operation (third unit is for standby purposes).
3. The bioassay results obtained by the UV equipment are used to calculate the UV dose. Bioassay tests are conducted using live microorganisms. The required UV dose is determined by measuring the microorganism inactivation level.

CONCLUSIONS

The following conclusions are offered based on the results of this study:

1. Pending and Proposed D/DBP rules will require modifications in many water treatment plant disinfection systems.

2. Disinfection with free chlorine forms high levels of DBP concentrations at the GCSD water system. With the currently configured water treatment plants, GCSD will not be in compliance with recently adopted and proposed drinking water regulations.

3. Several short and long term measures were evaluated to comply with upcoming D/DBPregulations.

4. Short term chlorination and UV radiation for required pathogen inactivation with chloramination for residual disinfection is the preferred alternative to comply with the current and future D/DBP regulations.