Modeling and Mitigating Hydrogen Sulfide in Municipal Interceptors from a High Strength, High Temperature Industrial Wastewater

John Siczka, P.E.[1,*]
Bill Oldenburg[2]
Brian Vander Loop[2]
Peter McCarthy[2]
Bill Desing[1]

[1] CH2M HILL
[2] Green Bay Metropolitan Sewerage District
[*] To whom correspondence should be addressed. Email: jsiczka@ch2m.com

ABSTRACT

In 2008, the Green Bay (Wisconsin) Metropolitan Sewerage District acquired the De Pere Wastewater Treatment Facility and interceptors from the City of De Pere. Two of those interceptors received wastewater from paper mills exhibiting high biochemical oxygen demand and high temperatures. Mill wastewater contributed 80 percent of the total interceptor flows, making conditions highly conducive to sulfide generation. Control measures were necessary to prevent unacceptable hydrogen sulfide concentrations in the interceptors. A computer model was used, along with 7 months of collected field data, to assess the effectiveness of treatment alternatives. The calibrated sulfide generation factor in the model was lower but within a magnitude of the recommended value by Pomeroy-Parkhurst. To eliminate vapor phase hydrogen sulfide issues in one of the interceptors, a force main was installed to allow wastewater to be pumped from one of the mills directly to the treatment plant. A biological slime layer that formed in the force main appeared to inhibit sulfide generation or transfer of sulfide to the wastewater. The slime layer resulted in elevated force main pressures and lower flow rates. Hydrogen peroxide addition successfully reduced the slime layer. The two mills discharging to the second interceptor employed liquid phase chemical treatment using ferrous chloride and hydrogen peroxide to mitigate sulfide generation.

KEYWORDS: odor, hydrogen sulfide, paper mill, interceptor

INTRODUCTION

In 2008, the Green Bay [Wisconsin] Metropolitan Sewerage District (GBMSD) acquired the De Pere Wastewater Treatment Facility (DPF) and tributary interceptors from the City of De Pere. The interceptors included the 8,060-meter (5-mile) Ninth Street Interceptor/Ashwaubenon Creek Interceptor (NSI/ASC) and the 2,625-meter (1.6-mile) reach of the West Side Interceptor (WSI) located on the DPF's property. Both interceptors receive wastewater from paper mills that exhibits high biochemical oxygen demand (BOD) and high temperatures. Mill wastewater contributed 80 percent of the total NSI/ASC and WSI flows. The high strength, high temperature wastewater and the small contribution of domestic wastewaters created conditions highly conducive to sulfide generation. Field measurements of vapor phase hydrogen sulfide (H_2S) in the NSI/ASC indicated an average H_2S concentration of 100 parts per million volume (ppmv), with peaks of 350 ppmv. In the WSI, average H_2S concentrations were 200 to 300 ppmv, with

peaks greater than 1,000 ppmv. These high concentrations raised concern regarding public safety, worker safety, nuisance odors, and corrosion.

Due diligence work performed before acquisition of the interceptor from the City of De Pere revealed issues concerning the structural integrity of the interceptor. High pressure cleaning with a rotating head jetting nozzle revealed a 1,610-meter (1-mile) section of the NSI/ASC that required immediate rehabilitation. Closed circuit television inspection of the WSI showed significant levels of corrosion within the DPF fence line that also required immediate rehabilitation. Sulfide generation or vapor phase H_2S control was necessary to prevent unacceptable H_2S concentrations in the interceptors.

METHODOLOGY

The project goal was to confirm the mills' contribution to sulfide generation in the interceptors and to develop and implement a long-term solution to control vapor phase H_2S. To do so, the following steps were followed:

1. Use a computer model to confirm the mills' contribution to sulfide generation.

2. Develop both interim and permanent solutions.

3. Develop interim vapor phase H_2S concentration limits for a short-term solution to protect both the public and District staff.

4. Review field monitoring data regularly to assess the effectiveness of treatment alternatives.

RESULTS

Estimating Sulfide Generation/Emissions

CH2M HILL used its INTERCEPTOR model to estimate sulfide generation and emissions in the interceptors and force main conveyance pipelines. INTERCEPTOR predicts the generation, transport, and fate of H_2S in wastewater collection systems. Most other sulfide models predict only the concentration of sulfides in the wastewater liquid phase, but INTERCEPTOR also estimates sulfide vapor phase concentrations, which are important to sizing and locating odor and corrosion control devices. INTERCEPTOR uses a simultaneous solution of liquid- and gas-phase steady state mass balances to accurately represent the following reactions and processes:

*   Liquid phase–based generation of sulfides
*   Temperature and biochemical oxygen demand (BOD) effects on sulfide generation
*   Liquid phase bulk transport of sulfides
*   Liquid phase natural oxidation of sulfides
*   pH-dependent sulfide species distribution: H_2S, HS^-, S^{-2}
*   Liquid-vapor mass transfer of H_2S
*   Liquid drag-induced natural ventilation rates
*   Vapor phase bulk transport of H_2S
*   Concrete pipe corrosion rate estimation

The model requires inputs for each section of pipe—type (gravity flow, force main), length, and slope—and initial values for flow, BOD_5, temperature, dissolved sulfide concentration, and dissolved oxygen concentration. Sampling data were collected from the interceptor, mills, and other sidestreams for model inputs and calibration. Dissolved sulfide and vapor phase H_2S sampling data from the interceptors were used to calibrate the model. Vapor phase H_2S sampling data was collected using OdaLog® portable gas collection instruments. The model was used first to confirm the mills' contribution to sulfide generation, then to estimate the effectiveness of various alternatives to control sulfide generation and emissions.

INTERCEPTOR MODELING INPUTS AND RESULTS

Mills A and B discharge into the NSI/ASC interceptor, whereas Mills C and D discharge into the WSI. Exhibit 1 is a map of the collection system showing the interceptors and mills. Exhibit 2 contains vapor phase H_2S sampling data from manhole WSI-004 of the WSI. The manhole is on the DPF at the facility's southerly fence line. To model sulfides, flow and monitoring data were collected from various manholes along each interceptor, the four mills, and major sidestream sewers that discharge to the NSI/ASC and WSI. Minor sidestream tributary flows and loads were estimated using rooftop counts applied against GBMSD established flow per household data.

Exhibits 3 and 4 show both modeling-predicted dissolved sulfide and vapor phase H_2S concentrations and sampling results under average loading conditions. Exhibit 5 summarizes selected model inputs to the NSI/ASC and WSI models. Modeling and sampling results generally are in good agreement, especially in the liquid phase, but some differences can be seen between measured and modeled vapor phase values. The reason is that the measured values were taken over a wide range of flow and loading conditions that on average likely differ from the average conditions used for the model. Both exhibits show that significant sulfide concentrations are generated along the NSI/ASC and WSI, resulting in high vapor phase H_2S concentrations that contribute significantly to corrosion of the interceptors. The models were run under numerous scenarios, including different loading conditions, different mill discharge temperatures, with only one mill operating, and with no mills operating. The models and sample results helped to confirm that the mills were the source of high vapor phase H_2S concentrations on both the NSI/ASC and WSI.

Establishing Interim Vapor Phase H_2S Limits

GBMSD required the mills to begin immediate addition of chemicals to reduce vapor phase H_2S concentrations in the interceptors and to begin moving toward a permanent solution. GBMSD's adopted standards for vapor phase H_2S limits concentrations in its interceptors to an average of 2 ppmv and an instantaneous peak of 10 ppmv. Knowing that these levels might be difficult to meet through chemical treatment, GBMSD acted to develop interim limits to determine the amount of chemical the mills needed to add to reduce H_2S concentrations in the interceptors to levels required to protect public health and safety until a permanent solution could be developed. The allowable limits of H_2S concentrations can be established based on corrosion, worker safety, public safety, and nuisance odors. GBMSD requested that corrosion not be the primary consideration in setting the limits, because chemical addition was to only be a short-term solution. Odor complaints were rare since the limit was intended to be a short-term solution, so nuisance odors also were not a primary consideration in recommending the limits.
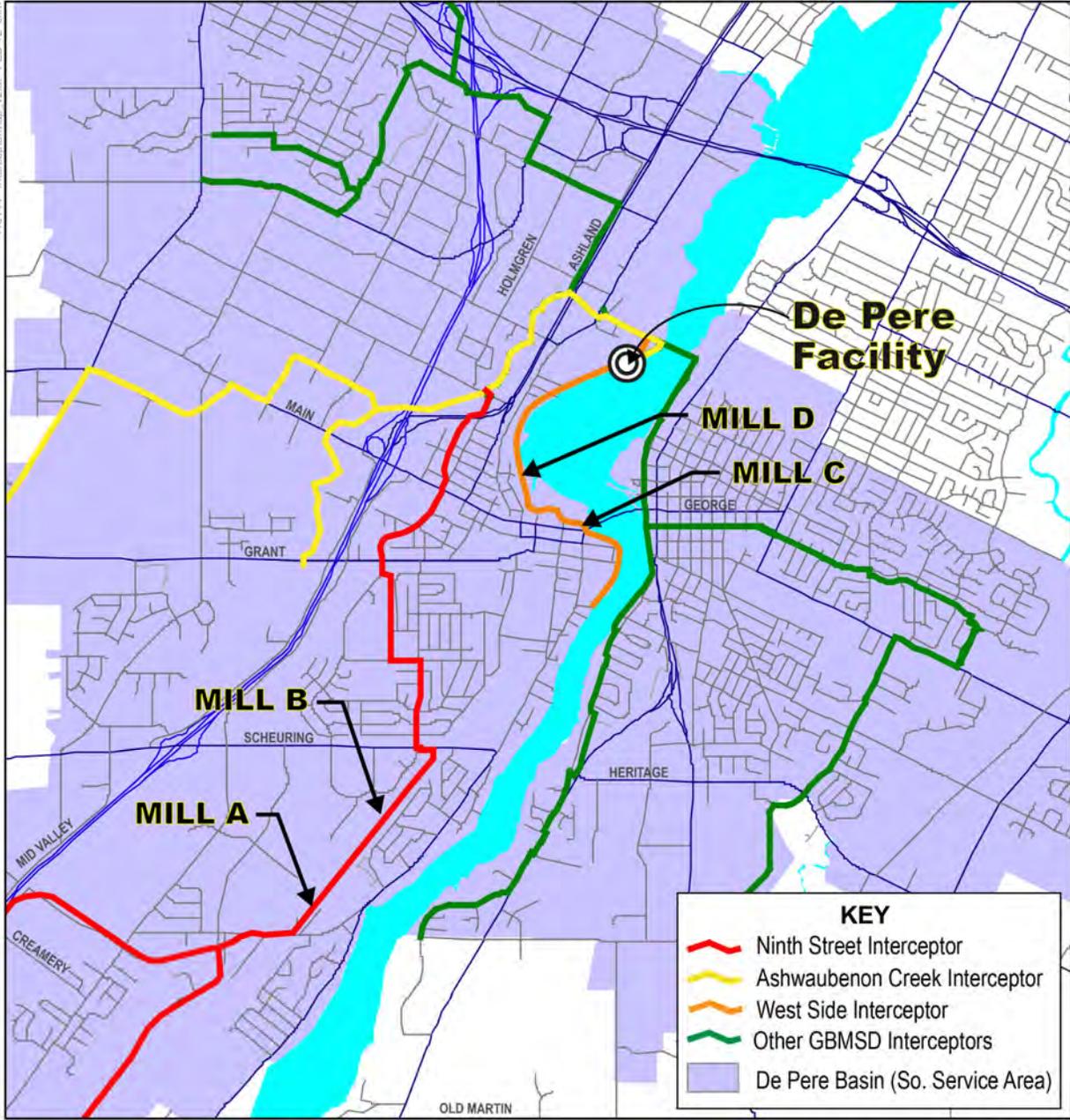
Exhibit 1. Collection System Map.
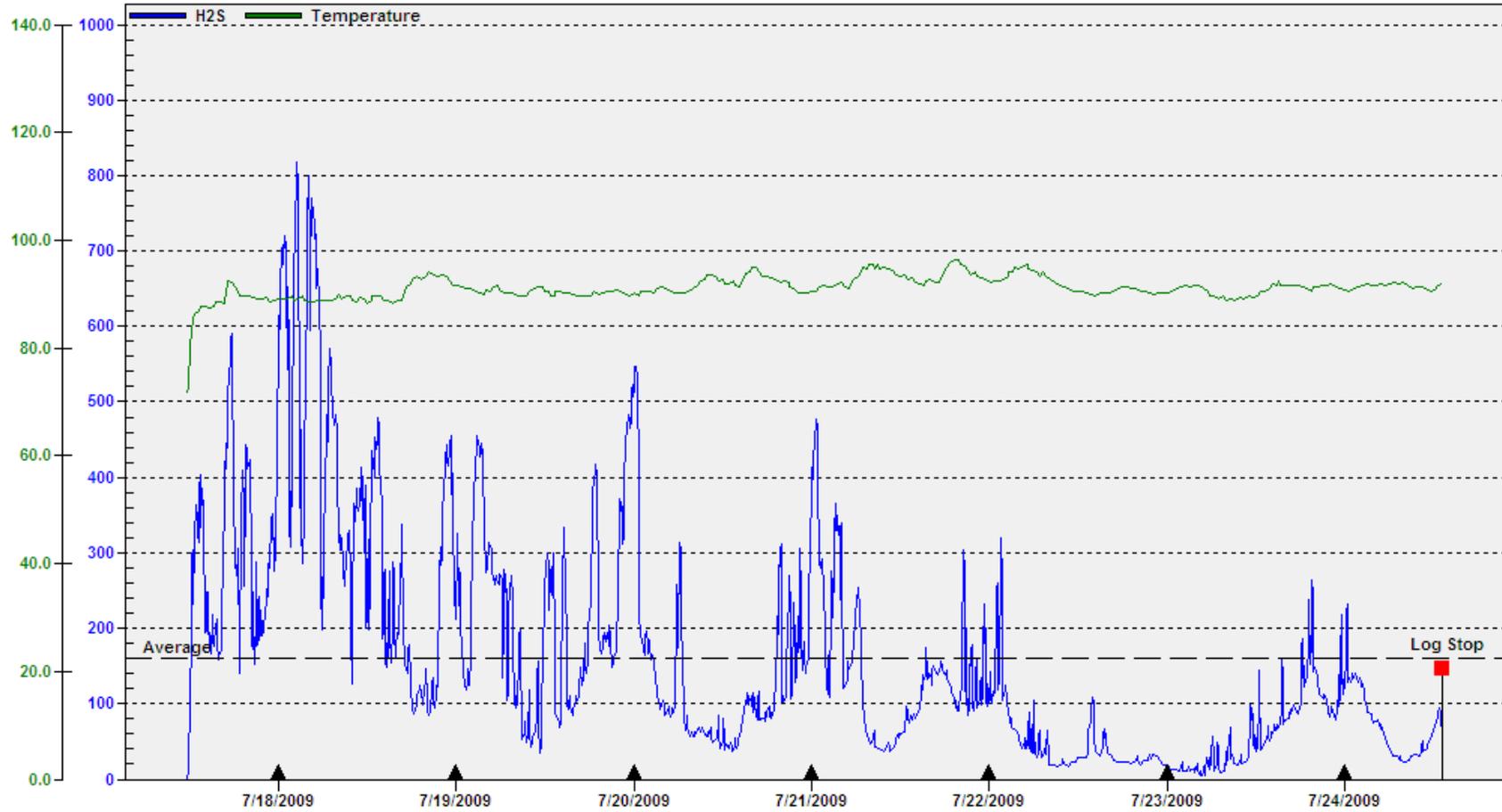
Exhibit 2. WSI Vapor Phase Hydrogen Sulfide Concentrations at WSI-004
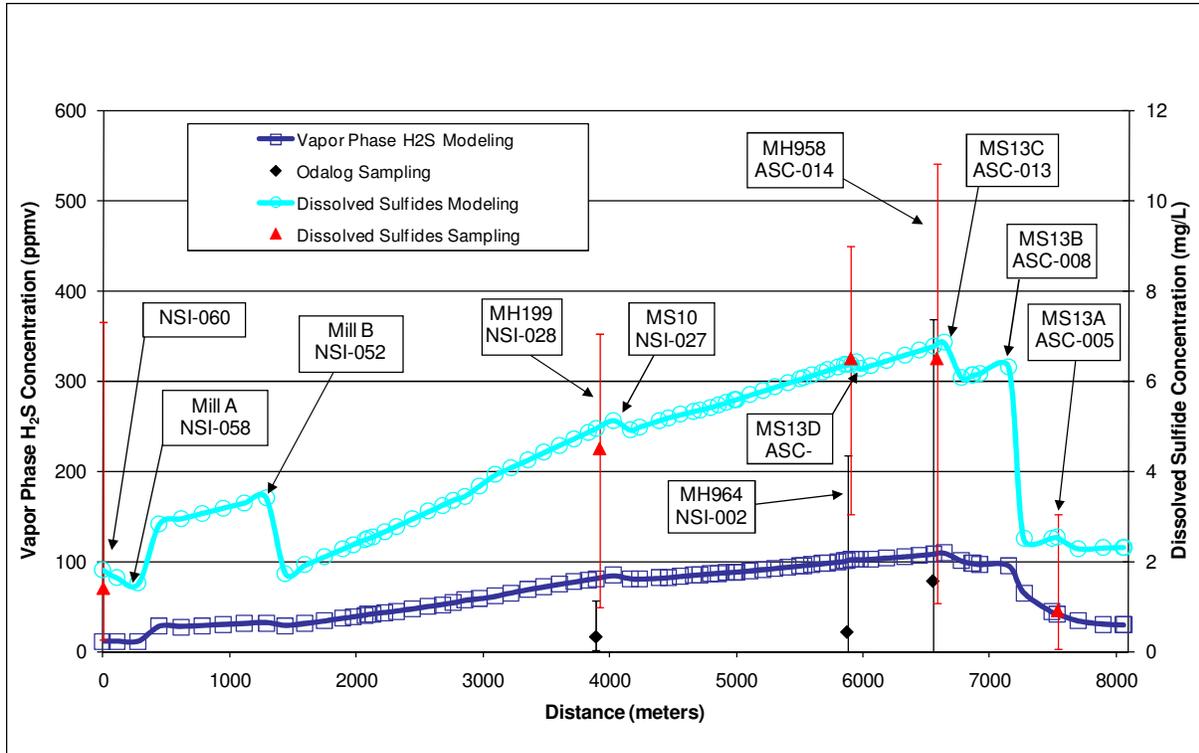
Exhibit 3. NSI/ASC Average Loading Condition: Modeling-Predicted Sulfide Concentrations and Sampling Data
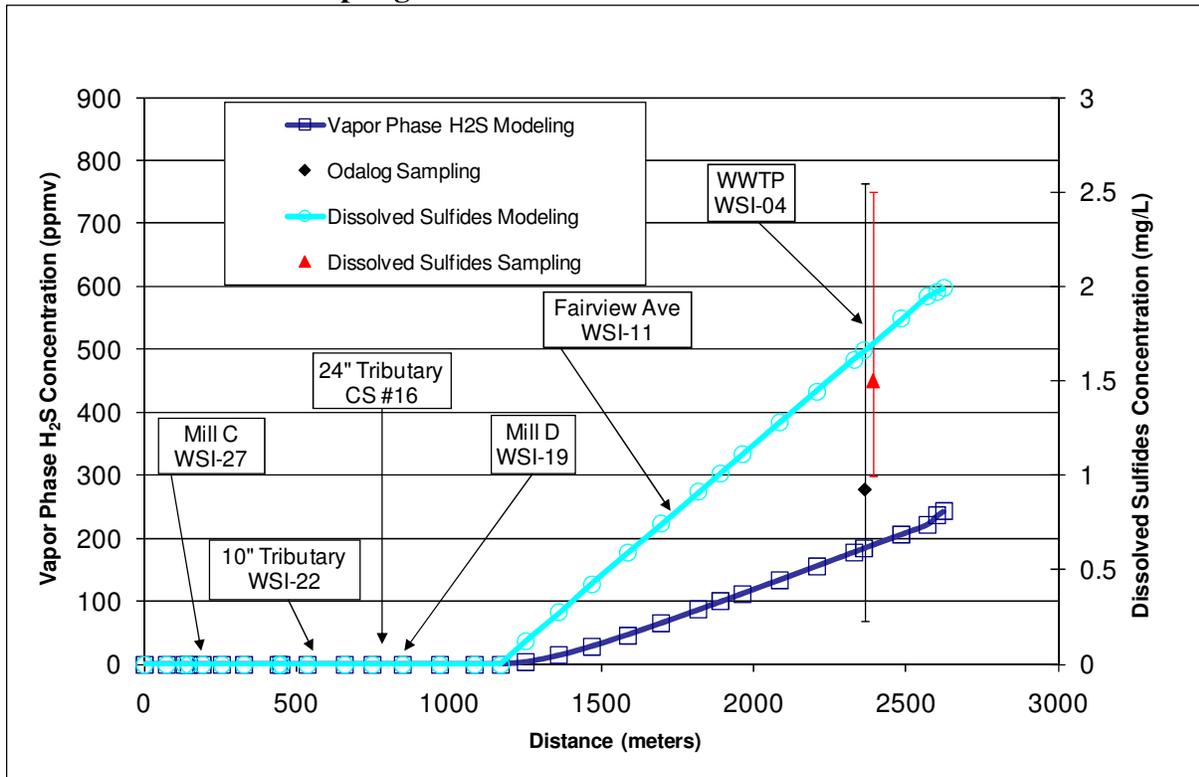
Exhibit 4. WSI Average Loading Condition: Modeling-Predicted Sulfide Concentrations and Sampling Data

Exhibit 5. Modeling Selected Inputs: Baseflow, Mills, and Sidestreams

Location and Parameters	Flow [m³/h / (gpd)]	BOD (mg/L)	Temperature [°C / (°F)]	Dissolved Oxygen (mg.L)	Dissolved Sulfides (mg/L)
NSI/ASC					
Upstream of Mills (NSI-060)	27.7 (175,600)	200	13.9 (57.0)	2	1.8
Mill A (NSI-058)	38.5 (244,300)	1,959	35.4 (95.8)	0.5	1.8
Mill B (NSI-052)	120 (767,000)	2,259	42.5 (108.5)	0.5	0.5
MS10 sidestream (NSI-027)	20.5 (130,000)	188	12.8 (55.0)	2	2
MS13D sidestream (ASC-020)	11.0 (70,000)	1,364	15.6 (60.0)	0.5	3
MS13C sidestream (ASC-013)	31.5 (200,000)	261	15.0 (59.0)	1	0
MS13B sidestream (ASC-008)	386 (2,450,000)	211	14.0 (57.2)	1	0
MS13A sidestream (ASC-005)	71.0 (450,000)	290	17.9 (64.2)	1	0
WSI					
Upstream of Mills (WSI-031)	20.9 (132,500)	243	18.3 (65.3)	1.7	0
Mill C (WSI-027)	210 (1,333,100)	676	39.6 (103.2)	2.2	0
10-inch sidestream (WSI-022)	12.9 (81,890)	200	15.8 (60.5)	2.2	0
24-inch sidestream (CS #16)	9.1 (57,400)	200	17.8 (64.0)	1.9	0
Mill D (WSI-019)	19.4 (122,900)	5,358	36.5 (97.7)	1.8	0
Foxview Ave. sidestream (WSI-013)	0.23 (1,440)	200	16.8 (62.3)	2	0
River Ave. sidestream (WSI-012)	0.48 (3,040)	200	16.8 (62.3)	2	0
Fairview Ave. sidestream (WSI-011)	0.77 (4,880)	200	16.8 (62.3)	2	0
Brown County Fairground tributary (CS #13)	0.34 (2,170)	200	16.8 (62.3)	2	0

Note: Location identifiers in parentheses are manhole numbers.

It should be noted that National Institute for Occupational Safety and Health (NIOSH) standards and other proposed standards for worker exposure are lower than the recommended limits for the following reasons:

- There would be some dilution of the air in the interceptor headspace before it would be inhaled by a public receptor.

- Experience in measuring H_2S vapor phase concentration at other utilities, especially those in warm climates, has shown that concentrations in the 20 to 40 ppmv range are not unusual and have not resulted in known hazards to the public at limited exposure time variables. However, utilities often seek to reduce concentrations below the 20 to 40 ppmv range because of infrastructure corrosion, work safety, or odor concerns.

- The 40 ppmv instantaneous limit is below the Immediately Dangerous to Life or Health

concentration of 100 ppmv and the OSHA 50 ppmv short-term Permissible Exposure Limit. This afforded some level of protection to workers when opening manholes, although all confined space entry requirements and regulations were to be followed.

Exhibit 6 shows H_2S exposure limits from several different sources and agencies. Based on this information and engineering judgment, the recommendation was to limit the H_2S concentrations in the interceptors to the following in order to protect public health and safety:

- A daily, 24-hour running average of no greater than 20 ppmv
- A maximum instantaneous peak no greater than 40 ppmv

Exhibit 6. Hydrogen Sulfide Exposure Limits

Agency	Average	Ceiling	Notes and Additional Requirements
OSHA Permissible Exposure Limit for General Industry. (29 CFR 1910.1000 Z-2 Table)	NA	20 ppmv	The ceiling concentration of 20 ppmv can be exceeded if no other measurable exposure occurs during the 8-hour work shift, but not more than 50 ppmv for a single period up to 10 minutes.
American Conference of Governmental Industrial Hygienists	10 ppmv: time weighted average (TWA). The TWA concentration is for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect.	15 ppmv: *Threshold Limit Value—Short-Term Exposure Limit (TLV–STEL).* A 15-minute TWA exposure that should not be exceeded at any time during a workday, even if the 8-hour TWA is within the TLV–TWA.	TLVs are not standards, but guidelines designed for industrial hygienists to use in making decisions regarding safe levels of exposure to chemical substances found in the workplace. In using these guidelines, industrial hygienists are cautioned that TLVs are only one of several factors to be considered in evaluating specific workplace situations and conditions.
NIOSH Recommended Exposure Limit	NA	10 ppmv for 10 minutes	The recommended exposure limit is an exposure limit recommended by NIOSH scientists to OSHA. Recommended exposure limits are science-based recommendations rather than legal standards. They are based on animal and human studies.
National Institute for Occupational Safety and Health		100 ppmv: immediately dangerous to life or health concentration	

Interim Chemical Treatment

Field tests of several treatment chemicals were conducted on the interceptors with varying degrees of success. INTERCEPTOR was used to establish initial, conservative dosages, and then dosages were reduced to provide the required vapor phase H_2S concentrations at the lowest costs. OdaLog data were reviewed weekly to assess the effectiveness of the treatment chemical and to adjust chemical dosage. The mills were responsible for selecting and dosing the chemicals with guidance provided by GBMSD and its consultant. Treatment chemicals attempted on the NSI/ASC included ferric chloride, BIOXIDE® (calcium nitrate), a proprietary peroxide/calcium nitrate/catalyst blend, and proprietary ozone/oxygen. Mill B was the only mill operating. For various reasons, Mill A was not operating for an extended period of time, but when it did operate it used BIOXIDE chemical treatment. Ferric chloride was observed to be not as effective as BIOXIDE, but the ferric chloride dosage may not have been adequate. The peroxide/calcium nitrate/catalyst blend and ozone/oxygen did not consistently meet established limits at an acceptable cost. Mill B selected BIOXIDE as it achieved the interim H_2S limits at an acceptable cost. Exhibit 7 shows vapor phase H_2S data at manhole ASC-013 after BIOXIDE addition began on March 13, 2009. Chemical dosing requirements were slightly higher than estimated by the model to accommodate H_2S peaks caused by the highly variable mill waste discharge, which ranged from 0 to 1,000 ppmv at Mill B. The approach controlled the vapor phase H_2S concentration in the NSI/ASC to the allowable concentrations of 20 ppmv average and 40 ppmv peak throughout the summer of 2009.

Mills C and D worked toward a permanent solution by collaboratively performing trial tests with various chemical treatments in an effort to determine the most cost-effective solution to successfully mitigate the hydrogen sulfide generation in the WSI. The mills tested calcium nitrate, peroxide, a proprietary peroxide/calcium nitrate/catalyst blend, a proprietary liquid organic scavenger of sulfide and other reduced sulfur compounds, and ferrous chloride/hydrogen peroxide. Each trial test except that for ferrous chloride/hydrogen peroxide proved to be either ineffective or unreliable in meeting the established H_2S limits at acceptable costs. The ferrous chloride/hydrogen peroxide treatment is described in the next section.

Permanent Solution

Permanent solutions were developed to control sulfide generation and vapor phase H_2S. For the NSI/ASC, a dedicated force main to convey mill waste from Mill B to the DPF was selected and constructed to contain the mill waste and avoid the accumulation of H_2S in the open headspace of a gravity sewer. A second mill waste force main from the DPF to the Green Bay Wastewater Treatment Facility (GBF) was also constructed. Construction of the force mains was completed in January 2010. They give GBMSD the flexibility to treat all or part of the mill wastewater at either facility. The force mains effectively removed the Mill B's high volume, high strength mill wastewater from the NSI/ASC interceptor. INTERCEPTOR was used to estimate sulfide generation in the force main. The estimated dissolved sulfide concentration at the DPF exceeded 100 mg/L because of length of the force main and the high temperature and high BOD of the mill wastewater. The model helped determine chemical dosing requirements to prevent sulfide toxicity from occurring in the facility's aeration basins. Jar tests assessed the performance and dosage requirements of such chemical additives as ferric chloride, ferrous chloride, sodium hypochlorite, and hydrogen peroxide.
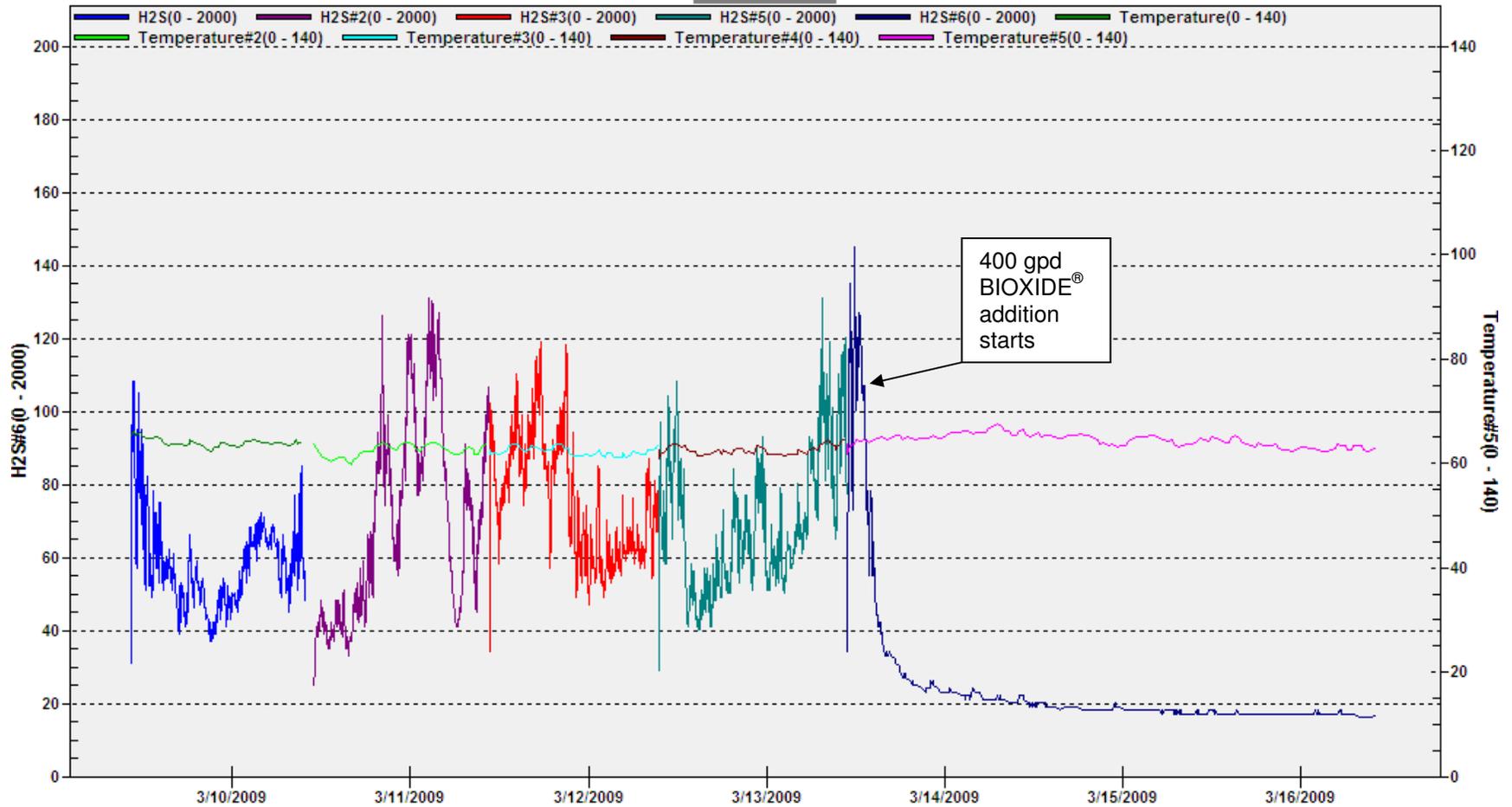
Exhibit 7. NSI/ASC Vapor Phase H₂S Monitoring Results at Manhole ASC-013

Tanks and metering pumps were provided at the DPF and the Intermediate Chemical Feed Building (between the DPF and GBF) to dose ferric chloride or BIOXIDE. Mill A is for sale, and the equipment operates only when it is shown to potential buyers. BIOXIDE is dosed during these showings. Sample data and INTERCEPTOR results both verified that Mill B generates significantly more sulfide in the NSI/ASC than Mill A because of higher flow rate. Exhibit 8 shows the precipitous drop in the vapor phase H_2S concentration in the NSI/ASC when Mill B began conveying waste through the mill waste force main.

Mills C and D determined that ferrous chloride/hydrogen peroxide successfully mitigated H_2S generation in the WSI. Ferrous chloride is fed at the Mill C discharge and hydrogen peroxide fed at the Mill D discharge. Exhibit 9 shows the impact of ferrous chloride/hydrogen peroxide addition at manhole WSI-004. Both mills were operating on August 29, 2011, before Mill D halted operation on September 13. Mill D continued to dose hydrogen peroxide at a lower dose while shut down to mitigate vapor phase H_2S. GBMSD instructed both mills to cease chemical addition for a 24-hour period starting on September 18 to assess the effectiveness of the chemical treatment system. Exhibit 8 shows the vapor phase H_2S concentration increased rapidly upon stopping chemical addition. Chemical addition resumed on September 19, where upon the vapor phase H_2S concentration decreased rapidly. Both mills continue to optimize the chemical dosages. The ferrous chloride/hydrogen peroxide system used was developed US Peroxide, which termed the system Peroxide Regenerated Iron-Sulfide Control® (PRI-SC®). In PRI-SC, ferrous chloride is added first and reacts with sulfide to form ferrous sulfide (FeS). Hydrogen peroxide is added farther downstream to regenerate spent iron salt (FeS) resulting in ferrous iron, ferric iron, and elemental sulfur. PRI-SC can allow for sulfide control to lower concentrations with lower iron dosages. Depending on the circumstances, PRI-SC may also be less expensive than dosing iron alone.

DISCUSSION

Extensive use of INTERCEPTOR in modeling the interceptors under various conditions helped to confirm that the mills were the cause of the high vapor phase H_2S concentration observed in both the NSI/ASC and WSI. The model assisted in evaluating and selecting dosages for chemical treatment in the interceptors and the mill waste force main, evaluating the effectiveness of temperature and BOD reductions in the mill waste, and developing chemical cost-sharing ratios for the mills for each interceptor.

Temperature was the parameter that most greatly affected sulfide generation and vapor phase transfer in both the NSI/ASC and WSI models. The average measured temperature in the WSI at the DPF fence line was 34.4°C (94°F), with peaks up to 37.8°C (100°F). To calibrate the models, the model's sulfide generation factor required an adjustment based on the field data to reflect the fact that the mill waste sulfide generation factor was different from that for most municipal interceptors that carry predominantly domestic wastewater. Sulfide generation is based on the following equation developed from the work of Parkhurst and Pomeroy:
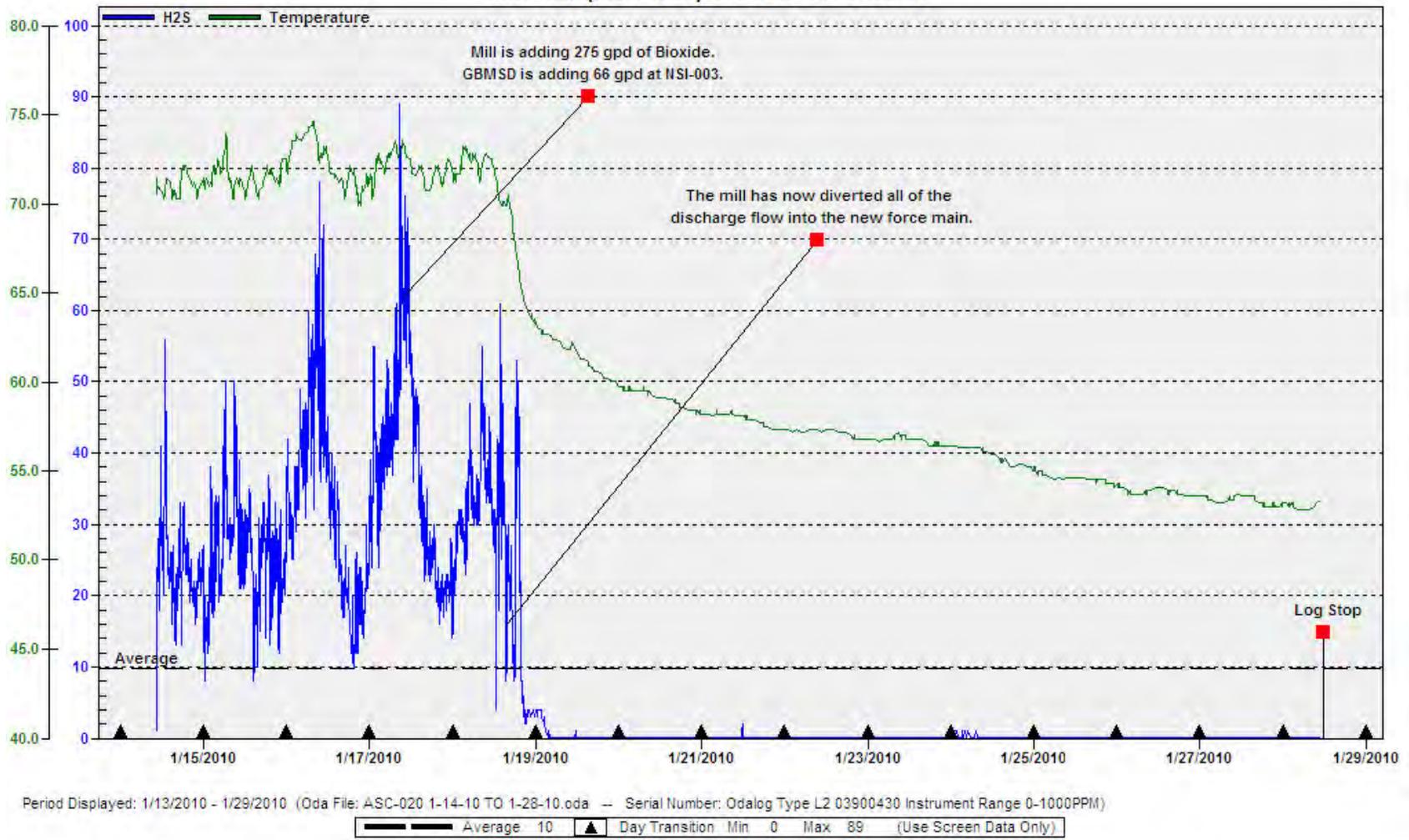
Exhibit 8. NSI/ASC Vapor Phase Hydrogen Sulfide Concentrations at Manhole ASC-020—Mill B Discharging to Mill Waste Force Main (Mill A not Operating)

WSI-004 8-29-11 - 9-27-11 Manhole located near south fence line at De Pere facility

[GPRS Signal Strength]

Mill C in operation and dosing ferrous chloride
Mill D not operating but dosing hydrogen peroxide

Mill C in operation
Mill D not operating
No chemical addition at either mill

Mill C in operation and dosing ferrous chloride
Mill D in operation and dosing hydrogen peroxide

Mill C in operation and dosing ferrous chloride
Mill D not operating but dosing hydrogen peroxide

Mill C in operation and dosing ferrous chloride
Mill D in operation and dosing hydrogen peroxide

Average

Period Displayed: 8/29/2011 - 9/27/2011 (Oda File: 20120207__02.oda -- Serial Number: Odalog Type L2-RTx 03100167 Instrument Range 0-1000PPM)

| Average | 8 | ▲ | Month Transition | Min | 0 | Max | 438 | (Use Screen Data Only) |

Exhibit 9. WSI Vapor Phase Hydrogen Sulfide Concentrations at Manhole WSI-004 – Ferrous Chloride/Hydrogen Peroxide Addition

$$\varphi_g \quad = M'/3600 \times BOD_E \times A$$

where:

> φ_g =   sulfide generation term (g/s)
> M' =   sulfide generation factor (m/s)
> BOD_E =   effective BOD (mg/L)
> A   =   biofilm surface area (m^2)

and

$$BOD_E = BOD_5 \times 1.07^{(T-20)}$$

where:

> T   =   wastewater temperature (°C)

and

$$A = PERIM_{liq} \times length$$

where:

> $PERIM_{liq}$ =   wetted-pipe or liquid perimeter (m) calculation documented in natural ventilation module
>
> Length   =   pipe length (m)

Sulfide generation factors less than the Pomeroy-Parkhurst recommended value of 8.89×10^{-8} m/s were necessary to calibrate the models to match field data. The data indicate that sulfide generation factors were 1.3×10^{-8} m/s for the NSI/ASC and 4.3×10^{-8} for the WSI. The factors were within an order of magnitude of the Parkhurst and Pomeroy recommended value. This indicates that Parkhurst Pomeroy relationship remains valid for high BOD and temperature wastewaters, although sulfide generation may be lower or the effective, BOD_E may be low.

The WSI is relatively airtight, with plugged pick holes and sealed perimeters on many manhole covers. This limits exposure of the general public to H$_2$S but increases the concentration of vapor phase H$_2$S in the interceptor headspace by limiting dilution air. The default headspace airflow in INTERCEPTOR is estimated to be proportional to the friction drag of the flowing water on the air above it. Others factors can affect airflow, including pressure and temperature gradients between the sewer and ground surface, and significantly affect vapor phase H$_2$S concentrations. These factors will be incorporated into future versions of INTERCEPTOR. Adjustment of airflow in the WSI model from the default free flowing airstream was necessary to calibrate the model.

The mill waste force main was placed into service in January 2010. The modeled estimated sulfide concentration at the DPF was high—roughly 110 mg/L—because of the force main and also the high temperature and high BOD of the mill wastewater. The modeled estimated sulfide concentration at the downstream GBF was only slightly higher at 117 mg/L, because the sulfate

necessary to generate sulfide mostly would be consumed between Mill B and the DPF and the amount of sulfate is limited. In July 2010, the measured dissolved sulfide concentrations in the mill waste force main was much lower than predicted, ranging from 1 to 2 mg/L at the DPF and 5 to 10 mg/L at the GBF. In April 2010, discharge pressures in the DPF to GBF mill waste force main were observed that were much higher than design pressures. Visual inspection of the force main indicated the presence of a 1.3-cm (0.5-inch) slime layer on the force main (Exhibit 10). Analysis of the slime layer indicated it was a proteinaceous slime unique to

Exhibit 10. Slime Layer in DPF to GBF Mill Waste Force Main

paper mill wastewater, and it is microbial in nature. Wastewater temperature measurements taken in July 2010 were as follows: Mill B = 40.6°C (105°F), DPF = 37.8°C (100°F), and Intermediate Chemical Feed Building between DPF and GBF = 31.1°C (88°F). The Intermediate Chemical Feed Building is located just over halfway between the 10.6 km (6.6 mile) DPF to GBF mill waste force main, and so a further decrease in mill wastewater temperature was expected before reaching the GBF. The very low dissolved sulfide concentrations in the mill waste force mains suggest that the proteinaceous slime could be inhibiting the activity of the sulfate-reducing bacteria biofilm. The slime could be covering the biofilm, or retarding the transfer of food to the bacteria or the transfer of sulfide to the wastewater. The slime layer may also be creating an environment not conducive to sulfate-reducing bacteria. In November 2011, 2½ years after the elevated discharge pressures on the DPF to GBF force main, Mill B began to observe elevated pressures in the Mill B to DPF force main. This suggested that the slime layer may grow slowly or be inhibited at elevated temperatures. The mill discharge temperature averages 40.6°C (105°F) but is lower in winter and higher in summer.

GBMSD considered various options to remove the slime layer, including pigging and dosing chemicals. Pigging was rejected because of concerns that the pig might become stuck. Jar tests were performed with acids, caustic, sodium hypochlorite, ferric chloride, and hydrogen peroxide. Sodium hypochlorite and hydrogen peroxide were both successful in breaking up the slime layer, but sodium hypochlorite was eliminated because of scaling similar to what GBMSD has experienced at other areas of its facilities. In October 2010, GBMSD dosed two totes of 35 percent hydrogen peroxide to the mill waste force main at the Intermediate Chemical Feed Building. Inspection of the force main showed that the slime layer had been removed. GBMSD then implemented a shock dosing schedule at the DPF and Intermediate Chemical Feed Building by adding 2,270 to 3,406 liters (600 to 900 gallons) of 35 percent hydrogen peroxide at each location at a rate of 284 liters per day (75 gallons per day) at each location every 2 months. After

shock dosing, the discharge pressure decreased and flow increased. However, the discharge pressure began to increase and flow began to decrease 2 days after the completion of shock dosing. GBMSD is now employing a maintenance dose of 114 liters per day (30 gallons per day) per location and optimizing the dose. GBMSD experimented with dosing hydrogen peroxide at only the DPF but found dosing at both the DPF and the Intermediate Chemical Feed Building is necessary.

REFERENCES

Parkhurst, J. D., and R. D. Pomeroy. 1972. "Oxygen Absorption in Streams." *Journal of the Sanitary Engineering Division*. ASCE. **98**, SAI, 101.