A Systematic Approach for Effective Collection System Sulfide and Corrosion Management Planning

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ABSTRACT

This paper presents a systematic, step-by-step approach to assist utilities in developing an effective, priority-driven, sulfide and corrosion management plan for their collection systems. Along with aging infrastructure, utilities are faced with problems with high hydrogen sulfide and corrosion in their collection systems. One of the main challenges in addressing these concerns is developing a method to prioritize critical areas of concern for rehabilitation/replacement and/or corrosion treatment. The systematic approach presented herein provides a comprehensive means which includes six key steps as listed below:

- Identification of potential Critical Areas of Concern (CAC) for corrosion
- Review of current schedule for Capital Improvements Projects (CIPs)
- Risk assessment of interceptor condition and risk rating of CAC
- Evaluation of odor control and corrosion treatment methods
- Rating of interceptor repair and replacement techniques
- Development of corrosion management program (CMP)

A case study is presented detailing the development of a comprehensive sulfide and corrosion management plan at the Trinity River Authority of Texas (TRA) Central Regional Wastewater System using the systematic approach listed above.

KEYWORDS

Collection system, corrosion management, sulfide, hydrogen sulfide, systematic approach

INTRODUCTION

Many utilities are faced with challenges associated with high hydrogen sulfide level and interceptor corrosion in their collection systems. Ignoring these issues can result in severe consequences including public complaints, pipeline/infrastructure failures, and worker/public safety concerns. To proactively solve and prevent the collection system odor and corrosion problems, it is crucial for utilities to develop an effective, comprehensive sulfide and corrosion management plan. A 6-step systematic approach for development of a comprehensive sulfide and corrosion management plan is discussed in the paper along with a case study which detailed the implementation process using the systematic approach.

SYSTEMATIC APPROACH

A 6-step systematic approach for developing an effective collection system sulfide and corrosion management plan is illustrated on **Figure 1** with each step discussed briefly in the following section.

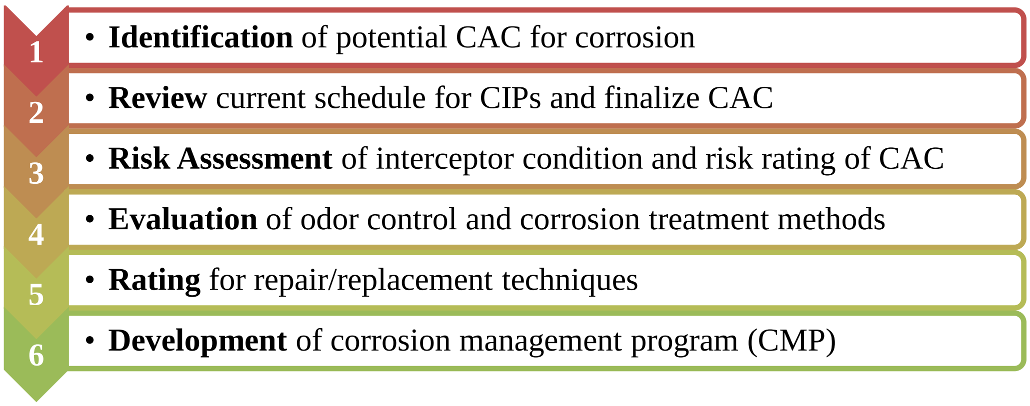

Figure 1 - A Systematic Approach for Collection System Sulfide and Corrosion Management.

Step 1. Identification of Potential CAC for Corrosion

The first step in the systematic approach for sulfide and corrosion management planning involves conducting field sampling to identify problem areas with high H_2S and/or sulfide levels. The initial sampling effort may include the collection of liquid and air grab samples to screen for potential CAC within the interceptor system. Further evaluations are necessary to prioritize the CAC because the initial grab sampling is often limited to single sulfide samples and H_2S data which might not reflect the average and peak conditions in the CAC. The continuous monitoring results might reveal some areas with only sporadically high H_2S which could be excluded in the CAC list. The detailed sampling effort should include continuous air-phase H_2S monitoring to record the variations over a relative longer period of time. Additional data such as temperature, oxidation reduction potential (ORP), liquid pH, and crown surface pH would also be recorded on detailed log sheets. Photographs and detailed field notes at each site investigated are often valuable in identifying CAC.

Step 2. Review of Schedule for CIPs and Finalize CAC

Once CAC have been identified, the existing schedule for capital improvement projects (CIPs) should be reviewed to identify pending/future pipeline relief and rehabilitation projects for comparison with the CAC identified in Step 1. Based on the detailed sampling results and current CIPs, CAC can be finalized. The current CIPs can then be updated to incorporate some of the CAC not previously included while some CAC can be rescheduled for more rapid implementation. The remaining CAC may require further evaluations for considerations of corrosion and odor treatment and/or replacement/rehabilitation.

Step 3. Risk Assessment of Interceptor Condition and Risk Rating of CAC

In this step, the existing interceptor condition data will be collected and risk ratings will be calculated for each pipe asset of the CAC identified. A risk rating which considers (1) the probability of structural asset failure (condition scoring) and (2) the expected consequences of that asset failure (failure scoring) is recommend for this approach. The overall condition scoring may include general condition, interceptor age, and corrosion level which are unique to each collection system. The consequence of failure scoring includes economic, environmental, and social/public health impacts such as the depth/size of the sewer pipes and the area served. The detailed process for determining the risk rating for each CAC is discussed in the TRA case study.

Step 4. Evaluation of Odor Control and Corrosion Treatment Methods
A wide range of chemical treatment methods are available for effective sulfide and odor treatment in collection systems including nitrate salts (Bioxide™), iron salts, and oxidizing agents such as hydrogen peroxide. Although the use of chemical treatment will significantly reduce sulfide and odor, residual sulfide and other odorous compounds may cause an odor nuisance in highly sensitive areas. Proven vapor-phase treatment technologies commonly used in collection systems include wet scrubbers, activated carbon systems, biofilters and biotrickling filters. Evaluation of the appropriate treatment methods is recommended to identify the best-fit solution for each CAC with considerations of economic and non-economic factors.

Step 5. Rating of Interceptor Repair and Replacement Techniques
A wide variety of repair and replacement techniques are available including open cut and trenchless methods. A numerical scoring system is assigned for each available options to assist in the decision making process, as discussed in the TRA case study.

Step 6. Development of Corrosion Management Program (CMP)
The final step in the systematic approach involves developing a comprehensive corrosion management program (CMP) to link the treatment program and rehabilitation/replacement projects identified for each CAC. Recommendations on monitoring and analysis, preventative maintenance, new product testing, and design standards are also valuable to the CMP. A corrosion protection and prevention initiatives coordinator can be assigned. In addition, development of an information management plan to link individual project data bases can significantly reduces time, effort, and cost when accessing and evaluating the existing data. Development of performance criteria is necessary to assess the effectiveness of the employed treatment program. The success of the CMP would be measured by completion of effective corrosion prevention and protection projects with progress tracked against the schedule.

CASE STUDY

The Trinity River Authority of Texas (TRA) Central Regional Wastewater System (CRWS) serves approximately 1.2 million people in the Dallas/Fort Worth area. The CRWS consists of about 320 km (200 miles) of sanitary sewers (primary interceptors), 1983 manholes, 5 lift stations, and over 21 km (13 miles) of force mains. With original interceptors constructed in 1955, some of the critical interceptors are now in poor condition due to hydrogen sulfide (H_2S) corrosion. **Figure 2** shows the CRWS service area with major interceptor systems identified. TRA recognized the need for a comprehensive collection system sulfide and corrosion management plan to address problems with high H_2S and interceptor corrosion on its Central Regional Wastewater System (CRWS) and engaged the team of Alan Plummer and Associates, Inc. (APAI) and Black &Veatch Corporation (B&V). APAI was responsible for overall project management and the treatment plant work (McMillen et al., 2008) while Black & Veatch focused on the collection system portion of the work.

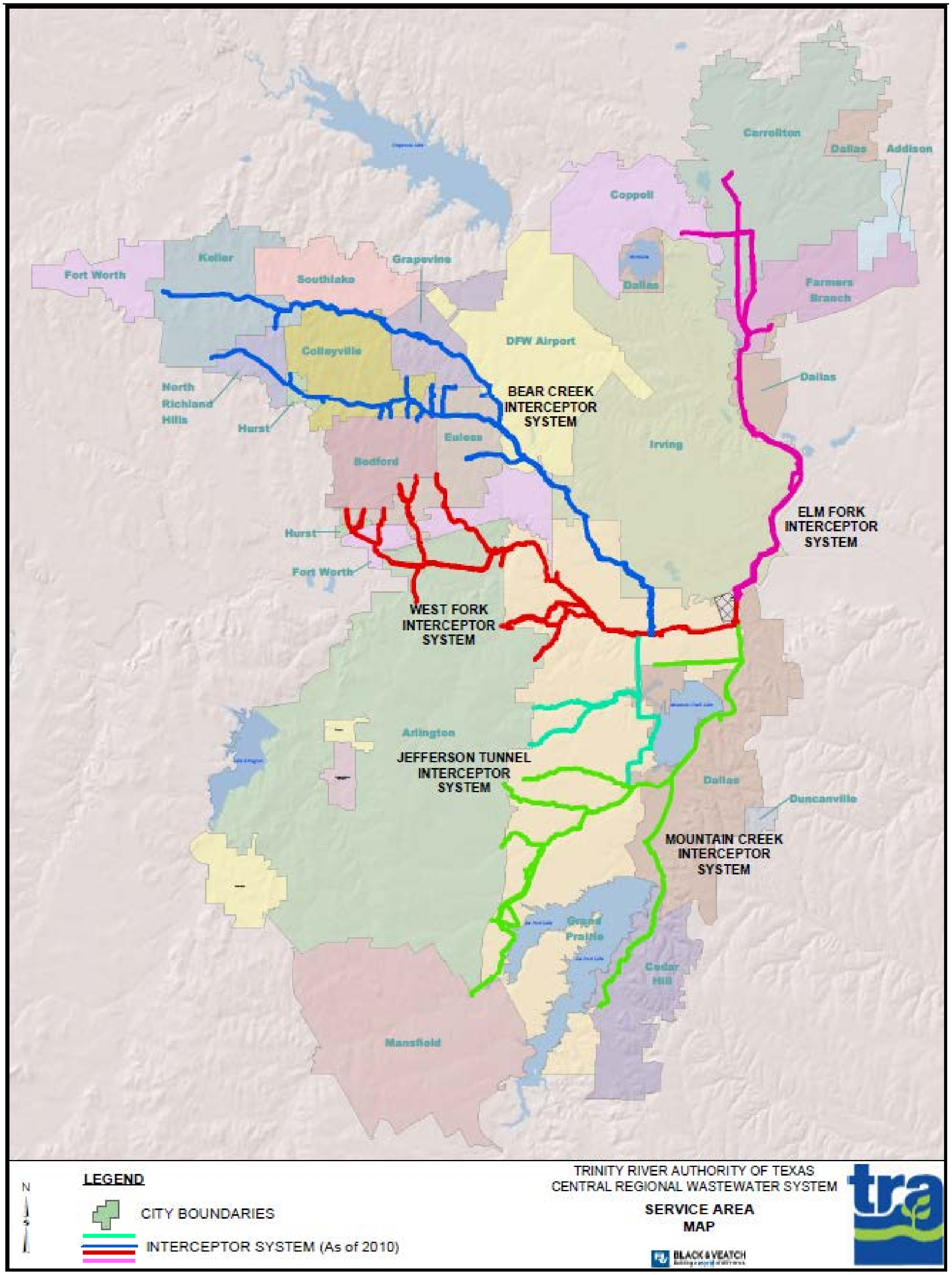

Figure 2 - Central River Wastewater System Interceptor Map of TRA.

A comprehensive management plan using the 6-step systematic approach was developed which included grab sampling to identify preliminary critical areas of concern (CAC) followed by detailed continuous monitoring of air-phase H_2S using OdaLog meters to further prioritize the CAC. Liquid-phase treatment was evaluated and chemical field trials were conducted for selected alternatives. A risk analysis was developed by assigning structural condition and consequence of failure ratings for each CAC. A five-year plan was developed which included a timeline for renewal and/or chemical treatments for the CAC identified. Recommendations for continued H_2S monitoring and analysis, preventative maintenance, new product testing, design standards, and program management activities are included in the corrosion management program (CMP). The following section provides detailed discussions of the TRA's corrosion management planning using the systematic approach described above.

Identification of Potential CAC for Corrosion

Extensive field sampling was performed over several months within the CRWS interceptor system to identify areas with high H_2S and/or sulfide levels and constructed of non-corrosion resistant materials. The initial testing involved collecting liquid and air grab samples at 46 locations to screen for potential CAC. Grab sampling data were recorded on detailed log sheets, which included dissolved and total sulfide, headspace H_2S, temperature, oxidation reduction potential (ORP), liquid pH, and crown surface pH. Photographs and detailed field notes were taken at each site with observations on current conditions. **Figures 3** and **4** show the dissolved sulfide and headspace H_2S data from the initial grab sampling at each of the 46 sampling sites.

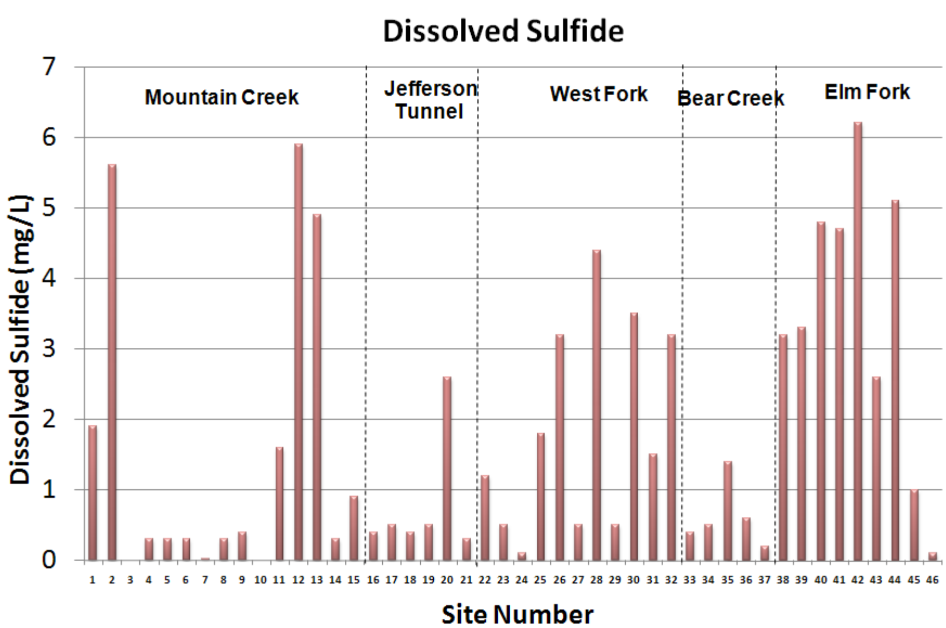

Figure 3 - Dissolved Sulfide Grab Sample Data for TRA

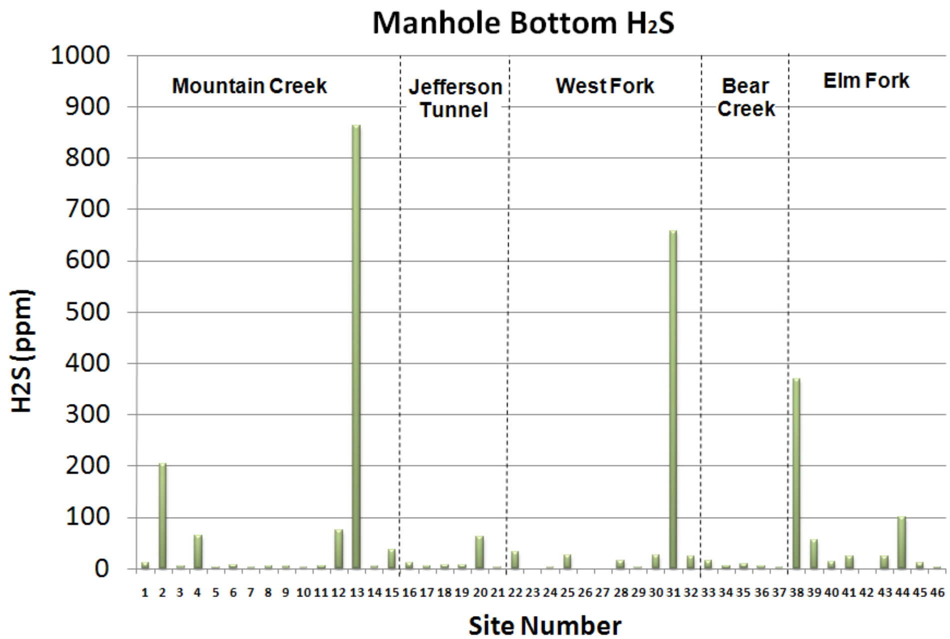

Figure 4 - Air-phase H_2S Grab Sample Data for TRA

A second phase of sampling was performed to gather more detailed data at each of the preliminary CAC to enable better prioritization of the CAC. This included additional sulfide and H_2S grab sampling, and continuous monitoring of the air-phase H_2S concentrations using OdaLog meter to record variations in H_2S over a longer period of time. **Figure 5** shows the OdaLog data recorded over a period of 3 days at one of the 46 CAC sites. The H_2S level varied from <20 ppm_v to 261 ppm_v with a 3-day average concentration of 65 ppm_v. A comparison of the grab and continuous sampling results shows the limitation of single grab sampling which recorded zero H_2S as shown in **Figure 4** and did not reflect the actual peak conditions and diurnal variations at the site.

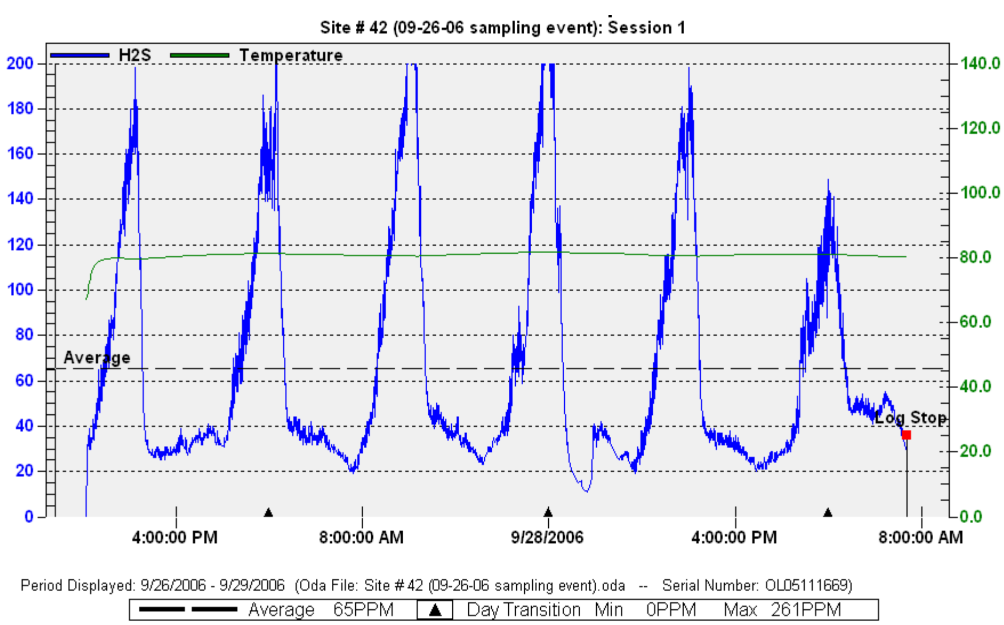

Figure 5 – OdaLog Sampling Data at Site No. 42.

Figure 6 shows a portion of the collection system map for TRA with grab sample data shown in boxes and OdaLog data shown in circles. Red, orange, green colors were used to indicate high, moderate, and low levels respectively. Additional information on the OdaLog and grab sampling at TRA is discussed in the technical paper titled "*Development of a Comprehensive Collection System Sulfide and Corrosion Management Plan for Trinity River Authority of Texas*" (Van Durme et al., 2011).

Based on the detailed sampling results, 20 reaches were designated as CAC for TRA CRWS.

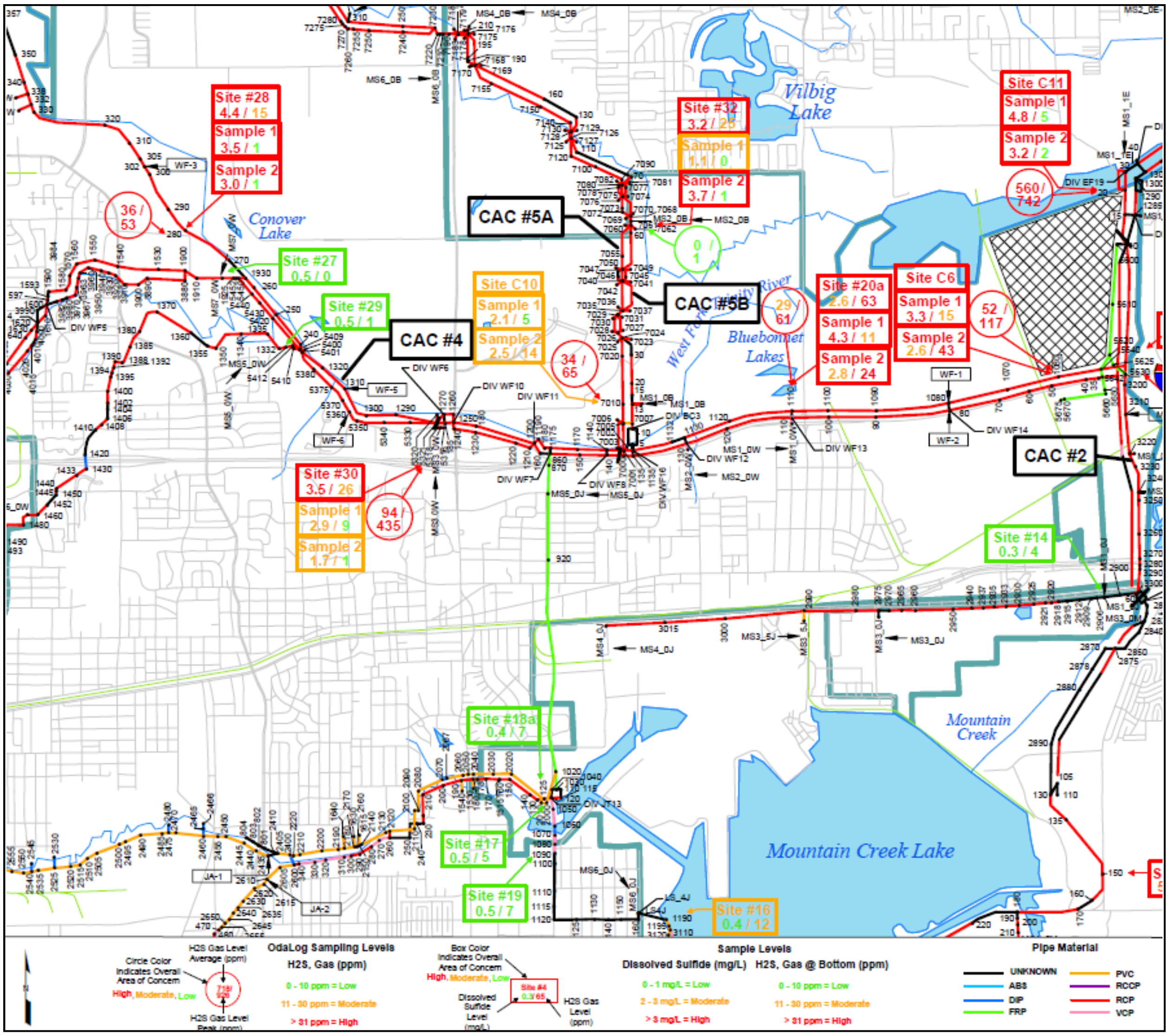

Figure 6 - System Map with Dissolved Sulfide and H_2S Data.

Review Schedule for CIPs and Finalize CAC

The existing CIPs were reviewed to identify pending and future pipeline relief and rehabilitation projects for comparison with the CAC identified in step 1. Based on the results of the detailed sampling, some of the CAC not presently scheduled for rehabilitation were added to the CIPs, while areas scheduled for the future rehabilitation were rescheduled for more rapid implementation. Six identified CAC were already scheduled for renewal. Other areas were selected for chemical treatment to prevent further corrosion and avoid pipeline failure.

As listed on **Table 1**, 14 reaches (shaded in yellow) were designated as CAC to be further evaluated for considerations of chemical treatment and/or replacement/rehabilitation. Areas where the CIP project involves a parallel relief line with the existing unprotected line remains in service were also designated as critical. For example, the relief projects WF-G, WF-1, and all the Elm Fork projects involve parallel relief lines where an existing line remains in service and is subject to corrosion.

The designated critical reaches cover a total of about 66 km (215,000 feet) or roughly 40 miles of pipeline. This remains a large territory, but the initial area was significantly reduced, so attention could now be focused on these critical reaches.

Table 1 - Designation of Critical Area of Concerns (CAC)

Reach Designation	Length, km (ft)	Sulfide, mg/L	H_2S, ppm_v	Relief Project ID	Relief Type
Mountain Creek Interceptor System					
MC 1	629 (2,063)	5.6	205	-	-
MC 2	3,759 (12,329)	5.6/1.9	205/12	10MC-1	Replace
MC 3	6,639 (21,775)	1.6/5.9	6/75	MC-5	Replace
MC 4	-	4.9	863	-	-
MC 5	-	4.9	863	MCSIPH	Siphon upgrade
MC 6	2,015 (6,608)	4.9/0.9	863/37	30MC-1	Replace
West Fork Interceptor System					
WF 1	10,663 (34,975)	1.2	33	-	-
WF 2	4,693 (15,394)	1.2	33	WF-11B	Replace
WF 3	2,093 (6,866)	3.2	0	WF-11A	Replace
WF 4	2,534 (8,313)	3.2/3.5	0/26	-	-
WF 5	1,943 (6,372)	3.5	26	WF-G	Replace
WF 6	5,823 (19,100)	1.5	658	WF-1	Replace
WF 7	4,685 (15,368)	1.5	658	10WF-1	Rehab
Bear Creek Interceptor System					
BC 1	4,949 (16,232)	3.2	25	BCSIPH	Siphon upgrade
Elm Fork Interceptor System					
EF 1	3,054 (10,016)	5.1	101	EF-G (EF-5)	Parallel
EF 2	18,977 (62,246)	5.1	101	-	-
EF 3	3,935 (12,908)	2.6/6.2	25/0	EF-6/EF-R3	Parallel/Rehab
EF 4	2,073 (6,799)	4.7	25	EF-7	Parallel
EF 5	4,682 (15,358)	4.7	25	EF-2	Parallel
EF 6	7,711 (25,292)	3.3	55	EF-1/EF-R1/EF-R2	Parallel/Rehab

Notes: CAC shaded in yellow were to be further evaluated for considerations of chemical treatment and/or replacement/rehabilitation. All other CAC were already scheduled for renewal as part of the CIPs.

Assessment of Interceptor Condition and Risk Rating of CAC

The risk rating of a CAC was defined as the product of two factors: (1) the probability of structural asset failure as represented by condition scoring, and (2) the potential impacts of a failure as represented by consequence of failure scoring. For TRA, the interceptor conditions were evaluated in details and risk ratings were calculated for each pipe asset of the 14 CAC identified plus 2 additional reaches of interceptor identified based on TRA concerns.

Condition Scoring. Condition scores, representing the probability of structural asset failure, were based on a scale of 1 to 5 with 1 being very good (sound physical condition) and 5 being very poor (failed or near failure). The approach to developing condition scores for the interceptors was based on the following three factors.

- ***General condition score –*** Assigned by CRWS staff based on their knowledge and available closed-circuit television (CCTV) and inspection data.
- ***Interceptor age score –*** Assigned to each CAC based on the average age.
- ***Corrosion level score –*** Based on peak OdaLog readings, but if that data was not available then dissolved sulfide readings were used.

The overall condition score is calculated as the average of the general three scores. **Table 2** lists the general condition, interceptor age, and corrosion level scores for each CAC based on field sampling results.

Consequence of Failure (COF) Scoring. Consequence of failure scores provide the other critical component of the risk ratings that drive the priorities for planned improvements and the appropriate corrosion control practices for sewer assets. The consequence of failure assessment examined the potential impacts of a structural failure occurring for each CAC. Factors considered in this assessment included economic, environmental, and social/public health impacts. While this analysis has the potential to be particularly complex due to the challenges of quantifying these types of impacts, a simplified 1 to 3 scoring system was utilized for this analysis which was based on the Sewerage Rehabilitation Manual (SRM), 4th Edition, developed by the Water Research Centre (WRc, 2001). The specific assumptions and modifications to the SRM procedures for this project analysis are presented in **Tables 3** and **4** which considered five COF factors for determination of the overall COF score.

Table 2 - Condition Scoring for CAC.

CAC (1)	Basin	Diameter		Length		Condition Score			
		mm	inch	m	ft	General Condition (2)	Interceptor Age	Corrosion Level (3)	Overall Score (4)
9	Elm Fork	1050 - 2200	42 - 90	2,073	6,799	4.0	3.0	5.0	**4.0**
11	Elm Fork	750/2400	30/96	5,259	17,251	4.0	3.0	5.0	**4.0**
10	Elm Fork	2250	90	4,682	15,358	4.0	3.0	5.0	**4.0**
2	Mountain Creek	1950	78	2,015	6,608	3.0	1.0	5.0	**3.0**
4	West Fork	1500/1800	60/72	2,534	8,313	3.0	4.0	5.0	**4.0**
3B	West Fork	1200 - 1650	48 - 66	4,534	14,871	3.0	4.0	5.0	**4.0**
6B	Elm Fork	825	33	1,913	6,276	5.0	3.0	5.0	**4.3**
8B	Elm Fork	300 - 1800	12 - 72	11,803	38,713	4.0	3.4	3.0	**3.5**
5B	Bear Creek	750/1350	30/54	1,848	6,060	4.0	3.7	4.6	**4.1**
8A	Elm Fork	750 - 1650	30 - 66	7,175	23,533	2.0	2.0	5.0	**3.0**
1	Mountain Creek	600 - 1050	24 - 42	629	2,063	3.0	3.2	5.0	**3.7**
12	Mountain Creek	825/900	33/36	3,759	12,329	3.0	4.0	3.0	**3.3**
7	Elm Fork	900 - 1800	36 - 72	4,534	14,871	3.0	2.9	1.0	**2.3**
6A	Elm Fork	300 - 900	12 - 36	1,140	3,740	2.0	3.0	5.0	**3.3**
3A	West Fork	1900	78	6,129	20,104	2.0	1.0	3.0	**2.0**
5A	Bear Creek	900 - 2250	36 - 90	3,101	10,172	2.0	1.0	3.4	**2.1**

Notes:

(1) CAC designations from Table 1 were modified based on planned future improvements and parallel lines.
(2) General condition was based on inspection data and CRWS Technical Services system knowledge.
(3) Corrosion level were based on H_2S (ppm_v) from Odalog sampling round.
(4) Overall Score = Average of general condition, interceptor age, and corrosion level scores; 1.0 = Very good condition; 5.0 = Very poor condition

Table 3 – Consequence of Failure (COF) Evaluation Matrix for TRA.

Item	Description	COF Score	COF Score Number
Stream/Railroad Crossing	No	Low impact	1
	Yes	High impact	3
Area Served	0 - 4,000 hectare (0 - 10,000 acres)	Low impact	1
	4,000 - 12,000 hectare (10,000 - 30,000 acres)	Medium impact	2
	> 12,000 hectare (> 30,000 acres)	High impact	3
Existing Parallel Interceptor	Yes	Low impact	1
	No	High impact	3
Road Crossing	Any other.	Low impact	1
	Highly important road, traffic sensitive street; peak hours ONLY with adequate diversions	Medium impact	2
	Highly important road, traffic sensitive street; ALL DAY	High impact	3

Table 4 - Consequence of Failure (COF) Repair Cost Factors for TRA.

Repair Cost Factors (RCF) Pipe Sewers Up To and Including 900 mm (36-inch) in diameter						
Depth (feet)	0 – 8.75	8.76 – 12.0	12.01 – 15.25	15.26 – 18.5	18.51– 21.75	≥ 21.76
Depth (meter)	0 – 2.67	2.68 – 3.66	3.67 – 4.65	4.66 – 5.64	5.65 – 6.63	≥ 6.64
Good Ground	1.0	2.0	3.0	4.0	5.5	7.0
COF Score	1	1	2	2	2	3
Repair Cost Factors (RCF) Pipe Sewers Greater Than 900 mm (36-inch) in diameter						
Depth (feet)	0 – 8.75	8.76 – 12.0	12.01 – 15.25	15.26 – 18.5	18.51– 21.75	≥ 21.76
Depth (meter)	0 – 2.67	2.68 – 3.66	3.67 – 4.65	4.66 – 5.64	5.65 – 6.63	≥ 6.64
Good Ground	4.0	7.0	13.0	19.0	26.0	33.0
COF Score	2	3	3	3	3	3
Notes: 1 = Low cost; 2 = Medium cost; 3 = High cost.						

For TRA, assets marked as 3 or "High Impact" tended to be larger pipelines that might be under or near major roads or water bodies and/or servicing large areas. Failure of these assets would likely be a publicized incident and would tend to be expensive and/or difficult to repair. At the other end, the 1 or "Low Impact" assets tend to be smaller lines in low density areas and non-environmentally sensitive areas. Failure of these assets might require an immediate response by TRA staff, but it would not be a highly publicized or expensive incident and would be readily repaired at relatively low cost. The results of the overall COF scoring (averages of all five factors) are shown on **Table 5**.

Table 5 - Consequence of Failure (COF) Scoring for TRA.

Critical Area of Concern	Basin	Consequence of Failure (COF) Score					
		Stream/ Railroad Crossing	Area Served	Existing Parallel Sewer	Road Crossing	Repair Cost Factor	Overall Score
9	Elm Fork	3.0	3.0	3.0	3.0	3.0	**3.0**
11	Elm Fork	3.0	3.0	3.0	3.0	2.9	**3.0**
10	Elm Fork	3.0	3.0	3.0	3.0	3.0	**3.0**
2	Mountain Creek	3.0	3.0	3.0	3.0	3.0	**3.0**
4	West Fork	3.0	3.0	1.0	1.0	3.0	**2.2**
3B	West Fork	3.0	3.0	1.0	1.0	3.0	**2.2**
6B	Elm Fork	3.0	1.0	3.0	2.0	1.1	**2.0**
8B	Elm Fork	3.0	2.0	1.0	3.0	2.6	**2.3**
5B	Bear Creek	1.0	3.0	1.0	1.0	2.8	**1.8**
8A	Elm Fork	3.0	2.0	1.0	3.0	2.7	**2.3**
1	Mountain Creek	1.0	1.0	3.0	2.0	2.0	**1.8**
12	Mountain Creek	1.0	1.0	3.0	3.0	1.9	**2.0**
7	Elm Fork	3.0	1.0	3.0	3.0	2.9	**2.6**
6A	Elm Fork	1.0	1.0	3.0	2.0	1.3	**1.7**
3A	West Fork	3.0	3.0	1.0	1.0	3.0	**2.2**
5A	Bear Creek	1.0	3.0	1.0	1.0	2.7	**1.7**
Notes: Overall Score = averaged of all five COF scores; 1 = Low impact; 2 = Medium impact; 3 = High impact.							

Risk Rating. The COF scores were combined with the condition scores to calculate the risk ratings for each CAC as listed in order from highest to lowest risk on **Table 6.** The risk ratings are indicated on a CRWS interceptor map as shown on **Figure 7**. The highest risks are associated with assets where the chances of structural failure are relatively high, such as an old pipe with a history of structural failures, and where such a failure would have major impacts including widespread interruptions of service to contracting parties or large discharges of wastewater to sensitive water bodies. For TRA, the three highest rated CAC (9, 10, and 11) were all in the Elm Fork Basin. The CAC were further evaluated to determine which areas would be selected for chemical treatment and replacement/rehabilitation. Reaches of interceptor within a CAC were also split if parallel lines were included.

Table 6 - Risk Rating Prioritization Results for CAC.

Critical Areas of Concern (CAC)	Basin ID	Condition Score (1 - 5)	Consequence of Failure (COF) Score (1 - 3)	Risk Score (Condition x COF) (1 - 15)	Risk Rating
9	Elm Fork	4.0	3.0	12.0	High Risk
11	Elm Fork	4.0	3.0	12.0	
10	Elm Fork	4.0	3.0	12.0	
2	Mountain Creek	3.0	3.0	9.0	Medium Risk
4	West Fork	4.0	2.2	8.8	
3B	West Fork	4.0	2.2	8.8	
6B	Elm Fork	4.3	2.0	8.6	
8B	Elm Fork	3.5	2.3	8.1	
5B	Bear Creek	4.1	1.8	7.4	
8A	Elm Fork	3.0	2.3	6.9	Low Risk
1	Mountain Creek	3.7	1.8	6.7	
12	Mountain Creek	3.3	2.0	6.6	
7	Elm Fork	2.3	2.6	6.0	
6A	Elm Fork	3.3	1.7	5.6	
3A	West Fork	2.0	2.2	4.4	
5A	Bear Creek	2.1	1.7	3.6	
Notes: Risk Score, Low risk (1 – 7); Medium risk (7.1 – 10); High risk (10.1 – 15)					

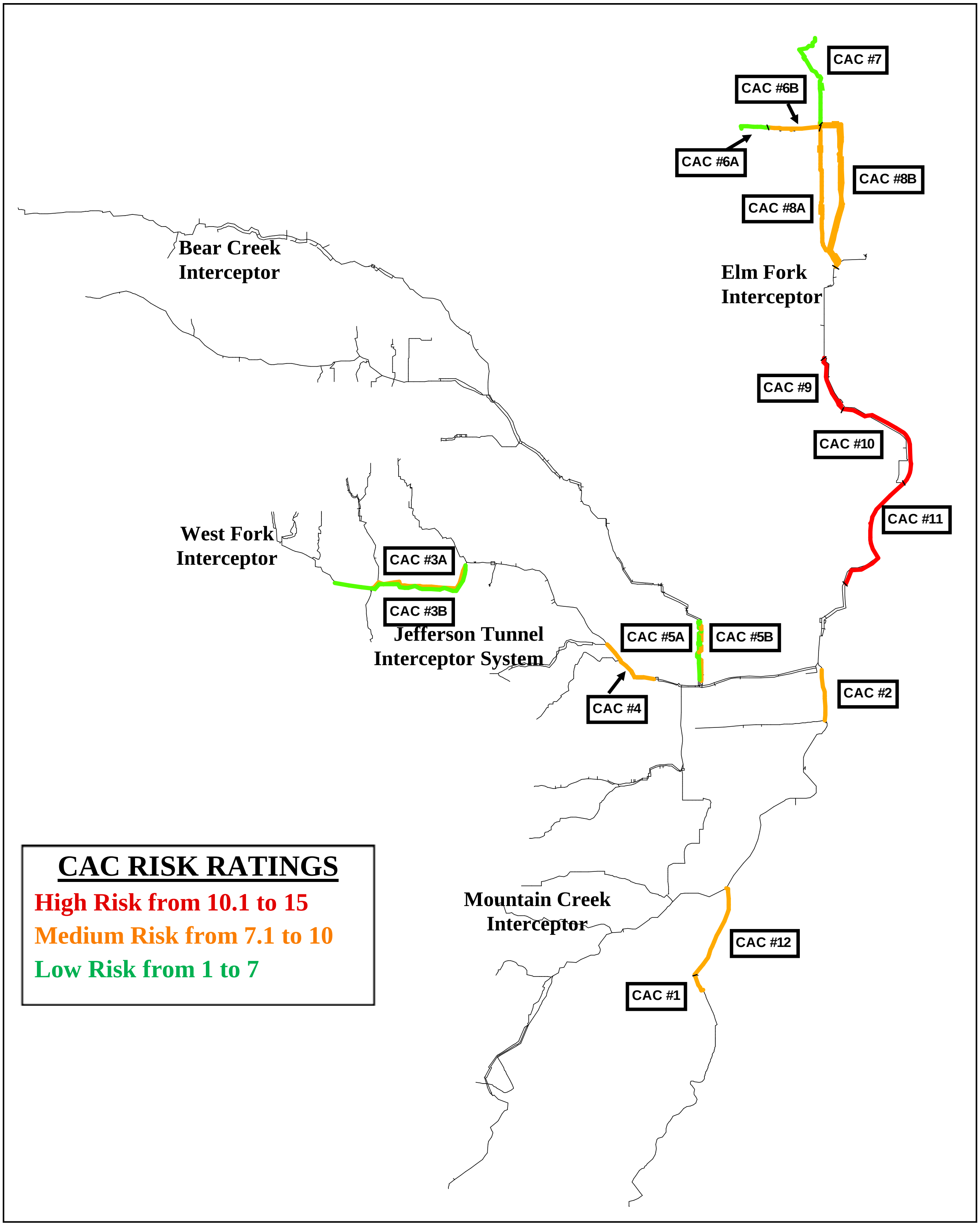

Figure 7 - CRWS Interceptor Map with CAC Risk Ratings.

Evaluation of Corrosion and Odor Treatment Methods

A variety of treatment methods for controlling corrosion and odor were evaluated for TRA with the main advantages and disadvantages compared.

Chemical Treatment for Corrosion Control. The following four chemical alternatives were identified as the best suited methods for CRWS collection system treatment considering maintaining alkalinity is one of the key considerations:

- Peroxide Regenerated Iron-Sulfide Control (PRI-SC™)
- Nitrate (BIOXIDE™)
- Hydrogen peroxide
- Magnesium hydroxide (Thioguard™)

Following the baseline sampling, extensive pilot testing of the U.S. Peroxide PRI-SC™ technology on the Mountain Creek Interceptor was performed and excellent results were observed. The PRI-SC™ technology uses iron salts, but included a regeneration process to reduce the iron required, which minimizes the impact on alkalinity and solids for the CRWS treatment plant and is appropriate for large interceptors and can treat long reaches. The results of the pilot testing showed significant improvement over the use of iron salts alone. Dissolved sulfide at control points was maintained below the target of 0.5 mg/L and headspace H_2S was significantly reduced. The testing also showed the variability of conditions relative to temperature and established that regular monitoring was necessary to optimize chemical dosages to maintain effective treatment and minimize overall treatment cost.

Although the PRI-SC™ technology reduces the iron requirements, there is still some iron being used. As more reaches are selected for sulfide control, it may be desirable to use products that have either a neutral or beneficial impact on alkalinity such as nitrates (BIOXIDE™). BIOXIDE™ is a proven, effective means of sulfide control and is typically more expensive than peroxide regenerated iron or iron salts alone, but it does not reduce alkalinity and it does not increase solids.

Hydrogen peroxide is a general purpose oxidant that can provide economical treatment for smaller line segments. It is a good fit as part of a comprehensive program using PRI-SC™ technology because peroxide is already being used in the system and operators are familiar with handling and equipment. Peroxide is relatively fast acting, so it can be dosed just upstream of desired control locations. However, it is consumed by wastewater organics and longer sewer lines require multiple injection sites.

Magnesium hydroxide is the one chemical considered that actually has a positive impact on wastewater alkalinity. Thioguard™ has been used by TRA for small applications, but it has not been pilot tested on larger interceptors by TRA, so site specific dosage rates were not established and the cost for treatment could not be well-defined.

All of the suggested chemical alternatives can be employed by TRA to control corrosion in the collection system. Some of the options offer low cost, but may reduce alkalinity and add solids, while other options cost more, but do not affect alkalinity and solids. The objective of a system-wide management plan is to implement a combination of chemicals that balances economic and non-economic factors. Information on treatment costs can be found in "*Development of a Comprehensive Collection System Sulfide and Corrosion Management Plan for Trinity River Authority of Texas"* (Van Durme et al., 2011).

Vapor-phase Treatment for Odor Control. While liquid-phase chemical treatment can significantly reduce sulfide formation and release in the collection system, trace amounts of sulfide can yield H_2S concentrations high enough to cause odor and corrosion problems especially in highly turbulent locations such as force main discharges and siphons. Vapor-phase treatment is often needed to control odor in these locations particularly where homes and businesses are located nearby. Also, in reaches where corrosion resistant materials have been used for pipelines and manholes, vapor-phase treatment of problem areas may be preferred to liquid-phase treatment of a large flow volume. In such cases, the H_2S concentrations may exceed 100 ppm_v, so care must be taken to select a suitable vapor-phase treatment device. Some of the manholes on the CRWS had H_2S peaks close to 1,000 ppm_v, but that represents an unventilated condition.

Most collection system applications have relatively low air volumes of 4.7 m^3/s (10,000 cfm) or less, so vapor-phase treatment units are typically small in size. For collection system applications situated close to homes, special consideration should be given to noise reduction measures for fans and, in some cases, pumps. Tall stacks are desirable from a dispersion standpoint, but shorter stacks may be necessary to minimize the visual impact in a neighborhood. Due to the proximity to homes, the treatment devices selected must provide high efficiency odor and corrosion control, particularly in locations with high inlet H_2S.

Various vapor-phase treatment technologies were evaluated for potential use in the CRWS collection system including biotrickling filter, biofilter, and activated carbon systems (**Figure 8**). The evaluation concluded that if liquid-phase chemical treatment was being used and headspace H_2S was under 20 ppm_v (annual average), then activated carbon or other dry scrubbing media would be the best choice, because it requires the least operator attention. If a high capacity carbon media was used, it should last at least a year before replacement is required. If liquid-phase chemical treatment was not used and H_2S was above 20 ppm_v, then some type of biological treatment would provide the most economical treatment. Biofilters were considered to be suitable for H_2S in the range of 20 to 40 ppm_v, while biotrickling filters could be applied for levels above 40 ppm_v or at locations where space was a concern. It was noted that biofilters provide complete odor control whereas biotrickling filters remove only H_2S, so in sensitive areas, carbon polishing may be needed to provide complete odor control.

Figure 8 – Vapor-phase Treatment Technologies for Odor Control.

Rating of Interceptor Repair and Replacement Techniques

A wide range of repair and replacement techniques were evaluated including open cut and trenchless methods. The open cut method is less complicated and does not require specialized equipment and skilled personnel. However, the surface disturbance and potential traffic restrictions caused by open cut may be undesirable. The open cut method is mostly used for full replacement, although it also can be used for pipeline rehabilitation. Trenchless methods require specialized equipment and skilled personnel. The surface disturbance and traffic restrictions are minimized when utilizing trenchless methods. The trenchless method is mostly used for pipe rehabilitation, with occasional use for pipe replacement.

A numerical scoring system was developed to rate the available options, which were then summarized in three tier groupings, as shown on **Table 7**. The tier rating is specific to the CRWS as it takes into account particular conditions and TRA historical usage and experience, with the following considerations:

- The results of the rating indicated that Tier 1 options for replacement and rehabilitation were either slip-lining or open cut. If the existing pipe has excess capacity and a smaller pipe cross section can be accommodated, then slip-lining would be the preferable option. If capacity is an issue, then open cut should be considered;

- If open cut is not feasible due to surface disruption and slip-lining is not feasible due to capacity requirements, consideration should be given to the Tier 2 options listed on **Table 7**. The common denominator in the Tier 2 options is the need for bypass pumping. If the need for bypass pumping can be minimized, these options could become more applicable. For example, if the flow can be diverted to a parallel line, the need for bypass pumping would be minimized.

It was recommended that further consideration be given to the replacement and rehabilitation method selection on a case-by-case basis during the design stage.

Table 7 - Summary of Replacement, Rehabilitation, and Repair Option Rating.

Tier	Group	Option	Planning Level Cost Range	
			$/ft/inch-diameter	$/ft/inch-diameter
Tier 1	Replacement & Rehabilitation	Open Cut	$1.9 to $2.6	$15 to $20
		Slip-lining	$0.8 to $1.6	$6 to $12
	Repair	Mechanical Rubber Seal	$130 to $390 Each	$1,000 to $3,000 Each
Tier 2	Replacement & Rehabilitation	T-Hab	$1.0 to $1.3	$8 to $10
		CIPP	$1.0 to $1.9	$8 to $15
		Composite Lining	$1.0 to $1.3	$8 to $10
		Spirally Wound Pipe	$1.0 to $1.3	$8 to $10
	Repair	Internal Grouting	$130 to $650 Each	$1,000 to $5,000 Each
Tier 3	Replacement & Rehabilitation	Deformed/Reformed	$1.0 to $1.3	$8 to $10
		Fold & Form	$1.0 to $1.3	$8 to $10
		FIPP	$1.0 to $1.3	$8 to $10
		Panel Lining	$0.8 to $1.0	$6 to $8
	Repair	External Grouting	$650 to $2,600 Each	$5,000 to $20,000 Each

Notes: CIPP = Cured-in-place Pipe; FIPP = Formed-in-place Pipe

Development of Corrosion Management Program (CMP)

A comprehensive corrosion management program (CMP) was developed to link the chemical feed program and rehabilitation and replacement projects for TRA. Planning level present worth costs were developed for each CAC to compare chemical treatment costs with capital improvements. All aspects of the various evaluations were discussed in a joint workshop with TRA and an initial plan for repair/replacement and chemical addition was developed for each CAC.

A life cycle analysis was used to compare the costs for CAC 2, 3A, 5A, and 8A which were identified as potential candidates for long-term chemical treatment versus rehabilitation and replacement. Based on the life cycle cost comparison, it was found to be more cost effective to provide long-term chemical treatment for CAC 3A and 8A through the 50-year life of the interceptors while rehabilitation/replacement is more cost effective for CAC 2 and 5A.

In addition to prioritizing CAC for rehabilitation/replacement and recommending the type of chemical treatment for areas not scheduled for immediate renewal, the CMP also incorporated recommendations for continued monitoring and analysis, preventative maintenance, new product testing, design standards, and program management, as follows:

- ***Ongoing monitoring and analysis program.*** The monitoring program would be performed by TRA staff and would include continuous H_2S monitoring with OdaLog meters to gather consistent data over an extended period of time. The OdaLog data would be used to identify "hot spots" for further evaluation, with sulfide, sulfate, pH, and other data collected to define the cause of the elevated H_2S. Corrosion monitoring was recommended to establish the relationship between H_2S and corrosion rates.

- ***Expansion of existing preventive maintenance program.*** To address corrosion issues, condition monitoring was recommended to provide necessary input to the maintenance program with increased cleaning and TV inspection to confirm the condition assessments. On-call maintenance contracts would be used to respond to preventative point repairs and limited interceptor lining or replacement requirements.

- ***Identification and testing of new corrosion prevention and protection products.*** A process to identify and test new corrosion prevention and protection products was also recommended. A well defined procedure would be established for prequalification with review and approval responsibilities within TRA. Vendors would be provided with prequalification criteria including experience, specifications, applications, financial stability, references, and other pertinent information. Testing procedures would be developed to avoid potential negative impacts and clearly define the length of the trial period. Products that prove beneficial would be adopted in the corrosion design standards.

- ***Design standards for corrosion prevention and protection***. Design standards provide a means to track performance, incorporate new products, and update and improve standards as required. The initial step was to establish a framework to organize the information regarding materials and systems that deal with corrosion. A design standards group composed of TRA staff and selected engineering consultants would capture the existing documented and undocumented guidelines and standards. These would be reviewed and approved and be immediately available for use in CRWS projects. After the existing standards are identified and approved, a gap analysis would determine required additions and improvements.

- ***CMP coordinator.*** A CMP coordinator is recommended to champion corrosion protection and prevention initiatives.

- ***Information management plan.*** The management plan would be put in place to link individual project data bases. Quantifiable performance measures would be developed for individual chemical feed systems with key performance indicators established as part of the ongoing assessment program.

The success of the CMP would be measured by the completion of effective corrosion prevention and protection projects. Progress would be tracked against the schedule and summarized in the quarterly report.

SUMMARY

This paper discusses a systematic, step-by-step approach for developing a comprehensive collection system sulfide and corrosion management plan for utilities confronted with high hydrogen sulfide and interceptor corrosion coupled with aging infrastructure. The approach provides a systematic management planning approach which focuses on prioritization of critical areas and considers economical and non-economical factors. The key steps involved in this comprehensive approach include:

- Identification of potential Critical Areas of Concern (CAC) for corrosion
- Review current schedule for Capital Improvements Projects (CIPs) and finalize CAC
- Risk assessment of interceptor condition and risk rating of CAC
- Evaluation of odor control and corrosion treatment methods
- Rating of interceptor repair and replacement techniques
- Development of corrosion management program (CMP)

A comprehensive management plan using the above mentioned systematic approach was developed for TRA Central Regional Wastewater System which included grab sampling to identify preliminary CAC followed by detailed continuous monitoring of air-phase H_2S for priorization of the CAC identified. A risk analysis was developed by assigning structural condition and consequence of failure ratings for each CAC. A five-year corrosion management program (CMP) was developed which included a timeline for renewal and/or chemical treatments for the CAC identified. In addition, recommendations for continued H_2S monitoring and analysis, preventative maintenance, new product testing, design standards, and program management activities were also included in CMP. The progress of the CMP would be tracked against the schedule as summarized in the quarterly reports.

ACKNOWLEDGEMENTS

The authors acknowledge the dedicated participation of TRA staff in all aspects of this comprehensive planning study and the overall project leadership of APAI.

REFERENCES

McMillen, J.; Jordan, B.; Rackley, W.; Tatum, W.; Woolsey, M. (2008) *Large-Scale Oxygen Injection for Odor Control at Primary Clarifiers at the Trinity River Authority of Texas*; Proceedings of Odors and Air Emissions Conference 2008, Phoenix, AZ.

Van Durme, G.; Koh, S.; Parsons, L.; Belvin, C. (2011) *Development of a Comprehensive Collection System Sulfide and Corrosion Management Plan for Trinity River Authority of Texas;* Proceedings of WEFTEC 2011, Los Angeles, CA.

WRc (2001) *Sewerage Rehabilitation Manual*, 4th ed.; Water Research Centre, UK.