

City of Riverside

**WASTEWATER COLLECTION AND TREATMENT
FACILITIES INTEGRATED MASTER PLAN**

**VOLUME 5: AIR QUALITY AND EMISSIONS CONTROL
CHAPTER 1: REVIEW OF THE 2005 ODOR CONTROL
MASTER PLAN**

FINAL
February 2008



**WASTEWATER COLLECTION AND TREATMENT
FACILITIES INTEGRATED MASTER PLAN**

**VOLUME 5: AIR QUALITY AND EMISSIONS CONTROL
CHAPTER 1: REVIEW OF THE 2005 ODOR CONTROL MASTER PLAN**

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REVIEW OF THE 2005 ODOR CONTROL MASTER PLAN

1.1 PURPOSE

The purpose of this chapter is to summarize the 2005 Odor Control Master Plan (2005 Report), completed for the City of Riverside (City) Regional Water Quality Control Plant (RWQCP); present its major conclusions and recommendations; and determine whether it is sufficient for air quality planning purposes. The 2005 Report is included in Appendix A for reference.

1.2 CONCLUSIONS AND RECOMMENDATIONS

A review of the 2005 Report is summarized as follows:

- The 2005 Report provides the RWQCP staff with adequate guidance for addressing odor issues. Therefore, the report is generally sufficient for odor control planning at the RWQCP.
- Odor emission and dispersion modeling would enhance the 2005 Report but appears unnecessary at this point because odor complaints are practically nonexistent, extensive residential and commercial encroachment is not expected in the near future, and significant increases in the amounts of emitted odors are not foreseen in the near future.
- Although the 2005 Report is generally sufficient for odor control planning purposes, it is not sufficient for general air quality planning purposes. The report focuses on odor and does not discuss other regulated air pollutants emitted from the RWQCP. Furthermore, the 2005 Report does not include a regulatory section detailing current and proposed air quality regulations. Volume 5, Chapter 2 - Review of Applicable Regulatory Requirements, presents existing and proposed sources of regulated air pollutants and provides a review of applicable regulatory requirements.

1.3 INTRODUCTION TO THE 2005 REPORT

The 2005 Report was triggered by the RWQCP initiative to minimize offsite odor nuisances, given the rapid development in the land surrounding the RWQCP and the elevated profile of the RWQCP in the community.

The stated purpose of the 2005 Report was to identify possible solutions to odor problems from sources throughout the RWQCP with an emphasis on the existing and proposed future upgrades to the primary clarifiers and solids handling facilities.

1.4 2005 REPORT CONTENT SUMMARY

The 2005 Report consists of an executive summary, seven chapters, and an appendix. Brief summaries of the seven chapters and the appendix are as follows:

- **Chapter 1 - Introduction.** Chapter 1 introduces the purpose the 2005 Report. It provides descriptions and schematics of existing (as of 2005) treatment processes including: liquid stream treatment, solids treatment, and miscellaneous processes. Additionally, Chapter 1 discusses the presence or absence of odor control facilities for the various treatment processes.
- **Chapter 2 - Data Collection and Analysis.** Chapter 2 discusses collection and analysis of hydrogen sulfide and odor data for the RWQCP. Specifically, it summarizes historical liquid- and gas-phase data, presents the findings of interviews with RWQCP operators, and presents observations from site visits. Based on the collected data, Chapter 2 identifies the processes with the highest potential for odor generation.
- **Chapter 3 - Typical Odor Control Strategies.** Chapter 3 describes odor control technologies and strategies that are typically used at wastewater treatment facilities. The chapter groups the technologies and strategies in the following five categories: chemical addition, operational procedures, foul air collection and treatment, process changes, and enhanced atmospheric dispersion. The chapter includes tables that summarize the advantages and disadvantages of various liquid- and gas-phase odor control options.
- **Chapter 4 - Odor Control Strategies for the RWQCP.** Chapter 4 identifies and discusses the odor control technologies and strategies that can be effective in controlling odors from the sources identified in Chapter 2. Specifically, Chapter 4 discusses and recommends odor control alternatives for each of the following facilities: headworks, existing and new primary clarifiers, existing and future solids processing facilities, Dissolved Air Flotation Tanks (DAFTs), existing and future Dewatering Facility, and existing and future Truck Loading Facility. The discussion includes preliminary design criteria for the recommended alternatives. Finally, Chapter 4 identifies odor dispersion modeling as an important tool in selecting and optimizing odor control approaches.
- **Chapter 5 - Permitting.** Chapter 5 identifies the potential implications of odor control facility modification or construction on the air permitting process. Also, the chapter mentions the possibility of the South Coast Air Quality Management District (SCAQMD) imposing specific odor concentration goals at the RWQCP fence line.
- **Chapter 6 - Preliminary Cost Estimates.** Chapter 6 presents preliminary cost estimates for odor control options recommended for existing facilities. The chapter does not provide cost estimates for odor control strategies and equipment related to

future facilities. Section 1.6 below presents updates to the 2005 Report cost estimates.

- **Chapter 7 - Conclusions and Recommendations.** Chapter 7 summarizes the conclusions and recommendations of the 2005 Report, which are presented below.
- **Appendix A - Liquid- and Gas-Phase Odor and Corrosion Control Technologies.** The appendix is divided into two parts. The first part discusses liquid-phase odor control technologies that involve the addition of chemicals to reduce volatilization of odorants by reducing their liquid-phase concentration. Various chemicals are discussed in detail and their advantages and disadvantages are summarized in a table. The second part of the appendix discusses gas-phase odor control technologies, including treatment methods and atmospheric dispersion methods.

1.5 CONCLUSIONS AND RECOMMENDATIONS OF THE 2005 REPORT

The 2005 Report presents conclusions and recommendation both in Chapter 7 and the Executive Summary. Conclusions and recommendations are as follows:

1.5.1 2005 Report Conclusions

1. Strong odors are emitted from several RWQCP locations, particularly the influent monitoring stations, primary clarifiers, and dewatering facility.
2. The strong odors at the influent monitoring stations are due to high dissolved sulfide concentrations in the influent wastewater.
3. Presence of strong odors near the headworks biofilter indicates that the biofilter may not be operating as designed.
4. Discontinuation of air drying at the site has significantly reduced odor complaints from neighboring areas.
5. Thickening of combined primary sludge at the Plant 2 Primary Clarifiers may be responsible for sludge septicity, high sulfide concentrations, and generation of significant odors from the primary clarifiers.
6. The lower RWQCP elevation compared to the surrounding area and its proximity to the river makes odor control difficult.

1.5.2 Recommendations of the 2005 Report

The report recommended the following odor control improvements at the RWQCP facilities:

1.5.2.1 General Improvements

1. Conduct periodic hydrogen sulfide and odor monitoring within the facility and in the surrounding area.

2. Increase atmospheric dispersion south of the solids processing facility by providing more vegetation and/or constructing an air dispersion fence.
3. Conduct air dispersion modeling to determine the odor impacts of open-air sources such as primary clarifiers and DAFTs.

1.5.2.2 Influent Monitoring Stations

1. Add iron salts 15 to 30 minutes upstream to control hydrogen sulfide emissions from the influent monitoring stations, primary clarifiers, and digesters.
2. If chemical addition is not sufficient in controlling odors, cover exposed treatment processes, vent the headspace, and treat the foul air.

1.5.2.3 Headworks Biofilter

1. Determine whether the headworks biofilter is plugged or channeling is occurring.
2. Replace the biofilter media every 5 years.

1.5.2.4 Plant 2 Primary Clarifiers

1. Re-evaluate the practice of re-settling and thickening primary sludge from Plant 1 in the Plant 2 Primary Clarifiers.
2. Evaluate the effectiveness of upstream chemical addition in reducing odors by conducting periodic hydrogen sulfide and odor surveys near the clarifiers.
3. If chemical addition is insufficient in reducing odors, cover the exposed clarifiers with flat or dome covers and vent the foul air to an odor control system.

1.5.2.5 Dewatering Facility

1. Proceed with the plan to replace the open belt filter presses with enclosed centrifuges to limit odor emissions.
2. Collect foul air from the following equipment: centrate line, centrifuge cake box, centrate tanks, and centrifuge casing.
3. Provide covers or hoods for belt conveyors and provide foul air collection at various locations along the length of the conveyors.

1.5.2.6 Truck Loadout Facility

Proceed with the planned odor control measures for the new Truck Loadout Facility, specifically:

1. Provide continuous foul air withdrawal from the truck loading facility at a rate of 12 to 30 Air Changes per Hour (ACH).
2. Provide direct air withdrawal from covered process equipment emitting odors.

3. Install magnetic interlocks and post signs to prohibit simultaneous entrance and exit of trucks to the enclosed truck loading area.
4. Ensure that truck operators are covering the truck bins before exiting the facility.

1.6 UPDATES TO THE 2005 REPORT COST ESTIMATES

This section normalizes the capital and annual cost estimates presented in the 2005 Report (based on December 2004 dollars) using the Engineering News-Record (ENR) Los Angeles Construction Costs Index (LACCI) of 8570 for August 2006. Table 1.1 presents the updated capital and annual cost estimates.

Table 1.1 Updates to the 2005 Report Cost Estimates for Odor Control Improvement Options Wastewater Collection and Treatment Facilities Integrated Master Plan City of Riverside			
Purpose	Options	Capital Cost	Annual Cost
Ambient H ₂ S Monitoring	One Jerome Model 631 H ₂ S Analyzer	\$10,000 to \$16,000 ⁽¹⁾	-
Ambient Odor Monitoring	Two Nasal Ranger [®] Field Olfactometers	\$3,100 to \$4,200 ⁽¹⁾	-
Wastewater Characterization	-	Up to \$52,000 ⁽²⁾	-
Odor Emission and Dispersion Modeling	-	\$55,000 to \$80,000 ⁽³⁾	-
Upstream Chemical Addition	Nitrate Addition	\$229,000	\$161,000
	Iron Addition	104,000	\$73,000
Odor Control at Plant 2 Primary Clarifiers	In-Ground Biofilters ⁽⁴⁾	\$16,700,000 ⁽⁴⁾	-
Odor Control at the Truck Loadout Facility	-	-	-
Notes:			
(1) Exact cost depends on the accessories desired.			
(2) Exact cost depends on number of: sampling sites, sampling frequency, and analytes.			
(3) Carollo estimate; exact cost depends on the extent of required sampling and the complexity of the model.			
(4) See Volume 4, Chapter 6 - Primary Treatment for details.			

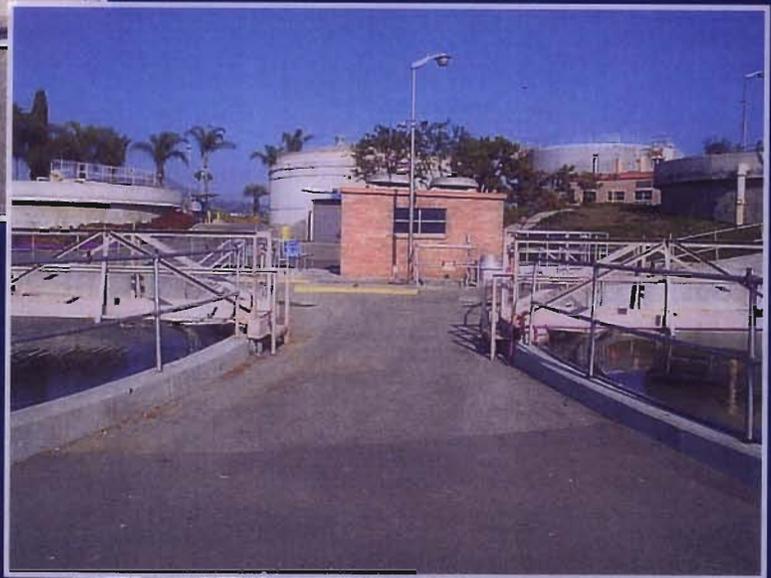
**CITY OF RIVERSIDE ODOR CONTROL MASTER PLAN FOR
THE REGIONAL WATER QUALITY CONTROL PLANT
(BROWN AND CALDWELL, MARCH 2005)**



CITY OF
RIVERSIDE

Regional Water Quality Control Plant

Odor Control Master Plan



March 2005

BROWN AND
CALDWELL



CITY OF RIVERSIDE

ODOR CONTROL MASTER PLAN

FOR THE

REGIONAL WATER QUALITY CONTROL PLANT



MARCH 2005



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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental and Industrial Hygienists
ACH	Air Changes per Hour
BFP	Belt Filter Press
BHP	Brake Horse Power
Cal-OSHA	California Occupational Safety and Health Administration
cfm	cubic feet per minute
D.O.	Dissolved Oxygen
D/T	Dilution-to-Threshold
DAFT	Dissolved Air Flotation Thickening
EPA	Environmental Protection Agency
FM	Force Main
fpm	feet per minute
gpd	gallons per day
H ₂ S	Hydrogen Sulfide
HRA	Health Risk Assessment
ISCST3	Industrial Source Complex Short Term
kWh	kilo Watts per Hour
lb	pounds
mg/L	milligrams per liter
MGD	million gallons per day
MICR	Maximum Individual Cancer Risk
NIOSH	National Institute for Occupational Safety and Health
O&M	Operation and Maintenance
ppbv	parts per billion by volume
ppmv	parts per million by volume
PVC	Polyvinyl Chloride
RAS	Return Activated Sludge
RSC	Reduced Sulfur Compound
RWQCP	Regional Water Quality Control Plant
SCAQMD	South Coast Air Quality Management District
TM	Technical Memorandum
VOC	Volatile Organic Compound
WAS	Waste Activated Sludge

EXECUTIVE SUMMARY

This odor control master plan was prepared for the City of Riverside to provide the Riverside Water Quality Control Plant (RWQCP) staff with guidance for identifying possible solutions to odor problems throughout the plant, with specific focus on the existing primary clarifiers and solids handling facilities and new upgrades to these facilities. En route to developing this master plan, existing facilities and historical data were reviewed, plant staff was interviewed, and some supplemental odor-related data collected.

Conclusions, recommendations and an estimate of the present worth of the recommended improvements and strategies are presented below. The cost information is limited to facilities currently in place; costs of future facilities were not determined. Where appropriate, options are provided to allow the City to select between various alternatives.

Conclusions

A review of the available data leads to the following conclusions:

1. Both historical and current data indicate strong odors at several plant locations, particularly at the influent monitoring stations, primary clarifiers, and dewatering facility.
2. High dissolved sulfide concentration in the influent wastewater is responsible for the strong odors observed at the influent monitoring stations.
3. Strong odors near the Headworks biofilter indicates that it may not be operating as designed.
4. Discontinuing air drying at the site has significantly reduced the complaints from neighboring areas.
5. The current practice of re-thickening the raw sludge from Plant 1 primary clarifiers at the Plant 2 primary clarifiers and slow withdrawal of the combined raw sludge appears to be responsible for high odor and sulfide levels at the primaries. Sludge septicity may be occurring based on bubbles found at the clarifier surface.
6. The lower elevation of the plant compared to its neighbors, and its location close to the river makes odor control difficult.

Recommendations

Recommendations for various facilities are as follows:

General Improvements

- Periodic monitoring of H₂S and odors within the facilities and at surrounding areas should be conducted and recorded to assist with prioritizing appropriate improvements.
- Improvements designed to enhance atmospheric dispersion, such as providing more vegetation and/or constructing an air dispersion fence should be used south of the RWQCP solids processing facilities to reduce impacts to businesses located south of the fenceline.
- Odor dispersion modeling should be performed to compare odor impacts of open processes versus covered processes (for example, primary clarifiers and DAFT tanks). The modeling results can be used for determining if covers are necessary for processes with low odors such as the DAFT tanks.

Influent Monitoring Stations

The following recommendations can reduce the odors emanating from the influent monitoring stations:

- Strategic chemical addition at the plant can result in significant improvement throughout. For example, iron salt addition at the influent monitoring stations or better yet, 15 to 30 minutes upstream can reduce the odors at the monitoring stations, the primary clarifiers and the digesters by tying up the sulfides present. The ferric chloride currently being added upstream of the primary clarifiers should be relocated upstream of, or to the influent monitoring stations.
- Cover open channels and withdraw and treat the foul air if chemical addition is not desirable or is insufficient to keep odors low.

Headworks Biofilter

The strong odors noted by BC staff near the east side of the Headworks biofilter indicates that it may not be performing as designed.

- The biofilter should be thoroughly evaluated to determine current performance. A smoke test will determine if the biofilter is clogged or if channeling is occurring.

- Bulk media biofilters typically require media replacement every five years. The City indicated that the media had not been replaced for more than eight years. The media should be replaced to improve performance and return the biofilter to design conditions.

Plant 1 Primary Clarifiers

The Plant 1 primary clarifiers are to be replaced with new clarifiers in the near future. In addition, gas phase sampling conducted by BC staff indicated low H₂S concentrations in the vicinity of Plant 1 clarifiers. No improvements are recommended for these clarifiers.

Plant 2 Primary Clarifiers

Strong odors were noted in the vicinity of the Plant 2 primary clarifiers. Liquid phase sampling also showed high dissolved sulfide concentrations.

- The current practice of re-settling and thickening Plant 1 primary solids in the Plant 2 primary clarifiers should be re-evaluated. The long retention time of sludge in the primaries may be contributing to the formation of septic sludge in the clarifiers. Co-thickening of raw and biological solids should be explored.
- Since design and construction of a cover, foul air collection and treatment system is likely to involve several years, upstream chemical addition is recommended initially. This option provides an economical short-term choice for reducing odors at the plant and allows the City time to evaluate the effectiveness of this method. H₂S and odor surveys can be performed periodically to determine the efficacy of upstream chemical addition. A background survey is needed for reference.
- If chemical addition is insufficient in reducing the odors, the City should proceed with the covering and ventilating the clarifiers. Upstream chemical addition can be terminated after completion of improvements. The ventilation and foul air withdrawal rates for all options are sufficient to reduce average H₂S concentration at the primaries below 5 ppmv. At these low levels, activated carbon becomes the cost-effective method for foul air treatment.
- If entry to the clarifiers is unnecessary, providing flat covers is recommended due to the reduced cost resulting from lower ventilation rates. Geodesic dome covers, which double the cost of covering the clarifiers, are necessary if personnel entry is desired for maintenance.

Dewatering Facility

Gas phase sampling conducted by BC staff indicated no H₂S near the dewatering facility; however, strong odors were noted. The current plan to replace the open belt filter presses with enclosed centrifuges should improve odor control by allowing the capture of odorants. The following recommendations should be implemented:

- Improve foul air collection at the classifying conveyor which discharges to the belt conveyor from the centrifuge.
- Provide foul air collection from the centrate line.
- Provide foul air collection from the centrifuge cake box, centrate tanks and centrifuge casing of the existing centrifuge.
- Make provisions to allow collection of foul air from future centrifuges.
- Provide covers or hoods for the belt conveyor, and foul air collection at various locations along the length of the conveyor. The foul air rate must be sufficient to provide a negative pressure of approximately 0.01 inches of water column, or a face velocity of at least 300 fpm.

Truck Loadout Facility

The truck loadout facility is currently being designed with features that will improve the capture of foul air from this process. Implement odor control measures currently planned for the new truck loadout facilities. These measures are as follows:

- Provide continuous ventilation and foul air withdrawal inside the truck loading facility to reduce odors, prevent equipment corrosion, and ensure operator comfort.
- Locate supply air registers and foul air withdrawal registers along opposing walls in the building to create a sweep of air for effectively capturing odors.
- Where feasible, provide direct foul air withdrawal from covered process equipment and maintain negative pressure at openings.
- Locate the truck loading operation in a separate enclosure or building, and provide a higher foul air withdrawal rate (between 12 and 30 ACH) in this building to capture foul air during truck loading.
- Install magnetic interlocks, or post signs prohibiting both entrance and exit doors at the truck loading enclosure from remaining open simultaneously.
- Ensure that truck operators are following proper procedures and covering the bins prior to exiting the facility.

Preliminary Cost Estimates

Preliminary cost estimates were generated for odor control strategies on facilities currently in place. The cost of odor control systems related to future facilities has not been determined. Presented are the estimated present worth for the H₂S and odor survey equipment, odor control modeling, wastewater characterization, upstream chemical addition, and odor control system improvements to the headworks, and primary clarifiers. The costs, presented in Table ES.1, are meant to guide the City in selecting the desired options.

Table ES.1.
Present Worth Costs of Odor Control Strategies for
Existing RWQCP Facilities

Purpose	Option/Criteria	Annual Cost	Capital Cost	Present Worth
Ambient H ₂ S Measurement	One Jerome Model 631x H ₂ S Analyzer; Cost depends on accessories desired	-	\$10,000 to \$15,000	\$10,000 to \$15,000
Odor monitoring	Two St. Croix Sensory, Inc., Filed Olfactometers; Cost depends on accessories desired	-	\$3,000 to \$4,000	\$3,000 to \$4,000
Odor Modeling	Cost depends on sampling and monitoring required	-	Up to \$50,000	Up to \$50,000
Wastewater Characterization	Cost depends on number of sites and sampling frequency	-	Up to \$50,000	Up to \$50,000
Upstream Chemical Addition	Nitrate Addition	\$154,300	\$218,700	\$2,315,600
	Iron Addition	\$70,000	\$99,300	\$1,050,900
Covering, Ventilating, and Treating Foul Air from Plant 2 Clarifiers	Leakage Prevention of Covered Area	\$155,300	\$3,929,400	\$6,040,000
	Prevent Corrosion Within Enclosure	\$184,400	\$3,469,100	\$5,975,200
	Dilute to Improve Treatability	\$95,800	\$4,276,900	\$5,578,900
	Personnel Entry	\$815,500	\$4,820,800	\$15,903,700

Total present worth based on 20 years, at a discount rate of 4% per annum for annual cost items. Based on December 2004 dollars.

1.0 Introduction

The City of Riverside (City) owns and operates the Regional Water Quality Control Plant (RWQCP) that serves the City of Riverside and surrounding communities. The plant receives wastewater flow from several large gravity sewer pipelines located along Riverside Avenue, Hillside Avenue, Acorn Street and Arlanza Street, and force main sewer pipelines located along Rubidoux Boulevard and Jurupa Road. The plant currently handles an average dry weather wastewater flow of 32 million gallons per day (MGD).

1.1 Purpose of the Odor Control Master Plan

This odor control master plan serves to provide RWQCP staff with guidance for identifying possible solutions to odor problems throughout the plant, with specific focus on the existing primary clarifiers and solids handling facilities and new upgrades to these facilities. The land surrounding the RWQCP is experiencing rapid development for commercial use, bringing potential odor receptors closer and raising the plant's profile in the community. In addition, the plant is bound on the west by Van Buren Boulevard, a major city thoroughfare accessed by thousands of commuters every day. Therefore, controlling odors at the plant is critical for ensuring the least impact to the community.

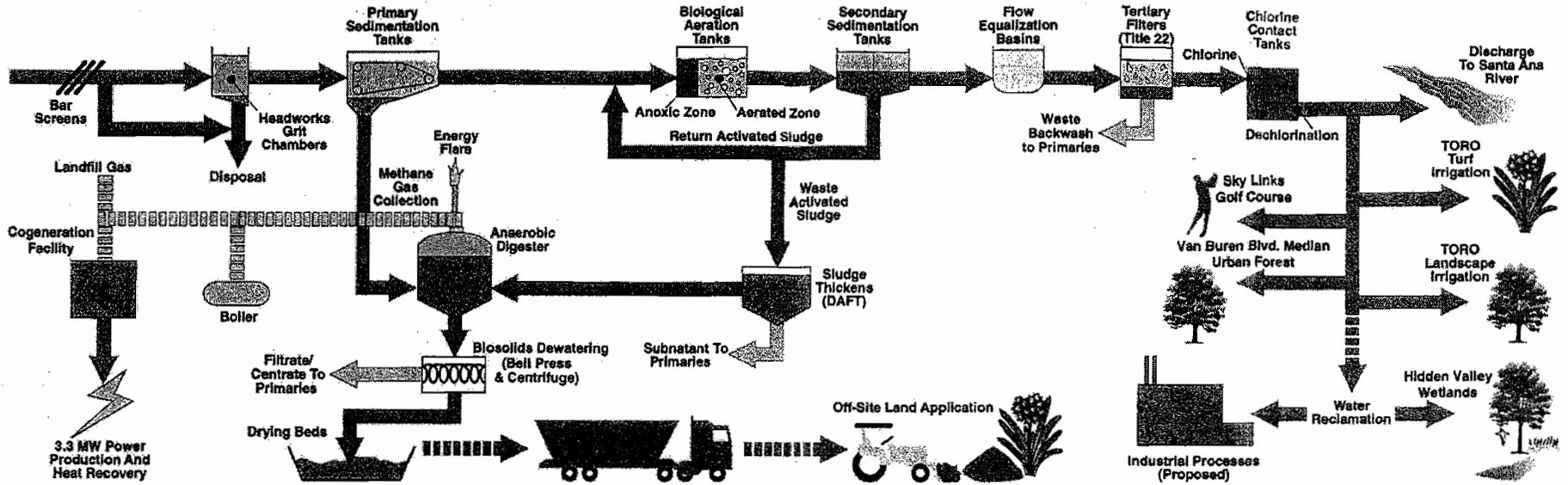
This master plan document describes the existing facilities, provides a review of historical data, summarizes data from recent sampling and outlines various liquid and gas phase treatment technologies for odor reduction and control. Finally, recommendations for providing odor control at various plant facilities, and cost estimates for implementing those recommendations are outlined in this document. An appendix with detailed descriptions of various liquid and gas phase treatment technologies for odor control is also provided.

1.2 Plant Description and Odor Control at Existing Facilities

The following paragraphs describe the existing facilities and odor control practices used in various parts of the RWQCP. A schematic diagram showing the various treatment processes at the plant is shown in Figure 1.1. An aerial photo of the plant showing locations of the facilities described below is provided in Figure 1.2.

Due to plant expansions that have occurred over several years, influent wastewater is treated using two identical treatment trains. The northeast part of the RWQCP comprises the older Plant 1 facilities, some of which were constructed in the 1930s, while the newer Plant 2 facilities are located in the southern part of the facility. Certain processes, such as solids handling and tertiary water treatment, are handled in common facilities which process flows from both Plant 1 and 2.

TREATMENT PROCESSES



ADAPTED FROM CITY OF RIVERSIDE INFORMATIONAL PUBLICATIONS

DATE MAR. 2005	PROJECT NUMBER 126576	SCHEMATIC DIAGRAM OF PROCESSES AT THE REGIONAL WATER QUALITY CONTROL PLANT, RIVERSIDE	FIGURE 1.1
BROWN AND CALDWELL IRVINE, CALIFORNIA			

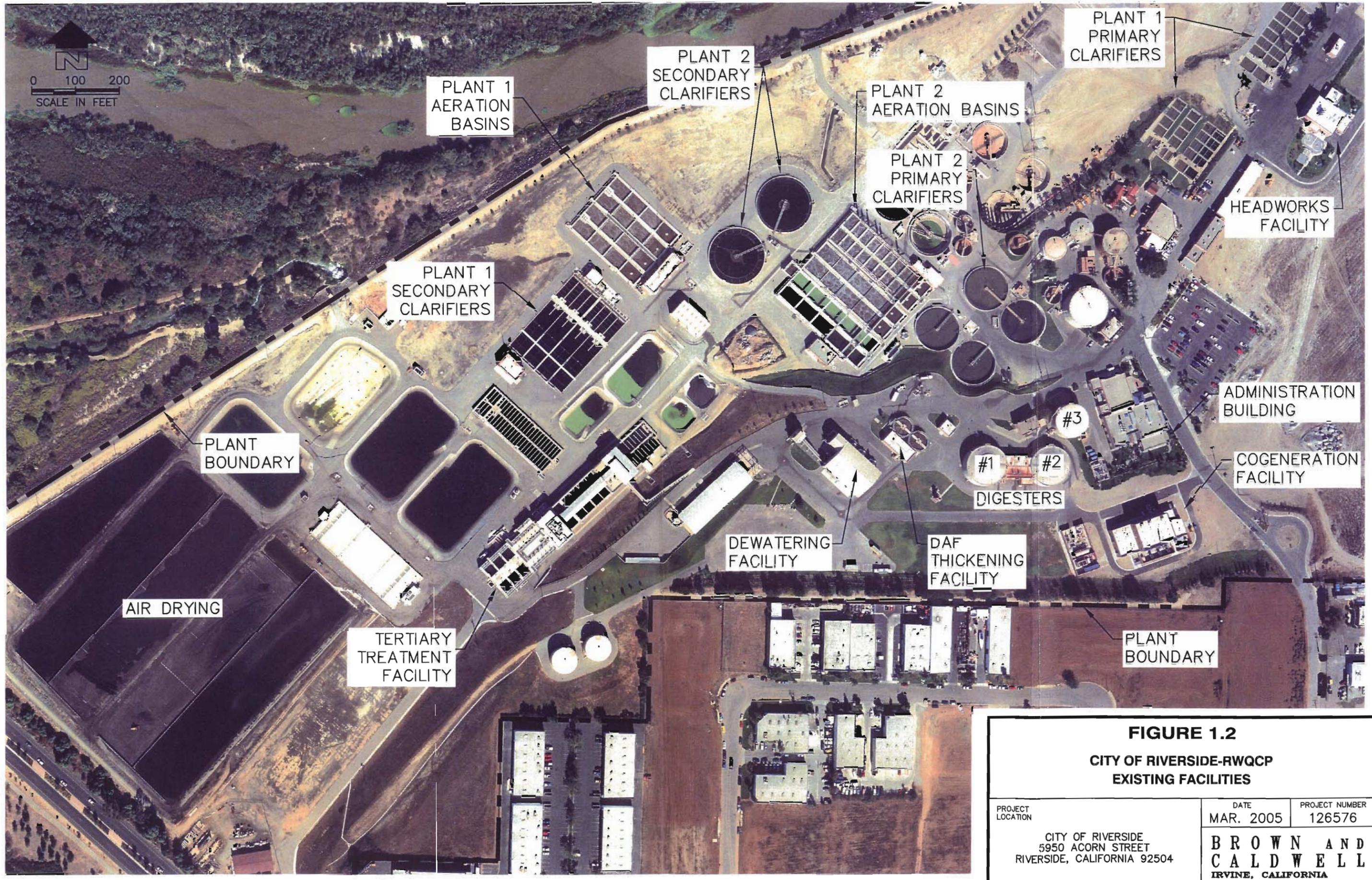


FIGURE 1.2
CITY OF RIVERSIDE-RWQCP
EXISTING FACILITIES

PROJECT LOCATION CITY OF RIVERSIDE 5950 ACORN STREET RIVERSIDE, CALIFORNIA 92504	DATE MAR. 2005	PROJECT NUMBER 126576
	BROWN AND CALDWELL IRVINE, CALIFORNIA	

1.2.1 Description of Liquid Stream Processes

The following paragraphs describe the various liquid stream processes at Plant 1 and 2.

Influent Stations

Influent wastewater enters the plant through two influent stations at the northeast corner of the plant, upstream of the Headworks facility. These stations allow flow monitoring and sampling of influent wastewater, which enters the plant through several gravity lines and force mains. The Jurupa/Rubidoux Monitoring Station receives wastewater from force mains located along Jurupa Road and Rubidoux Boulevard.

The second monitoring station receives combined flow from gravity sewer lines located along Hillside and Riverside Avenues, and Arlanza and Acorn Streets. While this monitoring station receives wastewater in a vault, the Jurupa/Rubidoux station flow monitoring flumes are located in open channels. Currently, no odor control is provided at the influent monitoring stations.

Plant Headworks

The plant headworks station houses bar screens, screenings compactors, aerated grit chambers, grit separation and dewatering system, screenings conveyors, and a grit disposal bin. These treatment operations are significant odor sources at most wastewater treatment plants (WWTPs), and are often the most odorous areas of a treatment plant. The headworks station at the RWQCP facility is currently ventilated with fresh outside air, and foul air is withdrawn at a higher rate from equipment and process areas to maintain negative pressure inside the building. The foul air is treated in a bulk media biofilter located adjacent to the headworks building before it is discharged to the atmosphere.

A distribution structure immediately downstream of the headworks distributes flow to the rectangular primary clarifiers (Plant 1). Iron chloride is dripped into the channel for sulfide control in the digesters.

Primary Clarifiers

Plant 1 has rectangular clarifiers at the northeast end of the facility, and Plant 2 has circular clarifiers located slightly southwest of the rectangular clarifiers. The clarifiers process raw wastewater from the headworks station, producing primary effluent and primary solids. Settled sludge from the Plant 1 clarifiers is sent to the Plant 2 clarifiers where it re-settles with the other raw wastewater solids. The thickened primary solids from the Plant 2 clarifiers are sent to the anaerobic digesters for stabilization. The effluent from the Plant 1 and 2 clarifiers is sent to the respective aeration basins for treatment.

Chlorine is added upstream of the Plant 2 clarifiers for odor control. Though iron chloride added upstream of Plant 1 clarifiers is intended for sulfide control in the digesters, it provides some odor control benefits at the Plant 1 primary clarifiers. No other odor control measures are currently in place; both Plant 1 and 2 clarifiers are uncovered.

Biological Aeration Tanks

Aeration basins remove organic material from the primary effluent wastewater. Return activated sludge (RAS) from the secondary clarifiers and recycle flow from the solids dewatering process is mixed with the primary effluent just upstream of the aeration basins. The air introduced into the basins creates an aerobic environment for the development and growth of aerobic microorganisms that break down organic compounds. Despite the higher levels of ammonia contained in the recycle streams going into the aeration basins, this process does not produce odorous compounds. The aeration tanks are open to the atmosphere and no odor control is provided at this process.

Secondary Clarifiers

The RWQCP facility includes several secondary clarifiers that receive effluent from the aeration basins, and produce secondary solids and effluent. A portion of the secondary solids is recycled as RAS. To maintain a healthy biological environment, a portion of the secondary solids is removed as waste activated sludge (WAS) for thickening and stabilization. Since most organic nutrients in primary effluent streams have been removed by upstream treatment processes, secondary effluent normally contains very few odor generating substances. Currently, no odor control is provided at the secondary clarifiers; No changes are required.

Secondary Effluent Flow Equalization Basins

The flow equalization basins receive the secondary effluent prior to tertiary filtration. While the basins are open to the atmosphere, they are not a significant odor source since the effluent is free from most nutrients and solids. No odor control is currently provided at the flow equalization basins, since this area is not a major source of odors.

Tertiary Filters and Chlorine Contact Tanks

The tertiary filters receive secondary effluent and provide Title-22 level treatment. Fine solids are removed during filtration, and the filters are frequently backwashed to remove accumulated solids from the filter media. The backwash liquid is stored in two tanks and returned to the primary clarifiers. Since this process handles effluent from which nutrients and most solids have been removed, development of odors is significantly reduced, thereby obviating the need for odor control. Currently the tertiary filters do not have any odor control system.

The treated effluent from the tertiary filters is chlorinated in the chlorine contact tanks. Since the final treated effluent is used for irrigation at golf courses, roadway medians and also for recharge into the Santa Ana River, it is dechlorinated prior to leaving the RWQCP.

1.2.2 Description of Solids Treatment Processes

The following paragraphs describe the various solids treatment processes at Plant 1 and 2.

Dissolved Air Flotation Thickeners

The dissolved air flotation thickeners (DAFTs) receive WAS from the secondary clarifiers. The solids are thickened in two DAFT tanks and the resulting thickened sludge is mixed with primary solids before being stabilized in the anaerobic digesters. The DAFT supernatant is recycled to the Plant 2 primary clarifiers. The two DAFT tanks, including a building that houses the auxiliary equipment such as pumps and air handling equipment, are located southwest of the Plant 2 primary clarifiers. The tanks are open to the atmosphere, allowing off-gassing of foul air. No odor control is currently provided at this facility. Odor control options for this process are discussed later in this document.

Anaerobic Digesters

Three anaerobic digesters at the RWQCP are located just north of the southeastern plant boundary. The fourth digester vessel is used as a day tank, and is located near the primary clarifiers. Anaerobic digestion of solids produces a variety of reduced sulfur compounds (RSCs) and nitrogenous organic compounds that may cause odors at the plant.

The digesters at the RWQCP have fixed covers; the gas generated is collected and sent to the cogeneration facility for energy recovery. The digesters are equipped with valves to provide pressure relief in the event of headspace pressurization.

Biosolids Dewatering Facility

Biosolids produced in the anaerobic digesters is processed in the Biosolids Dewatering Facility. This facility consists of a centrifuge, two belt presses, dewatered sludge conveyors, and sludge storage. Filtrate from the two belt presses, which cascades into collection basins, causes odors at this facility. Foul air is not collected from the centrate box, cake discharge box at the centrifuge. Thus, the potential for odors at this facility is high due to the processing of biosolids, which typically have a high content of organic sulfur and nitrogenous compounds.

BC's experience at other facilities indicates that reduced sulfur species, H₂S, amines and other odorous volatile organic compounds (VOCs) may be present.

These compounds pose a problem both for odor control and may also be regulated by the regional air pollution authority. Currently, foul air is withdrawn from two locations: at the belt filter presses and along the east wall of the dewatering room. Foul air withdrawal rates from these two areas are 6,000 cubic feet per minute (cfm) and 69,000 cfm respectively. Outside air is supplied to the facility through open rollup doors at the north and south ends of the building, as well as the west side in front of the belt presses. The foul air collected is discharged to the atmosphere without treatment. Odor control options for this facility are discussed later in this document.

Sludge Drying Beds

The dewatered sludge and other biosolids produced at the plant were formerly dried in the sludge drying beds located at the southwest corner of the plant. These beds have been phased out. Wet cake from the dewatering facility is currently transported offsite for further processing.

1.2.3 Description of Miscellaneous Processes

A cogeneration facility handles methane gas received from the digesters and the adjacent landfill. The gas is combusted for energy recovery using reciprocating piston generators. Exhaust from the engine generators contains no odors. However, emissions are governed by the plant's air emissions permit.

2.0 Data Collection and Analysis

Historic sulfide and odor data for the RWQCP were provided to BC to assist with developing the Odor Master Plan. BC conducted two additional visits to the RWQCP to verify and supplement the available data. Plant personnel were interviewed in the process. A discussion on available data to date, including results of the recent interviews and sampling events are discussed in this section.

2.1 *Historical Data*

Historical data provided by the City were used to determine conditions at various facilities throughout the RWQCP. In 1993, CH2M Hill determined the dilution-to-threshold (D/T) levels of foul air from various process units. In 1995, BC collected liquid phase data en route to designing the existing headworks. Since data were obtained by various consulting firms at different times, they can only be used as indicators of odor potential at various plant locations. A complete characterization of the system requires simultaneous sampling of both liquid and gas phase streams, and a detailed assessment of other factors such as wastewater flow rate, and odor control chemical dosage.

2.1.1 *CH2M Hill Odor Study*

In 1993, CH2M Hill conducted an odor study at the RWQCP to assess odors at various sources within the plant. The study did not consider the odor impacts of these sources outside the plant boundary or their potential for causing odor-related complaints. It focused mainly on evaluating the odor-generating potential and in-plant impacts at various onsite facilities. Odors were quantified by an odor panel.

Air samples collected from various processes throughout the plant were analyzed for relative odor by the dilution-to-threshold (D/T) approach. In this method, an air sample is analyzed by an odor panel, usually consisting of five to eight persons. The sample is successively diluted with clean air volumes until the objectionable odor can no longer be detected by 50 percent of the panelists. For example, a D/T value of 50 means that a volume of 1-liter of odorous or foul requires mixing with 49 liters of clean odor free air to diminish the objectionable odor below the sensory detection threshold of 50 percent of the panelists.

During the study, samples were obtained on two occasions. The first sampling event occurred on February 22, 1993. Some sample locations that had a D/T value below 50 during this sampling event were excluded from the next event (which occurred in June 1993) because the potential for odors from these sources was considered very low. The odor evaluation performed by the panel is summarized in Table 2.1.

Table 2.1. Results of Odor Sampling at the RWQCP (1993) ^(a)

Location of Sample	Odor, D/T February	Odor D/T June
Blank	8	16
Open Channel Flow Meter	55	678
Septage Dump - Offgas	318	484
Headworks - Offgas	24	Not Sampled
Nonaerated Grit - Offgas	249	996
Aerated Grit - Offgas	18	Not Sampled
Primary Sedimentation - Offgas	287	1194
Equalization Basins	16	Not Sampled
Activated Sludge - Offgas	11	Not Sampled
Secondary Clarifier - Offgas	8	Not Sampled
Gravity Filter - Offgas	14	Not Sampled
Chlorination - Offgas	9	Not Sampled
Final Effluent Discharge Weir - Offgas	Not Operational	Not Operational
Dissolved Air Flotation (DAF) - Offgas	12	Not Sampled
Digester - Offgas	5	Not Sampled
Belt Press - Offgas	104	Not Operational
Sludge Conveyor - Offgas	15	7
Sludge Storage - Offgas	50	23
Sludge Truck Loading - Offgas	8	15
Mixed Sludge Drying Bed - Offgas	Not Operational	16
Trickling Filter	13	29

(a) Average of multiple sampling at each location

2.1.2 *Brown and Caldwell Headworks Predesign Report*

In 1995, Brown and Caldwell (BC) produced a design report for the ventilation and odor control of the RWQCP headworks facility. The report identified various odor generating processes at the headworks. BC staff sampled the influent wastewater for dissolved and total sulfide concentrations, dissolved oxygen and other parameters shown in Table 2.2.

Table 2.2. Data from Brown and Caldwell Predesign Report (1995)

	Sewer Type	Flow (mgd)	pH	Temp (°C)	Max. Sulfide (mg/L)	Dis. Oxygen (mg/L)
Riverside	45" Gravity	12.3	7.5	21.7	1	0.7
Hillside	24" Gravity	(Total)	7.5	20.8	1	0.5
Rubidoux	14" Force main	1.9	7.6	20.8	1	0.7
Jurupa	18" Force main	3.2	7.6	21.8	1	1.9
Acorn	36" Gravity	2.2	7.6	21.8	1	1.5
Arlanza	51" Gravity	8.2	7.7	21.6	2	0.6

2.2 Data From Recent Sampling

BC visited the RWQCP in September and November 2004 to supplement and verify historical data. In September 2004, hydrogen sulfide (H₂S) concentrations were measured at various plant locations using a Jerome meter capable of measuring H₂S concentrations as low as 1 part per billion by volume (ppbv). The sampling results are presented on Figure 2.1. Strong odors and relatively high H₂S concentrations were noted near the influent monitoring stations (111 ppbv), Headworks (33 ppbv), east side of the headworks biofilter (40 ppbv), and Plant 2 primary clarifiers (48 ppbv).

In addition to gas phase sampling, liquid phase total and dissolved sulfide concentrations were measured in November 2004 using a LaMotte 4630 field test kit, which uses the methylene blue test method. The field kit can measure concentrations as low as 0.1 mg/L. The data obtained from various plant wastewater streams are summarized in Table 2.3.

Table 2.3. Dissolved and Total Sulfide Data from Various Plant Wastewater Streams (2004)

Location	Date / Time	Total Sulfide, mg/L	Dissolved Sulfide, mg/L
Rubidoux Force main	11/10/04, 11:30 AM	1.6	1.4
Jurupa Force main	11/10/04, 11:40 AM	0.1	< 0.1
Combined Gravity Sewers	11/10/04, 11:55 AM	0.7	0.3
Primary Clarifiers Distribution Structure (Plant 1)	11/10/04, 12:55 PM	< 0.1	< 0.1

Table 2.3. (cont'd) Dissolved and Total Sulfide Data from Various Plant Wastewater Streams (2004)

Location	Date / Time	Total Sulfide, mg/L	Dissolved Sulfide, mg/L
Primary Clarifier 10 Effluent (Plant 1)	11/10/04, 12:20 PM	< 0.1	< 0.1
Primary Clarifier 2 Effluent (Plant 2)	11/10/04, 01:15 PM	0.8	0.8
Primary Clarifier 4 Effluent (Plant 2)	11/10/04, 01:30 PM	0.4	0.3

2.2.1 Prediction of H_2S Concentration Using Dissolved Sulfide Concentration

Dissolved sulfide is present in wastewater as one of the following species: sulfide ion (S^{2-}), hydrosulfide (HS^-) or H_2S . The relationship between pH and liquid phase sulfide species is shown in Figure 2.2. A low pH favors a shift in the equilibrium of the various species towards H_2S , a sparingly soluble gas at standard conditions that can be easily liberated from the wastewater at turbulent areas.

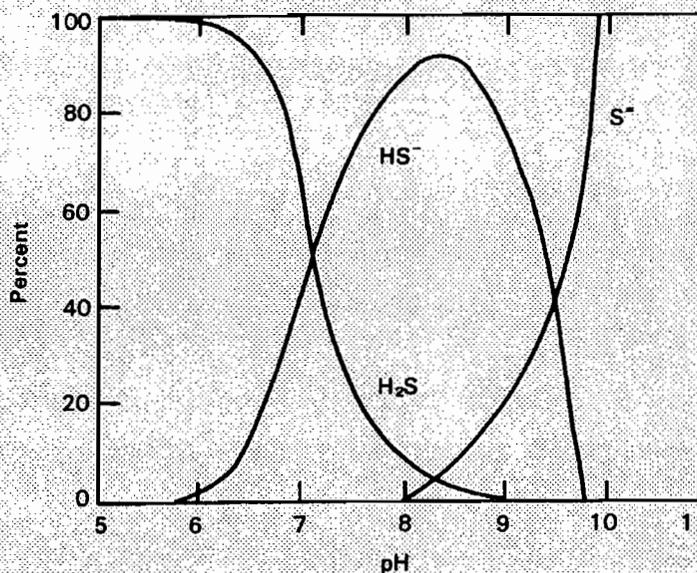


Figure 2.2. Relationship Between Liquid-Phase Sulfide and Wastewater pH
(Adapted from EPA Design Manual on Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants)

A reduction of wastewater pH to slightly lower than 6.0 favors a shift in the sulfide speciation to 100 percent H_2S . Wastewater at these conditions can easily release H_2S gas from solution if subject to turbulence. Conversely, all sulfides in wastewater are present either as S^{2-} or HS^- at pH greater than 9.0. Based on a database of sulfide data for various collection systems across the United States, the Environmental Protection Agency (EPA) reports that the amount of H_2S that exists above the wastewater typically varies between 2 to 20 percent of the equilibrium concentration (i.e. the amount of H_2S that would exist in the gas phase if sulfide laden wastewater is allowed to remain undisturbed for an indefinite amount of time).

The actual concentration will depend on wastewater turbulence and headspace ventilation provided. Ventilated spaces will exhibit lower H_2S concentrations because the liberated H_2S gas is constantly swept away by the supplied air. The liquid phase dissolved sulfide data from recent sampling events were used to predict the gas phase H_2S concentrations at RWQCP facilities that are presented in Table 2.4. Well ventilated headspaces may exhibit H_2S concentrations lower than those reported in Table 2.4.

Table 2.4. Estimated H_2S Concentrations at Various RWQCP Facilities

Location	Dissolved Sulfide, mg/L	Equilibrium* H_2S , ppmv	Possible** H_2S Concentration, ppmv
Rubidoux Force main	1.4	283	6 – 57
Combined Gravity Sewers	0.3	61	1 – 12
Primary Clarifier 2 Effluent (Plant 2)	0.8	162	3 – 32
Primary Clarifier 4 Effluent (Plant 2)	0.3	61	1 – 12

* Assumes pH 7.0 and temperature 25° C.

** Possible H_2S concentrations range between 2 percent and 20 percent of equilibrium values

2.3 Operator Interviews

During the site visit in September 2004, BC staff interviewed plant operators regarding complaints from businesses and local residents. They indicated that odor-related complaints from residents typically occurred during the evening hours, while complaints from businesses were mostly during the morning. Based on the plant layout (Figure 2.1), it is possible that the odors experienced by businesses located just south of the plant was from the sludge drying beds, while the odors experienced by residents are from the entire plant area.

The City staff also informed BC that Bioxide® is added at certain “problem spots” upstream of the RWQCP when the ambient temperature exceeds 90° F. This upstream addition is expected to have only minimal effects at the RWQCP.

2.4 Miscellaneous Observations

Various facilities at the RWQCP are located at elevations ranging between 25 to 50 feet below the surrounding commercial developments. Odors generated at most WWTPs typically diminish significantly at the fence line as the foul air mixes with fresh air. Often, the odor causing compounds react with other compounds in the air to form innocuous products. Due to its lower elevation compared to surrounding structures, the RWQCP is at a slight disadvantage with regard to air dispersion. However, dispersion may be enhanced by several methods, discussed later in this document.

During the recent site visits, BC staff observed the following operational practices that may contribute to odors:

- Solids from the Plant 1 primary clarifiers are re-settled in the Plant 2 clarifiers. BC staff observed bubbles on the liquid surface at the Plant 2 clarifiers, indicating the possibility of septic sludge in the clarifiers.
- Filtrate from the solids handling belt filter presses (BFPs) cascades into receiving basins.
- Solids from the BFPs are loaded onto open conveyors and loaded onto trucks for further offsite processing.

2.5 Summary of Data

Data from the 1993 CH2M Hill study show that the septage dump, non-aerated grit processing, primary sedimentation and belt presses all result in high odor loads. The 1995 BC report showed high sulfide concentration in the influent wastewater. The high incoming sulfides can produce high gas phase H₂S concentrations at facilities such as the influent monitoring stations and headworks.

Recent sampling data indicated that several influent sewer lines had high dissolved sulfide concentration, which can cause high H₂S concentrations at the influent monitoring stations. The liquid phase data indicated that some sulfide generation may be occurring in the Plant 2 primary clarifiers. Gas phase sampling conducted on a separate occasion showed that the influent monitoring stations, Plant 2 primary clarifiers, and the headworks biofilter were the process areas with the highest in-plant H₂S concentrations.

While no H₂S was detected near the dewatering facility, BC staff noted strong odors similar to other previously analyzed foul air containing nitrogenous compounds and RSCs. Some general observations and conclusions based on available historical and recent data are summarized in Table 2.5.

Table 2.5. Summary and Conclusions Based on Historical and Recent Data

CH2M Hill Odor Study (1993)	Brown and Caldwell Headworks Predesign Report (1995)	Brown and Caldwell Odor Control Master plan (2004)
<ul style="list-style-type: none"> • The most odorous processes at the plant are located at the upstream end. • The septage dump, non-aerated grit and primary sedimentation were the most odorous process. • Offgas from primary sedimentation was four times more odorous during June than in February. • Solids processing operations such as filter pressing and sludge storage were some potentially odorous downstream process. • The open channel flowmeter was significantly (more than ten times) more odorous during June than in February. 	<ul style="list-style-type: none"> • All influent sewer lines contained high total sulfide concentrations. • The 51-inch diameter Arlanza sewer main had both the highest flow and the highest total sulfide concentration (2 mg/L). 	<ul style="list-style-type: none"> • High gas phase H₂S concentrations were observed near the influent monitoring stations (111 ppb), Headworks biofilter (40 ppb), and Plant 2 primary clarifiers (48 ppb). • Rubidoux force main had high dissolved sulfide concentration (1.4 mg/L). • Wastewater from the gravity sewer lines had moderate dissolved sulfide concentration (0.3 mg/L). • Effluent at Plant 2 Clarifier No. 2, had high dissolved sulfide concentration (0.8 mg/L). • Strong odors noted near the dewatering facility.

Abbreviations

mg/L milligrams per liter
ppb parts per billion

3.0 Typical Odor Control Strategies

The typical odor control technologies and strategies used at wastewater processing facilities are discussed in this section. Potential odor control measures may be grouped into the following five distinct categories:

- Chemical Addition
- Operational Procedures
- Foul Air Collection and Treatment
- Process Changes
- Enhanced Atmospheric Dispersion

Each of the above methods is described in the following paragraphs. The odor control strategies specifically for the RWQCP are based on all five methods.

3.1 Chemical Addition

Addition of odor control products to the wastewater can provide significant odor reduction benefits at WWTPs. Ensuring an adequate supply of dissolved oxygen or nitrate-oxygen is an effective method for preventing formation of sulfides and odors. Alternatively, sulfides may be chemically precipitated using metal salts such as ferric chloride or ferrous chloride. Some odor control products such as sodium hypochlorite, potassium permanganate and other oxidants are fast reacting, rapidly reducing odors near the point of addition.

Iron salts require about 15 to 30 minutes to tie up inorganic sulfides in the wastewater. Other products such as nitrate (for example, calcium nitrate [Bioxide®]) need more reaction time, and are mostly used for preventing formation of odor generating sulfides by providing a source of oxygen. Thus, nitrates must be added well upstream of the WWTP to achieve the desired odor control. Some of the possible chemical treatment alternatives are briefly summarized in Table 3.1. Details on various liquid phase treatment options are provided in Appendix A.

Anaerobic conditions in the collection system cause sulfide generation in wastewater. Microbes in wastewater require an oxygen source for respiration and other metabolic processes. When available dissolved oxygen in the wastewater is consumed, oxygen bound in nitrate (NO_3^-) is used, followed by oxygen bound in sulfate (SO_4^{2-}). Oxygen depletion occurs rapidly in long gravity sewers and force mains. After nitrate-oxygen is consumed, any sulfate present is reduced to sulfide (S^{2-}). As discussed in Section 2.2.1, when wastewater pH drops below 9.0, a fraction of the sulfides is present as H_2S .

Table 3.1. Chemical Treatment Options

Treatment Option	Treatment Method	Advantages	Disadvantages	Dosage ¹
Oxygen Addition	Increases dissolved oxygen content of wastewater, preventing conversion of sulfates to sulfides	<ul style="list-style-type: none"> • Fast reaction time • Immediate odor control 	<ul style="list-style-type: none"> • Oxygen storage is hazardous • Accumulation of oxygen at pipeline high points can cause corrosion and increased power demand due to gas locking 	Varies, depending on existing dissolved oxygen content in the wastewater. Target D.O. of 2 mg/L
Nitrate Addition	Makes nitrate-oxygen available to microbes, preventing conversion of sulfates to sulfides	<ul style="list-style-type: none"> • Proven technology • Provides good downstream odor control 	<ul style="list-style-type: none"> • Unable to effectively treat pre-existing sulfides 	2.5 – 10 lb nitrate-oxygen per lb sulfide
Chemical Oxidation	Converts existing sulfides to non-odorous compounds by direct chemical action	<ul style="list-style-type: none"> • Fast reaction time • Immediate odor control • Excess dosing provides downstream odor control 	<ul style="list-style-type: none"> • Chemicals are usually hazardous • Chemical may be consumed by other non-odorous organic components of wastewater • Chemicals may have an impact on biological processes at the plant 	Varies depending on chemical
Metal Salts	Precipitates sulfides present into non-volatile form	<ul style="list-style-type: none"> • Moderately fast reaction time • Excess dosing provides downstream odor control 	<ul style="list-style-type: none"> • Reduces wastewater pH • Can cause corrosion of metallic equipment • Chemicals are hazardous 	Per lb of sulfide: Ferric chloride: up to 14 lb Ferrous chloride: 7-11 lb
Caustic Shock Dosing	Kills slime layer in pipelines (dose to pH > 12), preventing sulfide formation for up to two week duration	<ul style="list-style-type: none"> • Fast reaction time • Quick odor control 	<ul style="list-style-type: none"> • Increases wastewater pH at treatment plant temporarily • Can cause corrosion of concrete • Chemical is hazardous • Effectiveness varies 	Dosage varies based on length of pipeline to be treated
PRI-SC Technology	Ferrous ion provides initial odor control. Hydrogen Peroxide added downstream regenerates ferric ions for downstream odor control	<ul style="list-style-type: none"> • Immediate odor control • Regenerated ferric provides odor control and coagulation advantage at treatment plant 	<ul style="list-style-type: none"> • New technology • Hydrogen peroxide and ferrous chloride are hazardous 	Ferrous: 2.4 lb per lb sulfide Hydrogen peroxide: 1.7 lb per lb sulfide

Notes and Abbreviations

- 1 Based on BC experience
- D.O. Dissolved Oxygen
- lb Pound

3.2 Wastewater Process Design

Process and hydraulic design can have an impact on odor generation potential at WWTPs. Process modifications can help reduce odors at certain plant facilities by preventing septic conditions. For example, eliminating re-settling of Plant 1 primary solids in the Plant 2 clarifiers is a process modification that can provide odor control benefits at Plant 2. Hydraulic design can also impact the amount of odors at WWTPs. For example, submerged weirs at primary clarifier launders minimizes turbulence consequently reducing the amount of odors liberated from the liquid.

3.3 Operational Procedures

Improving operational procedures can also have a significant impact on odors throughout the WWTP. Some of the typical modifications include improved housekeeping, monitoring sulfide concentration in the influent wastewater for determining odor control product dosage, frequent inspection and replacement of biofilter media. Carefully scheduling odor-generating maintenance activities when neighboring areas are less inhabited (for example a business park after business hours) can reduce the amount of complaints due to odors.

3.4 Foul Air Collection

Direct withdrawal of foul air from equipment or covered basins/channels, ventilating with outside air, and withdrawing and treating the foul air generated is a common method of odor control. This method usually involves higher labor and capital expenses, and its implementation often requires approval from the local air pollution control agency. A properly designed and operated foul air containment and treatment system can virtually eliminate all odors. However, minimization of odors at the source or reducing the concentration in the liquid phase can reduce foul air volume and strength, and consequently, chemical and power usage at the foul air treatment process.

The foul air withdrawal rate can be based on four primary considerations briefly discussed below. A more detailed discussion is provided in Section 4.2.4.

3.4.1 Cover Area Leakage

Foul air is withdrawn from covered process equipment at a rate sufficiently high to produce a negative pressure of about 0.01 inches of water column at openings and gaps. The negative pressure ensures that no foul air escapes to the atmosphere, even at moderately strong winds.

3.4.2 Corrosion Prevention

The primary goal of this method is corrosion prevention. Corrosion of capital facilities typically occurs when H₂S concentration in headspaces exceeds 1 part per million by volume (ppmv). In this method, foul air is withdrawn continuously at a rate that prevents H₂S concentration from exceeding 1 ppmv. The air rate chosen must also provide sufficient negative pressure at gaps and openings (Section 3.4.1).

3.4.3 Treatability

The objective of this method is to withdraw the foul air at a rate sufficient to maintain foul air H₂S concentration between 5 ppmv and 15 ppmv. Foul air is “treatable” using economical biological treatment systems such as biofilters at this H₂S concentration range. However, the withdrawal rate must be increased if it is insufficient to provide negative pressure at gaps and openings. This method may require less foul air withdrawal than other methods, thus reducing blower size and power usage.

3.4.4 Personnel Entry

In this option, process equipment covers or enclosures are designed to allow personnel entry for maintenance activities. Due to health and safety concerns, the foul air withdrawal rate required must be selected to provide worker comfort and dilute H₂S concentrations below the permissible levels mandated by regulatory agencies.

3.5 Foul Air Treatment

The headspace formed by covering process equipment must be ventilated to prevent corrosion of equipment and structures under the covers, and to prevent escape of odorous air to the atmosphere. The foul air withdrawn usually contains several odorous compounds described below:

H₂S:	Hydrogen sulfide has a very strong characteristic rotten egg odor that is frequently objectionable even at very low concentrations. H ₂ S has a detection threshold of 0.5 ppbv.
Mercaptans:	Mercaptans are a class of RSCs that are commonly encountered in wastewater processing operations.
Disulfides:	Disulfides are a class of RSCs that are commonly encountered in solids processing facilities.
Amines:	Amines are compounds of nitrogen. They are typically encountered in solids processing facilities.

The withdrawn air must be treated to prevent nuisance odors to the surrounding community. The foul air treatment technology chosen will depend on several factors including cost, volume and nature of foul air, available infrastructure, and amount of treatment required. Since H₂S is usually the predominant odorous compound, its concentration in the foul air may be estimated using available data for initial selection of appropriate treatment methods.

A final decision on the treatment method should be made after the foul air has been fully characterized, since foul air with low concentrations of odorous compounds may be unsuitable for certain foul air treatment options. For example, scrubber, biofilters and bioscrubbers operate best when the H₂S concentration is between 5 and 15 ppmv.

If the estimated H₂S concentration is lower than 5 ppmv, activated carbon adsorption is typically more cost-effective. A brief description of the most common options is provided in the following paragraphs.

Chemical Scrubbers

Foul air containing H₂S and other odorous compounds may be treated using chemical scrubbers. A high pH solution of caustic soda and water is contacted with foul air in a packed bed. H₂S and other odorous compounds are drawn into solution. Sodium hypochlorite can also be added to oxidize the sulfides in solution. A packed bed scrubber utilizing an acid solution must be used for removing acid-soluble ammonia and amines from foul air, when necessary.

Bioscrubbers

Biological removal of odorous compounds from foul air is another option. A bioscrubber is a packed bed containing porous medium that supports bacterial colonies. Odorous compounds are absorbed into the biological film and converted to odorless products by microbes. Secondary effluent or potable water mixed with nutrients is periodically sprinkled on the media to supply both moisture and nutrients required for biological growth.

Biofilters

The foul air treatment mechanism in biofilters is similar to bioscrubbers. The primary differences between the two are the media used, and the construction. Bulk media biofilters use wood chips, yard waste compost and granular activated carbon. The medium is contained in an excavated trench, or within built up concrete walls. Foul air introduced at the bottom of the bed using a distribution header is treated as it passes through the biofilter. Water is periodically sprinkled over the biofilter, or within the media using soaker hoses, to keep it moist. Nutrients need not be supplied since they are normally available in the biofilter medium itself. Biofilters in modular containers are also available from several commercial vendors.

Activated Carbon

Foul air treatment using activated carbon is a proven technique that has been used successfully for several years. Foul air is introduced into a bed of activated carbon where odorous compounds are adsorbed onto the highly porous carbon surface. Activated carbon may be impregnated with caustic soda or caustic potash to increase its H₂S adsorption capacity. Catalytic carbon is the third type of carbon. It provides the highest H₂S adsorption capacity. Impregnated and catalytic carbon may be regenerated several times by washing with caustic solution and water, respectively. Virgin and catalytic carbon may be thermally regenerated offsite when their adsorption capacity is diminished or lost.

3.6 *Enhanced Atmospheric Dispersion*

Atmospheric dispersion of odorous air can be helpful in reducing downwind impacts of odor releases. This method of odor control relies on meteorological information and odor dispersion modeling studies for determining appropriate locations for facilities (during new construction) or foul air discharge stack geometry. Some important factors to be considered in this method include odor release height, exit velocity of foul air, temperature, building wake downwash, wind direction and wind patterns. This method may be limited by permit restrictions, and may only be applicable to foul air from selected processes. For example, the allowable daily emission (total mass or pounds per day) of VOCs may be regulated by the local air pollution control district.

Dispersion of odorous air occurs when it mixes with ambient air. The odors are diluted by mixing with ambient air as they are carried downwind. Dilution ratios of up to 50 parts fresh air to 1 part foul air may be achieved at typical WWTPs, depending on local atmospheric conditions and structures surrounding the WWTP. Since the presence of dispersion fences, vegetation and other structures enhances mixing, planting trees just inside the fenceline and/or installing dispersion fences may be an effective method of reducing odor impacts to the businesses surrounding the RWQCP.

The advantages and disadvantages of the foul air treatment options discussed above are summarized in Table 3.2. Details on these treatment methods are also provided in Appendix A. Possible locations for a foul air treatment system for the Plant 2 clarifiers are shown in Figure 3.1.

Table 3.2. Foul Air Treatment Alternatives

Treatment Alternative	Treatment Method	Advantages	Disadvantages
Chemical Scrubbers	Provides driving force for absorbing H ₂ S into caustic soda solution, where it is converted to an odorless compound. Sodium hypochlorite oxidizes other odorous compounds such as VOCs	<ul style="list-style-type: none"> • Effective for a large range of concentrations • Effective on different types of odor causing components 	<ul style="list-style-type: none"> • Requires storage and handling of hazardous chemicals • Requires more equipment compared to bioscrubbers for dosing chemicals and recirculating scrubbing solutions. • Requires soft water for operation, or period acid washing for removing scales
Bioscrubbers or Biotrickling Filters	Treatment is achieved by microbes, which convert odorous compounds to non odorous compounds	<ul style="list-style-type: none"> • Does not require hazardous chemicals • Effective on different types of odor causing compounds • Requires less power 	<ul style="list-style-type: none"> • Ineffective at low H₂S concentrations (< 5 ppm) • Requires higher detention time for VOC control, resulting in larger vessels compared to chemical scrubbers • Treatment efficiency is lower than chemical scrubbers
Biofilters	Treatment is achieved by microbes, which convert odorous compounds to non odorous compounds	<ul style="list-style-type: none"> • Does not require hazardous chemicals • Effective on different types of odor causing compounds • Requires less power 	<ul style="list-style-type: none"> • Ineffective at low H₂S concentrations (< 5 ppm) • Media may be acidic, requiring special handling during disposal • Treatment efficiency is lower than chemical scrubbers • Produces earthy odors from outlet gases, and may require polishing step for area with very stringent odor standards • Requires periodic media regeneration or replacement
Virgin Activated Carbon	Removes odor causing compounds by adsorption	<ul style="list-style-type: none"> • High treatment efficiency • Effective on a variety of odor causing compounds 	<ul style="list-style-type: none"> • Susceptible to moisture in foul air • Uneconomical for large volumes of foul air • Uneconomical for highly concentrated foul air • Offsite regeneration required • Lower H₂S adsorption capacity than other forms of activated carbon
Catalytic Carbon	Removes odor causing compounds by adsorption. Adsorbed H ₂ S is catalytically converted to soluble compounds.	<ul style="list-style-type: none"> • High treatment efficiency • Effective on a variety of odor causing compounds • Can be regenerated several times by washing with water, extending life • Onsite regeneration is possible • Can be thermally regenerated when capacity is diminished or lost after repeated regeneration cycles 	<ul style="list-style-type: none"> • Uneconomical for high concentration and large volumes • Media may be acidic, requiring special handling during disposal • Units may remain offline for extended time during regeneration
Impregnated Carbon	Activated carbon is impregnated with a strong base such as caustic soda or caustic potash. The carbon removes odor causing compounds by adsorption. Adsorbed H ₂ S is neutralized by the strong base.	<ul style="list-style-type: none"> • High treatment efficiency • Can be regenerated several times by washing with caustic soda or caustic potash, extending life 	<ul style="list-style-type: none"> • Susceptible to moisture in foul air • Uneconomical for high concentration and large volumes • Units may remain offline for extended time during regeneration • Cannot be thermally reactivated when capacity is lost after repeated regeneration cycles • Has a lower ignition temperature (225^o C) compared to other types of carbon, posing a fire danger • Absorbs oxygen during idle time. This exothermic reaction increases fire danger
Untreated Discharge / Atmospheric Dispersion	No treatment is provided. Reduces odor impacts by relying on atmospheric dispersion alone.	<ul style="list-style-type: none"> • Does not require any chemicals • Requires less power 	<ul style="list-style-type: none"> • No treatment is provided • Discharge of certain compounds may be precluded by local regulations • Susceptible to local atmospheric condition changes

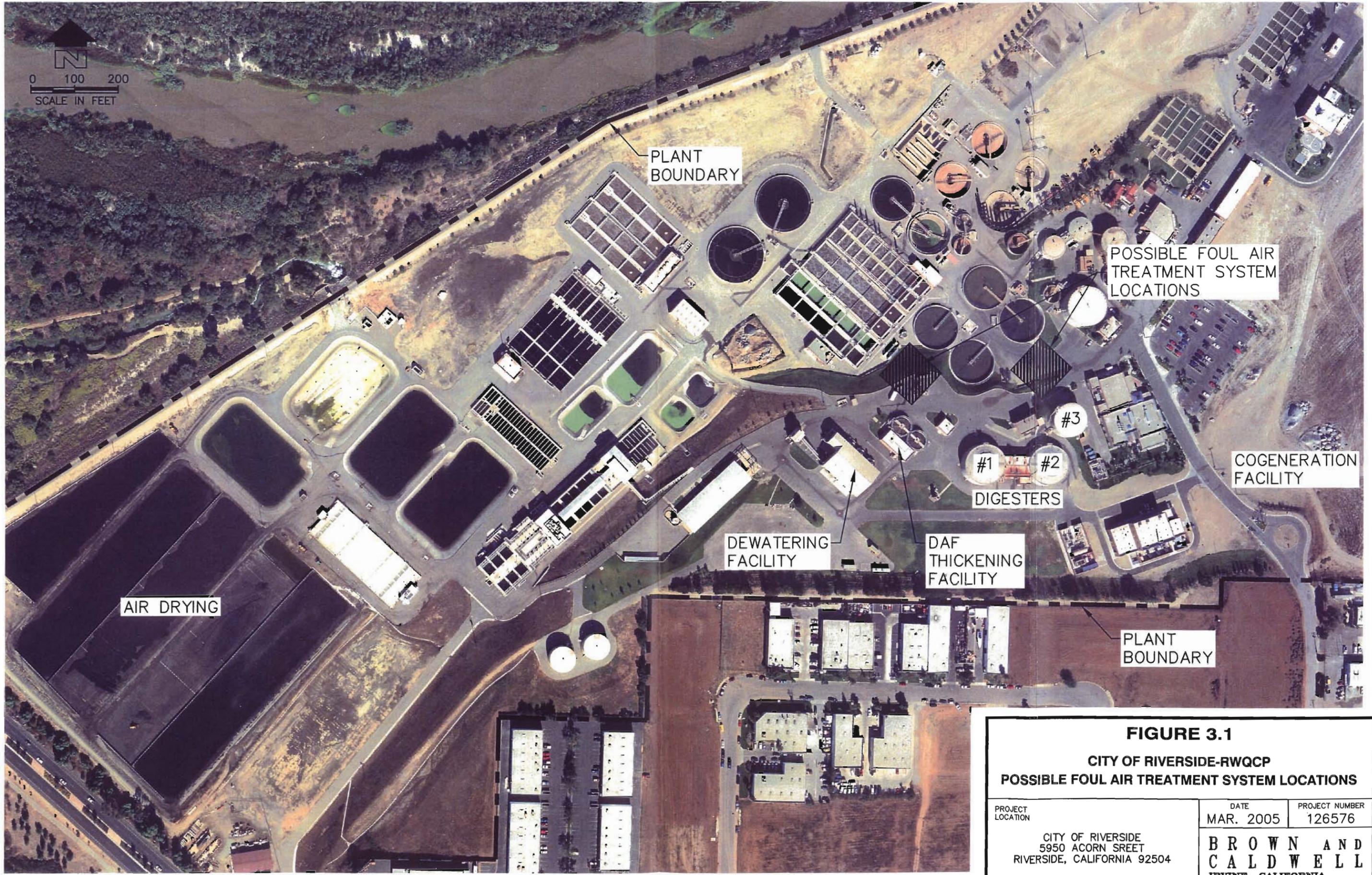


FIGURE 3.1
CITY OF RIVERSIDE-RWQCP
POSSIBLE FOUL AIR TREATMENT SYSTEM LOCATIONS

PROJECT LOCATION CITY OF RIVERSIDE 5950 ACORN SREET RIVERSIDE, CALIFORNIA 92504	DATE MAR. 2005	PROJECT NUMBER 126576
	BROWN AND CALDWELL IRVINE, CALIFORNIA	

4.0 Odor Control Strategies for the RWQCP

Several approaches or strategies, which combine the five methods discussed earlier, may be used to control odors at the RWQCP. These include preventative methods such as addition of chemicals upstream to stop or reduce sulfide generation, covering process equipment areas and treating captured foul air using one of several available technologies, or a combination of both. The choice of method will depend on the cost associated with each and the benefits realized. In addition, a phased approach may also be used for implementing immediate strategies, followed by other long term solutions for providing odor control.

Effective odor control planning and implementation requires targets to be set at a critical receptor (typically the closest non-City entity outside of the plant boundaries or at the fenceline). The most common target level is to achieve 5 odor units or less at the fenceline, i.e., the air sampled at the fenceline must only be diluted 4 fresh air volumes to 1 foul air volume to meet the odor objective. The City of San Diego has the following objective included in its design guidelines (December 1996):

"All MWWD facilities shall be designed to achieve 5 or less odor units (OU) at established critical receptors at least 99.5 percent of the time. Experience indicates that implementation of this criterion has resulted in absence of odor complaints. Typically, odor complaints do not occur when odor is below 5 OU. The City may select more stringent criteria at highly sensitive locations."

The City should endeavor to establish odor criteria prior to initiating the improvements noted in this Master Plan.

4.1 Odor Dispersion Modeling

Although data has been collected to characterize the odors at the several facilities within the plant, an odor dispersion modeling has not been performed. Results from an odor dispersion model can pinpoint to uncovered areas needing covers and show the effect of upstream chemical addition and covering of facilities on the plant environment and the surrounding areas. It also an important tool in determining the appropriate location, height and diameter of the treated foul air discharge stack. Odor dispersion modeling is an important element in planning improvement focused on meeting established odor targets.

4.2 Strategies for Odor Control at the Headworks and Primary Treatment Facilities

The strongest odors perceived at the plant emanated from the headworks and primary treatment facilities. Reducing odors at these facilities will greatly improve conditions at the plant and minimize the potential for complaints from neighboring areas. Strategies for reducing odors at these facilities are discussed below.

4.2.1 Headworks Odor Control

Some of the strongest odors at the RWQCP were observed in the vicinity of the Jurupa/Rubidoux influent monitoring station. Wastewater from the Rubidoux forcemain had a very high dissolved sulfide concentration (see Table 3.1). Agitation of wastewater as it flows through the flow-monitoring open channels and other structures can result in the release of significant amounts of H₂S gas at these stations. Implementation of upstream chemical addition can significantly reduce dissolved sulfide concentration in the influent wastewater and odors at this facility. A more detailed discussion on this option is provided in the section that follows.

The City currently adds ferric chloride to the wastewater upstream of the Plant 1 primary clarifiers for sulfide control in the anaerobic digesters. Addition of ferric chloride upstream of the influent monitoring stations may produce added benefits by reducing the dissolved sulfides at the stations as well as areas downstream.

Further reduction of odors may be accomplished by covering the flow-monitoring open channels and withdrawing foul air from both influent monitoring stations. A minimum airflow rate of 1.0 cfm/ft² should be used for providing adequate negative pressure at gaps and openings. A higher air flow rate may be necessary to adequately dilute odors. The choice of foul air treatment method will depend on the H₂S concentration. The foul air may be routed to the Headworks biofilter for treatment if sufficient capacity is available, or treated in a stand alone activated carbon unit.

4.2.2 Primary Clarifier Odor Control

Current data indicate that the strongest foul odors are detected around the primary clarifiers. Several options can be exercised for this particular facility.

Rapid Withdrawal of Primary Sludge

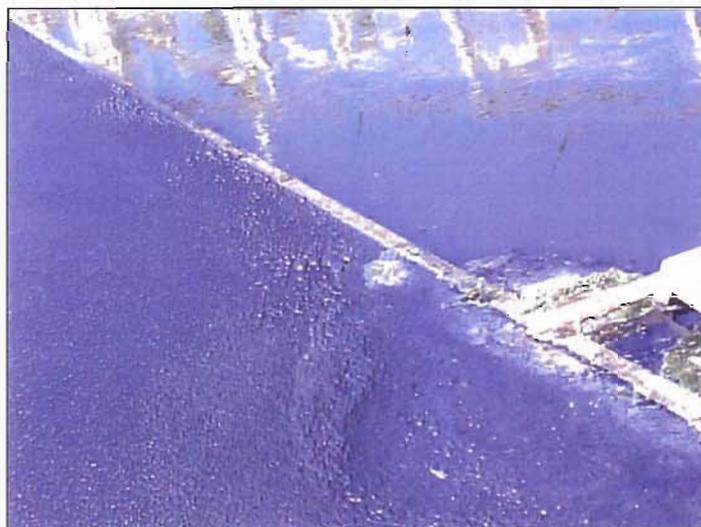
The practice of re-settling sludge from Plant 1 primary clarifiers in the Plant 2 clarifiers contributes to the formation of septic sludge in the Plant 2 clarifiers. This was witnessed during the recent plant visits when gas bubbles on the surface of some of the Plant 2 primary clarifiers were observed (see Figure 4.1), high level of sulfides measured, and strong odors detected.

The practice of re-settling and thickening of primary solids should be re-evaluated. The City should explore the possibility of thickening Plant 1 primary solids using gravity belt thickeners and conveying the thickened solids directly to the digesters. The Plant 1 primary solids may also be co-thickened using the existing DAFT process if adequate capacity is available. Co-thickening using DAFTs was discussed in detail in Technical Memorandum (TM) 2 on Digestion Options. An excerpt of the TM-2 recommendations is provided below:

TM-1 offered two thickening options, WAS only thickening and co-thickening of primary and WAS. Implementation of WAS only thickening would require construction of two (2) 39 foot diameter DAFTs. Implementation of co-thickening would require construction of two (2) 44 foot diameter covered DAFTs, new primary sludge pumps and piping to pump thinner primary sludge, bottom sludge degritting and new odor control.

The present worth value for the two thickening options when digestion is also considered is \$ 33.8 million for WAS only thickening and \$43.3 million for co-thickening. As noted in TM-1 other benefits of co-thickening would include possible increased primary sedimentation surface overflow rates and grit removal prior to digestion.”

Figure 4.1. Photograph of Gas Bubbles on Plant 2 Primary Clarifier Surface



Upstream Chemical Addition

The first option relies on upstream chemical addition for reducing incoming dissolved sulfide concentration. Due to the administrative and operational labor required, many municipal agencies including the City typically prefer not to operate upstream chemical addition programs. However, several product vendors can provide full service contracts, eliminating risks related to chemical handling and freeing the City's labor resources. Full service normally includes system installation and maintenance, product delivery, regular inventory checks, product replenishment, and dosage optimization. Most vendors can provide service within 24 hours of notice from clients.

Upstream chemical addition is one method for reducing influent sulfide load and odors at processes such as the influent monitoring stations and headworks. Odors are not eliminated in this method; rather, they are reduced to an acceptable level. Completely eliminating sulfides from the wastewater streams will require significant amount of product and is usually cost prohibitive.

The City currently uses chlorine gas for odor control at the Plant 2 primary clarifiers. Chlorine gas is cost-competitive with other odor control chemicals such as ferric chloride. However, most municipal agencies are transitioning to sodium hypochlorite (bleach) due to the safety and public health concerns. While hypochlorite provides the same odor control benefits as chlorine gas, it can be between 10 to 20 times more expensive than chlorine gas.

The cost of using chlorine gas versus iron chloride for odor control is essentially equal. Replacing chlorine gas with iron chloride addition at the front end of the plant or upstream can have a long range impact, helping reduce sulfide-related odors at the headworks, the primary clarifiers, and digesters. Iron, the key ingredient in iron chloride, does not react with too many other reactants and is therefore conserved to react with sulfides produced at downstream facilities such as the primary clarifiers and solids processing facilities. The cumulative effect of chemical addition (upstream and/or at the front end of the plant) and air dispersion may be sufficient to reduce odors at the fence line.

Based on past experience, iron chloride addition is likely to be the most beneficial to the RWQCF, but other products can be considered for full scale field testing by the City. A preliminary cost comparison between iron chloride and Bioxide, the other product known to the City, is presented in a subsequent section.

The following steps outline an approach to upstream chemical addition:

1. Characterize the incoming raw wastewater. Conduct 24-hour composite and diurnal sampling to determine peak and average sulfide (inorganic and organic) and VOC concentrations at the various sampling locations, including major gravity sewers and large pump station discharges entering the RWQCP.
2. Before implementing chemical addition, conduct an initial survey of H₂S and odors around at the plant and in the surrounding neighborhood to document current odor levels. For H₂S, sensitive analyzers such as a Jerome 631x H₂S Analyzer should be used. Odors can be surveyed using field olfactometers, such as the Nasal Ranger Field Olfactometer manufactured by St. Croix Sensory, Inc., This device that can produce on-site and immediate dilution-to-threshold values (such as those given in the 1992 CH2M Hill report). The recorded values can also be used to calibrate the odor dispersion model.

3. Determine the best locations for chemical addition based on available space, electricity, water and proximity to sensitive facilities such as schools and residential properties, since it may be undesirable to locate hazardous chemicals near such properties. Locations must be chosen appropriately to allow sufficient time for product to react with odor causing compounds.
4. Select an appropriate odor control product based on the pre-existing sulfide profiles, sulfide generation capability, product hazards and other considerations.
5. Invite product vendors to provide recommendations, and/or conduct product testing. Some vendors are willing to perform tests at no cost to the City.
6. Establish performance criteria for vendors, negotiate contract, and proceed with system installation.

Another technology that may prove useful at the RWQCP is peroxide regenerated iron for sulfide control (PRI-SC)TM, which uses iron salts in conjunction with hydrogen peroxide. The primary concept in this process is reintroduction of ferric ions at downstream locations using hydrogen peroxide. Wastewater in upstream reaches of the system is treated with ferrous salts for precipitating sulfides as ferrous sulfide (FeS). Hydrogen peroxide may be added at intermediate points downstream to oxidize the FeS precipitate to ferric ions and elemental sulfur. The resulting ferric ions provide additional odor control or act as a coagulant in the enhanced primary treatment process downstream of the hydrogen peroxide dosage location.

The overall cost of upstream odor control treatment and in-plant ferric chloride addition is expected to be lower with the PRI-SC system compared to operating separate upstream chemical addition and in-plant ferric chloride addition systems. However, full-scale testing and evaluation should be performed prior to full implementation and commitment to this concept.

Covering Equipment, Providing Ventilation and Treating Foul Air

If treatment of wastewater by dosing odor control products in the upstream reaches of the collection system is undesirable due to concerns about safety hazards and handling of odor control products, the second option is to capture foul air generated at the plant by installing equipment covers. The foul air withdrawn from below the covers must then be treated before being discharged to the atmosphere.

Covering process equipment and withdrawing and treating the foul air is a common odor control method employed. A properly operated odor control

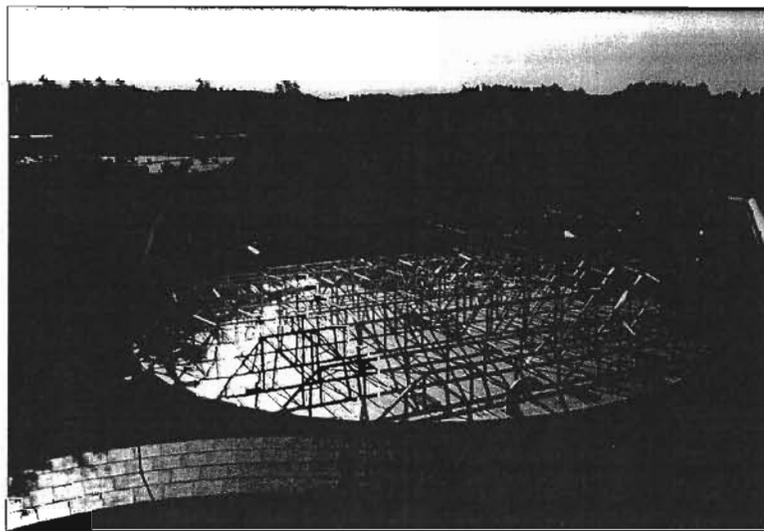
system can provide excellent odor control. However, some disadvantages of this method include:

- Significant capital cost, operation and maintenance, labor, chemical and power requirements
- Additional treatment stages may be required if the foul air contains a high concentration of odor causing compounds
- Inadequate maintenance of the system can lead to leakage of foul air from covered equipment, reducing the effectiveness of this method
- Potential handling and storage of large quantities of hazardous chemicals (for chemical scrubbers)

Covers

The two types of equipment covers used for foul air containment are flat covers and geodesic domes. Flat covers without supports may be used for clear spans of no more than 30 feet; truss supports are required when the span exceeds this length. A photograph showing truss supported flat covers for circular clarifiers is shown in Figure 4.2. Geodesic dome covers are the second option, and may be used for covering equipment with clear spans as large as 900 feet.

Figure 4.2. Photograph of Truss Supported Flat Covers For Circular Clarifiers



Materials of Construction

Aluminum is the most commonly used cover material as it provides good corrosion resistance, yet good strength and lightweight construction. Fiberglass is also frequently used, although its lifespan is shorter than aluminum since it is susceptible to ultraviolet radiation. A more recent option for flat covers is structural fabric. Fabric covers may be tailored to any shape,

but are unable to handle surface loading. The longevity of fabric covers is not yet proven.

Characteristics of Covers

Both dome and flat covers may be designed with the following characteristics:

Permanency:	Fixed, or removable to allow access
Accessibility:	Include hatches to provide access to covered spaces
Visibility:	Include clear panels to allow visibility
Aesthetics:	Designed to reflect sunlight, or resist surface oxidation
Sealing:	Gasketed, caulked or permanently sealed
Air Openings:	Openings may be incorporated, or fresh air may be allowed to enter through gaps between the covers and equipment

Foul Air Withdrawal Rates

Foul air must be withdrawn from covered process equipment to prevent corrosion of concrete structures and metallic equipment below the covers, and to prevent odorous air from escaping to the atmosphere. The foul air withdrawal rate may be selected based on one of the criteria discussed below.

Foul air withdrawal rates for Plant 2 clarifiers have been estimated. Covers are not recommended for Plant 1 clarifiers since they will be replaced in the near future. Covers for the new Plant 1 clarifiers may be designed as part of the replacement project. Cost estimates for all the options discussed below are presented in Section 5.

Criteria 1 - Prevent Leakage from Covered Area

The primary objective of this ventilation strategy is to ensure negative pressure at all leakage points along the covers; the amount of air withdrawn depends on the surface area of the covers, and presence of gaps between the covers and equipment. A close fit reduces gaps and openings, allowing less foul air to escape. Fresh air is drawn into the headspace at the gaps; alternatively, vents may be provided to allow fresh air into the headspace.

Based on BC's experience, a foul air rate of 0.5 to 1.0 cubic feet per minute (cfm) per square foot of cover provides sufficient negative pressure at openings. The lower rate may be used when a close fit between the covers and equipment reduces the number of openings and gaps.

Using this option, the total foul air rate for the four Plant 2 primary clarifiers will be approximately 34,000 cfm, and the anticipated H₂S concentration based on available dissolved sulfide data is 1.1 ppmv. Protecting the concrete structures under the covers using polyvinyl chloride (PVC) liner or spray-on epoxy coatings is recommended. Due to the moderately low H₂S concentration, foul air treatment using biological treatment technologies is unfavorable. Activated carbon is more suited for this application and is therefore the recommended option for treating the extracted air.

Criteria 2 - Prevent Corrosion Within the Enclosure

The foul air withdrawal rate is based on the headspace volume, and the nature of the space. The ventilation and foul air withdrawal rates are determined by calculating the air volume required to reduce H₂S concentration to approximately 1 ppmv. Corrosion of unprotected concrete and metallic surfaces and equipment is greatly reduced at this H₂S concentration.

Typically, 4 to 6 air changes per hour (ACH) are used for sweeping out foul air and reducing corrosion. For example, a headspace with a volume of 100 ft³ can be supplied with 400 to 600 ft³/hr of fresh air. The exact foul air withdrawal rate must be calculated based on the estimated H₂S generation rate to ensure that it is sufficient to reduce the H₂S concentration to 1 ppmv. The foul air rate must also be sufficient for producing negative pressure at gaps and openings.

The required rate of withdrawal for reducing H₂S concentration to 1 ppmv at the Plant 2 primary clarifiers is 38,000 cfm. Due to the low concentration of H₂S, activated carbon is an economical and efficient option for foul air treatment.

Criteria 3 - Dilute Foul Air to Improve Treatability

This method estimates ventilation rates by determining the H₂S concentration and supplying enough fresh air to dilute it to a predetermined concentration. The objective is to reduce the H₂S concentration to allow treatment using more cost-effective biofilters or bioscrubbers, which typically operate best 5 ppmv and 15 ppmv H₂S. However, if the calculated foul air rate is lower than 0.5 cfm/ft², it must be increased to this amount to ensure negative pressure at gaps and openings. The concrete must be protected against corrosion using polyvinyl chloride liners or spray-on epoxy coatings.

A foul air withdrawal rate sufficient to lower the H₂S concentration to 10 ppmv is chosen to enable treatment using the more cost-effective biological technologies. An activated carbon unit is typically provided for “polishing” treated air before discharge. The total estimated foul air rate for the four Plant 2 clarifiers is approximately 3,800 cfm. However, an air flow rate of at least 17,000 cfm is required to provide negative pressure at gaps and openings, and consequently reduces the H₂S concentration to approximately 2 ppmv. Due to the low concentration of H₂S, an activated carbon system is the recommended foul air treatment method for this option.

Criteria 4 - Personnel Entry

Flat panel covers are usually designed with hatch openings along the perimeter of circular clarifiers to allow personnel to wash down the weirs and for other maintenance activities. Hatch openings or removable panels are also provided at the center of clarifiers to allow maintenance of the scum skimmer and rake drive mechanisms.

However, if desired, clarifiers may be provided with geodesic dome covers to allow personnel to enter the headspace. A walkway can be provided for accessing the scum skimmer and rake drives. The ventilation rates in such headspaces must be increased for personnel health and safety. The typical ventilation rate chosen for such applications is 20 ACH, which ensures sufficient fresh air in the headspace and reduces H₂S concentrations to safe levels.

The exact foul air withdrawal rate must be calculated based on the estimated H₂S generation rate and other factors including the applicable local and federal regulations governing personnel entry into hazardous atmospheres. The National Institute for Occupational Safety and Health (NIOSH) lists a maximum exposure limit of 10 ppmv, with a 10-minute ceiling. The American Conference of Governmental Industrial Hygienists (ACGIH) and California Occupational Safety and Health Administration (Cal-OSHA) also list an exposure limit of 10 ppmv. The air flow rate must also be sufficient to provide fresh air for ensuring worker comfort during entry. Based on BC experience, 20 ACH was chosen for this option.

The total estimated foul air rate for the four clarifiers is 178,000 cfm; the estimated H₂S concentration is 0.2 ppmv. Due to the low H₂S concentration, activated carbon adsorption is the recommended foul air treatment technology.

Phased Approach - Combining Upstream Chemical Addition and Cover, Ventilate and Treat

The third option uses a phased approach. Since design and construction of covers for the Plant 2 primary clarifiers are likely to involve several years, the first phase focuses on providing immediate short-term odor control. This will be accomplished by adding odor control chemicals upstream of the RWQCP to reduce incoming sulfides. This approach allows the City time to delay the more expensive cover, ventilate and treat method and evaluate the effectiveness of upstream chemical addition alone. During Phase I, the City can survey the effectiveness of chemical addition and offsite odor impacts using the equipment mentioned earlier (i.e., the Jerome Meter and the field olfactometer).

If Phase I improvements fail to provide the desired control, equipment covers should be provided for capturing foul air. The withdrawal rates will be based on one of the four ventilation criteria discussed previously. Since the headspace H₂S concentration for all options is below 5 ppmv, the foul air can be effectively treated as described previously. Upstream chemical addition may be discontinued once the Phase II improvements are implemented.

4.2.3 Odor Control for New Primary Clarifiers

The odor control strategy for the existing primary clarifiers can also be used for the new primary clarifiers that will replace the existing Plant 1 clarifiers. Preventing formation of septic sludge by faster sludge withdrawal rates can reduce odors from this potential source.

4.2.4 Headworks Biofilter

During the September 2004 site visit, BC staff noted strong odors and a H₂S concentration of 40 ppbv along the eastern boundary of the Headworks biofilter. The RWQCP staff mentioned that the biofilter media had not been replaced since its installation eight years ago. Bulk media biofilters need periodic media replacement, typically once every three to five years. Uneven compaction can occur over time and can result in channeling, preventing foul air from receiving the contact time needed for treatment. These factors, including the relatively high H₂S concentration in the vicinity of the biofilter suggest that the unit may not be performing as designed.

It is recommended that the biofilter be inspected. A smoke test may be helpful in determining if channeling is occurring. Replacement of the biofilter media must be undertaken.

4.3 Strategies for Existing and Future Solids Processing Facilities

Several changes to the existing solids processing facilities are expected to occur in the near future, including construction of new dewatering and truck loading facilities and possibly expansion of the existing thickening system. Odor-related historical data

indicate that the existing facilities do not contribute significantly to the odors emanating from the entire plant. Improvements to the existing and future solids processing facilities proposed to mitigate any odor-related concerns are discussed below.

4.4 *Odor Control at Existing DAFT Tanks*

The 1993 study by CH2M Hill showed moderate odor at the DAFT process. The air sampling conducted by BC staff in September 2004 indicated low to moderate H₂S concentration (12 ppbv) near the open DAFT tanks. Dilution of odors by air dispersion may provide sufficient odor control at this facility. Increasing vegetation inside the southern fence near the DAFT tanks may provide sufficient dispersion to reduce odor impacts south of the fenceline.

Covering the tanks with flat covers, withdrawing foul air from the headspace, and discharging untreated air using a tall stack is another option. The stack must be located at a sufficient distance from buildings and other structures to prevent "building downwash." This phenomenon occurs when aerodynamic turbulence caused by structures such as buildings pull the discharged plume downward towards receptors at ground level. The effect reduces the opportunity for mixing and dispersion of the discharged air. An air dispersion modeling study will be useful in determining appropriate stack locations to prevent building downwash. Dispersion modeling comparison of downwind odor impacts of open tanks versus covered tanks will be useful in determining if tank covers are necessary.

4.5 *Odor Control at the Existing and Future Dewatering Facility*

The existing dewatering facility processes digested biosolids for producing wet cake that is hauled off-site. Biosolids are currently dewatered using filter presses and one centrifuge. BC staff noted strong odors in the vicinity of this facility. Filtrate from the BFPs that cascades into open collection basins (see Figure 4.3) is one of the main sources of odors at this facility. Since the filtrate sumps are not enclosed, foul air withdrawn above the sumps has little effect in reducing odors in the building.

Planned upgrades to the solids handling facility include the design of a new truck loadout facility, which will improve solids loading operations. Recent improvements to the dewatering facility included addition of a dewatering centrifuge, which has allowed less frequent operation of the BFPs and consequently reduced odors in the facility. However, during periods of higher dewatering demand, the BFPs are placed into service, resulting in noticeably higher odors.

Figure 4.3. Photograph of Existing Belt Filter Press



Since Operations staff reported that the BFPs will be phased out in the near future, modifications to the existing foul air collection system designed to improve ventilation and foul air collection at the BFPs will not provide any value. The City should focus on the following improvements, process and operational changes for reducing odors at the dewatering facility:

1. Improve foul air collection at the classifying conveyor which discharges to the belt conveyor.
2. Provide foul air collection from the centrate line.
3. Provide foul air collection from the centrifuge cake box, centrate tanks and centrifuge casing of the existing centrifuge.
4. Make provisions to allow connection of foul air from future centrifuges.
5. Provide covers or hoods for the belt conveyor, and foul air collection at various locations along the length of the conveyor. The foul air rate must be sufficient to provide a negative pressure of approximately 0.01 inches of water column, or a face velocity of 300 feet per minute (fpm).

Withdrawing foul air directly from process equipment such as the centrifuges can reduce odors both within the building and the vicinity by preventing foul air from escaping. The foul air may be treated using an activated carbon unit or modular biofilter. The appropriate treatment technology must be chosen after characterizing the foul air generated by these processes.

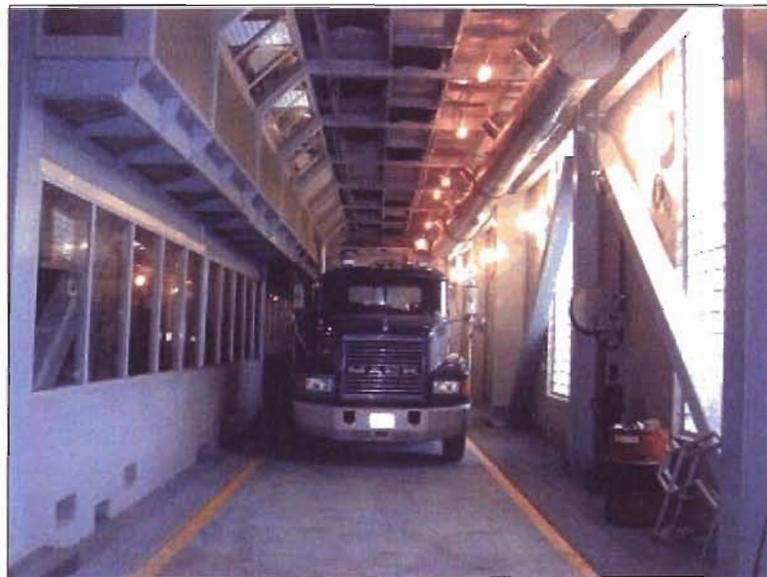
4.6 Odor Control at the Existing and Future Truck Loading Facility

Biosolids produced at the RWQCP were previously dried in air drying beds. Since the air drying process has recently been phased out, wet cake is hauled offsite with future planned heat drying. The City is currently designing a new truck loading facility for streamlining the dewatering and cake transport process. Since biosolids processing and

conveying can produce foul air containing compounds such as RSCs, amines, and H₂S, odors can be a significant concern at the truck loading facility. The new facility is being designed to control odors and treat foul air by implementing the following measures:

1. Providing continuous ventilation and foul air withdrawal inside the truck loading facility to reduce odors, prevent equipment corrosion, and ensure operator comfort.
2. Locating supply air registers and foul air withdrawal registers along opposing walls in the building to create a sweep of air for effectively capturing odors.
3. Where feasible, providing direct foul air withdrawal from covered process equipment and maintain negative pressure at openings. This will reduce the rate of foul air escaping into the facility, thus preventing odors.
4. Locating the truck loading operation in a separate enclosure or building, and providing a higher foul air withdrawal rate (between 12 and 30 ACH) in this building to capture foul air during truck loading. This approach has been used in Toronto, Ontario (Figure 4.4).
5. Installing magnetic interlocks or post signs prohibiting both entrance and exit doors at the truck loading enclosure from remaining open simultaneously. This will prevent odors being swept away outside the building by prevailing winds. Alternatively, air curtains may be used at the entrance and exit to isolate the foul air within this enclosure.
6. Ensuring that truck operators are following proper procedure and covering the bins prior to exiting the facility.

Figure 4.4. Photograph of Truck Loading Enclosure at Toronto, Ontario



The concentration of malodorous compounds in the foul air is expected to be very low due to the high foul air withdrawal rate. Therefore, foul air from the enclosed truck loading space may be treated using activated carbon. The dimensions of the truck loading facility based on the predesign and foul air withdrawal calculations are as follows:

Length:	70 ft	Volume:	21,000 ft ³
Width:	15 ft	Air Withdrawal Rate:	30 ACH
Height:	20 ft	Air Flow Rate:	10,500 cfm

The 10,500 cfm foul air rate may be treated in an activated carbon system. If necessary, combined foul air from the truck loading facility and other process equipment such as silos may be treated using one activated carbon system. Up to 15,000 cfm of air may be treated using a single carbon unit with a diameter of 8 feet and height of 12 feet.

5.0 Permitting

Air emissions from the RWQCP are subject to the stipulations of permit-to-operate issued by the South Coast Air Quality Management District (SCAQMD), which maintains jurisdiction over Riverside County. Installation of new foul air treatment systems, or modifications to existing systems are likely to be subject to the SCAQMD's new source review process. A health risk assessment (HRA) may also be required to prove that emissions from facilities pose a Maximum Individual Cancer Risk (MICR) no greater than 1 in a million. Air dispersion modeling using the Industrial Source Complex Short Term (ISCST3) method, the same model used for odor dispersion modeling, may be required to determine downwind concentration of toxic substances.

In addition to permit requirements, SCAQMD may also require the RWQCP to meet certain fence-line odor concentration goals. These concentration goals are usually based on the frequency of complaints received from the local community, as well as the potential for complaints when odor concentration exceeds a pre-determined value. For example, based on the history of complaints, the SCAQMD has established a fence-line H₂S concentration goal of 10-ppbv for the Orange County Sanitation District's wastewater treatment plants.

6.0 Preliminary Cost Estimates

Preliminary cost estimates were generated for odor control strategies on currently known facilities. The cost of odor control systems related to future facilities has not been determined. Presented are the estimated present worth for the H₂S and odor survey equipment, odor control modeling, wastewater characterization, upstream chemical addition, and odor control system improvements to the headworks, primary clarifiers, and truckload out facility. While foul air withdrawal rates for the new truck loadout facility have been presented in earlier sections, construction cost estimates are more appropriately handled as part of other documents, and are not presented here.

The annual and capital costs for the various cover, ventilate and treat options presented in Table 6.1 are intimately linked to the liquid phase dissolved sulfide concentration of the process streams, and the headspace gas phase H₂S concentrations of the processes requiring odor control. Changes in these parameters can render certain options cost prohibitive, while improving cost effectiveness of other options. Preventing leakage of foul air from covered equipment is the governing factor in determining the foul air withdrawal rates from the Plant 2 primary clarifiers. Since the foul air withdrawal rates calculated for the various options result in dilution of H₂S to below 5 ppmv, the "Treatability" criterion does not apply to odor control at the RWQCP and provides no significant cost benefit over other options.

Table 6.1. Present Worth Costs of Odor Control Improvements for Known RWQCP Facilities

Purpose	Option/Criteria	Annual Cost	Capital Cost	Present Worth
Ambient H ₂ S Measurement	One Jerome Model 631x H ₂ S Analyzer; Cost depends on accessories desired	-	\$10,000 to \$15,000	\$10,000 to \$15,000
Odor monitoring	Two St. Croix Sensory, Inc., Field Olfactometers; Cost depends on accessories desired	-	\$3,000 to \$4,000	\$3,000 to \$4,000
Odor Modeling	Cost depends on sampling and monitoring required	-	Up to \$50,000	Up to \$50,000
Wastewater Characterization	Cost depends on number of sites and sampling frequency	-	Up to \$50,000	Up to \$50,000
Upstream Chemical Addition	Nitrate Addition	\$154,300	\$218,700	\$2,315,600
	Iron Addition	\$70,000	\$99,300	\$1,050,700

Total present worth based on 20 years, at a discount rate of 4% per annum for annual cost items. Based on December 2004 dollars.

Table 6.1. (cont'd) Present Worth Costs of Odor Control Improvements for Known RWQCP Facilities

Purpose	Option/Criteria	Annual Cost	Capital Cost	Present Worth
Covering, Ventilating, and Treating Foul Air from Plant 2 Clarifiers	Leakage Prevention of Covered Area	\$155,300	\$3,929,400	\$6,040,000
	Prevent Corrosion Within Enclosure	\$184,400	\$3,469,100	\$5,975,200
	Dilute to Improve Treatability	\$95,800	\$4,276,900	\$5,578,900
	Personnel Entry	\$815,500	\$4,820,800	\$15,903,700
Truck Loadout Odor Control	Includes Ducting and Foul Air Treatment	---	---	---

Total present worth based on 20 years, at a discount rate of 4% per annum for annual cost items. Based on December 2004 dollars.

7.0 Conclusions and Recommendations

A review of the available data leads to the following conclusions:

1. Both historical and current data indicate strong odors at several plant locations, particularly at the influent monitoring stations, primary clarifiers, and dewatering facility.
2. High dissolved sulfide concentration in the influent wastewater is responsible for the strong odors observed at the influent monitoring stations.
3. Strong odors near the Headworks biofilter indicates that it may not be operating as designed.
4. Discontinuing air drying at the site has significantly reduced the complaints from neighboring areas.
5. The current practice of re-thickening the raw sludge from Plant 1 primary clarifiers at the Plant 2 primary clarifiers and slow withdrawal of the combined raw sludge appears to be responsible for high odor and sulfide levels at the primaries. Sludge septicity may be occurring based on bubbles found at the clarifier surface.
6. The lower elevation of the plant compared to its neighbors, and its location close to the river makes odor control difficult.

Recommendations for various facilities are as follows:

General Improvements

Improvements designed to enhance atmospheric dispersion may be used south of the RWQCP solids processing facilities to reduce impacts to businesses located south of the fenceline.

- Periodic monitoring of H₂S and odors within the facilities and at surrounding areas should be conducted, and recorded to assist with prioritizing appropriate improvements.
- Improvements designed to enhance atmospheric dispersion, such as providing more vegetation and/or constructing an air dispersion fence should be used south of the RWQCP solids processing facilities to reduce impacts to businesses located south of the fenceline.
- Odor dispersion modeling should be performed to compare odor impacts of open processes versus covered processes (for example, primary clarifiers and DAFT tanks). The modeling results can be used for determining if covers are necessary for processes with low odors such as the DAFT tanks.

Influent Monitoring Stations

The following recommendations can reduce the odors emanating from the influent monitoring stations:

- Strategic chemical addition at the plant can result in significant improvement throughout. For example, iron salt addition at the influent monitoring stations or better yet, 15 to 30 minutes upstream can reduce the odors at the station, the primary clarifiers and the digesters by tying up the sulfides present. The ferric chloride currently being added upstream of the primary clarifiers should be relocated upstream of, or to the influent monitoring stations.
- Cover open channels and withdraw and treat the foul air if chemical addition is not desirable or is insufficient to keep odors low.

Headworks Biofilter

The strong odors noted by BC staff near the east side of the Headworks biofilter indicates that it may not be performing as designed.

- The biofilter should be thoroughly evaluated to determine current performance. A smoke test will determine if the biofilter is clogged or if channeling is occurring.
- Bulk media biofilters typically require media replacement every five years. The City indicated that the medium had not been replaced for more than eight years. The media should be replaced to improve performance and return the biofilter to design conditions.

Plant 1 Primary Clarifiers

The Plant 1 primary clarifiers are to be replaced with new clarifiers in the near future. In addition, gas phase sampling conducted by BC staff indicated low H₂S concentrations in the vicinity of Plant 1 clarifiers. It is recommended that these clarifiers not be provided with covers at this time.

Plant 2 Primary Clarifiers

Strong odors were noted in the vicinity of the Plant 2 primary clarifiers. Liquid phase sampling also showed high dissolved sulfide concentrations.

- The current practice of re-settling and thickening Plant 1 primary solids in the Plant 2 primary clarifiers should be re-evaluated. The long retention time of sludge in the primaries may be contributing to the formation of septic sludge in the clarifiers. Co-thickening of raw and biological solids should be explored.
- Since design and construction of cover, foul air collection and treatment system is likely to involve several years, upstream chemical addition is recommended initially. This option provides an economical short-term choice for reducing odors at the plant and allows the City time to evaluate the effectiveness of this method. H₂S and odor surveys can be performed periodically to determine the efficacy of upstream chemical addition. A background survey is needed for reference.
- If chemical addition is insufficient in reducing the odors, the City should proceed with the covering and ventilating the clarifiers. Upstream chemical addition can be terminated after completion of improvements. The ventilation and foul air withdrawal rates for all options are sufficient to reduce average H₂S concentration at

the primaries below 5 ppmv. At these low levels, activated carbon becomes the cost-effective method for foul air treatment.

- If entry to the clarifiers is unnecessary, providing flat covers is recommended due to the reduced cost resulting from lower ventilation rates. Geodesic dome covers, which double the cost of covering the clarifiers, are necessary if personnel entry is desired for maintenance.

Dewatering Facility

Gas phase sampling conducted by BC staff indicated no H₂S near the dewatering facility. However, strong odors were noted. The current plan to replace the open belt filter presses with enclosed centrifuges should improve odor control by allowing the capture of odorants. The following recommendations should be implemented:

- Improve foul air collection at the classifying conveyor which discharges to the belt conveyor.
- Provide foul air collection from the centrate line.
- Provide foul air collection from the centrifuge cake box, centrate tanks and centrifuge casing of the existing centrifuge.
- Make provisions to allow connection of foul air from future centrifuges.
- Provide covers or hoods for the belt conveyor, and foul air collection at various locations along the length of the conveyor. The foul air rate must be sufficient to provide a negative pressure of approximately 0.01 inches of water column, or a face velocity of at least 300 fpm.

Truck Loadout Facility

Implement odor control measures currently planned for the new truck loadout facilities. These measures are as follows:

- Provide continuous ventilation and foul air withdrawal inside the truck loading facility to reduce odors, prevent equipment corrosion, and ensure operator comfort.
- Locate supply air registers and foul air withdrawal registers along opposing walls in the building to create a sweep of air for effectively capturing odors.
- Where feasible, provide direct foul air withdrawal from covered process equipment and maintain negative pressure at openings.
- Locate the truck loading operation in a separate enclosure or building, and providing a higher foul air withdrawal rate (between 12 and 30 ACH) in this building to capture foul air during truck loading.
- Install magnetic interlocks or post signs prohibiting both entrance and exit doors at the truck loading enclosure from remaining open simultaneously.
- Ensure that truck operators are following proper procedures and covering the bins prior to exiting the facility.

BROWN AND
CALDWELL

APPENDIX A

**LIQUID AND GAS PHASE
ODOR AND CORROSION CONTROL TECHNOLOGIES**

LIQUID PHASE ODOR CONTROL TECHNOLOGIES

Liquid phase control allows agencies the opportunity to capture or remove odor compounds while in a matrix that is controllable. Once odorants volatilize, it becomes more difficult to effectively capture all the foul air and treat them effectively. Openings and gaps in access holes, tank covers, etc., allow the foul air to escape, often times causing a nuisance in nearby areas. Chemicals can be added upstream of the RWQCP to reduce the liquid phase concentration of the odor compounds thus reducing the amount that volatilize and escape to the atmosphere.

Because of the high expense, chemicals are typically added to reduce the odor compound concentration, but not to completely eliminate it. The post-treatment gas phase concentrations are typically low enough to rely on dispersion and dilution from the fugitive emission points to the nearest receptors. Most agencies target an average of 5-10 ppmv of H₂S gas and 10-20 ppmv H₂S peak, depending on the location of the receptors.

Chemicals added to the wastewater stream to control sulfide-related odor and corrosion are subdivided into four groups: inhibitors, oxidizers, precipitators, and H₂S suppressors. The first group inhibits the formation of sulfides, whereas the second and third groups reduce the concentration of already-formed sulfides by oxidation or precipitation, respectively. The final category shifts the chemical equilibrium to favor dissolved sulfides (non-odorous ionic) instead of H₂S gas. This shift is accomplished by raising the pH of the liquid stream. Chemical addition to the wastewater can normally be expected to reduce pipeline corrosion because H₂S is reduced. However, even highly effective sulfide control will not completely alleviate corrosion or odor concerns.

Chemicals can be added to the wastewater in a number of ways. The simplest approach is to add directly to the wet well. It is also possible to pump through nozzles directly into the force main. Under turbulent conditions, such as the NBI crossing of Interstate 5, and pH below 7.0, the selected odor control chemical must reduce dissolved sulfide levels to less than 0.1 milligrams per liter (mg/L) to reach the gas phase target values mentioned previously. Thus, it is essential to select a chemical that can lower dissolved sulfides to this desired value. The following paragraphs describe some of the typical chemicals used for odor control.

Sulfide Inhibitors

Some chemicals inhibit or prevent the formation of sulfides by chemical or biological modification. Included in this category are: nitrates, anthroquinone, and caustic soda (NaOH) (when slugged, as opposed to dosed).

Nitrates. Sodium nitrate has been used for odor control in sewers, treatment plants, and lagoons. Sulfate-reducing bacteria will preferentially use nitrates, rather than sulfates, as an oxygen source, reducing nitrate to nitrogen gas. Continued use encourages increased development of nitrate reducers and minimizes sulfate reducers. In addition to its preventive mechanism, nitrate can also provide some chemical oxidation of existing sulfides. However, this mechanism requires up to two hours of detention time. One of the chief advantages of nitrates is that they are non-hazardous formulations.

Some chemical suppliers of nitrate formulations may add other compounds to the mix to achieve oxidation of sulfide. Altivia Chemicals, who produce a sodium nitrate (NaNO_3) product called Nitrazyme, proposes that 8 to 10 pounds of NaNO_3 is required to oxidize 1 pound of sulfide. US Filter provides a product using calcium nitrate (CaNO_3) marketed under the name Bioxide®. Some utilities currently inject Bioxide® at a dose rate of approximately 10 gallons per million gallons of wastewater. Note that there are about 3.5 pounds of $\text{NO}_3\text{-O}$ per gallon of Bioxide.

The nitrate solutions have been proven effective for force mains in particular. However, in some cases, dosage and cost have been high. In order to establish dosages and effectiveness, testing is normally recommended. Whether nitrate could effectively oxidize sulfides entering the pump station is an important question that a trial test may answer. A high dose rate at the pump station could result in carryover to the downstream gravity section to provide additional sulfide control.

Anthroquinone. This chemical is an organic inhibitor. It has the ability to modify a particular strain of sulfate reducing bacteria, thus interrupting the transformation of sulfate to sulfide. For this technique to work, the chemical must diffuse through the slime layer to reach the critical bacteria. This is best accomplished under alkaline conditions. One chemical company (Environmental Biocontrol, Inc.) has developed a method to diffuse the chemical into the wastewater on an intermittent feed basis. There has been some success with this approach. However, the chemical does not treat the sulfide that has already formed and is within the wastewater at the point of chemical addition.

The effectiveness of anthroquinone is reduced in large diameter pipelines due to the lower fraction contacting the slime layer. Because it is normally applied at intermittent intervals of every few weeks, it is not necessary to construct permanent dosing equipment. Conversely, the O&M staff must dedicate time to perform the dosing. US Filter supplies a formulation that combines Bioxide® and anthroquinone, marketed under the name Bioxide AQ®.

Other Biological Inhibitors. There are other biological inhibitors on the market that impede the ability of sulfate reducing bacteria (SRB) in the pipe slime layer to convert sulfates into H₂S gas. They perform this task either by killing the SRB or blocking the chemical pathway $SO_4 \rightarrow S^{2-}$. Two such products are Enzybate®, produced by Ashland, Inc., and Biogon®.

These products typically require a period of days to produce their ultimate inhibitory effect on the bacteria and achieve maximum effectiveness. Their beneficial effects generally diminish slowly as the bacteria regain their initial sulfate reducing capability. Although Enzybate® and Biogon® can substantially reduce the generation of H₂S gas, they usually do not control to very low values. They have had mixed results in other wastewater systems.

Caustic Slugging. A special application of pH control is caustic or high-pH “slugging.” By maintaining wastewater pH at 12 to 12.5 for about 20 minutes, inactivation of the slime layer can be achieved through microbial sterilization. Sodium hydroxide (caustic soda) is normally chosen for slug dosing, but lime can also be used. Sodium hydroxide produces a higher pH than lime and is more easily handled.

Periodic shock treatment with 25 or 50 percent sodium hydroxide solution is used by the Sanitation Districts of Los Angeles County and other agencies to control sulfide in problem areas with relatively small flows. It is dumped directly into a manhole or wet well, with an objective of maintaining a pH of at least 12.5 for a 20-minute slug of wastewater. The major advantage of caustic slugging is that it is an intermittent treatment. This can result in very economical sulfide control. The major disadvantage of caustic slugging is that its effectiveness diminishes with time. The length of time for sulfide regeneration varies with temperatures and the intensity of treatment.

Typically, however, this period is less than 2 weeks, and can be as little as 3 to 4 days. On the basis of dollars per pound of sulfide eliminated, however, this technique is often very attractive. Downstream handling of the high pH slug is needed in some cases to avoid affecting biological treatment processes at WWTPs (in this case, the RWQCP). If possible, the slug is diverted to a spare tank (primary clarifier), stored, and recycled over the 2 to 3 days following. Alternatively, the influent can be neutralized. This option is not viable if storage facilities are unavailable.

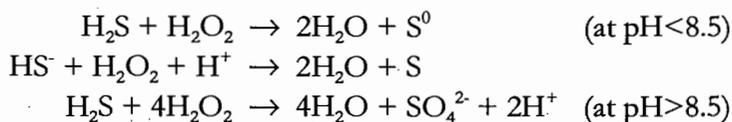
Sulfide Oxidizers

Several chemicals are used to oxidize soluble sulfide and H_2S to sulfate or elemental sulfur. Oxidizers can control odors and corrosion by several different methods:

- Direct chemical oxidation of hydrogen sulfide within the wastewater.
- Support of an aerobic bacterial community, particularly at the surface of the pipe wall slime layer, to oxidize sulfides and other odorous compounds.
- Maintenance of aerobic conditions in the wastewater, thereby preventing sulfide build-up.

Oxidizing agents can provide oxygen to the wastewater. This can create very high chemical demand in the upstream portion of the force main, leaving a potentially long section of force main in which sulfides could be generated after the oxidizer is expended. This could be remedied by constructing an intermediate dosing station, but this would increase neighborhood impact, maintenance, and capital cost. The most common chemicals used for this purpose are discussed below.

Hydrogen Peroxide. H_2O_2 is an effective oxidant. It is a strong oxidant capable of oxidizing the hydrosulfide ion (HS^-) (which oxygen cannot). An advantage of hydrogen peroxide is that it decomposes into oxygen and water. There are no chemical residuals added to the wastewater. Any oxygen remaining after oxidation of existing sulfide will prevent the formation of additional sulfide. The disadvantages are that H_2O_2 is considered hazardous at normal concentrations due to it being a strong oxidizer. It can also be somewhat costly. Reactions for oxidation of sulfide by H_2O_2 are:



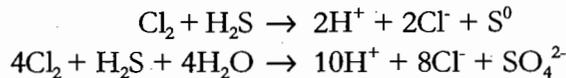
These reactions reflect the typical sulfide reactions in which elemental sulfur or ionic sulfate is produced. The literature suggests that the final reaction product is pH dependent; however, the final product is also dependent on the relative concentration levels of sulfide and oxidant. Since H_2O_2 will react with organic material, the dosage required is often greater than the dosage indicated by the above reactions. In general, H_2O_2 to sulfide weight ratios of 4:1 to 8:1 are often required.

For chemical oxidation, H_2O_2 requires up to 60 minutes detention time, although 90 percent of the reaction typically occurs within 15 minutes. The efficiency of treatment also depends on the level of iron (reaction catalyst) in the wastewater, wastewater pH, and temperature. For biological oxidation, H_2O_2 requires 30 to 180

minutes detention time. The efficiency of treatment also depends on the temperature, BOD, and the biomass available to effect the transformation.

H₂O₂ can be applied to the wastewater to alleviate the formation of odors downstream. The efficiency of treatment depends on the retention time, wastewater temperature, and wastewater BOD. This treatment method is generally most cost-effective for gravity sewers with detention times less than 3 to 4 hours and for force mains with detention times less than 2 to 3 hours. Although hydrogen peroxide is typically one of the more expensive control methods, it can provide good control.

Chlorine. Chlorine (Cl₂) is widely used for disinfection of municipal wastewater. Although Cl₂ is toxic to sulfide-forming bacteria, the dosage required to suppress sulfide formation is high, and it is sometimes more feasible to oxidize sulfide after it has formed. Cl₂ oxidizes sulfide chemically, according to the following reactions:



In theory, 2.22 pounds of chlorine per pound of sulfide (as S²⁻) are required for the first reaction, and 8.87 pounds of chlorine are needed for each pound of sulfide oxidized in the second reaction. Since both reactions often occur, the composite is usually somewhere between these ratios. Also, chlorine reacts with organic material, thus increasing the dosage needed. In practice, weight ratios (Cl₂ to sulfide) of 7 to 10 are often required for light-to medium-strength wastewater. Higher ratios are needed for high organic content wastewaters.

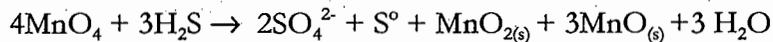
The use of chlorine requires eductor mixing to produce a chlorine solution. The benefit of using locations of natural or induced turbulence as application points must be weighed against the probability of liberating H₂S gas. For this reason, it may be desirable to feed chlorine solution upstream from points of turbulence. Because of its hazardous nature and stringent code requirements, chlorine is seldom used for new odor control systems, especially in the collection system.

Chlorine dioxide (ClO₂) is a gas similar in appearance and odor to chlorine. ClO₂, however, cannot be compressed and bottled and must be generated on-site (impractical in most situations). Stabilized ClO₂ is generated by adding acid and sodium hypochlorite (NaOCl) to a solution of chlorine.

Sodium hypochlorite is another chlorine option frequently used in collection systems and treatment plants. The primary advantage of liquid NaOCl (bleach) is its much safer handling compared to chlorine gas. However, commercial strength NaOCl (12 to 15 percent strength) is still considered a strong oxidizer and must be handled carefully and stored in appropriate equipment. Although sodium hypochlorite is

typically one of the more expensive control methods, it can provide good control and it is highly convenient to use. It is quite appropriate to treat small system flows. It is a candidate for further evaluation to determine its economic effectiveness.

Potassium Permanganate. Potassium permanganate (KMnO_4) is commonly used for iron and manganese removal in water treatment plants. It has also been used to treat sulfide-containing groundwaters. KMnO_4 oxidizes sulfide according to the following chemical reaction at neutral pH:



At alkaline or acidic pHs, other reactions occur. Potassium permanganate is commercially available in granular form and is usually dissolved in water prior to addition to wastewater.

Oxygen. Oxygen can be added through air injection or via high-purity oxygen (HPO) addition to force mains to achieve aerobic conditions in the wastewater to limit sulfide production. Oxygen addition also allows chemical and biological oxidation of the dissolved sulfide that already exists in the wastewater. Stoichiometric quantities indicate two parts of oxygen will oxidize one part of sulfide. In practice, dosage rates are typically three to six pounds of oxygen per pound of sulfide oxidized, plus the amount needed to maintain "fresh" sewage throughout the force main.

The major drawback to adding air or oxygen to a force main is crown bubble formation. Crown corrosion is a major potential problem to be evaluated. It is especially acute in force mains with an irregular profile or operating at low pressure. Given the right conditions, however, oxygen addition can be very cost-effective. A typical injection rate is 20 mg/L.

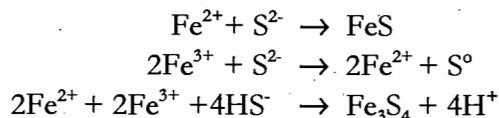
Air. Although air is more easily handled than oxygen, its oxidizing effect is several times less effective due to the lower dissolved oxygen level that can be achieved. The potential disadvantages of bubble formation and crown corrosion also apply. Air as well as pure oxygen can produce unintended corrosion in the crown of the force main. Dissolved air can be released at a low pressure or high point of the force main. This creates a gas pocket that allows H_2S and sulfuric acid to form and thereby accelerates corrosion.

Ozonation. Sulfide control by ozonation is a relatively new application. It is currently being tested in foul air applications. It is directly sprayed via mist into the foul air. We are not aware of any experience with direct addition of ozone to a force main. Ozone is produced by a corona discharge and is a hazardous vapor.

Sulfide Precipitation

When certain metal salts are added to wastewater, they react with dissolved sulfide to form an insoluble sulfide precipitate. This removes the dissolved sulfide that is responsible for H₂S odors: Copper, iron, and zinc can accomplish this precipitation, but due to cost and potential toxicity, iron is the only practical alternative. By the nature of their action, dissolved sulfides are converted to total sulfides which increases solids in the wastewater. Generally, iron addition in the interceptors provides excellent sulfide control well downstream--including at plant processes such as anaerobic digestion.

Iron Salts. Iron salts are used by hundreds of wastewater agencies nationwide with excellent results. Soluble ferrous (Fe²⁺) and ferric (Fe³⁺) combine with sulfide to form compounds such as iron sulfide (FeS), iron disulfide (FeS₂), and smythite (Fe₃S₄). Fe²⁺ and Fe³⁺ cations react with sulfide (S²⁻) and hydrosulfide (HS⁻), as shown in the following reactions:



Iron and dissolved oxygen may work in combination to reduce dissolved sulfide levels. Iron can lower dissolved sulfide efficiently to below concentrations of 0.5 mg/L at Fe to S weight ratios of 2:1 to 4:1. Lowering the dissolved sulfide concentration below 0.5 mg/L may require Fe to S ratios of up to 10:1, although some systems are able to achieve dissolved sulfides of 0.1 to 0.2 mg/L with low Fe to S weight ratios (<4:1).

Iron can be added as ferrous or ferric chloride or as ferrous sulfate. All of these compounds are provided as liquid solutions. They are highly acidic solutions and must be handled safely and stored in the proper equipment. Ferrous sulfate adds sulfate to the wastewater. This is undesirable when trying to control sulfide. One benefit of ferric addition over ferrous addition is that it raises the oxidation-reduction potential of the wastewater, assisting in the biological processes, as well as promoting sulfide oxidation. However, either chemical is considered a highly effective sulfide control.

Hydrogen Sulfide Suppressors

All of the listed H₂S suppressors reduce the formation of H₂S by elevating the wastewater pH. This reduces the proportion of odorous H₂S in solution and raises the proportion of non-odorous ionic species HS⁻ and S²⁻. At near neutral conditions, relatively small changes in the wastewater pH results in relatively large changes in the H₂S fraction dissociated in solution, according to the equilibrium reaction expressed by the following relationship:



At a pH of 7.0, approximately 50 percent of the constituents exist as H_2S . When the pH is raised to 8.0, only 8.3 percent is present as H_2S . At a pH of 9.0, the H_2S component drops to less than 1.0 percent. A major drawback of this approach is that the sulfide is never removed. If the wastewater pH shifts back, H_2S is again formed and released.

Caustic Soda. Caustic soda ($NaOH$) is often dosed into wastewater to moderately elevate the pH and prevent off-gassing of H_2S . This can strategically delay the release of H_2S . Caustic soda is a strong chemical that requires care in handling and usage. A 50 percent solution of caustic soda contains 42.5 percent hydroxide. Overdosing can result in elevated wastewater pH levels that can adversely affect treatment plant operations. Chemical dosage is unique to each system and contingent upon the specific water chemistry of the wastewater. It is not dependent on sulfide level. Caustic soda is also a potentially dangerous substance to handle, capable of causing severe damage to skin and other tissue, as well as being very corrosive to certain metals such as aluminum.

Increasing the wastewater pH up to 8.5 to 9.0 effectively minimizes off-gassing of H_2S by shifting the H_2S to bisulfide and sulfide ions. Off-gassing at this pH range will typically maintain gas-phase H_2S concentrations to less than 5 ppm. Work at Los Angeles County Sanitation District on this method in the early 1990s shows that very effective H_2S corrosion and odor control can be obtained in this manner. At continuous operation in this pH range (8.5 to 9.0), Los Angeles County staff has also discovered lower sulfide production in the slime layer since sulfate reducing bacteria growth is significantly stunted at this higher pH. Dosage rates of sodium hydroxide ($NaOH$) to reach this pH range are typically about 75 to 100 mg/L. The dosing rate for Six-Mile Creek was estimated from titration tests and will be refined during the current pilot test. This dosage rate is relatively insensitive to the dissolved sulfide concentration of the wastewater, being more a factor of the wastewater flow rate and water chemistry.

Hydrated Lime. pH adjustment can also be achieved with hydrated lime ($Ca(OH)_2$). This chemical falls in between the caustic soda (above) and Thioguard® (below) options in terms of both effectiveness and hazard. Handling is somewhat involved since it is a high-solids slurry and mixing of the stored chemical is required. The low wastewater flow speeds could produce lime settlement inside the pipes. Additionally, lime can produce calcium carbonate scaling under high pH conditions.

Thioguard®. Thioguard® is a proprietary alkaline slurry of magnesium hydroxide ($Mg(OH)_2$). Unlike caustic soda, it is considered non-hazardous. A 58 percent solution of Thioguard® contains 58.3 percent hydroxide. This corresponds to fewer pounds of magnesium hydroxide for a given situation: 37 percent more caustic soda and 27 percent more hydrated lime are necessary to neutralize the same amount of acid. However, Thioguard® can only raise the pH to between 8.5 and 9.0, even when

overdosed. At this pH range, H₂S is not totally shifted to HS⁻ and S⁼, and therefore odors are still possible. In contrast, caustic soda and hydrated lime can attain maximum pH values of roughly 14 and 12.5, respectively. While such elevated pH values can be trouble at the treatment plant, the capability to reach them means that even when the wastewater chemistry resists an increase in pH, the other H₂S suppressor chemicals can always raise the pH sufficiently. This is not always the case with Thioguard®, so H₂S control is compromised in such instances.

The handling characteristics of Thioguard® also sometimes present problems. Thioguard® is shipped as a high-solids slurry. Therefore, tank mixers are required and pumping is sometimes difficult. A minimum flow speed of about 2 ft/sec is required to keep the chemical in suspension. The conditions under which Thioguard® provides the most economical treatment are those in which the target pH of 9.0 is easily attainable, the wastewater dissolved sulfide values are very high (perhaps in the neighborhood of 5 to 10 ppm), and the wastewater moves through the lines at more than 2 ft/sec.

Table B-1 shows a qualitative comparison of the technologies described above. The non-economic ranking is comprised of chemical effectiveness, ease of use, and proven history of successful application.

Table B-1. Summary of Sulfide and Corrosion Control Chemicals

Method and chemical	Non-economic ranking	Advantages	Disadvantages
Inhibitors			
Caustic slugging	Low	<ul style="list-style-type: none"> • Can be mobile feed system • Often very cost-effective 	<ul style="list-style-type: none"> • Variable performance due to intermittent application • Operator attention at pump station and downstream slug handling required • Often variable performance • Does not reduce pre-existing dissolved sulfide component • Very corrosive to body tissue and certain metals
Nitrate formulations (Bioxide®)	Medium to High	<ul style="list-style-type: none"> • Relatively simple feed system • Can be used to prevent sulfide generation or oxidize existing sulfides • Chemical is safe to handle 	<ul style="list-style-type: none"> • Uncertain dosage requirement • Provides some sulfide removal; however, mainly a preventive measure • Bioxide® is a proprietary formulation

Table B-1. Summary of Sulfide and Corrosion Control Chemicals

Method and chemical	Non-economic ranking	Advantages	Disadvantages
Anthroquinone (normally added as nitrate supplement)	Low	<ul style="list-style-type: none"> • Simple intermittent feed system 	<ul style="list-style-type: none"> • Uncertain performance due to limited history • Bioxide/AQ® requires mixing in storage to maintain chemical in suspension • Bioxide/AQ® is a proprietary formulation
Oxidizers			
Hydrogen peroxide	Medium to High	<ul style="list-style-type: none"> • Relatively simple feed system • Provides certain control if dosage is sufficiently high • No byproducts • Effective in wide range of applications • Oxidizes many odorous compounds 	<ul style="list-style-type: none"> • High dosages and costs, at times • Strong oxidizer, requires handling precautions
Chlorine (Cl ₂) or sodium hypochlorite (NaOCl)	Medium to High	<ul style="list-style-type: none"> • Effective in wide range of applications • Provides certain control if dosage is sufficiently high • Rapid oxidation of sulfide • Oxidizes many odorous compounds 	<ul style="list-style-type: none"> • Safety concerns, especially of gaseous chlorine • High costs for NaOCl • Reacts with compounds other than sulfide
Potassium permanganate	Low	<ul style="list-style-type: none"> • Relatively powerful oxidant 	<ul style="list-style-type: none"> • Difficult to handle (solid material) • High cost
Air injection	Low	<ul style="list-style-type: none"> • Low cost • Relatively simple system 	<ul style="list-style-type: none"> • Limited to force mains • Potential for air binding and crown corrosion • Limited rate of oxygen transfer
High purity oxygen	Low	<ul style="list-style-type: none"> • Relatively low cost • Five times the solubility of air 	<ul style="list-style-type: none"> • Uncertain oxygen transfer rates • Potential for air binding and crown corrosion • Pressurized storage of oxygen • Safety concerns
Ozonation	Low	<ul style="list-style-type: none"> • Very strong oxidant 	<ul style="list-style-type: none"> • Complex generation equipment • Little experience in wastewater addition

Table B-1. Summary of Sulfide and Corrosion Control Chemicals

Method and chemical	Non-economic ranking	Advantages	Disadvantages
Precipitators			
Iron chloride	Medium to High	<ul style="list-style-type: none"> • Effective in wide range of applications • Cost-effective in high sulfide situations • Treats pre-existing dissolved sulfides • Could achieve sufficient odor control at reasonable cost if combined with air exhaust and treatment • Carryover helps reduce plant odors 	<ul style="list-style-type: none"> • Limited in controlling non-H₂S compounds • Sulfide control to low levels may be difficult • Adds solids to flow stream • Corrosive chemical • Widespread high dosages in collection system can have deleterious effect on receiving WWTP
Iron sulfate	Medium	<ul style="list-style-type: none"> • Can be effective in many situations • May be more readily available in certain parts of the country 	<ul style="list-style-type: none"> • Limited in controlling non-H₂S compounds
Hydrogen Sulfide Suppressors			
Continuous caustic addition	Medium to High	<ul style="list-style-type: none"> • Excellent corrosion and H₂S odor control when wastewater is not diluted or affected by acid additions • Dosage relatively insensitive to sulfide concentrations 	<ul style="list-style-type: none"> • Does not react liquid phase sulfide, which can "reappear" at lower pH • Can be high in chemical cost, as dosage is contingent on water chemistry • Hydrogen sulfide released at point of wastewater stream dilution due to pH depression • Handling and safety concerns • Potential treatment problems with high pH wastewater stream at WWTP
Hydrated Lime	Low	<ul style="list-style-type: none"> • Effective corrosion and H₂S odor control • Dosage relatively insensitive to sulfide concentrations 	<ul style="list-style-type: none"> • Relatively involved preparation and handling requirements, including tank mixers • Potential for re-release of H₂S since it does not react with sulfide • Largely insoluble slurry requires significant wastewater line speeds to remain in suspension • Calcium carbonate scaling potential • Potential of resultant high pH wastewater stream at WWTP

Table B-1. Summary of Sulfide and Corrosion Control Chemicals

Method and chemical	Non-economic ranking	Advantages	Disadvantages
Thioguard® (Mg(OH) ₂)	Low	<ul style="list-style-type: none"> • Safe to handle • Dosage relatively insensitive to sulfide concentrations • Limit to pH achievable (8.5-9.0) largely eliminates potential problems at WWTP • High proportion of hydroxide in solution • May tie up some sulfide as MgS or magnesium polysulfide 	<ul style="list-style-type: none"> • Requires wastewater flows of 2 ft/sec to keep insoluble slurry in suspension • Preparation and handling involves use of tank mixers • Potential for re-release of H₂S since it does not react with sulfide • Achievable pH does not totally suppress H₂S

GAS PHASE ODOR CONTROL TECHNOLOGIES

Often, it is not possible to achieve total control of gas phase H_2S by controlling the liquid phase sulfide concentration. Gas phase treatment of foul air may be used to prevent emission of odorous and toxic gases to the atmosphere and for minimizing impact to critical receptors such as local residents or businesses. Foul air treatment may also be needed if foul air is withdrawn from process areas. Several factors such as regulatory requirements, concentrations of various compounds in the foul air, and impact to residents will determine if treatment is necessary.

Several of the available alternatives can be implemented at the RWQCP, however, the choice will hinge upon space constraints, cost, and other factors. Carbon adsorption is a very popular method used by several agencies for foul air treatment. This method offers great versatility and is capable of handling variations in air flow and concentration very well. Other treatment methods such as chemical and mist scrubbers, bioscrubbers, and biofilters are also available. In addition, atmospheric dispersion of foul air without treatment may also be a viable option subject to approval from the local or regional regulatory agency. Each option listed above is discussed in greater detail in the sections below.

Carbon Adsorbers

Carbon adsorbers have been used for several decades for treating foul air. Adsorption is a process during which compounds are bound to the surface of the carbon medium. This process is physical in nature, and is similar to the interaction between dust and an electrostatic duster. The choice of activated carbon media depends on the nature of the foul air to be treated. The various types of carbon media available are virgin activated carbon, caustic impregnated carbon, catalytic carbon and other vapor phase carbons.

Virgin Activated Carbon. This medium is prepared by heating carbonaceous material such as coconut shells in the absence of oxygen, resulting in a porous structure. Virgin activated carbon has no additives to improve its adsorption capacity or to render it more effective. It therefore has a slightly reduced H_2S adsorption capacity compared with other carbon media. The H_2S capacity of virgin activated carbon varies between 0.01 and 0.02 grams per cubic centimeter (g/cc). The disadvantages of virgin carbon include the low H_2S removal capacity, and possibility of low media pH at the end of the useful life.

Caustic Impregnated Carbon. As the name implies, this type of carbon medium consists of activated carbon medium impregnated with caustic soda. Addition of a strong base to the carbon medium improves the H_2S capacity of the medium significantly. The typical H_2S capacity of impregnated carbon ranges from 0.10 to 0.15 g/cc. However, the adsorption capacity of other compounds such as VOCs is reduced. The primary disadvantage of impregnated carbons is their relatively low ignition temperature (approximately $200^{\circ}C$). In addition, the H_2S adsorption process

that is exothermic creates a hazardous condition by supplying heat to a readily ignited medium. Calgon Carbon's Sulfisorb and IVP carbon and Barneby-Sutcliffe's STI-X carbon are examples of impregnated carbon media.

Catalytic Carbon. This medium contains catalytic agents to improve the H₂S adsorption capacity of virgin activated carbon. The catalytic agent converts the H₂S to sulfuric acid (H₂SO₄), which can subsequently be washed out with water to regenerate the carbon. A small portion (< 5%) of the H₂S is converted to elemental solid sulfur, and reduces the H₂S capacity of the carbon by blocking pores in the media. Adsorption of VOCs over time also reduces the number of pore sites available and thus reduces the H₂S capacity of the carbon.

The carbon can be regenerated by washing with water. The low pH rinsate may be neutralized with lime or disposed into a sanitary sewer. Regenerated carbon usually loses 20% of the original capacity during the first regeneration cycle and approximately 5% of the original capacity on subsequent cycles. An example of such a medium is Calgon Carbon Corporation's Centaur HSV. The main disadvantage of these media is the low pH at the end of useful life, which requires the media to be neutralized with lime before disposal to a landfill. In addition, the regeneration cycle can be time intensive and can require several days during which the carbon vessels are taken out of service.

Other Vapor Phase Carbons. Recently, U.S. Filter Westates has developed a new carbon product named Midas OCM. The treatment principle of this medium is different from other carbon media. The H₂S in the foul air is converted to elemental sulfur, and therefore does not lower pH of the medium. Therefore, the medium may be handled as non-hazardous material at the end of its useful life, unlike other carbon products. Midas OCM has a high H₂S capacity of approximately 0.30 g/cc.

Chemical and Mist Scrubbers

Foul air treatment using chemical scrubbers has been the traditional method of choice at large municipal facilities such as wastewater treatment plants and large pump stations. The foul air to be treated is scrubbed in a packed tower using appropriate chemical solutions. Caustic soda is commonly used for scrubbing H₂S laden foul air, and VOCs are removed by scrubbing with an oxidizing solution consisting of a mixture of caustic soda and sodium hypochlorite.

Treatment efficiency depends on the contact between foul air and the scrubbing solution, so a packing medium with a high surface area to volume ratio (up to 30 ft²/ft³ of packing) is chosen. Since maximum transfer of compounds from air to liquid usually occurs with countercurrent flow, this mode is normally used in packed tower scrubbers. The foul air is introduced at the bottom of the tower and the scrubbing solution is distributed from the top of the tower. Uniform distribution of both gas and liquid may be ensured by using gas and

liquid distributors as needed. The typical empty bed retention time (EBRT) of foul air in the packed tower is 2 seconds.

The treated air exits at the top of the tower after passing through a mist eliminator to remove entrained liquid particles. The scrubbing solution is collected in a reservoir at the bottom of the tower and transferred back to the top using a recirculation pump. A portion of the scrubbing solution is periodically blown down from the reservoir, and make up water and chemical are added as required. While chemical scrubber systems are usually well suited to large installations requiring custom fabrication and installation of packed towers, package systems are also available from U.S. Filter. Such package systems have air flow capacities ranging from 1,000 cfm to 25,000 cfm.

Mist scrubbers are very similar to chemical scrubbers and provide foul air treatment by contacting it with a large liquid surface area. While chemical scrubbers use large surface area packing material to achieve this goal, mist scrubbers use a fine mist of liquid to maximize liquid surface area. The typical foul air detention time in mist scrubbers is between 1 and 10 seconds. Chemical and mist scrubber systems can provide high H₂S and VOC removal efficiencies (greater than 99%), but their primary disadvantage is that they require storage and use of hazardous chemicals. This disadvantage can be eliminated by using bioscrubbers, which are discussed in the following section.

Bioscrubbers

One emerging technology for treating foul air is bioscrubbers, also known as biotrickling filters or biotowers. Bioscrubbers are similar in construction to chemical scrubbers, but do not require hazardous chemicals for operation. A bioscrubber usually consists of a tower filled with an inert packing media such as polyurethane foam that acts as a substrate for growing microbial populations. Structural supports are provided at the bottom of the tower to support the packing media and optionally at the intermediate portion of the tower to prevent bed compaction. Bioscrubbers also include mist eliminators, inlet and outlet dampers, liquid recirculation pumps, and liquid distribution systems or spray nozzles.

Foul air enters the bioscrubber at the lower end of the tower, undergoes treatment, and is either discharged to the atmosphere or to secondary treatment processes. The microbial colonies can be initiated by recirculating secondary effluent from a wastewater treatment plant through the bioscrubber without foul air input for 24-hours. During normal operation, the recirculation stream provides moisture and nutrients to the microbial cultures, carries away byproducts, and regulates the operating temperature. If pH control is desired, it may be achieved by adding lime or diluted caustic solution to the recirculation stream.

In order to achieve a high treatment efficiency, the EBRT of the foul air is typically maintained above 15 seconds. A higher EBRT allows greater time for foul air to contact the recirculating liquid and the microbial growth in the packing media, thus improving mass transfer. If the foul air characteristics do not change significantly over prolonged durations,

microbial cultures acclimated to these foul air characteristics will experience preferential growth, improving bioscrubber efficiency over time. The Orange County Sanitation District (OCS D) conducted a pilot test for retrofitting existing chemical scrubbers to bioscrubbers. The pilot test showed that good removal of H₂S (between 95 and 99%) was possible at inlet concentrations between 3 and 30 ppmv. The removal efficiencies of VOCs and other reduced sulfur compounds ranged from 0 to 80%. The main disadvantage of bioscrubbers is that the technology is relatively new and unproven, with very few currently operational installations.

Biofilters

Another biological treatment option is a biofilter, which consists of an organic medium such as granular activated carbon (GAC), yard waste compost (YWC) or proprietary media. Foul air to be treated is introduced into a vessel containing the biological medium and moisture is supplied by irrigating the biofilter from the top. While biofilters have been used for odor control and foul air treatment for a long time, their popularity has increased recently due to regulatory issues, economic benefits and availability of engineered modular and package systems from various vendors.

Atmospheric Dispersion

Covering and ventilating process equipment will generate foul air bearing reduced sulfur compounds (RSCs) and other odorous compounds. Discharge of these compounds to the atmosphere may be regulated by the local air pollution control agency. However, in the absence of regulatory requirements, when impact to critical receptors such as local residents is the only concern, atmospheric dispersion of foul air may be sufficient. Dispersion is achieved by discharging the foul air through a stack. As the discharged exhaust air travels from the stack to receptors, it mixes with ambient air and is thus diluted. The stack is designed to maximize mixing of exhaust air with the ambient air by selecting the appropriate stack location, height and exit gas velocity. Atmospheric or odor dispersion modeling can be performed for predicting the concentration of odorous compounds at downwind locations and for proving that sufficient dilution will occur.

Emerging Technologies

A new and emerging technology that shows promise is a foul air treatment that produces hydroxyl (OH) radicals to react with H₂S and other malodorous compounds. Vapex Inc. manufactures these units. The treatment principle relies on quick acting OH radicals to neutralize H₂S molecules. The OH radicals are generated by mixing water and air with ozone, which is produced onsite by the Vapex unit. The water is atomized into a fine mist and introduced into the headspace that requires treatment. The air and ozone are introduced just upstream of the atomizer nozzle, and OH radicals are produced before the mist enters the headspace.

Since both ozone and OH radicals have very short half lives, they are quickly consumed. The treated air may contain small quantities of ozone and OH radicals. The treated air is

passed through chlorine tablets prior to discharge to react with the excess ozone. The Vapex unit is especially advantageous for pump stations since it provides local odor control, utilizes a minimal amount of floor space and provides economical service. Data from certain installations have indicated good removal of H₂S at concentrations of 10 ppmv or less, but were inconclusive in proving removal effectiveness at higher H₂S concentrations.