AECOM
500 West Jefferson Street
Louisville, KY 40202
aecom.com

Project name:
MSD Odor Control Master Plan

Project ref:
60644274

To:
Robin Burch
MSD Project Manager
4522 Algonquin Parkway
Louisville, KY 40211

From:
Amanda Foote

Reviewed By:
Alex Carciumaru
Janet Strickland

Date:
December 14, 2022

Final

Final Memo

Subject: Technical Memorandum #8B – Morris Forman Collection System New Odor Control Technologies Recommendation

1. Introduction

1.1 Odor Control Master Plan Background

In response to receiving a Notice of Violation (NOV) in November 2019 for failure to control odors from the Morris Forman Water Quality Center (WQTC, Plant) and its collection system, MSD entered into an agreed order with the Louisville Metro Air Pollution Control District (APCD) to develop and implement a phased District-wide Odor Control Master Plan. MSD has contracted AECOM to provide MSD with professional engineering services for the development of Phase I of the Odor Control Master Plan (Odor Control Master Plan), which is focused on the Morris Forman Service Area. MSD also contracted with a public relations firm to increase public engagement and communications during development and implementation of the phased Odor Control Master Plan.

The Morris Forman combined sewer collection system (Morris Forman Collection System) serves approximately 134 square miles across Jefferson County, Kentucky. Wastewater from the Morris Forman Service Area is collected and conveyed through numerous gravity trunk sewers, force mains, and pump stations. Several communities in the Morris Forman Service Area have experienced odors leading to a significant amount of complaints, specifically during the summer of 2019. Primary affected residents were in the Chickasaw, California, and Park DuValle neighborhoods. These complaints led to the development of a dedicated Odor Control Master Plan for the Morris Forman Service Area.

1.2 Purpose

This technical memorandum is intended to identify new odor technologies that may be potential options to implement into the Morris Forman Collection System.

1.3 Previous Documentation and Implementation Schedule

In accordance with the agreed order, MSD has submitted several documents to APCD to demonstrate ongoing odor control efforts. Table 1 shows MSD's completed and ongoing efforts towards the APCD agreed order.

Table 1 – Phase I Master Plan Implementation Schedule

Title		Due Date	Status
TM#1	Morris Forman WQTC Background Document Review	Q1 2021	Completed
TM#2	Collection System Background Document Review	Q2 2021	Completed
TM#3	Pump Stations Background Document Review	Q2 2021	Completed
TM#4	WQTC, Pump Stations and Combined Sewer System Planned Process Modifications	Q1 2021	Completed
TM#5	Current WQTC, Pumping Stations and Combined Sewer System Odor Impact Evaluation	Q2 2021	Completed
TM#6A, TM#6B, TM#6C	Morris Forman WQTC (TM#6A), Collection System (TM #6B), and Pump Stations (TM #6C) Sampling Phase Results Analysis	Q4 2022	Completed
TM#7A, TM#7B, TM#7C	Morris Forman WQTC Current Odor Technologies Performance Evaluation Collection System Current Odor Technologies Performance Evaluation Pump Stations Current Odor Technologies Performance Evaluation	Q4 2022	Completed
TM#8	**New Odor Control Technologies Recommendation**	**Q4 2022**	**Ongoing**
TM#9	**Odor Control Conceptual Design**	**Q4 2022**	**Ongoing**
Odor Control Master Plan Phase I Final Report		**Q4 2022**	**Ongoing***

**- The Final Odor Control Master Plan Phase I Final Report will be a comprehensive document which includes information about the Morris Forman Collection System, WQTC, and selected pump stations.*

2. Summary of Sampling Results

Liquid and Vapor sampling was performed in 2021 and 2022 at multiple locations within the Morris Forman collection system area. The sampling program and full summary of results can be found in

TM #6B under separate cover. The results were analyzed, and locations were assigned an odor control priority based on vapor sampling results and liquid sampling results, as shown in Table 2 and Table 3, respectively.

Table 2 – Collection System Vapor Sampling Results Summary

Sampling Location	Location Description	Potential Odor Receptors	Target Limit Exceedance(s)	Odor Control Priority
6	Ohio River Interceptor	Chickasaw residents, Adjacent properties near Plant	Odor, Pressure	High
4	Western Outfall	Chickasaw residents	Odor, Pressure	High
12	Western Outfall	Chickasaw residents	Odor	Moderate
5	Western Outfall	Chickasaw residents	Odor, Pressure	Moderate
11	Western Outfall	California residents	Odor, Butyraldehyde	Moderate
7	Southern Outfall	Park DuValle residents	Odor	Moderate
1	Northwestern Interceptor	Shawnee residents	Odor, Pressure	Low
3	Northwestern Interceptor	Shawnee residents	Odor, Butyraldehyde, Pressure	Low
8	Southern Outfall	Park DuValle residents	Odor	N/A
14	Southern Outfall	Park DuValle residents	Odor	N/A
2	Northwestern Interceptor	Shawnee residents	Odor	N/A
13	Western Outfall	California residents	Odor	N/A

Table 3 – Collection System Liquid Sampling Results Summary

Sampling Location	Location Description	Potential Odor Receptors	Target Limit Exceedance(s)	Odor Control Priority
4	Western Outfall	Chickasaw residents	BOD, TSS, and Ammonia	High
11	Western Outfall	California residents	BOD	Moderate
1	Northwestern Interceptor	Shawnee residents	BOD	Low
5	Western Outfall	Chickasaw residents	Ammonia	Low
6	Ohio River Interceptor	Chickasaw residents, Adjacent properties near Plant	BOD	Low

Sampling Location	Location Description	Potential Odor Receptors	Target Limit Exceedance(s)	Odor Control Priority
2	Northwestern Interceptor	Shawnee residents	-	N/A
3	Northwestern Interceptor	Shawnee residents	-	N/A
7	Southern Outfall	Park DuValle residents	-	N/A
8	Southern Outfall	Park DuValle residents	-	N/A
12	Western Outfall	Chickasaw residents	-	N/A
13	Western Outfall	California residents	-	N/A
14	Southern Outfall	Park DuValle residents	-	N/A

MSD is currently using Bioxide and oxygen injections on the Ohio River Force Main and other sewers within the service area, and they are regularly obtaining sampling results to determine their odor removal effectiveness. As discussed in TM #7B, the oxygen injection treatment has been successful in reducing the H_2S levels within the ORFM. However, there is a lack of odor control systems in the central downtown areas, towards the northwest and southwest portions of the MFWQTC collection system. As a result, and based on the results from the recent sampling program, the Western Outfall, and Grand Avenue Force Main are included in the consideration list for this memorandum and the Odor Control Master Plan.

3. Odor Control Technology Review

Feasible odor control technologies were identified and evaluated for odor removal efficiency, applicability, advantages, and disadvantages. Table 4 identifies the various odor control measures which will be considered for inclusion into the Collection System Odor Control Master Plan.

Table 4 - Odor Treatment Technology Summary

	Odor Control Technology	Description	Configuration(s)
Liquid Treatment Technologies			
1	Chemical Addition	Addition of odor control chemicals directly into wastewater stream	Bioxide (calcium nitrate), hydrogen peroxide, potassium permanganate, sodium hypochlorite, ferrous chloride, magnesium hydroxide
2	Oxygen Injection	Addition of oxygen into wastewater stream	Aeration systems or liquid oxygen injection
Vapor Treatment Technologies			
1	Adsorption	Attachment of odorous vapor compounds to surfaces	Dry media scrubbers, fixed bed reactors, or adsorber wheel; Can be combined with thermal gas treatment or biofiltration
2	Biological	Degradation of odorous vapor compounds via microorganisms	Biofilters, Bioscrubbers, and biotrickling filters
3	Ozonation	Generation of ozone (O3) for oxidation of odorous compounds and added to conveyance system headspace	Single source or multiple source ozone generators
4	Portable Odor Control System	Maintain negative differential pressure in the trunk headspace compared to the ambient environment	Trailer mounted pilot unit including an activated carbon unit and a fan.

3.1 Liquid Treatment Technologies

3.1.1 Liquid Chemical Addition Technology Summary

Chemical addition can be utilized to minimize the concentration of dissolved sulfides in influent wastewater streams. By minimizing the concentration of hydrogen sulfide in the wastewater process/sewer headspace, the structural integrity of the concrete is extended, and the odor concentration is considerably lowered.

Potential odor-reducing chemical agents include hydrogen peroxide, potassium permanganate, sodium hypochlorite, ferrous chloride, and magnesium hydroxide. Each of these technologies provide odor control and corrosion protection by removing dissolved H_2S and sulfide from wastewater through oxidation reactions with the exception of magnesium hydroxide. Magnesium hydroxide acts as a pH buffer which raises and maintains the pH in sewer systems at a level which inhibits the formation of H_2S. Chlorine gas has been excluded from further evaluation due to its toxicity.

3.1.1.1 Calcium Nitrate (Bioxide)

Nitrates are commonly used for H_2S and corrosion control in wastewater applications. Bioxide is the product name for Evoqua's calcium nitrate solution which inhibits the formation of H_2S and prevents corrosion of concrete and metals in conveyance systems. Bioxide is the product currently being injected at various locations within MSD's collection system.

3.1.1.2 Hydrogen Peroxide

Hydrogen peroxide may be used to chemically oxidize H_2S to elemental sulfur or sulfate, depending on the wastewater pH. For collection system applications, peroxide has been successfully applied in both force mains and gravity mains. The decomposition of excess peroxide in water and oxygen increases the dissolved oxygen concentrations of wastewater and produces no chemical residue. Peroxide can also reduce sulfide concentrations to near zero, depending on the dosage. Depending on the concentration of peroxide, the storage tank material varies from stainless steel and high-purity aluminum at high concentrations to polyethylene at lower concentrations.

3.1.1.3 Potassium Permanganate

Potassium permanganate is a strong chemical oxidizing agent that reacts with H_2S. Potassium permanganate is available in dry crystal, granule, or pellet form and must be mixed with water to approximately a 3 to 4% solution before use. When kept dry and cool, potassium permanganate is relatively stable. However, when contaminated with organics or acids, it can become unstable and decompose, causing potentially hazardous conditions. Potassium permanganate reactions in the wastewater produce manganese dioxide as a by-product. Manganese dioxide is a fluffy, brown flock that is practically nonreactive and settles as chemical solids in the treatment plant and will slightly increase solids products.

3.1.1.4 Sodium Hypochlorite

Sodium hypochlorite, commonly known as household bleach can be used to treat odorous compounds in wastewater when delivered at high concentrations. Industrial sodium hypochlorite is generally sold in aqueous solutions containing 5 to 15% sodium hypochlorite, with 0.25 to 0.35% free alkali (usually NaOH) and 0.5 to 1.5% NaCl.

3.1.1.5 Ferrous Chloride

Iron based products are widely used in the water and wastewater industry for the removal of suspended solids during the purification processes. Iron and other metals can chemically combine with dissolved sulfide to form relatively insoluble precipitates. Both ferrous and ferric metal salts can react with dissolved sulfide. The following four types of iron salt solutions are commercially available: ferrous sulfate, ferrous chloride, ferric sulfate, and ferric chloride.

3.1.1.6 Magnesium Hydroxide

Magnesium Hydroxide (Mg(OH)2), also known as Milk of Magnesia, is a viscous, mildly alkaline mixture widely known for its medicinal use. Industrial grade magnesium hydroxide is developed and adapted for use in municipal wastewater collection and treatment. Magnesium hydroxide (Mg(OH)2) provides a freely moving slow release source of non-carbonate alkalinity. It is easy to handle and adds no sodium or TDS. Alkalinity contributes to the properties of wastewater, many of which positively affect the physical, biological and chemical processes required for better wastewater transport and treatment. Raising the pH of the wastewater will shift the sulfide species from H_2S to HS-, thereby decreasing the concentration of aqueous phase H_2S.These solutions also provide Mg2+, an important micronutrient necessary for improved flocculation, clarification and biologic treatment.

3.1.2 Liquid Chemical Addition Technology Evaluation

Potential odor control chemicals were evaluated in terms of efficiency, reaction time, dosage and storage, potential byproducts, handling and delivery, and H_2S control in the subsequent sections.

3.1.2.1 Efficiency

All of the selected chemicals, except hydrogen peroxide and magnesium hydroxide, reach 100% efficiency within 5 to 10 minutes. Hydrogen peroxide is slightly slower – requiring 15 minutes to reach 90% effectiveness and 40 minutes to reach 100% effectiveness. Magnesium hydroxide would require approximately 20-40 minutes to adjust the pH to a level capable of inhibiting H_2S generation.

Bioxide reacts immediately with dissolved sulfides and prevents downstream formation of new sulfide.

Hydrogen peroxide and ferrous chloride have a catalytic relationship that causes a faster and more complete reaction with H_2S (<5 min) than either technology as a standalone. Generally, it is preferred to add these chemicals at two independent addition sites; with ferrous chloride injected first and then hydrogen peroxide injected downstream, but it is not required.

3.1.2.2 Reaction Time Duration

The reaction time duration for hydrogen peroxide, calcium nitrate, and sodium hypochlorite ranges from 1 to 2 hours, but 3 hours can be achieved by increasing the dosage rate. The reaction time duration for magnesium hydroxide has a wide range and is dependent on the initial pH. With proper dosing, it can last several hours to days in the sewer. Ferrous chloride has a long control duration at approximately 20 hours, while the control duration of potassium permanganate is only 1 hour.

3.1.2.3 Dosage, Storage Volume, and Footprint

Typically, a 30-day supply of liquid chemical is recommended to be stored at an injection site. Due to their densities and lower dosage rates, hydrogen peroxide and potassium permanganate have the smallest storage volumes and footprint requirements. Dosage and storage of ferrous chloride and calcium nitrate usually requires a slightly larger storage volume. Sodium hypochlorite and magnesium hydroxide generally have the largest footprints.

3.1.2.4 By-products

Hydrogen peroxide and calcium nitrate do not produce unwanted by-products and hydrogen peroxide can increase the dissolved oxygen in the wastewater if the initial dosage is set higher than the stoichiometric requirement. Potassium permanganate and ferrous chloride will produce high biosolids and heavy metal loadings downstream. Additionally, ferrous chloride consumes dissolved oxygen. Addition of sodium hypochlorite can produce chlorinated VOCs, air, and odor emissions. Magnesium hydroxide produces free Mg ions that bind with sulfides and assist with other wastewater treatment processes.

3.1.2.5 Chemical Handling Requirements

The least restrictive chemical in terms of handling requirements is magnesium hydroxide. The solution is a slurry that is not a fire or spill hazard. The slurry may pose a health hazard, so personal protection such as glasses and gloves are required for its handling. Tanks for magnesium oxide must not be constructed of aluminum. Tanks must be equipped with agitation devices because pipes and equipment may become plugged if the slurry is inadequately mixed. Tank must also be heated to ensure the slurry does not freeze. Dried slurry may release nuisance particulate matter, and the storage area must be properly ventilated to reduce the buildup of air contaminants.

Bioxide solution contains no substances that are listed on the EPA Extremely Hazardous Substances List. The active ingredient is nitrate oxygen which is a stable compound and can be stored outdoors.

All of the other chemical addition technologies require health and safety precautions due to their inherent hazardous properties. Potassium permanganate must be handled and stored as a dry powder and mixed into solution prior to injection as a liquid. This may require an equalization tank and/or mixer. Sodium hypochlorite has a short shelf life in storage tanks. Ferrous chloride tanks must be installed indoors with temperature control, or the solution will freeze. Storage tanks for potassium permanganate, sodium hypochlorite, and ferrous chloride can be made of FRP, PVC, polyethylene, or polypropylene. Double wall tanks are not typically required. All chemical systems must be closed-looped and be built with containment or dykes. Secondary containment from vehicular traffic, fire, and spills is also required. Tanks should have a bottom drainpipe with an emergency relief valve on the end. Leaks or spills must be dealt with using proper personal protection equipment, including safety goggles, chemical resistant gloves, neoprene boots, lab coat, and SCBA respirator. The storage area must be properly ventilated to reduce the buildup of air contaminants.

Hydrogen peroxide has more stringent handling requirements, and all skin/eye contact, absorption, inhalation, and ingestion should be entirely avoided. The product is not flammable; however, it is not stable and readily decomposes to oxygen. Therefore, it must be maintained at a specific temperature based on the concentration. It has a long shelf life in storage tanks, and the preferred material of the tanks and piping is stainless steel. The tanks must be installed with emergency dilution capabilities, heat sensors, and leak detection. Leaks or spills must be dealt with using proper personal protection equipment including safety goggles, chemical resistant gloves, neoprene boots, impermeable apron, and SCBA respirator. The storage area must be properly ventilated to reduce the buildup of air contaminants.

3.1.2.6 Chemical Delivery Requirement

Since magnesium hydroxide is not considered a hazardous substance, delivery requirements are not restrictive. Delivery of the other chemicals must adhere to strict and specific requirements. Populated areas should be avoided for public safety reasons, but these chemicals may be transported through a residential development. Vendors must comply with any local by-laws concerning the transportation of dangerous goods and associated truck routes.

Similar to the handling requirements, hydrogen peroxide also has more stringent delivery restrictions than the other chemicals. Delivery of hydrogen peroxide must follow a direct route, avoid populated areas, and travel on commercial truck routes only. Drivers must also be provided with specific training on the handling and off-loading of hydrogen peroxide.

3.1.2.7 Preferential Control of H_2S

Hydrogen peroxide, ferrous chloride, and calcium nitrate have preferential control of H_2S, and their effectiveness is not reduced by other compounds that may be in the wastewater. In addition, hydrogen peroxide may also react with other corrosive/odorous compounds after neutralizing H_2S. Potassium permanganate and sodium hypochlorite will react with many chemicals simultaneously and do not show preference for H_2S, thereby requiring a higher initial dose to ensure that H_2S is eliminated. Their ability to oxidize other odors (caused by organics and reduced compounds), in addition to H_2S, provides more significant vapor phase odor control than chemicals that remove only H_2S. Sodium hypochlorite reacts with ammonia to provide residual odor control.

All the oxidizing chemicals will have a minor effect on controlling the odor, mercaptans, amines, or VOCs before entering the vapor phase. The main mechanism of magnesium hydroxide does not specifically target H_2S. Instead, it alters the pH to a level which does not promote the formation of H_2S. Raising the pH in the wastewater will depend on other acidic compounds and sources.

3.1.3 Oxygen Injection

Oxygen can be introduced directly into wastewater streams to inhibit the generation of sulfides and sulfate-reducing bacteria. Oxygen can be administered to wastewater systems through various methods including addition of pure oxygen or on-site oxygen generation systems such as fine bubble diffusers.

3.2 Vapor Treatment Technologies

3.2.1 Adsorption

Adsorption involves the attachment of odorous compounds to a solid surface and is typically performed in conjunction with biological treatment. Common adsorbents include activated carbon, activated alumina, and silica gels. Carbon has a high surface-to-volume ratio which provides a large amount of surface area for odors to be adsorbed. The media adsorbs a wide variety of odorous compounds including H_2S and odor causing organic compounds. In an activated carbon odor treatment system, pollutants are removed from the air by physical adsorption onto the surface of the activated carbon particles. Media specific to odor control applications can be modified with alumina, or other chemical binders, which also absorb and oxidize adsorbed odor contaminants. The odorous gases are collected and held within the media pores where the contaminants are converted to a harmless solid substance which remains in the media. Other dry media types can be combined with activated carbon media within an odor control system to enhance the odor removal performance of the unit. Media impregnated with potassium or sodium permanganate increase the range of odor causing compounds which can be removed from an odorous inlet airflow. Organic compounds, along with reduced sulfur compounds, aldehydes, and H_2S, can be removed by these types of dry media. An example photo of a carbon adsorption system is shown in Figure 1.

Operation of dry media odor control units is straightforward. The media bed can be arranged for either vertical or horizontal airflow through the treatment vessel. Vertical airflow systems are usually contained within cylindrical vessels where odorous air enters the bottom of the unit and flows upwards through the media to be discharged from the top of the unit. Horizontal airflow units arrange the media in a “V” shape from the bottom to top of the unit vessel. Air passes through the “V” media beds from the open end of the “V” to the point at the exhaust side. Horizontal airflow vessels are not as tall as cylindrical units and are supplied with access hatches on the top of the unit for easy media replacement. Due to the short retention time required in a dry media system, the footprint of an adsorption vessel is less than that of a biofilter while being able to control the same wide range of odor causing compounds.

Figure 1 – Example Carbon Adsorption System (Amer Air Intl)

Dry media selected for odor control applications must be capable of performing within an airstream that has a high relative humidity when removing odors from a wastewater source. Humidity in wastewater applications can reach over 98%. Condensation can wet the dry media and fill void spaces that are the sites of odor removal. Media with hydrophobic properties can resist high humidity environments but further protection from condensation and water droplets may be required. A mist eliminator should be installed on the inlet side of the vessel to trap any fines, greases, or water droplets entrained within the airstream. Inlet dehumidification may be required in very wet inlet airflows where ambient and process temperature differences will lead to significant condensation formation. Dehumidifiers warm the air to reduce the relative humidity of the air and help to warm the media and process vessel. While effective, dehumidification is an energy intensive process that is high in operating and maintenance costs. Keeping the inlet odorous air, dry media, and vessel close in temperature range minimizes condensation formation without the need for dehumidification. This can be achieved by insulating the dry media unit to minimize the temperature difference between the media, vessel walls, and process air. AECOM has successfully used insulation wrapping around dry media vessels without employing dehumidification to minimize condensation formation on previous installations. This is a cost-effective solution which maintains system performance.

Dry media units are sized based on the mass inlet loading of odorous compounds and the inlet air velocity. To ensure a reasonable media life, the volume of dry media within a vessel can be sized to hold a specific mass of odor compounds. Dry media removes 99.5% of all inlet odor compounds until the media capacity to do so has been reached. The media in a unit is spent when all the void space within the media is full with adsorbed and oxidized odor contaminants. When this occurs any additional odor compounds will pass through the vessel until the existing media is replaced with a new batch. The life of the media will be longer with lower inlet odor concentrations. When odor loading is high, the void space in the media is more rapidly filled which reduces the system life and increases the frequency of media replacement.

3.2.2 Biological Treatment

Biological systems rely on the activity of microorganisms to degrade organic contaminants from the vapor stream. The microorganisms feed on odorous substances and oxidize them. The oxidation is a conversion from the odorous compounds to CO_2, H_2O, or another other odorless compound(s). Therefore, biological systems sustainably reduce odorous emissions and do not leave residues (such as scrubbing liquids or adsorbents). In addition, biological treatments inherently do not require the addition of chemical agents and do not have large associated energy costs as they are operated at atmospheric pressure and ambient temperatures. The materials, installation, and operational costs for biological systems are often the lowest among odor control technologies.

3.2.2.1 Biofilters

Biofiltration is an odor control technology involving physical adsorption, aqueous absorption, and bacterial oxidation of odorous compounds. Fundamentally, a biofilter is a box filled with a media such as soil, compost, or an engineered inorganic substrate, to support the growth of bacteria which metabolize odorous compounds present in a foul air stream. Biofilters have been used to treat odors in several different applications ranging from various wastewater treatment plant processes, pumping stations, collection systems, and food waste recycling plants among others.

Biofilters are versatile in their design and can be constructed as in-ground basins, stand-alone containers, or above-ground units. Units can be provided as packaged systems with their own Stainless Steel or Fiber Reinforced Plastic vessels (see Figure 2 and Figure 3 for example), or they can be constructed on-site with the pouring of a concrete vessel. Modular units include a fan and exhaust stack and can treat flow rates up to 10,000 cfm. Biofilters can be either covered by a roof or removable panels or left uncovered for air to disperse directly out from the media. Covered designs allow treated air to be routed to an external stack for discharge and produce an elevated dispersion profile of exhausted air. The design of large units is more expensive in capital cost, but it provides better performance in terms of off-site odor impingement to the sensitive receptors.

A disadvantage of biofilters is that sulfurous and nitrogenous organic or inorganic compounds that transit through the filter bed media can cause acidification due to their oxidization products (e.g., sulfuric, and nitric acid). In these situations, a combination with other treatment processes should be considered.

Due to the relatively long retention time through the media bed, the technology is best suited for moderate airflow volumes. Large airflow rates will require a larger footprint and may only be practical if the space for a unit is available.

Figure 2 – Example Biofilter Configuration

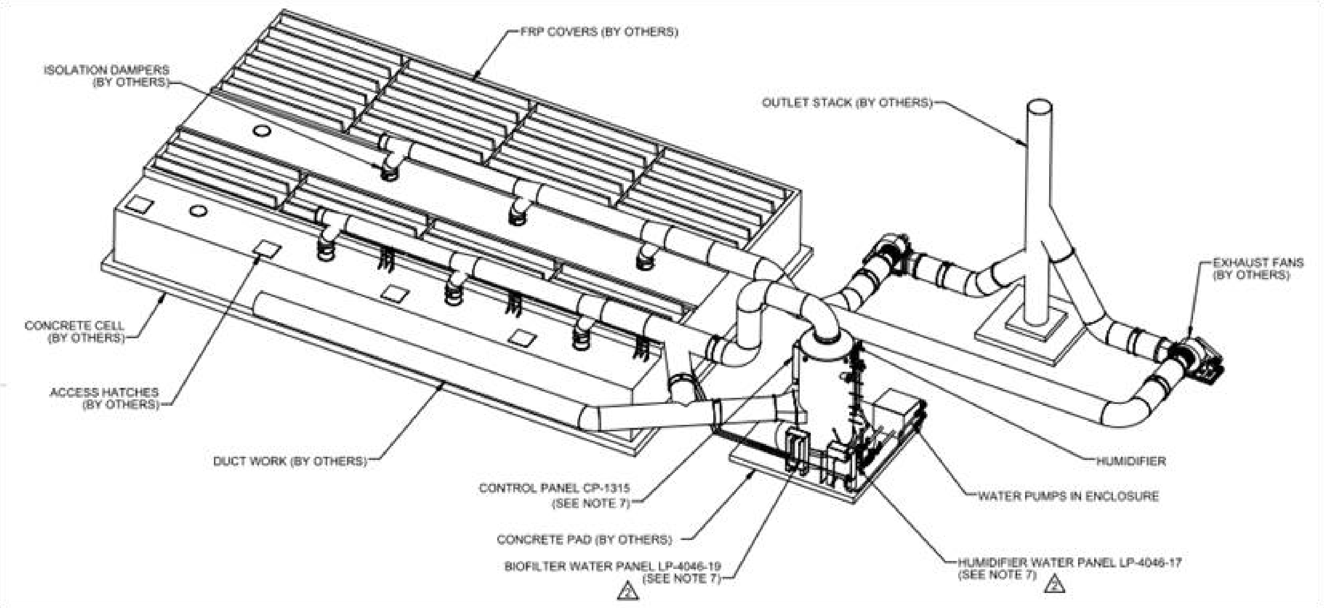

Figure 3 – Example Biofilter Schematic

Different types of media can be utilized in a biofilter system. Practical experience has shown that yard compost, sludge compost, and wood and bark chips are used in removing H_2S and other odor causing contaminants. Engineered inorganic media has been developed using inert substrates on which various buffers and nutrients have been impregnated to support an optimal environment for microbial oxidation of odorous compounds. The engineered media is resilient to compaction and settling which lead to an increased pressure drop across the media and reduced removal efficiencies. Compared to organic media, engineered inorganic media generally has higher and more consistent removal efficiency along with a longer media life. Media replacement is between 2 to 4 years for organic media and 10+ years for engineered inorganic media. Many inorganic media suppliers provide a 10-year media life guarantee.

Biofilters are very effective at treating a wide range of odor causing compounds including H_2S, organic reduced sulfur compounds (such as methyl mercaptan (MM), dimethyl sulfide (DMS), and ethyl mercaptan (EtSH)), and selected volatile organic compounds (VOCs) when the contaminants loadings are within the limits of the biofilter media performance removal. When the average H_2S inlet loading is above 30 ppm, the pH of the bed is prone to be lowered due to the higher incidence of sulfuric acid as a by-product of microbial H_2S metabolization. This can reduce the removal of organic reduced sulfur compounds and VOCs, as these compounds are more readily oxidized at a neutral bed pH. At high H_2S inlet concentrations (>30 ppm), the biofilter also starts to oxidize H_2S to elemental sulfur which deposits inside the media and can result in a higher pressure drop across the media. Greater pressure drop requires more power to be consumed by the biofilter process fan to move the odorous air through the media bed for treatment. If H_2S inlet concentrations are lower, i.e. average of nearly 0 ppm for an extended period (3 to 4 months), there will be a drop in microbe population as the H_2S “food” is in lower supply. The system will continue to remove H_2S, but if the biofilter is turned off for an extended period, the population of microbes metabolizing the odor contaminants will die off. This does not impact the life expectancy of the media, and the system can be returned to operation. Over a few weeks of operation, the microbe population will grow back to consume and treat the inlet H_2S. Removal efficiency will increase as the microbe population is reinstated during the acclimation period. This also occurs during system start-up and commissioning. Vendors recommend performance testing of a new system to be completed following a three (3) to four (4) week acclimation period.

Biofilters require less maintenance than other odor treatment technologies as there are limited moving parts aside from the process fan(s) and pump(s) for recycling pre-treatment humidification water. Inorganic media is designed to last 10 years or more and therefore will rarely require removal and replacement. Water is needed to humidify the inlet air to 99% relative humidity to aid in the biofiltration process or for irrigation of the media as specified by the vendor. The humidification chamber can be integrated into a packaged, or on-site constructed concrete biofilter vessel.

To operate a biofilter, inlet air travels through a packing material which is continuously sprayed with water. The packing and spraying create water droplets through turbulence which increases the water surface area and aids in humidifying the inlet air stream. The humidity in the air aids in the adsorption of odorous contaminants onto the moist biofilm which surrounds the media treatment particles and supports the odor metabolizing microbes. Water also needs to be applied to the media bed at vendor defined intervals to keep the biofilter media bed moist and to remove biomass or elemental sulfur buildup. This process is called irrigation and typically occurs for an hour or two every few days. The water used in the humidification chamber can be collected in a sump and recirculated back through the spray headers and packing, while the water for irrigation cannot be recycled since it contains the removed biomass and elemental sulfur. If a bioscrubber unit is paired upstream with a biofilter system, a humidification system is no longer required.

Typical removal efficiency of H_2S through a biofilter is 99%. This is accompanied with removal of other odor causing compounds such as those present in the STS air; MM, DMS, and EtSH.

3.2.2.2 Bioscrubbers

Bioscrubbers are similar to biofilters as they are both based on aqueous adsorption, absorption, and bacterial oxidation of the odorous contaminants. Similar to a biofilter, odorous air in a bioscrubber is moved through a bed of high surface area media in which microorganisms grow and biodegrade the odorous contaminants of the inlet air. The media used in bioscrubbers is inorganic and engineered by specialist vendors to withstand a low pH (1-3) environment which develops through oxidation of H_2S in the system. The media is designed to last for 10 years or more and is typically guaranteed for 10 years of service before requiring a media bed change out. In contrast to biofilters, where irrigation is periodic, water is continuously sprayed and distributed over the top of the media counter-currently to the flow of air. Airflow travels from underneath the media, up through the bed, and then out of the unit to further treatment stages or directly exhausted to the atmosphere. Horizontal airflow through a bioscrubber system is therefore not common. Due to the bottom-up airflow configuration bioscrubbers are commonly designed in a tower configuration. To lower the height of a bioscrubber treatment tower, some vendors offer units which come with several individual bioscrubber cells which each treat a fraction of the overall system airflow. However, this requires a larger quantity of process piping and media to maintain. Concrete vessels can be used to house bioscrubbers. However, due to the low pH of recycled process water in the system, vessels need to be lined for corrosion protection. The benefits of a concrete vessel include a reduced system height as the system footprint can be poured on-site and enlarged over a pre-constructed fiber-reinforced plastic tower unit.

The water spray headers are located at the top of the vessel and deliver water down onto the top of the media counter-current to the airflow direction. Water percolates through the media and is collected at the bottom of the vessel in a sump. Water is returned to the spray headers at the top of the unit through recirculation pumps located adjacent to the units. The microbes which oxidize H_2S prefer an acidic environment and create sulfuric acid as a by-product of H_2S treatment. The pH of the recirculated water in the system is at an optimal condition when ranging from 1 to 3. To maintain the quality of the recirculated water, a small percentage is drained and replaced with clean water in the bioscrubber sump. An example picture and schematic of a bioscrubber is shown in Figure 4.

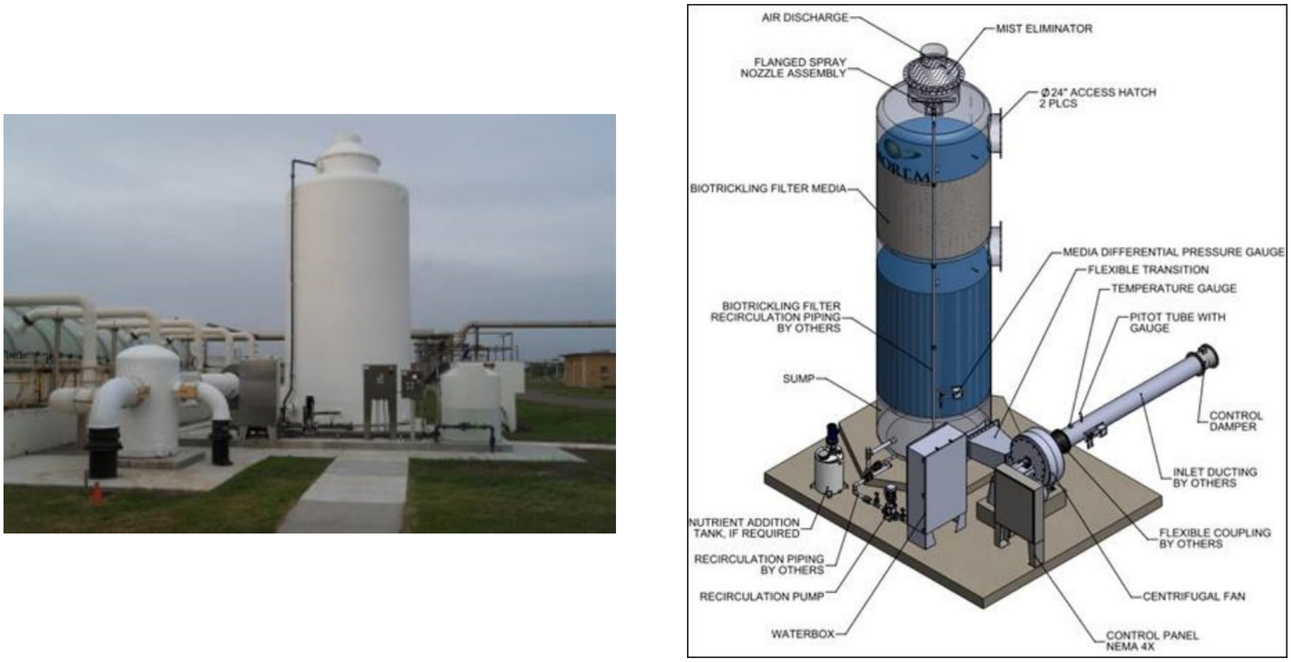

Figure 4 – Example Bioscrubber Filter System

Since the pH of the recirculated water is low (1-3), the water that is drained to maintain water quality in the scrubber unit may need to have its pH neutralized. Most clients dictate the minimum or maximum pH of a solution that can be drained into sewer systems. A caustic addition system can be used to dose the drained water with a basic solution to neutralize the pH to meet these requirements. However, the use of caustic can create handling and safety issues for maintenance. Therefore, the addition of a caustic system should be avoided, if possible, to minimize maintenance and chemical handling by operations staff.

Bioscrubbers have a lower media bed retention time than biofilters. The reduced retention time results in a lower volume of media required to treat the inlet odorous air. The footprint of bioscrubbers is therefore smaller than that of biofilter systems. Bioscrubbers are excellent at removing high levels of H_2S, over a range of 50 to 400 ppm, but they have limited capacity in removing other compounds such as MM, DMS, EtSH and VOCs. For this reason, bioscrubbers are most effective for applications where inlet H_2S levels are high. However, they do still remove low level H_2S concentrations effectively. For example, AECOM has installed bioscrubber systems in applications where the average H_2S concentration is 2 ppm. The systems run effectively at the low H_2S level, while providing capacity for higher levels of H_2S is present in the future. Like biofilters, the microbe population which metabolizes the odor compounds grows to equilibrium with the available “food” (H_2S). Odor removal for a bioscrubber only system is low at a minimum of 75%. This is due to the low removal rates of the reduced sulfur compounds aside from H_2S.

The presence of other odor causing compounds requires a second stage treatment technology to maximize removal efficiencies. When paired with a second stage such as dry media or photoionization technology, the system can be highly effective at cleaning air with multiple odor compounds and a high H_2S loading. The upstream bioscrubber would act as pre-treatment stage to remove inlet H_2S, and the dry media unit would capture the remaining low concentration odor contaminants and any remaining H_2S. Because the media bed life of a dry media system is determined by the concentration of inlet odor contaminants, removing H_2S with a bioscrubber upstream of a dry media unit extends the life expectancy of the dry media.

Bioscrubber maintenance is similar to that of an inorganic media based biofilter, aside from requiring a nutrient solution to be added to the recirculated water in the system to support the health of the microbes. Water is continuously sprayed over the media bed to assist in phase transfer of the contaminants to the microbes, to supply nutrients, and to promote favorable microbial environmental conditions. The nutrient solution can be continually added to the recirculated water using small metering pumps. The nutrient solution can be pumped out of a dedicated storage tank, but the solution will need to be mixed and prepared by maintenance staff at least once a month. If exposed to the elements the water in the bioscrubber sump can freeze during winter months. Consequently, the water will need to be to maintain the temperature of the inlet air at, or above, 50°F. Below 50°F the microbes begin to slow the rate at which they oxidize H_2S. This will reduce the removal efficiency performance of the system. To warm the water and air, an immersion heater can be installed within the sump and programmed to turn on below a certain water temperature. To ensure the heater element is not exposed to the inlet air, the level of the sump water must be monitored by an ultrasonic device, or float switch. If the water level drops too low, the heater will be shut-off and will not turn-on until the water level is restored. By enclosing the bioscrubber system and sump within a dedicated heated building heating requirements for the sump water will be reduced, as the unit would be better protected from the elements and ambient temperature.

3.2.2.3 Biotrickling Filters

These systems work similarly in that they use microorganisms, media and water. Odorous or polluted air is collected and forced up through the structured media within the vessel. But in biotrickling filters, the microorganisms grow within the media.

The key differentiator of biotrickling filters is that they do not recirculate water. The water used in these systems passes through only once to rinse the metabolized compounds away and to provide nutrients for the optimal growth of microbes. And while at first glance this might seem inefficient, biotrickling filters and bioscrubbers actually use identical amounts of water to treat identical airflows. An example schematic biotrickling filter is shown in Figure 5.

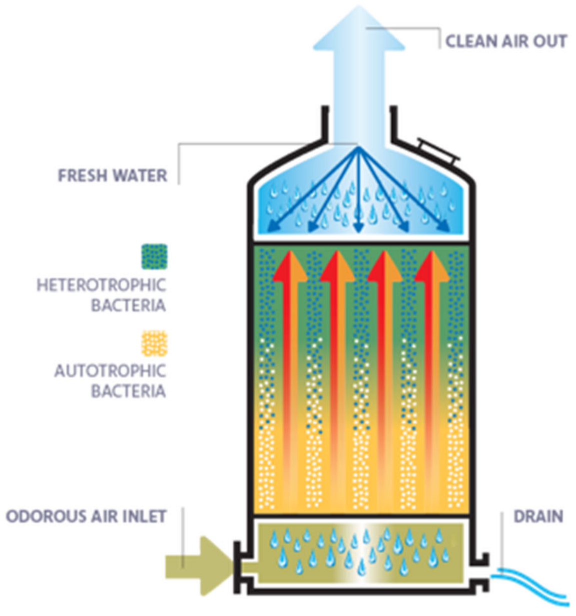

Figure 5 – Example Biotrickling Schematic

Research has shown that biotrickling filters support a greater diversity of bacteria. As impacted air is forced upward through the vessel, it encounters different types of microorganisms. That diversity has been shown to eliminate a larger quantity and variety kinds, of the compounds produced in industrial processes. This is why biotrickling filters can remove a host of compounds —such as H2S, NH3, volatile fatty acids, organic odors and select VOCs— with great efficiency.

In addition to being more effective than bioscrubbers, biotrickling filters also are less expensive, have lower operating costs, and are easier to maintain because they do not include the extra pumps and piping necessary for water recirculation.

3.2.2.4 Bioscrubber-Biofilter Combination

A bioscrubber-biofilter combination system involves adding moisture to reduce the odor load into the biofilter. A unique advantage of this system is that it inherently includes a buffering effect that prevents high concentrations of odors from entering the biofilter and stabilizes the biofilter media temperature. As previously noted, the biofilter moisture content is a key parameter that impacts the odor removal efficiency of the biofilter.

3.2.3 Ozonation

Ozone is a highly reactive form of oxygen, with three oxygen atoms (O3) instead of two (O2). The third oxygen atom is what makes ozone such a powerful oxidant, as it will react indiscriminately with other compounds to return to its more stable dioxygen form. Historically, this characteristic has resulted in the use of ozone technology as a powerful disinfectant and polishing tool for water treatment. More recently, ozone has also found applications in the wastewater industry for the treatment of odor and corrosion in wastewater collection systems, where it has been shown to be highly effective in oxidizing odorous compounds.

Ozone is generated by introducing sufficient electrical or optical energy to a flow of oxygen. This can be accomplished in several ways (e.g., as one of the by-products of photoionization systems), but the corona discharge method is most commonly used to generate large amounts of ozone. In this method, oxygen molecules are passed through an electrical “corona” discharge field that causes the oxygen atoms to split. Ambient air can be used as a feed source for the oxygen; however, it is more common to use oxygen concentrators, which supply oxygen to the ozone generators at much higher concentrations, to increase ozone production. Though some of the oxygen atoms revert back to their dioxygen forms, some of the individual atoms combine with other dioxygen compounds to form ozone. This method is preferable to UV ozone generators because UV generators tend to produce less ozone over time and generate more harmful by-products.

One advantage of ozone systems is that the system components are much simpler than other treatment technologies (consisting mainly of an ozone generator, oxygen concentrator, air compressor, tubing, and electrical equipment). As a result, ozone systems tend to be lower in cost. Although the actual size of the ozone generators are small, it is important to note that ozone systems also require the design of a ventilation contacting/retention system to allow the ozone and odorous air stream enough contact time to mix and oxidize the odorous compounds. This contact time can be achieved by injecting the ozone directly into an expanded section of ductwork or into a stand-alone contact chamber.

Safety is another important consideration for ozone systems. Even at low concentrations, the highly reactive and oxidizing nature of ozone makes it a primary irritant that especially affects the eyes and respiratory systems. People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors. Ozone can also be harmful to sensitive vegetation and ecosystems such as parks. Ozone itself also has an antiseptic odor, chlorine like smell that may be disagreeable. To safeguard against possible leaks, ozone monitors and alarms will have to be used. A safety interlock between the ozone generating equipment and ventilation system will also ensure that no ozone is generated unless the ventilation system is in operation. In addition to this, all materials that may come in contact with the ozone must also be chosen carefully, as ozone can cause some materials to deteriorate (e.g., tubing for conveying the ozone must be Teflon-lined).

Ozone systems can either be configured as a single-source system or as multiple smaller systems combined into a larger system for redundancy. Larger systems can be completely self-contained units with the corona chamber, electrical panel, and transformers fully enclosed in a metallic casing.

Maintenance requirements for ozone systems are relatively simple and can be completed by anyone with knowledge of basic plumbing skills. Basic maintenance activities include cleaning/flushing the corona cells, replacing compressor filters, checking safety components, and checking oxygen output. Note that in a rack-mounted system, the entire system does not need to be maintained at once and individual generators can be rotated for maintenance.

It should also be noted that though the use of ozone has proven successful in water treatment and wastewater applications, its application for large-scale gas-phase odor treatment is relatively new. One reason for this is that ozone is less reactive in the gas phase than in the liquid phase. Another limitation of ozone systems is that odorous compounds may not have the contact residence time with the ozone to completely react if there is moisture or particulate matter in the inlet air flow. Considering the high humidity characteristics of the sewer air to be treated, this limitation may hinder the system’s ability to obtain consistent contaminant removal results. A mist eliminator may be required as a result.

3.3 Pilot Odor Control Alternatives

3.3.1 Portable Odor Control System

Portable odor control systems are available for pilot tests to evaluate for a defined duration the efficiency of several technologies such as: carbon adsorption, biofilter, photoionization, biotrickling filter, and negative headspace pressure units. These types of units are connected to a collection service/access manhole and extract the air from the collection system. Pressure sensors installed upstream and downstream of the extraction location will define the unit's influence area. During the pilot test, the air quality at the unit discharge will be evaluated for the treatment technology evaluation. Figure 6 and Figure 7 show a unit used on the pilot test.

Figure 6 – Example Pictures 1 of Negative Pressure Pilot Unit

Figure 7 – Example Picture 2 of Negative Pressure Pilot Unit

This pilot test was successfully implemented for a project with the City of Toronto.

3.3.2 Temporary Chemical Injection

Several chemical vendors offer pilot tests to evaluate several types of chemicals for H_2S, odor, and other odor compound reduction. These temporary injection units use different chemical combinations to remove H2S and other odor compounds. Different chemicals can be injected into the force main and gravity section of a sewer system to obtain a prolonged chemical reaction that would not be achievable using only one type of chemical injection. H2S monitoring sensors and air grab samples are used to evaluate the system combination and efficiency.

3.4 Technologies Comparison Summary

Table 5 outlines the advantages and disadvantages of each potential odor control technology considered as part of this memorandum.

Table 5 – Odor Control Technologies Evaluation

Technology	Advantages	Disadvantages
Liquid Phase Technologies		
Chemical Injection	• Moderate capital costs • High removal of H_2S and dissolved sulfides • Minimal space required	• Chemical handling safety and environmental concerns • Reduced efficiency during peak loading • High long-term operation costs • Focuses on H_2S reduction and ignores contributions of other contaminants
Oxygen Injection	• High removal efficiency for odor, H_2S and RSC • No hazardous chemicals required • Smaller footprint	• May require high oxygen usage • Oxygen dosage requirements may be difficult to determine • Delivery and storage requirements
Vapor Phase Technologies		
Adsorption	• Excellent removal efficiency for odor, H_2S and RSC removal • Equipment is technologically simple and adaptable to many treatment formats • Wide range of commercial products available • Wide variety of target contaminants • Multiple levels treatment	• Activated carbon adsorption can be costly on the media replacement frequency • Non-selective method • May have additional requirements based on the type of adsorbent applied • Requires regeneration or replacement of adsorbent material • Often results in rapid saturation and clogging of reactors without a dehumidification system
Biofiltration	• Efficiently eliminates biodegradable organic matter • High removal of BOD and suspended solids • Up to 10,000 cfm are available as a modular unit	• Requires maintenance of optimal conditions for organisms • Slow process adaptation for intermittent operation • Potential sludge production and uncontrolled degradation products • High H_2S peak loadings may cause biofilter to acidify • High capital costs
Bioscrubber	• High reliability and efficiency for H_2S removal • Small footprint	• Performance is dependent on operation of recirculation system • Lower removal efficiencies for RSCs • Water demand requirements for recirculation system
Biotrickling	• High reliability and efficiency for H_2S removal • Tower arrangement, small footprint	• Performance is dependent on the inlet loading • Lower removal efficiencies for RSCs • Water demand requirements for recirculation system

Ozonation	• High efficiency for H2S and RSC removal and corrosion prevention • Simplicity of treatment design	• Relative new technology for odor control application • Safety and environmental concerns due to possibility of unreacted ozone remaining in air stream • Performance limited by inlet air humidity • Extensive space requirements for contact chamber
Pilot Odor Control Alternatives		
Portable Odor Control System	• Can be setup in a short amount of time • Simplicity of treatment design • Highly effective in mitigating odor issues for a defined area.	• Depending on where the access manhole is located, may cause temporary road closures to perform the pilot • Not a permanent solution
Temporary Chemical Injection	• Allows quick testing of alternative chemicals to determine effectiveness • High removal of H_2S and dissolved sulfides • Minimal space required	• Chemical handling safety and environmental concerns • High long-term operation costs • Focuses on H_2S reduction and ignores contributions of other contaminants

4. New Odor Technologies Recommendation

As described in Section 2, odor control is recommended on the Grand Avenue Force Main and the Western Outfall. After reviewing the sampling results, described in TM #6B, a preferred technology is recommended for odor control on these sewers.

4.1 Grand Avenue Force Main Pilot Study

Bioxide is currently injected at five (5) locations within the Morris Forman collection system; however, based on the sampling results, the Bioxide, which is intended to mitigate high H_2S within the force main, is not performing as intended (see TM #7B). The sampling results in TM #6B indicate that both H_2S and odor values were high within the Ohio River Force Main.

Since the Bioxide system is not performing well on the ORFM on its own, a pilot study for an alternate chemical is recommended to be performed on the Grand Avenue Force Main. The Pilot study would be initially deployed on the Grand Avenue Force Main, and if deemed successful, could be incorporated full scale on the ORFM. The chemical to be used for the pilot study will need to be determined after further evaluation of the force main layout/configuration, and characteristics of the flow within the force main. The selected chemical would be evaluated for effectiveness of reducing both odor and H_2S levels, as well as the length of pipe the benefits extend for.

4.2 Western Outfall Pilot Study

The Western Outfall is routed through two of the neighborhoods specifically named in the Notice of Violation; California and Chickasaw. Both of these neighborhoods frequently experience nuisance odors, and a large number of odor complaints are generated from these two neighborhoods. The sampling results, fully described in TM #6B, indicate that the manholes located on the Western Outfall contain high odor and H_2S levels. In addition, this sewer runs at positive pressure, which means that all of the nuisance air is expelled from the sewer headspace at the various manhole points along the pipe. This gravity sewer is a prime candidate for a negative pressure pilot unit installation. The negative pressure unit could be installed at one or more locations along the sewer to keep the pipe running at negative pressure, so that the nuisance air is carried downstream towards the Morris Forman WQTC. The number of units running concurrently would depend on unit availability from the vendor, as well as MSD's budget to perform the pilot testing. Once the pilot unit is installed, sampling can be repeated at the same locations sampled as part of this Master Plan effort, to see if impact the pilot unit has on the results. A conceptual layout will be provided in TM #9. If the pilot unit proves successful, a similar pilot or a full-scale unit could be installed on the Ohio River Interceptor and the Southern Outfall, both which also had high odor and H_2S levels and are routed through neighborhoods listed in the Notice of Violation.

5. Conclusions

As previously described, an odor control pilot systems are recommended to be installed on the Grand Avenue Force Main and the Western Outfall. Based on the Bioxide effectiveness results, a pilot study using a different chemical for chemical injection is recommended on the Grand Avenue Force Main. A negative pressure pilot test is proposed for the Western Outfall interceptor sewer. If the pilot studies prove to be successful, full scale systems can be installed on these sewers, as well as on the Ohio River Interceptor and Southern Outfall.