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Las Vegas Strip Odor Remediation

Francell R. Rodriguez
UNLV, francell_rodriguez@yahoo.com

Daniel Hoskins
UNLV, danielhoskins2000@yahoo.com

Guadalupe Gutierrez
UNLV, gtzlupe@aol.com

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LAS VEGAS STRIP ODOR REMEDIATION FALL 2011

*Daniel Hoskins
Francell Rodriguez
Guadalupe Gutierrez*



Table of Contents

1. Executive Summary.....	1
2. Problem Statement.....	2
3. Background	2
4. Odor Control Alternatives.....	5
4.1. Nitrate Addition	5
4.2. Biofiltration Systems	6
4.3. Granulated Activated Carbon	8
4.4. Do Nothing Scenario	10
5. Design Considerations.....	11
5.1. Design Goals.....	11
5.1.1. Efficiency	11
5.1.2. Footprint	11
5.1.3. Costs.....	11
5.2. Design Parameters	11
5.2.1. Nitrate	11
5.2.2. Biofiltration	13
5.2.3. GAC.....	22
6. Cost Analysis	27
6.1. Nitrate	27
6.2.1. Initial Costs.....	27
6.2.2. Annual Costs.....	27
6.3. Biofilter.....	29
6.3.1. Initial Costs.....	29
6.3.2. Annual Costs.....	31
6.4. Granulated Activated Carbon	32
6.4.1. Initial Costs	32
6.4.2. Annual Costs	33
7. Discussion.....	34
7.1. Design.....	34

7.2 Cost	35
8. Recommendation.....	36
9. References	38
Appendices.....	40
Appendix A.....	40
Appendix B.....	42
Appendix C.....	44
Appendix D.....	46
Appendix E	48
Appendix F	54

List of Tables

Table 1: Nitrate Parameters.....	11
Table 2: Wood Chips Biofilter Design Parameters	14
Table 3: EBCT vs. SLR (Depth = 3.3 ft)	16
Table 4: Initial and Daily Water Needed in Media (Depth = 3.3 ft).....	16
Table 5: EBCT vs. SLR (Depth = 3.3 ft).....	16
Table 6: Initial and Daily Water Needed in Media (Depth = 4.1 ft).....	16
Table 7: Average Monthly Evapotranspiration at Boulder City Weather Station	19
Table 8: Temperature Effect on H ₂ S and Ca(OH) ₂	22
Table 9: Activated Carbon Design Parameters	23
Table 10: Annual Amount of Carbon Needed	24
Table 11: Mini Phoenix Plus Design Data (Calgon Carbon).....	27
Table 12: Existing Wood Chip Biofilter Systems Capacities and Costs	30

List of Figures

Figure 1: Generation of Hydrogen Sulfide in Sewers.....	3
Figure 2: Hydrologic Scenarios (V&A Consulting Engineers)	4
Figure 3: Biofiltration System.....	6
Figure 4: EBCT vs. SLR	17
Figure 5: Area of Bed vs. Water Evaporated.....	17
Figure 6: Odor Control System Suction Inlet Assembly	19
Figure 7: Air Distribution Pipe (4" Diameter).....	20
Figure 8: Flow Rate vs. Cost of Existing Biofilter Systems.....	30
Figure 9: Annual Water Demand	31
Figure 10: Material Comparison	34
Figure 11: Land Usage Comparison.....	34
Figure 12: Energy Comparison	35
Figure 13: Water Usage Comparison	35
Figure 14: Cash Flow Analysis	36

1. Executive Summary

Las Vegas Boulevard is a world renowned travel destination in the heart of our city. One of a kind tourist attractions dot the landscape along the strip: from the carnival rides high atop the Stratosphere to the beautiful Bellagio fountains, from breathtaking Cirque du Soleil shows to the Fremont Street Experience, Las Vegas is a place that people come expecting to be “wowed,” and the city wants to provide that experience. For the most part, the city delivers and people leave with a good overall impression, but there are some areas that could be improved upon. The unprecedented growth of the Las Vegas Strip in the last decade has resulted in some engineering challenges, including the control of odors in the sewer lines. The odor is mainly caused by hydrogen sulfide emissions, which is unpleasant and can also promote sewer corrosion and cause explosions. In Las Vegas, mainly during summer, unpleasant odors escape from the sewer system in parts of the city, with one of the most notable locations being at the intersection of Las Vegas Blvd with Flamingo Rd, right at the heart of the Las Vegas Strip. This is a byproduct of biological processes that occur in the wastewater as it flows through the sewer system toward the wastewater treatment plant.

The project described in this report looks at four alternatives to eliminate this odor issue: biofiltration, Granulated Activated Carbon (GAC) filtration, nitrate addition and the alternative of doing nothing. Each alternative was evaluated based on effectiveness, land usage, energy consumption, water and material usage, and cost. Cost was further broken down into initial costs and annual costs, and then a cash flow analysis was performed to evaluate the cost over a 30 year timeframe.

Nitrate had the smallest land, energy and water footprints while GAC had the smallest material usage. Effectiveness of all three technologies was sufficient to eliminate it as one of the criteria for evaluation. Initial costs for biofiltration, GAC, and nitrate addition were estimated to be \$72,040, \$102,283 and \$3,505 respectively. Annual costs for the biofiltration, GAC, and nitrate addition were \$3,723, \$10,136 and \$10,957 respectively. Through the use of the cash flow analysis, it was determined that over the 30 year timeframe evaluated, biofiltration (\$335,000) was significantly less than either nitrate addition (\$779,000) or GAC (\$810,000). From a strict odor control perspective, biofiltration proved to be an ideal design for the Las Vegas Strip. Not only does the system provide a more aesthetically acceptable design, but it remediates the problem at a significantly lower price.

2. Problem Statement

Sewer systems are one part of a city's infrastructure that most people don't think about until there is a problem because they are buried underground. These problems include backed up pipelines, overflowing storm canals, and undesirable odors emanating from sewer systems. In the latter issue, the odor is caused by numerous chemicals that are primarily a byproduct of bacterial breakdown of the organic matter found in sewage, with the primary odor causing chemical being hydrogen sulfide.

There are several areas around our city that have odor issues associated with the sewer system, and this project looks to evaluate one of them, the area around the intersection of Las Vegas Blvd and Flamingo Rd in Las Vegas, Nevada. This location was chosen due to its high visibility as a location along the world famous Las Vegas Strip, which is the primary economic driver of the city. Four different alternatives for dealing with this odor problem will be evaluated in this project: nitrate addition, biofiltration, granulated activated carbon filtration, and leaving the system as it is. The first three options provide methods to alleviate the odor problems in the area, while the last evaluates the ramifications of allowing this odor to be a nuisance in the center of our tourists' playground.

3. Background

Hydrogen sulfide is a poisonous, colorless, and flammable gas that causes the recognizable "rotten egg" smell in concentrations ranging from 0.5 ppb to 100 ppm ("H₂S Fact Sheet," 1978). Above this level, the gas temporarily disables the ability to smell, making it extremely dangerous in high concentrations. Hydrogen sulfide also has a specific gravity of roughly 1.2, which means that it is heavier than air and poses a risk of collecting in the low points of a given system.

The Occupational Safety & Health Administration (OSHA) has several regulations concerning maximum Permissible Exposure Limits (PEL). For hydrogen sulfide, 29 CFR 1910.1000 states that the PEL for general industry is 20 ppm and 29 CFR 1926.55 states that the PEL is 10 ppm for the construction industry.

In sewer systems operating under anaerobic conditions, hydrogen sulfide is typically produced in the slime layer (e.g. biofilm) that covers the walls of the pipe, as seen in Figure 1. This occurs when the bacteria present in the sewer system, typically *Desulfovibrio desulfuricans* (U.S. Environmental Protection Agency [USEPA], 1985), reduce sulfate present in the sewage to hydrogen sulfide. In addition

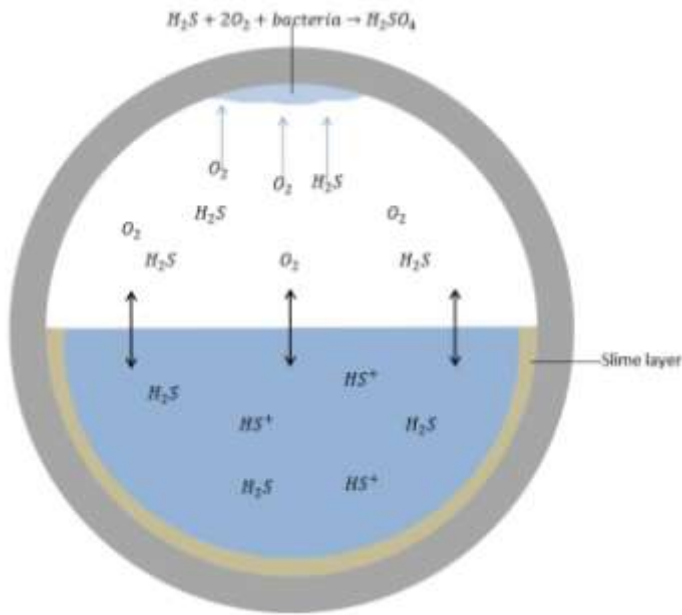
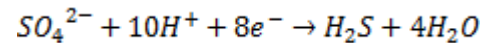
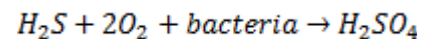


Figure 1: Generation of Hydrogen Sulfide in Sewers

to sulfate, desulfovibrio also require hydrogen atoms from organic material to fuel their processes. The following shows the reaction of sulfate with hydrogen to form hydrogen sulfide (USEPA, 1985).



Hydrogen sulfide will also react with oxygen to form sulfuric acid, which can lead to corrosion (Fig. 1). This reaction is also brought about by bacteria, and as such, moisture must also be present in order for the bacteria to survive. The



following equation shows the formation of sulfuric acid.

There are several variables that affect hydrogen sulfide production in sewers, including: temperature, pH, surface area, detention time and the hydrologic characteristics of the sewer.

- Temperature increases biologic activity up to a certain temperature. The EPA notes that sulfide production increases by a rate of 7%/1.2° F up to 86° F (USEPA, 1985). With Las Vegas temperatures reaching well over 86° F for several months a year, hydrogen sulfide production can be expected to be high.
- pH of the wastewater affects the ratio of H₂S to HS⁻. As pH levels increase, H₂S dissociates into HS⁻ and H⁺, which do not cause odor problems and cannot release to the atmosphere. At a neutral pH of 7, the ratio of H₂S to HS⁺ is 1:1, while at pH of 6 the ratio is 9:1 (USEPA, 1985).
- Hydrogen sulfide is primarily produced in the biofilm along the wall of the sewer pipe. As wetted surface area increases, sulfide production increases.

- There is a positive relationship between detention time and hydrogen sulfide production. As the detention time increases there is more time for bacteria to utilize all free oxygen, creating the anaerobic condition under which hydrogen sulfide is created.
- Hydraulic characteristics affect hydrogen sulfide release into the atmosphere. Areas of turbulence increase hydrogen sulfide release.

Hydrogen sulfide tends to partition to the air where there is a high amount of turbulence in the sewer system. There are many hydraulic scenarios that can lead to disturbances in wastewater flow and lead to turbulence. Areas of transition, such as from one pipe size to another, or from a pipe into a manhole, are just two of the scenarios that can lead to turbulence. Other factors that can lead to turbulence include: changes in elevation, slope, diameter and material properties. Some of these scenarios are seen in Figure 2.

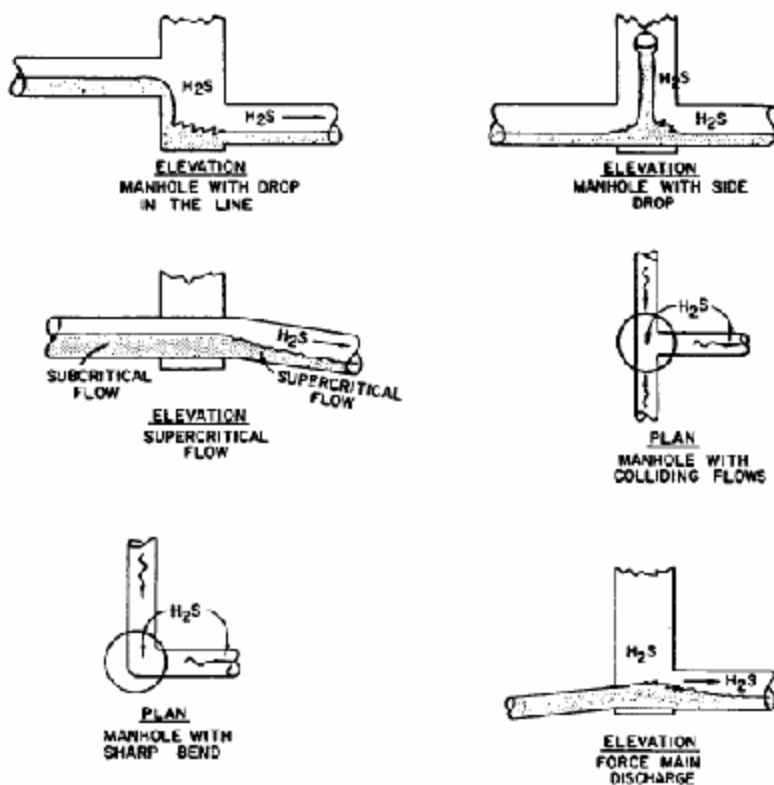


Figure 2: Hydrologic Scenarios (Chapman et al., 2007)

At the intersection of Flamingo Rd and Las Vegas Blvd there are several hydrologic scenarios that are potential causes of turbulence. Going north on Las Vegas Blvd towards Flamingo Rd in front of the Bellagio there is a large diameter pipe that discharges into a smaller diameter pipe. There is an approximate 9" difference between the diameters of these two pipes, producing high turbulence. Another possible cause of odor is on Flamingo Rd between Bellagio and Caesar's

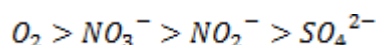
Palace. At this location there is a pipe with a relatively large slope discharging into a manhole. The high slope causes a high velocity, ultimately causing undesired turbulence.

4. Odor Control Alternatives

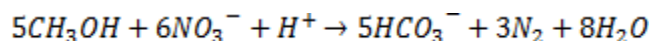
4.1. Nitrate Addition

As was discussed previously in this report, the odor associated with sewer systems is primarily a byproduct of bacterial activity that creates hydrogen sulfide in anaerobic conditions. This is due to the bacteria using the most readily available form of oxygen. This will typically be sulfate once all the free oxygen has been used. Nitrate, if it is introduced into the system will be used prior to the sulfate. The nitrate will be oxidized to form nitrite, which will be further broken down to form nitrogen gas. Both the nitrate and nitrite will be utilized before sulfate. This can be explained by reduction potentials. The order of reduction potentials for the compounds that bacteria can use for oxygen in the sewer are as follows.

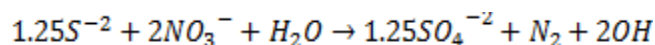
Redox potential from highest to lowest:



Denitrification occurs via two different mechanisms: autotrophic denitrification and heterotrophic denitrification. Heterotrophic bacterial denitrification occurs with an organic carbon source acting as an electron donor (Sengupta et al., 2006). This type of denitrification will continue taking place as long as there is sufficient organic content and nitrogen to oxidize. Sewer systems have ample organic content, which make them good candidates for this type of denitrification. An example of heterotrophic denitrification is shown below (Mathioudakis et al., 2006).



Autotrophic denitrification can take place without the presence of organic elements. Typical electron donors in this type of denitrification are hydrogen or sulfur. This type of denitrification will first oxidize any sulfide in a system prior to heterotrophic denitrification taking place (Mathioudakis et al, 2009). *Thiobacillus denitrificans* and *thiomicrospira denitrificans* are two of the types of sulfur oxidizing denitrifying bacteria (Mathioudakis & Aivasidis, n.d.). Autotrophic denitrification is illustrated in the following equation (Sengupta, 2006).



So, in order to limit the production of hydrogen sulfide in sewer systems, anaerobic conditions must be eliminated. This can be accomplished by inducing either aerobic or anoxic conditions. Addition of oxygen

into a system provides challenges due to its low solubility and high utilization rate (Mathioudakis et al., 2009). Adding NO_3^- , on the other hand, presents its own problems. Care must be taken to use the proper amount of NO_3^- . Too much nitrate can cause problems at the waste water treatment plant or further down the line in the environment in the form of algal blooms. The water treatment plant may have a denitrification process currently or may have to look into adding one if dosage is consistently high.

4.2. Biofiltration Systems

Biological treatment of odor control can be accomplished throughout the major treatment phases: preliminary treatment, primary treatment, secondary treatment, sludge dewatering, and tertiary treatment. At each different phase, odor is controlled by absorbing the odors that each process produces and directing these odors through pipes to odor control systems. Biofilter systems remove

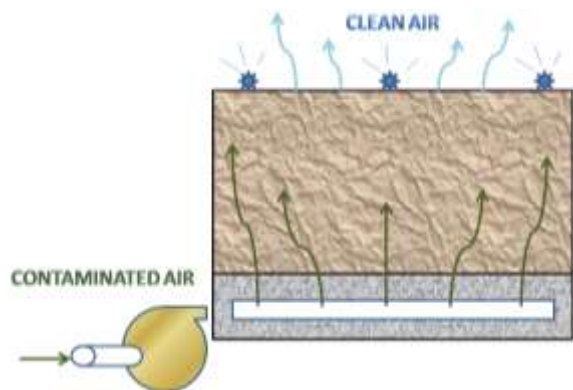


Figure 3: Biofiltration System

odorous material and gases by using bacteria that consume these compounds. Up to 99.5 % of hydrogen sulfide gas is removed in these systems (CCWRD, n.d.). Figure 3 illustrates a biofilter system. The process begins with the transportation of odorous gases to the biofilter system. These gases are evenly distributed in a gravel layer that is located immediately under a biofilter media layer. In between these two layers, under acidic conditions of 1-2 pH values, thiobacillus bacteria remove hydrogen sulfide. Further up in the biofilter's woodchip layer, at pH levels of 6.5-8, different bacteria reside and remove different odor causing compounds such as volatile organic compounds (VOCs). The biofilter's uppermost layer can be composed of bark that protects the bacteria residing in the lower layers and also helps the system conserve moisture. The ideal moisture conditions in the system are regulated by irrigating the system.

The odorous air is removed in the moist natural compost layers of the filter media; the bacteria that live on these layers feed off the compounds in the odorous air and cause two major byproducts: biofilm waste and clean air (Menikpurav et al., 2007). The compounds processed by the bacteria include gases, particulate matter, and volatile organic compounds (Menikpurav et al., 2007). In developing nations, biofilters are the ideal solution for controlling odorous gases since relative to other odor control systems, they are economical and easy to maintain (Menikpurav et al., 2007).

Parameters that play a significant role in the performance of a biofilter include: the number of layers in the system, the particle distribution, porosity, moisture-holding capacity, nutrient content, pH value and temperature in the media (Menikpurav et al., 2007).

Water content is a key parameter on the efficiency of biofiltration. Water is needed to maintain an ideal living condition for the bacteria in the media and serves as a means of transport for nutrients which keep the bacteria alive (Badilla et al., 2010). Properly controlling the water content is important, because not having enough water in a biofilter will make living conditions impossible for bacteria and will also cause the media to deteriorate sooner. On the other hand, excess water will reduce the transporting of compounds through media pores since water will occupy this space, making it impossible for the bacteria to efficiently biodegrade the compounds. Furthermore, excess water can wash out the microbial biomass on the media (Boswell, 2004). Badilla et al. conclude that moisture content in biofilters correlates to the bacteria present, operational costs, and the efficiency of a biofilter; according to the study, ideal moisture ranges are 30-60% for most materials, 70-80% for peat, 65-78% for compost, and 96% for soils.

Another major aspect of the efficiency of biofilters is the nutrient concentration present in the biofilter media. Nitrogen, phosphorous, potassium, and magnesium are important nutrients that should be present in media; however, excess of nutrients may cause overproduction of biomass in the media which may lead to clogging in the media pores (Acuna et al., 2009).

Controlling temperature and how much influent gas goes in a biofiltration system is typically tougher than managing the other parameters. Temperature is critical in hydrogen sulfide removal. For example, during colder months removal efficiencies in biofilters usually drop due to a decrease in biological activity. The ideal temperature range for removal efficiency is 77-95° F; within this range the microbial activity doubles with every 18° F increase (Boswell, 2004). Moreover, Martin et al.'s model on optimizing hydrogen sulfide odor in biofilters shows that the effect of increasing residence time (which is affected by media porosity, gas flow rate, and biofilter volume) increases effluent liquid concentrations of the hydrogen sulfide byproduct, thus producing cleaner air.

It is important to consider proper moisture distribution and the durability of the media used. Cardenz-Gonzales et al. list moisture distribution and the durability as the most important factors in a biofilter's efficiency. Materials typically used as media include "compost, wood chips and bark, peat, soil and sand mixtures, activated carbon, lava rock, and synthetic organic and inorganic materials" (Boswell, 2004).

Compost is one of the best media materials; as described by Cadenaz-Gonzalez et al. compost has “high specific surface area, low pressure drop, high nutrient composition, high microbial diversity, good water holding capacity and low cost.”

The pH in biofilters is also one of the most significant factors in a biofilter’s efficiency. The pH levels tend to correlate with temperature and are optimal at low levels (2-4) for hydrogen sulfide removal and higher levels (5-7) for removal of organo-sulfur compounds (Boswell, 2004). For optimal removals when both of these sulfur compounds occur, multilayer biofilters are designed with the lower pH levels existing at the bottom of the biofilter. Acidic and neutral layers form depending on hydrogen sulfide and organic compounds concentrations. Two main organisms found in biofilters are autotrophs and heterotrophs. Autotrophic organisms differ from heterotrophic organisms in that they create food from inorganic materials or from an energy source such as sunlight (e.g. plants and photosynthesis) while heterotrophs depend on organic sources (e.g. fats, carbohydrates, proteins) for their food. When high concentrations of hydrogen sulfide are present, autotrophic organisms such as thiobacillus consume the hydrogen sulfide and produce sulfuric acid which limits the growth of heterotrophs. Therefore, lower biofilter media typically have a low pH level (~1). Generally, the pH level increases (~6) in upper levels of the biofilter where the hydrogen sulfide levels are insignificant and where heterotrophs are allowed to grow, feeding on the VOCs in the air. Current pH managing options include: addition of crushed limestone in the media, mixing the humidification water with a buffering solution, and addition or reduction of water removals in the biofilter (Boswell, 2004).

A 3-foot deep biofilter designed to treat 85,000 m³/hr of air flow would require an 8,000 ft² area, requiring approximately 600 tons of compost (Boswell, 2004). Such large land area and media needs are a major drawback when using this technology. In the past, several air control agencies did not believe that biofilters could be considered a reliable air control technology due to their apparent “fragile nature” (Boswell, 2004). This reluctance influences a deeper concern about optimizing all parameters that influence an efficient biofilter.

4.3. Granulated Activated Carbon

Granulated Activated Carbon (GAC) is a medium composed of 90-95% pure carbon and is manufactured by charring raw materials, which include wood charcoal, and lignite (Haywood, 1937), coconut shells and bones, among other things. These raw materials are subjected to a procedure known as activation by heat treatment, which occurs in the presence of small amounts of oxygen, to increase their internal

surface area and activity. Once the process is completed, activated carbon becomes extremely porous and contains a very large internal surface area available for adsorption or chemical reactions. Activated carbon can be ground to a great extent to where one gram contains 120,000 particles and 1 in³ has a combined internal and external surface area of over 20,000 yd² (Haywood, 1937). The activated carbon is then used to concentrate or store odorous material and it can be removed or destroyed in an economical way in sewage. It was first introduced to sewage treatment in 1931 and has been implemented to several plant operators due to its effectiveness (Haywood, 1937).

Research has found that the internal surfaces of activated carbon can be used as catalyst sites for the chemical conversion of hydrogen sulfide to sulfur in the presence of air (Wilson, 1979). When hydrogen sulfide comes into contact with activated carbon, an acid based neutralization or oxidation reaction can occur. These reactions lead to elemental sulfur and ultimately to sulfites, sulfates, and their corresponding acids. The elemental sulfur produced is less reactive and non-volatile and will therefore remain on the carbon (Bandosz, 2000). Thus, hydrogen sulfide can be removed by absorption and the oxidation to sulfur.

The treatment of hydrogen sulfide, or any other gas that can be treated by carbon, is done by the installation of an activated carbon column. Odorous air is pumped into the column and comes in contact with the carbon, then exits as clean air. As the odorous air comes in contact with the activated carbon the influent sorbs to the porous surface of the carbon. When all of the available surface area in the activated carbon is used, the odor concentration of the effluent will become the same as the influent. This is known as odor breakthrough and new or reactivated carbon needs to be introduced into the column (Wilson, 1979).

There are three main types of activated carbon that have been used in sewage treatment. The types of carbon that have been used in the past include: unimpregnated (virgin) carbon, impregnated carbon, and ammonia injected carbon. The virgin carbon is unmodified carbon and is the most widely used type because it has a high capacity for removal of a variety of odorous VOCs. It also has a lower cost per pound and a lower density, which makes it easier to use. Studies have shown that the use of virgin carbon decreases the concentration of hydrogen sulfide and has a higher breakthrough capacity than the other types of carbon (Bandosz, 2000).

Impregnated carbon has chemicals such as NaOH or KOH added and has proven to have high breakthrough capacity, but only where there is a high amount of hydrogen sulfide found in air. The

impregnation of activated carbon reduces the surface area and pore volume available for physical adsorption and thus limits the adsorption capacity for other contaminants. In a sewer there are many gases found along with hydrogen sulfide in which physical adsorption is the preferred removal method (Turk, 1993). Since impregnated carbon has a low capacity of physical adsorption it is usually not the best choice.

Ammonia injected carbon, unlike impregnated carbon, does not limit the carbon's capacity for physical adsorption of other odorous gases. Ammonia is lighter than air and is desorbed rapidly and replaced by heavier gases. Therefore, the use of ammonia injected and virgin carbon have been found to be successful (Turk, 1993).

Activated carbon is typically 99.9 % efficient in the removal of odorous compounds. Activated carbon adsorbs both odorous and non-odorous compounds. One concern with the usage of activated carbon is that the useful life of the carbon may be reduced by the adsorption of the non-odorous compounds (Wilson, 1979). This can result in large activated carbon usage rates, which can prove to be uneconomical. Overall, activated carbon has proven to be a very reliable and effective treatment for sewer odor control.

4.4. Do Nothing Scenario

In any engineering project, it is important to evaluate the investment against the benefit to be realized from that project. In this project, the consequences of preserving the status quo, that is- doing nothing to abate the odor was also considered. This option has advantages and one advantage is that there are no direct costs to leave the system as it is. It also does not require additional space like the other options. The disadvantages of this option are that the problem with odor will remain and the sewer will be corroded with time due to sulfuric acid formation, potentially decreasing the service life of the system. The odor could affect the image of Las Vegas, hurting tourism in general, and the businesses around this area specifically.

5. Design Considerations

5.1. Design Goals

5.1.1. Efficiency

The efficiency of the chosen alternative must be sufficient to lower hydrogen sulfide to below the odor threshold.

5.1.2. Footprint

Land use, power consumption, water and material usage will be compared to assess which alternative has the smallest footprint.

5.1.3. Costs

Initial and annual costs will be evaluated to assess which technology is the most cost effective over a 30 year time frame.

5.2. Design Parameters

5.2.1. Nitrate

<i>Parameters for Nitrate Addition</i>	<i>Typical Values</i>
Wastewater Flowrate	Values will be a product of velocity (2-10 fps) and pipe size (14"-36")
Concentration of Hydrogen Sulfide	Values of 0.2-300 ppm have been found in sewer systems

Table 1: Nitrate Parameters

5.2.1.1. Flowrate

Flowrate (Q) is essential for the calculation of nitrate needed. This value can be obtained with the help of CCWRD's "Design and Construction Standards for Waste Water Collection Systems," which can be found on their website. The velocity (V) that is specified for gravity fed sewers in Clark County is between 2-10 fps. Using these values, along with the diameter of the pipe to calculate area (A), the flowrate can be determined based on the following equation.

$$Q = AV \quad (1)$$

Flowrate was modeled with Flowmaster software. Due to the fact that there is an assortment of pipe sizes both to the north and to the south of the intersection, flowrate was calculated based on the largest

diameter pipe with the largest slope on both laterals feeding into the Flamingo line. Using the Flowmaster software, the 50% flowrate of the line running from the north into the Flamingo Rd/Las Vegas Blvd intersection was calculated to be 3.02 million gallons per day (MGD) based off of the characteristics of an 18" diameter line located on this lateral. Rearranging the above equation for flowrate to calculate velocity yields a value of 2.64 fps, which falls within Clark County's specifications. The 50% flowrate of the line running from the south into the Flamingo Rd/Las Vegas Blvd intersection was calculated to be 5.46 MGD based of the characteristics of a 30" diameter line located on this lateral. This returns a velocity of 1.72 fps, which does not meet the design specifications and could be one area that is contributing to the formation of hydrogen sulfide. The north and south lines running into the Flamingo Rd/Las Vegas Blvd intersection converge into a 36" line running east along Flamingo Rd. Combining the flowrates from the two lines gives a total flow of 8.48 MGD.

5.2.1.2. Concentration of Hydrogen Sulfide

Concentrations of hydrogen sulfide are necessary to calculate the amount of nitrate needed based on chemical reactions. A concentration of 30 ppm_v was used in this analysis based on CCWRD's recommendations for a worst case scenario. The 30 ppm_v was converted to molality in solution using Henry's Law as stated by Carroll (1991). Henry's Law solved for molality in solution (m_{H_2S}) follows:

$$m_{H_2S} = \frac{\gamma_{H_2S} * P}{H} \quad (2)$$

Where γ_{H_2S} is mole fraction of hydrogen sulfide in air and P is total pressure in the system, atmospheric pressure in this case, 101.325 kPa. Henry's constant (H) was taken to be 991 kPa/molal (Carroll, 1990).

Mole fraction of a gas is calculated as follows:

$$30 \text{ ppm}_v = \left(\frac{30 \text{ L } H_2S}{10^6 \text{ L Air}} \right) \left(\frac{\frac{\text{mole } H_2S}{22.4 \text{ L}}}{\frac{\text{mole Air}}{22.4 \text{ L}}} \right) = 0.00003 \frac{\text{mole } H_2S}{\text{mole Air}} \quad (3)$$

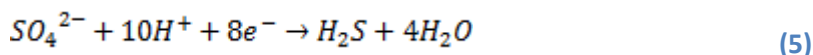
Inserting these values into equation 2 to solve for molality in solution:

$$m_{H_2S} = \frac{(0.00003)(101.325 \text{ kPa})}{\left(991 \frac{\text{kPa}}{\text{molal}}\right)} = 3.07 \times 10^{-6} \text{ molal } H_2S = 3.07 \times 10^{-6} \frac{\text{mole } H_2S}{\text{kg } H_2O}$$

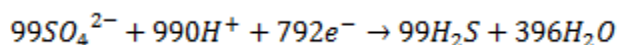
With this concentration of hydrogen sulfide per mass of water, the total moles of hydrogen sulfide per day can be calculated:

$$\left(3.07 \times 10^{-6} \frac{\text{mole } H_2S}{\text{kg } H_2O}\right) \left(\frac{3.785 \text{ kg } H_2O}{\text{gal } H_2O}\right) \left(\frac{8480000 \text{ gal } H_2O}{\text{day}}\right) = 98.53 \frac{\text{mole } H_2S}{\text{day}} \quad (4)$$

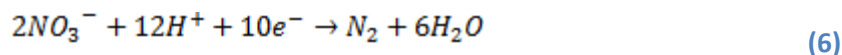
With this value rounded up to 99 moles H_2S /day, equation 5 can be balanced to evaluate the equivalent number of moles of sulfate and hydrogen atoms:



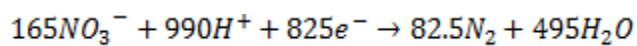
Which balances to:



Equation 6 shows the conversion of nitrate to nitrogen gas in the presence of nitrate reducing bacteria and organic matter to supply the hydrogen atoms (USEPA, 1985):



Equation 6 can be balanced, with the information obtained from balancing equation 5, to determine the amount of nitrate needed in mole/day.



This can be converted to nitrate needed in pounds/day as follows:

$$\left(\frac{165 \text{ mole } NO_3^-}{\text{day}}\right) \left(\frac{62 \text{ g } NO_3^-}{\text{mole } NO_3^-}\right) \left(\frac{\text{lb}}{454 \text{ g}}\right) = 22.4 \frac{\text{lb } NO_3^-}{\text{day}}$$

5.2.1.3. Proposed Design

A storage tank and pump is the most suitable design for dispensing a nitrate solution in this application. The tank chosen was a “Snyder Industries Vertical Storage Tank: Model 17137,” with dimensions of 86” diameter by 56.5” height. The “Masterflex® C/L® Variable-Speed Tubing Pump: Model WU-77122-20” was chosen for the pumping needs. Please see Appendix B for the proposed design schematics of the nitrate addition system.

5.2.2. Biofiltration

Table 2 outlines important design parameters per Burton et al. recommendations and their associated values when designing a wood chip media biofilter to address hydrogen sulfide produced odors.

<i>Parameters</i>	<i>Typical Values</i>	
Air Flow* (Q)	440	ft ³ /min
Depth of Medium (D)	3.3-4.1	ft
Surface Loading Rate (SLR)	33-328	ft ³ /ft ² hr
Volumetric Loading Rate (VLR)	33-328	ft ³ /ft ³ hr
Empty Bed Contact Time (EBCT)	30-60	s
Temperature	59-95	°F
H ₂ S Elimination Rate	2.27-3.68	g/ft ³ hr
H ₂ S Inlet Concentration**	0.00001-0.0005	g/L ³
Moisture Content	50-65	%
pH Value	6-8	-
Porosity	35-50	%
Plenum Depth	0.50-0.66	ft
Distribution Pipe Diameter Size	0.33	ft

*Obtained from CCWRD's sewer system analysis (refer to Appendix A)

**30 ppm used per CCWRD's recommendation (worst case scenario)

Table 2: Wood Chips Biofilter Design Parameters

5.2.2.1. Media

As mentioned before, the biofilter media can be composed of various materials. A wood chip media will be considered in this design analysis since this material is more readily available and is economical in the Las Vegas area. Wood chips must be able to provide appropriate surface area and porosity, structural support, moisture retention, and nutrient availability qualities. Moderately large wood chips will provide a sufficient surface area, air movement, and odor control removal. Careful consideration must be given to wood chip media when designing for structural support and moisture retention since too much or too little water can affect the structural support, porosity, air distribution characteristics of the system and ultimately, its efficiency.

5.2.2.2. EBCT

The EBCT indicates the amount of time it takes for odorous compounds to be metabolized by bacteria. This value depends on media depth and odorous gas loading rate. Typically, hydrogen sulfide requires 30-60 seconds (in organic media) to metabolize. This range will be used for the analysis.

5.2.2.3. Surface Loading Rate and Media Depth

By using Burton et al.'s SLR values between 33 and 328 ft³/ft²hr, typical depth of media values between 3.3-4.1 ft, and the air flow of 440 ft³/min (CFM) as calculated for the sewer system of the site, different scenarios for the area of the bed, volume of the bed, VLR and EBCT were calculated as shown in Table 3

and 5. The highlighted red fields in the tables indicate for which SLR simulations the VLR and the EBCT fall outside of the Burton et al.'s design parameters of 33-328 ft³/ft³hr (VLR) and 30-60 s (EBCT). Figure 4 illustrates the result of these tables showing that when using a depth of medium of 3.3 ft and 4.1 ft and airflow of 440 CFM, the EBCT desired values correspond to SLR values of 197–328 ft³/ft²hr and 262–328 ft³/ft²hr, respectively. Since the simulation for media depth of 3.3 ft results in a wider range of SLR values, this media depth will be chosen over a depth of 4.1 ft. In order to achieve the maximum removal rate in the biofilter, it is preferred to use the maximum EBCT of 60 s. Thus, the design SLR, area of bed, volume of bed, VLR, and EBCT values will be 197 ft³/ft²hr, 134.0 ft², 442.2 ft³, 60 ft³/ft³/hr, and 60 s, respectively. These values are obtained with the following equations:

$$\text{Area} = \frac{\text{Airflow}}{\text{Surface Loading Rate}} = \frac{440 \frac{\text{ft}^3}{\text{min}} * \frac{60 \text{ min}}{1 \text{ hr}}}{197.0 \text{ ft}^3/\text{ft}^2\text{hr}} = 134.0 \text{ ft}^2 \quad (7)$$

$$\text{Volume} = \text{Area} * \text{Depth} = 134.0 \text{ ft}^2 * 3.3 \text{ ft} = 442.2 \text{ ft}^3 \quad (8)$$

$$\text{Volume Loading Rate} = \frac{\text{Airflow}}{\text{Volume}} = \frac{440 \frac{\text{ft}^3}{\text{min}} * \frac{60 \text{ min}}{1 \text{ hr}}}{442.2 \text{ ft}^3} = 60 \text{ ft}^3/\text{ft}^3\text{hr} \quad (9)$$

$$\text{Empty Bed Contact Time} = \frac{\text{Volume of Bed}}{\text{Air Flow}} = \frac{442.2 \text{ ft}^3}{440 \frac{\text{ft}^3}{\text{min}}} * \frac{60 \text{ sec}}{1 \text{ min}} = 60 \text{ sec} \quad (10)$$

5.2.2.4. Porosity

Ima and Mann achieved a 63% ± 1.3% porosity for a wood chip biofilter with the following wood chip size and percentage distribution: <2 mm (9.8%); 2 to 2.4 mm (2.5%); 2.4 to 3.4 mm (4.5%); 3.4 to 6.7 mm (14.2%); 6.7 to 19 mm (49.9%); 19 to 25 mm (9.5%); > 25 mm (9.5%). To achieve Burton et al.'s specified porosity of 35-50%, a similar wood chip size and percent distribution to Ima and Mann could be used with the exception of using a higher percentage of <2 mm (.08 in) wood chips and a smaller percentage of >25mm (0.98 in) wood chips.

Surface Loading Rate (ft ³ /ft ² hr)	Area of Bed (ft ²)	Volume of Bed (ft ³)	Volume Loading Rate (ft ³ /ft ³ hr)	Empty Bed Contact Time (s)
33	804.7	2,640.0	10	360
66	402.3	1320.0	20	180
98	268.2	880.0	30	120
131	201.2	660.0	40	90
148	178.8	586.7	45	80
164	160.9	528.0	50	72
197	134.0	442.2	60	60
230	115.0	377.1	70	51
262	100.6	330.0	80	45
295	89.4	293.3	90	40
328	80.5	264.0	100	36
Depth of Medium (ft)	3.3	Air Flow (ft ³ /min)	440	

Table 3: EBCT vs. SLR (Depth = 3.3 ft)

Total Media Mass (lb)	Water Mass in Media (lb)	Initial Needed Water Mass (lb)	Initial Needed Water Volume (Gal)	Water Evaporated in December (Gal/day)	Water Evaporated in July (Gal/day)
37,388	3,739	14,955	1,793	25.4	275.2
18,694	1,869	7,478	897	12.7	137.6
12,463	1,246	4,985	598	8.5	91.7
9,347	935	3,739	448	6.4	68.8
8,308	831	3,323	398	5.6	61.1
7,478	748	2,991	359	5.1	55.0
6,279	628	2,512	301	4.2	45.9
5,341	534	2,136	256	3.6	39.3
4,674	467	1,869	224	3.2	34.4
4,154	415	1,662	199	2.8	30.6
3,739	374	1,496	179	2.5	27.5
Wood Chip Density (lb/ft ³)	14.2	Media Moisture (%)	10%	Desired Media Moisture (%)	50%

Table 4: Initial and Daily Water Needed in Media (Depth = 3.3 ft)

Surface Loading Rate (ft ³ /ft ² hr)	Area of Bed (ft ²)	Volume of Bed (ft ³)	Volume Loading Rate (ft ³ /ft ³ hr)	Empty Bed Residence Time (s)
33	804.2	3,297.9	8.0	450.0
66	402.1	1,649.0	16.0	225.0
98	268.1	1,099.3	24.0	150.0
131	201.0	824.5	32.0	112.5
148	178.7	732.9	36.0	100.0
164	160.8	659.6	40.0	90.0
197	134.0	549.7	48.0	75.0
230	114.9	471.1	56.0	64.3
262	100.5	412.2	64.0	56.3
295	89.4	366.4	72.0	50.0
328	80.4	329.8	80.0	45.0
Depth of Medium (ft)	4.1	Air Flow (ft ³ /min)	440	

Table 5: EBCT vs. SLR (Depth = 3.3 ft)

Total Media Mass (lb)	Water Mass in Media (lb)	Initial Needed Water Mass (lb)	Initial Needed Water Volume (Gal)	Water Evaporated in December (Gal/day)	Water Evaporated in July (Gal/day)
46,734.8	4,673.5	18,693.9	2,241.5	25.4	275.2
23,336.7	2,336.7	9,347.0	1,120.7	12.7	137.6
15,578.3	1,557.8	6,231.3	747.2	8.5	91.7
11,683.7	1,168.4	4,673.5	560.4	6.4	68.8
10,385.5	1,038.6	4,154.2	498.1	5.6	61.1
9,347.0	934.7	3,738.8	448.3	5.1	55.0
7,789.1	778.9	3,115.7	373.5	4.2	45.9
6,676.4	667.6	2,670.6	320.2	3.6	39.3
5,841.9	584.2	2,336.7	280.2	3.2	34.4
5,192.8	519.3	2,077.1	249.1	2.8	30.6
4,673.5	467.3	1,869.4	224.1	2.5	27.5
Wood Chip Density (lb/ft ³)	14.2	Media Moisture (%)	10%	Desired Media Moisture (%)	50%

Table 6: Initial and Daily Water Needed in Media (Depth = 4.1 ft)

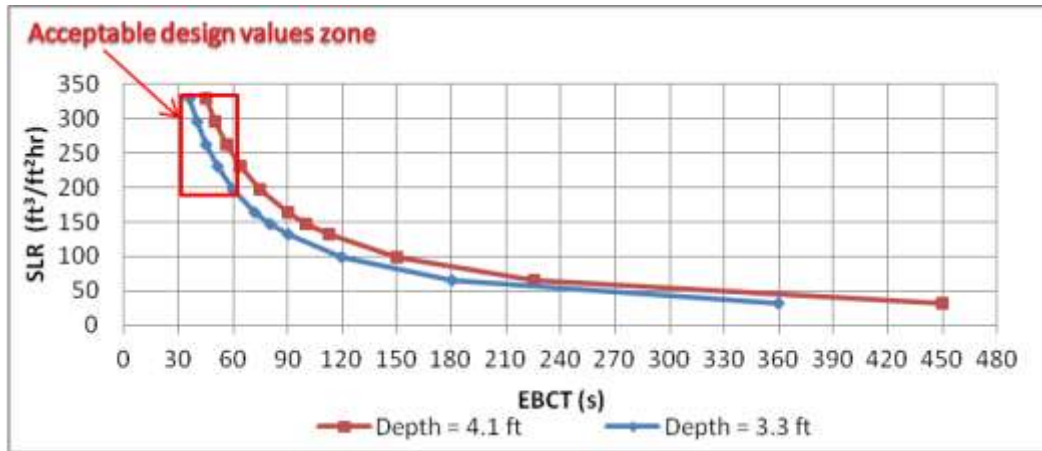


Figure 4: EBCT vs. SLR

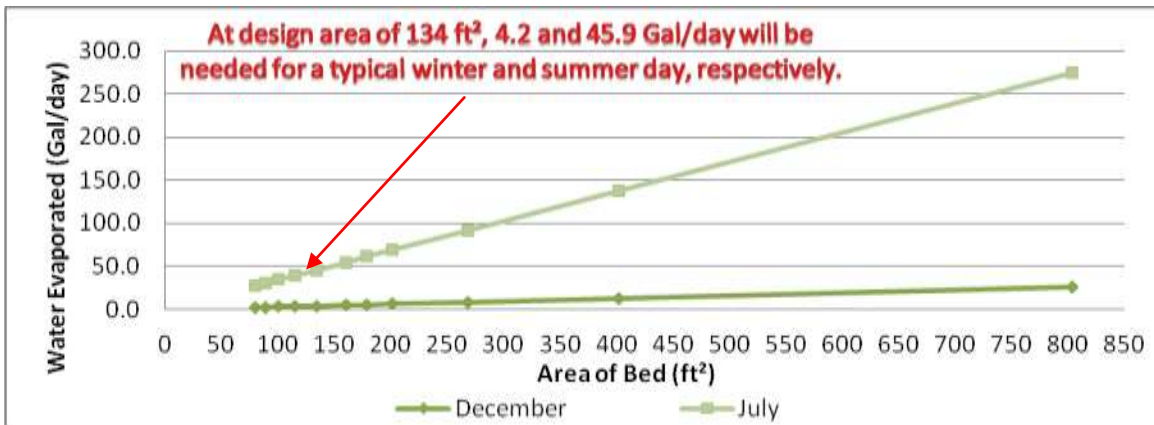


Figure 5: Area of Bed vs. Water Evaporated

5.2.2.5. Moisture Content

It is important to take into account that the Las Vegas Valley's climate generally consists of hot and dry summers, with high temperatures exceeding the 100s °F and lows in the 70s °F, and generally mild falls, springs, and winters, with high temperatures in winter averaging in the 50-60s °F (Gorelow et *al.*, 2005). Given Las Vegas temperature and climatic conditions, it is assumed that the wood chips for the design media will have 10% moisture content. Given 10% moisture content, desired media moisture content of 50-65%, and a typical wood chip density of 14.2 lb/ft³ as noted by Aerts (1991), daily water needed to sustain the biofilter can be calculated. The initial water volume needed by the biofilter to achieve the desired moisture content of 50% is estimated in Tables 4 and 6, which take into account different volume scenarios. Furthermore, in order to account for daily water evaporation, potential evapotranspiration (PET) data for the nearest weather station (Boulder City) was acquired. Table 7 has

PET values obtained from Shevenell (1996), showing the expected evaporation amounts in Las Vegas throughout the year.

The PET pan evaporation values were used to determine how much water will be needed daily to keep the ideal moisture content in the biofilter. Although pan evaporation depicts a higher evaporation rate than that of wood chips due to the different thermal properties of the materials, this is a fair approximation since constant aeration in the biofilter will result in an increase of evaporation. In addition, Tables 4 and 6 list the amount of water that will be needed on a typical day during the months of July and December under different SLR and media depth simulations. These results are illustrated in Figure 5.

Month	Calculated PET Pan Evaporation (ft)
Jan	0.1309
Feb	0.2087
Mar	0.4380
Apr	0.7025
May	1.0315
Jun	1.2330
Jul	1.4180
Aug	1.1585
Sep	0.9311
Oct	0.5361
Nov	0.2205
Dec	0.1191

Table 7: Average Monthly Evapotranspiration at Boulder City Weather Station (Shevenell, 1996)

Given the design results found in the *Surface Loading Rate and Media Depth* section and Table 4, the design biofilter will

initially need 301 gallons of water to provide desired moisture condition, and will need approximately 4 and 46 gallons of water during a typical winter and summer day, respectively. The following equations were used to obtain these values:

$$\text{Total Media Mass} = \text{Volume of Bed} * \text{Wood Chip Density} = 442.2 \text{ ft}^3 * 14.2 \frac{\text{lb}}{\text{ft}^3} = 6,279 \text{ lb} \quad (11)$$

$$\text{Water Mass in Media} = \text{Total Media Mass} * \text{Media Moisture} = 6,279 \text{ lb} * 10\% = 628 \text{ lb} \quad (12)$$

$$\begin{aligned} \text{Initial Needed Water} &= \text{Total Media Mass} * \text{Desired Media Moisture} - \text{Water Mass in Media} \\ &= 6,279 \text{ lb} * 50\% - 628 \text{ lb} = 2,512 \text{ lb} * \frac{1 \text{ gal}}{8.34 \text{ lb}} = 301 \text{ Gal} \end{aligned} \quad (13)$$

$$\begin{aligned} \text{Water Evaporated in December} &= \text{Area of Bed} * \text{Potential Evapotranspiration} \\ &= 134 \text{ ft}^2 * 0.1309 \text{ ft} * 7.48 \frac{\text{Gal}}{\text{ft}^3} * \frac{\text{December}}{31 \text{ day}} = 4.2 \text{ Gal/day} \end{aligned}$$

5.2.2.6. Irrigation and Humidification System

There are three typical methods to provide the moisture needed in biological filters: humidification of the inlet air stream (prior to reaching the plenum), deep irrigation of the media throughout the lowest layer (just above the plenum), and surface irrigation of the upper layers (this is usually done in dry, warm climates). Given the amount of water needed daily as described in the previous section (*Moisture Content*) and the nature of the climate in Las Vegas, surface irrigation will be used for the proposed design.

5.2.2.7. Air-Ducting and Fan System

Major aspects that must be considering in sizing air ducting and the fan system are air flow rate, equal air distribution, and corrosion control. Since the ductwork for the air distribution system will be located in the lowest section of the biofiltration system, the system must be designed for high stress levels, and acid and corrosion resistance. It is important to note that at the air collecting point of the system, the odorous air must be collected as close to the water surface as possible as seen in Figure 6.

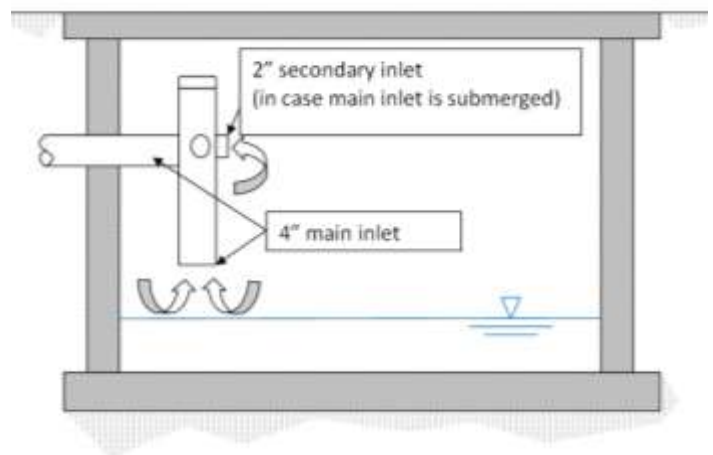


Figure 6: Odor Control System Suction Inlet Assembly

The pipe sizes here reflect the typical pipe sizes used per CCWRD's recommendations.

The typical fan used in biofilters is the backward-inclined impeller fiberglass centrifugal pressure fan at optimal pressures between 0.5 and 12 inches of water column. A blower is typically sized for a maximum of 12 inches of pressure loss, where a 12-inch pressure loss indicates the need to replace the wood chip media. As shown in Appendix C, *MK Plastics's* PRVS 125 High Pressure/Low Volume Centrifugal Fiberglass Blower, a 2500 RPM speed meets the design 440 CFM air flow and maximum 12 inches of water column pressure loss criteria.

5.2.2.8. Media Plenum and Under-drain Piping System

A biofilter plenum, or the foundation of a biofilter, can be design as a rock-media filled or open plenum. For better structural support, given Burton et al.'s recommendations, a gravel-media plenum will be used with a plenum depth of 0.66 ft. This requires that all materials used in the plenum be acid resistant.

Per Burton et al.'s recommendations, PVC distribution pipes with diameters of 0.33 ft will be used. These perforated pipes (at 45° angle from vertical) are placed throughout the media to distribute the airflow. Figure 7 shows the typical air distribution pipe, perforation and drainage spacing per CCWRD's Whitney Lift Station project schematics. When designing the perforation diameters, it is important to not oversize the orifices since air will not be allowed to reach the end of the pipe. It is equally important to not undersize the orifices since this may cause pressure loss and insufficient flow. In addition, pipes in the rock-media must be designed in such a way that condensed water can be easily drained and not plug the system. Also, acid is likely to form in rock-media plenums (due to more surface area), requiring proper acid drainage and treatment. In addition, the plenum should be designed with cleanouts at all ends to easily flush out long-term particle sedimentation.

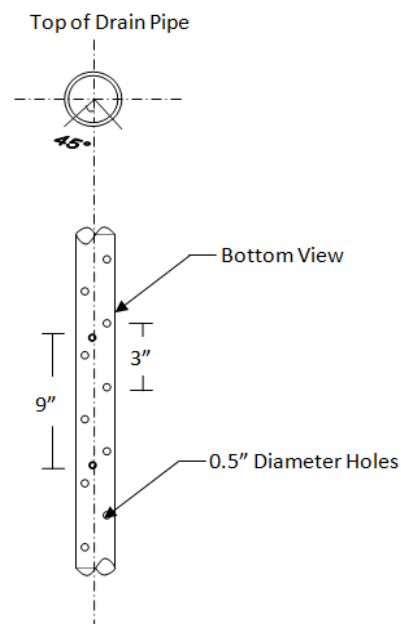


Figure 7: Air Distribution Pipe (4" Diameter)

5.2.2.9. Temperature and Acid Formation Treatment

Although the desired temperatures for ultimate biofilter performance fall between 59 and 95 °F, Burton et al. note that higher temperature (95 to 140 °F) operations are accepted as long as they remain relatively constant. The temperature conditions in a biofilter are very significant for determining if the volume required to treat inlet hydrogen sulfide concentrations meets the design volume parameters. Similarly, a change in temperature also affects how much hydrogen sulfide is removed. Table 8 shows that an increase in temperature in a biofilter equates to an increase in the volume of a mole of gas, ultimately lowering the hydrogen sulfide concentration in grams per liter of gas. This change also lowers the mass loading rate of sulfur. Dividing the mass loading rate of sulfur by Burton et al.'s elimination rate of hydrogen sulfide (with a factor of safety of 2) yields to the required volume needed to treat hydrogen sulfide. The decrease of hydrogen sulfide concentration in grams per liter results in a decrease of yearly hydrogen sulfide mass removed and thus in a reduction of mass of calcium hydroxide buffer needed to neutralize the acid formed as a result of treatment within the filter.

Ultimately, Table 8 shows that the required bed volume to treat 440 ft³/min airflow with 30 ppm_v hydrogen sulfide concentration at typical Las Vegas temperatures will vary between 14.9 ft³ and 16.5 ft³.

These values are acceptable since they are below the 442.2 ft³ design volume. Furthermore, this analysis helps determine the calcium hydroxide buffer amount (1226-1354 lb) needed to neutralize the acid formed by the mass of hydrogen sulfide (565-624 lb) treated in the filter. These calculations are outlined in the following equations:

Volume occupied by one mole of gas at a temperature of 15°C and pressure of 1.0 atm:

$$V = \frac{nRT}{P} = \frac{(1 \text{ mole}) \left(0.082057 \text{ atm} * \frac{L}{\text{mole}} * K \right) (273.15 + 15^\circ C) K}{1.0 \text{ atm}} = 23.6 \text{ L} \quad (15)$$

Converting hydrogen sulfide concentration from ppm to g/L:

$$30 \text{ ppm}_v = \left(\frac{30 L}{10^6 L} \right) \left(\frac{34.08 \frac{g}{\text{mole } H_2S}}{23.6 \frac{L}{\text{mole } H_2S}} \right) = 0.000043 \text{ g/L} \quad (16)$$

Mass Loading rate of S²⁻ in g S/h:

$$M_s = \left(\frac{440 \text{ ft}^3}{\text{min}} * \frac{60 \text{ min}}{\text{hr}} \right) \left(\frac{0.000043 \text{ g } H_2S}{L} \right) \left(\frac{28.3 L}{\text{ft}^3} \right) \left(\frac{32 \text{ g } S^{2-}}{34.08 \text{ g } H_2S} \right) = 30.4 \text{ g } S^{2-}/h \quad (17)$$

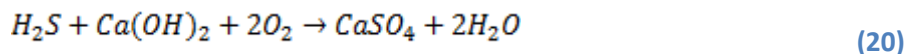
Required volume assuming 50% of Burton et al.'s elimination rate for hydrogen sulfide in a wood chip filter:

$$V_{Req} = \left(\frac{30.4 \text{ g } \frac{S}{h}}{\frac{3.7}{2} \text{ g } \frac{S}{\text{ft}^3} * h} \right) = 16.5 \text{ ft}^3 \quad (18)$$

Mass of hydrogen sulfide applied to filter in lb per year:

$$H_s S, \frac{lb}{\text{year}} = \frac{\left(\frac{440 \text{ ft}^3}{\text{min}} * \frac{60 \text{ min}}{\text{hr}} \right) \left(0.000043 \frac{g}{L} \right) \left(\frac{28.3 L}{\text{ft}^3} \right) \left(24 \frac{h}{d} \right) \left(365 \frac{d}{yr} \right) \left(2.2 \frac{lb}{kg} \right)}{10^3 \frac{g}{kg}} = 624 \text{ lb/yr} \quad (19)$$

Chemical equation for mass of calcium hydroxide buffer needed to neutralize the acid formed as a result of treatment within filter:



Equation 20 shows that the molar ratio of H₂S to Ca(OH)₂ is one to one, which means that about 2.17 lb of Ca(OH)₂ will be required per lb of H₂S, due to the difference in their molecular weights (H₂S=34.08 g/mol, Ca(OH)₂= 74.08 g/mol):

$$Ca(OH)_2, \frac{lb}{year} = 2.17 * 624 \frac{lb}{year} = 1,354 \text{ lb/year}$$

Temperature (°F)	Mole of Gas Volume (L)	H2S Inlet Concentration (g/L)	Mass Loading rate of S ²⁻ (g S ²⁻ /h)	Required Volume (ft ³)	Yearly H2S Mass Removed (lbs/yr)	Yearly Ca(OH) ₂ Mass Required (lbs/yr)
59	23.6	0.000043	30.4	16.5	624	1354
64	23.9	0.000043	30.0	16.3	617	1340
70	24.1	0.000042	29.7	16.1	611	1326
75	24.4	0.000042	29.4	16.0	605	1313
81	24.6	0.000042	29.1	15.8	599	1300
86	24.9	0.000041	28.8	15.7	593	1287
91	25.1	0.000041	28.5	15.5	587	1274
97	25.4	0.000040	28.3	15.4	581	1262
102	25.6	0.000040	28.0	15.2	576	1250
108	25.9	0.000040	27.7	15.1	570	1238
113	26.1	0.000039	27.5	14.9	565	1226
Air Flow (CFM)	440	H2S Elimination Rate (g/ft ³ hr) Factor of Safety	3.7 2	H2S Inlet Concentration (ppm)	30	

Table 8: Temperature Effect on H₂S and Ca(OH)₂

5.2.2.10. Proposed Design

Please see Appendix B for proposed design schematics for biofiltration.

5.2.3 GAC

Table 9 shows important parameters that should be considered when designing for an activated carbon column.

Parameter	Equation	Definition	Typical Values	Considerations	Reference
Freundlich Isotherm	$q = KC_f^{1/n}$	empirical model	-	-	(Metcalf, 2003)
q	-	mass of contaminant adsorbed	0.12 g H ₂ S /cm carbon	values may vary depending on sewers	(Turk, 1993)
Unit Weight of Carbon	-	-	30 lb/ft ³	use impregnated carbon	(Lagrega, 2000)
Flow Rate (Q)	Mannings Equations $Q = V * A$	-	-	needs field work	main source CCWRD
Diameter of Unit	-	-	<10 ft	size of space where the unit will be placed	(USACP, 2001)
Carbon Usage Rate	$CUR = C_f V / q * C_o$	Ensure a proper usage rate of the activated carbon	-	-	(Lagrega, 2000)
C _f	-	desired effluent concentration (mg/L)	-	to be determined	(Lagrega, 2000)
V	-	velocity of influent	-	needs field work	(Lagrega, 2000)
C _o	-	initial concentration (mg/L)	-	to be determined	(Lagrega, 2000)
Volume of Adsorber	$V = CUR * COP * SF / \rho$	provide a large enough area to facilitate contaminant removal	-	-	(USACP, 2001)
COP	-	carbon change out period (days)	-	-	(USACP, 2001)
ρ	-	bulk density of carbon	-	-	(USACP, 2001)
S.F	-	safety factor to provide extra non-carbon-containing volume	1.2-2.5	-	(USACP, 2001)
Height of Column (H)	$H = V / A$	provide a large enough area to facilitate contaminant removal	-	-	(Lagrega, 2000)
EBCT	V / Q	empty bed time contact	15 min	-	(Lagrega, 2000)
V	-	Bulk Volume of GAC (m ³)	-	-	(Lagrega, 2000)
Q	-	Volumetric flow rate (ft ³ /min)	-	-	(Lagrega, 2000)
Bed Depth (L)	$L = V / A$	depth of carbon bed	3-5 ft	-	(USACP, 2001)
A	-	adsorber bed area	-	-	(USACP, 2001)
V	-	adsorber volume	-	-	(USACP, 2001)

Table 9: Activated Carbon Design Parameters

5.2.3.1. Freundlich Isotherm

The Freundlich adsorption isotherm is an important parameter that dictates the effectiveness of activated carbon. The Freundlich equation is as follows:

$$q = KC_f^{1/n} \quad (21)$$

Where q is the mass of the contaminant that is adsorbed, K and 1/n are constants of the Freundlich equation that vary from contaminant to contaminant and C_f is the final concentration of the contaminant. To remove a large amount of the contaminant and be efficient with the use of activated carbon, the K and 1/n values should be large (Lagrega, 2000).

The Freundlich isotherm can vary depending on the type of carbon being used. For the purpose of this design the carbon that will be used is Centaur HSV, a vapor phase virgin GAC with an adsorption capacity of 0.69 g H₂S/g carbon and a carbon density of 560 kg/m³ (Calgon Carbon, 1996). With the adsorption capacity, the amount of carbon needed to remove a concentration of H₂S can be determined. Table 10 shows the amount of carbon required per year to remove a concentration of 30 ppm_v hydrogen sulfide, at typical temperatures in Las Vegas.

Temperature (°F)	Mole of Air per Min (mole/min)	Mole of H ₂ S per Min (mole/min)	Concentration of H ₂ S (kg/min)	Concentration of H ₂ S (kg/yr)	Amount of Carbon Needed (lbs/yr)
59	5.23	0.00015697	0.005349547	2773	1827
64	5.18	0.000155456	0.005297943	2746	1809
70	5.13	0.000153971	0.005247326	2720	1792
75	5.08	0.000152514	0.005197667	2694	1775
81	5.04	0.000151084	0.005148939	2669	1758
86	4.99	0.000149681	0.005101116	2644	1742
91	4.94	0.000148303	0.005054173	2620	1726
97	4.90	0.000146951	0.005008086	2596	1710
102	4.85	0.000145623	0.004962832	2573	1695
108	4.81	0.000144319	0.004918389	2550	1680
113	4.77	0.000143038	0.004874735	2527	1665
Air Flow (ft ³ /hr)	440		H ₂ S Inlet Concentration (ppm)	30	

Table 10: Annual Amount of Carbon Needed

5.2.3.2. Operating Parameters

5.2.3.2.1 EBCT

The contact time is the amount of time that the contaminant spends in contact with the activated carbon. For moderately adsorbable compounds an EBCT of 15 minutes is required to go from levels of low ppm to ppb. A larger contact time is required to go from medium ppm levels to low ppb levels, which typically is approximately 30 minutes (USACP, 2001).

5.2.3.2.2. Adsorber Volume

Factors that can affect the size of the adsorbers include the change out rate, and carbon usage rate. The carbon contactor change out depends on the reactivation company's fees, as well as the schedules for other projects. The optimum carbon usage is based on column studies. Also, the carbon vessel should have an additional 20-50% bed expansion allowance that is built in for backwashing purposes (USACAP, 2001).

5.2.3.2.3. Bed Depth

The bed depth is the depth of the carbon bed inside the activated carbon column. This is a direct function of the contactor diameter and volume. The bed depth is determined by dividing the adsorber volume by the bed area (Lagrega, 2000).

5.2.3.3 Sizing a Carbon Column

When designing a carbon column there is the option of using a large diameter column that is short or a smaller diameter column that is tall. Either type of column can hold the same amount of carbon. The diameter can be estimated using a reasonable superficial velocity. Superficial velocity is the velocity that the vapor would attain through the carbon bed if the column was empty. The equation is as follows:

$$V = Q/A \quad (22)$$

In this equation Q is the vapor flow rate and A is the cross-sectional area of the vessel. Typical superficial velocities are 5 to 50 cm/s. As superficial velocities increase, the pressure drop through the vessel increases. This results in increased energy costs (USACAP, 2001). For the purpose of this design a superficial velocity of 25 cm/s will be assumed to minimize cost (USACAP, 2001). The following are calculations to determine the size of the column.

Determining the diameter of the column:

$$A = \pi \frac{D^2}{4} \quad (23)$$

Using equations 22 and 23,

$$D = \sqrt{\frac{4 * Q}{\pi * V}} = \sqrt{\frac{4 * 0.133 m^3 / s}{\pi * 25 cm / s * 1 m / 100 cm}} = 0.823 \text{ m} = 3.14 \text{ ft}$$

The height of the carbon column will be determined by using a required carbon amount of 457 lbs for a period of 3 months, calculated from Table 10.

$$\text{Amount of Carbon Required} = V * \text{Carbon Density} \quad (24)$$

$$\text{Volume} = \frac{\pi}{4} D^2 H \quad (25)$$

Combining these two equations and solving for H gives

$$H = 4 * \frac{\text{Amount of Carbon Required}}{\pi * D^2 * \text{Carbon Density}} = 4 * \frac{457}{\pi * 0.823^2 * 560} = 1.534 \text{ m} = 5.86 \text{ ft}$$

Thus, a column with a diameter of approximately 4 ft with a height of 5 ft would be required. The size of the column will vary depending on the availability of the manufacturer.

5.2.3.4 Unit Recommended

The unit that satisfies the calculated parameters and that is effective in removing a hydrogen sulfide concentration of 30 ppm_v is provided by Calgon Carbon and is called a P-800 Mini Phoenix Plus. The design data for this unit can be seen in Table 11. Please see Appendix D for the proposed unit's design schematics.

Model	Air Flow Capacity Range cfm(m ³ /hr)	HF Carbon Volume ft ³ (m ³)	Number of Canisters	System Dimensions ¹ (LxWxH) feet (meters)	System Operating Weight ² pounds (kg)	System Weight ³ (Maximum) pounds (kg)	System Pressure Drop ⁴ inches WC (N/m ²)	Fan Horsepower HP
P-400	350-400 (595-680)	26 (0.7)	8	16 x 8 x 7.8 (4.9 x 2.5 x 2.4)	4,500 (2,050)	6,600 (2,240)	22 (5,480)	5
P-800	700-800 (1,190-1,360)	26 (0.7)	12	19 x 8 x 7.8 (5.8 x 2.5 x 2.4)	5,200 (2,370)	8,600 (3,910)	28 (6,980)	7.5

Table 11: Mini Phoenix Plus Design Data (Calgon Carbon, 1996)

The Mini-Phoenix Plus is an integrated 3-stage system which consists of a first stage carbon unit followed by Phoenix technology for the second and third stages. The Phoenix technology consists of directing foul air into a series of chambers which contain radial flow canisters. When the air passes through these canisters the hydrogen sulfide is converted into H₂SO₄. The H₂SO₄ can then be washed off with water, which restores the activated carbon capacity. One chamber in the system is water regenerated while the rest of the system treats the foul air (Calgon Carbon, 1996).

6. Cost Analysis

6.1. Nitrate

6.2.1 Initial Costs

Initial costs for this installation are assumed to be the costs associated with the storage tank, pump and tubing, and trenching to lay the tubing between the storage tank and the application point located in a manhole. The tank selected for this project is a Snyder Industries Vertical Storage Tank: Model# 17137. This retails for \$799.99 at northerntools.com. The pump chosen is a Masterflex® C/L® Variable-Speed Tubing Pump: Model WU-77122-20. This pump retails for \$580.00 at masterflex.com. Costs for installing approximately 25 feet of tubing into the concrete are estimated to be approximately \$85.00 per linear foot for a total of \$2,125.00. This price includes labor, trenching and repaving. The total initial costs are estimated to be \$3,504.99.

6.2.2 Annual Costs

6.2.2.1. Bioxide®

The cost of nitrate for this option is calculated based on the amount of nitrate needed and the percentage of nitrate contained in the solution used. CCWRD uses Bioxide® for odor control currently at

a cost to them of \$2.11 per gallon. The Material Safety Data Sheet (MSDS) (refer to Appendix E) states that Bioxide® has 30-70% calcium nitrate tetrahydrate, $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, by weight. Using the lower value of 30%, the pounds of nitrate per pound of Bioxide® was calculated in the following manner.

$$\frac{\text{molecular weight of } (\text{NO}_3^-)_2}{\text{molecular weight of } \text{Ca}(\text{NO}_3^-)_2 \cdot 4\text{H}_2\text{O}} = \frac{\left(\frac{124 \text{ g}}{\text{mole}}\right)\left(\frac{\text{lb}}{454 \text{ g}}\right)}{\left(\frac{236 \text{ g}}{\text{mole}}\right)\left(\frac{\text{lb}}{454 \text{ g}}\right)} = 0.525 \frac{\text{lb NO}_3^-}{\text{lb Ca}(\text{NO}_3^-)_2 \cdot 4\text{H}_2\text{O}} \quad (26)$$

$$\left(0.525 \frac{\text{lb NO}_3^-}{\text{lb Ca}(\text{NO}_3^-)_2 \cdot 4\text{H}_2\text{O}}\right) \left(0.3 \frac{\text{lb Ca}(\text{NO}_3^-)_2 \cdot 4\text{H}_2\text{O}}{\text{lb Bioxide}^\circ}\right) = 0.158 \frac{\text{lb NO}_3^-}{\text{lb Bioxide}^\circ} \quad (27)$$

The MSDS gave the specific weight of Bioxide® as 1.4-1.5 g/ml. This was converted to lb/gal in the following manner using the lower end of given values.

$$\left(\frac{1.4 \text{ g}}{\text{ml}}\right)\left(\frac{\text{lb}}{454 \text{ g}}\right)\left(\frac{1000 \text{ ml}}{\text{L}}\right)\left(\frac{3.785 \text{ L}}{\text{gal}}\right) = 11.67 \frac{\text{lb Bioxide}^\circ}{\text{gal Bioxide}^\circ} \quad (28)$$

Using the preceding values obtained, nitrate was calculated in pounds of nitrate per gallon of Bioxide® in the following manner.

$$\left(0.158 \frac{\text{lb NO}_3^-}{\text{lb Bioxide}^\circ}\right) \left(11.67 \frac{\text{lb Bioxide}^\circ}{\text{gal Bioxide}^\circ}\right) = 1.84 \frac{\text{lb NO}_3^-}{\text{gal Bioxide}^\circ} \quad (29)$$

Using the value calculated in the design parameters section of 22.4 lbs of nitrate needed per day, the pounds of nitrate per gallon of Bioxide® and the cost given above, the cost per year is as follows:

$$\left(22.4 \frac{\text{lb NO}_3^-}{\text{day}}\right) \left(\frac{\text{gal Bioxide}^\circ}{1.84 \text{ lb NO}_3^-}\right) \left(\frac{365 \text{ day}}{\text{year}}\right) \left(\frac{\$2.11}{\text{gal Bioxide}^\circ}\right) = \$9380.30 \text{ per year} \quad (30)$$

6.2.2.2. Labor

Clark County currently has 18 Bioxide® stations being maintained using approximately 80 hours of labor per month. This was used to calculate the number of hours of labor required per Bioxide® station per year. Average hourly wages are based off the “WRD WW COLLECTION SYSTEMS OPERATOR” classification found at clarkcountynv.gov. An hourly labor rate of \$29.59 was used based on the midpoint of the salary range \$23.21-\$35.97.

$$\left(\frac{\frac{80 \text{ hours labor}}{\text{month}}}{18 \text{ Bioxide}^\circ \text{ Stations}}\right) \left(\frac{12 \text{ months}}{\text{year}}\right) = 53.3 \frac{\text{hours labor}}{\text{year}} \text{ per Bioxide}^\circ \text{ Station} \quad (31)$$

$$\left(53.3 \frac{\text{hours labor}}{\text{year}} \text{ per Bioxide® Station} \right) \left(\frac{\$29.59}{\text{hour labor}} \right) = \$1577.15 \text{ per year} \quad (32)$$

6.3 Biofilter

6.3.1 Initial Costs

Important parameters to consider when analyzing the initial cost of the biofilter include: media, plenum, structure, irrigation system, air ducting system, fan system and under drain piping system. Since the complexity and difference of all these parameters varies, there is difficulty in calculating initial cost. The initial cost may be found at low or high dollar amounts since “there are many variations to biofilter design that range from very elaborate equipment and controls to a simple hole in the ground” (EPA, 2003). Nevertheless, considering previous wood chip biofilter designs in the United States provides an educated estimate of total initial costs.

The U.S. Environmental Protection Agency and the Office of Air Quality Planning and Standards prepared a report that presents various biofilter systems with their specific design parameters and costs associated with each system (EPA, 2003). Eight of these facilities that use wood chip biofilters are listed in Table 12. These facilities are located in New Jersey, Hawaii, Virginia, California, New York, Minnesota, and Iowa. They treat different odor sources such as compost, food waste, sewage, and wastewater treatment plant odor emissions. The flow rates range from 2,400 CFM to 210,000 CFM and bed areas from 565 ft² to 42,000 ft². The total costs (for design, construction, and start up) of these systems vary from \$11,400 to \$495,500. When the cost per air flow of these different systems is calculated, a range of \$2.36/CFM to \$37.06/CFM can be observed.

Figure 8 compares the flow rate treated at each facility and the corresponding total initial costs. This comparison shows that the total initial cost for the designed 440 CFM flow rate will be proportional to the initial cost of these other systems. The trend line equation from Figure 9 yields a total initial cost of approximately \$72,040:

$$\text{Total Initial Cost} = 2.2 \frac{\$}{\text{CFM}} * 440 \text{ CFM} + \$71,072 = \$72,040 \quad (33)$$

This total initial cost will cover design costs, constructions cost (labor, media, plenum, structure), and startup cost (irrigation system, plenum, air ducting, fan system, and under drain piping system).

Facility	Odor Source	Flow Rate (CFM)	Area (ft ²)	Cost (\$)	Cost per Air Flow Rate (\$/CFM)
Cape May County Municipal Utilities Authority, Cape May, NJ	Compost	2,400	600	49,800.00	20.75
UNISYN Corporation, Wiamanilo, HI	Food Waste	2,500	625	11,400.00	4.56
Rivanna Water and Sewer Authority, Charlottesville, VA	Sewage	2,825	565	14,300.00	5.06
Harrisburg/Rockingham Regional Sewer Authority, Mt. Crawford, VA	Compost	3,150	790	58,000.00	18.41
Central Contra Costa Sanitary District, Martinez, CA	WWTP	3,500	700	129,700.00	37.06
East Hampton Municipal Solid Waste, East Hampton, NY	Compost	50,000	10,000	135,400.00	2.71
Western Lake Superior Sanitary District, Duluth, MN	WWTP	50,000	11,800	387,000.00	7.74
Davenport Municipal Utilities Authority, Davenport, IA	Compost	210,000	42,000	495,500.00	2.36

Table 12: Existing Wood Chip Biofilter Systems Capacities and Costs

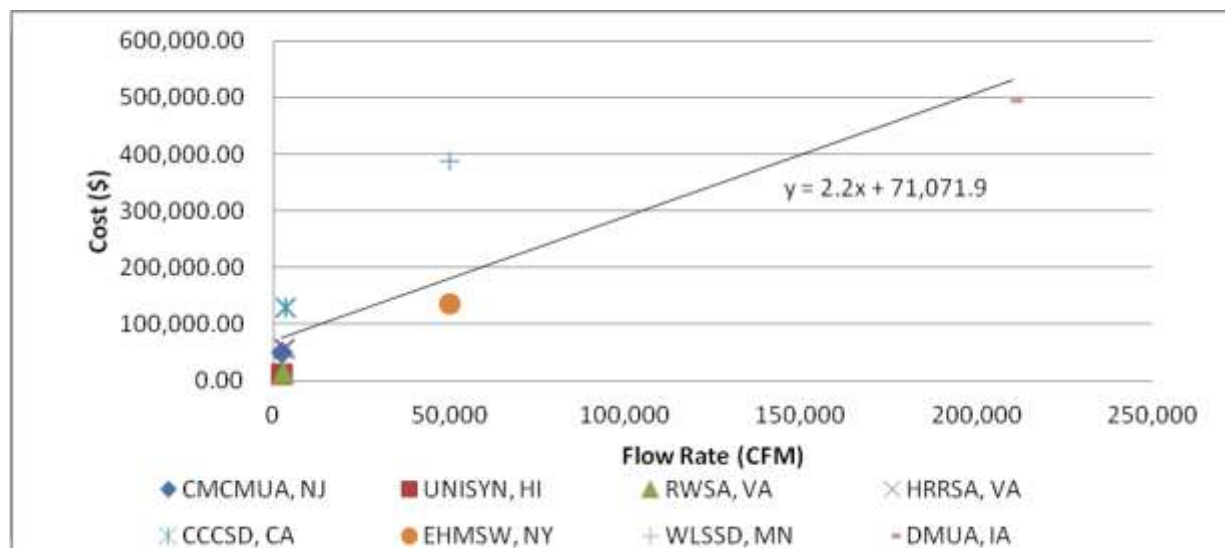


Figure 8: Flow Rate vs. Cost of Existing Biofilter Systems

6.3.2 Annual Costs

6.3.2.1 Media

Per Willie et al., biofilter wood chips are priced at \$0.54/ft³ with a lifecycle of 1.2 years. The total annual cost associated of the biofilter media would be \$198.99 as shown in the following equation:

$$\text{Media Cost} = \text{Volume of Bed} * \text{Price} = 442.2 \text{ ft}^3 * \frac{\$ 0.54}{\text{ft}^3} * \frac{1}{1.2} \text{ year} = \$198.99 / \text{year} \quad (34)$$

6.3.2.2 Water Use

Using Table 7's average monthly evapotranspiration values and summing up each month's water need at the design area of 134 ft² result in an expected total of 8,147 gallons used during a year.

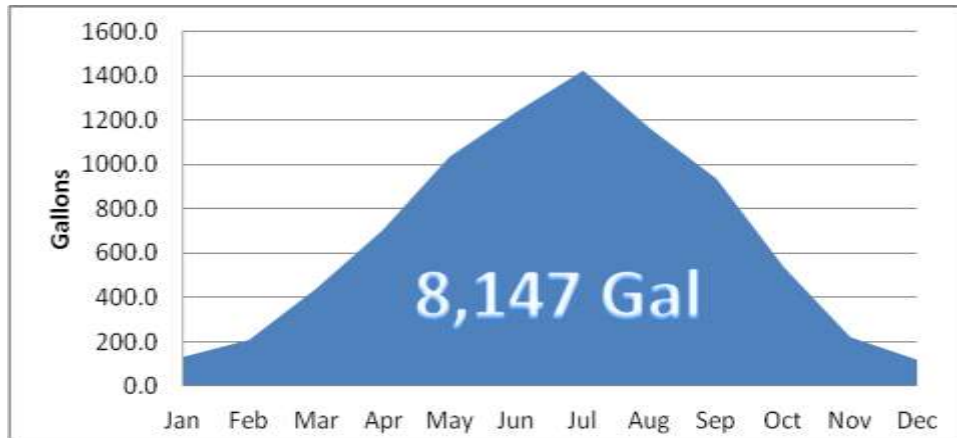


Figure 9: Annual Water Demand

Assuming a business account with a 5/8" meter, and since water need will not exceed 5,000 gallons in any given month, water is charged at \$1.16/1000 gallons (Tier 1). Furthermore, monthly charges include SNWA's commodity charge, reliability charge, and service charge priced at \$1.06, \$.038, and \$10.07, respectively. The total annual cost for water use can be calculated as shown in the following equation:

$$\text{Water Cost} = \frac{\$1.16}{1000 \text{ Gal}} * \frac{8,147 \text{ Gal}}{\text{yr}} + \frac{\$1.06 + \$0.38 + \$10.07}{\text{month}} * \frac{12 \text{ month}}{\text{yr}} = \$147.57/\text{yr} \quad (35)$$

6.3.2.3 Acid Formation Treatment

Using an average of 1,288 lbs of calcium hydroxide buffer needed to neutralize the acid formed in the designed biofilter and a lime industry company's (*Lhoist North America*) calcium hydroxide price of \$238.35/ton, a total annual cost of \$153.50 for acid treatment will be expected.

$$\text{Calcium Hydroxide Cost} = 1,288 \frac{\text{lb}}{\text{yr}} * \frac{1 \text{ ton}}{2000 \text{ lb}} * \frac{\$ 238.35}{\text{ton}} = \$153.50/\text{yr} \quad (36)$$

6.3.2.4 Electricity Use

Electricity consumption in a biofilter can be attributed to the blower. The blower's power rating when operating between pressure losses of 0.5 and 12 inches of water column is approximately 1.8 bhp (1.5 kW). Assuming that the blower will operate on a 24 hour basis and given NV Energy's current electricity rate, the total electricity costs per year are \$1,443 as outlined in the following equation:

$$1.5 \text{ kW} * 24 \frac{\text{hr}}{\text{day}} * 365 \frac{\text{day}}{\text{yr}} * 0.10978 \frac{\$}{\text{kWh}} = \$1,443/\text{yr} \quad (37)$$

6.3.2.5 Labor

Per the Environmental Protection Agency and the Office of Air Quality Planning and Standards' report cost analysis on biofilters, an annual labor cost of \$1,780 can be used by assuming a \$17.8/hr labor rate and a typical 100 hours of operation, maintenance, and supervision required to maintain a biofilter system.

6.4 Granulated Activated Carbon

6.4.1. Initial Costs

Initial costs for activated carbon include the cost of the carbon, columns and the blowers used to draw the air in the system. The unit used for the carbon treatment is the Mini-Phoenix Plus unit which has an approximate cost of \$100,000, which includes the fan. The amount of carbon used is 1,827 lbs/ yr. The typical cost of activated carbon taken from Calgon Carbon is \$1.25 / lb (Calgon Carvon, 1996). The total cost for a yearly supply of activated carbon would be \$2,283.

6.4.2. Annual Costs

6.4.2.1. Media

The carbon being used is called Centaur HSV provided by Calgon Carbon. The price is \$1.25/ lb. In a year 1,827 lbs of carbon are needed to treat 30 ppm of hydrogen sulfide. This gives a total cost for the media of \$2,283 a year.

6.4.2.2. Water Usage

The amount of water needed to regenerate the carbon is approximately 444.4 gallons per regeneration. The carbon will be regenerated 10 times in a year. Using equation 35 the total cost of water used to backwash the carbon in a year is \$143.28.

6.4.2.3. Electricity Use

The fan used in the Mini Phoenix provides 7.5 hp. This is equivalent to 5.5 kW. Using equation 37 the total cost for electricity is \$5,308.

6.3.1.1 Labor

The operating labor of activated carbon unit is very low. One quarter operator hour per shift is what is typically required (EPA). Assuming a \$17.8 / hr rate, the cost of the labor per yr is \$1,624.

6.3.1.2 Disposal

The carbon in the canister units should be regenerated after the water cannot regenerate the carbon any longer. For larger vessels, common practice is for a carbon vendor to pick up the spent carbon and replace it with fresh carbon. The spent carbon is then returned to a central facility for regeneration. EPA encourages both solvent recovery and reuse of spent carbon as pollution prevention and waste minimization techniques. In some cases, the nature of the solvents, including their extremely hazardous nature or the difficulty in desorbing them from the carbon may make disposal the preferred option. In these cases, an entire canister may be shipped to a secure landfill. The cost of landfill disposal could vary considerably, depending on the number of canisters disposed and the location of the landfill. Based on data obtained from two large landfills the disposal cost would range from approximately \$35 to \$65 per canister excluding transportation costs (Mussatti, 2002). The Mini Phoenix Plus unit contains 12 canisters and if the cost is \$65 for the disposal of one canister then the disposal of the carbon on a yearly basis is \$780.

7. Discussion

7.1 Design

One of the most important goals from the technologies' analyses is to determine the resource usage of each technology, namely material, land, energy, and water footprint.

Materials: The primary material that would be used in the nitrate addition system will be the nitrate used in Bioxide®. Based on the nitrate needed and the amount of nitrate per gallon of Bioxide®, this amounts to 8,180 lbs per year. For the biofilter, when utilizing 442.2 ft³ of wood chip media, 6,279 lbs of the media will be required. Furthermore, since this amount of media is expected to be replaced every 1.2 years, the total annual media amount is 5,232 lbs. In addition, 1,290 lbs/yr of calcium hydroxide are needed to neutralize the acid formed in filter. For the GAC system, the amount of carbon needed was calculated to be 1,827 lbs/yr by dividing the amount of contaminant being removed by the adsorption capacity of the carbon.

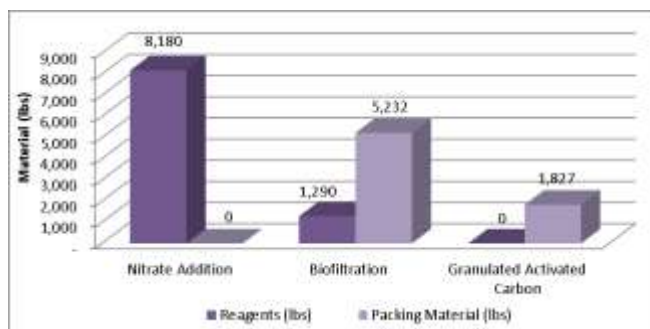


Figure 10: Material Comparison

Land: The storage tank for the Bioxide® solution has a diameter of 7.2 feet and a height of 4.7 feet. The canister is expected to be placed on a 7.5'x7.5' (56 ft²) concrete foundation. The 134 ft² biofilter will be placed in a buried concrete box with 4" thick walls, resulting in a 155 ft² land usage. The Mini-Phoenix Plus ® system's dimensions are 19'x8'x7.8' (LxWxH). Assuming that the system will be placed on a 19.5'x8.5' base, a 166 ft² of land will be required.

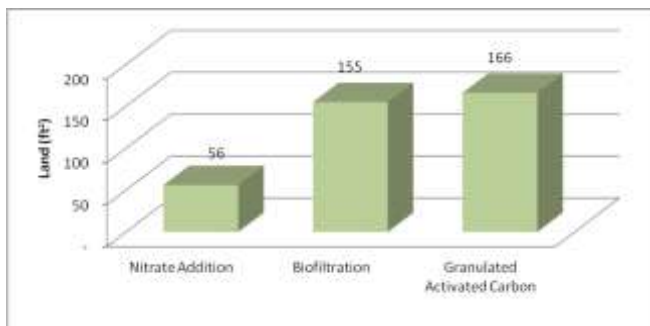


Figure 11: Land Usage Comparison

Energy: When using a 40 W rated Masterflex® C/L® Variable-Speed Tubing Pump to move the Bioxide® solution in the nitrate addition system to the injection point, 350 kWh are expected to be used annually. The biofilter's MK Plastics's PRVS 125 High Pressure/Low Volume Centrifugal Fiberglass blower is rated at 1.5 kW, using a yearly 13,140 kWh. Similarly, the 48,355 kWh of the GAC system was calculated given the unit's rated power over a year.

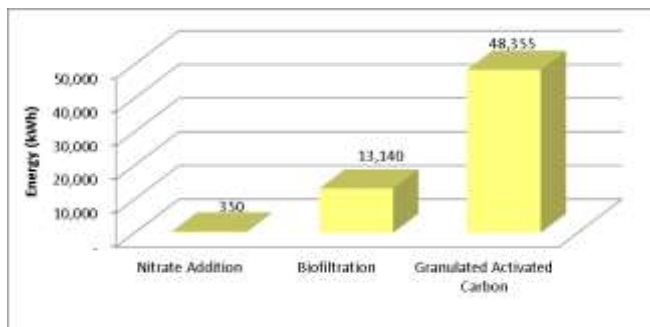


Figure 12: Energy Comparison

Water: For a nitrate addition system the manufacturer provides the nitrate in a solution form and external water use will not be necessary. When considering the evaporation throughout the year on a biofiltration system and the need to keep the media at specific moisture, a water demand of 8,147 gallons can be expected. The GAC system analyzed in this report has a water capacity of 444.4 gallons that will be regenerated.

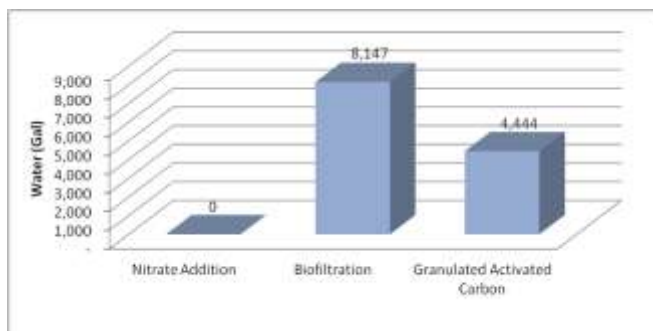


Figure 13: Water Usage Comparison

The media will be regenerated with water ten times during the year requiring a total of 4,444 gallons a year.

7.2 Cost

According to past history of price changes in the United States it is suggested that a minimum annual inflation rate of 3 % and maximum 7% can be expected in the future (Stanley, 2002). In estimating cost, inflation should be taken into consideration. Thus, an inflation factor of 5% was used as an average between minimum and maximum values.

The initial cost and annual cost were taken for each design, with an inflation rate of 5 % and a cash flow analysis was made over a span of 30 years. (refer to Appendix F)

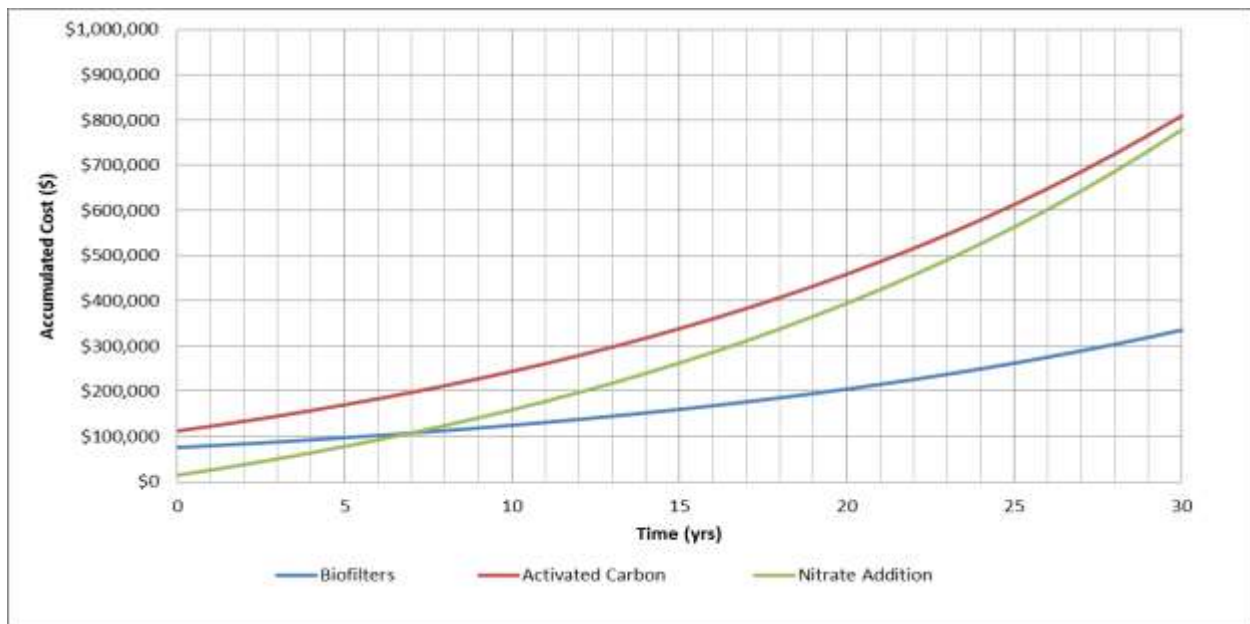


Figure 14: Cash Flow Analysis

From Figure 14 it can be seen that nitrate addition is the most economical alternative for the first seven years. After seven years nitrate addition exceeds the cost of biofilters and increases highly over time. The three technologies are expected to last more than seven years thus, biofiltration is the most cost effective alternative.

8. Recommendation

When considering resource usage, it can be concluded that the GAC alternative uses the least amount of reagents and packing material while nitrate addition uses the least amount of land, energy and water. Furthermore, when considering costs, nitrate addition is the most effective for the first seven years. Since the ideal odor control technology will have a lifespan of more than seven years biofiltration is a preferred technology. Although biofiltration is not the most effective when it comes to resource usage, it is the most cost effective technology by a large margin, and it is for this reason that cost overrides the other design criteria. Given a thirty year life span, the overall cost for either GAC or nitrate addition is more than double the cost of biofiltration. In addition, among the three technologies, biofiltration offers a more aesthetical design given that it will serve as a planter and odor treating system.

Given that this project strictly looked at odor control, biofiltration is the recommended solution in this location. It is cost effective and can be implemented in an aesthetically pleasing manner. It does have a drawback though, as it does not address corrosion in the sewer system that is a direct result of the

hydrogen sulfide. This corrosion can severely lower the lifespan of a sewer system, leading to costly repairs and replacements. It is for this reason that it is recommended that further research be done on the corrosion in the sewer system so as to evaluate whether another option would be more appropriate if all the issues associated with hydrogen sulfide are included.

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Appendices

Appendix A

Determination of Air Flow in Pipes

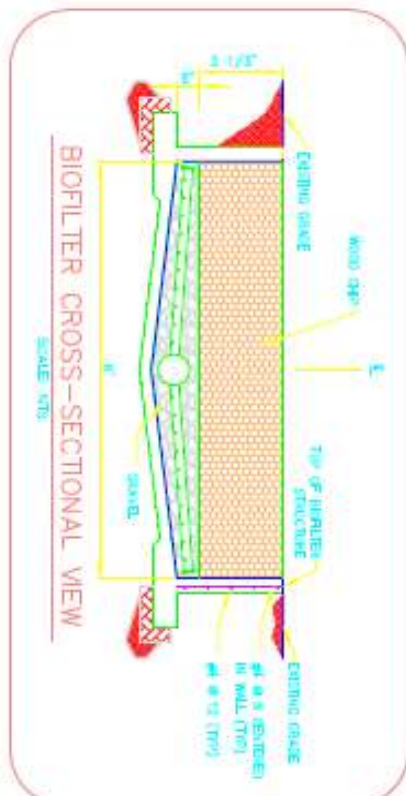
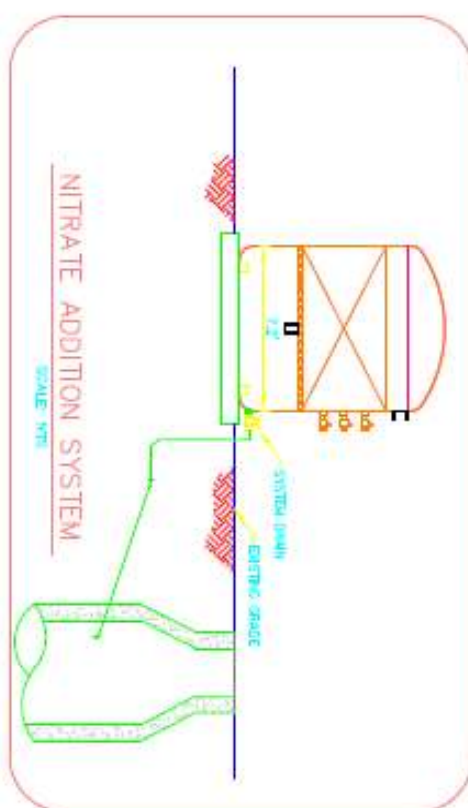
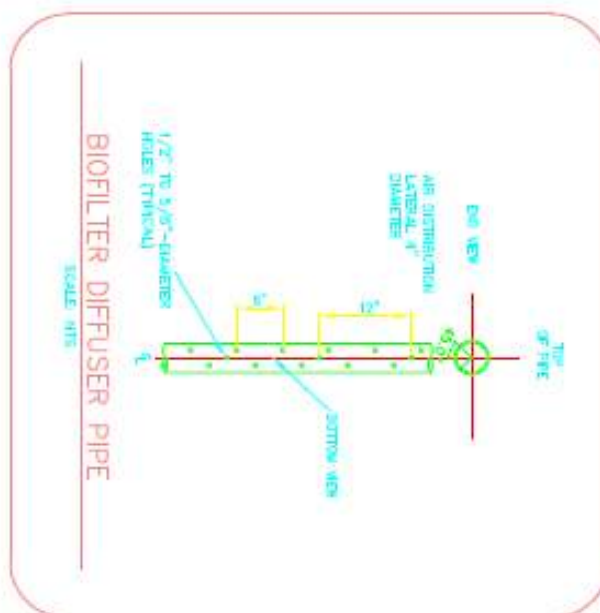
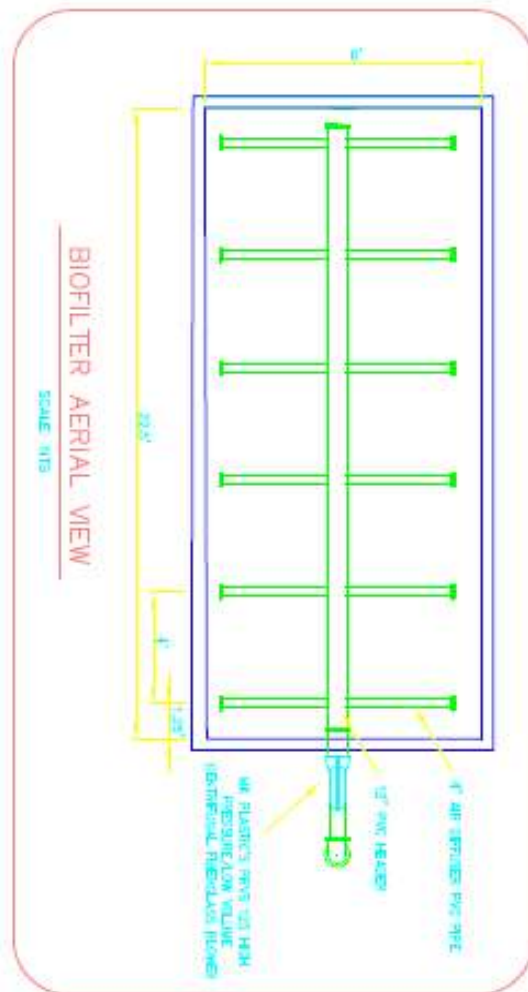
Down-stream going North on S. Las Vegas Blvd Towards Flamingo										
AIRFLOW LOAD EVALUATION										
No.	Element Description or Identification	Structure Diameter in.	Structure Height ft	Cross-section Area in2	Volume ft3	Air Changes Per Hour	Airflow* CFM	Airflow* CFH	Cumulative Airflow* CFM	Cumulative Airflow* CFH
1.01	UN350B1-UNB50B	48.00	5.50	1,809.56	69.12	8.00	9.22	552.92	9.22	552.92
1.02	URHS100-URHS9	48.00	4.67	1,809.56	58.68	8.00	7.82	469.48	7.82	469.48
1.03	UN350B-UN350A	48.00	5.95	1,809.56	74.77	8.00	9.97	598.16	17.79	1,067.64
1.04	UN350A-UN350A1	48.00	3.52	1,809.56	44.23	8.00	5.90	353.87	5.90	353.87
1.05	URHS70A-URHS70	48.00	6.75	1,809.56	84.82	8.00	11.31	678.58	11.31	678.58
1.06	URHS70-URHS60	48.00	7.69	1,809.56	96.64	8.00	12.88	773.08	47.89	2,873.17
1.07	URHS60-URHS50	48.00	7.81	1,809.56	98.14	8.00	13.09	785.15	60.97	3,658.32
1.08	URHS50-URHS40	48.00	9.26	1,809.56	116.36	8.00	15.52	930.92	76.49	4,589.24
1.09	URHS40-URHS30	48.00	8.90	1,809.56	111.84	8.00	14.91	894.73	91.40	5,483.96
1.10	URHS30-URHS20	48.00	8.45	1,809.56	106.19	8.00	14.16	849.49	105.56	6,333.45
1.11	URHS20-URHS1	48.00	9.72	1,809.56	122.15	8.00	16.29	977.16	107.69	6,461.13
1.12	URHS1-UFS150Z	48.00	9.00	1,809.56	113.10	8.00	15.08	904.78	120.64	7,238.23
						Total	146.14	CFM		
						Total	8768.31	CFH		

Down-stream of W. Flamingo Rd										
AIRFLOW LOAD EVALUATION										
No.	Element Description or Identification	Structure Diameter in.	Structure Height ft	Cross-section Area in2	Volume ft3	Air Changes Per Hour	Airflow CFM	Airflow CFH	Cumulative Airflow* CFM	Cumulative Airflow* CFH
2.01	UFS150Z-UFS130D	48.00	13.35	1,809.56	167.76	8.00	22.37	1,342.09	22.37	1,342.09
2.02	UFS130D-UFS140Z	48.00	13.79	1,809.56	173.29	8.00	23.11	1,386.32	23.11	1,386.32
2.03	UFS140-UFS130B	48.00	14.05	1,809.56	176.56	8.00	23.54	1,412.46	46.65	2,798.78
						Total	69.01	CFM		
						Total	4140.87	CFH		

Down-stream going North on S. Las Vegas Blvd Towards Flamingo										
AIRFLOW LOAD EVALUATION										
No.	Element Description or Identification	Structure Diameter in.	Structure Height ft	Cross-section Area in2	Volume ft3	Air Changes Per Hour	Airflow* CFM	Airflow* CFH	Cumulative Airflow* CFM	Cumulative Airflow* CFH
3.01	UN320B-UFS170Z	48.00	6.70	1,809.56	84.19	8.00	11.23	673.56	11.23	673.56
3.02	UFS170Z-UFS160Z	48.00	7.70	1,809.56	96.76	8.00	12.90	774.09	12.90	774.09
3.03	UFS160Z-UFS150Z	48.00	9.00	1,809.56	113.10	8.00	15.08	904.78	27.98	1,678.87
						Total	39.21	CFM		
						Total	2352.42	CFH		

Appendix B

Proposed Design Schematics for Nitrate Addition and Biofiltration Systems



Appendix C

MK Plastics' PRVS 125 High Pressure/Low Volume Centrifugal Fiberglass Blower

PRVS 125 PERFORMANCE HIGH PRESSURE/LOW VOLUME CENTRIFUGAL FIBERGLASS BLOWER

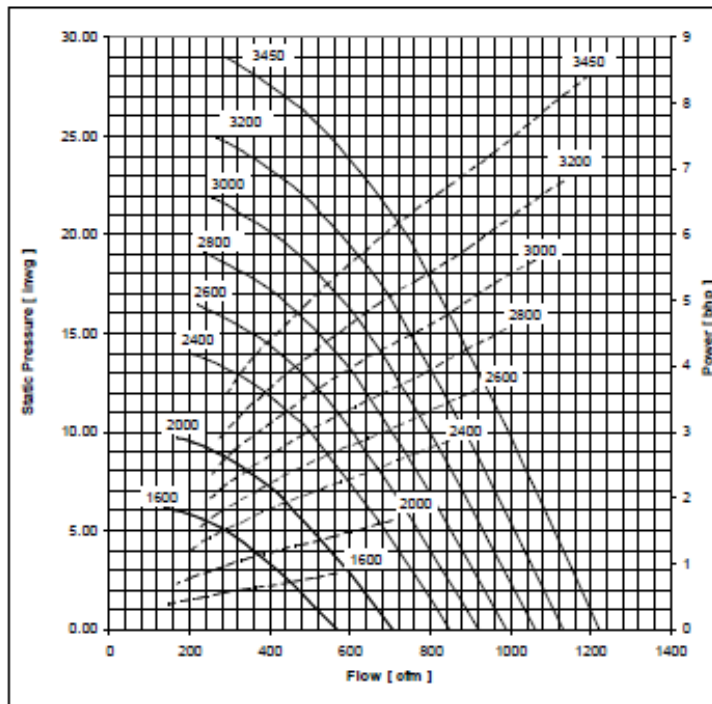
Impeller DIA. [in] = 20.50"

Max. Speed [rpm] = 3540

Outlet Area [ft²] = 0.114

Max. Motor Frame = 256T

Flow	O.V.	STATIC PRESSURE, inches of water																			
		4		6		8		10		12		14		16		18		20		26	
CFM	FPM	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
250	2273	1420	0.39	1670	0.58	1891	0.78	2089	1.00	2267	1.22	2433	1.45	2589	1.67						
350	3162	1582	0.62	1805	0.85	2005	1.10	2189	1.36	2359	1.63	2517	1.90	2670	2.19	2814	2.49	2951	2.79	3323	3.74
450	4091	1782	0.92	1979	1.22	2153	1.51	2326	1.82	2487	2.14	2635	2.46	2779	2.79	2914	3.13	3043	3.48	3409	4.58
550	5000	1999	1.40	2182	1.73	2345	2.07	2495	2.41	2635	2.76	2779	3.14	2914	3.52	3043	3.91	3164	4.30		
650	5909	2232	2.03	2397	2.40	2551	2.79	2691	3.18	2826	3.58	2951	3.99	3070	4.40	3191	4.83	3311	5.28		
750	6818	2476	2.84	2623	3.25	2767	3.69	2901	4.13	3026	4.58	3147	5.05	3261	5.51	3370	5.97				
850	7727	2726	3.88	2864	4.34	2991	4.79	3117	5.29	3238	5.80	3353	6.31								



Performance certified is for installation type D: Ducted Inlet, Ducted Outlet. Power rating (BHP) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories).

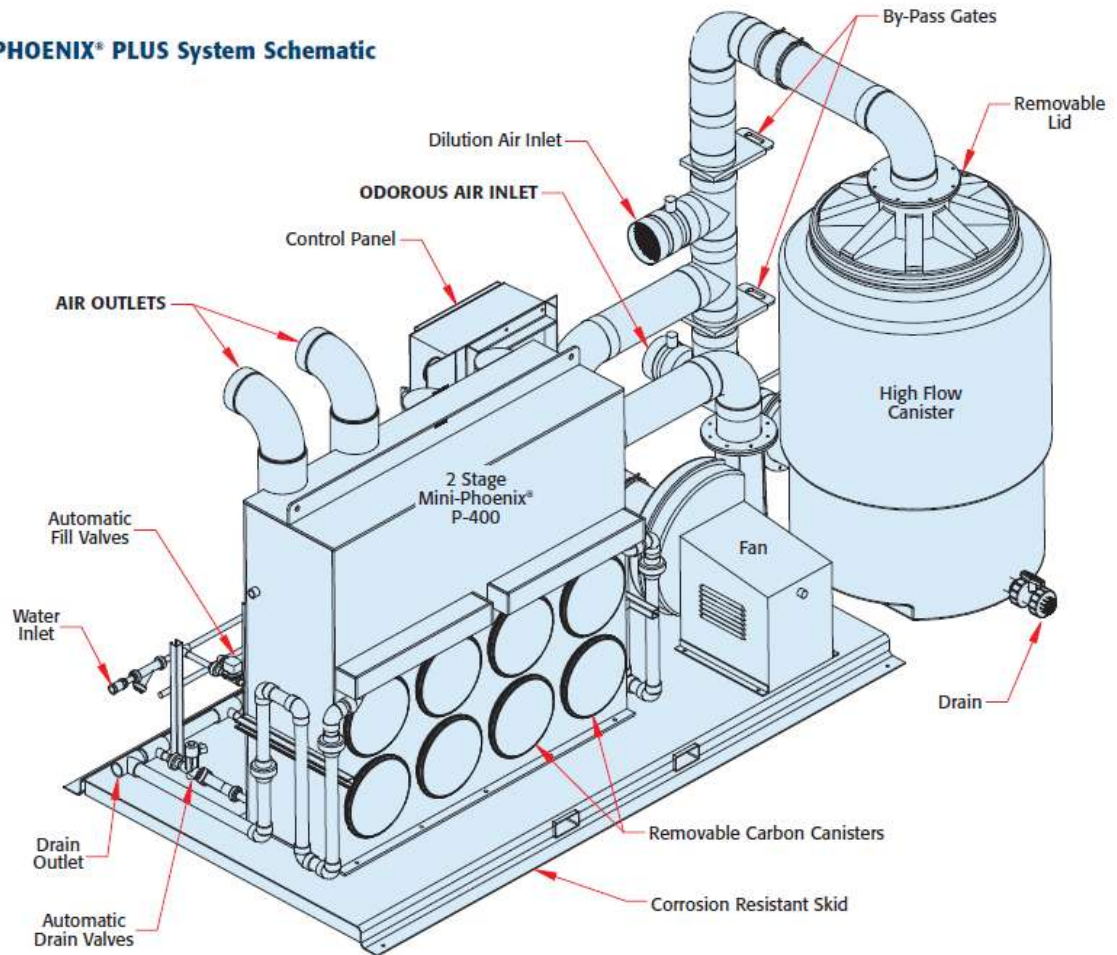
Standard Conditions
70°F
0.075 lb/ft³

— CFM vs. SP
--- BHP

Appendix D

Proposed Unit's Design Schematics for GAC System (Calgon Carbon)

MINI-PHOENIX® PLUS System Schematic



Appendix E
Siemens Material Safety Data Sheet



Siemens Industry, Inc.
Water Technologies Business Unit

Material Safety Data Sheet

SECTION 1 – CHEMICAL PRODUCT AND COMPANY INFORMATION

Product: Bioxide® Plus 71

Chemical Family: Odor Control Compound

Manufacturer's Name: Siemens Industry, Inc. - Water Technologies Business Unit
Address: 2650 Tallevast Road, Sarasota, FL 34243

Product/Technical Information Phone Number: (941) 355.2971

Medical/Handling Emergency Phone Number: CHEMTREC (800) 424.9300

24 hours a day
Transportation Emergency Phone Number: CHEMTREC (800) 424.9300
24 hours a day

Issue Date: April 2009

Revision Number / Date: Rev 2 April 2011

SECTION 2 – COMPOSITION INFORMATION

<u>Chemical Name</u>	<u>Percent by Weight</u>	<u>CAS#</u>
Calcium Nitrate Tetrahydrate	30-70	13477-34-4
Sodium chlorite	<2.8	7758-19-2
Water	Balance	7732-18-5

SECTION 3 – HAZARDS IDENTIFICATION

Appearance & Odor: Colorless to amber liquid with a slight chlorine odor.

Emergency Overview: Spills will make the floor slippery. Do not allow the product to evaporate to dryness as the dry residue can ignite upon contact with combustible materials.

Fire & Explosion Hazards: Not flammable.

Primary Route(s) of Exposure: Skin and eye contact, and inhalation.

Inhalation – Acute Effects: Inhalation of vapors or mists may cause irritation to the respiratory tract. Breathing vapor or mists may be harmful.

Skin Contact – Acute Effects: Occasional brief contact with the liquid is not expected to result in significant irritation. Prolonged contact may cause irritation.

Eye Contact – Acute Effects: Eye contact will irritate and may burn the eyes.

Ingestion – Acute Effects: May be harmful if swallowed. May cause gastrointestinal irritation and nausea.

SECTION 4 – FIRST AID MEASURES

Inhalation First Aid: Remove affected person to fresh air. Give artificial respiration ONLY if breathing has stopped. Obtain medical attention.



Siemens Industry, Inc.
Water Technologies Business Unit

Material Safety Data Sheet

Skin Contact First Aid: Immediately remove clothing from affected area and wash skin with flowing water and soap. Clothing should be washed before reuse. Obtain medical attention if irritation persists.

Eye Contact First Aid: Immediately irrigate eyes with flowing water continuously for 15 minutes while holding eyes open. Contacts should be removed before or during flushing. Obtain medical attention if irritation develops.

Ingestion First Aid: If victim is alert, rinse mouth with water and give water to drink. Do not induce vomiting. If spontaneous vomiting occurs, have affected person lean forward with head down to avoid breathing in vomitus. Rinse mouth again and give more water to drink. Obtain medical attention immediately.

Medical Conditions Aggravated: Pre-existing disorders of the following organs or systems include: respiratory system (including asthma and other breathing disorders), and gastrointestinal system.

Note to Physician: Chlorine dioxide vapors are emitted when this product contacts acids or chlorine. If these vapors are inhaled, monitor the patient closely for delayed development of pulmonary edema which may occur up to 48-72 hr after inhalation.

SECTION 5 – FIRE FIGHTING MEASURES

Flash Point/Method: Not applicable

Auto Ignition Temperature: Not applicable

Upper/Lower Explosion Limits: Not applicable

Extinguishing Media: Use extinguishing agent suitable for the surrounding fire.

Fire Fighting Procedures: Firefighters should wear full protective clothing and a NIOSH/OSHA approved positive pressure self-contained breathing apparatus. Approach fire from upwind to avoid hazardous vapors and toxic decomposition products. Use flooding quantities of water as fog or spray. This product becomes a fire or explosion hazard if allowed to dry, so use water spray to keep fire-exposed containers cool.

Fire & Explosion Hazards: If this product is allowed to dry it can ignite upon contact with combustible materials.

Hazardous Products of Decomposition and/or Combustion: Gaseous oxides of sodium and nitrogen when heated above the melting point of the solid 306.8° C.

NFPA Ratings: HEALTH -1 FLAMMABILITY - 0 REACTIVITY - 1

Material Safety Data Sheet

SECTION 6 – ACCIDENTAL RELEASE MEASURES

Wear appropriate personal protective equipment (See Section 8). Stop leak if safe to do so without risk. Ventilate area. If safe to do so, absorb spill with inert material, (e.g., dry sand or earth), then place into a chemical waste container. Do not use organic materials, such as wood shavings, wood dust or paper, to absorb spills. Flush area with flooding amounts of water. **DO NOT DUMP ON THE GROUND OR INTO ANY BODY OF WATER.** All disposal methods must be in compliance with all Federal, State, Local and Provincial laws and regulations. Regulations may vary in different locations. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator.

SECTION 7 – HANDLING AND STORAGE

Handling: Wash thoroughly after handling. Use with adequate ventilation. Do not get in eyes, on skin, or on clothing. Do not breathe mists or vapors. Wear all recommended personal protective equipment (See Section 8).

Storage: Protect from physical damage and freezing. Store in a cool well ventilated place away from incompatible materials such as combustible, organic, or other readily oxidizable materials. Avoid storage on wood floors. Keep containers tightly closed. Do not store in very warm areas where the liquid may evaporate.

SECTION 8 – PERSONAL PROTECTION/ EXPOSURE CONTROL

Respiratory Protection: If use conditions generate mists or vapors, wear a NIOSH-approved respirator with acid gas canisters.

Skin Protection: Wear rubber gloves and other protective clothing such as coveralls and rubber boots as appropriate to prevent skin contact. Wear a rubber apron if splashing is likely.

Eye Protection: Wear chemical goggles. In addition, wear a faceshield when connecting and disconnecting piping or if splashing is likely.

Ventilation Protection: General exhaust ventilation under normal use conditions. If vapors or mist are generated use local exhaust ventilation.

Other Protection: Recommend means of washing the eyes with a gentle flow of cool to tepid water be readily available in all areas where this material is handled or stored. Employees should wash their hands and face before eating, drinking, or using tobacco products.

Exposure Limits: Exposure limits have not been established for this product or its components.

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point: > 212 °F

Freezing Point: < 25 °F

Specific Gravity: 1.4 – 1.5 at 70 °F

Solubility in Water: Complete

Volatile Percentage: 30%

pH: 8.0 – 10.0

Material Safety Data Sheet

SECTION 10 – STABILITY AND REACTIVITY

Stability: This product is stable under normal use conditions.

Incompatibilities: Avoid contact with wood and other flammable organics, flammable or combustible materials, cyanides, sodium hypophosphite, or boron phosphide.

Polymerization: Hazardous polymerization will not occur.

Decomposition: After water has evaporated, this material may thermally decompose producing oxides of nitrogen. Explosive and toxic chlorine dioxide gas will be generated on contact with acids or chlorine.

Conditions to Avoid: Do not allow to evaporate to dryness. Do not heat to 1000° F as an explosion may occur in the presence of reducing agents or inorganic materials.

SECTION 11 – TOXICOLOGICAL INFORMATION

Toxicological Data: Not established for this product. However, for its components:

Calcium nitrate: Oral (rat) LD50 = 302 mg / kg

Sodium chlorite: Oral (rat) LD50 = 165 mg / kg

Chronic Effects: The toxicity of nitrates is due to their in vivo conversion to nitrites which may lead to methemoglobinemia. Sodium nitrate may react with secondary and tertiary amines to form nitrosamines, some of which are suspect cancer agents.

Mutagenicity: Sodium chlorite, a minor component of this material, has tested positive in some studies with laboratory animals. The significance of these results for human health is unclear because the oxidizing effects of the chlorite or the salty effects of the sodium may significantly affect the ability of the tests to accurately detect mutagens.

Carcinogenicity: There are no known carcinogenic effects of this product.

Neurotoxicity: No data available for this product or its components.

Other Effects: The substance may cause effects on the blood, resulting in formation of methemoglobin when ingested.

Target Organs: Target organs include the skin, eyes, digestive tract and respiratory system.

SECTION 12 – ECOLOGICAL INFORMATION

The ecological effects are not known. Safely store product to prevent release to the environment and water supplies.

SECTION 13 – DISPOSAL CONSIDERATIONS

Material that cannot be used, or chemically reprocessed for use, and empty containers should be disposed of in accordance with all applicable regulations. Product containers should be thoroughly emptied before disposal. Generators of waste material are required to evaluate all



Siemens Industry, Inc.
Water Technologies Business Unit

Material Safety Data Sheet

waste for compliance with RCRA and any local disposal procedures and regulations. NOTE: State and local regulations may be more stringent than federal regulations.

SECTION 14 – TRANSPORTATION INFORMATION

Domestic Transportation: This material is not considered a hazardous material for domestic transportation purposes.

International Transportation: This material is not considered a dangerous good for international transportation purposes.

SECTION 15 – REGULATORY INFORMATION

OSHA HAZARD COMMUNICATION STANDARD: Health hazard

CERCLA HAZARDOUS SUBSTANCE No RQ: None

SARA SECTION 311/312:

Acute Health = Yes

Chronic Health = No

Fire = No

Pressure Release = No

Reactivity = No

SARA SECTION 313: No

OSHA PROCESS SAFETY (29CFR1910.119): No

CALIFORNIA PROPOSITION 65: Not listed.

SECTION 16 – OTHER INFORMATION

Disclaimer: The information contained herein is based on data considered accurate. However, no warranty is expressed or implied regarding the accuracy of these data or the results to be obtained from the user thereof. It is the buyer's responsibility to ensure that its activities comply with federal, state, provincial and local laws.

Revision Indicator: Legal Entity name change 04/01/11

Appendix F
Cash Flow Analysis Tables

Biofiltration System Cash Flow Analysis (440 cfm, 30 ppm)					
Year	Inflation Factor (5%)	Initial Cost	Annual Cost	Inflated Cost	Accumulated Cost
0	1.00	\$72,040.00	\$3,723.00	-	\$75,763.00
1	1.05	-	\$3,723.00	\$3,909.15	\$79,672.15
2	1.10	-	\$3,723.00	\$4,104.61	\$83,776.76
3	1.16	-	\$3,723.00	\$4,309.84	\$88,086.60
4	1.22	-	\$3,723.00	\$4,525.33	\$92,611.93
5	1.28	-	\$3,723.00	\$4,751.60	\$97,363.52
6	1.34	-	\$3,723.00	\$4,989.18	\$102,352.70
7	1.41	-	\$3,723.00	\$5,238.63	\$107,591.33
8	1.48	-	\$3,723.00	\$5,500.57	\$113,091.90
9	1.55	-	\$3,723.00	\$5,775.59	\$118,867.49
10	1.63	-	\$3,723.00	\$6,064.37	\$124,931.87
11	1.71	-	\$3,723.00	\$6,367.59	\$131,299.46
12	1.80	-	\$3,723.00	\$6,685.97	\$137,985.44
13	1.89	-	\$3,723.00	\$7,020.27	\$145,005.71
14	1.98	-	\$3,723.00	\$7,371.29	\$152,376.99
15	2.08	-	\$3,723.00	\$7,739.85	\$160,116.84
16	2.18	-	\$3,723.00	\$8,126.84	\$168,243.68
17	2.29	-	\$3,723.00	\$8,533.18	\$176,776.87
18	2.41	-	\$3,723.00	\$8,959.84	\$185,736.71
19	2.53	-	\$3,723.00	\$9,407.84	\$195,144.55
20	2.65	-	\$3,723.00	\$9,878.23	\$205,022.77
21	2.79	-	\$3,723.00	\$10,372.14	\$215,394.91
22	2.93	-	\$3,723.00	\$10,890.75	\$226,285.66
23	3.07	-	\$3,723.00	\$11,435.28	\$237,720.94
24	3.23	-	\$3,723.00	\$12,007.05	\$249,727.99
25	3.39	-	\$3,723.00	\$12,607.40	\$262,335.39
26	3.56	-	\$3,723.00	\$13,237.77	\$275,573.16
27	3.73	-	\$3,723.00	\$13,899.66	\$289,472.82
28	3.92	-	\$3,723.00	\$14,594.64	\$304,067.46
29	4.12	-	\$3,723.00	\$15,324.37	\$319,391.83
30	4.32	-	\$3,723.00	\$16,090.59	\$335,482.42

GAC System Cash Flow Analysis (440 cfm, 30 ppm)					
Year	Inflation Factor (5%)	Initial Cost	Annual Cost	Inflated Cost	Accumulated Cost
0	1.00	\$102,283.00	\$9,995.25	-	\$112,278.25
1	1.05	-	\$9,995.25	\$10,495.01	\$122,773.26
2	1.10	-	\$9,995.25	\$11,019.76	\$133,793.03
3	1.16	-	\$9,995.25	\$11,570.75	\$145,363.78
4	1.22	-	\$9,995.25	\$12,149.29	\$157,513.07
5	1.28	-	\$9,995.25	\$12,756.75	\$170,269.82
6	1.34	-	\$9,995.25	\$13,394.59	\$183,664.41
7	1.41	-	\$9,995.25	\$14,064.32	\$197,728.73
8	1.48	-	\$9,995.25	\$14,767.54	\$212,496.27
9	1.55	-	\$9,995.25	\$15,505.91	\$228,002.18
10	1.63	-	\$9,995.25	\$16,281.21	\$244,283.39
11	1.71	-	\$9,995.25	\$17,095.27	\$261,378.66
12	1.80	-	\$9,995.25	\$17,950.03	\$279,328.69
13	1.89	-	\$9,995.25	\$18,847.53	\$298,176.23
14	1.98	-	\$9,995.25	\$19,789.91	\$317,966.14
15	2.08	-	\$9,995.25	\$20,779.41	\$338,745.54
16	2.18	-	\$9,995.25	\$21,818.38	\$360,563.92
17	2.29	-	\$9,995.25	\$22,909.30	\$383,473.22
18	2.41	-	\$9,995.25	\$24,054.76	\$407,527.98
19	2.53	-	\$9,995.25	\$25,257.50	\$432,785.48
20	2.65	-	\$9,995.25	\$26,520.37	\$459,305.85
21	2.79	-	\$9,995.25	\$27,846.39	\$487,152.24
22	2.93	-	\$9,995.25	\$29,238.71	\$516,390.96
23	3.07	-	\$9,995.25	\$30,700.65	\$547,091.60
24	3.23	-	\$9,995.25	\$32,235.68	\$579,327.28
25	3.39	-	\$9,995.25	\$33,847.46	\$613,174.75
26	3.56	-	\$9,995.25	\$35,539.84	\$648,714.59
27	3.73	-	\$9,995.25	\$37,316.83	\$686,031.42
28	3.92	-	\$9,995.25	\$39,182.67	\$725,214.09
29	4.12	-	\$9,995.25	\$41,141.80	\$766,355.89
30	4.32	-	\$9,995.25	\$43,198.89	\$809,554.79

Nitrate Addition System Cash Flow Analysis (440 cfm, 30 ppm)					
Year	Inflation Factor (5%)	Initial Cost	Annual Cost	Inflated Cost	Accumulated Cost
0	1.00	\$3,504.99	\$10,957.45	-	\$14,462.44
1	1.05	-	\$10,957.45	\$11,505.32	\$25,967.76
2	1.10	-	\$10,957.45	\$12,080.59	\$38,048.35
3	1.16	-	\$10,957.45	\$12,684.62	\$50,732.97
4	1.22	-	\$10,957.45	\$13,318.85	\$64,051.82
5	1.28	-	\$10,957.45	\$13,984.79	\$78,036.61
6	1.34	-	\$10,957.45	\$14,684.03	\$92,720.64
7	1.41	-	\$10,957.45	\$15,418.23	\$108,138.87
8	1.48	-	\$10,957.45	\$16,189.14	\$124,328.02
9	1.55	-	\$10,957.45	\$16,998.60	\$141,326.62
10	1.63	-	\$10,957.45	\$17,848.53	\$159,175.15
11	1.71	-	\$10,957.45	\$18,740.96	\$177,916.11
12	1.80	-	\$10,957.45	\$19,678.01	\$197,594.11
13	1.89	-	\$10,957.45	\$20,661.91	\$218,256.02
14	1.98	-	\$10,957.45	\$21,695.00	\$239,951.02
15	2.08	-	\$10,957.45	\$22,779.75	\$262,730.77
16	2.18	-	\$10,957.45	\$23,918.74	\$286,649.51
17	2.29	-	\$10,957.45	\$25,114.68	\$311,764.19
18	2.41	-	\$10,957.45	\$26,370.41	\$338,134.60
19	2.53	-	\$10,957.45	\$27,688.93	\$365,823.53
20	2.65	-	\$10,957.45	\$29,073.38	\$394,896.91
21	2.79	-	\$10,957.45	\$30,527.05	\$425,423.95
22	2.93	-	\$10,957.45	\$32,053.40	\$457,477.35
23	3.07	-	\$10,957.45	\$33,656.07	\$491,133.42
24	3.23	-	\$10,957.45	\$35,338.87	\$526,472.29
25	3.39	-	\$10,957.45	\$37,105.81	\$563,578.10
26	3.56	-	\$10,957.45	\$38,961.11	\$602,539.21
27	3.73	-	\$10,957.45	\$40,909.16	\$643,448.37
28	3.92	-	\$10,957.45	\$42,954.62	\$686,402.99
29	4.12	-	\$10,957.45	\$45,102.35	\$731,505.34
30	4.32	-	\$10,957.45	\$47,357.47	\$778,862.81