Building a legacy – *your* legacy.

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April 12, 2016

The Honorable Mayor, City Council and Staff
c/o Mark Casey
City of St. Anthony Village
3301 Silver Lake Road NE
Minneapolis, MN 55418-1603

Re: St. Anthony Village 1,4-Dioxane Feasibility
St. Anthony Village, MN
WSB Project No. 3183-00

Dear Honorable Mayor, City Council, and Staff:

We are pleased to present to you the attached St. Anthony Village 1,4-Dioxane Feasibility Report which analyzed the following options for addressing concerns presented by the presence of 1,4-Dioxane (Dioxane) in the City's water supply:

- Option 1: Blend City Wells
- Option 2: Construct Deeper Mount-Simon Hinckley Wells
- Option 3: Purchase Water from Minneapolis Water
- Option 4: Purchase Water from St. Paul Regional Water
- Option 5: Implement a Water Treatment System for Dioxane

Additionally attached for your consideration is a resolution accepting the feasibility report and authorizing preparation of final plans, specifications, and advertisement for bid of Option 5.

If you have any questions or concerns, you may call me at 763-287-7182, and I will be present at your April 12, 2016 Council Meeting.

Sincerely,

WSB & Associates, Inc.

Todd E. Hubmer, PE
City Engineer

Attachments

St. Anthony Village
3301 Silver Lake Road NE • St. Anthony, MN 55418

FEASIBILITY Report

December 8, 2015

St. Anthony Village 1,4-Dioxane

City of St. Anthony Village
Hennepin and Ramsey Counties, Minnesota

WSB Project No. 3183-00

WSB & Associates, Inc.
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ST. ANTHONY VILLAGE 1,4-DIOXANE FEASIBILITY STUDY

FOR THE

CITY OF ST. ANTHONY VILLAGE, MINNESOTA

December 8, 2015

Prepared By:

WSB & Associates, Inc.
701 Xenia Avenue South, Suite 300
Minneapolis, MN 55416
763-541-4800
763-541-1700 (Fax)

CERTIFICATION

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Greg F. Johnson, PE

Date: December 8, 2015 Lic. No. 26430

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1. EXECUTIVE SUMMARY

The St. Anthony Village City Council authorized WSB & Associates, Inc. to study the available options to address 1,4-Dioxane (Dioxane) that has been detected in the City's water supply and provide a long term, reliable source of potable water that meets all the recommended State and Federal health guidelines. This Feasibility Report summarizes these options. There may be sources of third-party funding to pay for some or all of the costs associated with remedial action to address the Dioxane contamination. This Feasibility Report does not attempt to assess the likelihood or scale of such funding, and does not evaluate remedial options based on funding source or amount.

Dioxane has been detected in the City's three drinking water wells since March 2015, likely emanating from the Twin Cities Army Ammunition Plant in Arden Hills (TCAAP). Dioxane is used to stabilize chlorinated solvents and can be found in personal care products, laundry detergents, and food in small amounts. TCAAP used Dioxane as an additive in the solvents used at the facility. Other contaminants from TCAAP have been detected since the early 1980s in the aquifers supplying groundwater for the City. In contrast, Dioxane was recently classified as an emerging contaminant by the Environmental Protection Agency (EPA), and testing for Dioxane in the aquifers below the City first occurred in March 2015.

This report summarizes five options that were selected for analysis as possible means to address Dioxane in the City's drinking water:

- Option 1 – Blend the existing wells;
- Option 2 – Construct deeper Mount-Simon Hinckley wells;
- Option 3 – Purchase water from Minneapolis Water;
- Option 4 – Purchase water from St. Paul Regional Water; and
- Option 5 – Implement treatment to remove Dioxane.

During initial screening, Options 1 and 4 were determined to be either ineffective and/or clearly inferior to other measures, and were therefore not analyzed in detail. Costs were evaluated for Options 2, 3, and 5 as these were the options that were determined to be most feasible. A 3.5% inflation rate was assumed for the O&M costs to match other programs within the City. The total estimated 20-year capital costs and operation and maintenance costs for each of these options is as follows:

Option	Estimated Capital Cost	Finance Cost (4% Interest)	Estimated 20-Year O&M Cost (3.5% inflation rate)	20-Year Cost of Purchasing/ Producing Water	Estimated Total 20-Year Cost
2	$7,115,600	$3,356,000	$2,812,300	$4,954,000	$18,237,900
3	$9,480,300	$4,471,200	$4,487,800	$17,472,000	$35,911,300
5	$7,177,600	$3,385,200	$1,080,200	$4,954,000	$16,597,000

2. INTRODUCTION

2.1 Authorization

The St. Anthony City Council authorized WSB & Associates, Inc. to study the available options to address 1,4-Dioxane (Dioxane) that has been detected in the City's water supply and provide a long term, reliable source of potable water that meets all the recommended State and Federal health guidelines. This Feasibility Report summarizes these options.

2.2 City Standards and Objectives

The City of St. Anthony Village has the following Standards and Objectives as they relate to providing drinking water for its residents and customers:

1. Provide safe, reliable, and high quality drinking water for its residents and customers
2. Provide adequate quantities of water for fire protection and maximum day demands
3. Provide a robust drinking water system that can withstand the test of time
4. Be environmentally responsive
5. Be fiscally responsible
6. Maintain its own destiny and control

2.3 Study Scope

This report summarizes five options that were selected to address Dioxane in the City's drinking water:

- Option 1 – Blend the existing wells;
- Option 2 – Construct deeper Mount-Simon Hinckley wells;
- Option 3 – Purchase water from Minneapolis Water;
- Option 4 – Purchase water from St. Paul Regional Water; and
- Option 5 – Implement treatment to remove Dioxane.

2.4 Background

Trichloroethylene (TCE) has been detected in the City's water supply since the 1980's and this contaminant is currently being treated at the City's water treatment plant. Dioxane testing in St. Anthony wells first occurred in March of 2015 by the Minnesota Department of Health. This testing was initiated in response to the presence of Dioxane at levels higher than the Health Risk Limit (HRL) in nearby municipal supply wells.

This testing indicated that Dioxane is currently present in the City's three drinking water wells. In addition to the MDH testing, the City has been testing for Dioxane monthly since March of 2015. The results of the Dioxane tests are shown in Table 1.

Table 1: Dioxane Concentrations in City Wells

Date	Well No. 3	Well No. 4	Well No. 5
March 2015	Not Sampled	0.90 ppb	0.57 ppb
June 2015	0.37 ppb	1.5 ppb	Not Sampled
August 2015	0.34 ppb	1.5 ppb	0.99 ppb
September 2015	0.41 ppb	Not Sampled (*)	1.0 ppb
October 2015	0.39 ppb	Not Sampled (*)	0.94 ppb
November 2015	0.32 ppb	Not Sampled (*)	0.99 ppb

(*) Not sampled because well has been shut down

Dioxane is used to stabilize chlorinated solvents and can be found in personal care products, laundry detergents, and food in small amounts. The TCAAP in Arden Hills used Dioxane as an additive in the solvents used at the facility and has been identified as the source of the contamination into the aquifer. The current Dioxane concentration at TCAAP has recently been detected as high as 60 parts per billion (ppb).

Dioxane is classified as an emerging contaminant by the Environmental Protection Agency (EPA). Currently, there is not an established Maximum Contaminant Level (MCL) for Dioxane. However, the EPA has identified thresholds of 3.5 parts per billion (ppb) to prevent a 1:100,000 increase in cancer risk level and 0.35 ppb to prevent a 1:1,000,000 increase in cancer risk level.

At least one EPA region has recommended 0.35 ppb as the appropriate limit for Dioxane. At the state level, allowable levels of Dioxane in drinking water have been established. The Minnesota Department of Health (MDH) has recommended keeping exposures at or below a health risk limit (HRL) of 1 ppb over a lifetime. Similarly, the states of California and Massachusetts have established recommendations at 1 ppb and 0.3 ppb, respectively.

The City currently operates three groundwater wells (Well Nos. 3, 4, and 5) to supply the City's drinking water. Until the City recently stopped using Well No. 4, the City was operating two wells full time with the third well for peaking and back up when one of the other wells was out of service for repair and maintenance. Having one current well with high levels of 1,4 Dioxane is now burdening the City's daily operations. Test results by the MDH, independently verified by the City, have shown the presence of Dioxane in the City's wells. The concentrations have ranged from 0.35 ppb in Well No. 3 to 1.5 ppb in Well No. 4. The concentrations detected in Well No. 4 have increased when compared to the previous test results.

3. EVALUATION OF OPTIONS

The City's ability to operate its municipal drinking water supply system has been impacted by the presence of Dioxane at levels over 1ppb in Well No. 4. The uncertainty of future impacts to the remaining two wells by Dioxane has initiated the need for the City to evaluate alternatives to provide dependable safe supplies of water to the public at levels less than 1 ppb.

This report summarizes five options that were selected for analysis as possible means to address Dioxane in the City's drinking water:

- Option 1 – Blend the existing wells;
- Option 2 – Construct deeper Mount-Simon Hinckley wells;
- Option 3 – Purchase water from Minneapolis Water;
- Option 4 – Purchase water from St. Paul Regional Water; and
- Option 5 – Implement treatment to remove Dioxane.

Descriptions for each option, the benefits and costs are provided below:

3.1 Option 1: Blend City Wells

The first option is to blend the City's three existing groundwater wells prior to distribution in an effort to dilute the higher concentrations of Dioxane to acceptable health levels.

Description
St. Anthony draws its drinking water from three wells, labeled Well Nos. 3, 4, and 5 (Well Nos. 1 and 2 were taken out of service and abandoned). Well Nos. 4 and 5 draw water exclusively from the Jordan Aquifer, while Well No. 3 is screened to draw water from both the Jordan and Prairie du Chien Aquifers. To meet the City's water needs, the City must have two wells operating at any given time, and sound management also requires having the third well available as a backup during maintenance of other wells, or in the event of an emergency.

Historically, the City would rotate usage of the wells. Since the installation of the Carbon plant, the City has primarily depended on the operation of Well Nos. 4 and 5, as the operation of Well No. 3 appears to deplete the carbon in the filters at a more rapid rate than the use of the other two wells

The current wells are not equipped with Variable Frequency Drives ("VFDs"), meaning that water is drawn at equal flow rates from the two wells that are operating. This limits the ability of the current operation to blend water from the wells in a controlled and efficient manner.

The concentrations of Dioxane have varied between Well Nos. 3, 4, and 5, with Well Nos. 3 and 5 staying below 1 ppb, and Well No. 4 exceeding 1 ppb. The City has not used Well No. 4 since Dioxane levels detected in this well exceeded 1.0 ppb.

Well Nos. 3 and 5 could be blended to reduce the total concentration of Dioxane in Well No. 4 to below 1 ppb at the point of consumption. The long term viability of blending is unknown as Dioxane concentrations may increase to levels that prohibits blending.

The City is currently blending Well Nos. 3 and 5 to keep Dioxane concentrations below 1 ppb. However, Well No. 3 is currently in need of rehabilitation, which would require taking it out of service for a number of months. The City does not currently have a viable means to blend Wells No. 4 and 5 to keep Dioxane below 1 ppb during the rehabilitation of Well No. 3. The City may need to add VFDs to the existing wells in order to control the blending process, provide flexibility in the use of the existing wells, and control the concentration of Dioxane into the system.

Advantages
This option would provide the following advantages:

1. Minimal additional capital costs and operator training
2. Can be done immediately
3. Addition of variable frequency drives for pumps could provide better blending
4. Buys time while longer-term solutions are evaluated and implemented and MCL regulations are further updated

Disadvantages
This option would provide the following disadvantages:

1. There is a reasonable likelihood that the Dioxane concentration in the City's aquifer could increase over time based on historical concentrations and trends (see Table 1 in Section 2.4). As stated previously, the concentrations detected at the TCAAP are as high as approximately 60 ppb and the concentrations detected in the City wells has increased over the short time period the City has been monitoring.

2. If the MDH establishes an MCL for Dioxane at or near 1 ppb, the City will be left without a technology to effectively meet the future regulations. Dioxane is currently classified as an emerging contaminant, meaning not enough information is known on the contaminant and an MCL has not yet been established. It is expected that the EPA will continue to study this contaminant and could set an MCL at some point in the future. Blending the water could be only a short term solution depending on a future MCL that could be established by the EPA.

3. The City currently has Well No. 4 shut down because the Dioxane concentration in this well now exceeds the MDH's recommended health risk limit. Although it is unknown until additional sampling and laboratory results become available;

there is a reasonable likelihood that the contaminant plume will eventually move towards Well Nos. 3 and 5 and produce higher concentrations of Dioxane as these wells are used to pump more water from the aquifer. This condition could also prohibit blending depending on the concentrations of Dioxane detected over time.

4. Blending the well water would not remove Dioxane from the environment like other treatment options. Blending the well water reduces the concentration at the point of consumption but the overall concentration within the environment would remain untreated.

5. The manganese levels in Well No. 3 are the greatest of the three wells. Therefore, pumping this well at a higher rate to blend and reduce the Dioxane concentrations in the blended water would increase the manganese levels that are treated by the water treatment plant. Shorter filter runs would be experienced because of the higher manganese concentrations. This would require the filters to be backwashed more frequently and higher chemical dosages would be required to oxidize and treat the higher levels of manganese at the water treatment plant.

6. Blending the City's wells could become more complicated in the future when Well No. 3 requires major rehabilitation. Well No. 3 has been grandfathered-in as a multi-aquifer well and the DNR no longer allows multi-aquifer wells to be constructed. The DNR may not allow major rehabilitation or redesign to be done to this well. Therefore, a new well may need to be constructed that could produce higher concentrations of Dioxane.

7. Because of aquifer limitations, at least three wells must always be operable to provide firm capacity and supply adequate volumes of water for the City's demands. If one well goes down, with only two wells in service blending could be prohibited.

<u>Estimated Capital and Long Term O&M Costs</u>
The City well pumps are not equipped with VFDs that would allow the pumping rates to be varied as needed to optimize blending. The wells can be manually throttled to adjust the pumping rates, resulting in reduced capacity and consumption of additional energy.

This option does not appear to be feasible as concentrations of Dioxane in the City's wells are likely to exceed 1ppb at which point blending will no longer provide drinking water below 1 ppb. Ultimately, this option does not have the ability to reduce Dioxane concentrations should they increase in the City's wells in the future. Therefore, estimated capital and O&M costs to implement Option 1 were not further studied.

3.2 Option 2: Construct Deeper Mount-Simon Hinckley Wells

The second option analyzed was to construct and utilize deeper Mount-Simon Hinckley wells instead of the Jordan Aquifer wells that are currently being used by the City. The

City of New Brighton is currently using the Mount-Simon Hinckley Aquifer to supply its water system.

Description

The Mount-Simon Hinckley Aquifer is the deepest bedrock formation in the Twin Cities and at a significantly deeper depth than the Jordan Aquifer. This aquifer is confined and less susceptible to surficial contaminants such as Dioxane that exists in the Jordan Aquifer. Options were analyzed to convert the existing wells into deeper Mount-Simon Hinckley wells or drill new wells into the Mount-Simon Hinckley Aquifer.

New Mount-Simon Hinckley wells can potentially be drilled although it is very uncommon for the DNR to approve them. The State of Minnesota currently has a moratorium that restricts the use of the Mount-Simon Hinckley Aquifer in the Twin Cities Metropolitan Area. Therefore, the DNR does not issue appropriation permits to cities to pump groundwater from this aquifer.

The City would be required to receive a variance from the DNR before this option could be fully analyzed. There is no guarantee that the DNR would issue a variance for these wells to St. Anthony Village. Variances are provided only when no other water supply options exist for a public water system.

Well No. 4 in St. Anthony Village cannot be converted into a deeper Mount-Simon Hinckley well because a 10-inch casing would need to be installed inside the existing 18-inch casing to comply with the Minnesota Well Code. The 10-inch casing would not allow a large enough well pump to be installed inside the well to produce the needed capacity to make this option feasible. Well Nos. 3 and 5 could potentially be converted to Mount-Simon Hinckley wells; however, this option is not cost effective since it would require the open hole at that base of the existing Jordan wells to be completely grouted. This is very costly and difficult from a constructability standpoint.

Advantages

This option would provide the following advantages:

1. The Mount Simon-Hinckley Aquifer does not contain any known concentrations of TCE or Dioxane.

2. The Mount-Simon Hinckley Aquifer is better confined and protected from other potential contaminants or sources of surface contamination compared to the upper aquifers (Jordan Aquifer, etc.).

3. The City of St. Anthony would maintain control of its water production and water rates.

Disadvantages

This option would provide the following disadvantages:

1. The Mount-Simon Hinckley Aquifer is likely to contain concentrations of radium that exceed the EPA MCL for combined Radium 226+228.

    - Radium is required to be removed from drinking water to below the MCL. The City's existing treatment system, specifically the greensand filters, would remove most of the radium.
    - Once the radium is removed, it will accumulate on the filter media, making the media radioactive.
    - Radium cannot be effectively backwashed from greensand media, so the media would need to be replaced on a more frequent basis to reduce the plant operators' exposure to the radioactive media.
    - Disposal of radioactive media is expensive and very few landfills across the country will accept the material.
    - The water treatment plant HVAC systems would likely need to be increased in size and modified to provide more air changes throughout the day as the radium will decay to radon gas.
    - The air quality within the treatment facility could be become hazardous when radon is emitted into the air. This has been found to occur during filter backwashing when the radioactive filter media is cleaned.

2. The average static water levels in the Mount-Simon Hinckley Aquifer are approximately 125-feet deeper than the static water levels in the Jordan Aquifer in the area of St. Anthony Village. As a result, larger well pumps would be required inside the Mount-Simon Hinckley Wells to pump water from its deeper water levels. This would increase the City's electrical utility costs.

3. Constructing and pumping deeper Mount-Simon Hinckley Aquifer wells could produce groundwater well interference with the City of New Brighton's water supply wells. Currently, the City of New Brighton is utilizing Mount-Simon Hinckley wells that were constructed before the state moratorium went into effect for the Mount-Simon Hinckley Aquifer in the Twin Cities. The groundwater interaction at this aquifer depth was unknown at the time of this study, and extensive groundwater modeling would be required to predict the potential interference effects between these wells.

4. It would likely take the DNR at least two years to evaluate and approve the use of the Mount-Simon Hinckley Aquifer and another one to two years to design and construct new Mount-Simon Hinckley wells. The City would continue drinking Dioxane from existing wells during this time.

<u>Estimated Capital and Long Term O&M Costs</u>
Estimated capital and long term O&M costs were based on present worth analysis on the assumption that the capacity of the Mount-Simon Hinckley Aquifer is less than the existing capacity of the Jordan Aquifer wells within the City. Therefore, four Mount-Simon Hinckley wells were assumed to be needed to meet the City's water demands.

The total estimated cost for Option 2, including contingency and indirect costs, is shown in **Table 2** along with the O&M costs over a 20 year life cycle. A detailed cost estimate for Option 2 can be found in **Appendix D**.

Table 2: Option 2 Estimated Costs

Estimated Capital Cost	Finance Cost (4% Interest)	Estimated 20-Year O&M Cost (3.5% Inflation Rate)	20-Year Cost of Purchasing/ Producing Water	Estimated Total 20-Year Cost
$7,115,600	$3,356,000	$2,812,300	$4,954,000	$18,237,900

3.3 Option 3: Purchase Water from Minneapolis Water

The third option analyzed was to purchase water on a wholesale basis and receive treated water directly from Minneapolis Water through a connection to the City's water distribution system.

<u>Description</u>
Minneapolis Water treats water supplied from the Mississippi River and distributes drinking water to the City of Minneapolis and other surrounding communities. This is a very large and complex water system that dates back to 1867. The main treatment processes include filtration, disinfection, sedimentation, and filtration. Minneapolis produces an average of 57 million gallons per day.

Minneapolis Water Pipeline 16 runs from the Hilltop Reservoir along the western border of St. Anthony Village. This watermain has a capacity of over 40,000 gallons per minute (gpm) according to Minneapolis Water staff. This pipeline can be connected to the City of St. Anthony's water system to meet the City's water demands.

An interconnection to Minneapolis Water would need to provide adequate fire protection and meet the City's maximum day demands. The City's hydraulic grade line (HGL) and existing elevated water tower is at least 40 feet higher than the available HGL in the Minneapolis water distribution system at the interconnection point during static conditions.

The City's existing water distribution system is not sized to transmit adequate flow rates from the Minneapolis water distribution system to the City's elevated water tower. Therefore, two water booster stations and two 20-inch watermains would need to be constructed from interconnection points with Minneapolis Water to St. Anthony Village's water tower to provide system redundancy in the event that one booster station failed or one watermain experienced a break.

One watermain would run from the corner of Stinson Boulevard NE along Kenzie Terrace and north along Silver Lake Road to the water tower at a length of approximately 8,100-feet. The second watermain would run from the corner of Stinson Boulevard NE and Silver Lane NE to 33rd Ave NE and to the water tower at a length of approximately 7,600-feet. Flow meters would need to be installed inside the booster pumping stations to record the volumes of water purchased from Minneapolis Water. Minneapolis Water staff studied potential interconnections to its water distribution system and provided a memorandum that summarizes this study (see **Appendix A**). The estimated time to implement this option would be approximately two to three years.

<u>Advantages</u>
This option would provide the following advantages:

1. The City is no longer responsible for treatment and removal of TCE and Dioxane from the drinking water supply.

2. City residents that currently have home water softeners would save on their individual water softening costs. Minneapolis Water softens its drinking water to approximately 80 parts per million (ppm) hardness or about 5 grains. Residential customers that soften their water may save an average of $6.75 per month in salt costs.

3. If the ability to draw from the Jordan Sandstone aquifer was retained, connecting with the Minneapolis system would provide some redundancy in water supplies.

4. Does not rely on groundwater aquifers which are being closely monitored by the DNR in portions of the Metro Area.

<u>Disadvantages</u>
This option would provide the following disadvantages:

1. The City currently controls its water quality. Purchasing water from Minneapolis Water would relinquish this control to others while the City would not be able to address water quality changes.

2. Surface waters, such as the Mississippi River, commonly contain emerging contaminants' which could pose a water quality concern if the EPA establishes MCLs for these constituents within the water. For example, pharmaceuticals are currently being studied by the EPA and could possibly require further treatment in the future for drinking water that stems from a surface water supply. This treatment process may result in an increase in the cost of water.

3. The City would lose control of its water rates by purchasing water from Minneapolis Water.

4. The water quality of Minneapolis' drinking water differs in quality than that provided by the City of St. Anthony Village.

- Although the concentrations are less than the MCL, Minneapolis' water contains higher levels of disinfection byproducts (Haloacetic Acids, Total Trihalomethanes, etc.) than the water distributed by the City of St. Anthony Village.

- Minneapolis' water is supplied from surface water, meaning the influent water quality has potential to fluctuate throughout the course of a year. In the spring time during snowmelt and in the summer time during algae blooms, the water quality within the Mississippi River can produce higher levels of taste and odor compounds.

5. The potential exists for hazardous materials to spill into the Mississippi River, either from tanker trucks, rail cars, storm sewers or other sources along the river.

6. The age and redundancy of the Minneapolis Water distribution system is of concern. The utility contains hundreds of miles of old steel pipe that is yet to be lined or replaced. These maintenance costs may increase the future cost of Minneapolis Water.

7. Minneapolis Water most likely has concerns with the long term reliability of the Mississippi River as its water source. They are currently considering implementing back-up groundwater wells for its surface water supply. In the event of a historic drought or an intentional or unintentional contamination event, the utility would likely not have enough backup capacity in their groundwater wells to continue to serve all of its customers.

8. The City's existing water rates would increase. The City would need to collect enough revenue from water users in the City to cover the cost of purchasing water from Minneapolis Water as well as to maintain its own existing water distribution system (such as the water tower, watermains, hydrants, meters) within the City.

9. At least two watermain connections, two booster stations, and 20-inch watermain would need to be constructed across St. Anthony Village to provide redundancy in case one of the watermains broke or required maintenance.

10. The City would spend in excess of $17 million over 20 years to purchase water from Minneapolis Water.

<u>Estimated Capital and Long Term O&M Costs</u>
Estimated capital and long term O&M costs were based on present worth analysis on the assumption that a new 20-inch watermain would need to be installed from two of the potential connection points defined by Minneapolis Water to the existing St. Anthony Village water tower, running approximately 15,000-feet in length.

Due to the difference in the hydraulic grade lines (ground elevation plus water pressure) between the two water distribution systems, two booster pump stations would be required near the connection points to pump water from the Minneapolis water distribution system to the elevated water tower and distribution system in St. Anthony Village. These booster stations would require the acquisition of property for their construction.

The total estimated cost including contingency and indirect costs, is shown in **Table 3** along with the O&M costs over a 20 year life cycle. A detailed cost estimate for Option 3 can be found in **Appendix D**.

Table 3: Option 3 Estimated Costs

Estimated Capital Cost	Finance Cost (4% Interest)	Estimated Annual O&M Cost (3.5% Inflation Rate)	20-Year Cost of Purchasing/ Producing Water	Total 20-Year Cost
$9,480,300	$4,471,200	$4,487,800	$17,472,000	$35,911,300

<u>Current Minneapolis Water Rates</u>

The Minneapolis Water bulk water rate was $2.73 per 1,000 gallons purchased in 2015. The City of St. Anthony Village water rates are in a tiered system ranging from $2.98 to $4.97 per 1,000 gallons depending on the volume of water used. The City would need to purchase approximately 320 million gallons per year from Minneapolis Water. This would add an additional cost to the utility of approximately $873,600 per year or $17,472,000 over 20 years.

By removing the current chemical and pumping costs that are being paid by the City to operate its existing water treatment facility and wells on a daily basis, the City could save approximately $39,800 per year in chemical costs, $53,120 in filter media replacement costs, and $86,990 per year in pumping costs. These cost savings would be minor in comparison to the costs to maintaining the City's entire water system. Therefore, the City would still need to charge its customers about the same current water rates in addition to paying the Minneapolis bulk water rate while continuing to operate and maintain its existing water system.

The Minneapolis Water bulk rate includes some funding for future capital improvements and maintenance. Minneapolis Water uses a 10-year pro forma rate model in which the rates are set in advance and increased between 2.5 to 4.0 percent annually, depending on the timing of the utility's planned capital improvements. The proposed rate increase for 2016 is 3.99%.

3.4 Option 4: Purchase Water from St. Paul Regional Water

The fourth treatment option analyzed was to purchase water on a whole sale basis from St. Paul Regional Water Services (SPRWS) through a connection with the City of Roseville's water distribution system. The City of Roseville receives its drinking water from SPRWS through the Dale St. Reservoir.

Description

Minimal information has been provided by the City of Roseville to analyze this treatment option. It was unknown at the time of this study if the City of Roseville's water distribution system (watermains, booster station, storage, etc.) can supply the required fire protection and maximum day water demands for St. Anthony Village. However, enough aspects of the St. Paul Water system were evaluated to conclude that St. Paul Regional Water Services would have all of the same issues that would be experienced with Minneapolis Water, and possibly more issues such as Roseville infrastructure upgrades.

Advantages and Disadvantages

Similar advantages and disadvantages occur with this treatment system as does with the connection to the Minneapolis Water system.

Estimated Capital and Long Term O&M Costs

It is expected that the costs to purchase water from SPRWS would be as much as, if not potentially more than, the estimated cost to purchase water from the Minneapolis Water system. The capital costs required to connect to the Roseville water distribution system are anticipated to exceed the cost of connection to the Minneapolis Water system.

3.5 Option 5: Implement a Water Treatment System for Dioxane

The fifth alternative analyzed is to remove Dioxane to below the recommended health advisory levels at the existing water treatment plant in St. Anthony Village.

Description

The City's existing water treatment plant is designed to remove iron, manganese, and trichloroethylene (TCE) from the City's three groundwater wells. Greensand filters are used to filter the iron and manganese and granular activated filters (GAC) are used to adsorb and remove the TCE. These treatment processes are not capable of removing Dioxane from the City's water supplies. The low adsorptive capacity of Dioxane limits the effectiveness of treatment by GAC according to the United States EPA (Source – *EPA Treatment Technologies for 1,4-Dioxane: Fundamentals and Field Applications*). Conventional treatment methods such as air stripping and reverse osmosis are ineffective at removing Dioxane due to its low vapor pressure and high solubility. The following treatment technologies have been evaluated by the EPA at the pilot and full scale levels for Dioxane:

1) Advanced Oxidation
   (a) Ultra-Violet Light with Hydrogen Peroxide
   (b) Hydrogen Peroxide with Ozone
2) Bioremediation

After careful review of the advantages, disadvantages, and costs for each of the above treatment processes, Ultra-Violet Light with Hydrogen Peroxide was further evaluated as the most feasible treatment option to treat Dioxane in the City's wells. Hydrogen

Peroxide with Ozone and Bioremediation were not further evaluated but are further discussed in Appendix C.

Advanced Oxidation with Ultra-Violet Light and Hydrogen Peroxide

Advanced oxidation processes (AOP) are commercially available for treating Dioxane in drinking water. Hydrogen peroxide absorbs ultraviolet (UV) light and produces hydroxyl radicals that oxidize and breakdown Dioxane to non-toxic compounds consisting of carbon dioxide, water, and residual chloride.

The typical UV and hydrogen peroxide treatment system can effectively remove Dioxane from drinking water supplies to levels below the current 1ppb HRL and future levels that may be considered by the EPA (see **Figure 1**).

Figure 1
UV/Hydrogen Peroxide Treatment System, Trojan Technologies UVPhox

There are currently dozens of surface and groundwater UV-oxidation installations designed for Dioxane removal in operation today. These installations collectively treat over 250 million gallons of drinking water each day.

A UV/Hydrogen Peroxide treatment system was piloted inside St. Anthony Village's existing water treatment plant with assistance from Trojan Technologies, Inc. on August 27, 2015. Representatives of the Minnesota Department of Health were present to observe the pilot study. Water was obtained from a sample tap located downstream of the existing greensand filters and upstream of the existing GAC filters. The pilot water was spiked with excess Dioxane in concentrations ranging between 169 to 197 ppb at variable flow rates ranging from 0.5 to 2.0 gpm to simulate and demonstrate the effectiveness of the system at removing higher concentrations of Dioxane if they occurred in the City's wells in the future.

The removal percentages achieved from the pilot study ranged from 76.56 to 99.96 percent, varying by the concentration of hydrogen peroxide added to demonstrate that a full scale system could remove Dioxane from the City's water. The Minnesota Department of Health did not require any additional testing in addition to the parameters that were tested in the pilot study. A copy of the pilot study report, as prepared by Trojan Technologies, is included in **Appendix B**. A follow-up pilot study is recommended during the final design phase if this option is selected.

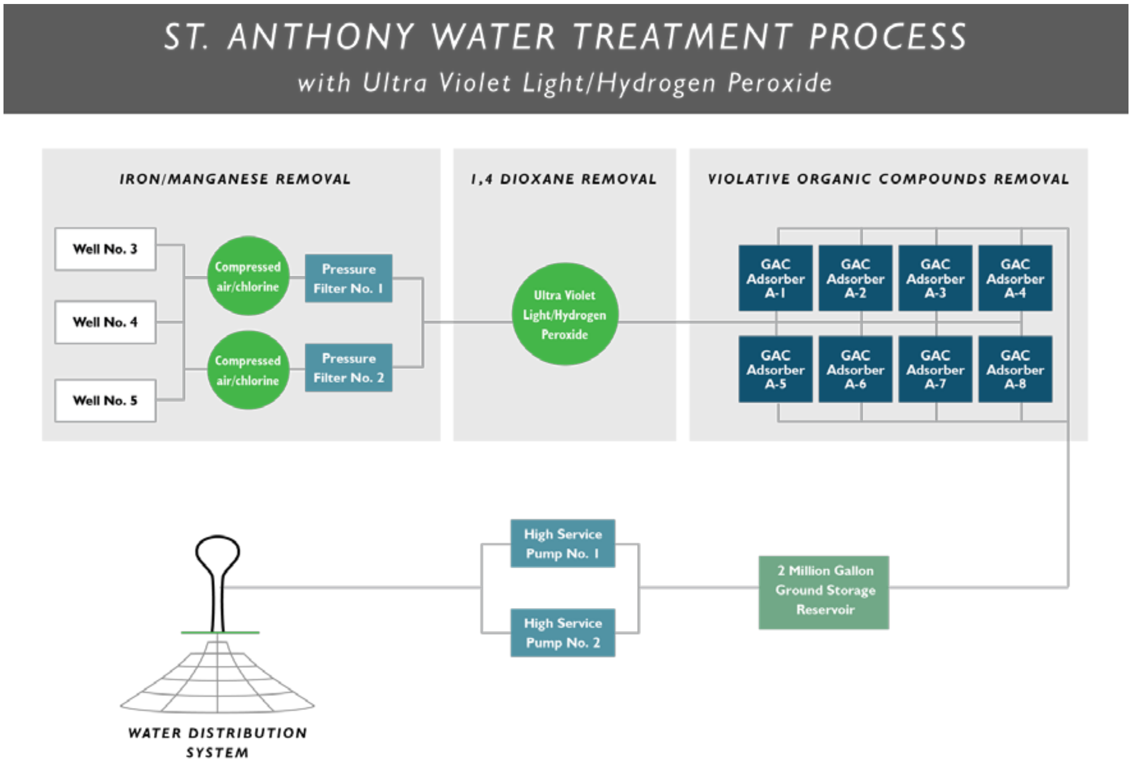
The cost analysis anticipated installing three UVPhox units inside a new masonry or precast concrete building, or WTP addition that would be constructed adjacent to the existing water treatment plant. Each unit would have a treatment capacity of 1,250 gpm in which two units combined could treat 2,500 gpm (capacity of two wells pumping) with the third unit providing redundancy in case one unit fails or requires maintenance.

The new building or WTP addition would include a chemical storage room to contain a 5,000 gallon bulk storage tank, 100 gallon day tank, and chemical feed system for feeding hydrogen peroxide. The existing effluent piping from the existing greensand filters would be routed into the new building or WTP addition through a common header pipe, metered, and connected to the individual treatment units. Automated control valves would be used to split the flow between the unit(s) that are called for service via an expanded plant automation control system (PLC/SCADA) to meet the City's water demands.

The treated effluent water from the treatment system would be routed back into the existing pipe gallery of the GAC filter building where the excess hydrogen peroxide would be quenched and removed by the GAC filters. The estimated time to implement this option is approximately two years.

Figure 2 shows the location where a full scale UV light and hydrogen peroxide treatment system could be implemented in the City's existing treatment process.

Figure 2 – Existing St. Anthony Village WTP with UV Light and Hydrogen Peroxide Treatment



Advantages of AOP Treatment with Ultraviolet Light and Hydrogen Peroxide

This option would provide the following advantages:

1. This treatment option physically destroys and removes Dioxane from the environment. While the AOP would reduce the concentrations at the point of consumption, it would also help “clean-up” the Dioxane that exists in the environment. There are no other contaminates created that require hazardous disposal.

2. Cleaning up Dioxane from the aquifer would reduce risk to other users of the aquifer located downstream of St. Anthony Village.

3. The UV and hydrogen peroxide feed system could be implemented with the existing treatment process that already includes pretreatment for iron and manganese and downstream GAC filters for removing excess hydrogen peroxide.

4. The City would maintain complete control of its water supply, water quality, and water rates without being dependent on another water utility.

5. The City would be able to pump each of its wells as needed to meet the City’s water demands unlike the current condition that requires Well No. 4 to be shut down.

6. Dioxane could be effectively removed from the City’s water supply ensuring compliance with the current and future EPA and MDH recommended health risk limits.

7. Other treatment benefits include enhanced disinfection and removal of TCE and other volatile organic compounds (VOCs), N-nitrosodimethylamine (NDMA), endocrine disruptor compounds, and pesticides.

Disadvantages

This option would provide the following disadvantages:

1. Implementing the treatment option would require additional operator training and time to operate and maintain the treatment system.

2. Treatment would involve a significant up-front capital expenditure.

3. The City would be reliant on a single equipment vendor (Trojan Technologies).

4. Although AOP Treatment with Ultraviolet Light and Hydrogen Peroxide appears to have robust treatment capability for a wide array of contaminants, the City would be dependent on the effectiveness of the system in treating other contaminants that may emerge.

5. The City would be reliant on a single groundwater source.

Estimated Capital and Long Term O&M Costs

Estimated capital and long term O&M costs were based on present worth analysis. The total estimated cost for Option 5, including contingency and indirect costs, are shown in Table 4 along with the estimated O&M costs over a 20-year life cycle. A detailed cost estimate for Option 5 can be found in **Appendix D**.

Table 4: Option 5 Estimated Costs

Estimated Capital Cost	Finance Cost (4% Interest)	Estimated O&M Cost (3.5% Interest Rate)	20-Year Cost of Purchasing/ Producing Water	Total 20-Year Cost
$7,177,600	$3,385,200	$1,080,200	$4,954,000	$16,597,000

4. COMPARISON OF OPTIONS

Table 5 provides a comparison of the advantages and disadvantages of each Dioxane treatment option while **Table 6** provides a comparison of the total 20-year cost of each Dioxane option.

Table 5: Comparison of Options

Option 1 (Blend Wells)		Option 2 (Construct Mt. Simon-Hinckley Wells)		Option 3 and 4 (Purchase Water from Minneapolis or St. Paul)		Option 5 (Implement Treatment)	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Low capital and O&M costs	Does not provide permanent solution to meet MDH and EPA considerations	No TCE in source water	Radium must be removed from source water	No TCE	Vulnerable to emerging contaminants	Removes Dioxane from environment completely	More operator training required for operations staff
Can be done immediately	Short term solution only	No Dioxane in source water	Sand filters become radioactive. Disposal of radioactive material is expensive. Exposure to staff will require changes to plant	No Dioxane	Seasonal changes in water quality	City maintains control of its water quality and rates	Increased annual operating costs
Addition of VFDs could provide better blending	Increased manganese concentrations		DNR likely would not allow	Softened water	Vulnerable to hazardous spills	Cleaning up the aquifer of Dioxane would reduce liability and risk of other downstream users	The City would be reliant on a single equipment vendor
	Pumps need to be throttled or VFDs installed		Potential groundwater well interference	Could serve as a back-up source	Age of system	Will remove other TCE, other VOCs, and other emerging contaminants	The City would be reliant on a single groundwater source
	Does not remove Dioxane from environment		Higher pumping costs	Does not rely on groundwater aquifers	Loss of control of water quality and rates		
	Well No. 3 is multi-aquifer well		Does not remove Dioxane from environment		Minimal system redundancy		
	Reliant on operation of all three wells for blending to occur				Does not remove Dioxane from Environment		

TABLE 6 – COMPARISON OF TOTAL COSTS

OPTION	20-YEAR TOTAL COST
2	$18,237,900
3	$35,911,300
5	$16,597,000

APPENDIX A

PRELIMINARY ANALYSIS OF PROVIDING WATER TO SAINT ANTHONY VILLAGE MEMORANDUM

Minneapolis
City of Lakes

Public Works - Water Treatment and Distribution Services
Engineering
4300 Marshall St. NE
Minneapolis, MN 55421
www.minneapolismn.gov

Memorandum

To: Glen Gerads

CC: Shahin Rezania

From: Peter Pfister

Date: 8/18/2015

Subject: Preliminary Analysis of Providing Water to Saint Anthony Village

Objectives

1. Identify one or more locations for connection between the City of Minneapolis and Saint Anthony distribution systems. Factors to consider:
    a. Size / capacity of the main to which connection is to be made.
    b. Length of required connecting main and other possible indicators of an economical connection.
2. Characterize the approximate static and residual pressures at the potential points of connection, assuming a maximum steady flow of 3,000 GPM into the Saint Anthony distribution system.
3. Items not in the scope of this analysis include:
    a. Research into utilities, geotechnical, or other conditions that may impact constructability or cost.
    b. Consideration of siting for pumping station or pressure reducing valves or vaults.
    c. Detailed condition assessment of existing water mains under consideration.
    d. Detailed hydraulic analysis.
    e. Cost estimates

Summary of Findings

The Saint Anthony Village water system is south of the Hilltop finished water reservoirs owned by the City of Minneapolis. The portion of the Minneapolis Distribution System that abuts the Saint Anthony Village water system is a boosted pressure zone, called Northeast High Service Area. It is assumed undesirable from the City of Minneapolis standpoint to connect to mains within the Northeast High Service Area. However, a major pipeline, Pipeline 16, is located near the border of Saint Anthony Village, and is not part of the Northeast High Service Area. Pipeline 16 is provided its pressure by the Hilltop reservoirs. Minneapolis has a pumping capacity of over 40,000 GPM to maintain the levels at Hilltop, so the 3000 GPM demand for Saint Anthony Village can be readily accommodated.

Two potential options for connection to the City of Minneapolis water system by Saint Anthony Village were identified for evaluation:

1. Connection to Pipeline 16 at one of several possible locations between 40th Avenue Northeast and Lowry Avenue Northeast.
2. Providing a connection to the outlet piping of the Hilltop reservoirs at Stinson Boulevard between 45th Avenue NE (County Road E) and 5th Street NW, and routing a new water main South on Stinson, East on County E, and South on Silver Lake Road and connecting with the existing 12" Saint Anthony Village water main. This new water main could possibly be combined with a main serving the City of New Brighton. The length of the main required would be approximately 4,400 feet along this route. Because of the length of the main and the significance of the roads along the route, this option was not considered further.

Four potential locations for connection to Pipeline 16 were evaluated, with any number of other locations potentially being viable for consideration.

Further Discussion of Option 1

Pipeline 16 is a 48-inch welded steel water main constructed 1949-1950, which begins at the Hilltop Reservoirs. There are a total of four interconnected reservoirs at Hilltop with a total capacity of 72 million gallons. The pressure for Pipeline 16 under normal operation is controlled by the level in the Hilltop Reservoirs and regulated by a control valve located downstream where the pipeline runs through the Columbia Heights treatment campus. The City of Minneapolis has adequate pumping capacity with sufficient redundancy to be able to continue to maintain sufficient levels in the Hilltop Reservoirs to accommodate additional consumption as considered in this study. Pipeline 16 is part of the City of Minneapolis outer transmission main loop and is routed south along Arthur Street, Benjamin Street, and Stinson Boulevard to Lowry Avenue NE, and continues south. Pipeline 16 was field-lined in 1963 with cement mortar. Elevations and pressures are as follows:

- Hilltop Reservoirs Water Surface Elevation
  - Range: 1054 -1074 feet above Mean Sea Level (MSL) (overflow)

- Pipeline 16 Control Valve at Columbia Heights Campus
  - Outlet Pressure HGL
    - Approximate Range = 1045 – 1061 feet above MSL
    - Normal Operation = 1050 feet above MSL

Table 1 lists several possible connection points to Pipeline 16 giving ground elevation at these points, as well as the corresponding approximate hydraulic grade lines based on the normal control valve outlet pressure of 1050 feet MSL. Head losses are not included, as the flow in Pipeline 16 is typically in the range of 25-35 MGD and head losses for purposes of this analysis are relatively small. Also included are approximate distances to potential points of connection to the Saint Anthony distribution system. It is assumed given the size of the Pipeline 16 that further evaluation of residual pressures is unnecessary at this time.

Table 1 – Summary of Possible connections to Saint Anthony Village Distribution System

Option	Connection Location (Minneapolis)	Connection Location (St. Anthony Village)	Ground Elevation (ft MSL) at point of connection to MPLS	Approx. Grade Line (ft) at point of connection to MPLS[1]	Correspond ing pressure (psi) at point of connection to MPLS	Approx. Length of New Connecting WM (ft)
1-A	Pipeline 16	40th Avenue at Arthur Place NE (8" Water Main)	980	70	30	1,100
1-B	Pipeline 16	Stinson Boulevard at 27th Avenue NE (8" Water Main)	918	132	57	50
1-C	Pipeline 16	Stinson Boulevard at 26th Avenue NE (north of intersection) (8" Water Main)	924	126	55	50
1-D	Pipeline 16	Stinson Boulevard at Lowry Av. NE (10" Water Main)	932	118	51	450

1 – Based upon "typical" control valve outlet pressure of 1050' as provided by City of Minneapolis Water Operations. Ranges of expected pressures may be predicted by varying control valve outlet pressure within the ranges provided above.

Other Options not Evaluated

Connection to other water mains to the west of Saint Anthony Village was not considered because all of these mains were within the Northeast High Service area. Northeast High Service Pump Station has a firm capacity of 2,500 GPM, which is less than the stated maximum demand of 3,000 GPM for Saint Anthony Village.

APPENDIX B

ST. ANTHONY VILLAGE UV-AOP PILOT PROJECT TROJAN UVPHOX ADVANCED OXIDATION SYSTEM PILOT SYSTEM TEST REPORT

Saint Anthony Village UV-AOP Pilot Project

TrojanUVPhox™ Advanced Oxidation System

Pilot System Test Report

October 16, 2015

TROJAN TECHNOLOGIES INC.
3020 GORE ROAD. LONDON, ONTARIO, CANADA N5V 4T7 T 519.457.3400 F 519.457.3030 WWW.TROJANUV.COM

Table of Contents

1 INTRODUCTION

This document describes the work performed to demonstrate the ultraviolet/hydrogen peroxide (UV/H_2O_2) advanced oxidation process (AOP) for treating various 1,4-dioxane present in the potable groundwater well of The City of St. Anthony Village, Minnesota water treatment plant. The primary goals of the study were to demonstrate the ability of the UV/H_2O_2 process to treat the contaminants in question and provide the basis to determine the economic costs of implementing and maintaining a full-scale system. To facilitate these goals Trojan Technologies has supplied, installed and operated a small pilot-scale UV/H_2O_2 system. The tests were performed on August 26th and 27th, 2015. This document provides a brief description of the procedures and results of these tests.

The treatment process at the St. Anthony water treatment plant comprises greensand filtration for iron, manganese and turbidity removal followed by GAC for 1,4-dioxane and VOC removal. 1,4-dioxane is very poorly adsorbed by GAC and the required change-out frequency makes it prohibitively expensive to operate. It is proposed to locate UV/H_2O_2 AOP upstream of the GAC contactors to allow the oxidation process to treat 1,4-dioxane and many of the VOCs and allow the GAC to quench the residual H_2O_2 leaving the UV reactor and provide a second barrier to VOCs.

2 UV-OXIDATION FUNDAMENTALS

2.1 TREATMENT MECHANISMS

UV-based advanced oxidation processes rely upon the simultaneous mechanisms of direct UV photolysis and UV oxidation to degrade chemical contaminants in water. UV-photolysis is the process by which chemical bonds of the contaminants are broken by the energy associated with UV light. UV-photolysis does *not* require the addition of H_2O_2. UV-Oxidation systems rely on the in-situ generation of hydroxyl radicals (•OH) by way of the UV-photolysis of H_2O_2 and the subsequent oxidation of chemical contaminants by those hydroxyl radicals.

Hydrogen peroxide is commercially available as aqueous solutions of varying strength. The solutions most commonly employed in UV oxidation processes for water treatment are either 35% or 50% by weight and are certified to meet NSF/ANSI Standard 60 requirements. Hydrogen peroxide is a relatively weak absorber of UV light having a molar absorption coefficient at 254 nm of 19.6 L $mole^{-1}$ cm^{-1}. Nevertheless, the quantum yield of hydrogen peroxide UV photolysis is relatively high. Therefore, the UV/H_2O_2 process is one of the most efficient advanced oxidation processes.

Hydroxyl radicals are extremely reactive, short lived and unselective transient species. The mean lifetime of hydroxyl radicals in natural water in the presence of natural organic matter (NOM) and alkalinity is estimated to be in the order of 10 μs (Oppenlander 2002). Therefore, the high reactivity and short life of these chemical species result in the requirement of in-situ generation of these oxidants. They will not exist beyond the boundaries of the UV reactor volume.

Hydroxyl radicals can oxidize organic and inorganic compounds by various types of reactions, comprising electron transfer reactions, hydrogen abstraction and electrophilic addition. In UV oxidation treatment processes the desired reactions are the oxidation of specific contaminant molecules.

2.2 WATER QUALITY PARAMETERS

2.2.1 UV Transmittance

UV transmittance (UVT) is the ratio of UV light transmitted through the sample to that transmitted through a reference solution. UVT is measured using a UV spectrophotometer. Reagent grade water is typically used as the reference solution (i.e., UVT = 100%). UV absorbance (A_λ)] measures the amount of light absorbed by a solution over a given path length (l) and at a given wavelength (**λ**). UVT and UV absorbance are related by the following equation:

$$UVT=10^{-A\lambda}x100$$

The typical cell pathlength is 1 cm and both transmittance and absorbance values are commonly reported per cm. A key reference wavelength, and one at which UVT is often reported, is 254 nm. This wavelength is used because it is the wavelength at which a low pressure mercury UV lamp emits light. Transmittance decreases in the presence of UV absorbing substances and particles that either absorb or scatter UV light. This results in a reduction of available UV energy for disinfection and oxidation. The UV transmittance is the most important water quality parameter used in the sizing of a UV system. A UV system designer may compensate for low transmittance by increasing the residence time or the amount of equipment.

2.2.2 Hydroxyl Radical Scavenging Demand

While the desired reaction in UV oxidation systems is between photogenerated hydroxyl radicals and contaminant molecules the unselective nature of hydroxyl radical reactions result in reaction pathways that consume hydroxyl radicals by reaction with constituents of the background water matrix. Examples of these hydroxyl radical scavenging reactions are the oxidation reactions with the natural organic matter (NOM) present in natural waters or reactions with carbonate and/or bicarbonate ions. Hydrogen peroxide itself will react with hydroxyl radicals and, therefore, is considered a hydroxyl radical scavenger. All of these scavenging reactions have the effect of reducing the steady state concentration of hydroxyl radicals in the water. Since the rate of contaminant degradation is proportional to the steady state concentration of hydroxyl radicals, these hydroxyl radical scavenging reactions reduce the rate of contaminant degradation. The level of scavenging reactions associated with a water sample can be quantified and is referred to as the hydroxyl radical scavenging demand of the water. Trojan routinely determines the scavenging demand of water samples at its laboratory in London, Ontario.

2.3 THE ELECTRICAL ENERGY PER ORDER PARAMETER

In sizing UV systems for Environmental Contaminant Treatment, a different metric is used than for UV systems for disinfection. This metric is called Electrical Energy per Order, or E_{EO} (Bolton et al. 1996).

E_{EO} is the electrical energy (measured line power draw) required to reduce the contaminant concentration by one order of magnitude (one log, or 90%) in one cubic meter (m^3) or 1000 gallons (kgal) of water (depending on the choice of flow units). Typical units are:

$$\left(\frac{kWh}{kgal \bullet order}\right) \text{ or } \left(\frac{kWh}{m^3 \bullet order}\right).$$

E_{EO} is a reactor, contaminant, and water-quality specific metric and the figure of merit accepted by the Photochemistry Commission of the International Union of Pure and Applied Chemistry for UV-photolysis/UV-oxidation technologies. It is a measure of the efficiency with which a given contaminant is treated by UV-photolysis and UV-oxidation. Different contaminants will have different E_{EO} values in the same UV reactor in water with the same water quality. Different reactors will have different E_{EO} values as the term measures a UV reactor's hydraulic, optical and electrical efficiency (when comparing two reactors treating the same contaminant under the same conditions). E_{EO} is directly proportional to the required power draw: the lower the E_{EO}, the lower the power required by the system. The following formula can be used to compute the E_{EO} of a UV treatment system in units of kWh/kgal/order with flow in gallons per minute (gpm) and power draw in kilowatts (kW):

$$E_{EO}\left(\frac{kWh}{kgal \bullet order}\right) = \frac{measured\ reactor\ power\ draw\,(kW)}{flowrate\,(gpm) \times 0.06 \times \log\left(\frac{C_o}{C}\right)}$$

Where

- 0.06 is a conversion factor that converts minutes to hours and normalizes the flow rate on a 1000-gallon basis
- C_o is the concentration of contaminant at the influent of the reactor
- C_f is the concentration of contaminant at the effluent of the reactor

In general, the energy required to reduce the contaminant initially by 90% is the same as the energy required to treat 90% of the remaining contaminant, for a total of 99% reduction (log-linear kinetics). In other words, the same energy is needed to reduce 100 units of contaminant to 10 units of contaminant as is needed to reduce 10 units of contaminant to 1 unit of contaminant.

A related term to E_{EO} is the electrical energy dose (EED) which is determined by dividing the system power draw (kW) by the flow rate. Typical units of EED are kWh/kgal or kWh/m^3.

2.3.1 Parameters affecting E_{EO}

- Reactor design. Different reactors (even those using the same type of lamp) can have significantly different E_{EO} values for a given water and contaminant. This is due to reactor characteristics such as lamp spacing, lamp orientation, and location of influent/effluent ports. Therefore, E_{EO} is a reactor-specific measure. The implications of this are that project specifications cannot specify design E_{EO} values as they will differ from UV system to UV system.
- Reactor Lamp Type. Properties of the lamp such as UVC power conversion efficiency and emittance spectrum can have a significant impact on E_{EO}.
- Water quality. Water quality parameters that impact E_{EO} are:
  - UV transmittance (UVT): E_{EO} increases as UVT decreases. That is, as the water becomes less transmissive to UV light, more power is required to achieve a desired log reduction in the contaminant concentration.
  - Hydroxyl radical scavenging demand: E_{EO} increases as the hydroxyl radical scavenging demand of the water increases. That is, with greater competition for

hydroxyl radicals due to the water matrix, fewer radicals are available to react with the contaminant.

These water quality parameters impact various reactors and lamp types differently.

- Lamp age. E_{EO} increases as lamps age. That is, more power is required at the end of the lamp life than at the beginning in order to achieve the same effectiveness. This is because the lamp's UVC electrical efficiency decreases over time.
- Flow rate. In general, because E_{EO} is normalized by the flow rate, reactor systems treating different flow rates can be compared. However, such comparisons should be made cautiously as empirical evidence and theoretical analysis have shown that the E_{EO} value decreases to an asymptotic value as flow rate increases. This is due to increases in reactor hydraulic efficiency with increases in turbulence and mixing at higher flow rates. Reactors must be specifically designed for certain conditions, including flow rates.
- Hydrogen Peroxide Concentration. E_{EO} is a strong function of H_2O_2 concentration. The irradiation of H_2O_2 produces hydroxyl radicals which accelerate the degradation of contaminants in the water. The higher the H_2O_2 concentration the more UV it absorbs and the more radicals are formed. However, H_2O_2 itself scavenges hydroxyl radicals. Therefore, the greater the concentration of H_2O_2, the greater the scavenging of hydroxyl radicals. Therefore, E_{EO} varies inversely with H_2O_2 concentration but this is not a linear relationship.
- Contaminant. Different contaminants will have a different E_{EO} value in the same reactor in water with the same quality. This is due to differences in the quantum yield, molar absorption coefficient, and hydroxyl radical reaction rate (i.e., their fundamental kinetic parameters).

3 PILOT SYSTEM DESIGN

3.1 APPROACH TO THE UV-AOP STUDY

While it was the objective of this study to demonstrate the capability of the UV/H_2O_2 system to treat 1,4-dioxane present in the St. Anthony groundwater, it was decided to inject additional 1,4-dioxane upstream of the UV reactor. This was done to allow the UV/H_2O_2 pilot system to demonstrate treatment of 1,4-dioxane that exceeds 3-log (i.e., >99.9%) reduction.

The primary water quality parameters that influence the efficiency of UV/H_2O_2 treatment are the UV transmittance (UVT) of the water and its hydroxyl radical scavenging demand. The UVT of the water affects the efficiency of delivering the UV photons to the target chemical (i.e., H_2O_2). Similarly, the hydroxyl radical scavenging capacity quantifies the overall demand for hydroxyl radicals due to all constituents present in the water.

Trojan received a water sample from St. Anthony in July 2015. The sample was collected upstream of the GAC filters and is representative of the water that would supply the pilot system. This sample was evaluated for the water quality parameters that potentially impact the efficiency of UV/H_2O_2 treatment. Figure 1 presents a summary of the data for the St. Anthony water sample. The key conclusions from the water quality analysis are that the UVT is very high at 96.3% and the hydroxyl radical scavenging capacity is moderately high. The moderately high hydroxyl radical scavenging capacity is due to the relatively high alkalinity and resulting bicarbonate ion concentration. These results are consistent with the measurement of pH, alkalinity and DOC and together provide a strong indication that UV oxidation should be efficient in this water. The UV absorbance spectrum which is plotted between 200 nm and 300 nm is consistent with the other measured water quality parameters.

Environmental Contaminant Treatment
Sample Report- CONFIDENTIAL

16-Oct-15

Project Name/Site	Sample Description	Sample Date
Saint Anthony Village, MN	**Before GAC**	**07/09/15**
Treatment Objectives	**1.50**	**log 1,4-D**
Sizing	**3x2-D72AL75s**	**reactor(s)**
	10.0	**ppm H_2O_2**
Hydroxyl Radical Scavenging		
Low	**Scavenging**	

Analytical Results

Parameter	Units	Result
pH		**7.8**
alkalinity	mg/L as $CaCO_3$	**276.2**
UVT_{254nm}	% transmission	**96.3**
DOC	ppm	**1.2**
Nitrate	ppm as NO_3^-	**0.3**

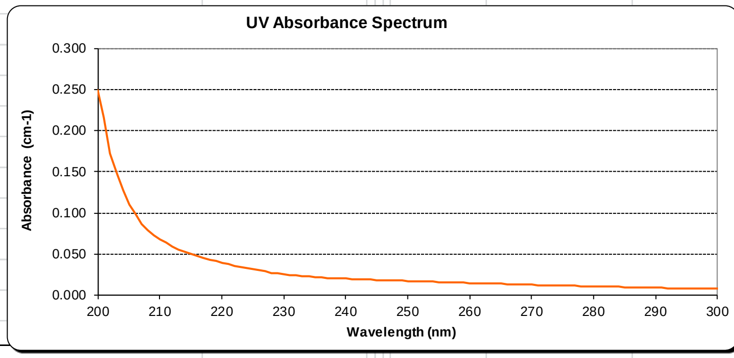


Figure 1: Summary of Filtered St. Anthony Water Quality

3.2 UV-AOP PILOT SYSTEM DESIGN

This document focusses on the UV/H_2O_2 AOP treatment system design, test procedures and results. The main components of the pilot system comprise the feed supply, chemical injection and mixing, flow measurement, the UV reactor with influent and effluent sample ports as well as the GAC contactor. The UV reactor was a TrojanUVPhox™ A02 system comprising 2 low-pressure high output amalgam lamps that each draws approximately 100 W of electrical power. The total power draw is about 200 W.

A photograph of the pilot set-up is shown in Figure 2. Trojan's UV/H_2O_2 pilot system was conveniently shipped in a small crate with pre-assembled UV reactor inlet and outlet piping and components together with two chemical injection pumps and electrical supply components. The pilot system is supplied with filtered St. Anthony water. Two chemical injection systems were provided. One was a hydrogen peroxide injection pump, tubing and nozzle to deliver the required H_2O_2 dose to the reactor feed water. A second injection system metered the 1,4-dioxane solution. The H_2O_2 stock was injected into the reactor influent stream just upstream of a static mixer. An influent sample port was located downstream of a rotameter which provided accurate flow measurement. The pipe transitions from 1" to 3" diameter to match the UV reactor influent flange. The UV reactor itself is 6" diameter with 3" influent and effluent flanges. The effluent pipe leaving the reactor is immediately reduced to 1” diameter and exits vertically before turning and continuing on to the GAC vessel. The effluent sample port is located between the UV reactor and the GAC contactor.

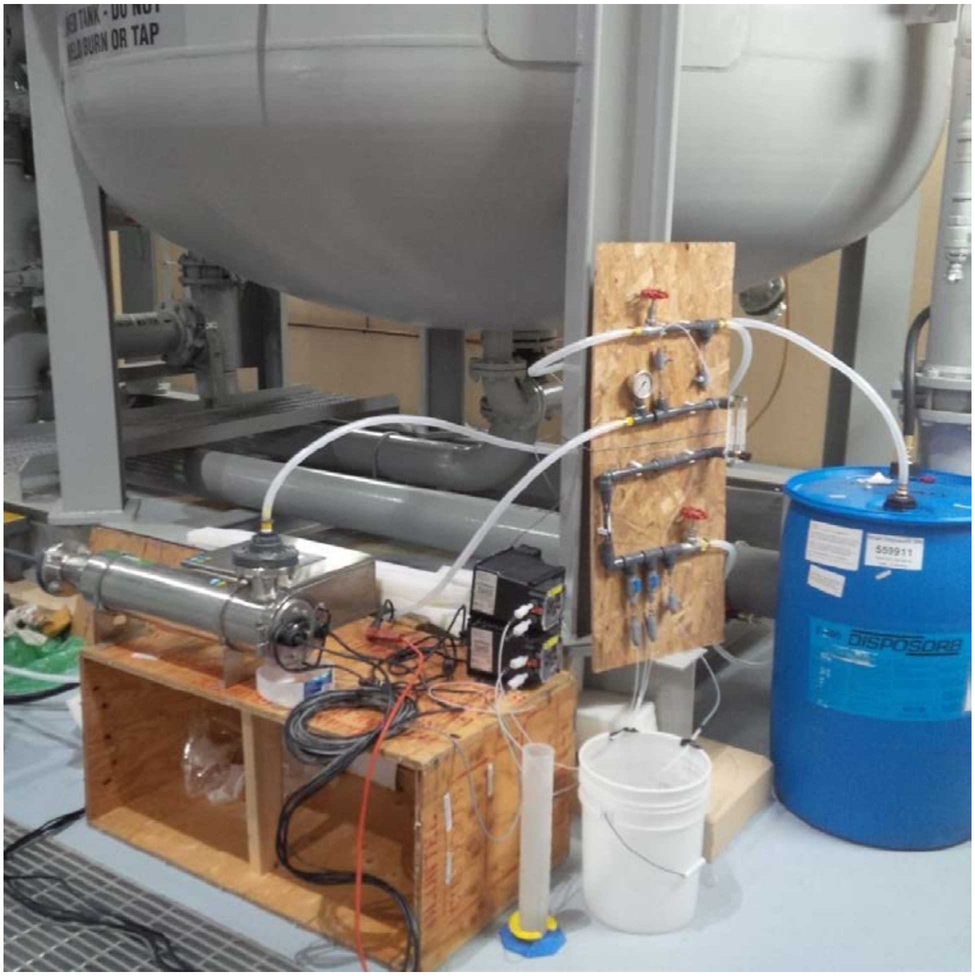


Figure 2: Photo of UV/H_2O_2 Pilot System

The system performance was determined by collecting pairs of water samples from the UV reactor influent and effluent sample ports and analysing contaminant concentrations in these samples. In order to quantitatively determine the system performance it is necessary to have effluent contaminant concentrations that are above the analytical reporting limit. Therefore, many of the proposed test conditions were expected to produce water with measurable contaminant concentrations.

Trojan recommended quenching residual hydrogen peroxide and adsorbing residual contaminants leaving the UV reactor with a granular activated carbon (GAC) contactor. The size of the contactor is typically defined by the empty-bed-contact-time (EBCT) and a minimum of 2 to 4 minutes is recommended for quenching most of the H_2O_2. The City of St. Anthony supplied GAC contactor comprising a 55 gallon drum, shown in Figure 2. The proposed test matrix described below indicates a flow range between 0.5 and 2 gpm and therefore the EBCTs provided range from about 20 minutes to about 80 minutes. This should be more than enough to reduce residual H_2O_2 leaving the UV reactor to non-detect.

It was important to ensure that the samples were collected when the system was operating at steady state and that the injected chemicals (i.e., 1,4-dioxane & H_2O_2) were completely mixed. There are two alternatives to ensure that the system is operating under steady state conditions prior to sample collection. The simplest is to wait for at least five hydraulic retention times (HRTs) after a process change before collecting samples. One HRT is defined as the time required for one system volume to pass through the system assuming plug flow conditions. In this case, the system volume is defined as the total water volume between the injection ports and the effluent sample port. Thus, the HRT is calculated by dividing that volume by the flow rate. A conservative approach to allow for deviations from plug flow is to allow five HRTs to pass before assuming that the system is at steady state.

4 UV-AOP SYSTEM TEST PROCEDURES

4.1 UV-AOP MIXING TEST PROCEDURE

The mixing test was performed with hydrogen peroxide as the tracer chemical. The hydraulic residence time distribution within the system, from the H_2O_2/1,4-dioxane injection ports to the final effluent sample port, was assessed, which allowed the equilibration time to be calculated and used for subsequent tests. This tracer study involved initiating the injection of a known concentration of tracer compound (e.g., 6 ppm H_2O_2) into the influent stream at time zero with the UV lamps off and collecting a series of samples at the influent and effluent sample ports. It was recommended that samples be collected as frequently as necessary to adequately define the tracer curve (i.e., concentration vs. time curve). By monitoring the H_2O_2 level in the effluent samples, the time required for the system (between injection and effluent ports) to reach steady state was determined. The time required to reach steady state determined from this test was used to determine run times for the subsequent performance tests.

4.2 UV-AOP PERFORMANCE TEST PROCEDURE

The UV-oxidation system operating parameters to be investigated during this study included flow and hydrogen peroxide dose. The flow range for the pilot tests was between 0.5 and 2.0 gpm (0.5, 1.0 & 2.0 gpm). Hydrogen peroxide was dosed into the influent stream at concentrations between 0 and 20 ppm (i.e., 0, 5, 10, & 20 ppm). That provided a test matrix of 3 x 4 totaling 12 unique test runs. In addition, a run with the UV power off provided a control condition that allowed the sample collection, handling and analytical procedures to be validated. Other test conditions with 0 ppm H_2O_2 and especially with no UV did not need to be performed with all of these conditions. The recommended test matrix is provided in Table 1. For each run influent and effluent sample pairs were collected and analyzed for 1,4-dioxane and H_2O_2.

Table 1: Test Matrix

Test No.	Flow	$[H_2O_2]$	UV Lamps
	(gpm)	(mg/L)	(on/off)
1	0.5	0	off
2	0.5	0	on
3	0.5	5	on
4	0.5	10	on
5	0.5	20	on
6	1.0	5	on
7	1.0	10	on
8	1.0	20	on
9	2.0	5	on
10	2.0	10	on
11	2.0	20	on

Run number 1 was a control run intended to demonstrate that negligible contaminant reduction occurs in the absence of UV and H_2O_2. This test was also intended to validate the integrity of the contaminant and H_2O_2 stock injection, sample collection, handling and analytical procedures. Run 2 was with no H_2O_2 and will demonstrate the level of 1,4-dioxane treatment by direct UV photolysis, which was expected to be negligible. The remaining 9 test runs cover 3 H_2O_2 concentrations and 3 flow rates.

Quantitative analysis of the UV AOP system performance is typically based upon measurement of the contaminant log reduction and the system's electrical energy per order (E_{EO}) parameter. These parameters require measurable levels of contaminants in both the reactor influent and effluent streams. Therefore, the influent concentration of contaminant must be sufficiently high that the effluent will be comfortably above the analytical detection limit. The influent concentration of contaminants can be adjusted based on the analytical detection limits and the expected log reduction provided by the system. Trojan predicted that up to ~3.5-log reduction of 1,4-dioxane will be provided in Test No. 5. Given an analytical method detection limit for 1,4-dioxane of 0.07 µg/L Trojan planned for a maximum influent 1,4-dioxane concentration of about 200 µg/L.

Trojan recommended that a small GAC contactor be installed to both quench residual H_2O_2 leaving the UV reactor and to adsorb the low µg/L levels of 1,4-dioxane that are expected in the UV reactor effluent. St. Anthony provided a 55 gallon Disposorb™ drum of GAC for this purpose that contained 165 pounds of GAC. The empty-bed-contact-time (EBCT) required for quenching residual H_2O_2 is approximately 4 minutes or less which would only require about 8 gallons of GAC bed. Therefore, assuming an apparent density of 0.5 g/cc the GAC bed totals 40 gallons and the associated EBCT at 2 gpm would be 20 minutes which is more than adequate for both peroxide quenching and organic adsorption.

4.3 SAMPLE HANDLING AND ANALYSIS

The above test matrix presented in Table 1 resulted in the collection of 22 water samples (11 influent & 11 effluent) for analysis of 1,4-dioxane and H_2O_2. All the samples to be analysed for 1,4-dioxane were sent to Pace Analytical Services, Inc. in Minneapolis at the completion of the tests on August 27th where they were analysed by EPA method 522 which has an analytical reporting limit of 0.07 µg/L.

Trojan measured the concentration of H_2O_2 using the *N,N-diethyl-p-phenylenediamine (*DPD*)*/Peroxidase method based on that described by Bader & Hoigne (Wat. Res., Vol. 22, No. 9, pp. 1109-1115). A Hach DR890 colorimeter was used for this method.

Prior to collecting samples, the sample ports were flushed to waste to ensure that the collected sample was representative of what was in the adjacent pipe at the time of sampling. The ports were flushed and samples collected at approximately 200 ml/min to minimize the disruption of flow through the UV system. Further, the sampling procedure comprised collecting the influent sample first followed immediately by the effluent sample once the system was at steady state.

5 RESULTS AND DISCUSSION

The results of the tracer test are summarized in Figure 3. This test was performed at 0.5 gpm and H_2O_2 injection was initiated at time zero. Influent and effluent samples were subsequently collected every 5 or 10 minutes and analysed for H_2O_2 concentration. As Figure 3 demonstrates, the influent H_2O_2 concentration climbed rapidly and plateaued between about 6.5 to 7.0 mg/L by slightly more than 5 minutes after turning the pump on. The effluent H_2O_2 concentration did not reach the same level until after 15 minutes and the two sample ports did not reach the same concentrations (i.e., steady state) until about 30 minutes after beginning the test. To be conservative, it was decided to wait for 40 minutes after adjusting the operating conditions before collecting samples for runs performed at 0.5 gpm. The corresponding times to reach steady state for the 1 gpm and 2 gpm tests were 20 minutes and 10 minutes respectively.

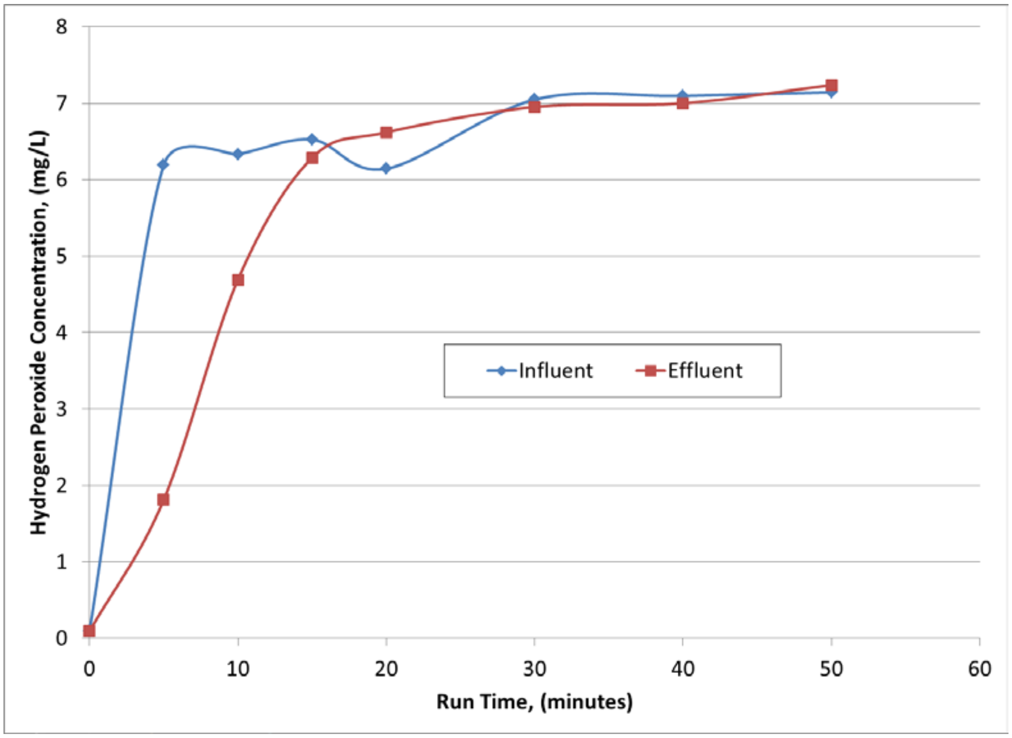


Figure 3: Tracer Test Results Operated at 0.5 gpm

The results of all 11 tests are summarized in Table 2 below. The tests were performed in the order listed.

Table 1: Data Summary

Test No.	Flow	Target $[H_2O_2]$	UV Lamps	$[H_2O_2]$		1,4-D		1,4-D Log Reduction	EEO, kWh/kgal/ order
				Influent	Effluent	Influent	Effluent		
	(gpm)	(mg/L)	(on/off)	(mg/L)	(mg/L)				
1	0.5	0	off	0.0		191	187	0.01	
2	0.5	0	on	0.0		190	159	0.08	86.18
3	0.5	5	on	5.7	1.7	193	2.1	1.96	3.40
4	0.5	10	on	9.9		189	0.082	3.36	1.98
5	0.5	20	on	21.1	6.1	197	**0.07**	**3.45**	**1.93**
6	1.0	5	on	5.5	3.0	172	11.7	1.17	2.86
7	1.0	10	on	10.5	6.0	186	2.3	1.91	1.75
8	1.0	20	on	19.6		192	0.44	2.64	1.26
9	2.0	5	on	6.8	5.4	170	39.6	0.63	2.63
10	2.0	10	on	11.0	8.5	169	17.9	0.98	1.71
11	2.0	20	on	20.1	15.7	170	7	1.39	1.20

Figure 4 presents a comparison of the target H_2O_2 dose and the measured H_2O_2 concentration at the UV influent port. It is observed that the measured H_2O_2 concentration matches the target value reasonably well. On average, the measured H_2O_2 dose was 109% of the target value.

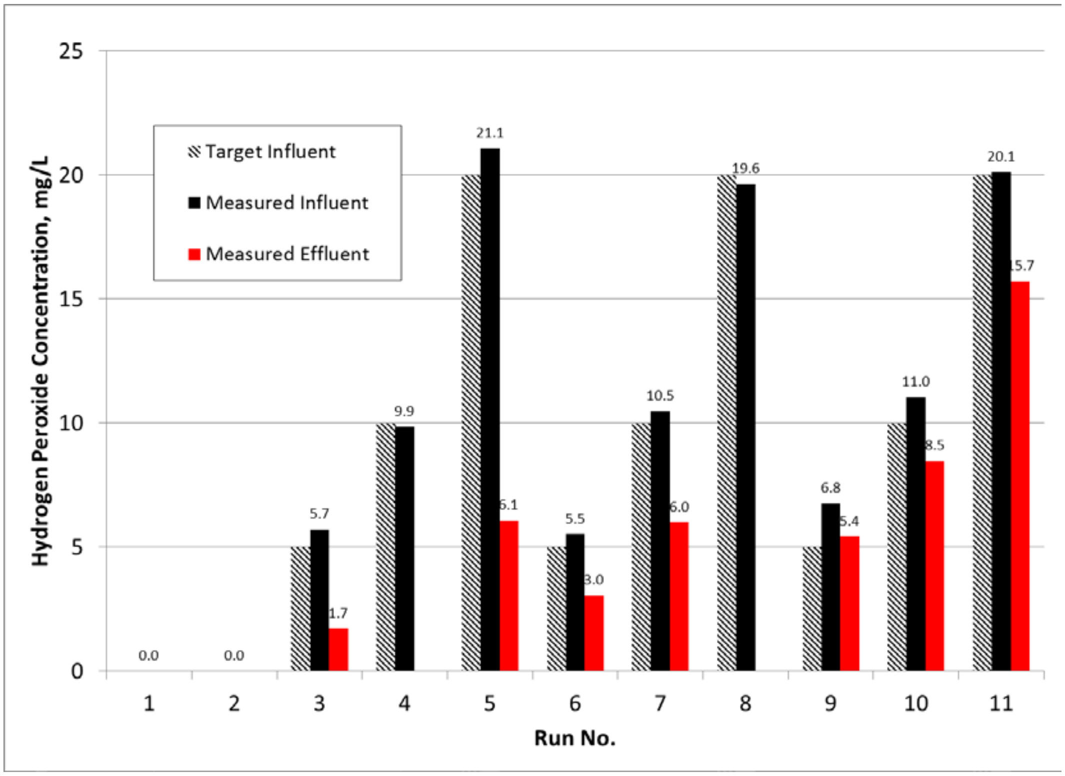


Figure 4: Comparison of Target and Measured H_2O_2 Dose

Figure 5 plots the measured influent and effluent 1,4-dioxane concentrations. 1,4-dioxane was injected at a rate that should provide a relatively constant concentration for all 11 runs. The average influent 1,4-dioxane concentration was 183.5 µg/L and varied from 169 to 197 µg/L. Effluent concentrations varied widely, as expected based on the varied operating conditions of the tests, and ranged from 187 µg/L for Run 1 to below the analytical method detection limit of 0.07 µg/L for Run 5.

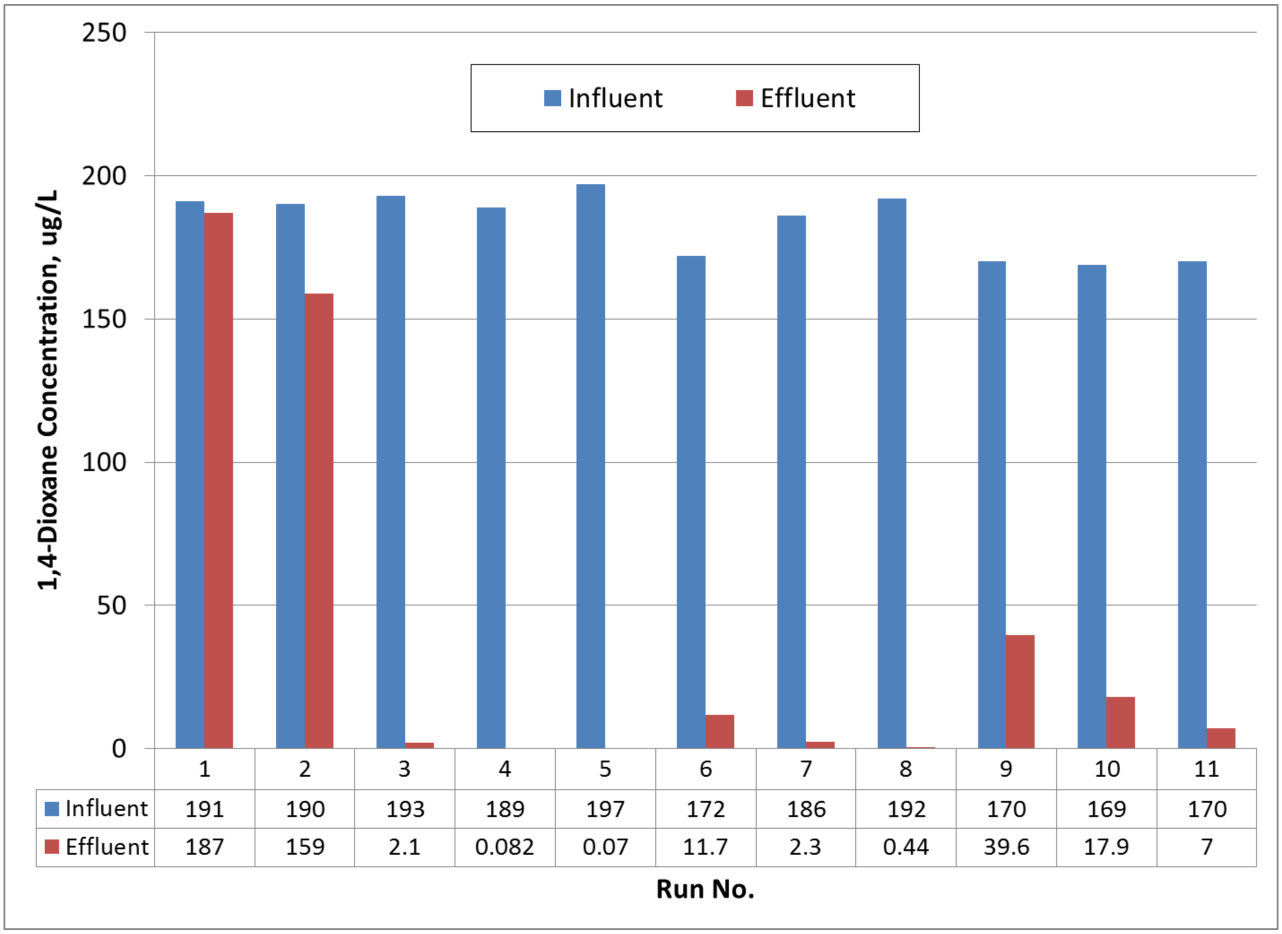


Figure 5: 1,4-Dioxane UV Reactor Influent and Effluent Concentrations

Run 1 was a control test that was not expected to provide any treatment of 1,4-dioxane. This was conducted to demonstrate that the system operation and sample collection, handling and analytical procedures did not produce anomalous results. As Table 2 and Figure 5 show, the influent and effluent 1,4-dioxane concentrations for run 1 were almost identical. Run 2 was performed to demonstrate that significant 1,4-dioxane destruction does not occur in the absence of H_2O_2. The results demonstrate that only 0.08-log destruction of 1,4-dioxane occurred and it is possible that a trace of H_2O_2 may have been present even though the H_2O_2 pump was off. For all the other test runs in which both UV energy and H_2O_2 were present the 1,4-dioxane reductions were substantial.

Figure 6 presents the log reduction of 1,4-dioxane that was measured for each of the 11 test runs. Log reduction is calculated by taking the logarithm of the influent 1,4-dioxane concentration divided by the effluent 1,4-dioxane concentration (i.e., $\text{Log}(C_{inf}/C_{eff})$). As discussed, the log reduction for runs 1 and 2 were negligible. Referring to the test matrix presented in Table 2, runs 3, 4 and 5 were all performed at 0.5 gpm with run 3 at 5 ppm H_2O_2, run 4 at 10 ppm H_2O_2 and run 5 at 20 ppm H_2O_2. It is observed in Figure 6 that the log reduction increases as the H_2O_2 dose increases. Nevertheless, the increase from run 4 at 10 ppm H_2O_2 to run 5 at 20 ppm H_2O_2 appears to be quite low. It is important to note that, as reported in Table 2, the effluent concentration for run 5 was below the analytical detection limit of 0.07 µg/L. The corresponding log reduction calculation for run 5 used 0.07 µg/L as the effluent concentration even though the actual concentration was less than 0.07 µg/L. Therefore, the actual log reduction would be some value greater than the 3.45-log reported for run 5 and plotted in

Figure 6. Similarly, runs 6, 7 and 8 were all performed at 1 gpm with 5, 10 and 20 ppm H_2O_2 doses respectively. For these runs we observe that the log reduction values increased from 1.17-log at 5 ppm to 1.91-log at 10 ppm and to 2.64-log at 20 ppm H_2O_2. Runs 9, 10 and 11 were performed at 2 gpm again with 5, 10 and 20 ppm H_2O_2 dose targets. The measured 1,4-dioxane log reduction values for these runs increased from 0.63-log to 0.98-log and to 1.39-log with increasing H_2O_2 dose. These results show that by increasing H_2O_2 dose from 5 ppm to 10 ppm resulted in an average log reduction increase of 63% while increasing from 10 ppm H_2O_2 to 20 ppm H_2O_2 resulted in an average log reduction increase of 40% (based on runs 7, 8, 10 & 11). This is the expected result in that there is a diminishing benefit to contaminant log reduction due to H_2O_2 dose increases. This is because although increasing the H_2O_2 concentration increases the rate of hydroxyl radical generation it also increases the rate of hydroxyl radical scavenging by H_2O_2. The results presented in Figure 6 also illustrate that the measured 1,4-dioxane log reduction increases as the flow rate decreases. Analyzing the data presented in Figure 6 and Table 2 indicates that reducing the flow rate by 50% results in an average log reduction increase of 83%. This is also consistent with expectations because it is known that UV reactor efficiency can decrease at low flow rates due to poor hydraulic flow patterns (i.e., poor mixing) in the reactor leading to broad UV dose distributions.

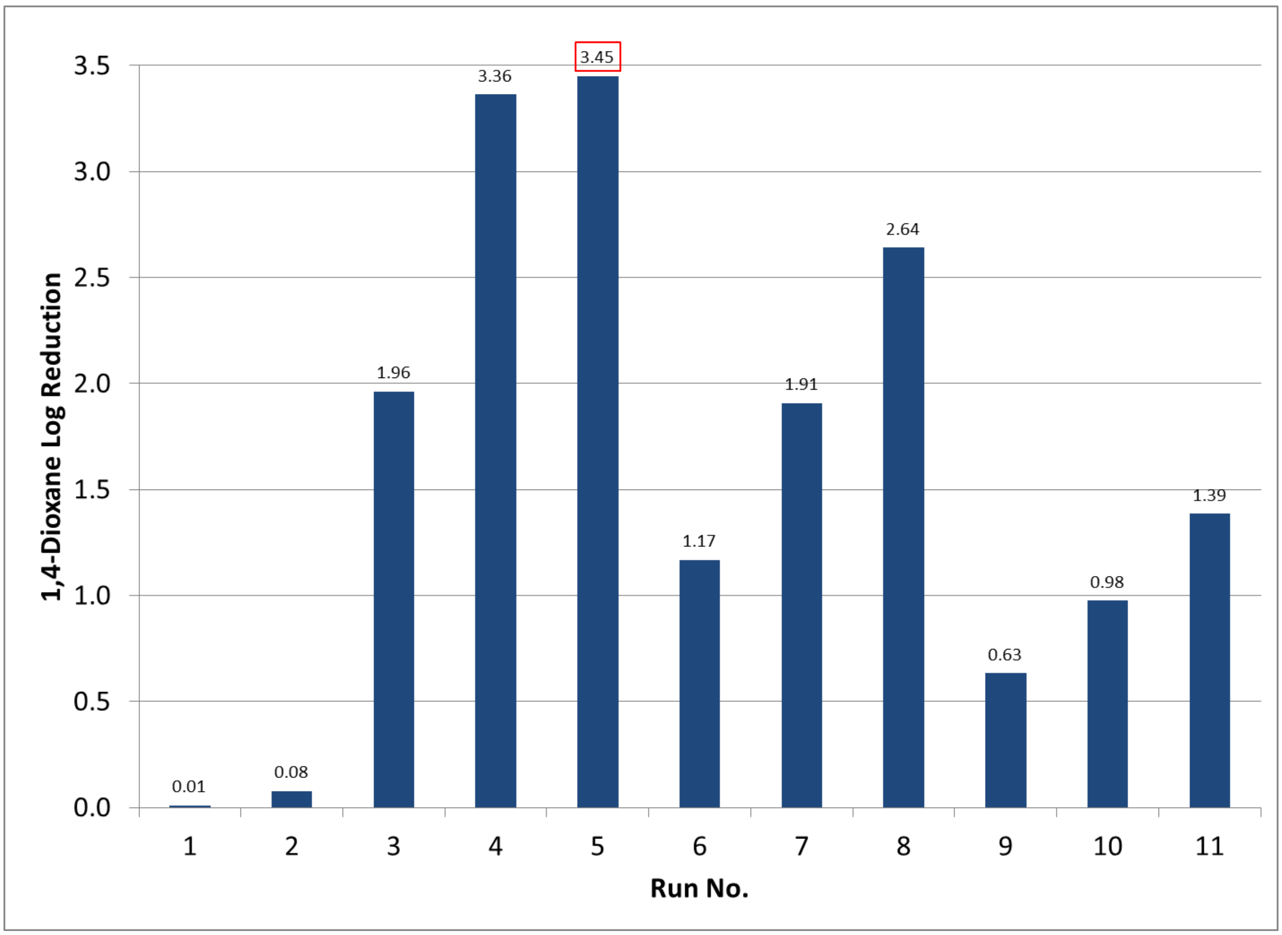


Figure 6: Summary of 1,4-Dioxane Log Reduction Data

Another method of describing the treatment performance is to examine the electrical energy per order (E_{EO}) parameter for 1,4-dioxane, as described previously. The E_{EO} is calculated by dividing the UV electrical power by the flow rate and by the 1,4-dioxane log reduction. Therefore, lower E_{EO} values represent more efficient treatment. The E_{EO} is presented for all 11 runs in Table 2 and plotted in Figure 7 as a function of the measured influent H_2O_2 concentrations. The first conclusion from examining Figure 7 is that the E_{EO} decreases as H_2O_2 dose increases. Also, although the system flow rate does not have a significant impact on the E_{EO} it does appear that the lowest flow of 0.5 gpm did result in slightly higher values. This is consistent with our expectations of the reactor hydraulic efficiency as a function of flow rate. It is also apparent that the correlation between E_{EO} and H_2O_2 dose is non-linear. This is also consistent with the expected diminishing benefit of increasing the H_2O_2 dose, as explained above.

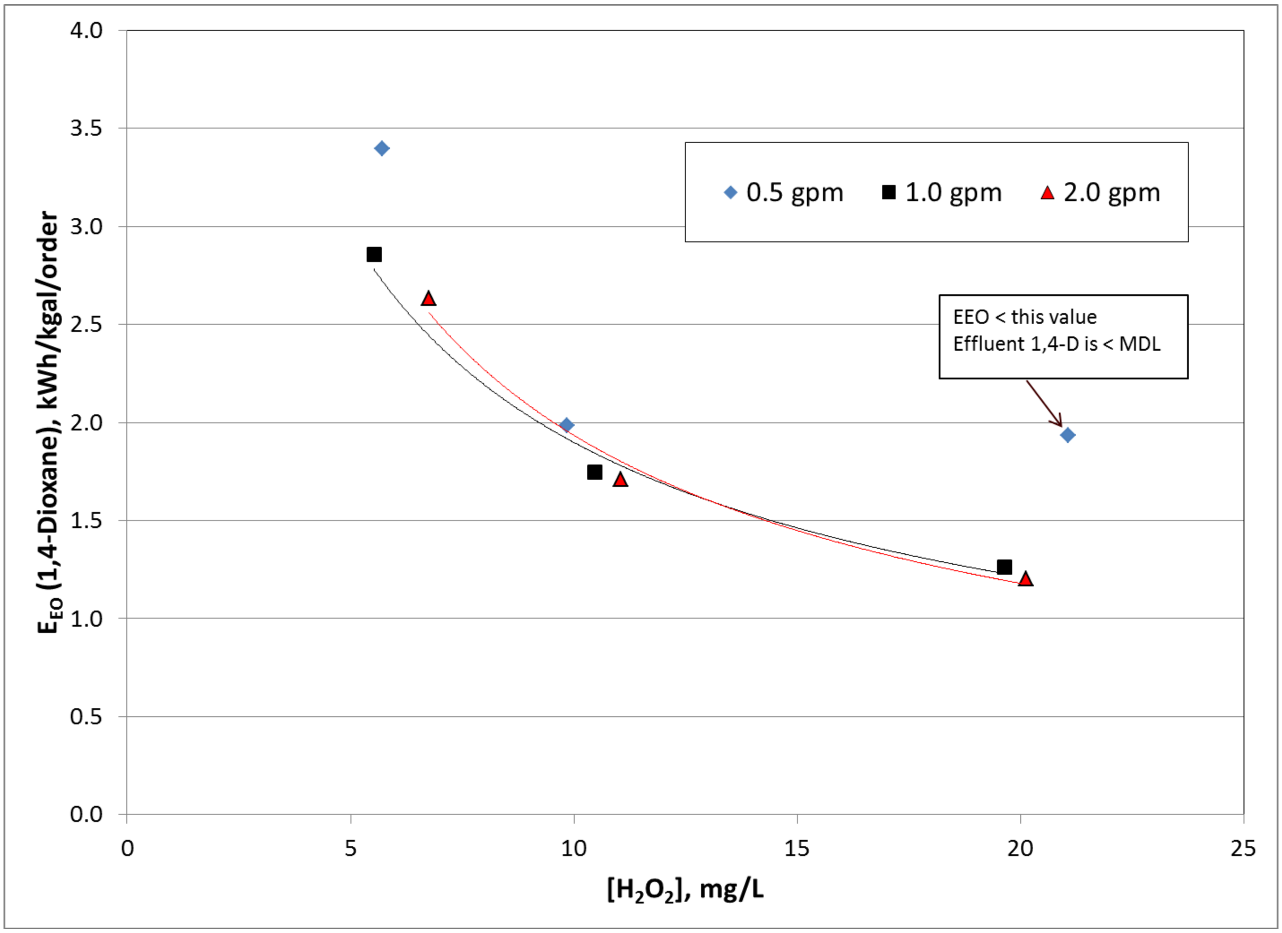


Figure 7: 1,4-Dioxane Electrical Energy per Order as a Function of H_2O_2 Dose and Flow

The same data is examined in Figure 8 which plots the measured log reduction of 1,4-dioxane as a function of the electrical energy dose (EED). The EED term was introduced in Section 2 and is determined by dividing the UV system power by the flow rate. This is a measure of the UV energy provided per unit volume of water treated. As Figure 8 demonstrates, the log reduction of 1,4-dioxane is proportional to both the EED and the H_2O_2 dose. Note that the effluent 1,4-dioxane concentration was below the MDL for the highest EED and highest H_2O_2 dose.

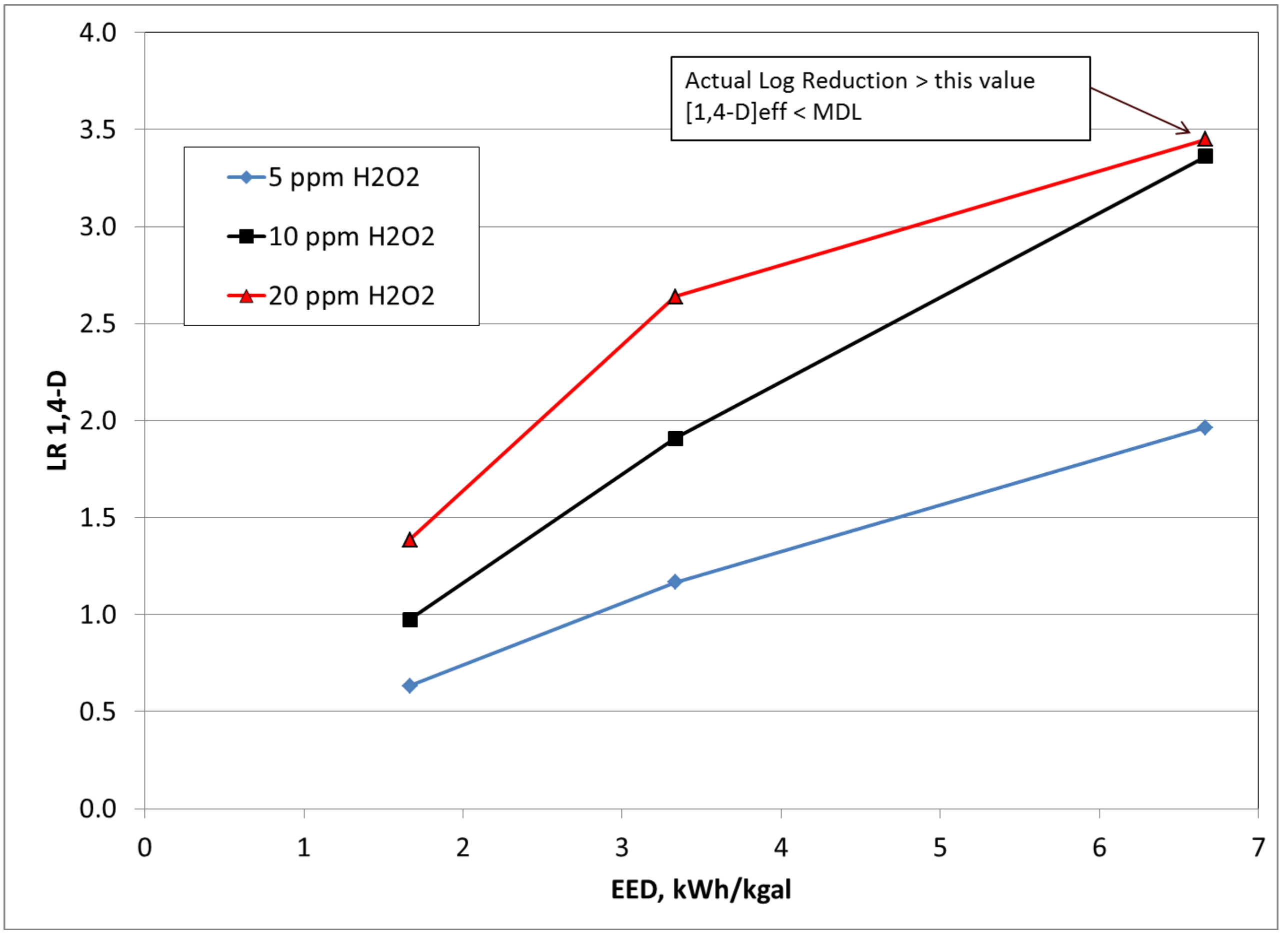


Figure 8: 1,4-Dioxane Log Reduction (LR) as a Function of Electrical Energy Dose (EED)

6 FULL-SCALE SYSTEM SIZING

This section is intended to describe the basis of sizing the UV/H_2O_2 AOP System for Saint Anthony proposed by Trojan Technologies.

Trojan's general approach to UV oxidation system sizing relies upon the combination of understanding the fundamental photochemistry of the UV oxidation process together with a thorough understanding of the hydraulic and optical performance of Trojan reactors, as well as extensive full-scale experience to provide, with confidence, performance warranties for all Trojan UV oxidation systems.

Specifically, the sizing method that Trojan typically employs is comprised of the following steps:

1) Through a combination of bench-scale experimentation and literature review determine the fundamental photochemical kinetic parameters for the specific contaminants that govern the rate of contaminant destruction by the UV photolysis and UV/H_2O_2 process. These fundamental kinetic parameters include the quantum yield and molar absorption coefficient as a function of the irradiation wavelength which together determine the rate of direct photolysis of the contaminant in response to a delivered UV dose. They also include the second order rate constant for the reaction between the contaminant and the hydroxyl radical. The water constituents could undergo photochemical reactions generating reactive species such as triplet states and radicals which could affect the contaminant photochemistry/chemistry in that specific water. These parameters and the role of water constituents on various contaminant structures, including pesticides, algal toxins, taste-and-odor causing compounds, pharmaceuticals and so on are determined by performing properly designed collimated beam experiments.
2) Determine the UV transmittance (%*T*, also abbreviated as UVT) across the radiation wavelength relevant to the UV application and the hydroxyl radical scavenging capacity of representative water samples. The water UVT is measured over the wavelength range from 200 to 400 nm using a calibrated spectrophotometer. The scavenging capacity of the water is determined from a properly designed collimated beam methodology.
3) Input these parameters together with the system design parameters (flow and treatment goal) into Trojan's proprietary mathematical model of the UV photolysis and UV/H_2O_2 process for the TrojanUVPhox™ reactor.
4) Trojan's proprietary model comprises the following system characteristics:
   a) It incorporates the photochemical kinetics for direct UV photolysis and hydroxyl radical based UV-oxidation by modeling the contaminant destruction kinetics for the given water quality defined by the UVT and the hydroxyl radical scavenging demand.
   b) It utilizes computational fluid dynamics (CFD) and UV intensity models to characterize the product of the hydraulic behavior and the UV intensity gradients within Trojan's various reactors. This task requires a detailed knowledge of the internal dimensions and structures of each possible reactor model together with the lamp spectral power distribution and efficiency, quartz sleeve UV light transmitting characteristics, and their specific geometric positioning inside the UV reactor relative to the flow patterns.
   c) Specific reactor characteristics used in the modeling have been calibrated and subsequently re-validated using numerous sets of full-scale, real world results. The TrojanUVPhox design incorporates the knowledge base accumulated from Trojan's extensive experience.
5) The model output provides the optimum combination of UV power and H_2O_2 concentration resulting in a minimum NPV for the system.
6) Trojan has extensive full-scale experience in applying both the UV direct photolysis and UV/H_2O_2 process in various water treatment applications. These full-scale installations comprise projects treating contaminants including pesticides, industrial solvents, cyanides, taste-and-odor

causing compounds, algal toxins, pharmaceuticals and personal care products, endocrine disrupting compounds, NDMA and 1,4-Dioxane. Numerous systems, including Tucson's 5,800 gpm airport remediation project utilizing the TrojanUVPhox D72AL75 installation, the 100 MGD Groundwater Replenishment System in Orange County California and the 50 MGD UV oxidation system in Aurora, Colorado are designed for low-pressure UV oxidation of various contaminants.

6.1 DESIGN CRITERIA

The full-scale design criteria together with measured water quality are summarized in Table 3.

Table 3: City of St. Anthony Water Village Treatment System Design Specifications

UV SYSTEM DESIGN SPECIFICATIONS	
Design Flow	3000 gpm
Average Flow	1250 gpm
Target 1,4-dioxane Log Reduction	2.0-Log
Measured UV Transmittance	96%

The model output for the projected water quality at the peak flow conditions (i.e., 3000 gpm at 96% UVT) provides an electrical energy per order (E_{EO}) value of 0.41 kWh/kgal/order for 1,4-dioxane when 18 ppm of H_2O_2 is present. This value is associated with the UV output at the end-of-lamp-life (EOLL) condition as well as an appropriate level of conservatism. Trojan has proposed to reduce 1,4-dioxane by 2.0-log (i.e., 99.0%) in this stream with 2 parallel trains of 2 TrojanUVPhox™ D72AL75 reactors plus one redundant train. This system is described in a separate proposal.

While Trojan's preferred approach to sizing UV-AOP systems is to rely upon our proven mechanistic sizing model, as described above, there are several aspects of the empirical scale-up approach that should be discussed. Full-scale UV reactors typically have superior treatment efficiency compared with pilot-scale reactors for the following reasons.

In UV-based AOP systems, most UV photons that are transmitted through the water and reach the wall of the reactor are absorbed by the wall material and do not contribute to the contaminant treatment process. This loss of photons at the reactor wall and other surfaces within the UV reactor represents an inefficiency of the reactor. Conversely, if a large fraction of photons that are emitted by the lamps are absorbed by constituents in the water, a desired result, then the reactor is said to have high absorption efficiency. This reactor absorption efficiency can be increased by providing a longer pathlength for the photons to travel before they reach a surface. Similarly, reactors typically have higher efficiencies when operated at higher flow rates. This is a result of better hydraulic performance (i.e., mixing) that better approaches the ideal plug flow behaviour. The result of these phenomena is that the relatively small pilot reactors operated at relatively low flows generally have a lower efficiency (i.e., higher E_{EO}) than larger full-scale reactors. It is therefore, not recommended to assume that a full-scale system will have the same E_{EO} as a pilot-scale system when operated with the same water quality and H_2O_2 dose.

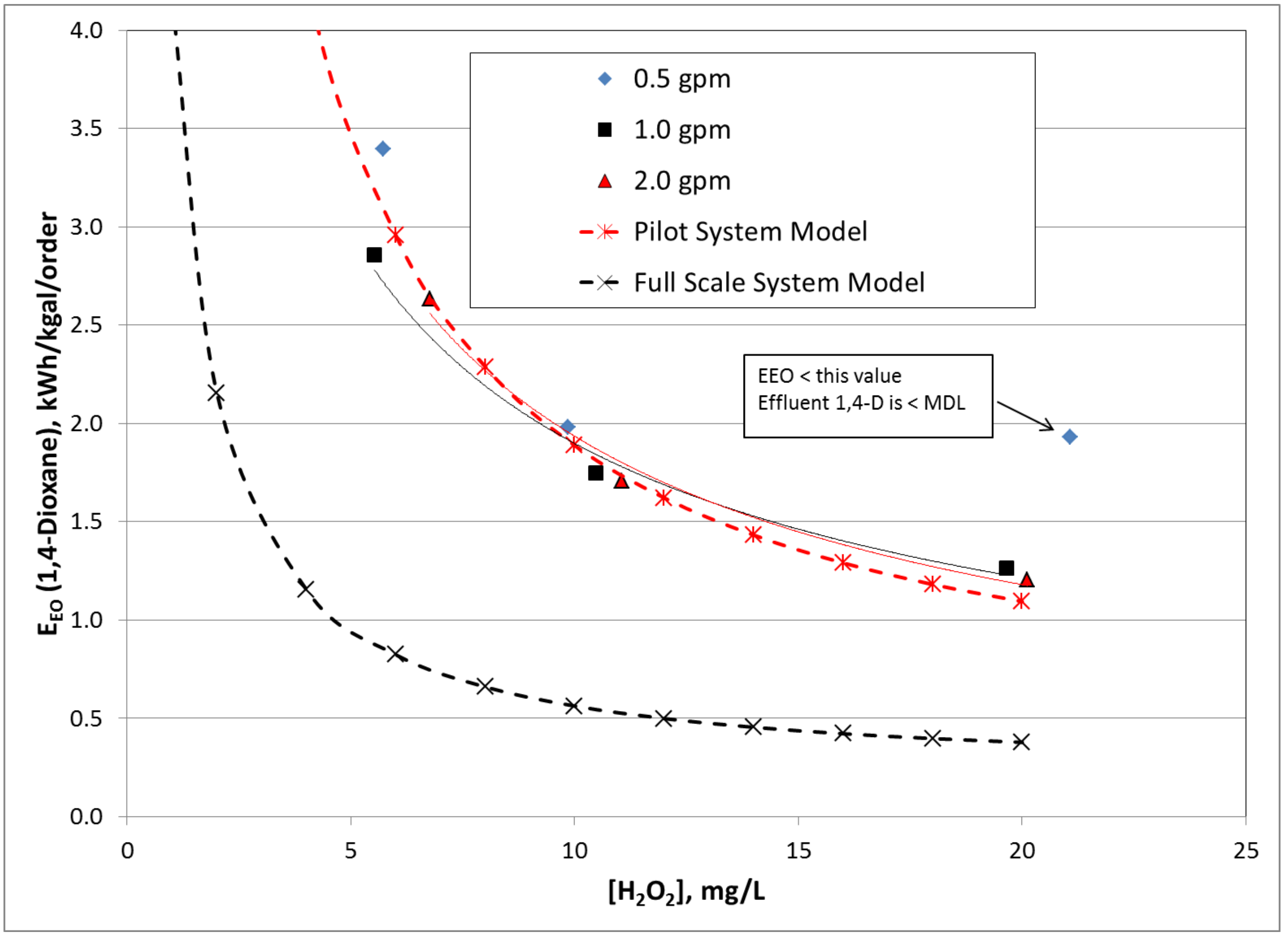


Figure 9: Comparison of Pilot Data and Model Prediction with Full-Scale Prediction

Figure 9 presents the pilot E_{EO} data for 1,4-dioxane from Figure 7 together with the full-scale model of the E_{EO} for 1,4-dioxane in 2 parallel trains of 2- D72AL75 TrojanUVPhox reactors treating 3000 gpm of filtered water by 2-log reduction of 1,4-dioxane. The full-scale design at those peak conditions has an associated E_{EO} of 0.41 kWh/kgal/order at about 18 mg/L of H_2O_2 as shown in Figure 9. Also shown in Figure 9 is the model result for the pilot-scale system at the 2 gpm operating condition. The improved efficiency of the full-scale system relative to that of the pilot system was explained earlier. This full-scale prediction also accounts for the lamps operating at their end-of-life condition with an allowance for sleeve fouling and a safety factor.

7 CONCLUSIONS

The data generated from operating a TrojanUVPhox™ A02 pilot-scale UV reactor together with H_2O_2 injection at the Saint Anthony Water Treatment Plant has demonstrated that the UV/H_2O_2 AOP is effective at treating 1,4-dioxane in the filtered Saint Anthony groundwater. Specifically,

- A water sample demonstrated high UV transmittance (>96.3%) making it a very good candidate for UV/H_2O_2 AOP treatment despite a moderately high hydroxyl radical scavenging demand.
- Greater than 3.4-log (>99.96%) destruction of 1,4-dioxane was demonstrated by the pilot system.
- 1,4-dioxane log reductions were shown to be proportional to both the H_2O_2 levels dosed and UV energy delivered (i.e., EED). Therefore, the same log reduction target could be achieved by increasing H_2O_2 and reducing power or vice versa. This supports the conclusion that the process is operationally flexible and able to be optimized to minimize the overall cost of treatment.
- The E_{EO} values for 1,4-dioxane were shown to vary inversely with the H_2O_2 level dosed. That is, the E_{EO} decreases with increasing H_2O_2 and vice versa.
- Destruction of 1,4-dioxane was achieved using UV/H_2O_2 with relatively low E_{EO} values (~1.2 - 3.4 kWh/kgal/order) depending primarily upon the H_2O_2 dose selected. Full-scale EEOs are expected to be lower since larger reactors are more efficient than pilot-scale equipment.
- Trojan's model of the UV/H_2O_2 process was demonstrated to match the pilot data very well. This same model was adjusted for the full-scale system parameters and provided the basis for the full-scale system recommendation.
- The proposed full-scale UV/H_2O_2 system comprises three parallel trains of 2-D72AL75 TrojanUVPhox reactors (2 duty trains, 1 redundant train) each with 18 ppm H_2O_2. This system will treat 3000 gpm of 96%T water by 2-log (i.e., 99%) reduction of 1,4-dioxane.
- The process was demonstrated to be relatively simple to operate. Full-scale system controls simplify those operations further.

APPENDIX C

Evaluation of Hydrogen Peroxide with Ozone and Bioremediation for Treatment of Dioxane

Appendix C –
Evaluation of Hydrogen Peroxide with Ozone and Bioremediation for Treatment of Dioxane

<u>Ozone/Hydrogen Peroxide</u>

Ozone with hydrogen peroxide was not piloted or further evaluated for treating Dioxane at the City's existing water treatment plant for the following reasons:

1. Typically used for high turbidity waters (surface waters) where the Ultraviolet Transmittance Value (UVT) is too low for UV light to effectively pass through the water and be absorbed by the hydrogen peroxide. Because the City's water contains low turbidity, iron, and manganese downstream of the existing greensand filters, the water produces a very high UVT which is much better suited for UV light with hydrogen peroxide.

2. This process can form assimilable organic carbon (AOC) byproducts that may require an additional treatment process to remove them.

3. Generally requires a larger building footprint.

4. Typically higher O&M costs compared to UV/hydrogen peroxide.

<u>Bioremediation</u>

Ex situ bioremediation of groundwater involves putting contaminants in the extracted groundwater in contact with microorganisms in attached or suspended growth biological reactors. *Ex situ* bioremediation was selected to treat Dioxane in groundwater at the Lowry Landfill Superfund site near Denver, Colorado. Between 1960 and 1980, the site was used for co-disposal of industrial and municipal solid wastes. Industrial waste liquids that contained spent solvents including Dioxane were placed in unlined pits and subsequently contaminated shallow groundwater (Source – *EPA Treatment Technologies for 1,4-Dioxane: Fundamentals and Field Applications*).

Ex situ bioremediation was not further evaluated for St. Anthony Village as the treatment process was determined to be very difficult to pilot and too costly to implement if it was determined to be an effective treatment technology. In addition, it is possible that the Minnesota Pollution Control Agency (MPCA) and the MDH would not approve this method. There are no known public water systems that utilize bioremediation for treatment of Dioxane.

APPENDIX D

Cost Estimates

Option 2 Detailed Costs

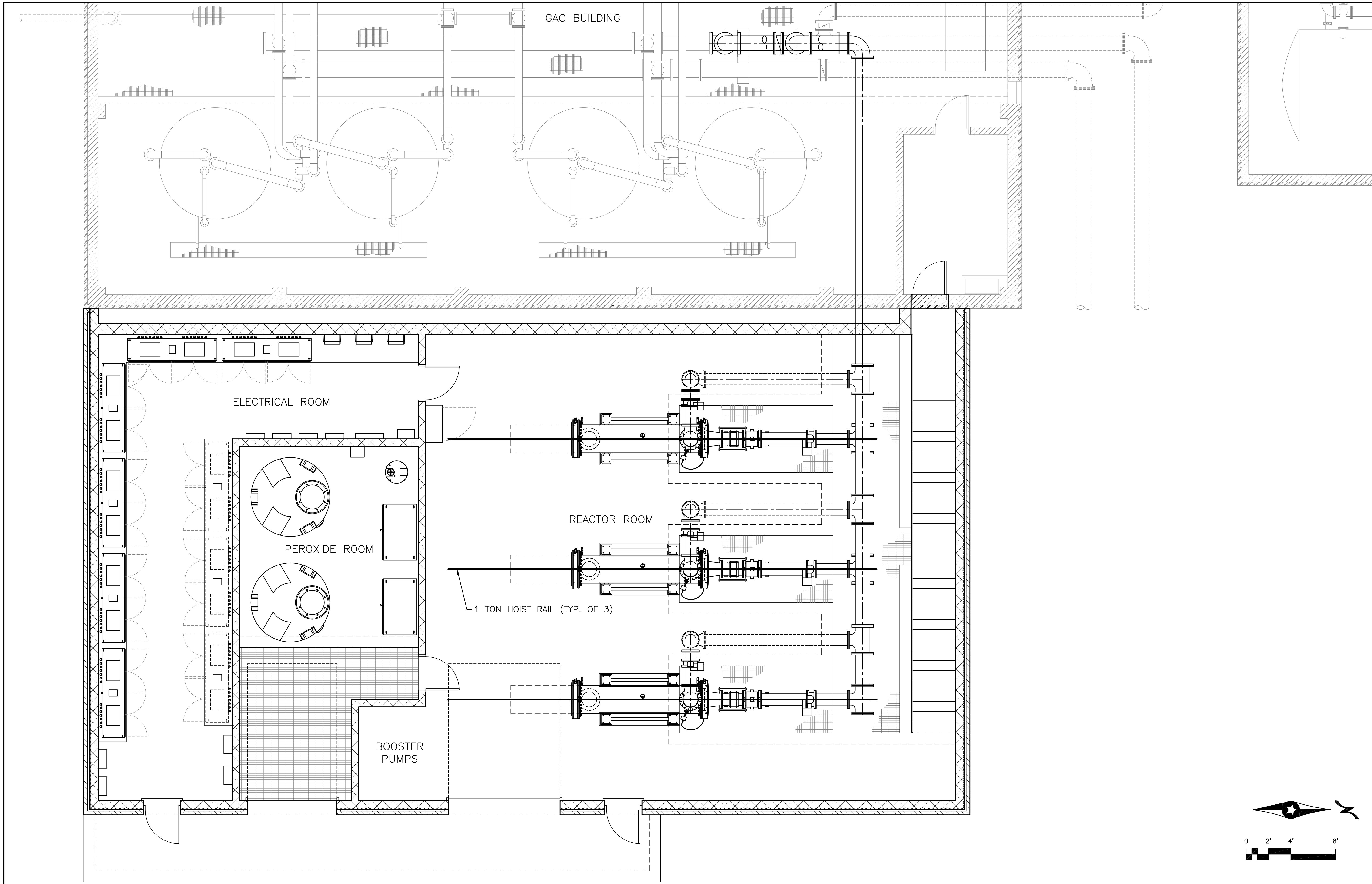
OPTION 2: MOUNT-SIMON HINCKLEY WELLS				
ESTIMATED CAPITAL COST				
ITEM	NO.	UNIT	UNIT COST	COST
Drill Mount - Simon Hinckley Well	4	Each	$ 350,000	$ 1,400,000
Groundwater Study	1	Lump Sum	$ 75,000	$ 75,000
Misc. DNR Requirements for Approval	1	Lump Sum	$ 50,000	$ 50,000
Pump Houses	4	Each	$ 850,000	$ 3,400,000
HVAC System Upgrade	1	Lump Sum	$ 25,000	$ 25,000
			TOTAL:	$ 4,950,000
			INDIRECT (25%):	$ 1,237,500
			SUBTOTAL:	$ 6,187,500
			CONTINGENCY (15%):	$ 928,125
			GRAND TOTAL:	$ 7,115,625
ESTIMATED ANNUAL O&M COST				
ITEM	NO.	UNIT	UNIT COST	COST
Hazardous Waste Disposal - Media	1	Lump Sum	$ 50,000	$ 50,000
Media Replacement	1	Lump Sum	$ 1,728	$ 1,728
Additional Well Pump Maintenance	1	Lump Sum	$ 10,000	$ 10,000
Additional Power Usage (Depth)	456,375	KWHr	$ 0.0823	$ 37,560
			TOTAL ANNUAL:	$ 99,288
			PER 20 YEARS:	$ 1,985,753.25
			PER 20 YEARS WITH 3.5% INFLATION RATE:	$ 2,812,253.54

OPTION 3: PURCHASE WATER FROM MINNEAPOLIS WATER						
ESTIMATED CAPITAL COST						
ITEM	NO.	UNIT	UNIT COST			COST
20-inch Water Main	15,750	Lin Ft	$	260	$	4,095,000.00
Land Acquisition	2	Each	$	350,000	$	700,000.00
Booster Pump Station	2	Lump Sum	$	900,000	$	1,800,000.00
				TOTAL:	$	6,595,000.00
				INDIRECT (25%):	$	1,648,750.00
				SUBTOTAL:	$	8,243,750.00
				CONTINGENCY (15%):	$	1,236,562.50
				GRAND TOTAL:	$	9,480,312.50
ESTIMATED ANNUAL O&M COSTS						
ITEM	NO.	UNIT	UNIT COST			COST
Proposed Pumping Costs	1	Per Year	$	32,434	$	32,434.00
Demand Charges	1	Per Year	$	15,036	$	15,036.00
Replacement Pumps - 2500 gpm	2	Per Year	$	8,000	$	16,000.00
Replacement Pumps - 3500 gpm	1	Per Year	$	5,000	$	5,000.00
Heat	1	Per Year	$	4,235	$	4,235.00
VFD Replacement - 100 HP	2	Per Year	$	1,910	$	3,820.00
VFD Replacement - 150 HP	1	Per Year	$	2,320	$	2,320.00
SCADA Integrator	1	Per Year	$	20,000	$	20,000.00
Building Maintenance	1	Per Year	$	5,000	$	5,000.00
Watermain Replacement	1	Per Year	$	54,600	$	54,600.00
				TOTAL ANNUAL:	$	158,445.00
				PER 20 YEARS:	$	3,168,900.00
				PER 20 YEARS WITH 3.5% INFLATION RATE:	$	4,487,843.71

Individual Water Softening	1	Per Month	$	6.75	$	6.75

OPTION 5: IMPLEMENT A WATER TREATMENT SYSTEM						
ESTIMATED CAPITAL COST						
ITEM	NO.	UNIT		UNIT COST		COST
General Conditions	1	Lump Sum	$	651,279	$	651,279
General Site Work	1	Lump Sum	$	94,750	$	94,750
Building and Treatment	1	Lump Sum	$	4,247,110	$	4,247,110
				TOTAL:	$	4,993,139
				INDIRECT (25%):	$	1,248,285
				SUBTOTAL:	$	6,241,424
				CONTINGENCY (15%):	$	936,214
				GRAND TOTAL:	$	7,177,637
ESTIMATED ANNUAL O&M COST						
ITEM	NO.	UNIT		UNIT COST		COST
Electrical Costs for Trojan Units	1	Lump Sum	$	9,884	$	9,884
Heating Cost	1	Lump Sum	$	1,750	$	1,750
Hydrogen Peroxide	1	Lump Sum	$	25,302	$	25,302
Additional Power Usage	1	Lump Sum	$	1,200	$	1,200
				TOTAL ANNUAL:	$	38,136
				PER 20 YEARS:	$	762,720.00
				PER 20 YEARS WITH 3.5% INFLATION RATE:	$	1,080,175.50

OPTION 5: IMPLEMENT A WATER TREATMENT SYSTEM					
DETAILED ESTIMATED CAPITAL COST					
#	ITEM	UNIT	NO.	UNIT COST	COST
1	**GENERAL CONDITIONS**				
1.1	General Conditions, building permits, bonds, insurance, mobilization, contractor project management, construction superintendent, and contractor profit	1	1	$ 651,279	$ 651,279
	General Conditions Total Estimated Construction Costs				**$ 651,279**
2	**GENERAL SITE WORK**				
2.1	Site preparation and tree removal	LS	1	$ 9,000	$ 9,000
2.2	Silt fence	LF	150	$ 5	$ 750
2.3	Finish grading and turf restoration	LS	1	$ 25,000	$ 25,000
2.4	Site utilities	LS	1	$ 50,000	$ 50,000
2.5	Pavement	LS	1	$ 10,000	$ 10,000
	General Site Work Total Estimated Construction Costs				**$ 94,750**
3	**BUILDING AND PROCESS EQUIPMENT**				
3.1	Excavating and backfilling with select granular material	CY	1035	$ 20	$ 20,700
3.2	Structural Pilings	LF	1080	$ 50	$ 54,000
3.3	Cast-in-Place Concrete (footings and floor slabs)	CY	96	$ 600	$ 57,600
3.4	Precast Concrete	LS	1	56350.00	$ 56,350
3.5	Unit Masonry Assemblies	LS	1	209300.00	$ 209,300
3.6	Misc. Metal Work	LS	1	46000.00	$ 46,000
3.7	Rough Carpentry	LS	1	6000.00	$ 6,000
3.8	Building Insulation	LS	1	36800.00	$ 36,800
3.9	Fully Adhered Membrane Roof System	LS	1	66700.00	$ 66,700
3.10	Caulking and Sealants	LS	1	29900.00	$ 29,900
3.11	Door Frames and Hardware	LS	1	12000.00	$ 12,000
3.12	Painting	LS	1	24000.00	$ 24,000
3.13	Process Piping, Fittings, and Valves	LS	1	250000.00	$ 250,000
3.14	Water Quality Analyzers	LS	1	15000.00	$ 15,000
3.15	Trojan Treatment Equipment and Chemical Feed Systems	LS	1	2300000.00	$ 2,300,000
3.16	Chemical Feed System, Piping and Valves	LS	1	150000.00	$ 150,000
3.17	Flow Meters	EA	3	10000.00	$ 30,000
3.18	Overhead Hoist and Beam	LS	1	45000.00	$ 45,000
3.19	Plumbing and HVAC	LS	1	104000.00	$ 104,000
3.20	Electrical General Provisions	LS	1	170000.00	$ 170,000
3.21	Instrumentation and Controls	LS	1	250000.00	$ 250,000
3.22	UV Replacement Lamps	EA	296	$ 1,060	$ 313,760
	Building and Process Equipment Construction Costs				**$ 4,247,110**



ADVANCED OXIDATION WATER TREATMENT
FOR THE CITY OF
ST. ANTHONY, MINNESOTA

WSB & Associates, Inc.
701 Xenia Avenue South, Suite 300
Minneapolis, MN 55416
Tel: (763) 541-4800 • Fax: (763) 541-1700
wsbeng.com
engineering · planning · environmental · construction

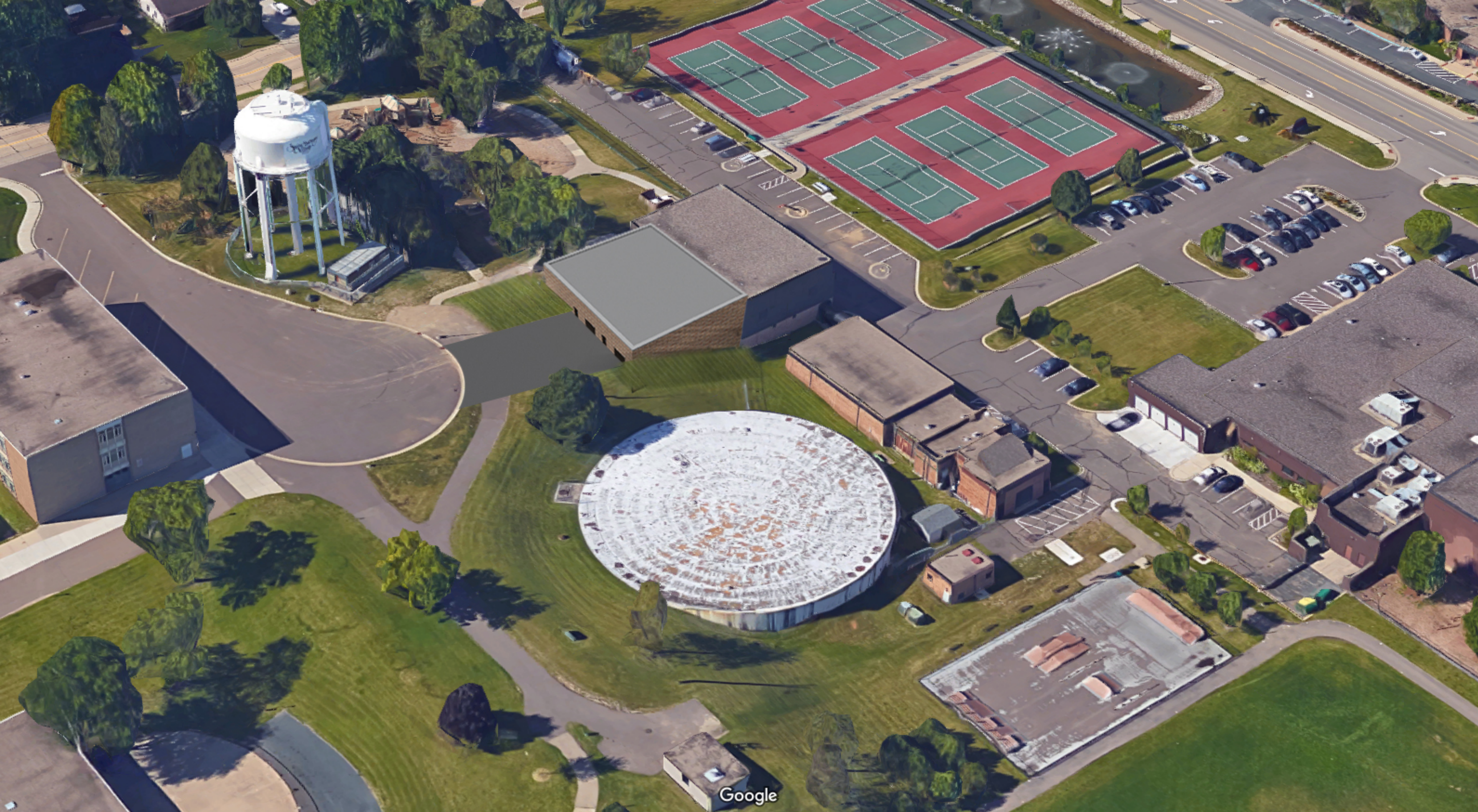
I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA

DATE: ? LIC. NO:

SCALE: AS NOTED
PLAN BY: DESIGN BY: CHECKED BY: PROJECT NO: ? RECORD COPY BY: DATE
REVISION NO. DATE EXPLANATION

WSB PROJECT NUMBER 02170-290


ANTHONY
TREATMENT PLANT
POLICE
DEPARTMENT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CITY OF ST. ANTHONY VILLAGE

RESOLUTION 16-037

A RESOLUTION RECEIVING FEASIBILITY REPORT, ORDERING PLANS AND SPECIFICATIONS, AND AUTHORIZING THE ADVERTISEMENT OF BIDS, FOR THE ADVANCED OXIDATION WATER TREATMENT FACILITY

WHEREAS, a feasibility report was prepared by WSB & Associates, Inc. with reference to the available options to address the presence of 1,4-Dioxane (Dioxane) in the City's source water, and

WHEREAS, the City of St. Anthony Village desires to move forward with Option 5 to construct an advanced oxidation water treatment facility for the removal of Dioxane, and

WHEREAS, the report provides information regarding whether the proposed project is necessary, cost effective, and feasible.

NOW, THEREFORE, BE IT RESOLVED, by the City Council of the City of St. Anthony Village that:

1) The City receives the recommendation and findings of the St. Anthony Village 1,4 Dioxane Feasibility Study.

2) The City orders the preparation of construction plans and specifications for the construction of an Advanced Oxidation Water Treatment Facility.

3) The City authorizes the advertisement of bids for the Advanced Oxidation Water Treatment Facility.

4) The City designates WSB & Associates, Inc. as the engineer for this improvement.

Adopted this 12th day of April , 2016.

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Jerome O. Faust, Mayor

ATTEST:____________________________
Nicole Miller, City Clerk

Reviewed for administration: ______________________________
Mark Casey, City Manager