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Disinfection Evaluation

Alternatives Analysis

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Revision	Description	Author		Quality Check		Independent Review	

Sign-off Sheet

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Executive Summary

In the fall of 2018 the City of Hastings encountered water quality concerns that prompted the City to seek an evaluation of alternatives for disinfecting the City's municipal water supply. Each month the City tests certain parameters for its water supply in accordance with requirements of the Safe Drinking Water Act (SDWA) enacted by the Environmental Protection Agency (EPA) and enforced by the Minnesota Department of Health (MDH). On the 18th day of September, Hastings' water department received word that one of the required tests came back positive for *E. coli*. As part of the standard protocol MDH conducted a retest to verify the results. The retest results were determined on the 22nd day of September, and did not show *E. coli*, however, did show positive results for Total Coliform (TC). This constituted a second positive test, necessitating a notice of violation (NOV) and a mandatory boil advisory for the impacted community. Included in the protocol was the requirement to install interim disinfection systems at each of the water supply wells.

In response to these events, the City decided to initiate an evaluation of alternatives to disinfect the water supply on a permanent basis. The alternatives identified for evaluation include the following alternatives for the water system:

- Disinfection with liquid sodium hypochlorite
- Disinfection with chlorine gas
- Disinfection with ozone combined with chlorine
- Disinfection with ultraviolet light combined with chlorine
- Disinfection with shock chlorination
- Filtration
- Comprehensive inspection and maintenance program
- Status Quo/Do-nothing alternative

Although the City of Hastings has not had previous problems with their water system, the do-nothing alternative was highly discouraged by MDH. A brief analysis showed that disinfection with either ozone or ultraviolet light would require a significantly higher investment than both chlorine-based systems and would require pairing with a chlorine-based system to provide a lasting disinfection residual in the distribution system. Both shock chlorination and an inspection and maintenance program were also considered as alternatives, but still leave the overall system with heightened vulnerability to pathogens due to the possibility of contamination entering the distribution system and not being repressed by disinfection residuals.

To better compare the costs of the alternatives, preliminary layouts were designed for the Hastings Water Treatment Plant (WTP) and for each city Well where systems would need to be installed. The preliminary layouts allowed a rough capital cost estimate to be made for the installation of each system. Additionally, yearly operational costs were estimated for each type of system. A summary of these costs is shown below in Table 1.

Table 1: 10 Year Net Present Cost

System Type	Capital Costs*	Operational Costs	10-Year Net Present Cost**
Sodium Hypochlorite	$155,000	$99,000	$958,000
Chlorine Gas	$351,000	$44,000	$708,000
Ozone***	$3,000,000	$104,000	$3,844,000
Ultraviolet Light***	$750,000	$22,000	$928,000

* Capital costs do not include soft costs, such as design and engineering

** Calculated assuming a 4% rate of return, and no equipment replacements

*** Would have to be paired with a chlorine-based system, resulting in additional costs

1.0 INTRODUCTION

On the 18th day of September, Hastings' water supply received word that one of the tests came back positive for *E. coli*. As part of the standard protocol MDH conducted a retest to verify the results. The retest results were determined on the 22nd day of September, and did not show *E. coli*, however did come back positive for Total Coliform (TC) bacteria. According to the USEPA, "Generally coliforms are bacteria that are not harmful and are naturally present in the environment. They are used as an indicator that other, potentially harmful, fecal bacteria (indicated by the *E. coli* species) could be present."[1] The positive TC sample following the initial *E. coli* detection constituted a second positive test result, necessitating a notice of violation (NOV) and a mandatory boil advisory for the impacted community according to the USEPA *Revised Total Coliform Rule*.[2] To investigate the incident, the Minnesota Department of Health (MDH) conducted a Level 2 Assessment of the City's drinking water system. This assessment identified no sanitary defects in the system and was unable to pinpoint the cause of the incident. However, possible causes include a change in flow pattern due to seasonal uses, a backflow event, and the construction of a new water main.

Based on the findings from the Level 2 Assessment, MDH strongly recommends that the City of Hastings implement permanent, continuous chlorination of the water system. MDH noted that the system's size makes it vulnerable to contamination and recommends maintaining a total chlorine residual of 1.0 part per million (ppm) or a free chlorine residual of at least 0.5 ppm in all parts of the distribution system.

As a result of the water quality concerns, the City decided to seek an evaluation of alternatives for disinfecting the City's municipal water. The purpose of this evaluation is to examine the feasibility of implementing permanent disinfection for the City of Hastings' municipal drinking water, so that an informed decision can be made regarding disinfection of the City's municipal drinking water moving forward. Budget level cost estimates have been prepared for each alternative so that meaningful comparisons and candid discussions can take place amongst stakeholders.

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[1] United States Environmental Protection Agency. *Addressing Total Coliform Positive or E. coli Positive Sample Results in EPA Region 8*. USEPA.
[2] For more information on when boil advisories are triggered, see the *Revised Total Coliform Rule: A Quick Reference Guide.* USEPA (2013).

2.0 BACKGROUND

The City of Hastings draws drinking water from six municipal wells, all drawing groundwater from the Jordan aquifer, which are labeled City Wells 3 through 8. The wells extend between 280 and 497 feet deep, and pump at approximately 1,100 gallons per minute (gpm). An existing water treatment plant (WTP) serves Wells 3 & 5. Existing water treatment is accomplished by simple chemical addition of fluoride, and the additional removal of nitrates by ion exchange at the WTP. The water distribution system contains approximately 27 miles of trunk water main (ranging in diameter from 10 inches to 16 inches) out of a total of over 110 miles of water main.

While groundwater sources such as the Jordan aquifer are typically of much higher quality than most surface water sources, groundwater sources can experience biological contamination, which can require treatment through disinfection. Disinfecting drinking water became common in the early 20th century, and brought about a significant decrease in rates of waterborne disease. The *10 States Recommended Standards for Water Works*, from which MDH bases many requirements, does not specifically require the disinfection of all groundwater supplies, but does require the disinfection of groundwater under the direct influence of surface water, for any groundwater supply of questionable sanitary quality, or where other treatment is provided.[3]

Apart from contamination at the water source, contamination can occur in the water distribution system through backflow events or when pipes are open during construction and maintenance. For distribution systems of significant size, such as Hastings' distribution system, contamination during distribution can be a very real threat. This threat is reflected in the assessment from MDH that identified possible causes such as a change in flow pattern due to seasonal uses, a backflow event, water main maintenance, and the construction of new water main. In order to combat the threat of contamination within the distribution system, disinfection residuals are often maintained throughout the distribution system, mitigating bacterial growth all the way to the tap.

[3] The *10 States Recommended Standards for Water Works* is a report on recommended policies and specifications for public water supplies, produced by the Water Supply Committee of the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. The current edition was updated in 2012.

3.0 SUMMARY OF ALTERNATIVES

A number of alternatives are available for consideration. Disinfection alternatives include chlorine, both in pure gas and liquid form (sodium hypochlorite), ozone, and ultraviolet (UV) light. Chlorine has been the traditional disinfection mechanism implemented in water treatment systems, but both ozone and UV light have generated significant interest as alternative technologies. However, neither ozone nor UV provide the disinfectant residual throughout the distribution system from the source to the tap. As a result, implementation with either alternative would require pairing with a chlorine-based system to achieve the residual aspect. Another disinfection alternative is to implement a shock chlorination program, which is the intermediate periodic dosing of high-concentration chlorine to disinfect the distribution system.

Apart from disinfection, implementing a stringent inspection and maintenance program for the distribution system is considered as an alternative to help reduce the likelihood of future contamination events. Filtration is also considered as method to remove pathogens from the source water before they enter the distribution system. Finally, continuing with the current approach (sometimes referred to as the status quo or do-nothing approach in alternative analysis) is also considered.

3.1 CHLORINE GAS DISINFECTION

Chlorine gas is a desirable disinfection agent for a variety of reasons. Chlorine gas can be precisely metered, can be installed in a physically compact system, is highly effective, and does not degrade over time. Collectively these features make chlorine gas a fairly consistent disinfecting agent. Additionally, chlorine gas is a relatively inexpensive chemical when compared with other alternatives. However, the hazards associated with storing chlorine gas require vigorous attention to containment and precautionary measures, which can lead to higher capital expenses when compared with other disinfection alternatives.

Chlorine gas disinfection systems are able to provide the residual disinfectant in the water distribution system all the way to the tap. As discussed in the Background, maintaining a residual disinfectant is an important consideration for disinfection systems, due to the potential threat of contamination from within the distribution system itself.

3.2 SODIUM HYPOCHLORITE DISINFECTION

Sodium hypochlorite is another common disinfection agent. Unlike chlorine gas, the storage of sodium hypochlorite poses fewer significant health hazards, which leads to significant logistical advantages when retrofitting existing systems. Because of this, capital costs are often lower when implementing sodium hypochlorite systems when compared with chlorine gas systems. While sodium hypochlorite can also be precisely metered, the efficacy of sodium hypochlorite degrades over time, requiring operators to adjust dosing rates to maintain constant disinfection in worst case scenarios. Chemical costs for sodium hypochlorite are typically higher than chlorine gas.

Sodium hypochlorite disinfection systems, like chlorine gas systems, are able provide the residual disinfectant in the distribution system all the way to the tap.

3.3 OZONE DISINFECTION WITH CHLORINE RESIDUAL

Ozone disinfection causes significantly higher inactivation of viruses, Giardia cysts, and cryptosporidium than chlorine-based disinfectants. Additionally, ozone treatment can lead to improved color, taste, and odor of product water. While the higher level of disinfection and water quality may be desirable for systems with lower quality source water, they are not necessary for Hastings' system from a regulatory compliance perspective due to the relatively high-quality source water. Ozone systems are very expensive, and require a higher level of operator maintenance skills and training compared to the chlorine-based disinfection systems.

Unlike chlorine-based disinfection, ozone does not produce a residual disinfectant. As such, the *10 States Standards for Water Works* requires that ozone systems be paired with another disinfection system, such as a chlorine-based system, which produces a measurable residual. Pairing systems inherently adds cost to the overall approach due to the dual systems required.

3.4 ULTRAVIOLET LIGHT DISINFECTION WITH CHLORINE RESIDUAL

Disinfection using UV light, in contrast with the other disinfection systems discussed above, does not add any chemical to the water supply, but instead disinfects through bombardment with high energy light. UV treatment requires a higher quality source water than other disinfection alternatives, including limited water hardness. This could be problematic, as the Jordan Aquifer is known to have high hardness, approximately 274 mg/L as $CaCO^3$.[4] The *10 States Standards* require UV disinfection influent water hardness to be less than 120 mg/L as $CaCO^3$, so an iron and manganese prefilter may be required.

As with ozone, UV disinfection does not provide a residual disinfectant throughout the distribution system and must be paired with a chlorine-based disinfection system to provide the residual. Pairing systems inherently adds cost to the overall approach due to the dual systems required.

3.5 SHOCK CHLORINATION DISINFECTION

Shock chlorination is the process of dosing high concentrations of chlorine for short periods of time to manage existing bacterial contamination within a system. Shock chlorination necessitates a complete flush of the system after each shock, during which time consumers could not use City water. This process would be much the same as the flushing process following system disinfection in the fall of 2018, which could provide logistical challenges for the City.

The main drawback to shock chlorination is that it does not provide continuous disinfection, which was the type of permanent disinfection recommended by MDH. Continuous disinfection ensures that disinfection residuals are always present in the distribution system and can help mitigate an instance of contamination at any time. This is an important feature because contamination can enter the system without warning.

[4] Water hardness is the sum of multivalent cations, often estimated as the concentrations of Calcium and Magnesium, expressed as $CaCO^3$. Very hard water is generally >180 mg/L as $CaCO^3$. Calcium and Magnesium concentrations for the Jordan Aquifer taken from the MPCA's *Baseline Water Quality of Minnesota's Principal Aquifers: Twin Cities Metropolitan Region* (1999).

Shock chlorination does not provide a disinfection residual and is generally utilized only after contamination has been detected through positive *E. coli* or TC tests. As such, shock chlorination is not sufficient to treat recurring instances of contamination.[5]

3.6 FILTRATION

Unlike disinfection through chlorination, ozonation, or UV light, filtration processes physically remove pathogens from water. Filtration occurs when some material, such as sand, granular activated charcoal, or a membrane allows water to pass through while retaining contaminants in the water, in this case, pathogens. While installing filters at each well and the WTP would help remove pathogens from the source water, filtration would not provide a residual disinfectant throughout the distribution system and must be paired with a chlorine-based disinfection system to provide the residual. Pairing systems inherently adds cost to the overall approach due to the dual systems required.

Installing filters would require more physical space at the wells and WTP than the other alternatives. The sites are relatively space limited, and so installing any type of filters would likely require building expansions, significantly increasing cost.

3.7 INSPECTION AND MAINTENANCE PROGRAM

A non-disinfection alternative to help prevent further contamination events is to implement a rigorous inspection and maintenance program for the distribution system. As pointed out by MDH, the source of contamination likely came from within the distribution system itself, and the likelihood of future contamination events could be reduced by aggressively inspecting and maintaining the distribution network. The goal of this alternative would be to reduce the likelihood of contamination entering the system, rather than inactivating the pathogens when they do enter. MDH would be supportive of this type of program, should the City choose to move forward with it.

The inspection and maintenance program would likely require an all-inclusive inspection of backflow prevention valves and plumbing cross connections in the city including all private properties. While a yearly inspection of all backflow prevention devices is required of owners by state law,[6] the City would need to actively enforce proper inspection and maintenance, which some residents might find intrusive. With over 7,800 metered connections, this would be an extremely labor-intensive undertaking. Assuming the City would be able to assist in inspection and provide any corrective action at a rate of one metered connection per hour (many of which contain more than one cross connection) the program would take a dedicated 150 hours per week of City staff time, which amounts to approximately 4 full-time staff positions, in order to check each connection each year. While the rate of inspections might be slowed down after the comprehensive first year of inspections, perhaps from 4 full-time staff down to 2 full-time staff, the inspection and maintenance program would require long-term City staff time. Additionally, the inspection and maintenance program would likely require an increased rate of water main replacement, to

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[5] Skipton, Sharon; Dvorak, Bruce; Woldt, Wayne; Kranz, William. *Drinking Water Treatment: Shock Chlorination*. University of Nebraska: NebGuide (2007).

[6] *Minnesota Plumbing Code – 603.4.2.* Minnesota Department of Labor and Industry (2015).

limit the chance of pipe failure, which would add further cost to the program.[7] Studies have shown that water costs in areas where these types of programs are popular can be 2-3 times higher than in the United States.[6]

No matter the rigor of the inspection and maintenance schedule, it will be impossible to stop all contamination events. Due to this, systems which do not chlorinate often employ vigorous treatment of water supplies to remove bacteria and nutrients from already high-quality source water, to make it more difficult for bacteria to grow should they enter the system.[8,9] These water treatment technologies can be very high cost and high maintenance, such as ozone and granular activated carbon. If the inspection and maintenance program alternative is selected, a decision will have to be made as to whether to implement additional treatment of source water.

3.8 DO-NOTHING ALTERNATIVE

The final alternative is the do-nothing alternative. The City of Hastings has not disinfected its groundwater in the past and could continue this practice in the future. However, to refrain from implementing a permanent disinfection system would go against the recommendations of both MDH and the *10 States Standards for Water Works*. Additionally, the *Standards* state that disinfection is required where other treatment is provided, which could come into play at the WTP, where other treatment is provided in the form of ion exchange. MDH has jurisdiction over what ultimately gets enforced, but has noted during discussion that they could require the City to implement continuous disinfection if positive *E. coli* or TC tests continue to occur.

Due to the potential for another contamination event and the consequences associated with additional positive *E. coli* or TC tests, the do-nothing alternative could become difficult for the City to endorse if additional compliance events are encountered.

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[7] Rosari-Ortiz, Fernando; Rose, Joan; Speight, Vanessa; von Gunten, Urs; Schnoor, Jerald. *How do you like your tap water?*. Science: Insights (2016).

[8] Waak, Michael; LaPara, Timothy; Halle, Cynthia; Hozalski, Raymond. *Occurrence of* Legionella *spp. in Water-Main Biofilms from Two Drinking Water Distribution Systems*. Environmental Science and Technology (2018).

[9] Smeets, P. W. M. H.; Medema, G. J.; van Dijk, J. C. *The Dutch Secret: how to provide safe drinking water without chlorine in the Netherlands.* Drinking Water Engineering and Science (2009).

4.0 ALTERNATIVES ANALYSIS

In order to better investigate the feasibility of implementing the disinfection alternatives, an alternatives analysis was run to compare the costs associated with implementing the alternatives in Wells 4, 6, 7, & 8 and two systems at WTP 1. The City wishes to install one type of system across all locations, and so the cost to install each system was estimated for each location, yearly chemical costs were estimated, and then the total costs were calculated. Sizing and pricing were carried out assuming each Well pumped continuously throughout the day at 1,100 gallons per minute (gpm), and assuming that two systems would be needed at the WTP to treat the larger flow. A lower operational cost could be assumed if the pumps do not run continuously. No cost analysis was completed for the Shock Chlorination or Filtration alternatives, as they were not recommended by MDH.

4.1 OPTION 1: CHLORINE GAS

Each chlorine gas system would require the same general feed equipment, such as a chlorine scale, booster pump, automatic shutoff system, etc., as shown in Appendix A with associated costs. Total, the general material cost amounts to $25,000 for each chlorine gas system.

Further, specific costs are associated with the retrofit of each system into the pumphouses for City Wells and into the chemical room of the WTP. In order to determine these costs, preliminary layouts were created for each system based on past layout drawings, as shown in Appendix B. The layouts were designed to meet the requirements in the *10 States Standards for Water Works*. Appendix B also details the specific costs associated with each retrofit. The overall material, retrofitting, and install costs for all chlorine gas systems amounts to $280,945, as shown in Table 2. Included in the estimate is a 25% factor for items such as unknowns, contingency, bonding, insurance and Contractor markup. This results in a total capital cost estimate of $351,181.

Table 2: Retrofitting Capital Costs for Chlorine Gas Systems

System Location	Install and Retrofitting Cost
Well 4	$16,700
Well 6	$31,220
Well 7	$39,375
Well 8	$11,750
WTP 1 (2 systems)	$31,900
General equipment Cost ($25,000/ system, 6 systems total)	$150,000
Subtotal costs for all systems	$280,945
Total estimated Capital Cost with Contingency, Bond, Insurance and Contractor Profit (25%)	**$351,181**

It should be noted that these capital costs do not include soft costs, such as design and engineering costs. Also, these estimates are preliminary, the degree of unknowns typically decreases during the design phase allowing cost estimates to become more accurate. Material costs were determined assuming a dosing rate of 1 ppm chlorine and a chlorine gas cost of $1.00 per pound. Under the assumed dosing rate each 1,100 gpm well would require 13.2 lb of chlorine gas per day, which was rounded to 15 lb per day to be conservative. Additionally, gas chlorination requires the operation of an approximately 3 kW booster pump. Approximate electrical costs were determined assuming the cost of industrial electricity in Hastings is $0.0683/kWh. As shown in Table 3, approximate yearly operational costs for all systems amount to $43,620.

Table 3: Operational Costs for Chlorine Gas Systems

Chlorine Gas	Chemical Cost
Unit Cost	$1/lb
Chlorine required per system	15 lb/day
Cost per system per day	$15/day
Cost per system per year	$5,475/year
Electrical	**Electrical Cost**
Unit Cost	$0.0683/kWh
Electricity required per pump	72 kWh/day
Cost per system per day	$4.92/day
Cost per system per year	$1,795/year
	Total Cost
Total estimated cost for all systems	**$43,620 per year**

4.2 OPTION 2: SODIUM HYPOCHLORITE

Each sodium hypochlorite system would require the same general feed equipment, such as the chemical tank, peristatic pump, chemical scale, etc., as shown in Appendix A with associated costs. Total, the general material cost amounts to $13,425 for each sodium hypochlorite system.

Unlike the chlorine gas systems, very few retrofits are anticipated for installing sodium hypochlorite disinfection systems, as shown through the layouts in Appendix B. The overall material, retrofitting, and install costs for all sodium hypochlorite systems amounts to $124,050, as shown in Table 4. Included in the estimate is a 25% factor for items such as unknowns, contingency, bonding, insurance and Contractor markup. Altogether this results in a total capital cost estimate of $155,063. It should be noted that these capital costs do not include soft costs, such as design and engineering costs. Also, these estimates are preliminary, the degree of unknowns typically decreases during the design phase allowing cost estimates to become more accurate.

Table 4: Retrofitting Capital Costs for Sodium Hypochlorite Systems

System Location	Install and Retrofitting Cost
Well 4	$7,000
Well 6	$8,500
Well 7	$7,000
Well 8	$7,000
WTP 1 (2 systems)	$14,000
General equipment costs ($13,425 per system, 6 systems total)	$80,550
Subtotal costs for all systems	$124,050
Total estimated Capital Cost with Contingency, Bond Insurance and Contractor Profit (25%)	**$155,063**

Operational costs were determined assuming a dosing rate of 1 ppm chlorine, a sodium hypochlorite cost of $3.00 per gallon, and a chlorine equivalent of 12% for the liquid sodium hypochlorite. Under the assumed dosing rate each 1,100 gpm well would require 110 lb of sodium chloride per day, or 11.0 gallons per day, which was rounded to 15 gallons per day to be conservative. As shown in Table 5, approximate yearly operational costs for all systems amount to $98,550.

Table 5: Operational Cost for Sodium Hypochlorite Systems

Sodium Hypochlorite	Chemical Cost
Unit Cost	$3/gal
Chlorine required per system	15 gal/day
Cost per system per day	$45/day
Cost per system per year	$16,425/year
Total estimated cost for all systems	**$98,550 per year**

4.3 OPTION 3: OZONE GAS

Ozone systems are very expensive. The two suppliers contacted for preliminary costs estimated lump sums of $400,000 and $600,000 in capital costs per system. Taking the lower quote, and assuming two systems to treat the WTP, the capital costs would be $2,400,000. Included in the estimate is a 25% factor for items such as unknowns, contingency, bonding, insurance and Contractor markup. Altogether this results in a total capital cost estimate of $3,000,000. It should be noted that these capital costs do not include soft costs, such as design and engineering costs. Also, these estimates are preliminary, the degree of unknowns typically decreases during the design phase allowing cost estimates to become more accurate. Due to the high capital cost, retrofitting costs were not determined, because they would be insignificant compared to the overall system cost.

Operational costs for ozone systems come from electricity used to generate the ozone, as each system would have approximately 29 kW of installed power. Operational costs were determined assuming the cost of industrial electricity in Hastings is $0.0683/kWh. As shown in Table 6, approximate yearly operational costs for all systems amount to $104,105. It must be noted that these costs do not include the costs for the paired chlorine-based system to provide the disinfection residual. While a small reduction in chlorine dose can be seen due to oxidation of iron and manganese by ozone, the reduction is likely to be insignificant given the chemistry of the Jordan aquifer.[10]

Table 6: Operational Costs for Ozone Systems

	Electrical Cost
Unit Cost	$0.0683/kWh
Electricity required per system	696 kWh/day
Cost per system per day	$48/day
Cost per system per year	$17,351/year
Total estimated cost for all systems	**$104,105 per year**

4.4 OPTION 4: ULTRAVIOLET LIGHT

UV light disinfection systems require relatively high capital costs. Preliminary cost estimates gave a lump sum of $100,000 in capital costs per system, for a total of approximately $600,000 for all systems, assuming two at the WTP. Included in the estimate is a 25% factor for items such as unknowns, contingency, bonding, insurance and Contractor markup. Altogether this results in a total capital cost estimate for UV to $750,000. It should be noted that these capital costs do not include soft costs, such as design and engineering costs. Also, these estimates are preliminary, the degree of unknowns typically decreases during the design phase allowing cost estimates to become more accurate. Retrofitting costs would need to be determined after the specific UV system model was selected, due to the large variety of system configuration, although they could be significant due to the amount of space required to pull out and replace the UV lightbulbs, which can be in excess of 5 feet long.

Operational costs for UV systems come from replacement of UV bulbs, replacement of bulb protection sleeves, and electricity used to power the bulbs. Bulbs are generally designed to be replaced every year, and protection sleeves every two years. Each system would have approximately 2.8 kW of bulb wattage. Operational costs were determined assuming the cost of industrial electricity in Hastings is $0.0683/kWh. As shown in Table 7, approximate yearly operational costs for all systems amount to $21,752. It must be noted that these costs do not include the costs for the paired chlorine-based system to provide the disinfection residual.

[10] Iron and Manganese concentrations for the Jordan Aquifer can be found in the MPCA's *Baseline Water Quality of Minnesota's Principal Aquifers: Twin Cities Metropolitan Region* (1999).

Table 7: Operational Costs for UV Light Systems

Bulbs and Sleeves	Electrical Cost
Bulbs per system	$1,800/year
Sleeves per system	$150/year
Cost per system per year	$1,950/year
Electrical	**Electrical Cost**
Unit Cost	$0.0683/kWh
Electricity required system	67.2 kWh/day
Cost per system per day	$4.59/day
Cost per system per year	$1,675/year
	Total Cost
Total estimated cost for all systems	**$21,752 per year**

4.5 OPTION 5: INSPECTION AND MAINTENANCE PROGRAM

Costs for the inspection and maintenance program are difficult to determine, due to the high variability in time and effort required to inspect and maintain backflow prevention valves and plumbing cross connections at each metered connection throughout the City. Additionally, cost will highly depend on any increases to the rate of water main replacement and whether or not additional treatment is added to remove nutrients from the water. Due to these unknowns, no specific cost estimate was made, although the rough time analysis of 150 hours of City staff time per week illustrates how large of an undertaking an inspection and maintenance program might be.

5.0 CONCLUSION

MDH strongly recommends implementing permanent, continuous disinfection, although the City of Hastings has the option to continue operations as they have in the past. If the do-nothing alternative is selected, the City must be mindful of the impacts of contamination that can occur in a distribution system through backflow events or through construction and maintenance. The shock chlorination alternative is sufficient to treat contamination once it has been detected in the distribution system, but is generally not used to protect systems against the threat of contamination. The inspection and maintenance program alternative reduces the risk of a contamination event, but is labor intensive for the City to implement.

Ozone and UV disinfection provide excellent disinfection of water at the source, but do not provide a disinfectant residual which could continue fighting pathogens all the way to the tap. Due to this, either alternative would have to be paired with a chlorine-based disinfection system. Both chlorine-based disinfection alternatives are able to provide the disinfection residual.

A summary of a 10-year net present cost analysis is shown below in Table 8. This analysis was carried out assuming a 10-year operation lifetime, no equipment replacements and a rate of return of 4%.

Table 8: 10 Year Net Present Cost

System Type	Capital Costs*	Operational Costs	10-Year Net Present Cost**
Sodium Hypochlorite	$155,000	$99,000	$958,000
Chlorine Gas	$351,000	$44,000	$708,000
Ozone***	$3,000,000	$104,000	$3,844,000
Ultraviolet Light***	$750,000	$22,000	$928,000

* Capital costs do not include soft costs, such as design and engineering

** Calculated assuming a 4% rate of return, and no equipment replacements

*** Would have to be paired with a chlorine-based system, resulting in additional costs

6.0 REFERENCES

1. United States Environmental Protection Agency. Addressing Total Coliform Positive or E. coli Positive Sample Results in EPA Region 8. USEPA.

2. United States Environmental Protection Agency Office of Water. *Revised Total Coliform Rule: A Quick Reference Guide.* USEPA (2013).

3. *10 States Recommended Standards for Water Works.* Water Supply Committee of the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (2012).

4. *Baseline Water Quality of Minnesota's Principal Aquifers: Twin Cities Metropolitan Region.* Minnesota Pollution Control Agency (1999).

5. Skipton, Sharon; Dvorak, Bruce; Woldt, Wayne; Kranz, William. *Drinking Water Treatment: Shock Chlorination*. University of Nebraska: NebGuide (2007).

6. *Minnesota Plumbing Code – 603.4.2.* Minnesota Department of Labor and Industry (2015).

7. Rosari-Ortiz, Fernando; Rose, Joan; Speight, Vanessa; von Gunten, Urs; Schnoor, Jerald. *How do you like your tap water?* Science: Insights (2016).

8. Waak, Michael; LaPara, Timothy; Halle, Cynthia; Hozalski, Raymond. *Occurrence of* Legionella *spp. in Water-Main Biofilms from Two Drinking Water Distribution Systems*. Environmental Science and Technology (2018).

9. Smeets, P. W. M. H.; Medema, G. J.; van Dijk, J. C. *The Dutch Secret: how to provide safe drinking water without chlorine in the Netherlands.* Drinking Water Engineering and Science (2009).

Appendix A GENERAL EQUIPMENT COSTS

This Appendix contains the general materials and costs for chlorine gas and sodium hypochlorite disinfection systems, assuming a raw water flow of 1,100 gpm. Table 9 shows the cost for chlorine gas systems, and Table 10 shows the cost for sodium hypochlorite systems. In alternatives analysis, the lower of each general cost was used.

Table 9: General Chlorine Gas System Costs

Equipment	Cost Estimate Supplier 1	Cost Estimate Supplier 2
Gas feed manual rotameter	$800	Lump Sum $15,000
Dual 150# chlorine scale	$4,300	
Chlorine gas leak detector	$2,100	
Booster pump	$1,600	
Connection to low pressure water	$400	
Chemical injector assembly with quill and isolation valves	$425	
Automatic switchover apparatus and vacuum regulators	$3,500	
Chlorine gas shutoff valve system	$18,000*	$10,000*
Optional chlorine containment vessels – dual 150# Chlortainer system	$120,000**	N/A
Total Estimate Costs	**$31,125**	**$25,000**

* Highly recommended by MDH, due to location of wells, but not required
**Not included in total cost due to optional nature

Table 10: General Sodium Hypochlorite System Costs

Equipment	Cost Estimate Supplier 1	Cost Estimate Supplier 2
200-gallon dual containment tank	$3,000	Lump Sum
Peristaltic feed pump with required accessories and leak detection	$4,100	
Calibration tube assembly and bypass	$400	
Chemical scale	$5,500	
Chemical injector assembly with quill and isolation valves	$425	
Total Estimate Costs	**$13,425**	**$18,000**

Appendix B CHEMICAL FEED LAYOUT OPTIONS

A.1 WELL 4

Below are shown possible layouts for both the chlorine gas option, Figure 1, and sodium hypochlorite option, Figure 2, in the pumphouse for Well 4.

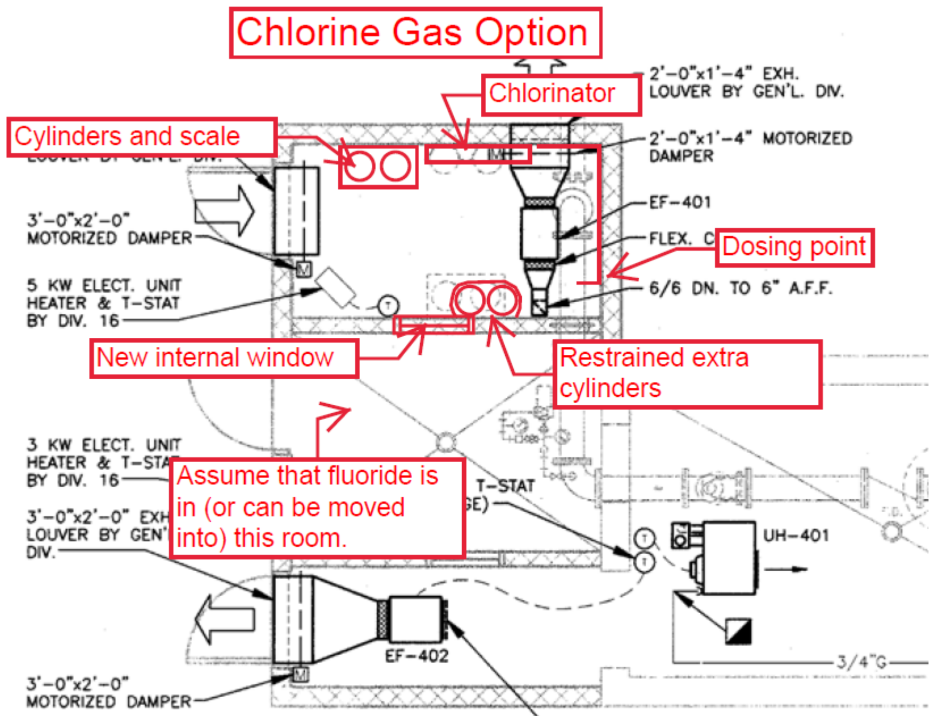

Figure 1: Chlorine Gas possible layout for Well 4

Table 11: Chloride Gas Retrofit Costs for Well 4

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	1	$2,800
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	2	$2,400
Heater	$550 ea.	0	$0
Demolition	Cut window		$1,500
Installation and electrical	-	-	$10,000
Total Estimate	-	-	**$16,700**

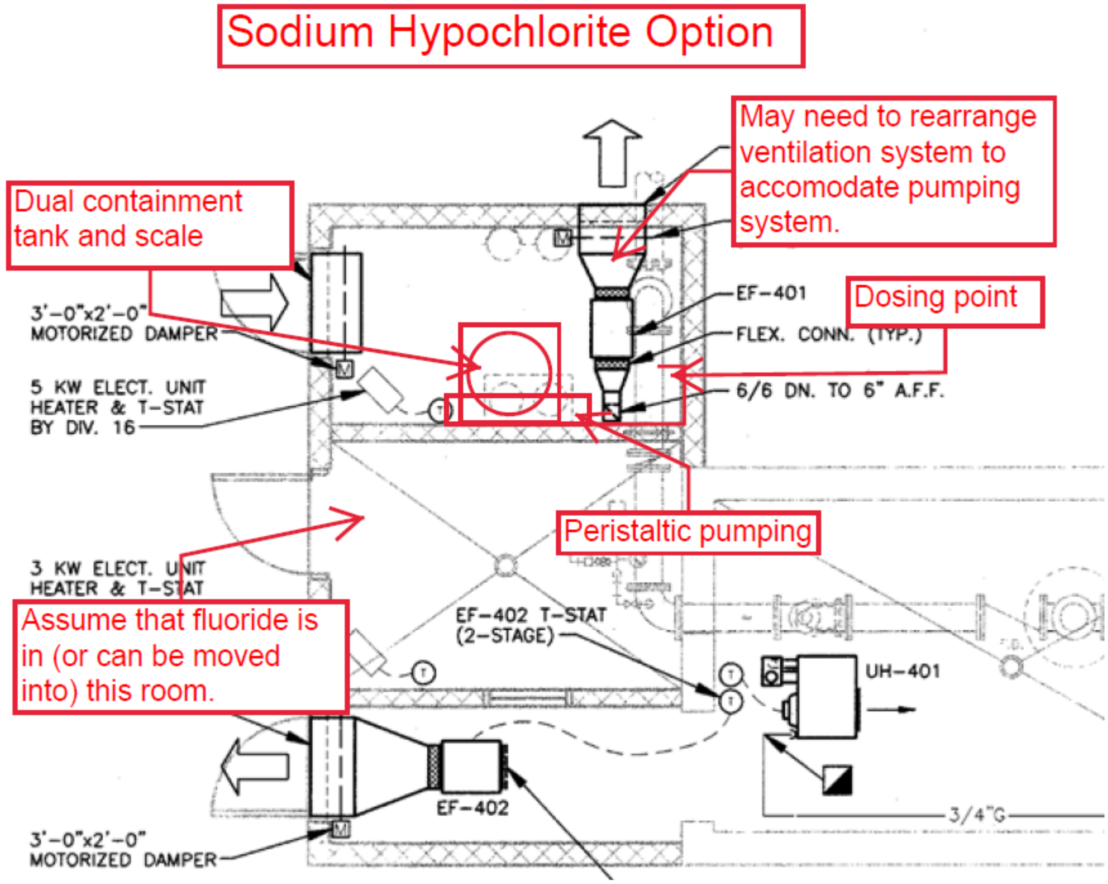

Figure 2: Sodium hypochlorite possible layout for Well 4

Table 12: Sodium Hypochlorite Retrofit Costs for Well 4

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	0	$0
Heater	$550 ea.	0	$0
Demolition	Nothing known		$0
Installation and electrical	-	-	$7,000
Total Estimate	-	-	**$7,000**

A.2 WELL 6

Below are shown possible layouts for both the chlorine gas option, Figure 3, and sodium hypochlorite option, Figure 4, in the pumphouse for Well 6.

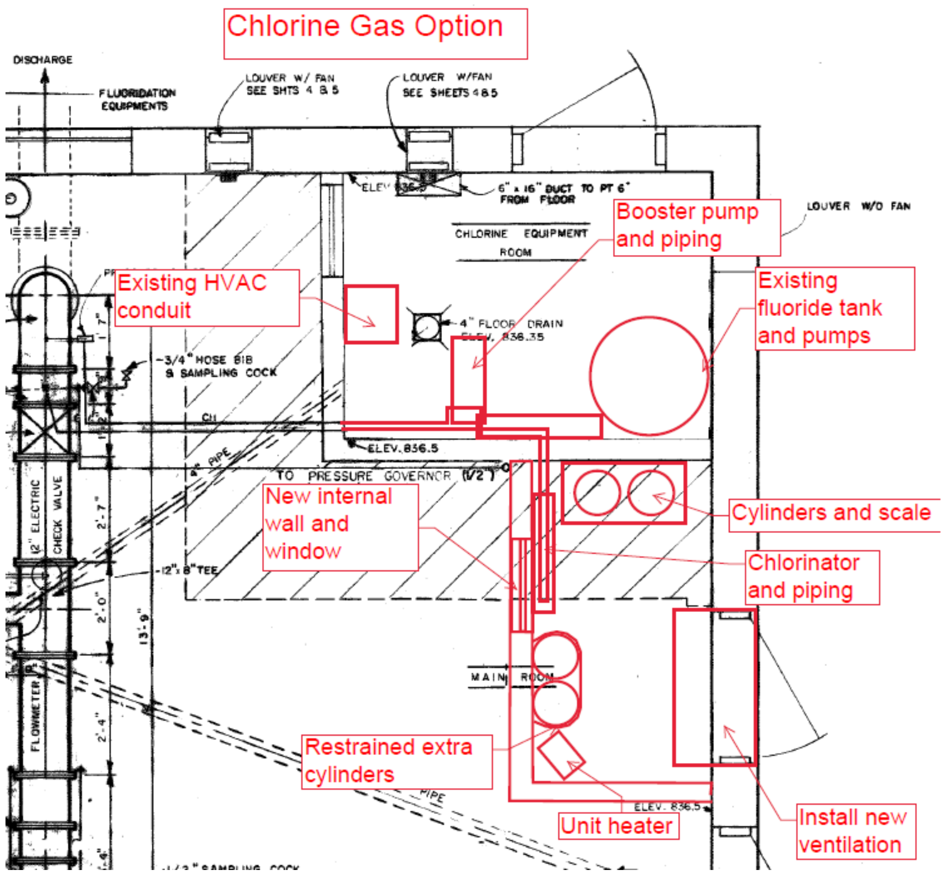

Figure 3: Chlorine gas possible layout for Well 6

Table 13: Chlorine Gas Retrofit Costs for Well 6

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	134 ft^2	$7,370
Internal window	$2,800 ea.	1	$2,800
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	1	$8,000
Light switch	$1,200 ea.	2	$2,400
Heater	$550 ea.	1	$550
Demolition	Plug floor drain		$100
Installation and electrical	-	-	$10,000
Total Estimate	-	-	**$31,220**

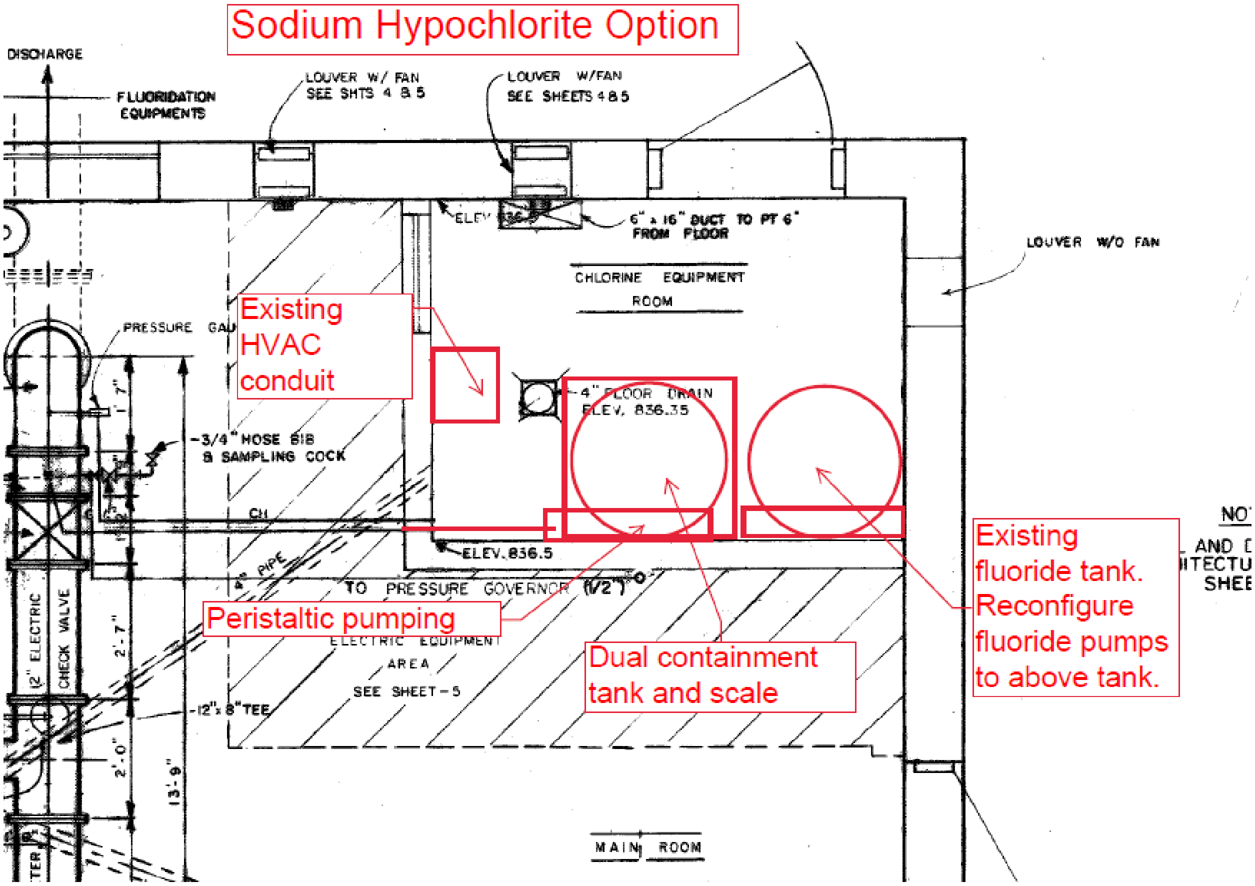

Figure 4: Sodium hypochlorite possible layout for Well 6

Table 14: Sodium Hypochlorite Retrofit Costs for Well 6

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	0	$0
Heater	$550 ea.	0	$0
Demolition	Reconfigure fluoride pumps		$1,500
Installation and electrical	-	-	$7,000
Total Estimate	-	-	**$8,500**

A.3 WELL 7

Below are shown possible layouts for both the chlorine gas option, Figure 5, and sodium hypochlorite option, Figure 6, in the pumphouse for Well 7.

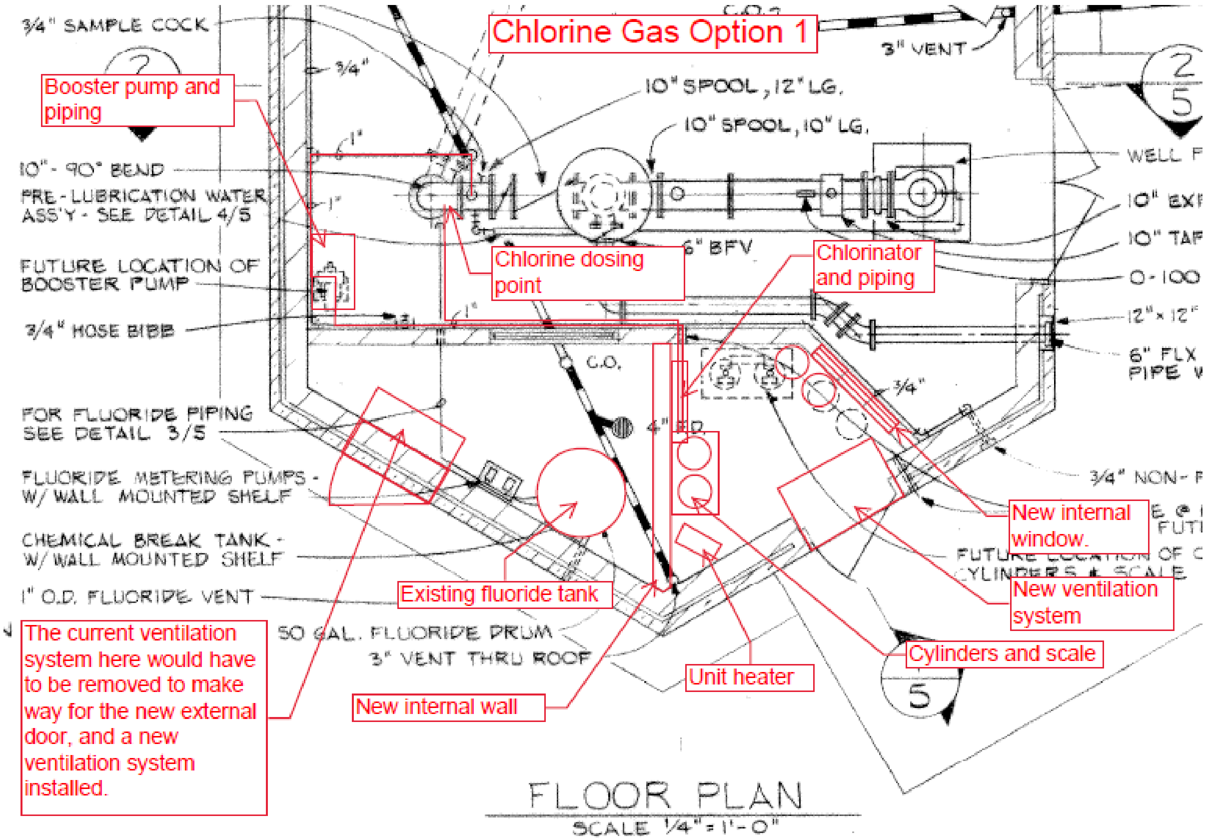

Figure 5: Chlorine Gas possible layout for Well 7

Table 15: Chloride Gas Retrofit Costs for Well 7

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$\$55/\text{ft}^2$	$75\ \text{ft}^2$	$4,125
Internal window	$2,800 ea.	1	$2,800
External door	$3,000 ea.	1	$3,000
Ventilation system	$8,000 ea.	2	$16,000
Light switch	$1,200 ea.	2	$2,400
Heater	$550 ea.	1	$550
Demolition	Existing ventilation system		$500
Installation and electrical	-	-	$10,000
Total Estiamte	-	-	**$39,375**

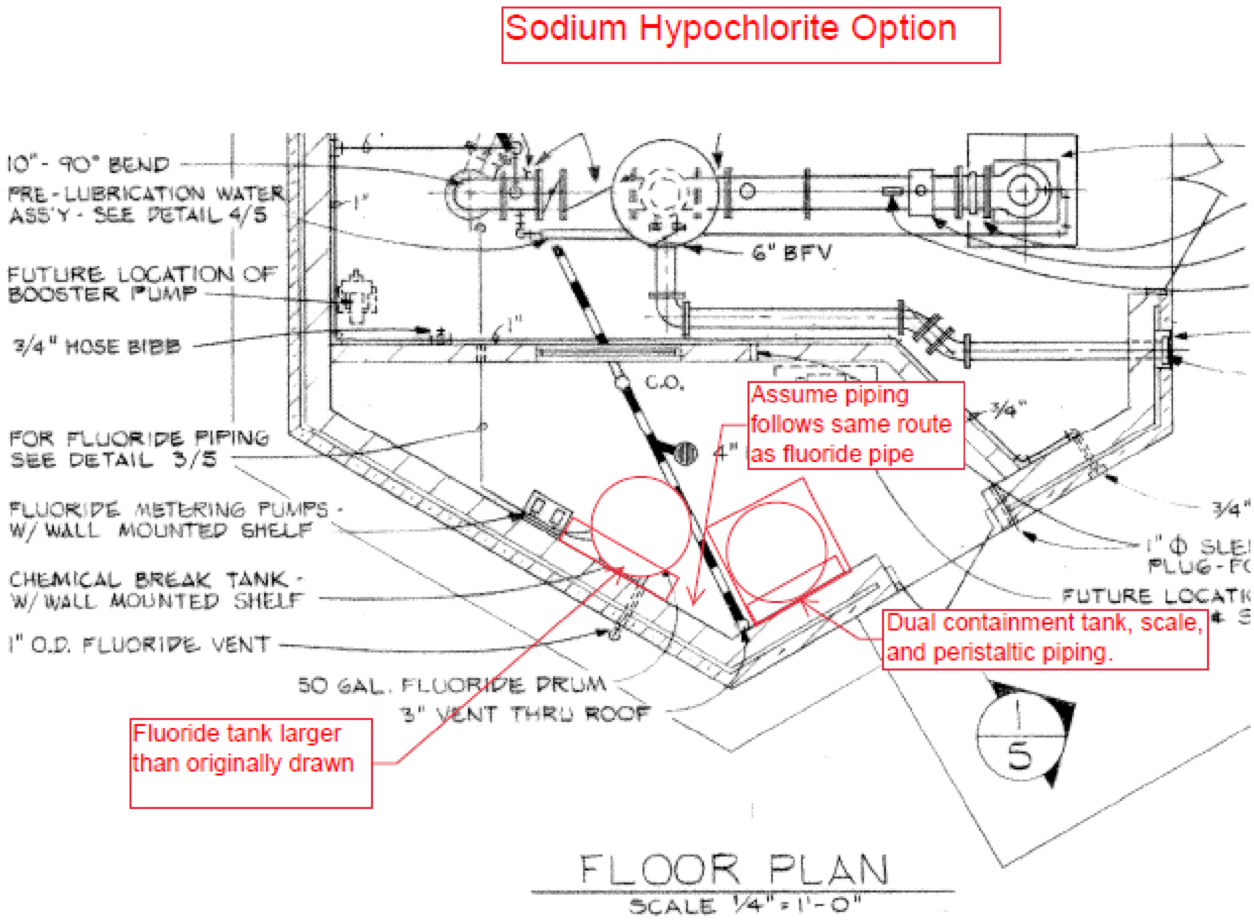

Figure 6: Sodium hypochlorite possible layout for Well 7

Table 16: Sodium Hypochlorite Retrofit Costs for Well 7

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	0	$0
Heater	$550 ea.	0	$0
Demolition	Nothing known		$0
Installation and electrical	-	-	$7,000
Total Estimate	-	-	**$7,000**

A.4 WELL 8

Below are shown possible layouts for both the chlorine gas option, Figure 7, and sodium hypochlorite option, Figure 8, in the pumphouse for Well 8.

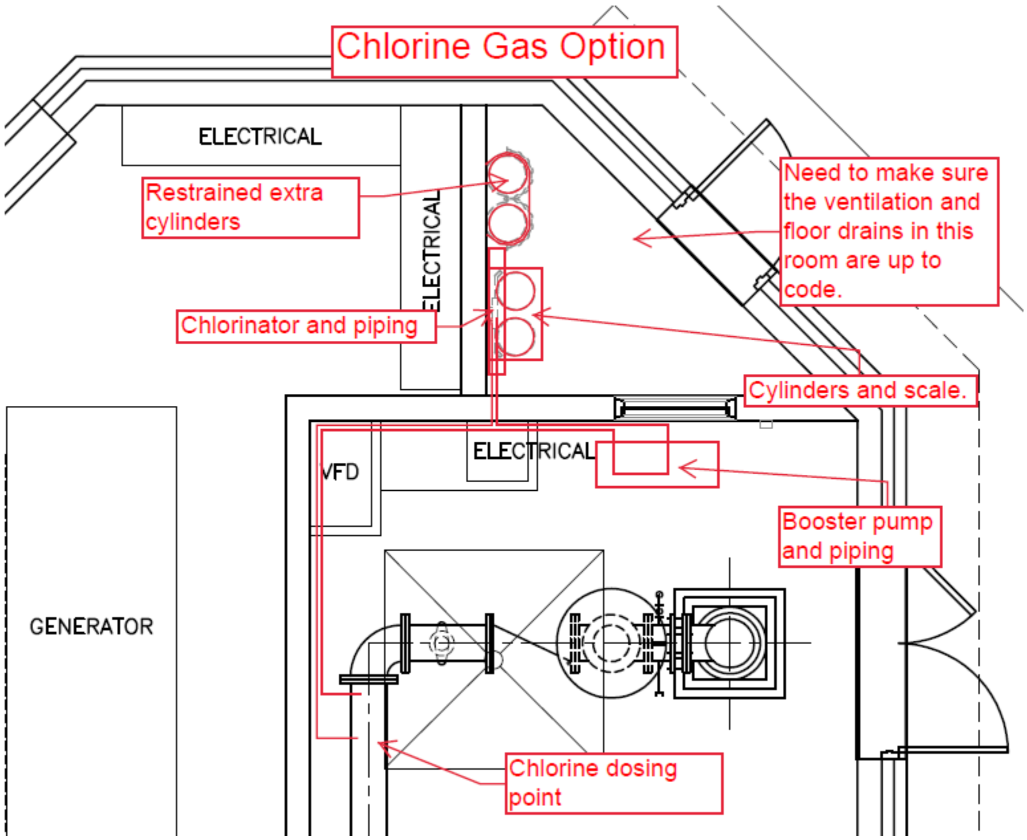

Figure 7: Chlorine Gas possible layout for Well 8

Table 17: Chloride Gas Retrofit Costs for Well 8

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	1	$1,200
Heater	$550 ea.	1	$550
Demolition	Nothing known		$0
Installation and electrical	-	-	$10,000
Total Estimate	-	-	**$11,750**

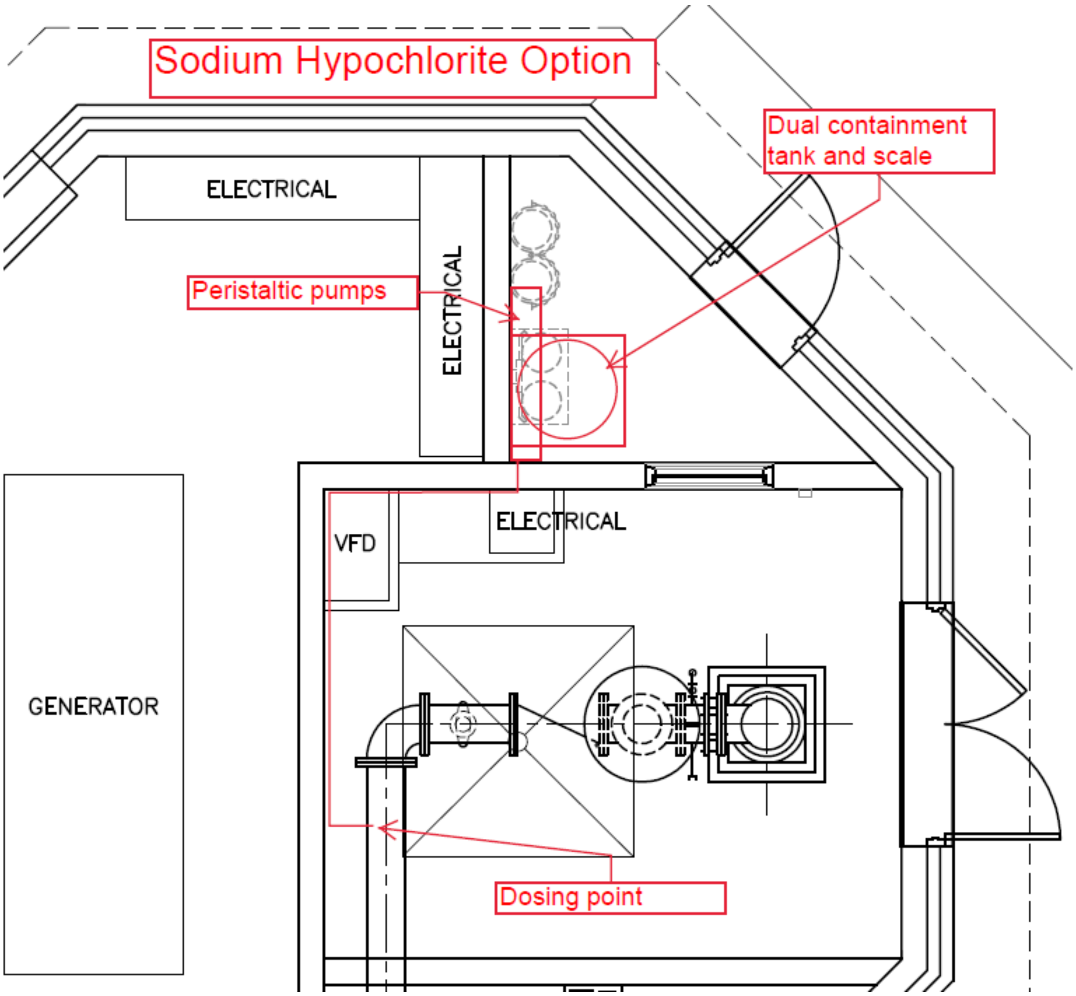

Figure 8: Sodium hypochlorite possible layout for Well 8

Table 18: Sodium Hypochlorite Retrofit Costs for Well 8

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	0	$0
Heater	$550 ea.	0	$0
Demolition	Nothing known		$0
Installation and electrical	-	-	$7,000
Total Estimate	-	-	**$7,000**

A.5 WTP 1

Below are shown possible layouts for both the chlorine gas option, Figure 9, and sodium hypochlorite option, Figure 10, in the pumphouse for WTP 1.

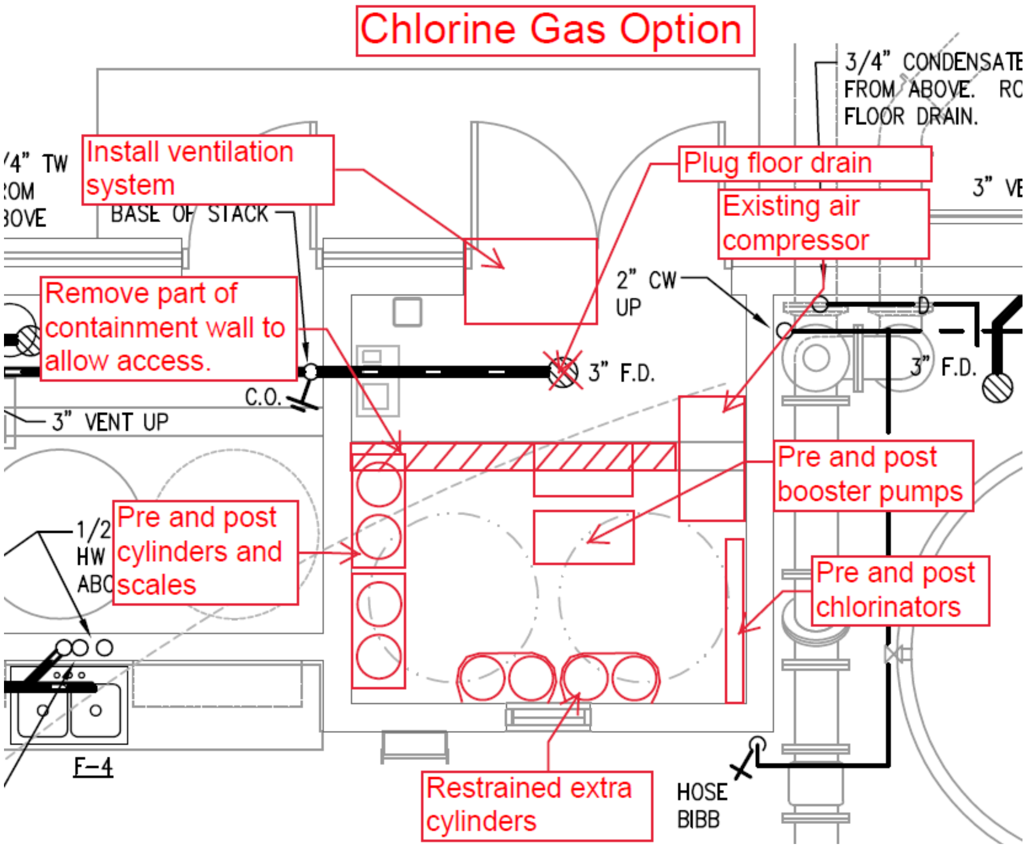

Figure 9: Chlorine Gas possible layout for WTP 1

Table 19: Chloride Gas Retrofit Costs for WTP 1

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	1	$8,000
Light switch	$1,200 ea.	2	$2,400
Heater	$550 ea.	0	$0
Demolition	Portion of curb, plug floor drain, likely need to move air compressor		$1,500
Installation and electrical	-	-	$20,000
Total Esimate	-	-	**$31,900**

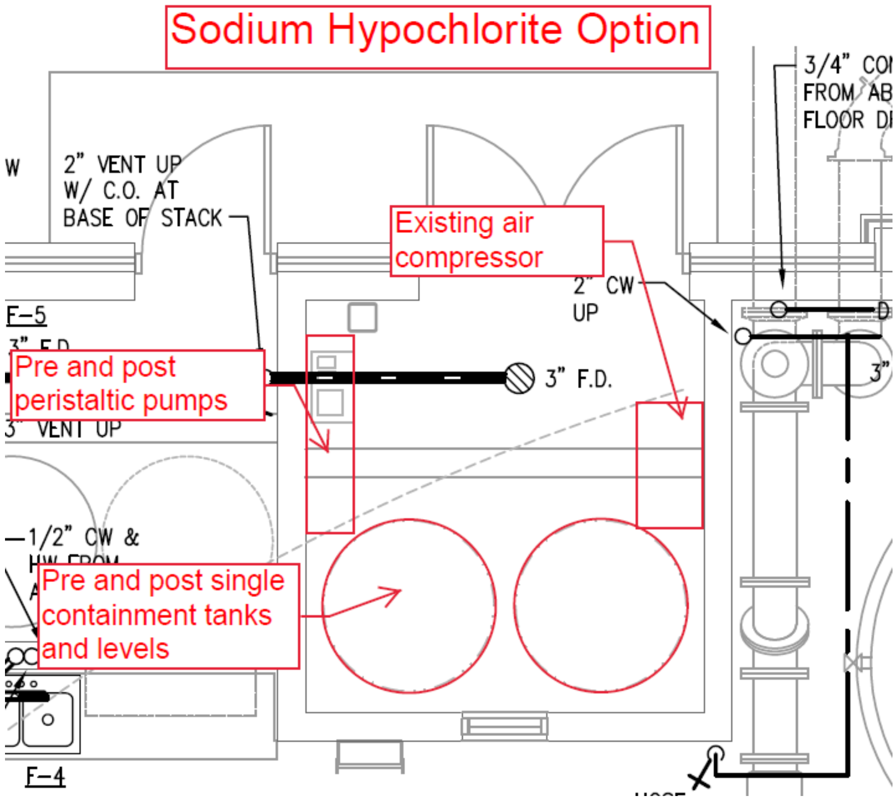

Figure 10: Sodium hypochlorite possible layout for WTP 1

Table 20: Sodium Hypochlorite Retrofit Costs for WTP 1

Retrofit Type	Unit Cost	Approximate Units	Total Cost
Internal wall	$55/ft^2	0 ft^2	$0
Internal window	$2,800 ea.	0	$0
External door	$3,000 ea.	0	$0
Ventilation system	$8,000 ea.	0	$0
Light switch	$1,200 ea.	0	$0
Heater	$550 ea.	0	$0
Demolition	Nothing known		$0
Installation and electrical	-	-	$14,000
Total Estimate	-	-	**$14,000**