Pilot Study Report

Pilot Study for the Removal of Iron

HENDE 163471

Henderson, Minnesota | November 15, 2021

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November 15, 2021

RE: Pilot Study for the Removal of Iron
Pilot Study Report
Henderson, Minnesota
SEH No. HENDE 163471

Mr. Lon Berberich
City of Henderson
600 Main St, PO Box 433
Henderson, MN 56044

Dear Lon:

Short Elliott Hendrickson Inc.® (SEH) is pleased to provide you this pilot study report for the reduction of iron concentration from water produced by Wells 1 & 2. The secondary purpose of the study was to identify processes, chemicals, and dosing required to optimize the treatment process. This study analyzes different treatment alternatives with respect to performance and operations.

Though the Pilot Study was substantially oriented toward review of the cities water source prior to treatment, a preliminary review of the city's water system was also completed as it pertains to removal of iron within the existing system.

If you have any questions, please do not hesitate to call John Thom at 612.618.9804 or Chris Knutson at 507.237.8383.

Sincerely,

Chris Knutson, PE
Senior Project Engineer
(Lic. MN)

AWK
c: John Thom, SEH
Tom Madden, SEH
Andrew Knapp, SEH

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Pilot Study Report

Pilot Study for the Removal of Iron
Henderson, Minnesota

SEH No. HENDE 163471

November 15, 2021

I hereby certify that this 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.

Chris Knutson

Chris Knutson, PE

Date: November 15, 2021 License No.: 49534

Reviewed By: Tom Madden Date: November 15, 2021

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Contents

Contents (continued)

List of Tables

List of Figures

List of Exhibits

Pilot Study Report

Pilot Study for the Removal of Iron

Prepared for City of Henderson, Minnesota

1 Introduction

1.1 Background

The City of Henderson operates a water system that includes two, an elevated water tower, and a water distribution system with multiple pressure zones. Well #1 is located next to the water tower, and Well #2 is approximately 600 ft away, at the bottom of a hill. Each well is capable of pumping raw water at a maximum rate of 500 gallons per minute (gpm), but each currently operate at 200 gpm. Both wells draw from the Jordan aquifer.

Both wells produce water that has an elevated iron concentration. High levels of iron in water can cause issues within the water system and lead to water quality complaints from the community. Common issues include water color complaints, staining of fixtures and laundry, clogged pumps and sprinklers, metallic water taste, and sediment buildup in the distribution system. Iron concentration averages approximately 1.97 mg/L at Well #1 and 1.24 mg/L at Well #2. The EPA secondary maximum contaminant level (SMCL) for iron is 0.3 mg/L. In Minnesota, water sources with iron contamination commonly also contain manganese contamination. This study evaluates manganese along with iron.

Short Elliot Hendrickson (SEH) was contracted to perform a feasibility with two main objectives: (1) determine an optimal process for the removal of iron to below SMCL levels, and (2) provide a report level layout and overall footprint of a water treatment plant that can run this process. A pilot study evaluating iron oxidation and removal with various types of filter media was completed in September 2021. A cost estimate for design and construction of a water treatment plant is included.

1.2 Drinking Water Standards

National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards that apply to public water systems. NPDWRs, or Primary Standards, set mandatory water quality standards for drinking water contaminants. These are enforceable standards called "maximum contaminant levels". The maximum contaminant level (MCL) is the highest level of a contaminant that is allowed in drinking water as delineated by the National Primary Drinking Water Regulations. These levels are based on consideration of health risks, technical feasibility of treatment, and cost-benefit analysis. MCLs are established to protect the public against consumption of drinking water contaminants that present a risk to human health. An MCL is the maximum allowable amount of a contaminant in drinking water which is delivered to the consumer. Individual states may create MCLs and recommendations that are more restrictive than EPA limits, but if the state designated MCL is less restrictive than EPA, the EPA MCLs will take primacy.

In addition, the EPA has established National Secondary Drinking Water Regulations (NSDWRs) that set non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" (SMCLs). They are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations such as taste, color, and odor. These contaminants are not considered to present a risk to human health at the SMCL.

1.3 Objectives

The following objectives were included in the study:

- Evaluate the type and dosage of chemicals required for coagulation, settling, corrosion control and disinfection.
- Evaluate the processes required for the oxidation of iron and manganese to below SMCLs (oxidized iron and manganese to be removed via filtration).
- Evaluate whether a settling tank is required for removal of iron and manganese. Many raw water supplies require additional time for oxidation processes to run to completion prior to filtration of iron and manganese. However, the addition of a detention tank adds cost to the project. This pilot study will determine whether this equipment is necessary.
- Evaluate a variety of filter medias for removal of oxidized iron. Greensand and silica media were evaluated.
- Develop a cost estimate for materials and report level sketch of a water treatment plant capable of providing water that meets EPA requirements to the community of Henderson.

2 Existing Facilities

2.1 Wells

The City of Henderson's water system consists of two wells that feed the distribution system: Well 1 and Well 2. Both wells are regularly operated.

2.2 Water Quality

The raw water in Wells 1 & 2 exceeds Secondary Drinking Water Standards for iron, and Well 2 exceeds standards for manganese. Iron and manganese contamination is not a health issue at the levels present in the raw water, but will cause staining on laundry and plumbing fixtures, can clog wells, pumps, sprinklers and other devices such as dishwashers and give a metallic taste to the water that can affect foods and beverages.

The maximum concentration of iron and manganese desired in the proposed WTP's effluent is 0.30 mg/L and 0.05 mg/L, respectively (based on EPA SMCLs). The raw water in Well 1 has an average of 1.97 mg/L iron, and 0.05 mg/L manganese. In Well 2, the raw water has an average of 1.24 mg/L iron, and 0.150 mg/L manganese. Table 1 summarizes the raw water quality for the City of Henderson.

Table 1 – Raw Well Water Quality

	Iron (mg/L)			Manganese (mg/L)		
	Min	Max	Avg	Min	Max	Avg
Well 1	1.27	2.24	1.97	0.020	0.091	0.050
Well 2	0.762	1.71	1.24	0.102	0.201	0.150
	pH			**TDS (mg/L)**		
	Min	**Max**	**Avg**	**Min**	**Max**	**Avg**
Well 1	7.59	8.07	7.73	621	799	650
Well 2	-	-	7.40	-	-	877
	Hardness (mg/L as CaCO3)			**Conductivity (Mohm-cm)**		
	Min	**Max**	**Avg**	**Min**	**Max**	**Avg**
Well 1	554	637	609	897	1026	923
Well 2	416	492	454	-	-	951

Source: Pilot Testing Data Collection, 4/20/21 Hawkins Inc Test

3 Pilot Testing Procedure and Equipment

3.1 Pilot Testing Procedure

A typical treatment process for manganese removal involves addition of an oxidant to promote precipitation, detention to allow the oxidation reaction to proceed to completion, chlorine addition, and removal via filtration. Iron can also be treated using these methods; however, its properties make it much easier to oxidize and remove. Removal efficiencies can range from 50% to 95% for both iron and manganese.

The treatment train used for the pilot test is as follows: chlorination, aeration, detention, and filtration. Testing was conducted to determine whether aeration and detention steps were required, or whether target iron concentrations could be met without the additional equipment required to complete these steps.

3.2 Water Chemistry for Iron and Manganese Removal

The most common treatment used for the removal of dissolved iron and manganese from drinking water supplies is chemical oxidation followed by physical removal via filtration. In this treatment approach iron (Fe) is oxidized from the soluble Fe^{2+} state to the less soluble Fe^{3+} state, and manganese (Mn) is oxidized from the soluble Mn^{2+} state to the less soluble Mn^{4+} state. The insoluble Fe^{3+} and Mn^{4+} oxides are precipitates that can be removed from water by filtration.

The oxidation process and rates for iron and manganese are significantly different. Iron oxidizes rapidly and relatively easily. Simple aeration or chlorine is effectively used in many water treatment systems for the removal of iron. Manganese requires a stronger oxidant and more time for the reaction to proceed to completion. The use of strong oxidants such as potassium permanganate or ozone has been shown to be successful in manganese removal processes. Catalytic media can also be used to aid in the manganese oxidation process. Effectively and efficiently removing iron and manganese from water requires the right combination of oxidant, time, and media.

3.3 Pilot Test Equipment

3.3.1 Raw Water Source

Testing occurred at Well 1 on the week of September 13th. Raw water for the pilot test was taken directly from the well.

3.3.2 Chemical Addition

The chemical feed systems used in the City of Henderson pilot testing were Blue-White Peristaltic metering pumps capable of feeding 3.5 gallons per day (GPD).

3.3.2.1 Chlorination

Chlorine was added to this process to oxidize iron and manganese prior to filtration. Oxidizing the iron and manganese allows for removal of these materials to below SMCL levels via filtration. On aeration/detention testing processes, chlorine was added prior to a 30 minute detention, followed by filtration. The chlorine source was a hypochlorite solution (all reported values are as chlorine). Tables 2 summarizes process characteristics, including chlorine dosage.

Table 2 – Process Train Characteristics

Well	#1			
	Column 1	Column 2	Column 3	Column 4
Filter Media Characteristics	Silica/Anthracite	Greensand/Anthracite	Silica/Anthracite	Greensand/Anthracite
Filter Loading Rate (gpm/ft^2)	3	3	3	3
Anthracite Effective Size (mm)	0.9 - 1.1	0.9 - 1.1	0.9 - 1.1	0.9 - 1.1
Silica Effective Size (mm)	0.45 - 0.55	-	0.45 - 0.55	-
Greensand Effective Size (mm)	-	0.3 - 0.36	-	0.3 - 0.36
Media Depth (in)	18" Silica	18" Greensand	18" Silica	18" Greensand
	12" Anthracite	12" Anthracite	12" Anthracite	12" Anthracite
Backwash Rate (gpm/ft^2)	20	20	20	20
Anionic Polymer Feed (mg/L)	0.005	0.005	-	-
Aeration	-	-	30 minute	30 minute
Chlorine Feed (mg/L)	9.853	9.853	12.240	12.240

Source: Pilot Testing Data Collection

3.3.3 Aeration

Aeration was selected as an additional oxidizing agent to aid in the iron and manganese removal process. Potassium permanganate is typically used to oxidize manganese. However, the addition of other oxidizing agents (like oxygen in air) can reduce the amount of permanganate needed. Unlike chlorine or other chemical oxidation methods, aeration does not create a chemical residual. It was the desire of the City of Henderson to minimize chemical feed and chemical residuals in their drinking water, thus aeration was selected as an option to evaluate.

A draft aerator was used to aerate the system, at an approximate rate of 15 cubic feet per minute to 1 cubic foot of water.

3.3.4 Detention

Detention provides time for oxidation reactions to occur. Incorporating detention increases iron and manganese removal and decreases the amount of permanganate required. The Ten State Standards (drinking water treatment standards in Minnesota) recommend a minimum detention time of 30 minutes.

Detention was achieved by using a 150 gallon tank with a feed and overflow rate of 5 gpm. This combination of tank size, feed rate and overflow rate results in a 30 minute detention time. Columns 3 & 4 utilized aeration & detention steps, while Columns 1 & 2 had no aeration or detention.

3.3.5 Filtration

Two different types of filter media were evaluated for this test, which were Greensand media and silica sand.

Greensand is a silica based catalytic filter media used for removing iron, manganese, hydrogen sulfide, arsenic and radium from groundwater supplies. It consists of silica sand with a manganese dioxide coating. The manganese dioxide coated surface acts as a catalyst in the oxidation reactions of iron and manganese, and the coating causes the surface of the media to have a black coloration. To improve the hydraulic performance of the filter, an anthracite cap was included. Hydraulic loading rates for greensand filters are typically between 2 and 8 gpm/ft^2. The backwash of a greensand filter fluidizes the filter bed, scrubs the media, and redistributes the media throughout the bed. The required backwash rate is typically between 10 and 25 gpm/ft^2. High loading rates of iron and manganese have been shown to be successfully treated using greensand media, however shorter filter run times are typically required as early breakthrough of precipitated minerals typically occurs.

Silica sand is effective at retaining solid and precipitated materials. In this test, anthracite was used in conjunction with silica sand to improve the hydraulic performance of the filter. Hydraulic loading rates for silica (sand) filters are typically between 0.5 and 6 gpm/ft^2. The backwash of a greensand filter fluidizes the filter bed, scrubs the media, and redistributes the media throughout the bed. The required backwash rate is typically between 10 and 20 gpm/ft^2.

The pilot study was conducted with four 8-inch diameter, 7-foot tall filters. Each filter has a 3/4-inch inlet, 1 1/2-inch backwash waste outlet, under drain system, air release system, rate of flow meters, sample taps, and filter media. The filter columns provide a total area of 0.35 ft^2 of surface area per column. Pressure taps are located on the inlet and outlets of the filter to obtain filter head loss by comparing the two pressures.

Columns No. 1 & 3 were bedded with 18 inches of silica sand along with 12 inches of anthracite. The silica media had an effective size of 0.45 to 0.55 mm, and the effective size of the anthracite was 0.9 to 1.1 mm. The filters were operated 3 gallons per minute per square foot (gpm/ft^2). The backwash rate was 20 gpm/ft^2, with a 3 cfm/ft^2 air scour.

Columns No. 2 & 4 were bedded with 18 inches of greensand along with 12 inches of anthracite. The greensand media had an effective size of 0.3 to 0.36 mm, and the effective size of the anthracite was 0.9 to 1.1 mm. The filters were operated 3 gallons per minute per square foot (gpm/ft^2). The backwash rate was 20 gpm/ft^2, with a 3 cfm/ft^2 air scour.

3.4 Sampling and Analysis

The influent water to the pilot trailer was tested for iron and manganese with a Hach 900 Colorimeter. Temperature and pH were measured using Hach HQ 40 pH meter. Calibration columns provided measurement of chemicals used. The volume of each chemical in milliliters was measured per unit of time and the dosage was calculated based on the flow to the individual treatment trains.

4 Pilot Test Results

4.1 Water Quality

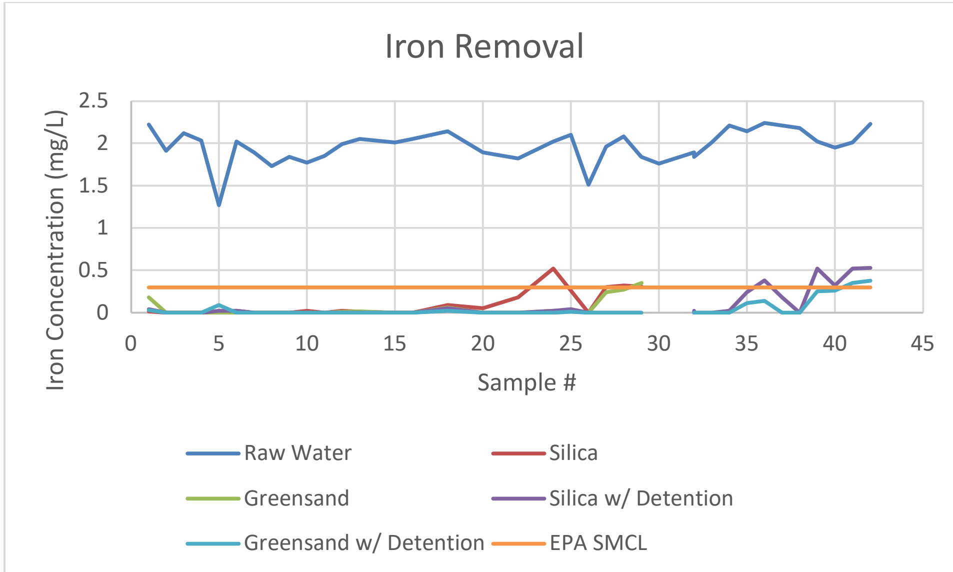
4.1.1 Iron

Table 3 summarizes the finished water quality from all columns. All iron average recordings in the finished water were below the EPA secondary standard of 0.30 mg/L. The maximum effluent readings in all columns occurred at high differential pressure, and these poor removal rates can be avoided with a proper backwash plan. Figure 1 compares raw water and finished water results to the secondary standards.

Table 3 – Finished Water Quality (Iron & Manganese)

Well	Column (Media)	Iron (mg/L)			Manganese (mg/L)		
		Min	Max	Avg	Min	Max	Avg
1	1 (S)	0.001	0.52	0.089	0.002	0.060	0.025
	2 (GS)	0.001	0.35	0.049	0.001	0.052	0.016
	3 (S+A/D)	0.001	0.53	0.082	0.001	0.060	0.023
	4 (GS+A/D)	0.001	0.38	0.046	0.001	0.04	0.015

Source: Pilot Testing Data Collection

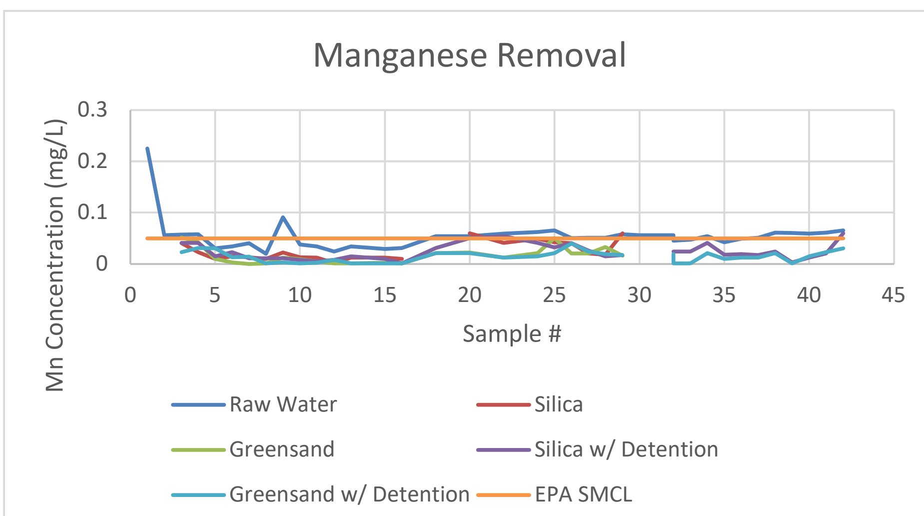


Source: Pilot Testing Data Collection

Figure 1 – Well 1 Iron Removal

4.1.2 Manganese

Both silica and greensand media were able to consistently reduce manganese to levels below the EPA SMCL (0.05 mg/L). The average iron concentration in the filter effluent for silica media was 0.025 mg/L and greensand media was 0.016 mg/L. The addition of a detention step was able to reduce these values to 0.023 mg/L and 0.015 mg/L, respectively. The highest level of removal occurred with greensand media with a chemical treatment plan of chlorine, along with aeration and detention. Figure 2 shows raw water and finished water manganese levels.



Source: Pilot Testing Data Collection

Figure 2 – Well 1 Manganese Removal

4.1.3 pH

The pH was measured periodically throughout the test. pH is a measure of the concentration of hydrogen ions in a substance (in this case, water) which shows how acidic or basic the substance is. At Well 1, the pH ranged between 7.59 and 8.07, with an average value of 7.73. At Well 2, the pH average pH was 7.4. Both of these wells provide water that is considered neutral pH.

4.2 Head Loss

Pressure taps enable the measurement of headless through the filters. Figure 3 plots the head loss for all runs. Column 1 reached a head loss of 7.7 feet of water during the trial, and column 2 reached a head loss of 5.5 ft. With aeration and detention steps added to the process, Column 3 reached a head loss of 4.7 ft of water, and column 4 reached a head loss of 4 ft.

Figure 3 – Well 1 Head Loss

4.3 Chlorine Residual

The average free chlorine residual in the finished water at without detention was 0.50 mg/L, and the average chlorine residual in the finished water at with detention was 0.49 mg/L. Table 7 summarizes the finish water chlorine residual for Well 2. It is likely that an additional 0.5 to 1.5 mg/L chlorine need to be added to the finished water to maintain a disinfection residual.

Table 4 – Chlorine Content

	Free Chlorine (mg/L)			Total Chlorine (mg/L)		
	Min	Max	Avg	Min	Max	Avg
Finished Water – No Aeration	0.09	1.70	0.50	0.30	6.52	2.57
Finished Water – With Aeration	0.01	1.16	0.49	1.02	6.22	3.14

5 Pilot Study Conclusions

5.1 Water Quality

Both silica and greensand media can bring iron and manganese levels into compliance with EPA SMCLs. These water quality targets were achievable both with and without detention. Greensand media with aeration and detention steps provided the lowest iron & manganese effluent concentrations for the longest period of operating time. Greensand media without aeration and detention provided longer filter runtimes than silica while meeting EPA SMCLs. All medias tested can be effective at meeting EPA recommendations with the addition of chlorine as an oxidant, and the determination for the recommended process will be determined by capital considerations.

6 Recommendations

The recommended treatment process for iron and manganese removal at the proposed water treatment plant is: chlorination followed by filtration. The manganese concentration in the source water is extremely low, making additional oxidation steps unnecessary. Target iron and manganese concentrations can be met without the addition of a detention step, so this step is omitted from the recommended process. Chlorination aides in the reduction of the iron and manganese and is also used as a post-treatment process disinfectant. Filtration with greensand media provides separation of the oxidized contaminates from the drinking water along with long filter runtimes, and the inclusion of anthracite in the bed improves hydraulic performance of the filter.

6.1 Design Criteria

The following design is recommended,

Chemical Addition:

- Chlorination
  - Dose: 10 mg/L
  - Location: front of process, before filtration

Filtration:

- Media: 18 inches of greensand, effective diameter 0.9 to 1.1 mm.
- Anthracite Base: 12 inches.
- Feed rate: 3 gpm/ft^2

Backwash:

- Backwash with air and water:
  - 20 gpm water per ft^2 of filter media.
  - 3 cfm air per ft^2 of filter media.

6.2 Estimate of Probable Costs

City of Henderson staff estimate an average day demand of 60,000 gallons per day (gpd). Based on current water usage, it has been assumed a filtration plant would be sized to treat between

250 to 300 gallon per minute. The flow required would be confirmed during preliminary design. This will provide plenty of additional capacity for future demands, along with the option to shutter the plant when water treatment is not necessary (e.g. overnight). Automated water treatment plants do not require operator attendance the entire time the plant is in operation, but do require operators to be on-call while the plant is in operation. It is estimated that a plant of this size would require 3.6 hrs of run-time to produce water for an average day. A high-level estimate of probable costs for the construction of a filtration plant, based these flows and on the design criteria identified in Section 6.1 is provided in Table 5.

Table 5 – Estimate of Probable Costs for 250 gpm Treatment Plant

Item	Cost
General Requirements (12%)	$426,000
Concrete	$450,000
Masonry	$185,000
Metals	$75,000
Thermal and Moisture Protection	$70,000
Openings (doors/hardware)	$80,000
Finishes (paint, floor sealer)	$75,000
Specialties	$10,000
Furnishings	$15,000
Plumbing	$125,000
HVAC	$135,000
Electrical	$900,000
Earthwork (excavation, backfill)	$80,000
Civil/Site Work	$250,000
Utilities	$180,000
Process Integration	$160,000
Process Equipment	$760,000
Total Construction Costs	**$3,976,000**
Engineering/Administration (17%)	$675,920
Contingency (25%)	$994,000
TOTAL	**$5,645,920**

7 Water Distribution System

7.1 Existing Condition

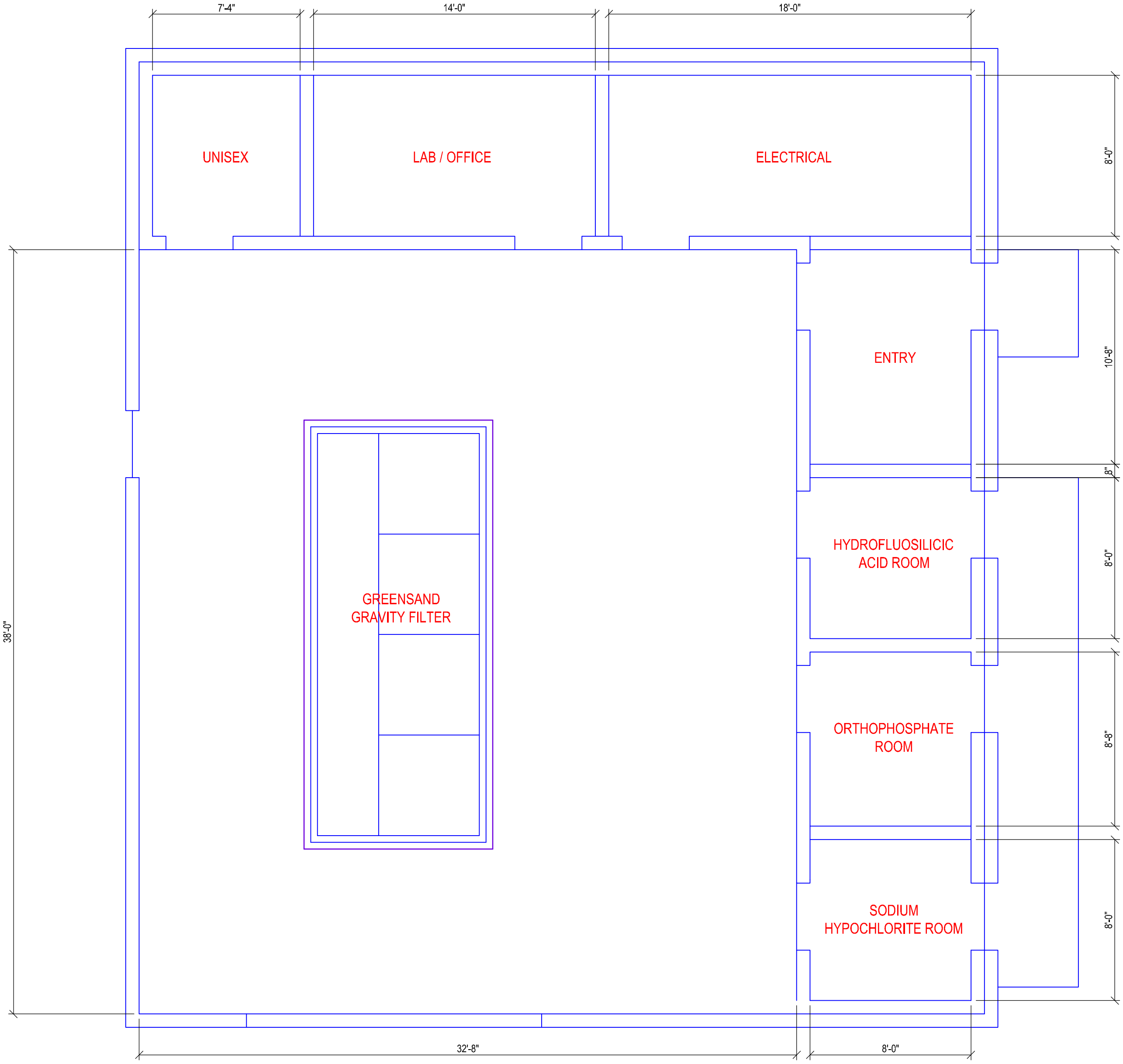
A preliminary review of the city's water system was also completed as part of the study. A map of the city's water system is attached as Exhibit 2 at the end of this report. Elevations throughout the city can vary from around 730-feet near the levee system to 970-feet in the Maple Ridge neighborhood. Because of the city of Henderson's unique topography, a combination of pumps and pressure reducing valves in combination with the water tower provide consistent pressure and distribution throughout the city. Water demand fluctuates on a regular basis and the system must be able to keep up and distribute water to where it is needed.

During a recent storm event, power was lost at both of the city's wells and the water tower was no longer being replenished. Though the water tower contained enough storage volume and elevation to temporarily serve the city's water system, over time the elevations dropped low enough such that service was lost to properties in the higher part of the city, primarily the Maple Ridge neighborhood. When power was restored to the wells and the water mains were replenished, iron that had previously settled in the pipes was mobilized by the water and circulated throughout the system. This resulted in high iron amounts at many properties.

7.2 Proposed Improvements

Though the Pilot Study was to study treatment of well water and necessary improvements needed prior to entering the distribution system, additional work will also be necessary to remove the iron that is currently within the water mains. Through discussions with city staff and council, it has also been determined that some additional improvements may be needed for other areas of the water distribution system. Our preliminary recommendations include:

- **Modeling of the existing water system.** By modeling the water system, recommendations toward removal or replacement of pressure reducing valves, water main pipe sizes, or additional looping can be made.
- **Additional flushing of water mains.** The City's current system does not remove iron from the water. It should be expected that even with a new filter plant, iron deposits currently within the water system will only be removed through extensive flushing . A water model would assist in developing a plan to systematically remove this iron.
- **Remove and replace older water mains.** Though most of the city's' water main system is either ductile iron or PVC, there are still areas of town with older cast iron pipes. It should be expected that these pipes will need replacement due to their smaller size (4-inches) or condition. These older pipes are also expected to contain higher amounts of iron deposits due to their age.
- **Upgrade communications systems for city infrastructure.** Though the alarm system at the wells was repaired after the recent storm event, it would be recommended that a SCADA system be installed at wells, booster stations, lift stations, and pressure reducing valves. This will allow real-time conditions to be reported to city staff and allow adjustments to be made remotely as needed.



FILE NO.
HENDE 163471

DATE:
11/15/2021

CONCEPTUAL WTP

HENDERSON, MINNESOTA

EXHIBIT
NO. 1

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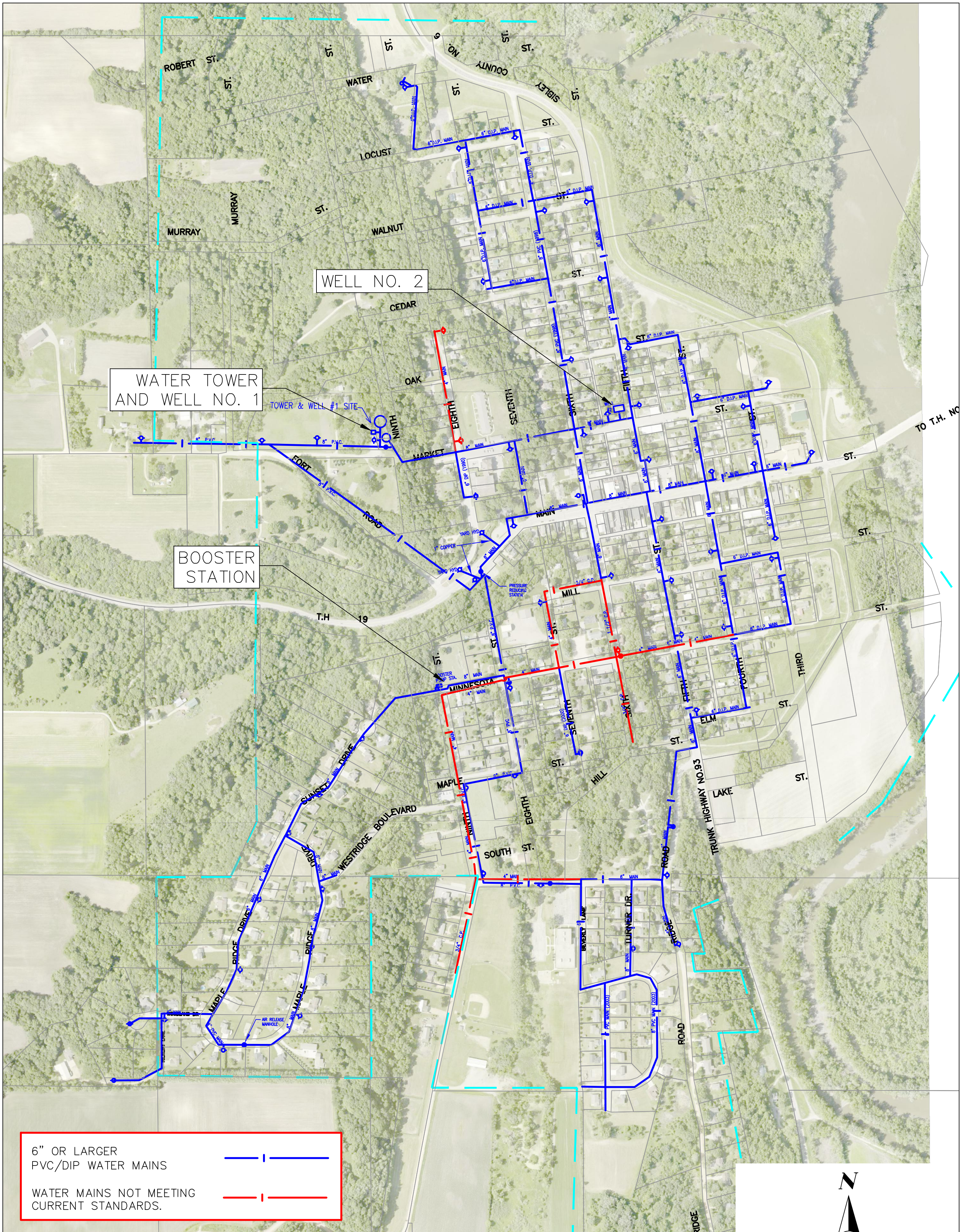

FILE NO.
HENDE 163471

DATE:
11/15/2021

EXISTING WATER SYSTEM

HENDERSON, MINNESOTA

EXHIBIT NO. 2

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