GET THE RED OUT!
REMOVING IRON AND MANGANESE FROM WELL WATER SUPPLIES

A. Lee Head, III, P.E.
Gregory R. Lushbaugh, P.E.
Brown & Gay Engineers, Inc.
108 West 8th Street, Suite 200
Fort Worth, TX 76102

ABSTRACT

The Spring Lake Wells Water Treatment Plant (Plant) is located in the City of Huntsville (City). Currently the water supply is treated with aeration, chlorine and polyphosphate before distribution to City residents. Each of the two wells, Well No. 19 and Well No. 20, has a capacity of 1,000 gallons per minute (gpm). Well tests have shown high iron and manganese concentrations and iron reducing bacteria in the Spring Lake Wells. Existing treatment methods have not been effective against these constituents.

As a result of the City's problems with high iron and manganese concentrations and iron reducing bacteria in the Spring Lake Wells, the City retained Brown & Gay Engineers, Inc. to evaluate alternative methods for removing iron and manganese. The alternative methods were evaluated against various criteria including additional space required, overall reliability, manufacturer's support, special operating skills, automation of the process, chemical use, required power, and total (capital plus operations) cost. The alternative methods were compared using a Benefit-Cost Analysis, which included a Present Worth Analysis that incorporated capital construction costs and operating costs. The options were then ranked accordingly to desirability, and Brown & Gay Engineers recommended the option that was determined to be the most desirable.

This paper will examine the alternatives that are generally available for removing iron and manganese from well water supplies, and the methodology that was used to identify the most desirable option for the City's Spring Lake wells.

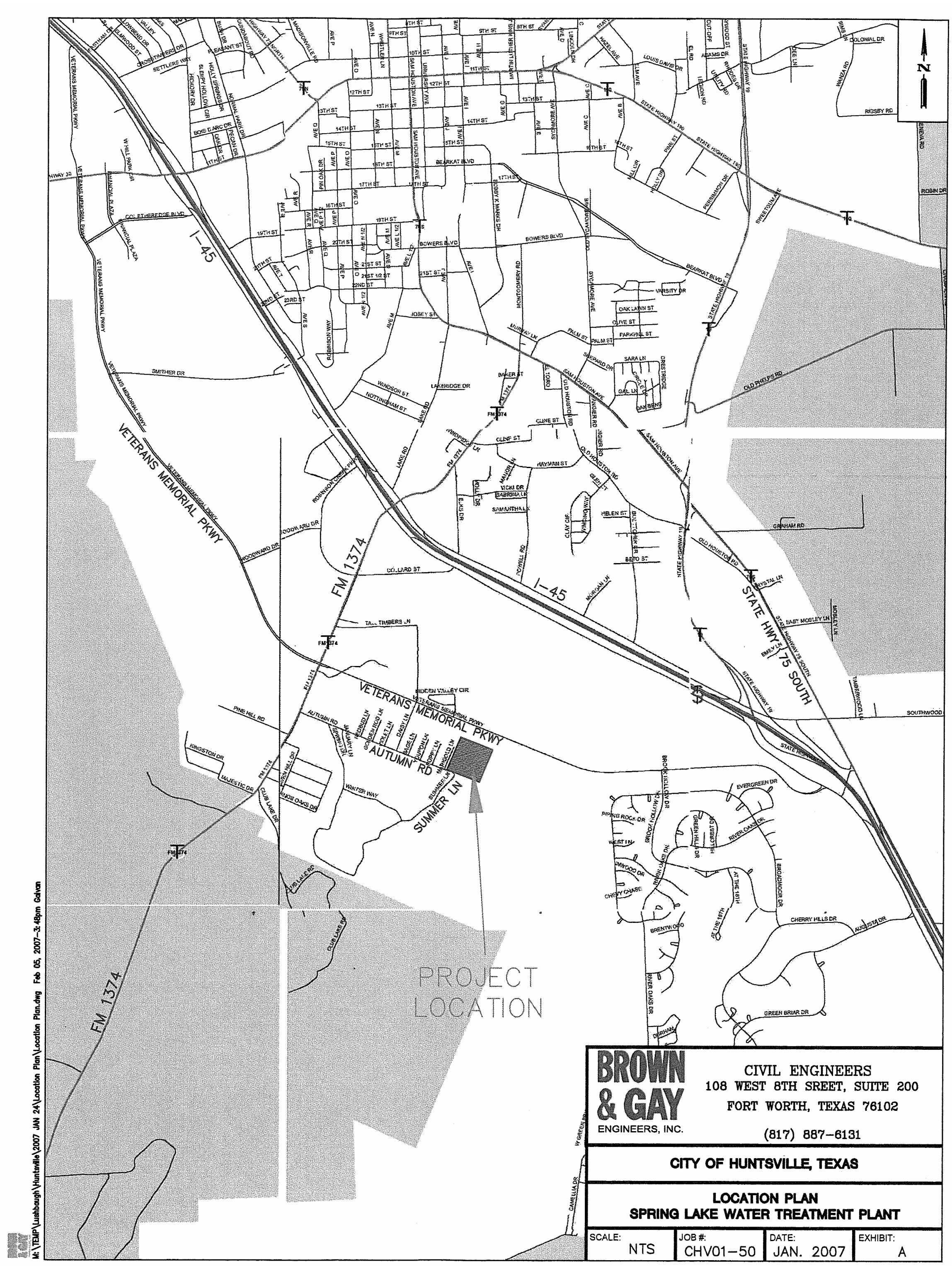
KEYWORDS

Iron, manganese, potassium permanganate, chlorine, polyphosphate, backwash, biocide, sequestering, oxidation, aerator, filter, greensand, ozone, membrane

INTRODUCTION

The Spring Lake Wells Water Treatment Plant (Plant) is located on the west side of the City of Huntsville (City). **Figure 1** shows the location of the Plant. The Plant pumps water from the ground, treats the water with aeration, chlorine and polyphosphate, and distributes the water to City residents. The Plant lies on a site that is approximately 164' x 185', and consists of two wells, one 500,000 gallon ground storage tank, one hydropneumatic tank, a booster pump station, gas chlorine and polyphosphate facilities.

Figure 1 – Spring Lake Wells Water Treatment Plant Location Plan



The two wells, Well No. 19 and Well No. 20, each have a capacity of 1,000 gallons per minute (gpm). The plant normally operates with only one well running, but at times the City uses both wells simultaneously, for a plant design flow of 2,000 gpm. When both wells are running, water from the two wells is combined prior to entering the ground storage tank. The plant's current capacity is 2,000 gpm, and a third 1,000 gpm well could be added in the future to provide a capacity of 3,000 gpm.

Statement of Problem

The Spring Lake wells have high iron and manganese concentrations, as well as "very aggressive" iron reducing bacteria as determined from several Biological Activity Reaction Tests (BART) taken a few years ago. Currently, the City uses a cascade aerator and chlorine to try to oxidize the iron and manganese then adds a polyphosphate to sequester it.

The current scheme for iron and manganese removal using a cascade aerator and adding chlorine and polyphosphate has not been successful, for a variety of reasons that may include poor mixing, high iron and manganese concentrations, and insufficient chemical feed amounts. A likely reason is that the polyphosphate cannot be expected to sequester 100% of the iron and/or manganese ions in the water. The cost of polyphosphate has increased tremendously and it is now cost-prohibitive. Also, the aerators are not effective in completely oxidizing either the iron or manganese at the concentrations in the Spring Lake wells because of the inefficiency of the aerator.

METHODOLOGY

Brown & Gay Engineers, Inc. evaluated seven different alternative methods for removing iron and manganese from the wells. These alternatives ranged from continuing with the existing process and periodically using a biocide and flushing the wells to using low pressure membranes with ozone. Each treatment option was evaluated based on whether additional site space is required, the reliability of the process, the mechanical reliability of the system, ease of operation, ease of regular maintenance, manufacturer's support availability, any special training required, the ability to automate the process, chemical use, power requirements, and of course total (capital plus operations) cost.

- Option No. 1 – Chemical Oxidation – Potassium Permanganate ($KMnO_4$) / Chlorine (Cl_2) with Pressure Greensand Filters
- Option No. 2 – Chemical Oxidation – $KMnO_4$/Cl_2 with Gravity Greensand Filters
- Option No. 3 – Chemical Oxidation – Ozone with Pressure Anthracite Filters
- Option No. 4 – Chemical Oxidation – Chlorine with a Proprietary Pressure Filter Media
- Option No. 5 – Chemical Oxidation – Ozone with Low Pressure Membranes
- Option No. 6 – Catalytic Filtration – Aeration with a BIRM Pressure Filter Media
- Option No. 7 – Biocide/Sequestering – Chlorine Dioxide and Polyphosphates

Option No. 1 – Chemical Oxidation – KMnO4/Cl2 with Pressure Greensand Filters

This system consists of feeding chlorine and potassium permanganate ($KMnO_4$) for the oxidation of iron (Fe) and manganese (Mn) into an insoluble form, followed by pressure filtering with greensand media for removal of the insoluble iron and manganese. The greensand is regenerated with potassium permanganate. Greensand is coated with manganese dioxide to absorb any Mn that is not oxidized.

The filters are loaded at a rate of 4 to 5 gpm/sf of filter surface area and require backwashing at a rate of about 20 gpm/sf periodically based on the Fe and Mn concentrations in the water. At combined Fe and Mn concentrations of below 15 mg/l, this process can reduce both the iron and manganese concentrations to near zero.

Chemical oxidation combined with greensand filters is one of the most common methods of removing iron and manganese from well water supplies. There are hundreds of applications across the US and Canada and numerous manufacturers who can supply the appropriate equipment. Because the greensand absorbs the Mn ions and serves as a buffer, the consequences of overfeeding or underfeeding potassium permanganate are reduced. The filter backwash can be fully automated making the operations less labor intensive.

The total project cost is lower than most alternative treatment options.

The drawbacks of this process are as follows:

- The high cost of potassium permanganate (currently at about $4.50/lb);
- The possibility of overfeeding potassium permanganate and pumping purple water to the City’s customers;
- Disposing of the backwash water (about 300,000 gallons per complete backwash);
- The possibility of binding the pressure filters and developing “mud balls” if sufficient organics are present in the source water (iron bacteria).

The preliminary opinion of probable construction cost is approximately $1.7 million with a preliminary opinion of probable annual operating cost of approximately $250,000.

Option No. 2 – Chemical Oxidation – KMnO4/Cl2 with Gravity Greensand Filters

This option is similar to Option No. 1, except that the filters are gravity fed. Like Option No. 1, if sufficient organics are present, then the pressure greensand filters could bind and develop “mud balls.” To counter this problem, gravity filters of similar size to the pressure filters in Option No. 1 are used, along with a longer contact time for oxidation. However, the treated water must then be pumped back into the ground storage tank prior to being pumped into the City’s system. Three or four low-head transfer pumps with VFD drives are needed for this function.

The advantages of the gravity filters are that they are accessible for inspection and/or maintenance and the risk of binding is greatly reduced if organic material is present.

The disadvantage is the additional capital and pumping costs for longer reaction time (up to 30 minutes), and a transfer pump station.

The preliminary opinion of probable construction cost is approximately $2.1 million with a preliminary opinion of probable annual operating cost of approximately $285,000.

Option No. 3 – Chemical Oxidation – Ozone with Pressure Anthracite Filters

Instead of using chlorine and potassium permanganate for oxidation and greensand filters, ozone can be used as the oxidant with dual media anthracite/sand pressure filters. Ozone is a very strong oxidant and can oxidize both iron and manganese almost immediately to an insoluble form that can be filtered. Because potassium permanganate is not required, greensand is also not required.
Ozone systems have become more common and do not require significant operator interface. Because the ozone is generated on-site, there is no chemical storage or feed equipment required, although chlorine feed is still required to maintain a disinfection residual.

Ozone systems, however, are more expensive to construct and operate than chlorine/potassium permanganate greensand filters.

The preliminary opinion of probable construction cost is approximately $3.7 million with a preliminary opinion of probable annual operating cost of approximately $323,000.

Option No. 4 – Chemical Oxidation – Chlorine with a Proprietary Pressure Filter Media

In lieu of using potassium permanganate with greensand filters, a company in California, Filtronics, has developed a proprietary filter media that requires only the use of chlorine as the oxidant. This media can also be loaded at about twice the filtration rate as either greensand or dual media filters with only a 4-minute backwash requirement (although the filters need to be backwashed more often).

There have been many of these systems put into operation across the country since the mid-1970's. Like the permanganate/greensand systems, these systems can be fully automated. There is a representative for this system located in Houston, Quest Technologies, Inc., to provide local support.

Because the filter-loading rate is greater, the pressure filters are smaller; and because individual backwashes use less water, the backwash retention basin can be also smaller, thereby reducing the overall construction cost. Because permanganate feed is not required, the annual operating costs are less as well.

Sulfur dioxide may need to be fed prior to filtration to control odors if H_2S is present in the well supply, and additional chlorine added after filtration to maintain an adequate chlorine residual. This is a proprietary system and is recommended to be pilot tested before proceeding.

The preliminary opinion of probable construction cost is approximately $1.5 million with a preliminary opinion of probable annual operating cost of approximately $85,000.

Option No. 5 – Chemical Oxidation – Ozone with Low Pressure Membranes

In extreme conditions (iron and manganese concentrations greater than 25 mg/l) using ozone as a strong oxidant followed by ultra-filtration is an effective way of reducing iron and manganese concentrations. This process can be the most effective overall under a variety of conditions. However, it is the most expensive in terms of both capital costs and annual operating costs, with the membranes requiring replacement every seven to ten years.

The preliminary opinion of probable construction cost is approximately $6.6 million with a preliminary opinion of probable annual operating cost of approximately $737,000.

Option No. 6 – Catalytic Filtration – Aeration with a BIRM Pressure Filter Media

BIRM (Burgess Iron Removal Method) media serves as a catalyst between dissolved oxygen and the soluble iron and manganese in the water to produce insoluble iron and manganese that can be filtered. The incoming water is aerated prior to the filters. Chlorine is added after filtration to maintain a disinfectant residual. The filter loading rate and backwash rate is comparable with greensand filters.

No other chemicals are used resulting in lower operating costs for the BIRM process than those requiring potassium permanganate or ozone. The compressor required to aerate the incoming supply is small (5 hp or less), therefore not requiring a significant amount of energy.

Because the BIRM media is lighter than greensand or anthracite, the backwash procedures must be carefully controlled to keep from washing the media away. In addition, chlorinated water cannot be used in backwashing the system, requiring the backwash supply to be dechlorinated. Organics may also adversely impact the BIRM media.

BIRM systems generally are available in smaller sizes (5 gpm or less), which would require at least 400 units to treat the 2,000 gpm design flow rate.

The preliminary opinion of probable construction cost is approximately $1.6 million with a preliminary opinion of probable annual operating cost of approximately $140,000.

Option No. 7 – Biocide/Sequestering – Chlorine Dioxide and Polyphosphates

In order to reduce iron bacteria present in both wells 19 and 20 and therefore (potentially) reduce the iron concentrations, the wells can be treated with a strong biocide such as chlorine dioxide or peroxide to kill the bacterial in both the well casing and the underlying water strata. Then, a polyphosphate can be used to sequester any remaining soluble iron and manganese.

This “shock” well treatment will be required about every six months.

This option requires the least capital cost to implement, but the ongoing operations cost for continued well treatment and polyphosphate feed are high. In addition, the overall success of using this process is questionable and could lead to the soluble iron and manganese coming out of solution in the distribution system creating the “red” or “black” water problems this project is attempting to eliminate.

The preliminary opinion of probable construction cost is approximately $290,000 with a preliminary opinion of probable annual operating cost of approximately $220,000.

Benefit Cost Analysis/Potential Benefits

A potential list of benefits the City would like to get from this project was developed in conjunction with the City staff. The following benefits were identified:

- Meets all Federal and State Drinking Water Regulatory requirements and is approved by TCEQ (not meeting this is a fatal flaw)
- Process meets treatment objectives (not meeting is a fatal flaw)
- Ability for remote operation and monitoring
- Ease of equipment accessibility
- Ease of operation
- Ease of maintenance
- Equipment is mechanically reliable
- Future regulation compliance
- Minimal interruption of service during construction
- Minimal interruption of service during maintenance
- Minimal regulatory involvement with TCEQ
- Minimal special training required for operation or maintenance
- Minimal vulnerability of equipment and/or process to sabotage or attack
- No additional site required
- Process is reliable (is consistent)

The benefits were then ranked through a pair-wise comparison; i.e. is benefit 1 better than, equal to, or worse than benefit 2, then 3 and so on. A weighting factor was then determined to place on each benefit, i.e. is the highest ranked benefit twice as beneficial as the next, 1.5 times beneficial, etc. The details of this Benefit Ranking are summarized in **Table 1**.

Table 1 – Benefits Ranking/Weighting Factors

Benefit	Rank	Weighting Factor
No additional site required	1	20
Process is reliable (is consistent)	2	15
Equipment is mechanically reliable	2	15
Ease of operation	4	13
Ease of maintenance	5	12
Minimal interruption of service during maintenance	6	6
Future regulation compliance	7	4
Minimal special training required for operation or maintenance	8	3
Minimal vulnerability of equipment and/or process to sabotage or attack	9	2.5
Minimal regulatory involvement with TCEQ	10	2
Ease of equipment accessibility	11	1.5
Ability for remote operation and monitoring	12	1
Minimal interruption of service during construction	13	0.75

RESULTS AND DISCUSSION

Results of Benefit-Cost Analysis / Final Ranking of Options

The seven treatment options were compared against the list of ranked benefits. A Benefit Score for each option was calculated based on how the option met the benefits listed in **Table 1**. A Present-Worth Analysis for each option was calculated based on construction and operating costs, and 5% inflation per year over a 20-year period. The Benefit Score divided by the Present-Worth, and multiplied by 100,000, yielded a Benefit/Cost Ratio, and the Final Ranking of Options presented in **Table 2**.

Table 2 – Results of Benefit-Cost Analysis / Final Ranking of Options

Option	Benefit/ Cost Ratio	Final Ranking
Option No. 4 – Chlorine with a Proprietary Pressure Filter Media	73	1
Option No. 6 – Aeration with a BIRM Pressure Filter Media	55	2
Option No. 1 – $KMnO_4/Cl_2$ with Pressure Greensand Filters	36	3
Option No. 2 – $KMnO_4/Cl_2$ with Gravity Greensand Filters	32	4
Option No. 7 – Biocide/Sequestering	30	5
Option No. 3 – Ozone with Pressure Anthracite Filters	22	6
Option No. 5 – Ozone with Low Pressure Membranes	10	7

Option No. 4, Chlorine with a Proprietary Pressure Filter Media (Filtronics), was the top ranked option, and was recommended for this project.

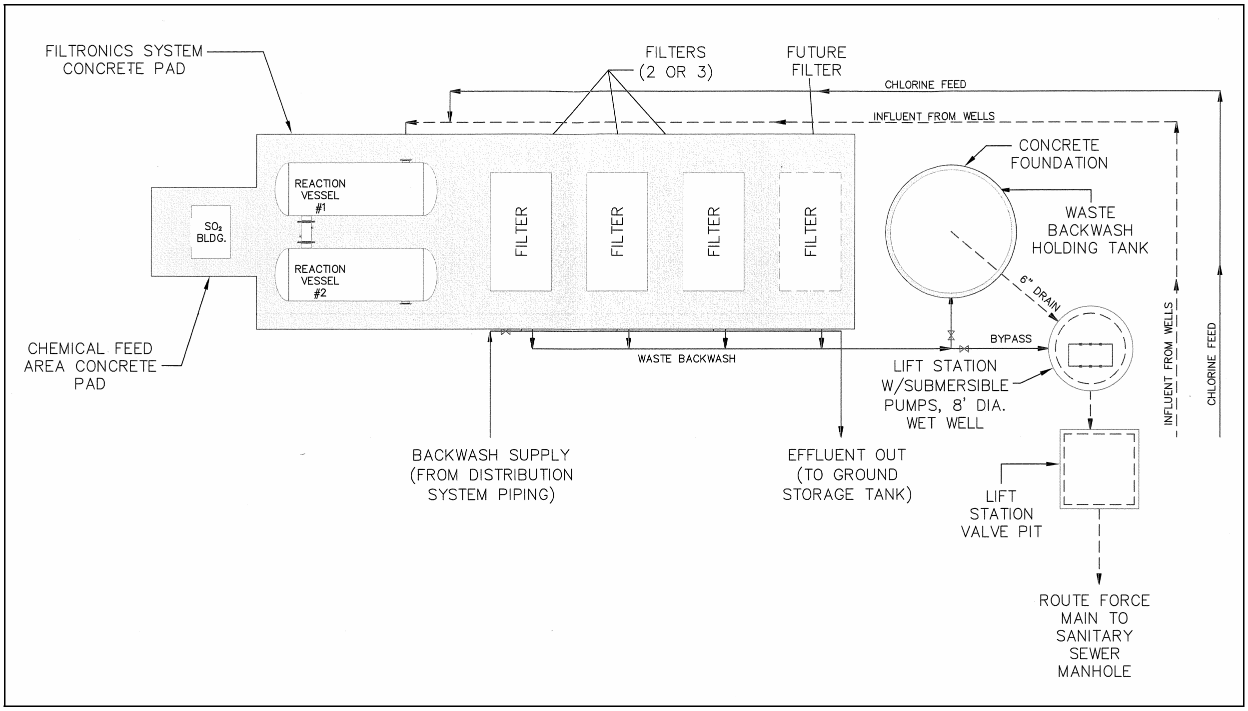
Filtronics has developed a proprietary filter media that requires only the use of chlorine as the oxidant. Filtronics has installed many of these systems in operation across the country since the mid-1970s. These systems can be fully automated. There is a representative for this system located in Houston, Quest Technologies, Inc., to provide local support. This media can also be loaded at about twice the filtration rate as either Greensand or dual media filters with only a 4-minute backwash rate (although the filters need to be backwashed more often).

The system uses relatively small pressure filters because a larger filter loading rate can be used compared to other technologies. Backwash volumes are smaller as compared to other systems, resulting in a smaller Waste Backwash Holding Tank. Because permanganate feed is not required, the annual operating costs are less than other systems.

The water from the wells will enter the first proposed Filtronics Reaction Vessel followed by the second Reaction Vessel. The water is then split between the Filtronics pressure filters, with each filter capable of treating 1,000 gallons per minute (gpm). The treated flow from the filters then enters the existing ground storage tank.

Figure 2 shows a flow schematic of the proposed equipment.

Figure 2 – Spring Lake Wells Water Treatment Plant – Flow Schematic



Filtration System

The system provided by Filtronics generally consists of the Reaction Vessels, Pressure Filters, piping and valves between the units, chemical feed facilities, and automation of the system.

Chemical Feed

If any H_2S is present in the wells, sulfur dioxide must be fed prior to filtration and chlorine added after filtration to maintain a chlorine residual. The actual dosages required will be dependent on the minerals and other constituents in the well water. Pilot testing will be required to confirm which chemicals (and their feed rates) will be required.

The existing onsite gas chlorine facilities can be used to feed chlorine gas. A 1" chlorine solution line will be routed from the existing chlorination facilities to the proposed Filtronics system.

Backwash System

The Filtronics system includes automatic backwashing for its filters. No operator intervention is required for normal backwashing; Solenoid-controlled valves will automatically open or close to switch the filter from treatment mode to backwash mode. Each filter is backwashed after running for approximately 8 hours. The required backwash rate for each filter is 2,000 gpm for 4 minutes, for a total of 8,000 gallons per backwash. Backwash water will be provided by piping from the header of the existing booster pumps onsite. The booster pumps will supply the required pressure to backwash the filters.

A 30,000 gallon Waste Backwash Holding Tank will be utilized to reclaim water used for backwashing to store at least one day's worth of backwash water. The tank will be a cylinder with hopper-type (cone) bottom for removing settled sludge from the tank bottom. The decanted portion of the backwash water will be returned to the process, by use of a pump that is part of the manufacturer's supplied system.

Onsite Lift Station

An onsite lift station is also required. The lift station will draw sludge from the bottom of the Waste Backwash Holding Tank, and pump it to the nearest sanitary sewer manhole. Also, if the backwash tank is out of service, flow will come directly from the filters to the onsite lift station. The proposed lift station includes an 8 ft. diameter wetwell containing 2 submersible 20 gpm pumps, and a valve vault.

CONCLUSIONS

- Various methods are available for removing iron and manganese from well water supplies.
- A treatment method should be chosen based on site-specific constraints and the particular needs of the client.

- For the City of Huntsville's Spring Lake Wells, chemical oxidation of the iron and manganese using chlorine, and removal of the resultant insoluble iron and manganese using a pressure filter with a proprietary filter media was determined to be the most desirable solution.

ACKNOWLEDGEMENTS

Brown & Gay Engineers, Inc. would like to thank the following staff of the City of Huntsville, Public Services Department for their assistance on the project:

Mr. Glenn Isbell, P.E., Director of Public Services
Mr. Bill Daugette, Operations Manager
Mr. Jason Pierce, Water Superintendent
Mr. Joe Massey, Water Plant Operator