UNIT WELL 15 – VOLATILE ORGANIC COMPOUND (VOC) MITIGATION

Madison Water Utility
Madison, Wisconsin

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Table of Contents

TABLES

FIGURES

APPENDICES

1. BACKGROUND

The Madison Water Utility (MWU) is developing a comprehensive plan to provide a reliable supply of high quality water cost effectively to the City's Zone 6 - East Service Area. The Zone 6 - East Service Area is served by five wells including Unit Well Nos. 7, 8, 11, 15, and 29.

This memorandum addresses water quality issues at Unit Well No. 15. Unit Well No. 15 is exhibiting concentrations of the regulated Volatile Organic Compound (VOC), tetrachloroethylene (PCE), that are steadily approaching the Maximum Contaminant Level (MCL) of 5 micrograms per liter (µg/L). In addition, detectable levels of trichloroethylene (TCE) are present in the water supply from Unit Well No. 15 (UW 15).

The primary objectives of this memorandum are to:

- Present the existing water quality at UW 15 and evaluate if the water quality can be improved by changes in well configuration or pumping,
- Evaluate available treatment options for the removal of the VOCs present in the water from UW 15,
- Make recommendations to the MWU as to the most cost-effective approach for UW 15.

2. DESCRIPTION OF UNIT WELL NO. 15 AND LOCAL GEOLOGY

UW 15 is located in a commercial setting east of the Madison Area Technical College along Highway 151, as shown in Figure 1, an aerial photograph of the Well No. 15 site and surrounding area.

UW 15, which is housed within a masonry block/brick building, has a production capacity of 2,200 gallons per minute (gpm). The well is operated continuously at its rated capacity. Chlorine and fluoride (hydrofluosilicic acid) are fed to the well pump discharge which is conveyed to a below-grade 0.15 MG cast-in-place concrete reservoir. A constant speed vertical diffusion vane pumping unit conveys the water from the reservoir directly to the distribution system.

The Madison groundwater system includes two bedrock aquifers, the shallow sandstone and deep sandstone, which are separated in much of the City by the Eau Claire Shale. This thin shale layer has a very low permeability and helps protect the deep aquifer from contamination that may originate near the land surface. This protection is not present in all parts of the City because the shale is missing in some locations, such as below the lakes, creating a conduit between the aquifers.

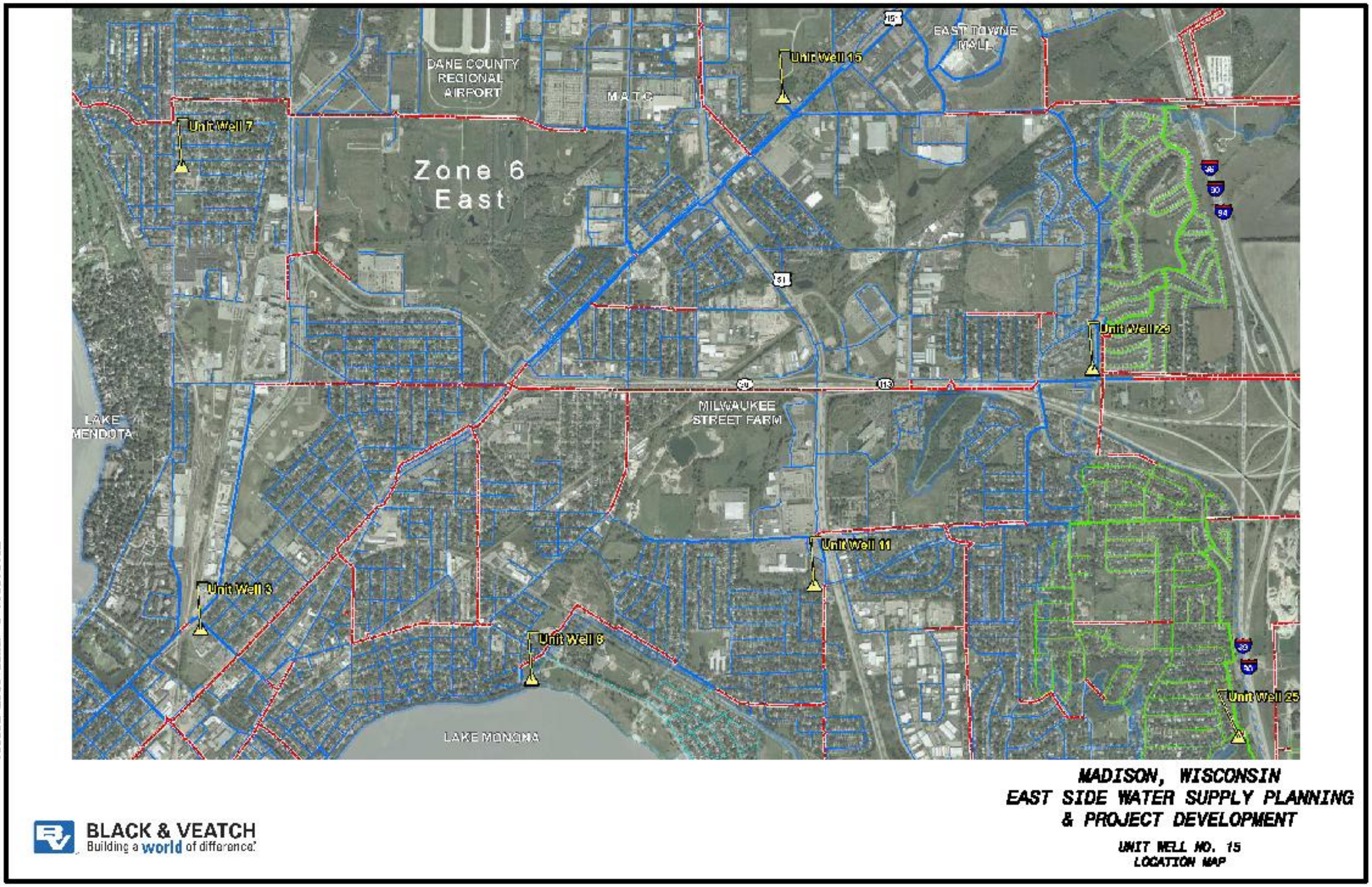


Figure 1: **Unit Well No. 15 Location Map**

Figure 2 shows a conceptual geologic cross section through the east side of Madison. At UW 15, the geology consists of an upper sand and gravel aquifer overlying the shallow sandstone. The shallow sandstone is separated from the deep sandstone aquifer by the Eau Claire shale. As part of this study, the latest UW 15 well logs were examined. The natural gamma log for UW15 shows that the Eau Claire Shale is present at UW15, but that the well casing does not extend as deep as the shale. Thus, the well is open to approximately 50 feet of the shallow sandstone and 500 feet of the deep sandstone aquifer. This open interval is also shown on Figure 2. The new geologic log for UW 15 indicates that the rock cuttings for the upper several hundred feet of the well, including the Eau Claire Shale, have been vandalized and are not available for interpretation, so that inferences about the presence of the shale are based on the geophysical log.

Figure 2 also conceptually depicts how a pollutant source in the upper aquifer can impact well water quality in UW 15. The contaminant may enter the well directly, or migrate into the lower aquifer through the well conduit.

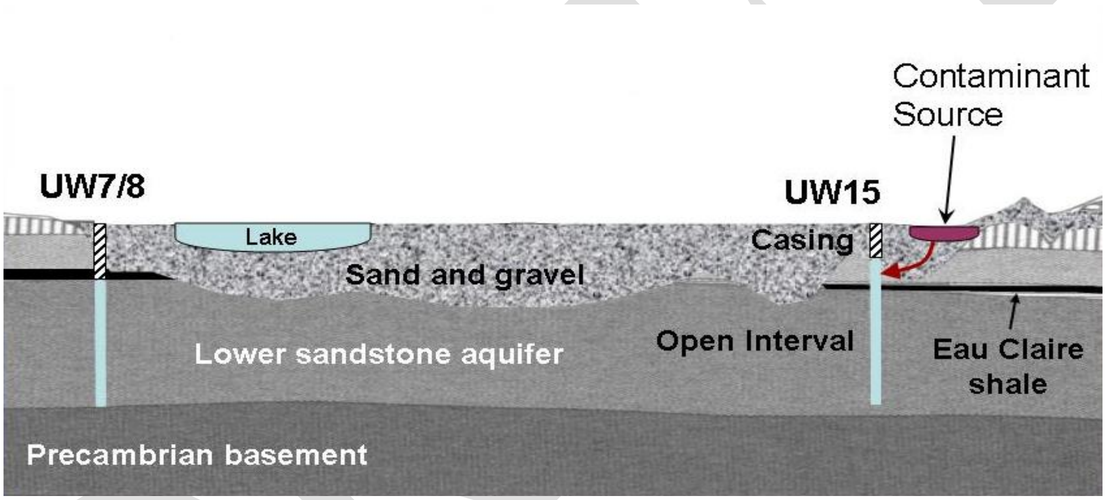


Figure 2: Conceptual Geologic Cross Section

3. FACILITY CONDITION ASSESSMENT

A comprehensive facility condition assessment of water supply, treatment, and distribution facilities was conducted in 2005. The MWU's Infrastructure Management Plan, dated November 2005, presents the results of the condition assessment and recommendations for facility improvements. In general, Unit Well No. 15 was in good condition. Recommended improvements included the replacement of the asphalt drive and parking lot and replacement of the access doors.

A facility inspection was conducted in June 2010. Construction of a new asphalt drive and parking lot was completed. The building access doors should be replaced as recommended in the 2005 Infrastructure Management Plan. The facility remains in good condition and no additional facility improvements were identified.

4. UW 15 GROUNDWATER QUALITY, TRENDS AND MITIGATION

4.1 UW 15 Water Quality and Tends

In general, the water supply from Unit Well No. 15 is of good quality. The exception, as noted above, is the presence of VOCs. Parameters of concern, and their associated concentration ranges for the period of 2008 – 2010, are presented in Table 1.

Table 1: Selected Raw Water Quality Parameters

Parameter	Concentration Range	Maximum Contaminant Level
Tetrachloroethylene (PCE)	3.1 – 3.9 µg/L	5 µg/L
Trichloroethylene (TCE)	0.33 – 0.41 µg/L	5 µg/L
Total Hardness	406 – 433 mg/L	-
Iron	0.01 – 0.04 mg/L	0.3 mg/L (Secondary MCL)
Manganese	0.0048 – 0.0128 mg/L	0.05 mg/L (Secondary MCL)

The concentration of PCE is steadily increasing and approaching the MCL of 5 µg/L. VOCs are a class of contaminants that include petroleum compounds and industrial solvents, several of which are known carcinogens. The purpose for assessing VOCs at UW15 is to determine whether there are any changes in the construction or operation of Well UW15 or changes in the vicinity of well UW15 that could eliminate or significantly delay the potential for exceeding the Maximum Contaminant Level (MCL) at UW15. This assessment considers the UW15's water quality, pumping rates, and hydrogeologic setting.

VOCs have been present since monitoring began in the late 1980s, as shown in Figure 3. Initial VOCs detected were PCE, TCE, and 1,1,1 TCA. In 1996, the TCE concentration started to decline and has leveled off at 0.33 ug/L in the last several years. This concentration is a small fraction of the 5 ug/l Maximum Contaminant Level (MCL), which is the concentration considered by the EPA acceptable for drinking water. The 1,1,1-TCA has always been low relative to its MCL (200 ug/L) and has very generally followed the TCE trend, in that it has decreased over the last decade.

The PCE concentration has an upward trend since monitoring started in November 1988. The trend is shown as three separate trend lines on Figure 3. From November 1988 through about May 1996, the PCE trend was similar to that for TCE, increasing at a relatively slow rate. From about May 1996 through October 2010, the rate of concentration increase has been slightly higher. The trend shown from 2008 through 2009 was significantly higher than the longer term trend. If this long term trend continues, PCE would exceed the 5 ug/L standard in about 2015, although if the 2008 – 2009 trend returns, the PCE could exceed the 5 ug/L standard within the next year or two.

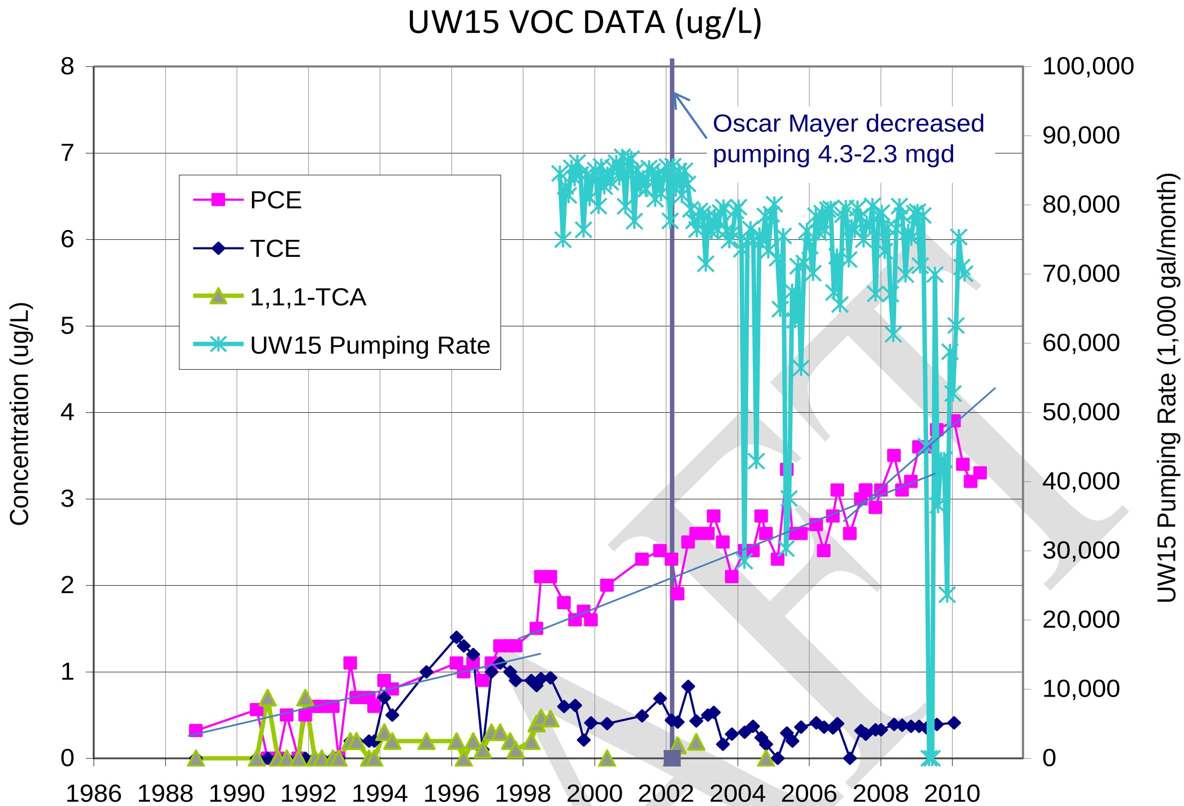


Figure 3: Volatile Organic Compound Concentrations in UW 15.

The source of the VOCs and the pumping rates at well UW 15 are important considerations in whether there is an opportunity to control the water quality at well UW 15. The presence of a group of VOCs (PCE, TCE, and 1,1,1-TCA) in the late 1980s would suggest one type of source (e.g., a metals operation that used and released various solvents) or multiple sources (e.g., a metals operation that used and released TCE and 1,1,1-TCA, and a dry cleaner that used and released PCE). The fact that the TCE has not tracked with the PCE concentrations demonstrates that at least some of the TCE is from a source other than biodegradation of the PCE.

The drop in TCE and 1,1,1-TCA, while PCE concentrations increase indicate that:

- The source of some or all of the TCE and 1,1,1-TCA has been depleted or remediated; or
- The pumping rates of wells in the area have changed to shift the capture zone of well UW15 away from the source of TCE and 1,1,1-TCA.

The acceleration in rate of PCE increase at about the same time that TCE and 1,1,1-TCA started to decline suggests that a change in pumping rate of UW 15 or a nearby well may have had an effect. The principal recent change in pumping on the east side was in 2002 when Oscar Meyer stopped pumping their wells. However, given this timing it cannot be the cause of the change in VOC trends at UW 15 in 1996.

Between 2004 and 2010, UW15 has had two periods of time of decreased pumping rate of more than one month duration, in approximately May through June 2005 and April 2009 through February 2010. During both of these periods, it appears that the PCE concentration at UW 15 increased above the long term trend line. These increases have been small (less than 1 ug/L), but they are significant with respect to the change that would exceed the MCL (i.e., from about 3 ug/L to 5 ug/L). These small increases appear to be temporary, potentially because of the short-term reduction in pumping rate.

Periods of low average pumping rates are likely to include longer periods when the pump is turned off completely. During those times, it is expected that downward flow would occur from the shallow aquifer into the lower aquifer, as seen at other wells tested in the City (e.g., the Larkin Street test well and the UW 29 sentry well). If this occurs at UW 15, PCE-contaminated water would flow from the upper aquifer to the lower aquifer when the pump is off. When the pump is turned back on, it would draw PCE from both the upper and lower aquifers, resulting in somewhat higher PCE concentrations. This condition would persist until the shallow aquifer water that flowed down the well is purged from the lower aquifer.

The increasing PCE concentration and correlation between lower pumping rate and increased PCE concentration at UW 15 would suggest that the PCE:

- Has an uncontrolled source relatively close to UW 15;
- The UW 15 casing does not extend all the way down to the Eau Claire Shale, so that the well is open to both the shallow and deep aquifers.
- Would flow into or close to UW 15 regardless of the pumping rate;
- Is entering the well from the shallow portion of the aquifer; and
- Can be diluted by pumping water from deeper zones of the aquifer.

Water quality in UW 15 reflects shallow groundwater quality, because it is drawing some groundwater from the shallow sandstone aquifer. The relatively low iron and manganese concentrations at UW 15 probably reflect shallow groundwater that is relatively aerobic (i.e., contains dissolved oxygen or nitrates) and is not sufficiently reducing to dissolve iron and manganese from the aquifer solids. This may indicate that a significant percentage of the water at UW 15 is coming from the shallow aquifer.

Results of the well construction, operation and water quality evaluation are summarized as follows:

- The geophysical log for UW 15 clearly shows the presence of the Eau Claire Shale. The source of PCE is probably from a dry cleaner or other sole use of PCE.
- The source of PCE appears to be relatively close to UW 15.
- The increasing PCE and chloride concentrations indicate a strong connection with the shallow groundwater system. This underscores the need for wellhead protection and watershed management to protect source water quality.
- Based on long term and recent concentration trends, the prediction in when PCE would exceed the 5 ug/L standard ranges from the next year or two to four years from now (i.e., in 2015).
- The rise in PCE concentration is expected to continue, at least in the near future, regardless of the pumping rate. Eventually the source of PCE may be depleted, but without remediation of the source this would take many years.

4.2 UW 15 Groundwater Quality Mitigation

As described above, it is expected that some actions will be required to maintain compliance with the 5 ug/L PCE MCL at UW 15. Modifications to the well construction or well operation may be implemented to reduce or eliminate source water from the upper aquifer, where the PCE is expected to be entering UW15. Options for groundwater management include the following:

1. Extending the well casing through the Eau Claire Shale, which would eliminate direct flow of water from the shallow aquifer, where the PCE is probably originating, into the well.
2. Minimizing the time that the UW 15 pump is off to prevent downward migration of contaminated shallow groundwater into the lower aquifer and the resulting short-term rise in PCE concentration.
3. Maintaining a relatively high average monthly pumping rate to dilute the PCE entering the well from the shallow aquifer.
4. Lowering the pump intake or installing an AquaStream or similar device to preferentially draw more water from deeper in the well.

The benefit of strategies 2, 3, and 4, to dilute the PCE-contaminated shallow aquifer water with deep aquifer water, may diminish in the long term, because PCE concentrations have been shown to be increasing over time.

Strategy 1, limiting production to only the lower sandstone aquifer, raises questions about how this well modification would affect production rates and water quality (e.g., what would the lower aquifer concentrations be for radium, iron and manganese). If the Eau Claire Shale is continuous around well UW 15, regional data suggest there is a strong likelihood that the PCE concentration would be eliminated under this strategy. However, the only data on the extent of Eau Claire Shale in this area is at UW 15. Therefore, the extent of the shale in this area is not well documented.

Based on these unknowns, it cannot be recommended, to use well casing and pumping modifications as a primary means to mitigate VOCs in UW 15 without additional information. It would be possible to conduct tests to provide additional data to evaluate the effectiveness of these well modification strategies, including confirming that the PCE is entering UW 15 from the shallow aquifer, determining the water quality of the deep aquifer, and confirming that the Eau Claire Shale has a very low permeability near UW 15. However, some uncertainty regarding the effectiveness of these well modification strategies would remain even with better information.

5. REGULATORY CONSIDERATIONS FOR WATER TREATMENT

If there is no relatively sure and short-term manner to improve groundwater quality through operation of the well, water quality improvements need to be achieved through above groundwater treatment. There are several treatment regulations that must be considered when designing a water treatment system and these are summarized below.

5.1 Best Available Technology

The U.S. Environmental Protection Agency (EPA) has designated Packed Tower Aeration and Granular Activated Carbon adsorption as the Best Available Technology (BAT) for the removal of VOCs from water supplies. Other forms of aeration have been developed since the BAT designation of the early 1990s. If alternate aeration technologies satisfy established regulatory criteria, they can be considered suitable for the removal of VOCs from drinking water supplies.

Chapter NR 809, *Safe Drinking Water* of the Wisconsin Department of Natural Resources (DNR) regulations identifies central treatment using packed tower aeration and granular activated carbon as the BAT available for achieving compliance with the MCLs for VOCs.

Chapter NR 811, *Requirements for the Operation and Design of Community Water Systems*, addresses organics removal in NR 811.48. The requirements for Packed Tower Aerators are presented in NR 811.48 (1). Of particular significance is the requirement that states "Unless waived by the department, the processes shall be designed to remove a minimum of 99 percent of the contaminant in question". Requirements for the tower, packing, and blowers are specified in this section of the regulation. The requirements for Granular Activated Carbon Filters are presented in NR 811.48 (2). In addition to specifying a maximum filtration rate of 6 gallons per minute per square foot for GAC pressure filters, the regulation requires the use of virgin GAC and stipulates design features of the carbon adsorbers.

5.2 Alternative Treatment Technology

NR 809.24 (3) states that "A public water system owner or operator may use an alternative treatment if it is demonstrated to the department, using pilot studies or other means, that the alternative treatment is sufficient to achieve compliance with the MCLs". It is under this section of the regulations that the DNR could consider the use of low profile aeration units for the removal of the VOCs in Unit Well No. 15.

5.3 Emission Thresholds – Aeration Technology

Chapter NR 445, *Control of Hazardous Pollutants*, applies to all stationary air contaminant sources which may emit hazardous contaminants. Table A of NR 445.07 specifies the emission thresholds, standards and control requirements for all sources of hazardous air contaminants. Presented in Table 2 are the specific requirements that pertain to emissions from aeration units removing PCE and TCE from drinking water supplies.

Table 2: Emission Thresholds for Sources of Specific Hazardous Air Contaminants

Contaminant	Threshold	Time Period
PCE	9.11 pounds/hour	24 hour average
	301 pounds/year	Annual
TCE	14.4 pounds/hour	24 hour average
	888 pounds/year	Annual

If the emissions from the aeration units installed at Unit Well No. 15 exceed the thresholds specified in Table 2, vapor phase treatment would be required to comply with the threshold values. This will be addressed in detail in the subsequent sections dealing with forced draft aeration and low profile aeration.

5.4 Future Regulatory Action – Tetrachloroethylene and Trichloroethylene

As part of a regulatory review required by the Safe Drinking Water Act, EPA has indicated its intention to revise the MCLs for PCE and TCE. Improvements in analytical capability, widespread occurrence in US groundwater, and health effects data that indicates both contaminants are carcinogens, are the factors influencing EPA's decision.
It is expected that in 2012, EPA will propose an MCL of 1.0 µg/L for both PCE and TCE. The revised MCLs would likely take effect in either 2014 or 2015. As such, the treatment units designed for Unit Well No. 15 should include the flexibility to achieve removal efficiencies that would facilitate compliance with the revised MCLs with minimal equipment modifications.

6. SITE LIMITATIONS

Unit Well No. 15 is located on a parcel of land that is approximately 110 feet in length and 60 feet in width (0.15 acres). The location of the well house and reservoir, standby engine generator and the parking area are depicted in Figure 4.

Each treatment option will require additional property to be purchased to accommodate the treatment building. Space requirements/limitations will be addressed in detail in the subsequent sections on treatment options.

7. OVERVIEW OF TREATMENT OPTIONS

As previously mentioned, regulatory authorities recognize forced draft aeration (such as packed tower aerators) and GAC adsorption as accepted treatment technologies for the removal of VOCs from water supplies. As such, both of these options have been considered for mitigation of the VOCs present in Unit Well No. 15.

Low profile aeration units have been demonstrated to effectively remove VOCs from water supplies. Because these units feature a compact footprint, have a lower vertical profile, and offer relative ease of maintenance, they have also been considered for treatment at Unit Well No. 15.

The following sections of this memorandum provide detailed information about conventional air strippers (forced draft aeration units), low profile aeration units, and GAC adsorbers designed specifically for Unit Well No. 15. Conceptual cost estimates (capital, operation and maintenance, and 20 year life cycle costs) have been developed for each treatment option.

8. CONVENTIONAL AIR STRIPPERS

8.1 Equipment Description and Design Parameters

Equipment drawings and budgetary equipment cost information was obtained for forced draft aeration units from an equipment vendor, WesTech, based upon the requirements to treat a flow of 2,200 gpm and achieve VOC removal efficiency of 99 percent. Given the current level of VOCs in the water from Unit Well No. 15, this would yield PCE and TCE concentrations below 0.04 µg/L in the aeration unit effluent. The information obtained from the equipment manufacturer is presented in Appendix A.

The aeration unit features an aluminum aerator housing shell with a removable bolted side panel designed for access to the aerator internals and to allow for cleaning/replacement of the Tripak media. The tower has a dedicated and standby blower with an aluminum hooded screen intake.

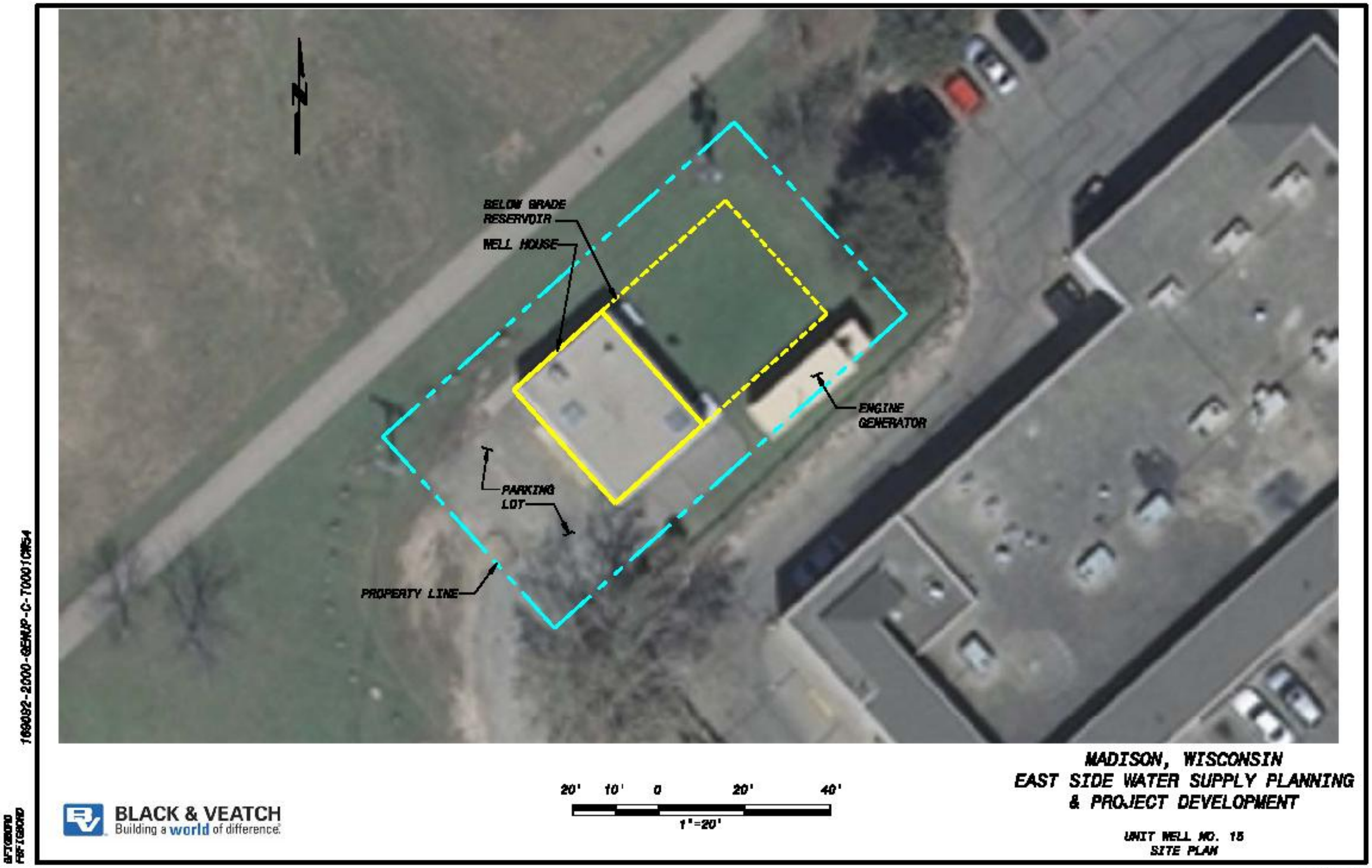


Figure 4: Unit Well No. 15 Site Plan

Tripak media is typically plastic or ceramic media that is designed to optimize the transfer of dissolved contaminants from the water column into the air stream that is forced through the aeration unit. It features a very significant amount of surface area to facilitate the transfer function. The depth of the Tripak media is a function of the amount of contaminant removal required. The higher the desired level of removal, the greater the depth of Tripak media necessary to affect the transfer function.

The forced draft aeration unit conceptual design for Unit Well No. 15 does not provide for redundant aeration units. It is anticipated that media cleaning and routine maintenance activities would not occur during peak demand periods.

Table 3 summarizes the key design elements of the WesTech forced draft aeration unit at a removal efficiency level of 99 percent.

Table 3: Forced Draft Aeration Unit Design Parameters

Parameter	
No. of Aeration Units	1
VOC Removal Efficiency	99 percent
Capacity of Aeration Unit	2,200 gpm
Hydraulic Loading Rate	24.7 gpm/sf
Air-to-Water Ratio	30:1
Dimensions of Aeration Unit	10 ft (l) x 13 ft (w) x 20 - 23 ft (h)
Media	1/2 – 1 inch Tripak
Media Height	10 – 15 feet
Forced Draft Blower Rating	6,075 scfm
Weight (filled with water)	15,000 lbs
Expected Media Cleaning Frequency	every 3-6 months

The inorganic parameters presented in Table 1, including hardness, iron, and manganese, are of significance because of their potential to impact the operation and maintenance of the forced draft aeration system by causing deposition on the media and internal structures of the treatment units. The fouling/plating potential can be reduced with the application of a phosphate-based sequestering agent that will minimize deposition on the media of the selected treatment system. However, phosphate-based sequestering agents will add undesirable phosphorous loads to the wastewater treatment system and could impact chemical stability in the water distribution system.

Without addition of a sequestering agent, provisions should be made for periodic cleaning of the Tripak media and the aerator internals. This typically consists of circulating a dilute citric acid solution throughout the media. Provision must be made for handling and disposal of the spent acid solution. Based upon information provided by the equipment vendor, it is expected that the forced draft aeration unit will require chemical cleaning at a frequency of two to four times each year. The cleaning cycle can generally be completed in one day. Given the importance of Unit Well No. 15 to the City's Zone 6 - East Service Area, it must be determined if the well can be removed from service when cleaning is required. If it is determined that the cleaning frequency would be operationally disruptive, a redundant aeration unit could be installed to maintain constant flow from the facility.

8.2 Building and Site Layout

Although the air stripper could be located outdoors above the reservoir, we understand MWU's preference is to locate the equipment in a building. A conceptual building plan and section is depicted in Figure 5. A conceptual site plan is depicted in Figure 6. As indicated on the site plan, additional property would need to be acquired to accommodate the building.

8.3 Operational Impacts

The installation of a conventional air stripper at the Unit Well No. 15 site would subject the well pump would to additional static and dynamic head resulting in a reduction in capacity. The static and dynamic head associated with installation of the conventional air strippers will reduce the capacity of the pumping unit by approximately 550 gpm. Therefore, the well capacity will be reduced from 2,200 gpm to approximately 1,650 gpm (25 percent reduction). The well pump efficiency will also be reduced from 84 percent to 80 percent.

The reduced capacity of the well pump (1,650 gpm) will be less than the capacity of the booster pump (2,000 gpm). To maintain the capacity of Well No. 15, pump modifications (Installation of additional stages and replacement of the motor) or replacement of the pumping unit would be required. A pump characteristic curve, which depicts the operational impacts associated with the installation of a conventional air stripper, is included in Appendix B.

8.4 Off-Gas Treatment

As summarized in Table 2, the Wisconsin DNR has established hourly and annual threshold values for sources of specific hazardous air contaminants. In the case of Unit Well No. 15, the aeration units would be venting the PCE and TCE that was removed from the water column to the atmosphere.

In order to determine if vapor phase treatment of the aeration unit off-gases would be necessary, the daily and annual volume of PCE and TCE released to the atmosphere was calculated, expressed in pounds per hour and pounds per year, respectively. The basis for the calculated PCE and TCE emission values was 100 percent removal of raw water concentrations of 4 µg/L of PCE and 0.4 µg/L of TCE at a flow rate of 2,200 gpm.

The calculated values, compared to the DNR emission threshold limits, are presented in Table 4.

8.5 Protection of Air Used in the Air Stripper

The design will need to consider that only clean air is used in the air stripper. The WDNR requires that 1)the air inlet is installed in a protected location and 2) The air inlet to the blower and the tower discharge vent is screened and provided with a downturned, hooded or mushroom cap to protect the screen from the entrance of extraneous matter including insects and birds, obnoxious fumes, all types of precipitation and condensation, and windborne debris or dust. The air inlet shall also be provided with a dust filter.

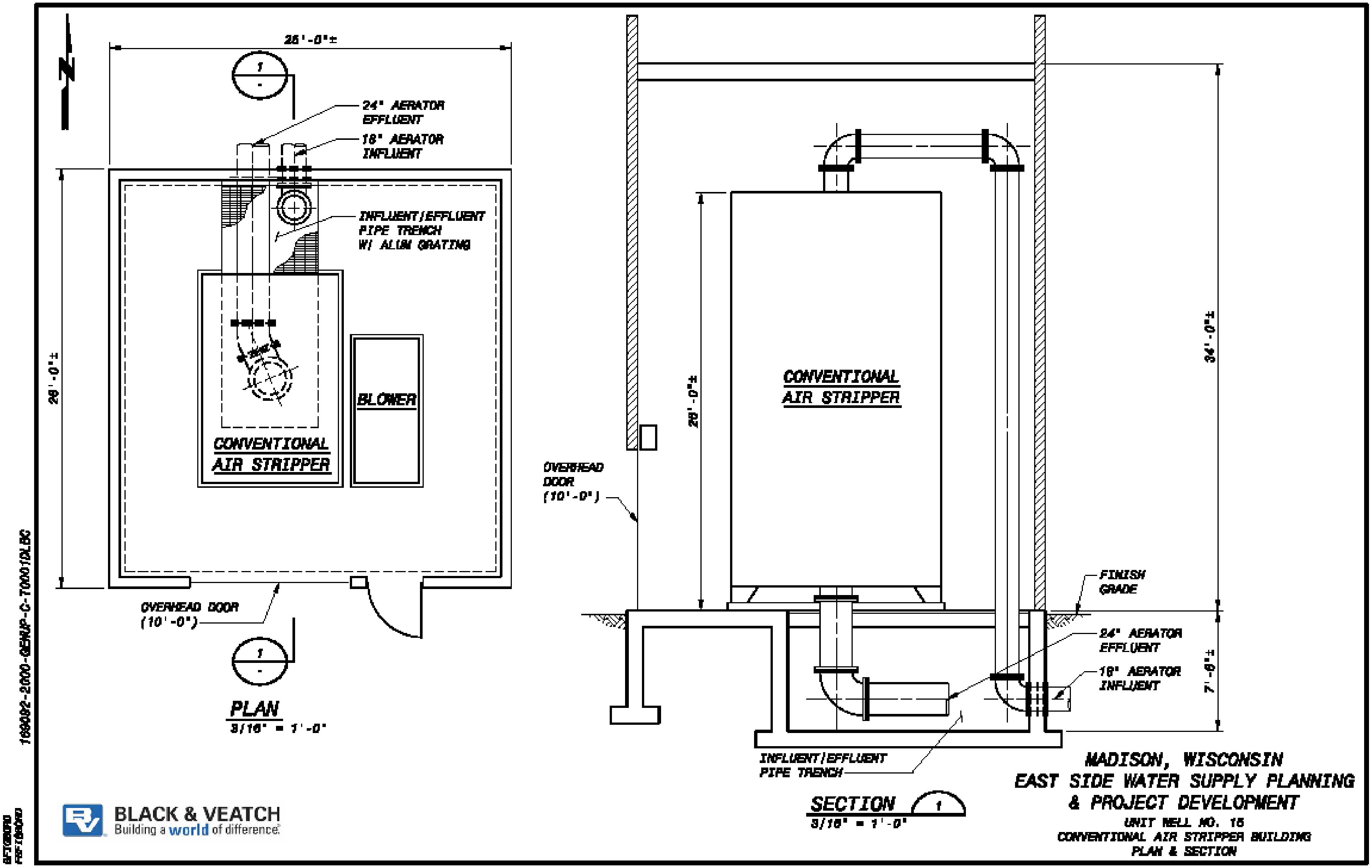
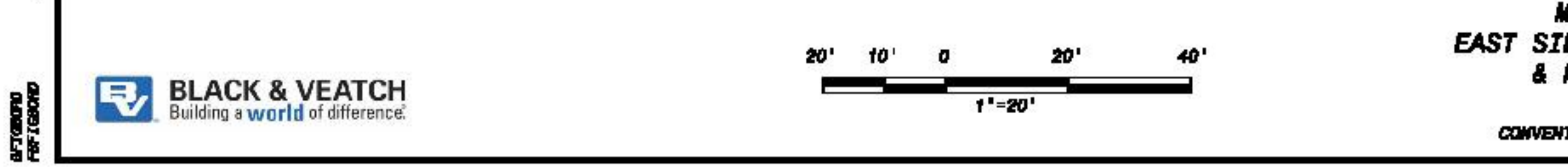


Figure 5: Conventional Air Stripper - Building Plan & Section



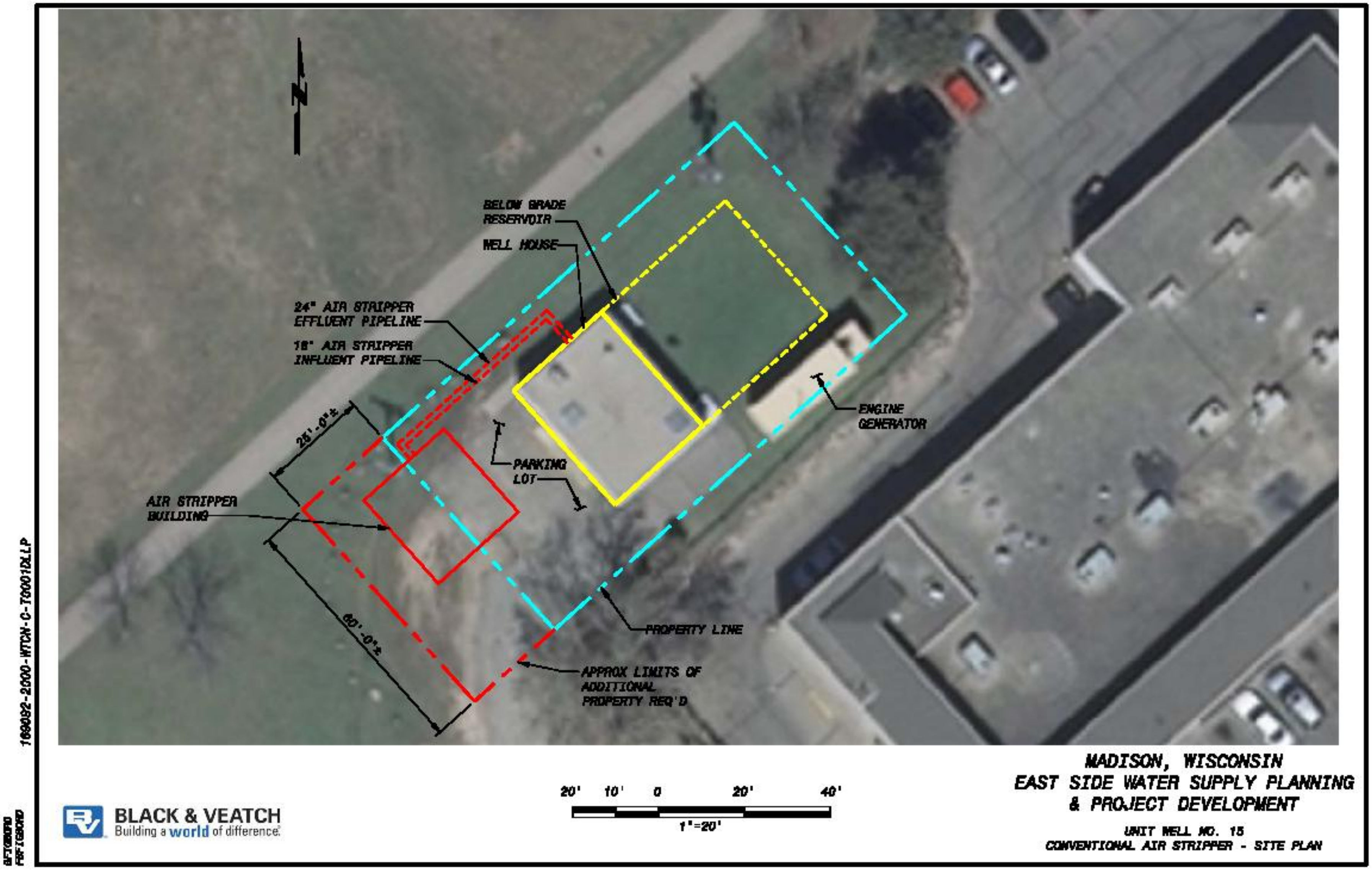


Figure 6: Conventional Air Stripper - Site Plan

Table 4: Calculated Aerator Emission Volumes

Contaminant	DNR Emission Threshold	Calculated Volume Emitted
PCE	9.11 pounds/hour	0.0030 pounds/hour
	301 pounds/year	26.75 pounds/year
TCE	14.4 pounds/hour	0.00030 pounds/hour
	888 pounds/year	2.67 pounds/year

As indicated in Table 5, the VOC emissions from the forced draft aerator would be substantially below both the hourly and annual emission threshold limits for both PCE and TCE. Therefore, vapor phase treatment of off-gas emissions will not be required by the DNR.

Although the DNR will not require the treatment of the VOC airstream emitted from the forced draft aerator, vapor phase GAC adsorption could be used to treat the aerator emissions. VOCs are removed from the airstream using a GAC adsorption unit which would operate at a pressure of approximately 28 inches with a loading rate of 50 scfm/ft2. The GAC adsorption unit would have dimensions of 11 ft. x 11 ft. x 7 ft for a square contactor.

The estimated installed capital cost for a vapor-phase GAC adsorption unit is $170,000 (Excludes building cost). Operating expenses would include the cost for replacement GAC, regeneration of the spent GAC, and cleaning of the adsorption vessel at the time of GAC replacement.

Another item to consider, relative to emissions from the aeration units, is the possibility that the raw water concentrations of PCE and TCE would increase over time. Given the uncertainty of the source of contamination, this is a distinct possibility. As such, the raw water concentration of PCE and TCE that would trigger the DNR requirement for vapor phase treatment was calculated. The trigger value used in this calculation was the annual threshold, as this is the more conservative of the emission threshold requirements. In the case of PCE, the raw water concentration would have to increase to approximately 41µg/L to trigger the requirement for off-gas treatment. For TCE, the raw water concentration would be approximately 91 µg/L.

9. LOW PROFILE AERATION

9.1 Equipment and Design Parameters

Low profile aeration units, which are based upon a cascading tray aeration concept, are becoming more prevalent in the water supply industry due to their compact design and ease of maintenance of the internal trays.

Equipment drawings and budgetary cost information was obtained for low profile aeration units from QED Environmental Systems, a company with numerous installations of low profile aeration units throughout the United States. The low profile unit conceptual design was based upon the requirements to treat a flow of 2,200 gpm and achieve a VOC removal efficiency of 99 percent. Given the current level of VOCs in the water from Unit Well No. 15, this would yield PCE and TCE concentrations below 0.04 µg/L in the aeration unit effluent.

The low profile aeration unit conceptual design for Unit Well No. 15 does not provide for redundant aeration. It is anticipated that media cleaning and routine maintenance activities would not occur during peak demand periods.

The information obtained from QED Environmental Systems is presented in Appendix A.

Two low profile units would be required to treat 2,200 gpm. Each aeration unit features a dedicated blower, a standby blower, and a stainless steel aerator housing with an internal 4 tray configuration. Table 5 summarizes the key design elements of the low profile aeration units that yield a removal efficiency level of 99 percent.

Table 5: Low Profile Aeration Unit Design Parameters

Parameter	
No. of Aeration Units	2
VOC Removal Efficiency	99 percent
Capacity of Each Unit	1,100 gpm
Hydraulic Loading Rate	3.4 gpm/sf
Air-to-Water Ratio	3.9 cfm/gpm
Dimensions of Aeration Unit	8.5 ft (l) x 12 ft (w) x 8.5 ft. (h)
Number of Trays per Unit	4
Forced Draft Blower Rating	5,200 scfm
Weight (filled with water)	22,000 pounds per unit
Expected Tray Cleaning Frequency	every 3 to 6 months

Because of the elevated hardness concentration in the water from Unit Well No. 15, provisions should be made for periodic cleaning of the trays and aerator internals. This typically consists of removal of the front door of the unit and pressure washing of the trays. The trays can either be pressure washed in place or removed and washed in a location with ready access to a drain. Alternatively, a dilute citric acid solution can be circulated in each unit. This requires the proper handling and disposal of the spent acid solution.

Based upon information provided by the equipment vendor, it is expected that the low profile aeration units will require cleaning at a frequency of two to four times each year. The cleaning cycle can be completed in less than one day. Given the importance of Unit Well No. 15 to the City's Zone 6 - East Service Area, it must be determined if the well can be removed from service when cleaning is required. If it is determined that the cleaning frequency would be operationally disruptive, a redundant aeration unit could be installed to maintain constant flow from the facility.

9.2 Building and Site Layout

Although the air strippers could be located outdoors above the reservoir, it is our understanding that MWU's preference is to locate the equipment in a building. A conceptual building plan and section is depicted in Figure 7. A conceptual site plan is depicted in Figure 8. As indicated on the site plan, additional property would need to be acquired to accommodate the building.

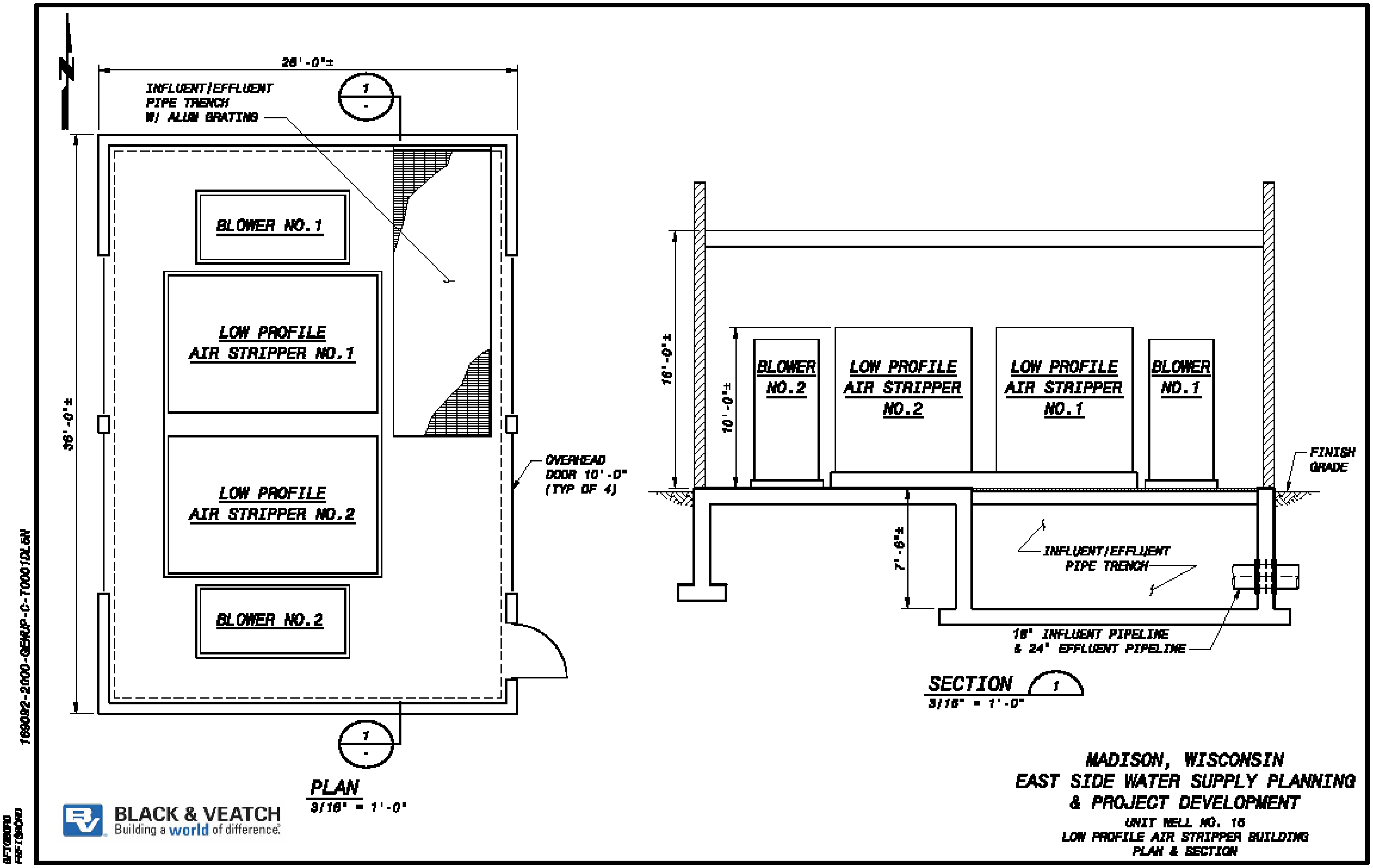


Figure 7: Low Profile Air Stripper - Building Plan & Section

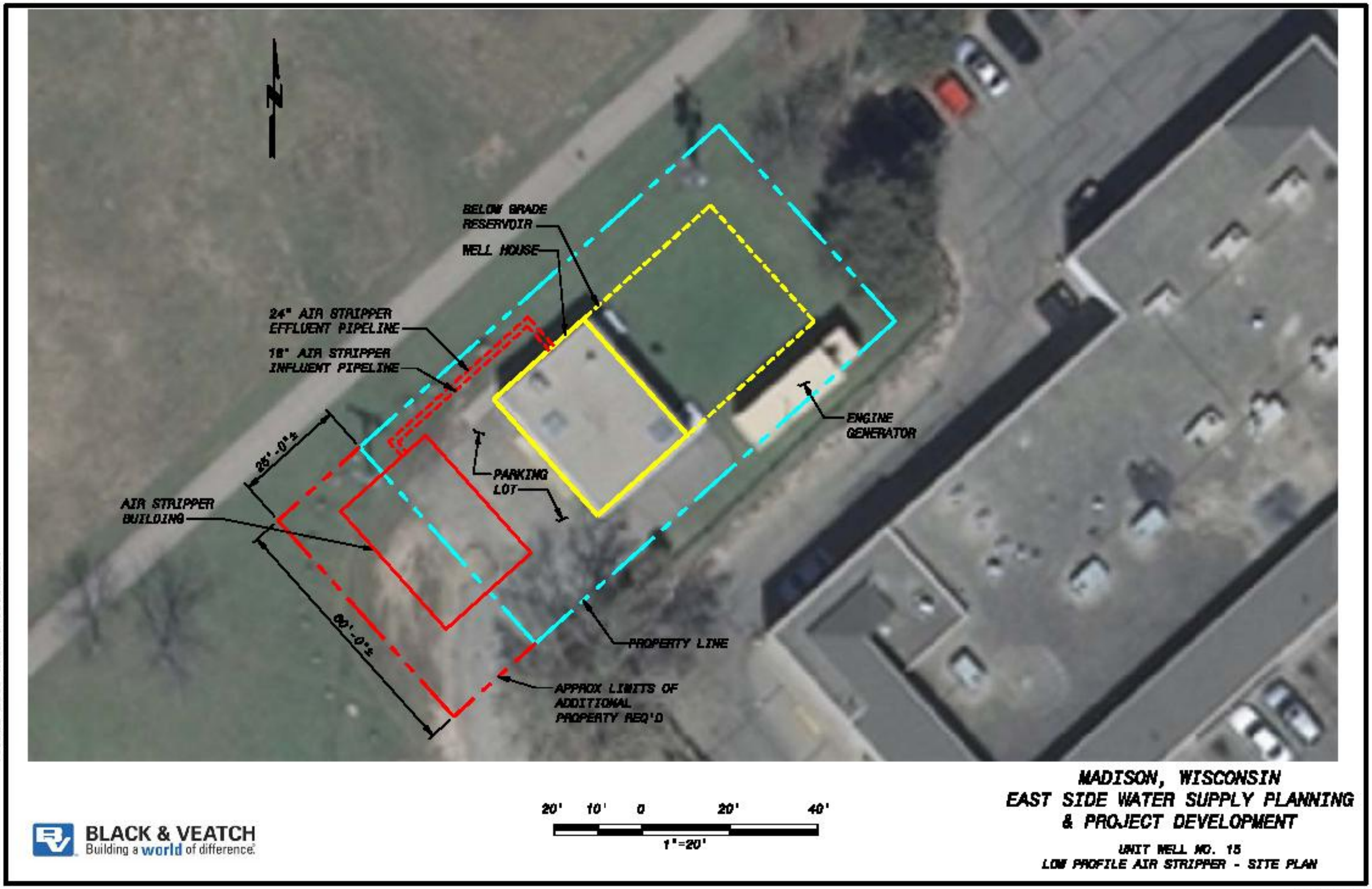


Figure 8: Low Profile Air Stripper - Site Plan

9.3 Operational Impacts

The installation of a low profile aerator at Unit Well No. 15 site would subject the well pump to additional static and dynamic head losses resulting in a reduction in capacity. The following paragraphs address each of these items. The static and dynamic head associated with installation of the low profile aeration units would reduce the capacity of the pumping unit by approximately 200 gpm. Therefore, the well capacity will be reduced from 2,200 gpm to approximately 2,000 gpm (9 percent reduction). The well pump efficiency will also be reduced from 84 percent to 83 percent.

The reduced capacity of the well pump (2,000 gpm) will be approximately equal to the capacity of the booster pump (2,000 gpm). To maintain the capacity of Well No. 15, it is likely that pump modifications (installation of additional stages and replacement of the motor) or replacement of the pumping unit would be required. A pump characteristic curve, which depicts the operational impacts associated with the installation of the low profile aerators, is included in Appendix B.

9.4 Off-Gas Treatment

The discussion of off-gas treatment for the low profile aeration units is the same as was presented for the forced draft aeration units.

10. GRANULAR ACTIVATED CARBON ADSORPTION

GAC Adsorption is a very effective mechanism for removal of the VOCs that are present in the raw water from Unit Well No. 15. Equipment drawings and budgetary cost information for GAC adsorbers was obtained from Siemens and WesTech, based upon the requirements to treat a flow of 2,200 gpm and achieve a VOC removal efficiency of 99 percent. Given the current level of VOCs in the water from Unit Well No. 15, this would yield PCE and TCE concentrations below 0.40 µg/L in the GAC adsorber effluent.

Table 6 summarizes the key design elements of the GAC adsorbers as provided by the contacted vendors.

Table 6: GAC Adsorption Unit Design Parameters

Parameter	Siemens	WesTech
No. of Adsorption Vessels	2	3
Capacity of Each vessel	1,100 gpm	733 gpm
Empty Bed Contact Time	7.5 minutes/vessel	13.6 minutes/vessel
Design Loading Rate	3.0 gpm/sf	5.9 gpm/sf
Dimensions of each Vessel	12 ft. diameter; 19 ft. height	12 ft. diameter; 16 ft. height
Vessel Carbon Capacity	30,000 pounds GAC	40,000 pounds GAC
Vessel Weight (filled with GAC and water)	120,000 pounds	Undetermined
Expected Media Replacement Frequency	1.6 years	Undetermined

Although Siemens and WesTech proposed the use of two and three vessels respectively, an additional vessel may be necessary in order to allow for occasional backwashing or “fluffing” of the GAC media while maintaining full capacity from the Unit Well No. 15 facility. An additional

GAC adsorption unit would not be required if backwashing operations could occur during off peak demand periods without adversely affecting operations.

The GAC contactors must be housed within a building in order to protect them from the elements (freezing temperatures). As such, a building with the dimensions of 54 feet in length by 24 feet in width is necessary to house the GAC vessels. As depicted in Figure 9, the site area would limit the construction of a building to accommodate the GAC adsorption vessels without property acquisition. The site limitations, coupled with a conceptual capital cost that is approximately 3.5 to 6 times higher than aeration technology, eliminate GAC adsorption from consideration as a viable treatment technology at Unit Well No. 15.

11. CONCEPTUAL OPINION OF PROBABLE PROJECT AND LIFE CYCLE COSTS

The following paragraphs present the conceptual opinion of probable costs for forced draft aeration and low profile aeration at Unit Well No. 15. The costs include the budgetary equipment costs provided by the vendors, costs associated with upgrades to the site and existing facilities to accommodate the treatment systems, operation and maintenance costs, and 20-year life cycle costs.

11.1 Conventional Air Strippers

Table 7 depicts the estimated capital costs associated with a forced draft aeration system with a capacity of 2,200 gpm that will achieve a removal efficiency of 99 percent. Should it be necessary to incorporate vapor phase treatment of off-gases, it is expected that this will increase the installed capital cost by approximately $170,000 for each system.

Table 7: Conceptual Opinion of Probable Project Costs Conventional Air Strippers

Description	Conceptual Opinion of Probable Project Costs
Building, piping and valves	$610,000
Equipment	$250,000
Polyphosphate storage and feed system (Recommended, but optional)	$25,000
Vertical Diffusion Vane Well Pump	$125,000
Administrative, Engineering, and Legal	$150,000
Contingency (Approx. 25%)	$290,000
Estimated Total Project Cost	**$1,450,000**

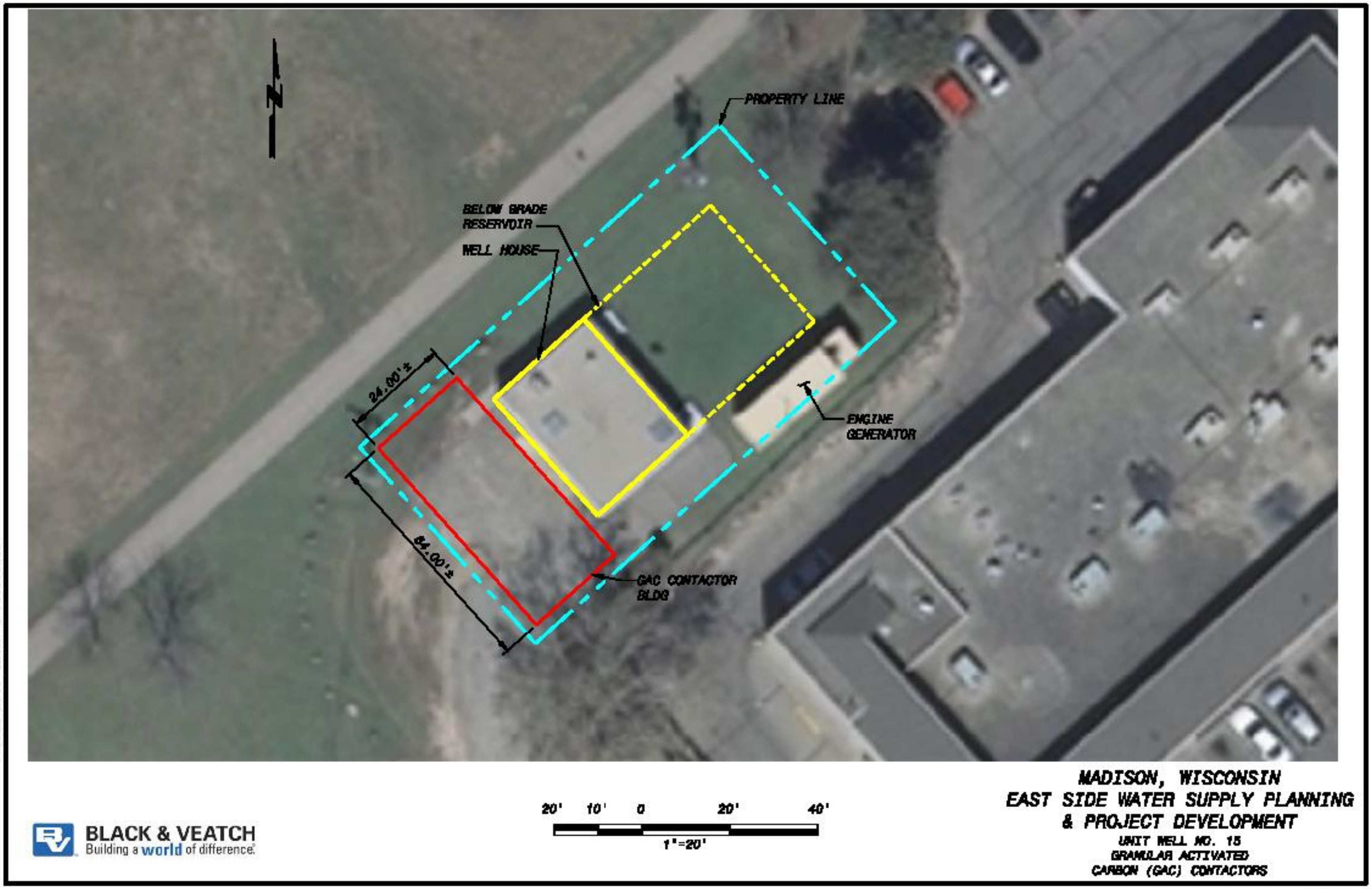


Figure 9 Granular Activated Carbon (GAC) Contactors

Table 8 depicts the estimated annual operation and maintenance costs for the conventional air stripper systems.

Table 8: Operation and Maintenance Cost Conventional Air Strippers

Description	Conceptual Opinion of Probable Annual Costs
Maintenance	$10,000
Electrical	$11,500
Chemicals	$1,500
Estimated Total	**$23,000**

11.2 Low Profile Aeration

Table 9 depicts the estimated capital costs associated with a low profile aeration system with a capacity of 2,200 gpm that will achieve a removal efficiency of 99 percent. Should it be necessary to incorporate vapor phase treatment of off-gases, it is expected that this will increase the installed capital cost by approximately $170,000 (Excludes building cost).

Table 9: Conceptual Opinion of Probable Project Costs Low Profile Aeration System

Description	Conceptual Opinion of Probable Project Costs QED Environmental Systems
Building, piping and valves	$615,000
Equipment	$675,000
Polyphosphate storage & feed system (Recommended, buy optional)	$25,000
Vertical Diffusion Vane Well Pump	$125,000
Administrative, Engineering, and Legal	$215,000
Contingency (Approx. 25%)	$415,000
Estimated Total Project Cost	**$2,070,000**

Table 10 depicts the estimated annual operation and maintenance costs for the low profile aeration system.

Table 10: Operation and Maintenance Cost Low Profile Aeration System

Description	Conceptual Opinion of Probable Annual Costs QED Environmental Systems
Maintenance	$10,000
Electrical	$9,000
Chemicals	$1,500
Estimated Total	**$20,500**

11.3 20-Year Life Cycle Costs

Presented in Table 11 are the 20-Year Life Cycle Cost Estimates for the conventional air stripper system and the low profile aeration system. An annual interest rate of four percent was used to calculate the 20-Year estimates.

Table 11: 20-Year Life Cycle Cost Estimates Forced Draft and Low Profile Aeration Systems

Aeration System	20-Year Life Cycle Cost Estimate
Conventional Air Stripper	$1,765,000
Low Profile Aeration System	$2,350,000

12. EVALUATION SUMMARY

Methods for managing groundwater sources together with three alternative treatment technologies were evaluated for removal of volatile organic compounds (VOC) at Unit Well No. 15. The treatment technologies included conventional air strippers, low-profile air strippers and granular activated carbon (GAC) adsorption units.

Groundwater management alternatives for reducing VOCs in UW 15 were not recommended due to the potential of unexpected outcomes such as an increase in radium, iron or manganese concentrations, or loss of water production rate.

Considering the site space limitations, GAC adsorption units are not considered a viable alternative for treatment at Unit Well No. 15. The use of conventional and low-profile air stripper units are both considered viable treatment options.

The height of the building required to accommodate conventional forced draft and low profile aerators is approximately 34 ft. and 16 ft., respectively. From an aesthetics standpoint, the use of low profile units will be less obtrusive.

The water hardness, iron and manganese concentrations will cause deposition on the conventional air stripper media and the low profile air stripper trays. Frequent cleaning of the media or trays will be required. Feeding a sequestering agent upstream of the equipment is recommended to reduce the cleaning frequency. It will be difficult to clean the Tripak media in a conventional air stripper. If the media is not effectively cleaned, the frequency of cleaning activities will increase. The design of the low profile air strippers facilitate a simplified and effective cleaning process.

The conceptual opinion of probable project cost and 20-year life cycle cost for a conventional air stripper is $1,450,000 and $1,765,000, respectively. The conceptual opinion of probable project cost and 20-year life cycle cost for low profile air strippers is $2,070,000 and $2,350,000, respectively.

The conceptual opinion of probable project cost would be approximately $620,000 lower for conventional air strippers. In addition, the estimated 20-year life cycle cost would be approximately $585,000 lower for conventional air strippers.

APPENDIX A

Equipment Information

APPENDIX B

Well Pump Characteristic Curves

APPENDIX C

Conceptual Opinion of Probable Construction Cost