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UNIT WELL 15 – VOLATILE ORGANIC COMPOUND (VOC) MITIGATION

Madison Water Utility
Madison, Wisconsin

Black & Veatch Corporation
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DRAFT

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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 VOC removal at UW 15.
- Make recommendations to the MWU regarding the need to consider future treatment for iron and manganese treatment and radium treatment.

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 rated 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.

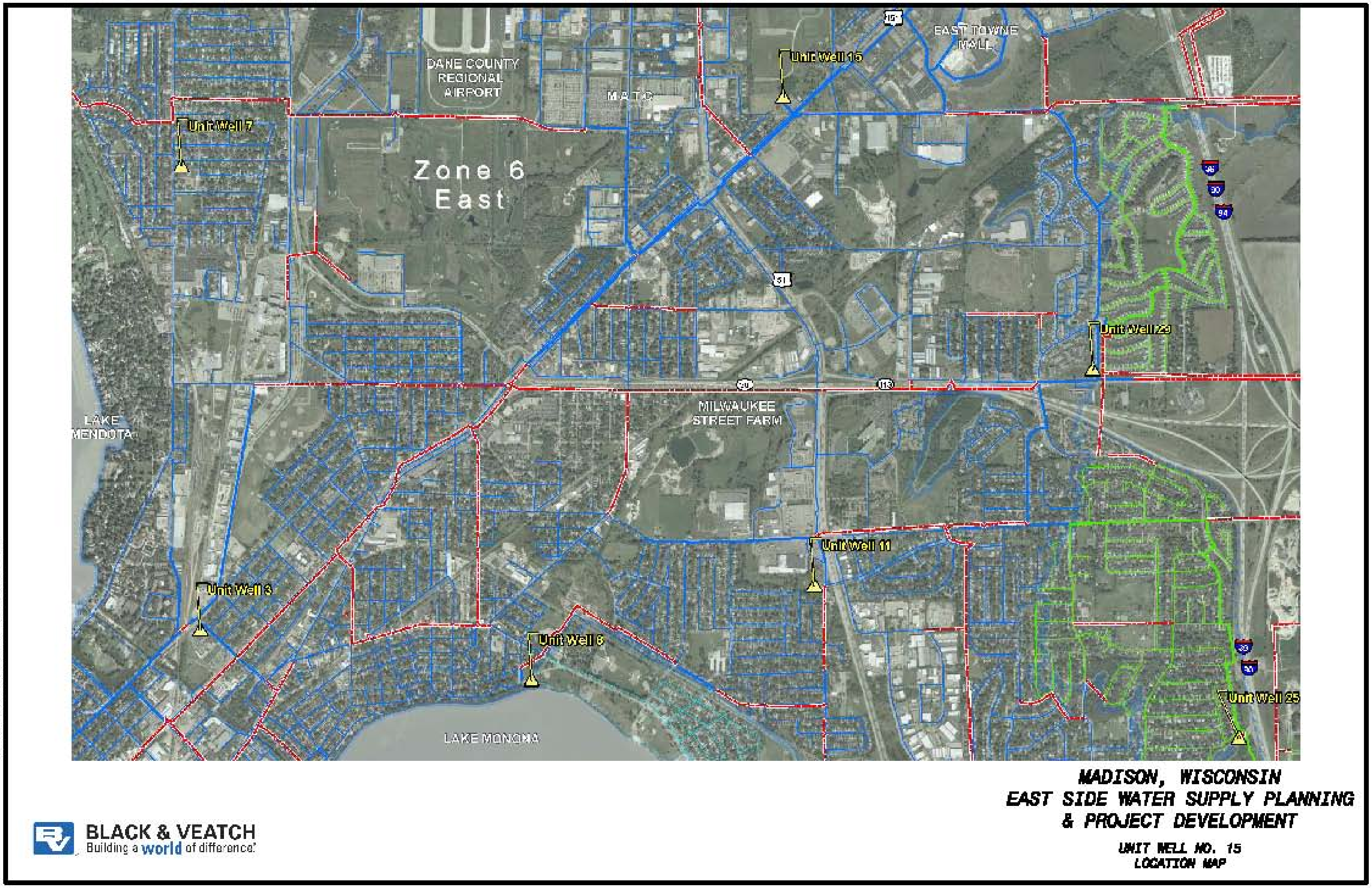


Figure 1: Unit Well No. 15 Location Map

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.

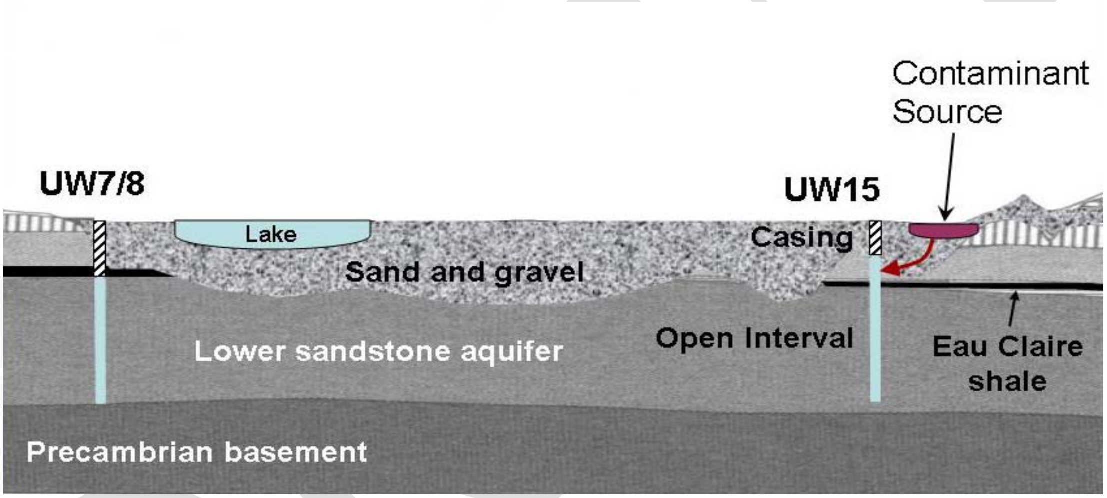


Figure 2: Conceptual Geologic Cross Section

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 is 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. Combined radium and iron and manganese are well below the Maximum Contaminant Levels (MCL). 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.

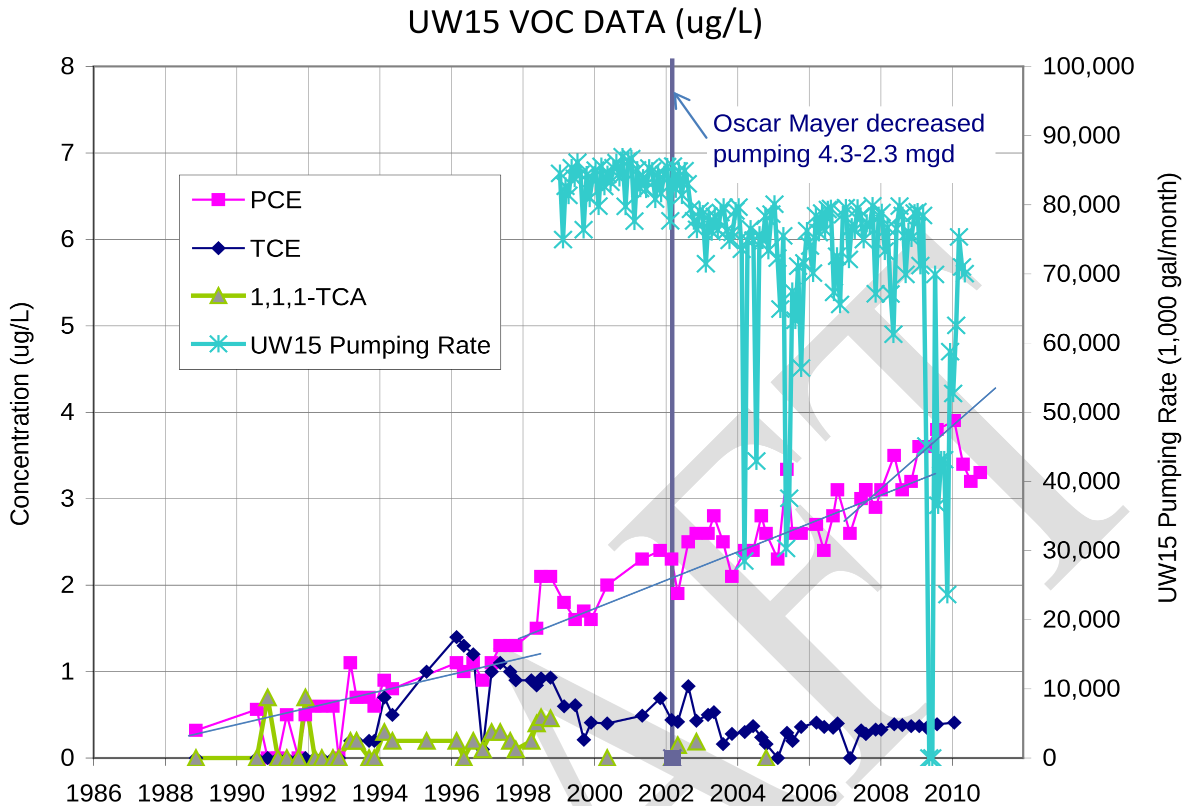
Table 1: Selected Raw Water Quality Parameters (2008 to 2010)

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)
Combined Radium	1.40 +/- 0.63 pCi/L	5 pCi/L

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.

Figure 3 indicates VOCs have been present in Well 15 since monitoring began in the late 1980s.. Initial VOCs detected were PCE, TCE, and 1,1,1 TCA. In 1996, the TCE concentration started to decline and in the last several years has leveled off at 0.33 ug/L. 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. Furthermore, as discussed in Section 5.4, the U.S.EPA is considering reducing the MCL for PCE to 1 ug/l.

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. A list of potential contaminant sources in the vicinity of UW-15 is listed in Madison Water Utility's Well Head Protection Program for UW-15.

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 a 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.

Radium levels in UW 15 are significantly below the 5 pCi/L standard. This is also indicative of groundwater from the shallow aquifer. Modifications to the well or well operation could increase water draw from the deeper aquifer, which may increase radium levels.

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 because there are no degradation products associated with PCE that typically occur after longer travel times in the groundwater
- The increasing PCE concentrations indicate a strong connection with the shallow groundwater system. This underscores the need for maintaining the existing 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 as early as 2012 to 2016..
- Within knowing the magnitude or location of the source of PCE, future concentrations of PCE in Unit Well 15 are difficult to predict.

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. Install a variable speed pump to minimize 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. 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, and 3, 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, could reduce production rates and decrease water quality (e.g., increase 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 greatly reduced 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.

Without better data regarding the magnitude and location of the PCE source, the vertical distribution of VOCs in the groundwater, and the extent of the shale around UW 15, it is difficult to recommend a groundwater management strategy. A good groundwater management strategy may decrease the overall cost and/or duration required for groundwater treatment. To make a better recommendation for a groundwater management strategy, three actions would be required. First, there needs to be an investigation into the soil and groundwater around UW 15 to determine the location and magnitude of the PCE source. This can be done through a limited number of soil borings and monitoring wells. Second, vertically discreet sampling of UW 15 would have to be completed to determine how much flow and the quality of the groundwater that is coming from the shallow aquifer. Third, the relative extent of shale around UW 15 needs to be better assessed. With this data, a more definitive groundwater management strategy could be determined.

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 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 Technoloies (BAT's) 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 811.53. The requirements for Packed Tower Aerators are presented in NR 811.53 (2). 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 811.53 (3). 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.

The specific requirements that pertain to emissions from aeration units removing PCE and TCE from drinking water supplies are presented in Table 2.

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 indicated in NR 811, treatment processes for removal of PCE and TCE will be designed to removal a minimum of 99 percent of the contaminants. As such, the treatment units designed for Unit Well No. 15 will provide compliance with the anticipated 1 ug/l limit.

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.

Some treatment facility configurations may require additional property to be purchased to accommodate the treatment building. Additional space requirements should be considered to accommodate future treatment components, if needed. Space requirements/limitations will be addressed 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 were 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.

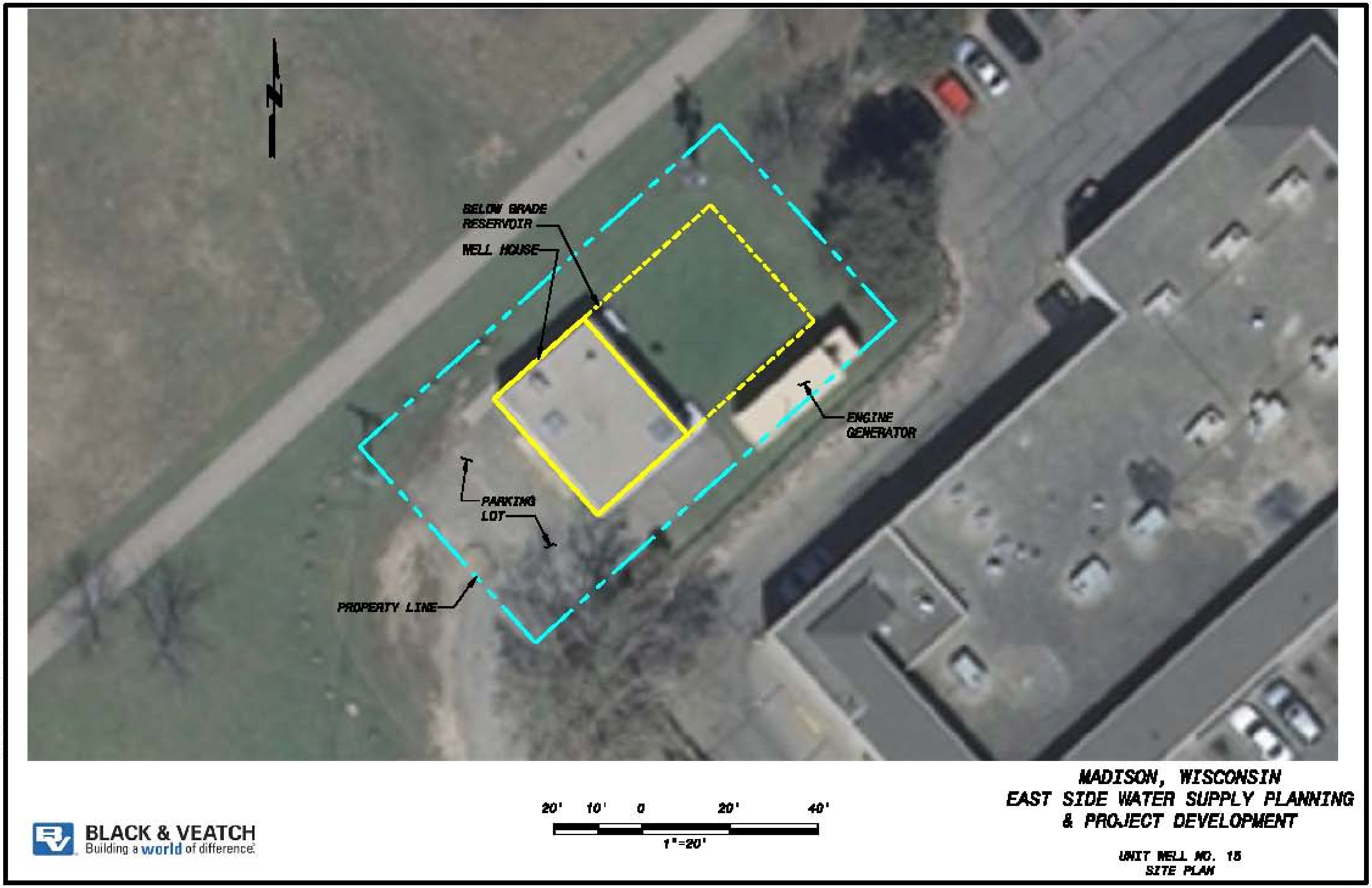


Figure 4: Unit Well No. 15 Site Plan

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.

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	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 significant 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. Therefore, sequestering agents are not recommended.

Provisions should be made for periodic cleaning of the Tripak media and the aerator internals to address periodic fouling. 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 or two 1,000 gpm air aeration units could be installed so that at least half of the Unit Well No. 15 capacity would be available.

8.2 Building and Site Layout

The air stripper will be located in a building to lessen visual impact and for ease of maintenance. There are two feasible locations for a treatment system - southwest of the existing building, in the current parking lot, and northwest of the existing building, which would be on top of the reservoir. The first option would require additional property acquisition but would be easier to construct. The second option could feasibly be built without property acquisition but the construction would be more complicated given the need to support the building on top of the reservoir and the need to work around the existing engine generator. conceptual building plan and section is depicted in Figure 5. A conceptual site plan is depicted in Figure 6 with the new building shown southwest of the existing building, which is the assumed option for this evaluation.

8.3 Operational Impacts

The installation of a conventional air stripper at the Unit Well No. 15 site would subject the well pump to additional static and dynamic head resulting in a reduction in capacity of approximately 550 gpm. Therefore, the well pump will be upgraded to meet required head and capacity. The installation of a variable speed drive will also be considered. 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. Based on the current VOC levels and removal efficiency, no off gas treatment is required.

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

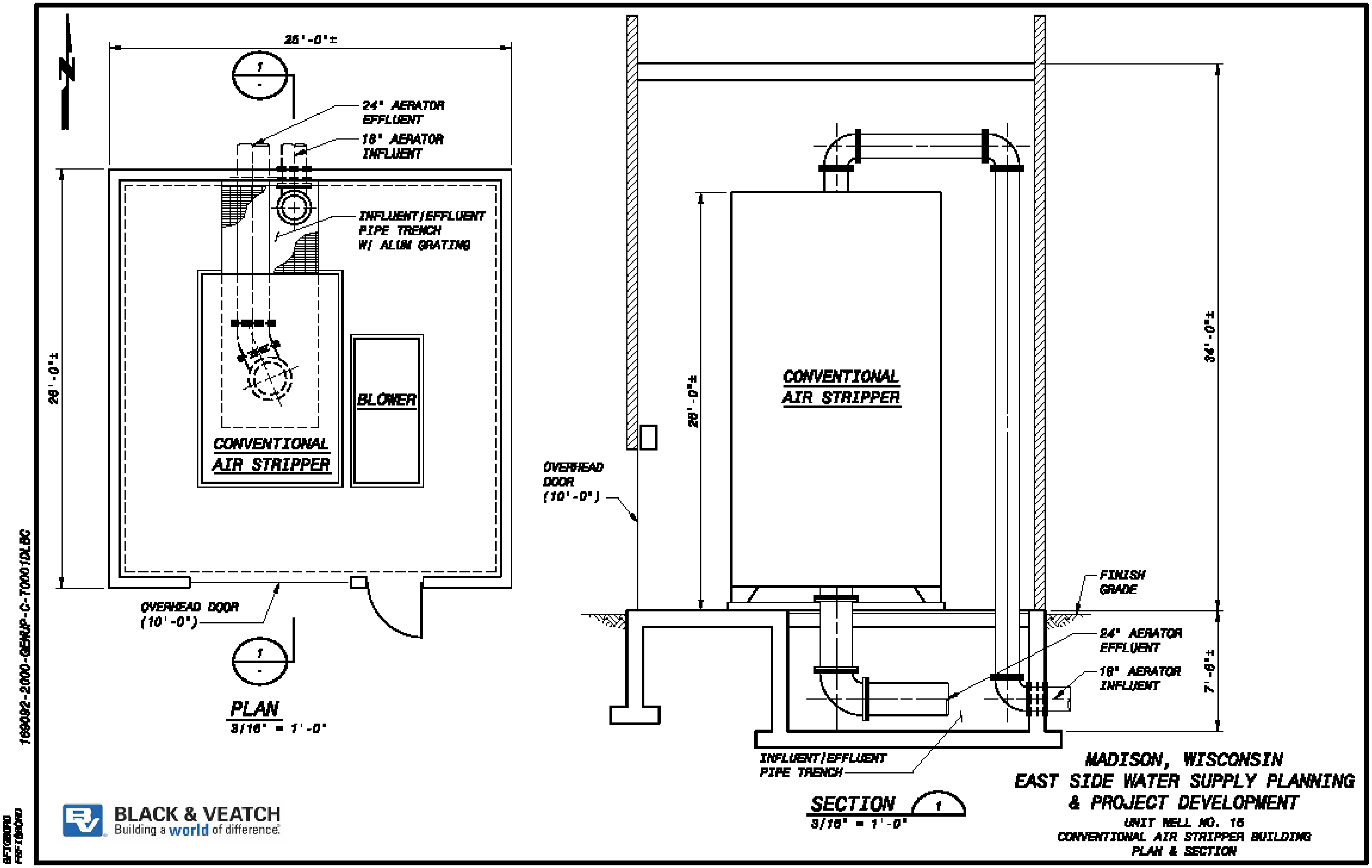


Figure 5: Conventional Air Stripper - Building Plan & Section

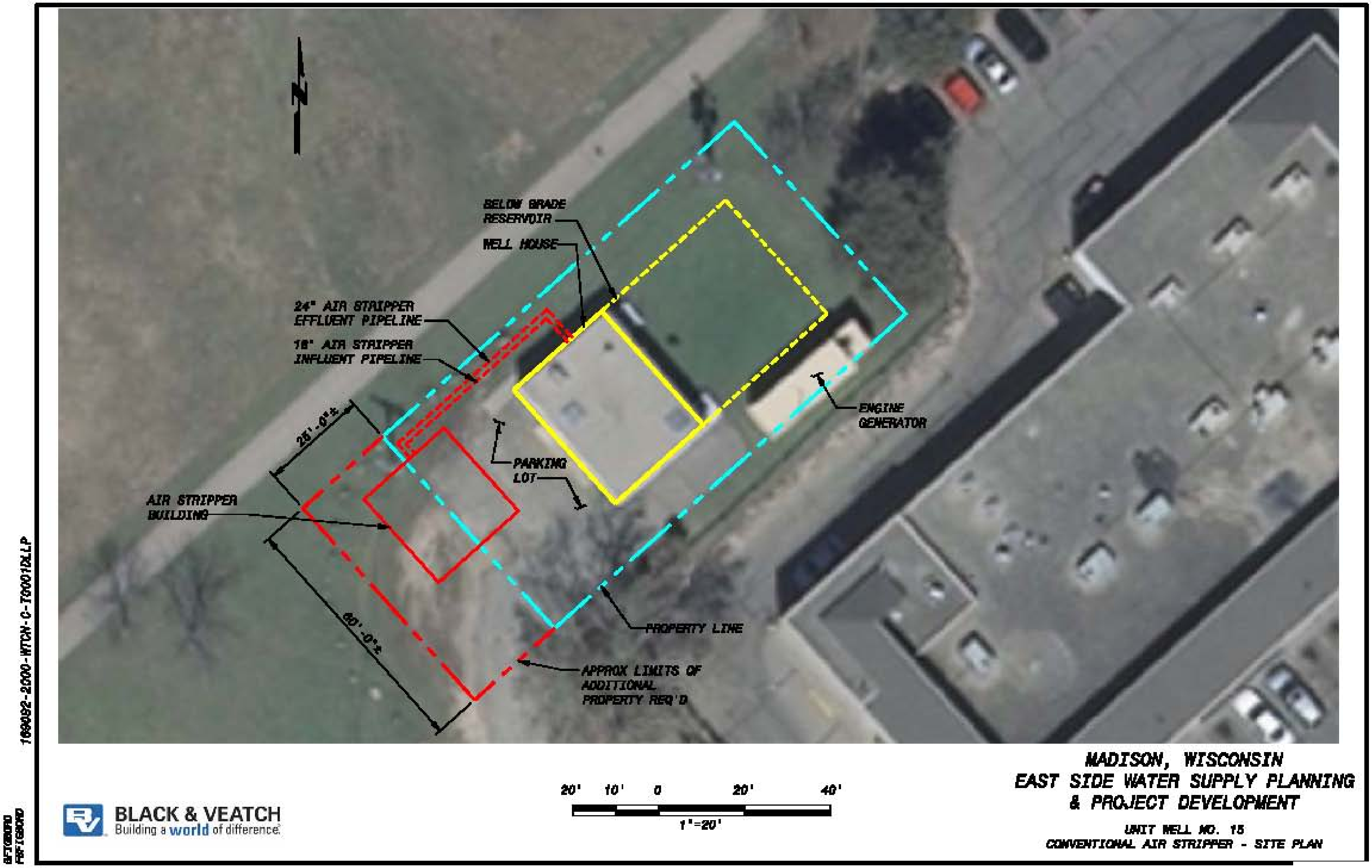


Figure 6: Conventional Air Stripper - Site Plan

Although the DNR will not require the treatment of the VOC airstream emitted from the forced draft aerator, vapor phase activated carbon adsorption could be used to treat the aerator emissions. For such a case, the offgas from the air stripper would be routed to two vapor phase carbon units operating in parallel. Each unit would have an approximately 8-foot by 10-foot foot print. The offgas would be heated to reduce the relatively humidity to less than 50% so that moisture from the offgas would not condense on the activated carbon. The building size would also be increased by approximately 50% to accommodate the vapor phase treatment system.

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. 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. Given the long-term monitoring results showing very gradual increases over time, it is very unlikely that PCE concentrations in the groundwater would increase to a level where off gas treatment is required.

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.

8.6 Conceptual Opinion of Probable Project and Life Cycle Costs

Table 5 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. A detailed breakdown of costs is presented in Appendix A. The costs include the budgetary equipment costs provided by vendors, building costs, and costs associated with upgrades to the site and existing facilities to accommodate the treatment systems. Costs do not include a redundant unit to facilitate cleaning.

Table 5: Conceptual Opinion of Probable Project Costs Conventional Air Strippers

Description	Conceptual Opinion of Probable Project Costs
Building (Complete and allowance for modifications to reservoir piping)	$720,000
Packed Tower (Installed)	$180,000
Vertical Diffusion Vane Well Pump	$125,000
Contingency (20%)	$200,000
Engineering/Legal/Admin	$200,000
Estimated Total Project Cost	**$1,425,000**

Should it be necessary to incorporate vapor phase treatment of off-gases, it is expected that this will increase the installed capital cost by the following amount:

- Increase Building Costs - $350,000
- Vapor Phase Carbon Treatment System (2 units) - $80,000
- Piping/Heaters/Controls - $150,000
- Engineering - $30,000
- Total of $610,000

There would also be increased operational costs associated with heating the offgas to reduce the relative humidity.

Table 6 depicts the estimated annual operation and maintenance costs for the conventional air stripper systems. These costs do not reflect operating costs associated with a vapor phase adsorption unit for offgas treatment.

Table 6: 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**

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 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 7: 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. Given the importance of Unit Well No. 15 to the City's Zone 6 - East Service Area, MWU should consider purchasing a redundant set of trays to allow for immediate replacement of fouled trays with clean trays to minimize shutdown time.

9.2 Building and Site Layout

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 with this configuration, additional property would need to be acquired to accommodate the building.

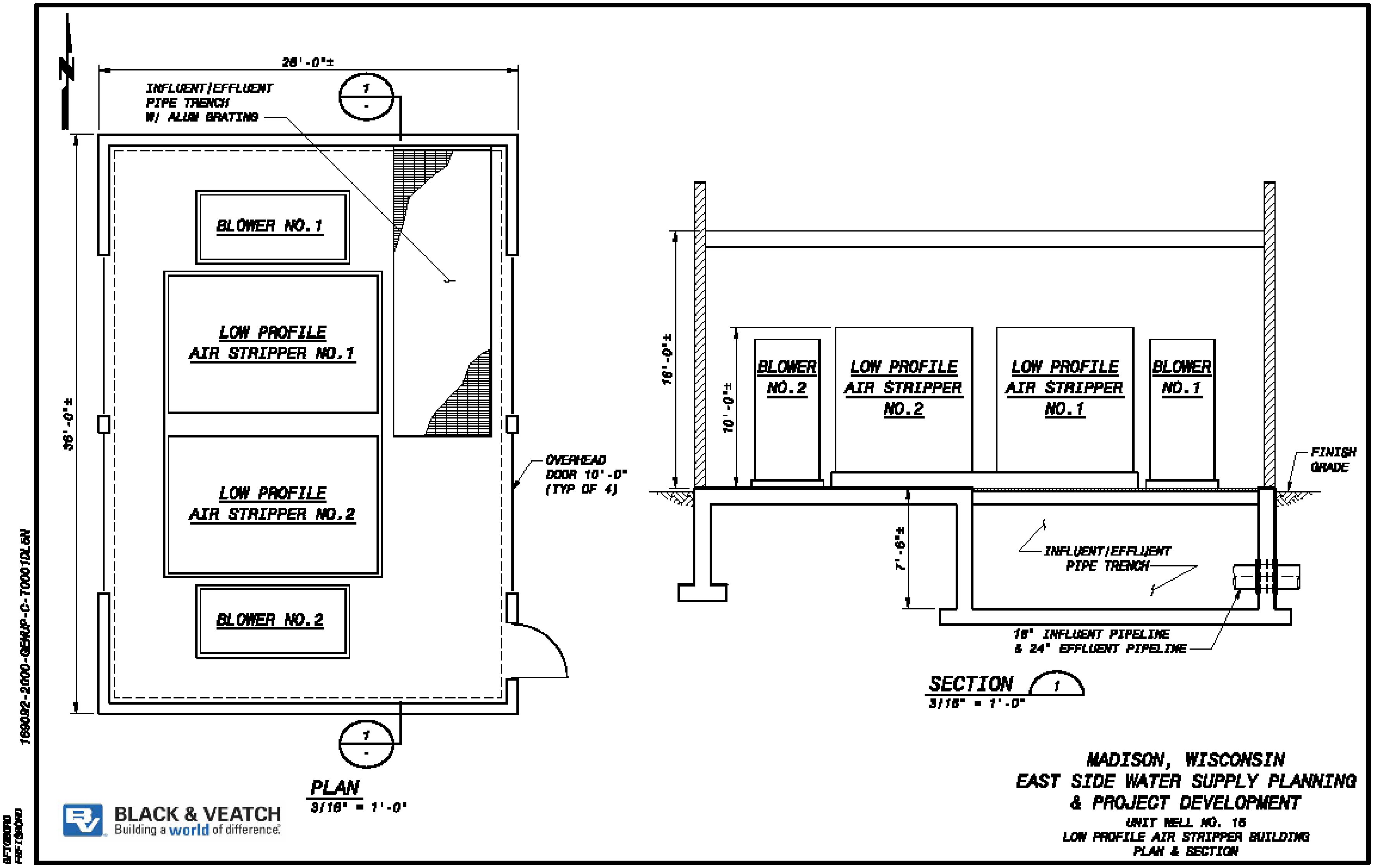


Figure 7: Low Profile Air Stripper - Building Plan & Section

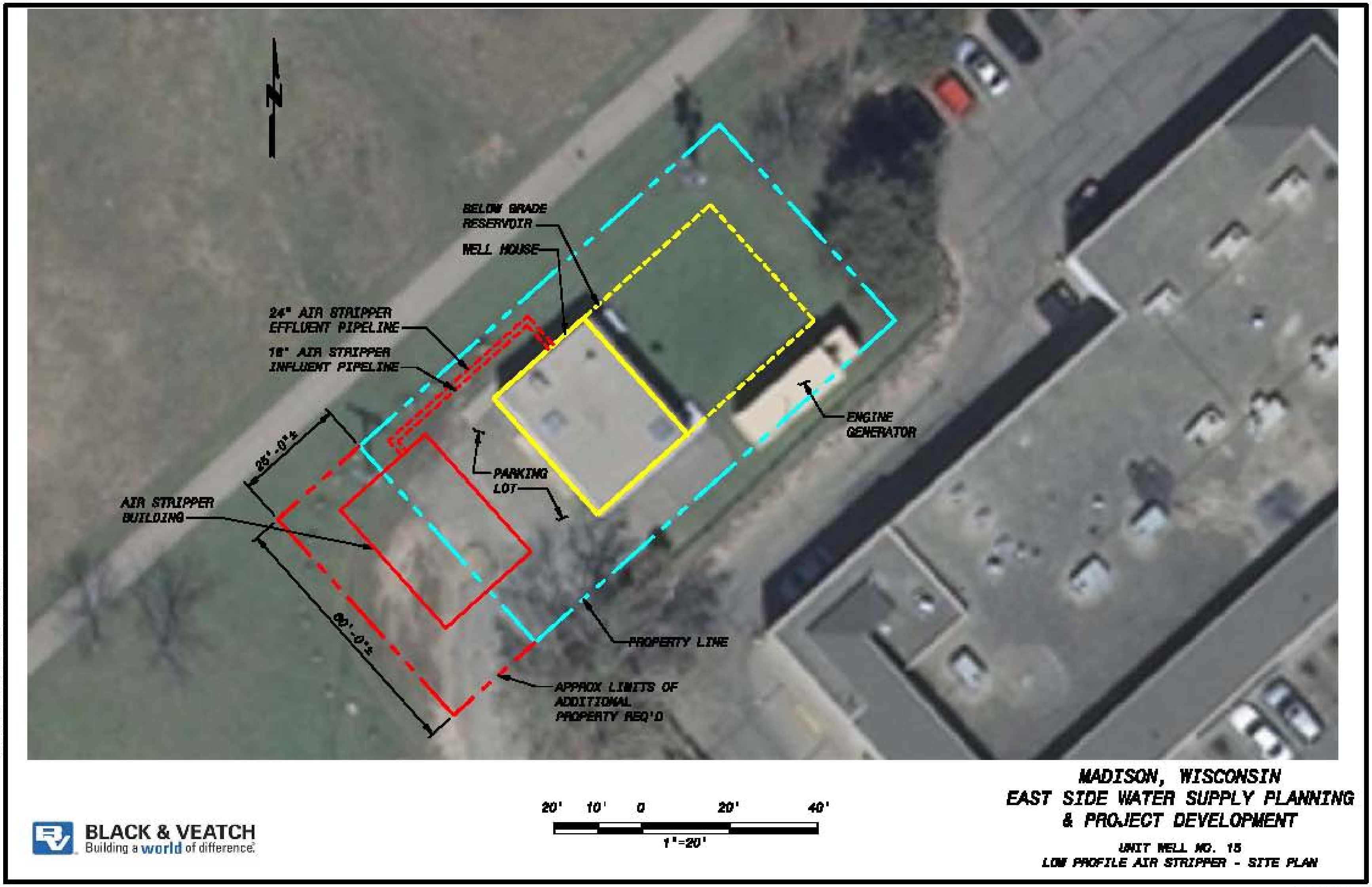


Figure 8: Low Profile Air Stripper - Site Plan

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. A pump characteristic curve, which depicts the operational impacts associated with the installation of the low profile aerators, is included in Appendix B. The deep well pump will be modified or replaced to provide the required capacity and head.

9.4 Off-Gas Treatment

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

9.5 Conceptual Opinion of Probable Project and Life Cycle Costs

Table 8 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. A detailed breakdown of costs is presented in Appendix C.

Table 8: Conceptual Opinion of Probable Project Costs Low Profile Aeration System

Description	Conceptual Opinion of Probable Project Costs for a Low Profile Air Stripper
Building (Complete and Allowance for Reservoir Modificatoions)	$730,000
Low Profile Air Stripper (Installed)	$324,000
Vertical Diffusion Vane Well Pump	$125,000
Contingency (20%)	$200,000
Engineering/Legal/Admin	$200,000
Estimated Total Project Cost	**$1,600,000**

Table 9 depicts the estimated annual operation and maintenance costs for the low profile aeration system. These costs do not reflect operating costs associated with a vapor phase carbon unit for offgas treatment.

Table 9: 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**

10. GRANULAR ACTIVATED CARBON ADSORPTION

10.1 Equipment and Design Parameters

GAC Adsorption is a very effective mechanism for removal of the VOCs that are present in the raw water from Unit Well No. 15. The advantage of GAC adsorption is that there would be no air emissions. The disadvantage is that a still large building would be required and as shown below, the operational expenses would be appreciably higher. 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 10 summarizes the key design elements of the GAC adsorbers as provided by the contacted vendors.

Table 10: GAC Adsorption Unit Design Parameters

Parameter	Siemens	WesTech
No. of Adsorption Vessels	4	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

Parameter	Siemens	WesTech
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 four 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 approximately 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.

10.2 Conceptual Opinion of Probable Project and Life Cycle Costs

Table 11 depicts the estimated capital costs associated with a granular activated carbon absorption system with a capacity of 2,200 gpm that will achieve a removal efficiency of 99 percent.

Table 11: Conceptual Opinion of Probable Project Costs Granular Activated Carbon Absorption System

Building (Complete with reservoir allowance)	$1,200,000
GAC Units (Installed)	$960,000
Vertical Diffusion Vane Well Pump	$125,000
Contingency	$420,000
Engineering/Legal/Administrative	$300,000
Estimated Total Project Cost	**$3,000,000**

Table 12 depicts the estimated annual operation and maintenance costs for the granular activated carbon absorption system.

Table 12: Operation and Maintenance Cost Granular Activated Carbon Absorption System

Description	Conceptual Opinion of Probable Annual Costs
Maintenance	$10,000
Electrical	$11,500
Carbon Use	$50,000
Estimated Total	**$70,000**

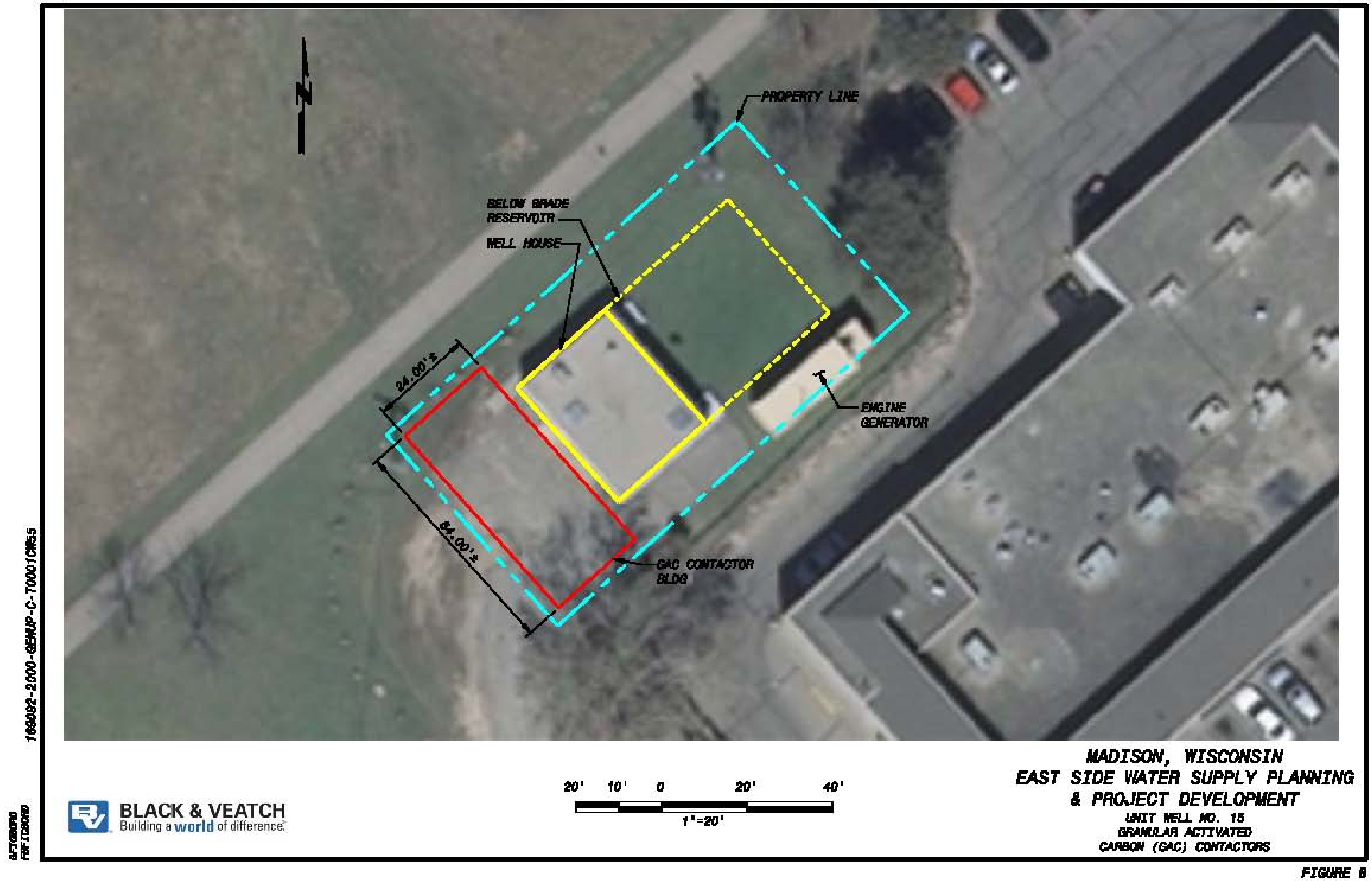


Figure 9 Granular Activated Carbon (GAC) Contactors

11. EVALUATION SUMMARY

This section presents an evaluation of the following three items:

- The recommended technology and location for VOC removal
- How the potential for future iron/manganese and/or radium removal should be considered.
- Appropriate investigations into the source of PCE around Unit Well No. 15.

11.1 VOC Treatment Technology

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.

In comparing alternatives, it is useful to compare total life-cycle costs of each alternative. A summary of capital, annual and 20-year life cycle costs for the three alternatives is presented in Table 13. An annual interest rate of four percent was used to calculate the 20-Year estimates.

Table 13: Summary of, Annual and 20-year Life Cycle Costs

Treatment System	Capital Cost Estimate	Annual Cost Estimate	20-Year Life Cycle Cost Estimate
Conventional Air Stripper	$1,425,000	$23,000	$1,740,000
Low Profile Aeration System	$1,600,000	$20,500	$1,800,000
Granular Activated Carbon Absorption System	$3,000,000	$70,000	$4,000,000

Considering the relatively large building foot print and the high life-cycle costs, , 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 not recommended due to water quality concerns. 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 facilitates a simplified and effective cleaning process.

Based on the above, the following recommendations are made:

- Because the life cycle costs of a low profile air stripper nearly identical to the conventional packed tower air stripper, the low profile air stripper is recommended for this application.
- As noted above, the low profile air stripper building can be located on either side the existing well house. The preferred location for the air stripper is northeast of the well house, one top of the existing reservoir, because no additional property would need to be purchased. However, a more detailed structural evaluation of the reservoir and well house is required to assess the feasibility of this option.
- Offgas treatment is not recommended at this point because the concentrations of VOCs in the offgas will be ten times below the minimum emission rates requiring treatment by the WDNR.
- The Well 15 pump will need to be upgraded to account for the increased pumping head created by the low profile air stripper. As the pump is upgraded, a variable frequency drive should also be added to the pump.

11.2 Future Treatment Considerations for Iron, Manganese, and Radium

Table 1 also presented the existing levels of iron and manganese and radium in the Unit Well No. 15. Currently, those concentrations do not warrant treatment as they are well below regulatory limits. However, these concentrations could increase over time, particularly if the well casing would be modified and more water is pumped from the lower aquifer. Radium, iron and manganese are dissolved minerals and do not form volatile compounds. As such, these contaminants are not appreciably removed through air stripping. Separate unit treatment processes would be required to control these contaminants. EPA Radionuclides Rule lists Best Available Technology (BAT) for radium as reverse osmosis (RO), ion exchange, and lime softening. Chapter NR 809, *Safe Drinking Water* of the Wisconsin Department of Natural Resources (DNR) regulations identifies zeolite softening, lime−soda softening, reverse osmosis, hydrous manganese oxides, and adsorptive resins as the BAT's available for achieving compliance with the MCLs for radionuclides. Chapter NR 809, *Safe Drinking Water* of the Wisconsin Department of Natural Resources (DNR) regulations identifies oxidation-detention-filtration, oxidation-filtration, greensand filtration and ion exchange as methods of removing iron and manganese.

Treatment for iron, manganese, and radium is not required at this time. However, treatment could be required in the future. To plan for this possibility, any acquisition of additional land, the design the treatment building, and the design of the process piping should consider how the process could be expanded to account for the potential future treatment.

11.3 Evaluation for Further Groundwater Investigations

As noted in Section 4.2, the VOCs in Unit Well 15 are coming from an unknown source. As part of protecting a public water supply, some investigation into the source of contamination is warranted, as is the benefits of extending the well casing to below the shallow aquifer to potentially reduce VOCs into the well.

APPENDIX A

Equipment Information

APPENDIX B

Well Pump Characteristic Curves

APPENDIX C

Conceptual Opinion of Probable Construction Cost