Design for Removal of VOCs at Drinking Water Well 18

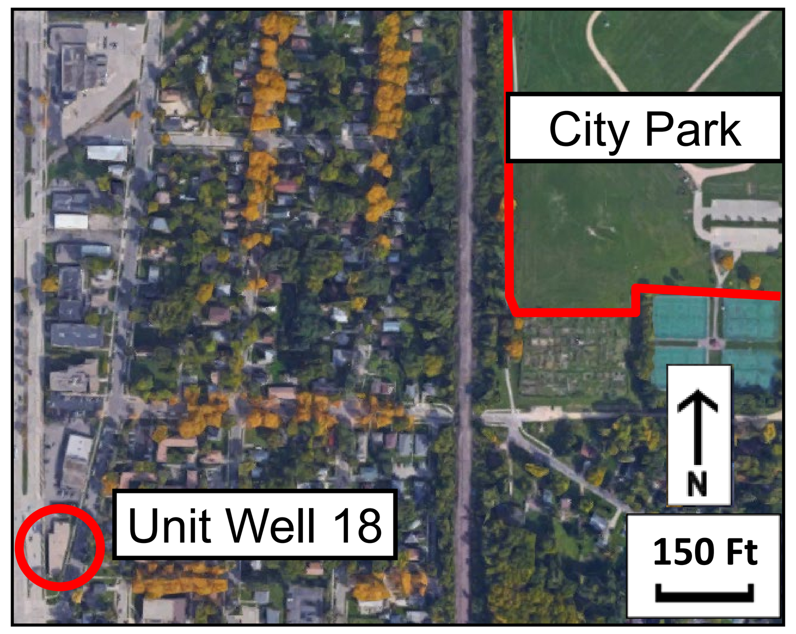
City A, USA

Project Background

Unit Well 18 is a year-round municipal well that serves City A's south neighborhoods. This well provides clean drinking water to over 250,000 residents daily. About a ¼ mile southwest of the well is City Park, which is located above an abandoned landfill that has been identified as the source of Volatile Organic Compounds (VOCs) contaminating Well 18. These VOCs are a potential health risk to the community.

The VOCs of interest identified by the Water Utility are tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichloroethane. The Water Utility's project aims to improve the water quality of Well 18 and prevent the VOC concentration from reaching the maximum contaminant level (MCL) set by the Environmental Protection Agency (EPA) of 5 micrograms per liter, or 5 parts per billion (ppb). PCE has the highest recorded concentration at 3.5 ppb as of January 2016. If the concentration increases beyond the MCL of 5 ppb, residents exposed to Well 18's water are at an increased risk of health problems including skin and eye irritation. Therefore, it is imperative to implement modifications to Well 18 that will mitigate the concentration of VOCs and provide safe drinking water to residents for years to come.

Aerial View of Well 18 and Reservoir



Aerial View of Well 18 and City Park

Methodology

The design team addressed multiple engineering analyses for the three alternatives considered: hydraulic, geotechnical, structural, construction, and sustainability. Using these analyses, the three alternatives were compared in a decision matrix to suggest a final design to the Water Utility.

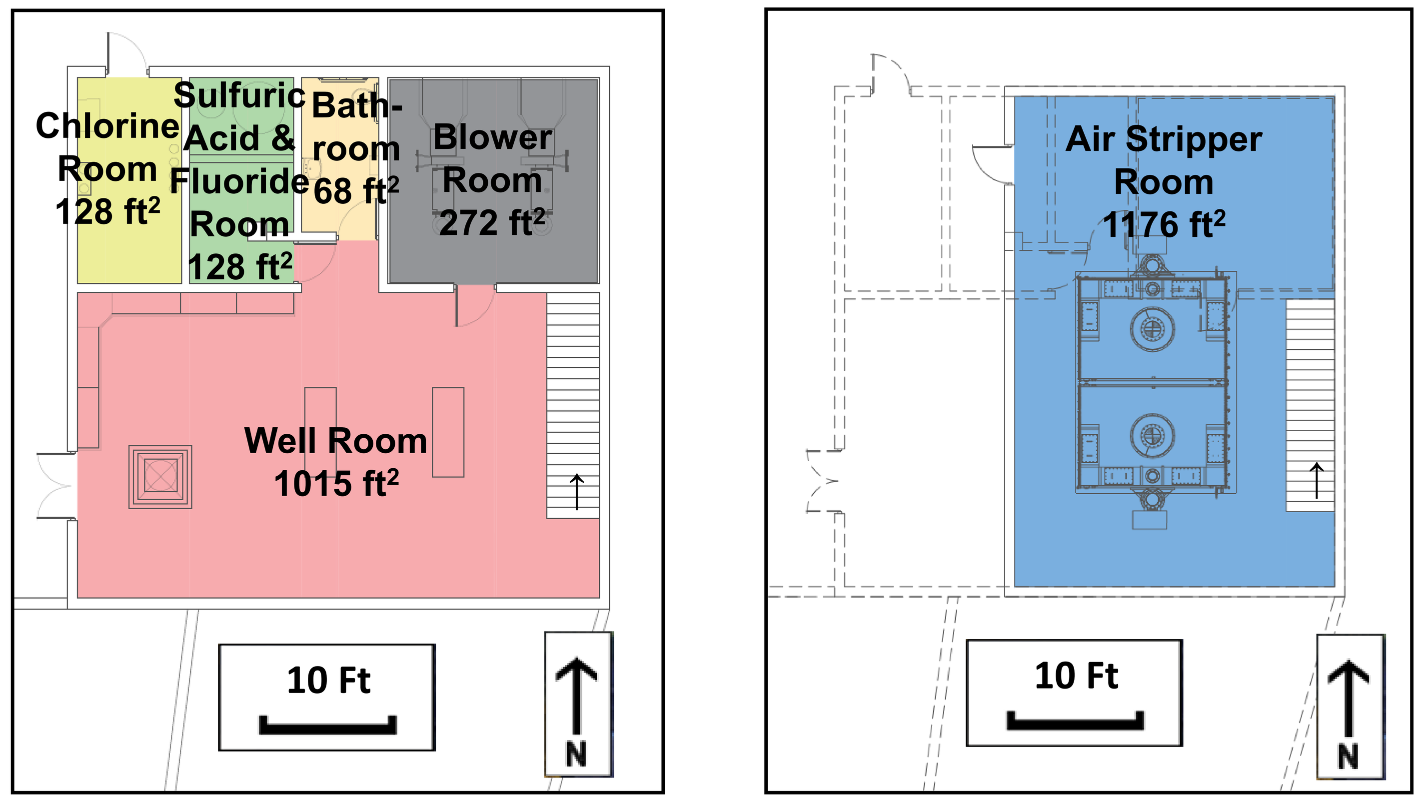
Design Options

The preliminary design phase of this project developed three design alternatives to mitigate the increasing concentration of VOCs. The first alternative considered was installing two low-profile air strippers. This would filter the VOCs from the water before distribution. The second alternative was extending the casing of the well into the lower, confined aquifer. Extending the casing would prevent VOCs from entering the well, but would expose the well to higher iron, manganese, and radium concentrations. The third alternative was blending the water with Unit Well 27. This option would require approximately 11,400 feet of new piping and extra booster pumps to be installed between the wells.

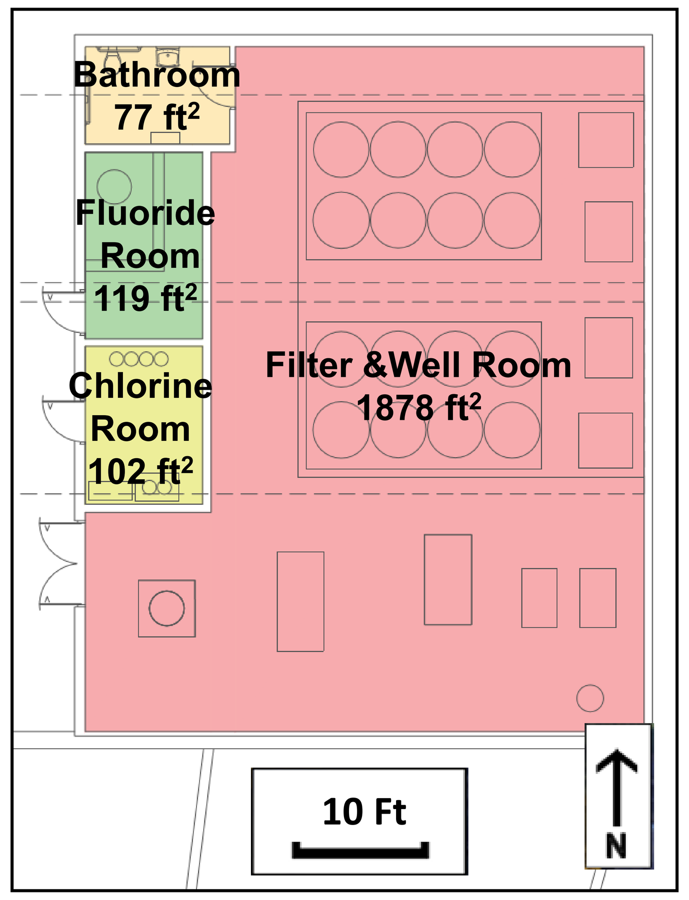
Other alternatives such as installing granular activated carbon (GAC) filters, installing a new well off-site, and treating the contaminant plume up-gradient were initially considered but did not perform as well during the decision process.

First Floor

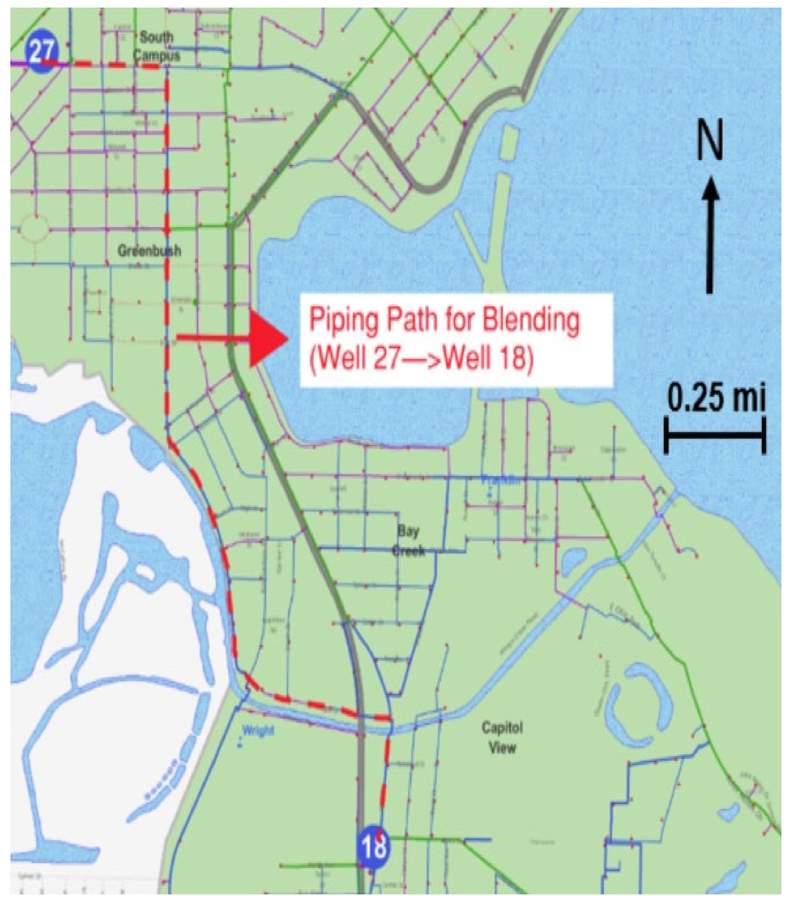
Second Floor



Alternative 1: Low-Profile Air Stripper Design Floor Plan



Alternative 2: Extended Well Casing Design Floor Plan



Alternative 3:Proposed Piping Path for Blending

Project Constraints

The following design constraints were considered:

Social: Construction noise, vibration, and required lane closures will affect the surrounding neighborhood through the duration of the project.

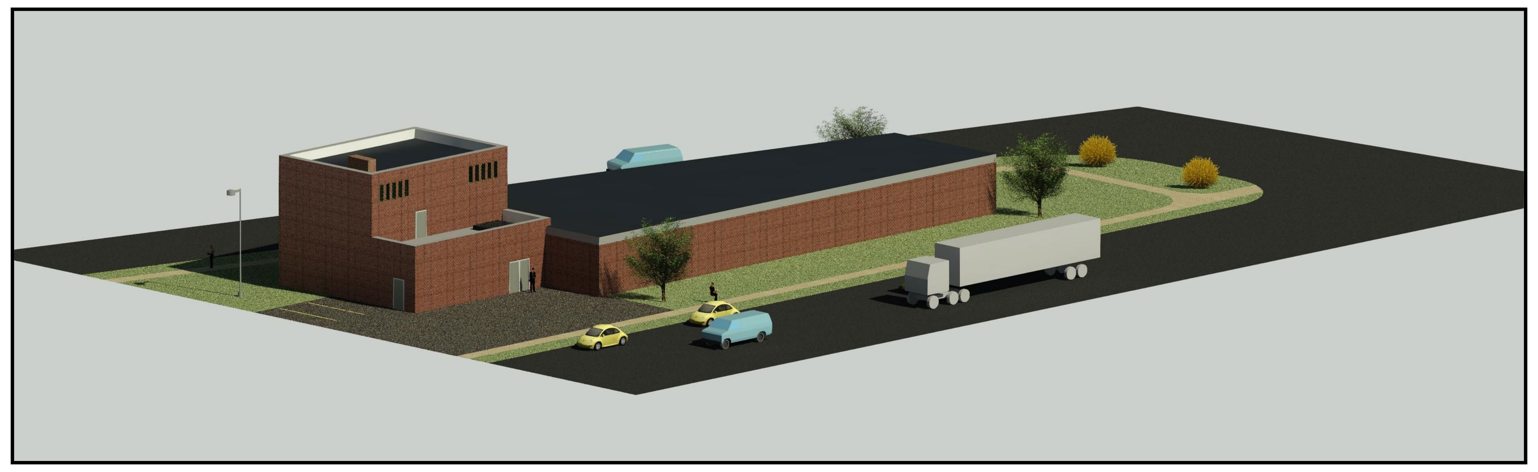
Environmental: Erosion control measures during construction and the containment of treatment chemicals will follow standards set by the EPA and OSHA.

Economic: The design team will consider alternatives that are appropriate for the Water Utility's budget of $4,400,000, which is divided into $3,500,000 for construction, and $900,000 for engineering, legal, administrative, property, and permitting costs.

Constructability: Due to the existing conditions, the available space on the 0.35-acre site is at a minimum, limiting accessibility for construction. The construction phase planning will be conscious of this space constraint to minimize transportation disturbances during the project.

Outcomes and Conclusions

The alternative recommended to the Water Utility, and accepted, was to rebuild the existing facility to accommodate two low-profile air strippers. This design will require construction to the existing building as well as an additional second floor. The Opinion of Probable Cost is $4,122,000. The anticipated duration of construction is approximately 12 months. Installing low-profile air strippers will lower the concentration of VOCs by over 90%, be within the Water Utility's budget, and is expected to have less social and environmental impacts (defined by the Constraints section) than the other alternatives. Overall, the low-profile air stripper alternative best met the design goals established by the Water Utility.



Alternative 1: Low-Profile Air Stripper Rendering

Knowledge and Skills Gained

The students applied their engineering curriculum to a real-world problem. They used their knowledge of civil engineering to evaluate alternatives, considered risks and benefits, and created a viable final design, while meeting the time and budget constraints of their client and internal organization. Their interaction with mentors and other members of the engineering profession taught them valuable communication skills, and gave them insights into questions about ethics, professional responsibilities, and the logistics of taking a design project to completion.

Design for Removal of VOCs at Drinking Water Well 18

Project Description

City A in the USA obtains municipal drinking water from wells screened in the underlying sandstone aquifer. Well 18 is a year-round municipal well that serves several neighborhoods in City A, providing clean drinking water to over 250,000 residents daily. The well is surrounded by residential and commercial land uses but is located 1,500 feet southwest of an abandoned landfill, now City Park. The city's Water Utility has identified the abandoned landfill as the source of Volatile Organic Chemicals (VOCs) that are leaking into the groundwater and have put the drinking water at risk of exceeding federal and state regulatory limits. VOCs are classified as primary contaminants by the Environmental Protection Agency and pose a risk to human health including an increased risk of cancer and problems with the liver, nervous system, and circulatory system. The VOCs present at Well 18 include tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1 trichloroethane. The top priority of this project was continuing the distribution of clean and safe drinking water to the City A community by preventing the VOC concentration from reaching the maximum contaminant level (MCL) set by the Environmental Protection Agency (EPA) of 5 micrograms per liter, or 5 parts per billion (ppb).

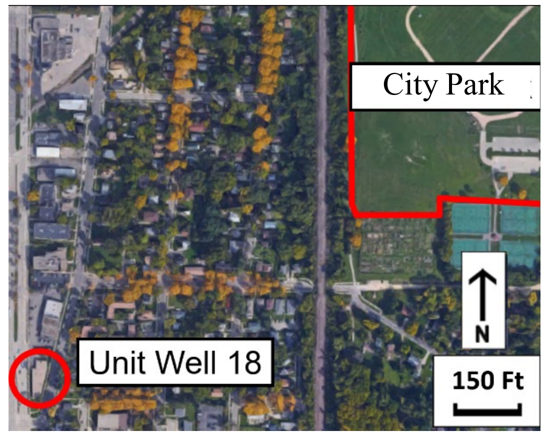


Figure 1: Aerial view of Unit Well 18 with respect to City Park.

Figure 2: Aerial view of Unit Well 18.

The Water Utility requested engineering services to evaluate methods to mitigate the risk of future non-EPA-compliant concentrations of VOCs. Options were not limited to the following, but were requested to include:

1. Treatment at the existing facility to include either packed tower air stripping, low profile air stripping, or granular activated carbon (GAC) adsorption.
2. Modification of the deep well to exclude water from the contaminated geologic formation.
3. Remediation of the contaminant plume up-gradient from Unit Well 18.
4. Drilling of a new deep well in an off-site location with transfer of that well water to Unit Well 18 to:
   - Serve as a replacement for the deep well at Unit Well 18, or
   - Be blended with water from Unit Well 18.

With the project goals established, the student team began collaborating with faculty members, professional engineers, mentors, and the public. The design included application of engineering principles in geotechnical, structural, hydraulic, environmental, and construction engineering. The student team prepared and submitted: a proposal (as though they were competing for the project); a formal preliminary design report describing the three concept designs; a listing of pertinent regulatory standards and professional codes; a geotechnical report; contract documents (construction contract, technical specification, construction plans); regular project management reports; regular peer evaluation reports; opinions of cost; and project schedules. Their work included three formal presentations along with a public meeting.

The student team developed three concept designs for mitigating the VOC contamination at Well 18: installing two low-profile air strippers; extending Well 18 casing into the lower confined aquifer; and blending Well 18 water with Well 27.

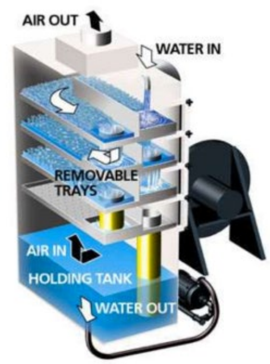


Figure 3 Alternative 1: Low-Profile Air Strippers

Integrating a low-profile air stripper at Well 18 will remove up to 90% of VOCs from the pumped groundwater. To accommodate a low-profile air stripper, the existing walls and roof housing Well 18 need to be demolished to construct a larger first floor with an additional second floor. New foundations are required to support the additional structural loads.

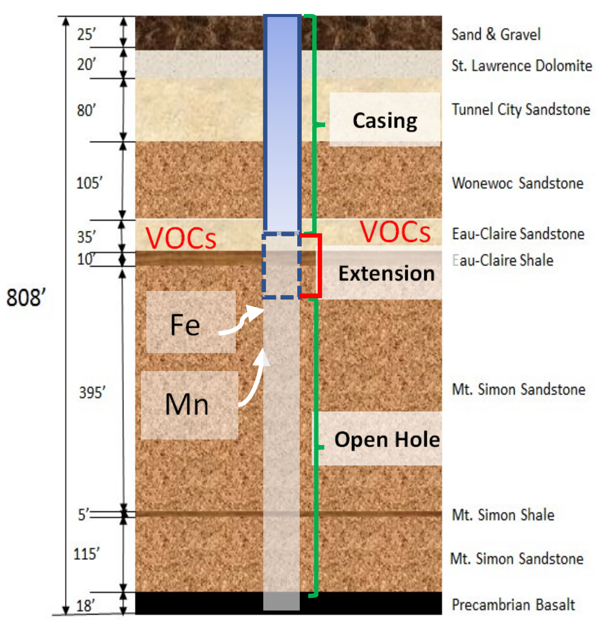


Figure 4 Alternative 2: Extend Well Casing into Lower Confined Aquifer

Extending Well 18's casing from the contaminated upper aquifer to 30-feet below the low-hydraulic-conductivity shale layer into the lower aquifer would reduce further contamination from VOCs. However, exclusively pumping water from the lower aquifer will require filtration for iron and manganese. To accommodate an iron and manganese filtration system with backwash tanks, the current building housing Well 18 will need to be demolished. A new, single-story addition to the north side of the existing reservoir will house the necessary filtration, with backwash tanks placed beneath the structure to conserve space.

Mixing water from Well 18 with water from Well 27 (located a mile northwest of Well 18) will reduce the concentration of VOCs and still provide the necessary water to the community. Blending between the two wells will require installation of 11,440 feet of pipe between the two wells and additional booster pumps at Well 18. Well 18 will need to house twice as much chlorine and fluoride chemicals to treat up to twice as much incoming water.

Figure 5 Alternative 3: Blending Water from Wells 18 and 27

The three alternative designs were evaluated based on their environmental, economic, and social sustainability, the Triple Bottom Line (Figure 6). Constructability was also considered, due to space constraints and adjacent development. Water treatment, energy consumption, traffic and community impacts, and financial costs and benefits were considered in determining the recommended alternative, with respect for the input of the Water Utility, experts, and the public. The student team ultimately recommended the low profile air stripper design for Well 18. Installing low-profile air strippers will lower the concentration of VOCs by over 90%, be within the Water Utility's budget, and have fewer social and environmental impacts than the other alternatives. Overall, the low-profile air stripper alternative best meets the design goals established by the Water Utility.

Figure 6. The Triple Bottom Line

Collaboration of Faculty, Students and Licensed Professional Engineers

Were licensed professional engineers (P.E.s) involved?
Two P.E.s from the local community served as mentors throughout the semester, meeting weekly with the student team. The mentors provided design supervision, lessons-learned experiences, critique and oversight for presentations and reports, and advice for client relationships and public meetings. In addition, overall instruction for the course was provided weekly by a P.E. Two student team presentations (at the preliminary and final design stages) were made to a panel of judges from the local P.E. community, thereby widening the students' exposure to other professionals and affording opportunities for additional critique of their work.

How did the students, faculty, and P.E.s interact?
The weekly contact between mentors and students allowed the students to benefit from the P.E.'s many years of experience. At the same time, the mentors and faculty expected the student team to retain responsibility for its own performance to the pre-established goals for time management, presentations, design components, deliverables, and schedules. Both mentors and faculty made themselves available for phone or email discussions as necessary and provided review of the student deliverables.

What did the students learn through the collaboration that would not have been learned in the classroom?
Communication and Collaboration as Components of Design: Collaboration between engineers, stakeholders, regulatory agencies, and the public is difficult if not impossible to teach in the classroom. In this project, the student team spoke directly to the city Water Utility and the public, learning to listen and balance the needs and requirements of various entities. The project constraints and needs then became critical elements of the three concept designs.

Multiple Right Answers: Most classroom activities and problems are designed to promote an understanding of the theory by having a single "correct" answer. In this project, having achieved an understanding of the engineering, environmental, and public constraints, the students prepared an evaluation matrix (Figure 7) in which weighted decision criteria were applied to three concept designs, all of which can be considered "right answers." The team and client made a recommendation to proceed with two low-profile air strippers, a design that effectively utilized the small site, provided long-term treatment for the drinking water, was within the established project budget, and met environmental, economic, and social sustainability goals.

VOC REMOVAL AT WELL 18					
		Weight of Criterion	**Low-Profile Air Stripper**	**Extended Well Casing**	**Blending**
Environmental	Energy Consumption	1	3	3	4
	Construction Impact	1.5	4	3	4
	VOC Mitigation	2	5	1	4
Social	Residential Approval	1.8	3	4	2
	Traffic Impact	1.4	4	4	1
	Community Impacts	1.6	4	3	3
Economic	O&M	1.2	4	4	3
	Capital Cost	1.3	3	4	2
	Life Cycle	1.5	4	4	4
Constructability	Site Area Size	1.7	4	4	2
	Site Alteration	1.5	4	2	1
	Time Sensitivity	1.2	3	3	1
Total Score			**79.5**	56.5	46.1

Figure 7: Evaluation Matrix – a higher score indicates a more desirable outcome.

Application/Integration of Multiple Disciplines: In this project, it was necessary for the student team to combine their individual skills for successful performance of the work, yet complete tasks in several disciplines of civil and environmental engineering. To do this, they identified the skill sets of each team member, assigned themselves tasks accordingly, and sought outside advice from mentors, faculty, and other students in areas where needs remained.

Learn to Identify the Uncertainties: Engineering projects have uncertainties, and awareness of the uncertainties informs the designers and user of related risks. Many classroom activities present the student with data and/or a set of assumptions upon which analyses are to be based. In this project, students were challenged to identify areas where they did not have or find pertinent information, or where certain information was not knowable prior to performing analyses. They correctly identified several items (geotechnical conditions, media head losses, contaminant concentrations over time, etc.) as items that should be noted and considered.

Protection of Public Health, Safety, and/or Welfare of the Public

The student team was challenged to evaluate the three design alternatives based on the Triple Bottom Line of environmental, economic, and social sustainability (Figure 6). Constructability was also considered, due to space constraints and adjacent development. Water treatment, energy consumption, traffic and community impacts, and financial costs and benefits were considered in determining the recommended alternative, with respect for the input of the Water Utility, experts, and the public.

Based on the Triple Bottom Line criteria, and as quantified in the project decision matrix (Figure 7), the student team recommended the low profile air stripper design for Well 18. Installing low profile air strippers will lower the concentration of VOCs by over 90%, be within the Water Utility's budget, and have fewer social and environmental impacts than the other alternatives. Overall, the low-profile air stripper alternative best met the design goals established by the Water Utility. This alternative was the most cost effective alternative, and it outperformed the other alternatives in both the environmental and social impacts evaluations. The low-profile air stripper is the only alternative that directly mitigates the risk of VOC contamination at Well 18, which was the ultimate design objective established by the Water Utility.

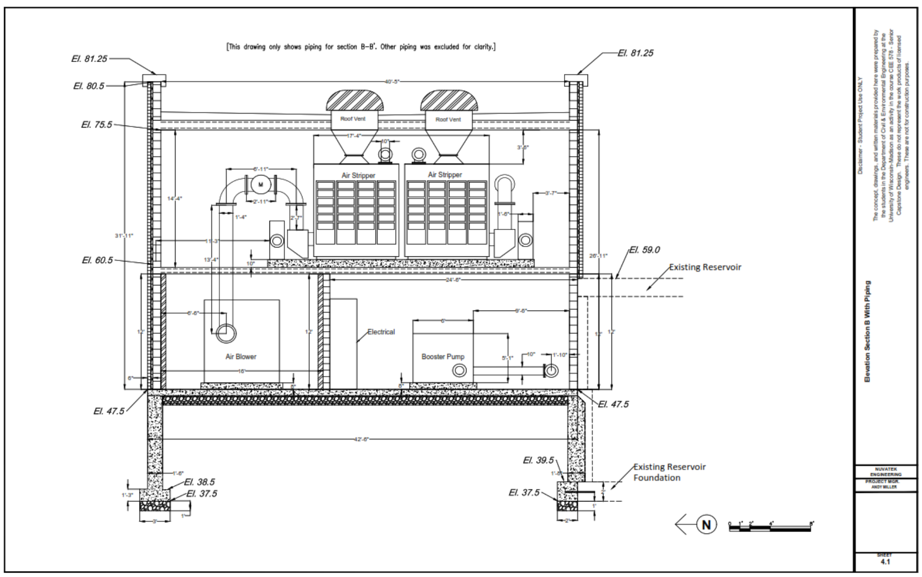


Figure 8. Final Design of Air Stripper Alternative

Multidiscipline and/or Allied Profession Participation

During this project, the work by the student team included structural, hydraulic, geotechnical, environmental, transportation, and construction engineering, drafting, estimating, scheduling, client and community interaction, review of regulatory requirements and professional standards, and preparation of written reports and construction documents. The five civil and environmental engineering students logged approximately 1,200 hours of design work, including team meetings and meetings with mentors and faculty.

Knowledge and Skills Gained

The students applied their engineering curriculum to a real-world problem. They used their knowledge of civil engineering to evaluate alternatives, considered risks and benefits, and created a viable final design, while managing themselves to meet the time and budget constraints of their client and internal organization.

Their interaction with mentors and other members of the engineering profession taught them valuable communication skills, and gave them insights into questions about ethics, professional responsibilities, and the logistics of taking a design project to completion.

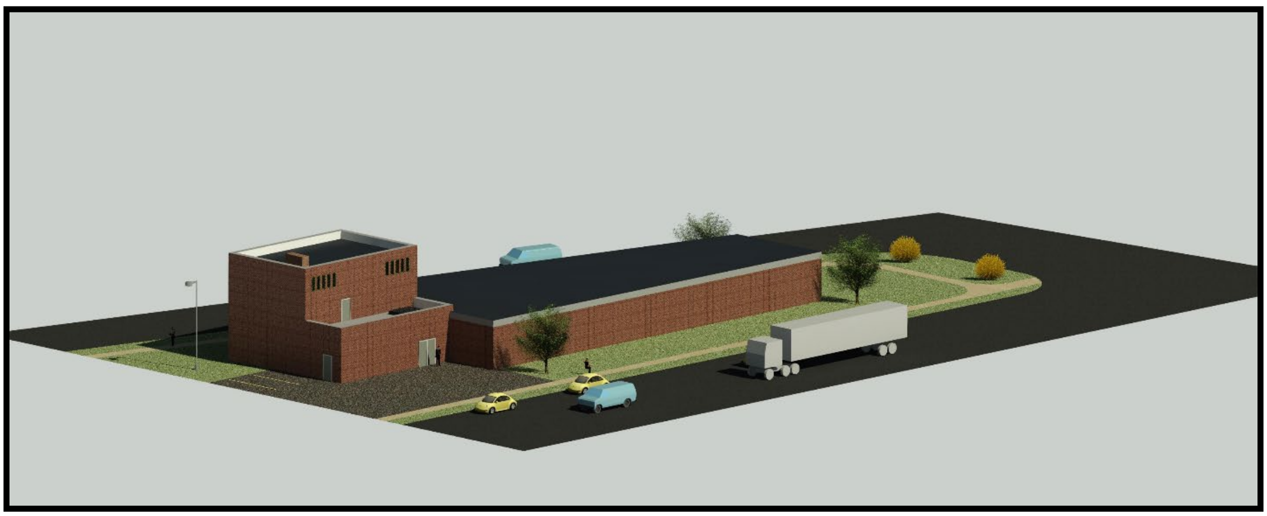


Figure 9 Rendering of Final Design

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In collaboration with two P.E.'s and city officials, a team of five undergraduate civil and environmental engineering students worked to develop a design for removing VOCs from groundwater so that Well 18 provides safe drinking water for City A neighborhoods. Social, environmental, economic, and spatial constraints were some of the major issues considered for this project. The opinions and concerns of the City A community were very important for the final design. Available space was limited at the approximately 0.35-acre site, and construction noise, vibrations and lane closures were concerns for the adjacent neighborhoods. In addition, the Water Utility established budget goals for the project.

During the preliminary design stage, the students considered six design options. Three of the options - including low-profile air stripping, blending water from multiple wells, and extending the well casing - were considered feasible for a secondary analysis. The team further developed these three design alternatives, preparing a concept design for each. Construction, environmental, geotechnical, and hydraulic engineering analyses were performed for the three alternatives to understand the technical implications.

The effect on the water supply was considered for all alternatives as well as the implications of all chemicals, waste, and emissions. Each alternative was evaluated through a life cycle cost analysis that incorporated initial construction and maintenance costs. Spatial constraints were important because the existing Well 18 facility occupies most of the property. Adding on-site treatment requires existing building demolition and reconstruction of a larger building with foundations capable of handling larger loads, as well as a more complex hydraulic system.

Having achieved an understanding of the engineering, environmental, and public constraints, the team prepared an evaluation matrix in which weighted decision criteria were applied to each concept design. Based on input from their collaborators and an expert panel, the team made a recommendation to modify the existing facility to construct two low-profile air strippers, thereby removing VOCs from the water before distribution.