Team 06

CLEAR H_2O

Creating a **L**ine-in **E**xtension for **A**rsenic **R**emoval

Final Design Report

ENGR339 / ENGR340
May 2014

CALVIN Engineering

CALVIN College

MY HEART I OFFER TO YOU LORD PROMPTLY AND SINCERELY

SAWYER

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1. Executive Statement

CLEAR H2O has successfully designed and constructed a filter component to remove arsenic below 10 µg/L. The filter has been designed to work in conjunction with the Sawyer® membrane filter which targets and removes biological pathogens. The CLEAR H2O filter will last for more than 5 months when filtering 80 liters of 100 µg/L arsenic contaminated water per day. See Figure I of the final prototype connected to the Sawyer® filter.

Figure I: Final Prototype connected to Sawyer® Filter

Problem

Many developing countries lack the water filtration infrastructure to deliver sufficient clean water required for healthy living. Many point-of-use (POU) filters have been installed or distributed for use on an individual or community scale to treat water at the source. POU filters such as the Sawyer® membrane filter are very effective at removing biological pathogens such as viruses and bacteria. However, most POU filters do not target inorganic contaminants such as arsenic or fluoride.

Arsenic poisoning is responsible for 1 in 5 deaths in Bangladesh.[1] It is found in natural mineral deposits and leaches into aquifers where it contaminates groundwater wells. It is odorless, tasteless, and deadly. Some POU filters are designed to remove arsenic, but they are often expensive, bulky, ineffective at removing biological pathogens, or incapable of indicating when the filter is exhausted and in need of replacement.

Solution

CLEAR H2O set out to design a filter component that would help alleviate the problem of arsenic poisoning in developing countries. The filter should be portable, durable, easy to use, and indicate when it should be replaced. See Figure II for a conceptual schematic of a filter component working with the Sawyer® filter.

Figure II: Filter Schematic

[1] Margie Mason. *Arsenic water killing 1 in 5 in Bangladesh*. http://www.nbcnews.com/id/37958050/ns/health-health_care/t/arsenic-water-killing-

Design Process

Media Selection

An extensive amount of time was dedicated to researching arsenic chemistry and arsenic adsorbent removal media. From this research, four engineered media were selected for testing: Bayoxide E33, AquaBind SP-70, AquaBind MP, and MetSorb. These media were selected due to their published performance from researched documents, their diversity in composition (two iron oxides, an alumina oxide, and a titanium dioxide, respectively), and their availability. Hematite, a natural mineral, was also chosen to test as research indicated it can successfully adsorb arsenic.

Batch Testing

These five media were then subjected to batch testing to determine their removal efficiencies. Three rounds of batch testing were performed, and from these tests, no removal trends were found for AquaBind MP or hematite. Both of these media were therefore eliminated from further testing.

Column Testing

Column testing was performed on the three remaining media: Bayoxide E33, AquaBind SP-70, and MetSorb. The purpose of column testing was to determine how long the media is capable of effectively treating contaminated water. The results of the second round of column testing can be seen in Figure III.

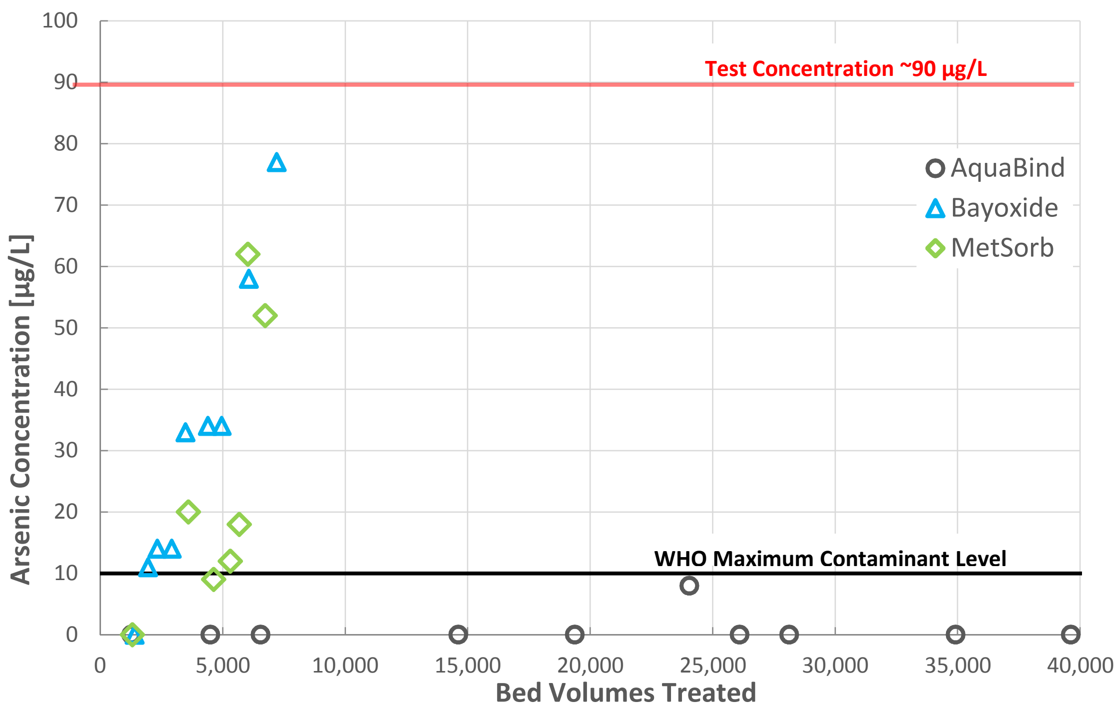


Figure III: Results of Column Testing #2

MetSorb and Bayoxide E33, both reached breakthrough early on between 2,000 and 5,000 bed volumes. However, AquaBind SP-70 was continuing to remove arsenic to below 10 µg/L at 40,000 bed volumes. AquaBind SP-70 was thus selected as the optimal removal media to maximize filter life.

Empty Bed Contact Time Testing

Testing was performed to determine how long the media needed to be in contact with the water to effectively remove arsenic. The results from this test indicated that an empty bed contact time (EBCT) of 88 seconds or greater was required for appreciable arsenic removal.

Head Loss Model

A head loss model was created to determine the required bed length and media grain size to result in a desired EBCT for the final prototype. According to the model, a final prototype filter length of 10.75-inches with an EBCT of 120 seconds requires a grain size of #25-#35 mesh.

Exhaustion Indication

A method for indicating when the filter should be replaced was thoroughly researched. A time-dependent method of indication was determined to be the best alternative due to cost and durability concerns of other methods. Time-dependent methods indicate when the filter should be replaced after a certain time has elapsed. The filter life is found through lab testing and pilot testing, with an assumed influent concentration and daily usage.

Timestrip® indicators were found to be the best time-dependent method for a POU filter. A time strip is activated by depressing a button that releases a dye. When the dye has reached the top of the column, the designed time has elapsed and the filter should be discarded and replaced. Figure IV displays a time strip before the button has been depressed and after about 15 days. Timestrip® indicators can be designed for a range of times from 5 minutes to one year. They are inexpensive, do not require a power source, and are easy to use and understand.

Figure IV: Timestrip® Indicators

Prototype Development

The prototype was developed through multiple iterations. Originally, the prototype was constructed with PVC and designed with replaceable media. However, due to safety concerns of the user, the final prototype was designed as a disposable filter cartridge. The prototype was designed in SolidWorks and 3D printed. See Figure V for a model of the prototype generated in SolidWorks.

Figure V: SolidWorks Model of Final Prototype

See Table I for the design specifications of the final prototype.

Table I: Final Prototype Specification

Media	Grain Size	Bed Length	Total Length	Diameter	Wall thickness	EBCT
SP-70	#25-35 mesh	10.75in	12.7in	2.2in	0.225in	120sec

The prototype can thread directly on to the Sawyer® filter. Glass wool was placed at the bottom to prevent media from exiting the nozzle. The dry media was then added, and a mesh was inset at the bottom of the thread to prevent media from spilling out the back of the filter. An O-ring was placed at the base of the thread to help create a watertight connection.

Cost Analysis

The prototype was very expensive to construct and cost about $250. However, this cost was almost completely composed of the expensive 3D-print material, and production costs would be greatly diminished. See Table II for the range of material production costs for the final prototype.

Table II: Material Estimates for Production

	Cost	Number
Injection Molding HDPE	$1.50 - $3.50	-
Media	$2.75 - 3.75	-
Mesh	$0.05 - $0.20	2
Timestrip	$0.10 - $0.50	1
	Total Cost:	**$4.40 - $8.20**

This estimate indicates that the material cost for a production model would be in the range of $5 to $10.

Conclusion

CLEAR H2O believes that a filter component that removes arsenic could be successfully implemented to work in conjunction with the Sawyer® filter. Test results indicate that CLEAR H2O's final prototype design could successfully remove arsenic from an influent concentration of 100 µg/L to below 10 µg/L for 5 months and filter 80 liters of water per day. See Table III for the final prototype specifications.

Table III: Final Prototype Specifications

Parameter	Specification
Filter Life	5 months
Envelope	2.2 x 2.2 x 13 in
Daily Flow	80 liters
Production Cost	$5 - $10
Exhaustion Indicator	Timestrip®

This filter design is portable, durable, easy to use, and indicates when it should be replaced. When working in combination with the Sawyer® filter, it would remove both arsenic and biological pathogens.

Further testing should be completed before this design is put into production. Temperature, pH, and the presence of competing ions should all be evaluated to determine their effect on the media's ability to adsorb arsenic. Pilot testing should also be performed to help accurately determine the life of the filter.

2. Introduction

2.1. Senior Design Course Description

Calvin's Engineering Program's capstone senior design project is composed of two courses: ENGR 339 and ENGR 340. The two courses combine for a total of six credits and are taken by all graduating seniors at Calvin. The first course, ENGR 339, is taken the fall semester of senior year and focuses on team formation and project identification and feasibility. The second course, ENGR 340, is taken the following semester and is focused on the completion of the design project formulated throughout the first course. Both courses integrate fundamental design norms and distinctly Christian perspectives into the many lectures used to outline the technical aspects of the design process.

2.2. Problem Statement

Typically, developed countries implement point-of-entry water filtration units that will either filter water prior to entering a distribution network or dwelling place; however, many developing countries do not possess the financial stability or distribution infrastructure necessary to provide their citizens with filtered water. Point-of-use (POU) filters are self-contained filters often used in developing countries to filter water at the point-of-use in a fast and efficient manner, e.g. bucket filters and biosand filtration units. Unfortunately, there are not a significant number of POU filters that effectively remove inorganic contaminants, like arsenic, from water, and the select few POU filter systems that do target inorganic contaminants are often complex, costly and/or bulky. The presence of inorganic contaminants, particularly arsenic, is a global threat (see Figure 1) and poses serious health threats to all who drink the contaminated water. Eliminating these contaminants through the usage of a simple, cost-effective POU filter would provide a way for many individuals to obtain safe drinking water.

Figure 1: Arsenic Contaminated Aquifers around the Globe[1]

2.3. Sawyer®

The faculty advisor for CLEAR H2O, Dr. David Wunder, has an ongoing relationship with Sawyer® and through this connection, CLEAR H2O formed its own relationship with Travis Avery, the Vice President of Marketing for Sawyer®. A leader in water filtration worldwide, Sawyer® products was very interested in the content of this project and generously offered project guidance and financial assistance throughout the project's duration.

2.4. Project Proposal

CLEAR H2O will eliminate arsenic from contaminated water through the creation of a downstream filter extension to the widely used Sawyer® PointOne hollow membrane POU bucket filter (see Figure 2). The filter component will utilize an existing filtration media designed for arsenic removal as the agent for removal. In addition, the filter component will clearly indicate when it is no longer sufficiently removing arsenic from water. Insufficient removal will occur when the post-treatment arsenic concentration levels are above the World Health Organization (WHO) guideline of 10 µg/L.[2]

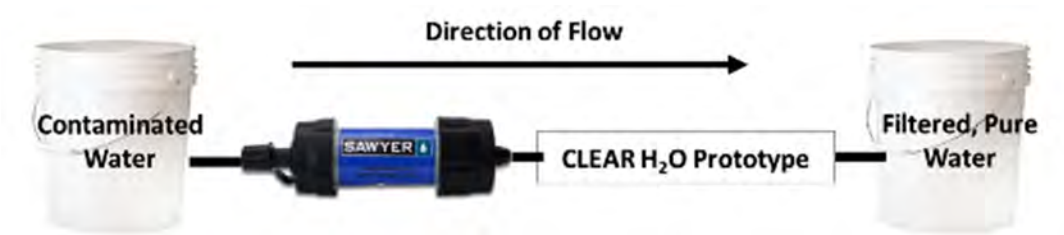


Figure 2: CLEAR H2O Project Diagram

2.4.a. Project Constraints

The following constraints formed by CLEAR H2O and Sawyer® were requirements the final extension must fulfill to be successfully implemented as a viable water filter.

Team Constraints

The filter module must remove the targeted contaminants below the levels recommended by the World Health Organization. WHO has set the recommended level for arsenic concentrations at 10 µg/L.[2,3]

Sawyer® Constraints

In addition to the WHO guideline, Sawyer® has mandated an additional constraint for the project. The filter must clearly indicate when the effluent concentrations are above the WHO guideline of 10 µg/L. The indication method implemented must be simple and unmistakable in its meaning.

2.4.b. Project Objectives

In addition to the constraints described in the previous section, a list of project objectives was also created. The intent of the following objectives was to narrow the final prototype to one that would integrate well with the existing Sawyer® membrane filter, and more importantly, to define objectives that would ensure a reliable, long-lasting prototype that could be easily understood and implemented in different cultures and lifestyles.

Team Objectives

CLEAR H2O's objectives for the filter enhancement concern the following features: size, ease of use, cost and robustness.

Point-of-use water filters are beneficial compared to other advanced filtration systems because they are traditionally portable and easily shipped. Most POU filters must be shipped to developing countries and excessively sized products prove difficult to ship and distribute upon arrival. Currently, the Sawyer® filter module is approximately 400 cm^3 [~25 in^3] or the size of a standard computer mouse. However, because a filtration media will be used as the removal agent in CLEAR H2O's extension, a larger module will be needed to increase the life of the product. CLEAR H2O has placed a high importance on making the filter as small as possible and has constrained the maximum volume to one liter [~60 in^3] (two and a half times the sizes of Sawyer® filter).

In addition to being small, POU filters are generally easy to use and understand. The targeted population for these filter extensions will be individuals in developing countries without much, if any, technical background. In addition, the contaminant removed by the extension is deadly and filter misuse can result in severe health effects. Thus, CLEAR H2O must ensure that the filter extension created will be unquestionably easy to use. To simplify use, the filter extension should rely solely on the head of the system to provide enough pressure for the water to filter through the filter enhancement and the Sawyer® filter.

Another objective considered was the robustness of the final product. It is important that the filter extension designed can withstand considerable negligence without malfunctioning. Too often complex technologies are implemented to assist developing nations and yet, when these systems break down, there is no one with the technological background to repair the damaged equipment. Designing a system that will last beyond its intended life in the midst of user disregard alleviates the chance of breakdown or repair.

Affordability is one of the more important characteristics of current POU systems. Because CLEAR H2O's targeted population is developing nations, an appropriate price must be set so that the individuals in these countries can purchase the arsenic-removing extension. Current point-of-use water filters generally cost anywhere from \$35 to \$80[4]. As such, the cost of the extension (with the cost of the Sawyer® filter included) may exceed current competitive prices, but CLEAR H2O hopes to mitigate this increase in price by using low-cost materials and creating a longer lasting extension.

Sawyer® Objectives

When presented with the project proposal, Sawyer® also received the list of objectives described above. Sawyer® indicated that the list was exhaustive and that they had no further objectives to add to the project.

2.4.c. Project Approach

There were four major phases to this project – initial research, initial lab testing, prototype development and final prototype. All were critical steps taken towards the completion of this project. The following sections provide more detail into what each phase entailed and why it was important for the project. A flow diagram of the design process used can be seen in Figure 3.

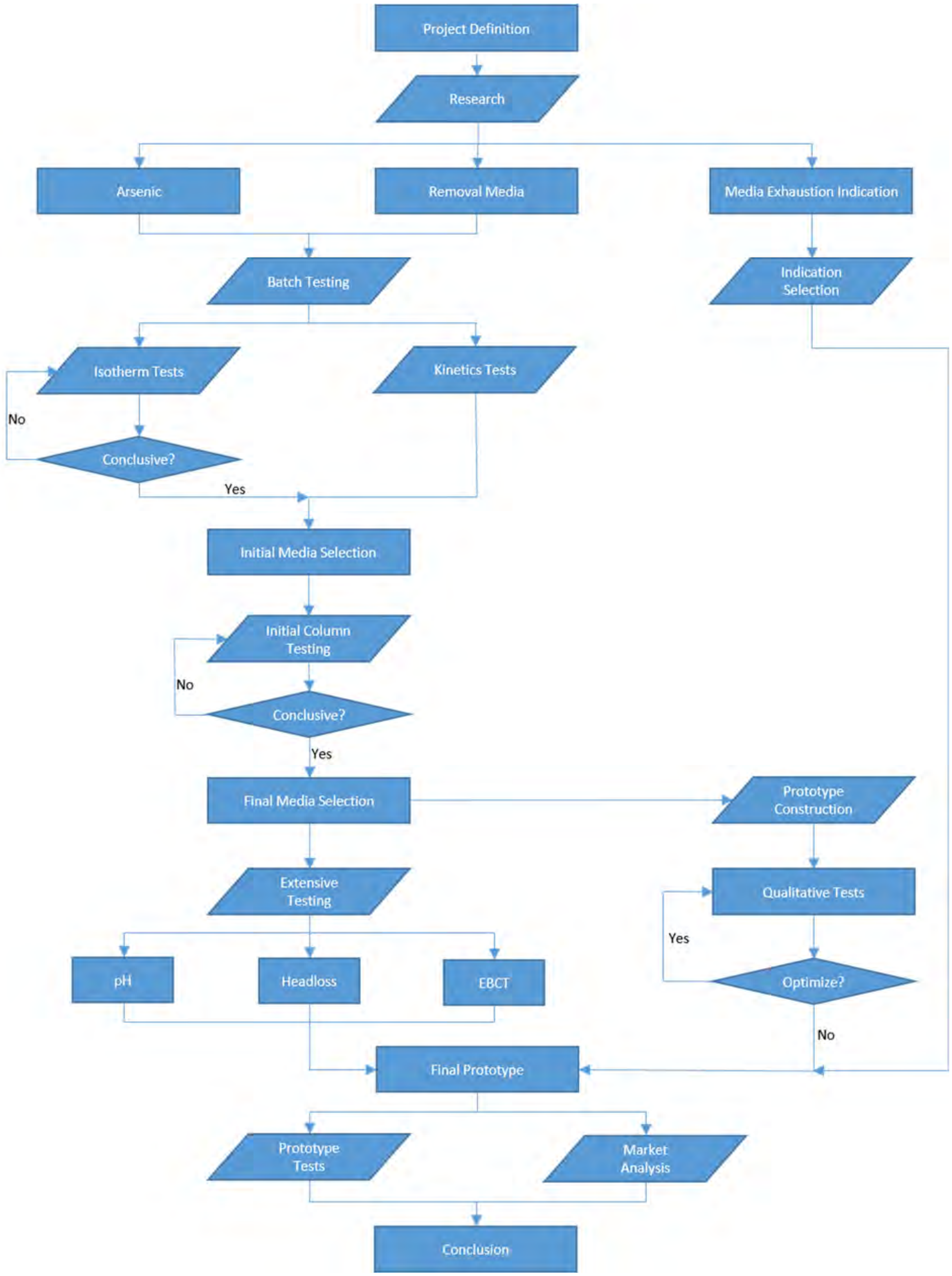


Figure 3: CLEAR H2O Design Process Flow Diagram

Initial Research

To create a filter extension with the aforementioned objectives and constraints, CLEAR H2O first needed a general understanding of arsenic chemistry, particularly arsenic's behavior in water and its adsorption chemistry. Thus, the first division of the project was arsenic research. Through this initial research, CLEAR H2O acquired an apt understanding of basic arsenic chemistry that would prove useful throughout the entire project. Also included in this initial research was an analysis on the health effects of arsenic and its pervasiveness as a global contaminant.

In addition, several engineered arsenic removal media and the current applications of these media in developing countries were researched. The result of this research was the selection of five testing media that would be used in initial laboratory testing.

Different media exhaustion indication methods were also researched during the initial research phase of the project. From the information obtained through this research, CLEAR H2O formed a list of potential media exhaustion indication techniques and then selected a specific method and product for use in the final prototype.

Initial Lab Testing

The most time-consuming aspect of this project was the initial rounds of lab testing. Prior to actual lab testing, research on common laboratory tests used to characterize media filtration effectiveness was performed. With this research completed, batch and column lab plans for determining particularly important characteristics of arsenic removal media were developed and completed. Several batch and column tests were then conducted over a seven-month period. The results from these initial tests were heavily used in selecting the prototype media.

Prototype Development

With the final prototype media known, additional laboratory tests were conducted on the selected media to determine its optimal operating conditions. The results of these tests aided in finalizing the configuration and specific properties (media grain diameter, volume, etc.) of the final media bed. In addition, several attempts were made to create a casing for the media. With each iteration, the filter housing fulfilled more of the aforementioned objectives. Eventually, a 3D-printed housing that could thread directly into the Sawyer® membrane filter was selected as the final model, as seen in Figure 4.

Figure 4: SolidWorks Rendering of Final Prototype

Final Prototype

The actual production costs of the 3D printed prototype were evaluated and then scaled up to an estimated large-scale, injection-molded production model. With the cost information known, a market study was conducted to determine the competitiveness of the filter extension and its viability as a legitimate business venture. Finally, several concluding observations were made about the final prototype, including its adherence to project constraints and objectives, fulfillment of design norms, potential improvements, and future testing.

2.5. Project Management

Effective project management is a critical component for the success of any project. CLEAR H2O utilized the various methods detailed below to promote a productive, efficient and enjoyable design project experience.

2.5.a. Team Members and Responsibilities

CLEAR H2O consists of four engineering students in the civil and environmental concentration. The students were joined by their shared belief that all individuals have the right to unrestricted access to pure, drinkable water. This belief has been the motivation behind CLEAR H2O's work throughout the senior design course. The following roles—project manager, team editor, production manager, and lab manager –were assigned to appropriately skilled individuals within the team to promote accountability and task ownership. Pictures and brief descriptions of the team members and their respective roles can be seen below.

Grant Mathews – Production Manager

Grant Mathews was born and raised in Anchorage, Alaska. Grant has a broad range of interests within the field, including: hydrology, water resources, site development, and groundwater remediation. In his free time, Grant enjoys being outside, hiking, fishing, and hunting. Grant has thoroughly enjoyed going to school in Grand Rapids and loves spending time on the West Side where he attends Servant's Community Church. In October, he will be marrying his wonderful fiancé, Blair, and he has accepted a civil engineering position at Triad Engineering in Anchorage.

The compatibility with current POU bucket filters and functionality of the final filter extension prototype was the main objective of the production manager. The production manager determined effective ways to utilize the selected media and ensure the filter extension clearly communicated when the effluent was no longer below 10 µg/L. The role required knowledge of current POU filter mechanics and a practical "jack of all trades" skillset.

Grant fulfilled all the aforementioned criteria. As an outdoorsman, Grant developed many skills that others in the team lacked. Grant possessed unique foresight and a practical knowledge of how things work together. In addition, Grant possessed the leadership skills required to direct others in assisting him with the prototype creation.

Jeshua Short – Laboratory Manager

Jeshua (Jesse) Short is from Cambridge, Ontario; however, he has spent the majority of his life as a missionary kid living in Thailand and Vietnam. Jeshua is passionate about water resources. He hopes to manage water development projects in Southeast Asia and incorporate ministry into his future engineering work. Jeshua actively participated in intramural soccer and volleyball teams, lived in Calvin's intentional living community Project Neighborhood, and was on the Calvin College ASCE Chapter leadership.

The lab manager was personally responsible for developing the lab plans used to test the ultimate effectiveness of the media tested throughout the design project. Thus, the lab manager had the clearest understanding of the chemistry involved in the project and the different methods that could be implemented to determine the most effective media type. Finally, this role also required an individual with exceptional communication skills, so that all members of the team easily and unquestionably understand the lab plans procured.

Jesse was uniquely qualified for this role. Jesse's passion for the people of Southeast Asia (much of Southeast Asia has high arsenic concentrations) had led to a deep curiosity in inorganic chemistry, particularly arsenic's behavior in water. Thus, Jesse had spent the most time researching the arsenic chemistry surrounding the project. In addition, Jesse demonstrated an ability to clearly communicate his thoughts in an easily understandable fashion.

Steve Taplin – Team Editor

Steve Taplin was born and raised in Lawton, Michigan, a little podunk town in Southwest Michigan. Steve thoroughly enjoys sports ("Go Pack Go!"), spending time with his beautiful wife, and of course grabbing a beer or two with good friends. Steve has accepted a general civil engineering position at Prein&Newhof, a consulting firm in Grand Rapids, MI, and is excited for what promises to be a rewarding job.

The team editor was personally responsible for guaranteeing professionalism in all written and presented works. More importantly, the team editor ensured that all submitted works thoroughly, effectively and concisely communicated their ultimate purpose to the targeted audience. The role of team editor required an eye for detail and a history of success in effectively communicating information through written works. In addition, the role required an excellence at tailoring technical information to audiences with less technical background.

Steve traditionally excelled at effectively communicating technical data in past courses, particularly past design courses. He is a perfectionist with an eye for detail. In addition, Steve had taken several communication classes throughout his education that uniquely qualified him to succeed in his role as Team Editor.

Lucas Timmer – Project Manager

Lucas Timmer was born and raised in Zeeland, Michigan, and he "feels the Zeel" for his hometown. At Calvin, Lucas was an intern for the Calvin Energy Recovery Fund and completed several green projects at CERF—including low-flow showerhead installations in dormitory suites and the installation of 142 new LED lights in the T&T (saving Calvin $23,000 per year in energy costs). Lucas accepted a position as a Water Resources Design Engineer at Spicer Group in St. Johns, Michigan. Besides engineering, Lucas is also passionate about road cycling, frisbee, hiking, watching his Detroit Lions and Tigers, and visiting national parks.

The role of the project manager was to encourage communication within the team and to enforce adherence to project deadlines. Furthermore, the project manager facilitated all project meetings and assigned intermediate tasks to team members. The project manager role required an outspoken individual who could clearly articulate the needs of the group and effectively promote progress. He must understand the scope of the project and always consider the "big picture". In addition, the role required that the project manager confront team members that were not adequately fulfilling their roles throughout the project.

Lucas Timmer was naturally qualified to fulfill this leadership role within the team. Lucas is a charismatic individual that strives for perfection in everything that he does. Moreover, Lucas is a compassionate soul that could not wrongly accuse anyone without indisputable proof. He had traditionally shown an aptitude for timely completion of work and has always worked well in a team.

2.5.b. Team Management

Effective time management and inter-team communication strategies were implemented to ensure adherence to self-established deadlines and timely submission of all required submittals. The following methods – project schedule, timesheets and weekly meetings – were implemented to encourage timely work and team unity.

Project Schedule

After the scope of the project was refined, a project schedule was immediately developed. Initially a Gantt chart was used to schedule the project, but this method proved ineffective because of the volatile nature of the lab tests. To replace the Gantt chart, a list of project milestones was created can be seen in Table 1. The role of the milestone list was to dictate when large decisions had to be made, so that the project could continue forward. Because the time required to complete many of this project's tests could not be estimated, cutoffs for testing phases needed to be established.

Table 1: Project Milestones

Task Description	Scheduled Deadline	Date Completed
Removal Media Acquired	10/17/13	11/2/13
Media Exhaustion Indication Research	11/1/13	11/17/13
Batch Testing	11/14/13	12/11/13
Initial Media Selection	11/14/13	12/11/13
Media Exhaustion Indication Selection	4/1/14	1/30/14
Column Testing	4/1/14	5/9/14
Final Media Selection	4/1/14	3/31/14
Initial Prototype Construction	4/28/14	4/23/14
Final Prototype Construction	5/1/14	5/9/14
Extensive Media Testing	5/9/14	5/9/14
Additional Testing	5/9/14	5/9/14

Timesheets

A spreadsheet with timesheets for the individual team members and the team as a whole was created to track the amount of time spent working on the project every week, and for the entire year. The timesheet was meant to promote accountability within the team by ensuring that everyone was doing an equal amount of work. Table 2 shows a summary of the timesheet information for both fall and spring semesters. The total hours worked on this project was 1489.

Table 2: Summary of Team Hours

	Grant Mathews	Jeshua Short	Steve Taplin	Lucas Timmer
Fall Semester Hours	157	158	178	166
Interim Hours	14	14	14	14
Spring Semester Hours	158	198	205	213
Total Hours	**329**	**370**	**397**	**393**

Weekly Meetings

Weekly meetings were held to discuss all aspects of the design project. The meetings included a brief progress report from each team member, an intentional brainstorming session on the direction of the project, the allocation of new tasks, and a question and answer period. Often the faculty advisor for CLEAR H2O, Dr. David Wunder, was present for these meetings and would offer technical knowledge and advice when consulted. These meetings were critical in establishing a cohesive and universal understanding of all aspects of the project.

2.6. Faith and Design

As a team of four distinctly Christian engineers, CLEAR H2O holds itself to an exceptionally high moral standard that naturally integrated itself into the fabric of this project. Design norms are moral guidelines that, "force the engineer to consider the broader impact of the design in which it will be embedded."[57] As such, CLEAR H2O considered many design norms throughout the course of the project. Three design norms were of particular relevance throughout the project and provided a platform on which important design decisions could be evaluated. These design norms were cultural appropriateness, caring and justice. Brief descriptions of these three design norms and their application within this project are included below.

2.6.a. Cultural Appropriateness

This design norm considers the people who will be using this product and seeks to provide a solution that will be implemented well into the culture that it is presented.[57] Cultural appropriateness pertains to all elements of the solution, i.e. size, use, introduction, etc., and as such, must always be considered in making design decisions. Many technologies implemented in developing countries are performed with good intentions, but for various reasons the technology will not (or cannot) be sustained by the locals. Too often, the technology is not sustained because it is too complex and the locals are incapable of properly operating and/or maintaining the solution. Other times, it is because the solution is inappropriate within a society's culture.

Cultural appropriateness is of particular importance with this project because the project directly addresses a serious problem with one of life's most precious resources: water. Because of this, extra concern had to be taken to ensure the final product could be easily used and maintained by anyone, regardless of age and technical knowledge. In addition, it was important to create a product that would not impede on any society's culture. This was among many reasons that the extension mimics several of the Sawyer® filter's features such as portability, ease of use, etc. Because the Sawyer® PointOne membrane filter has been successfully implemented in many countries, mimicking its properties eliminates some fear of the products rejection due to cultural inappropriateness.

2.6.b. Caring

As Christians, we are called to concern ourselves with the needs of others (Phil. 2:4). The design norm of caring addresses that call by emphasizing the importance of bettering human life through technology.[57] As engineers, our work holds paramount the safety, health, and welfare of others and that empowers us to be agents of restoration. With this project, CLEAR H2O hoped to realize its potential as an agent of restoration and to create a filter that could potentially better the lives of many people.

2.6.c. Justice

Justice is the concept of right fulfillment for all individuals and encourages the designer to consider the impact that a design may have on the rights of others. Water is the most abundant resource on Earth and is essential in sustaining life. Humans need pure water to sustain their life. The World Health Organization states that 20-50 liters of water per person per day[5] is required for healthy living and as such uninhibited access to water is a right that every human should have. Yet the reality is that many people do not have access to this quantity of potable water. There are many reasons why individuals do not have access to pure water; this project focuses on individuals whose access is inhibited by arsenic contamination. By creating a filter that removes arsenic from water, CLEAR H2O is promoting justice and fulfilling our mandate to "act justly and love mercy" as highlighted in Micah 6:8.

2.7. Acknowledgements

CLEAR H2O would like to extend a warm thanks to the following individuals who offered their expertise, resources and time towards the completion of this project:

David Wunder from the Calvin Engineering Department, for giving advice and guidance throughout the year and for providing the initial idea for the project; Graver Technologies, Apyron, and Severn Trent, for providing free media samples for testing (MetSorb, AquaBind, and Bayoxide E33 respectively); Gerry Van Kooten and Ralph Stearley from the Calvin Geology Department for information on hematite and directions to Champion Mine; David Benson from the Calvin Chemistry Department, for information on arsenic chemistry; Prein&Newhof for providing free arsenic testing, and Robert Erickson, Steve Bylsma, and the lab team for performing the tests and providing results in a timely manner; Rich Huisman, for the help in making stock solutions and providing lab materials; Wayne Wentzheimer from the Calvin Engineering Department, for providing testing space in the chemical engineering lab; Jennifer Ambrose and Heather Chapman from EHS, for giving guidance with lab safety and waste disposal protocol; Phil Jasperse, for assisting in testing columns and prototype fabrication; Robert DeKraker, for purchasing the items needed for testing and prototype development; Calvin Engineering Department, for preparing CLEAR H2O for a project of this magnitude and for providing funds to make this project a reality; and finally, Sawyer® who has provided guidance and financial support throughout the duration of this project.

Steve Taplin would like to thank his gorgeous wife, Rachel, for her love and support throughout the entire senior design process. In addition, Steve would like to extend a special thanks out to his parents, Steve and Chellie Taplin, for their financial and moral support throughout his college experience. Furthermore, Steve would like to extend a big thanks to his teammates for the hard work and dedication that they have all put into this project. The successes of this school year could not have been accomplished without the group of hardworking and competent individuals Steve got to spend every day (and many late nights) with. Finally, Steve would like to thank all the individuals that sustained the team with delicious homemade food… you know who you are and your kindness has not gone unnoticed.

Lucas Timmer would like to extend his gratitude to his parents, Lou and Lisa Timmer, and his two sisters, Corrin and Caitlin, for their encouragement over his past four years at Calvin. Lucas would like to especially send his thanks to his twin sister Corrin, who encouraged him through the stress of his senior year. Lucas would also like to thank his Grandpa and Grandma Hoogland and Grandma Timmer for their support throughout the years. Lucas also would like to thank his girlfriend Molly Dahmer for her encouragement and for her patience with Lucas as he worked diligently on this project. Finally, Lucas would like to thank his fellow teammates who made this project happen. Lucas appreciates all of the work that they have put in to making this project a success, and Lucas looks forward to seeing where their friendships will head in the years to come.

Grant Mathews would like to personally thank Bill and Susan Mathews for support in attending Calvin College as well as his fiancé Blair Price for encouragement throughout the semester and for tolerating late Friday nights spent working in the lab. Grant would also like to thank Steve, Jesse, and Lucas for their tireless work and for their ability to make late nights working in the lab not completely unenjoyable.

Jeshua Short would like to personally thank his grandfather, Robert Short, for his financial support throughout the four years at Calvin. Greg and Janet Short, Jeshua's parents, have been incredibly encouraging over the years and have supported him through every decision and hard time. Ali Cavanaugh, Jesse's girlfriend was also an incredible support and showed a lot of patience as senior design consumed much of his free time. In addition, Jeshua would like to thank his fellow team members for their excellent work and promotion of fun during the project's entirety.

A final special thanks goes out to Mitchell Feria and Eyosias Ashenafi, the honorary 5th and 6th members of CLEAR H2O who collected hematite and conducted lab sampling for the team respectively.

3. Research

There were three areas for which extensive research was needed to move forward with the project: arsenic, existing arsenic-removal media, and media exhaustion indicators. A thorough understanding of each was required to take the next steps in creating and completing laboratory tests and developing a final prototype that would remove arsenic below the WHO guideline of 10 µg/L and indicate when it is no longer removing arsenic.

3.1. Arsenic Research

Arsenic research was necessary to gain a better understanding of the health effects of arsenic as well as to determine which areas are impacted by high levels of groundwater contamination. Research was also necessary to learn how arsenic enters groundwater and what factors might impact concentration levels. Finally, a better understanding of arsenic chemistry was needed for future lab tests.

3.1.a. Arsenic Chemistry

The following sections provide overviews of the research completed on various aspects of arsenic chemistry.

General Chemistry

Arsenic is a metalloid and a naturally occurring element with atomic number 33, shown in Figure 5. Arsenic, in its elemental form, is a solid with a yellow, black or steel-gray coloration. Arsenic is widely distributed throughout the Earth's crust, usually combined with sulfur and other metals; it is odorless and tasteless. When combined with oxygen, chlorine, or sulfur, arsenic is labeled as inorganic; when combined with hydrogen or carbon, arsenic is categorized as organic.[6]

Figure 5: Arsenic in its Many Different Elemental Forms[7-9]

Arsenic has many oxidation states; the two most prevalent forms found in groundwater are arsenite and arsenate. Arsenite, or As(III), is trivalent and its ion is AsO_3^{3-}. Arsenite often exists in two compounds combined with sodium: sodium meta-arsenite ($NaAsO_2$) and sodium ortho-arsenite (Na_3AsO_3). Up to a pH of 9, arsenite exists as non-ionic H_3AsO_3 (see Figure 6). Arsenite has a neutral surface charge up to a pH of 9, as shown in Figure 7. This speciation hinders ion attraction from occurring between arsenite and a positively charged media surface.[12]

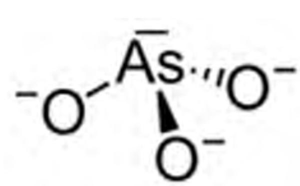


Figure 6: Chemical Structure of As(III)[11]

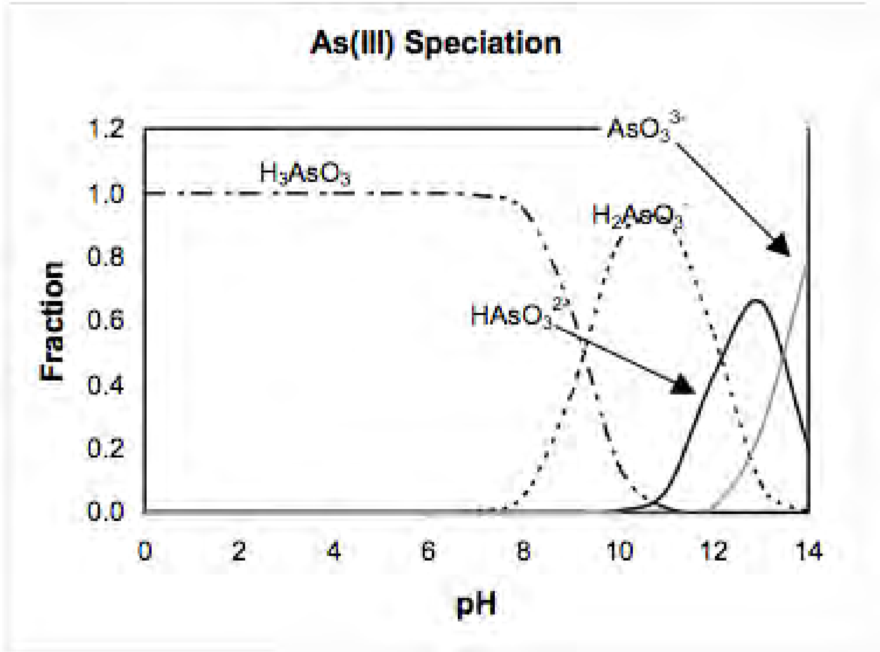


Figure 7: Arsenite Speciation[10]

Arsenate, or As(V), is pentavalent, and its corresponding ion is AsO_4^{3-} (see Figure 9). The non-ionic form of arsenate, H_3AsO_4, dominates at a pH below 2.3. At a pH greater than 2.3, ionic forms of arsenate dominate as shown in Figure 8. Because arsenate has negative ionic species above a pH of 2.3, arsenate can be removed by ion attraction with the removal media surface.

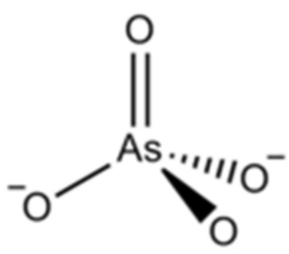


Figure 8: Chemical Structure of As(V)[13]

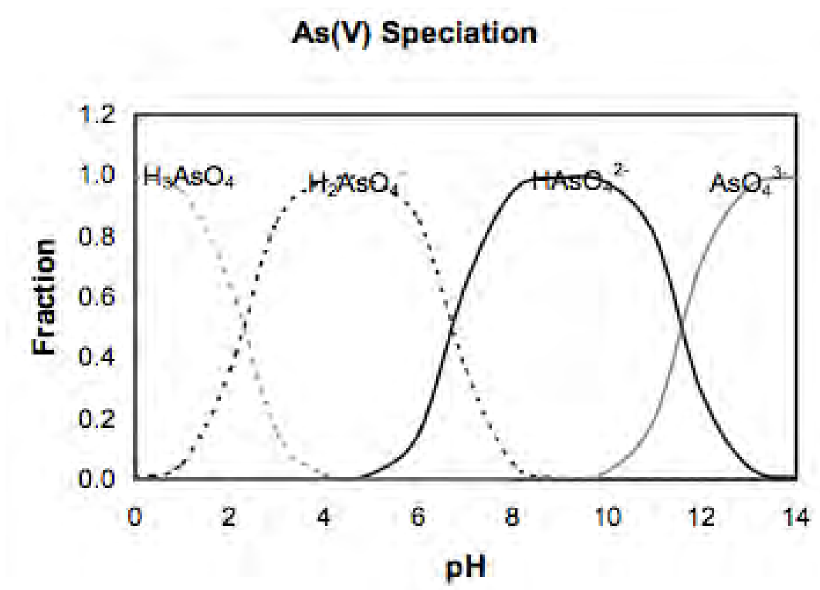


Figure 9: Arsenate Speciation[10]

Contamination of Water Sources

Arsenic contamination of water sources remains one of the biggest concerns of arsenic poisoning worldwide. Arsenic exists naturally and can be found in mineral deposits primarily with sulfur and other metals.[14] In groundwater where the pH is between 6.5 and 8.5, arsenic dissociates from its mineral deposit and contaminates the aquifer.[15] In addition, groundwater arsenic contamination is dependent on the time of exposure and the amount of arsenic present in the mineral deposits. The contamination generally occurs between 20 and 100 meters below the ground; below 100 meters underground, most arsenic deposits have been depleted and above 20 meters, the groundwater flows too fast for dissociation.[16] Figure 10 shows estimated risks of groundwater contamination based on hydrogeological conditions.[58]

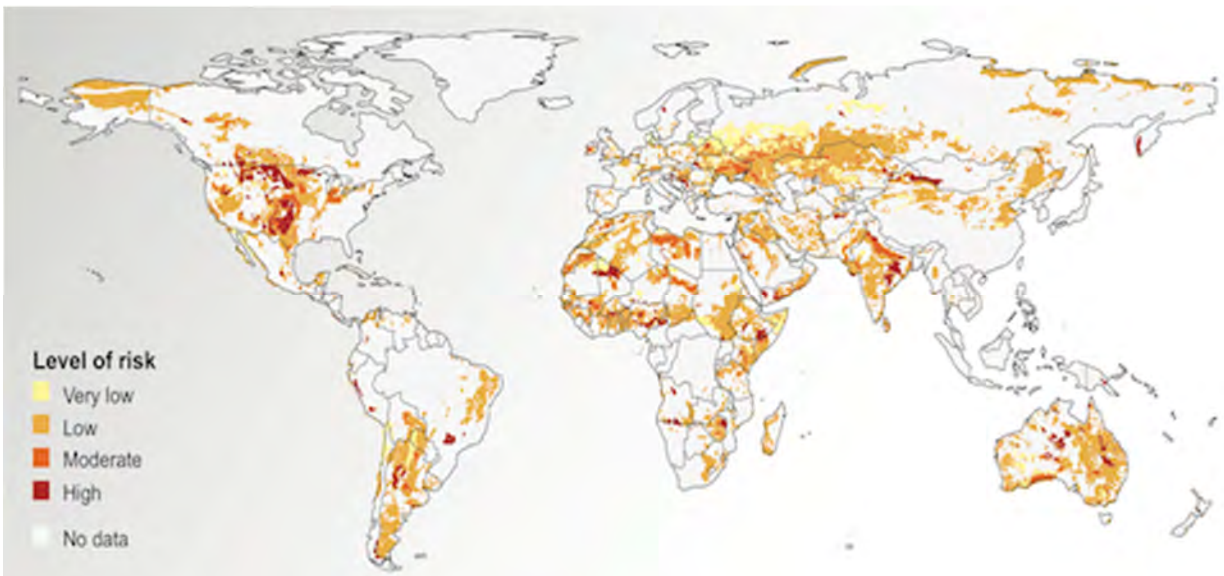


Figure 10: Estimated Risk of Arsenic in Groundwater Based on Hydrogeological Formations[58,59]

Although most arsenic contamination comes from natural means, anthropogenic arsenic poisoning is also a concern. Many pesticides contain arsenic and the runoff from the agricultural areas can contaminate surface waters at the receiving end of the storm runoff. In addition, arsenic is still used in industrial processes, such as in the production of semiconductors.[22] The waste generated by these industrial processes can also contaminate surface waters. Figure 11 shows the main sources of arsenic contamination.

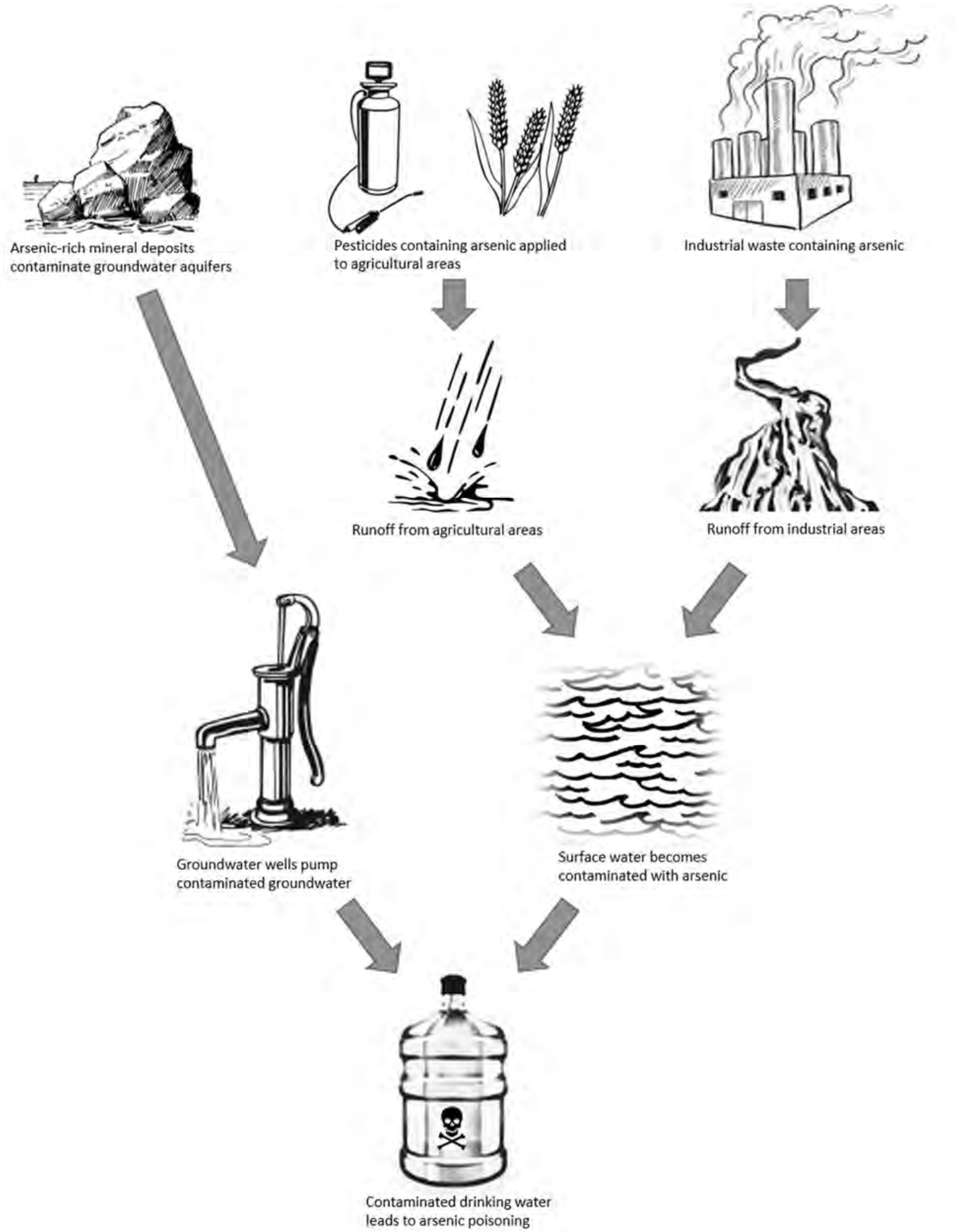


Figure 11: Main Sources of Arsenic Contamination

Adsorption Chemistry

Adsorption of arsenic to surface media occurs by three different processes. The first process is ligand exchange. A ligand is an ion/molecule that binds to a central metal atom to form a coordination complex. In the case of arsenate, the coordination complex is the three oxygen atoms, and the central metal atom is As(V). Ligand exchange occurs when one metal atom with a coordination complex replaces the coordination complex of another metal atom. In the case of activated alumina, the As(V) coordination complex bonds to the surface of the media after the release of a hydroxide and water molecule, as shown in Figure 12.

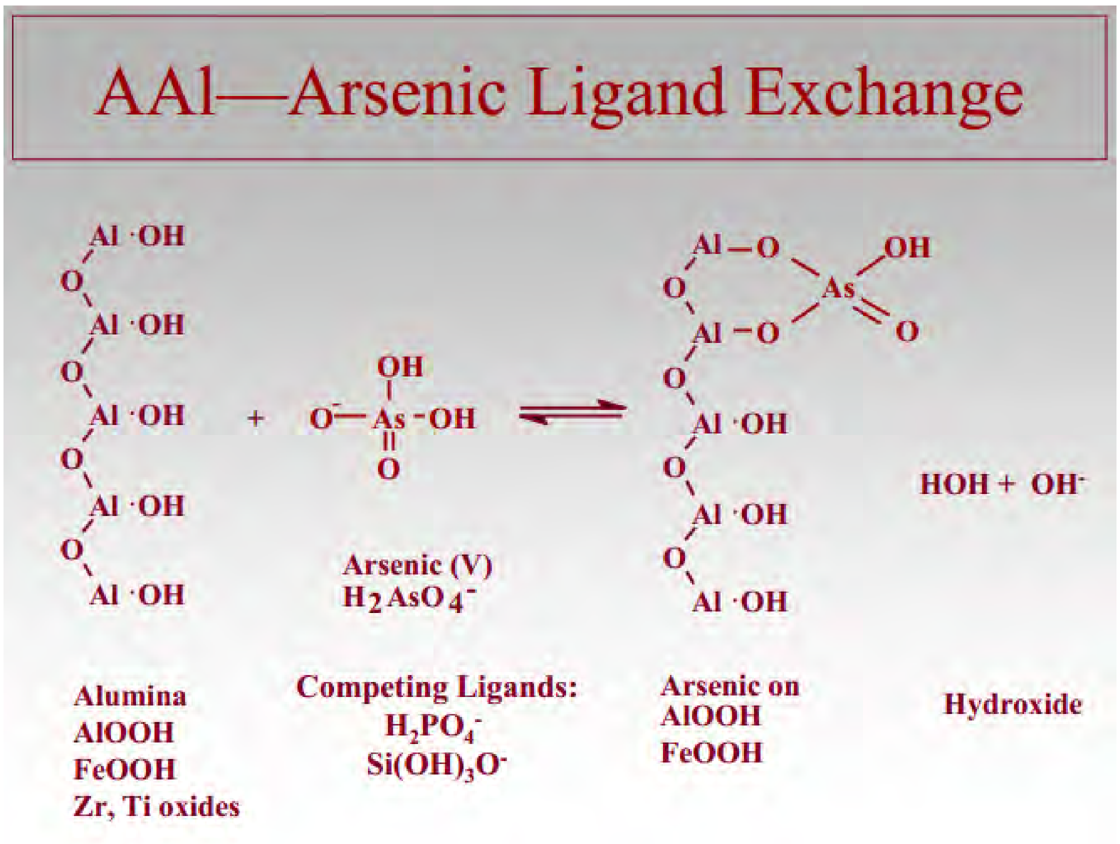


Figure 12: Chemical Adsorption of Arsenic to Aluminum and Iron Oxides by Ligand Exchange[17]

The second process of adsorption is ion exchange. Ion exchange involves the passing of ions from one electrolyte to another. This process is also known as electrostatic attraction. Acidity of the solution has a significant impact on the ability of a media surface to undergo ion exchange with arsenic. As pH increases, the media surface charge will change from positive, to neutral, and finally negative. The zero-point charge pH is the pH at which a media surface has a neutral charge. Experimental research from the Awwa Research Foundation (AwwaRF) indicates the zero-point charge of activated alumina is around 6.4 while iron-based media GFH and Bayoxide E33 have zero-point charges of 7.0 and 7.3, respectively.[18]

The final process of adsorption is surface precipitation. In this process, arsenic turns into a solid after contacting the media surface. Arsenic then readily diffuses to the surface of the media and is removed from the solution. The combination of these three adsorption processes results in the removal of arsenic from a solution to a media surface.

3.1.b. History of Arsenic

Regulatory History

In 1942, the United States Public Health Services (USPHS) set an interim drinking water standard at 50 µg/L; in 1962, the goal was set at 10 µg/L. This level was ruled as a minimum standard by the EPA in 2002, and as of 2006, 10 µg/L is officially enforced as the standard of compliance.[2] The World Health Organization has recommended the same minimum standard of 10 µg/L since 1993.[3] This level was chosen as the practical quantitation limit (PQL) due to limitations in testing and detection.[19] Because of these detection difficulties and compliance issues, many developing countries still only require the pre-1993 standard of 50 µg/L.[20] The maximum contaminant level goal (MCLG) set by the EPA is zero. This is the level for which there are no possible health effects.[19]

Historical Uses of Arsenic

Arsenic, in various forms, has a long history of use for different purposes. Due to its odorless and tasteless nature, arsenic was often used as an effective poison prior to 1836, the year when James Marsh developed a method for determining, post mortem, the presence of arsenic in bodily fluids. In the first half of the 20th century, arsenic was used in pesticides, and until 2003, copper chromated arsenate was used as a preservative in wood to resist decay.[21] Currently, arsenic is still widely used in the form of gallium arsenide and arsine gas, both of which are components in semiconductors.[22]

3.1.c. Health Effects of Arsenic

Typically, arsenic exposure occurs through ingestion, inhalation, and/or dermal interactions.[22] After exposure, the arsenic enters the body and disrupts cell enzyme activity and the production of adenosine triphosphate (ATP). The disruption of ATP prohibits cellular function and causes the affected cells to slowly die.[23] Acute inorganic arsenic poisoning occurs when a subject consumes approximately 0.6 mg/kg/day.[22] The symptoms of acute poisoning can be seen throughout the body's systems and include nausea, diarrhea, abdominal pain, excessive salivation, toxic cardiomyopathy (deterioration of heart muscle), skin rash, and seizures. It is not uncommon for renal and or respiratory failure to occur.[22] Chronic arsenic poisoning is also problematic and can take years to manifest. Health effects caused by long term exposure include skin lesions and hyperkeratosis (hardening of the skin), cancers, diabetes, neurotoxicity, and cardiovascular disease.[2] Because of arsenic's severe acute and chronic effects it has recently been listed as one of WHO's *10 Chemicals of Major Health Concern*.[2]

3.1.d. Global Concentrations

Because arsenic is a naturally occurring element, it is present globally, but usually in very low concentrations. The average range for arsenic levels in soil is 3 to 4 mg/kg.[24] In groundwater, the concentration of arsenic is usually below 10 µg/L. Regions where arsenic levels can be unusually high include mining areas, industrial sites (especially where electronic components are produced), waste disposal sites, agricultural areas with high pesticide use, and geologic formations containing arsenic-rich minerals.[24] Some regions with elevated concentrations of arsenic include Bangladesh, Argentina, Vietnam, and West Bengal, India. The United States also contains high arsenic concentrations as seen in Figure 13.

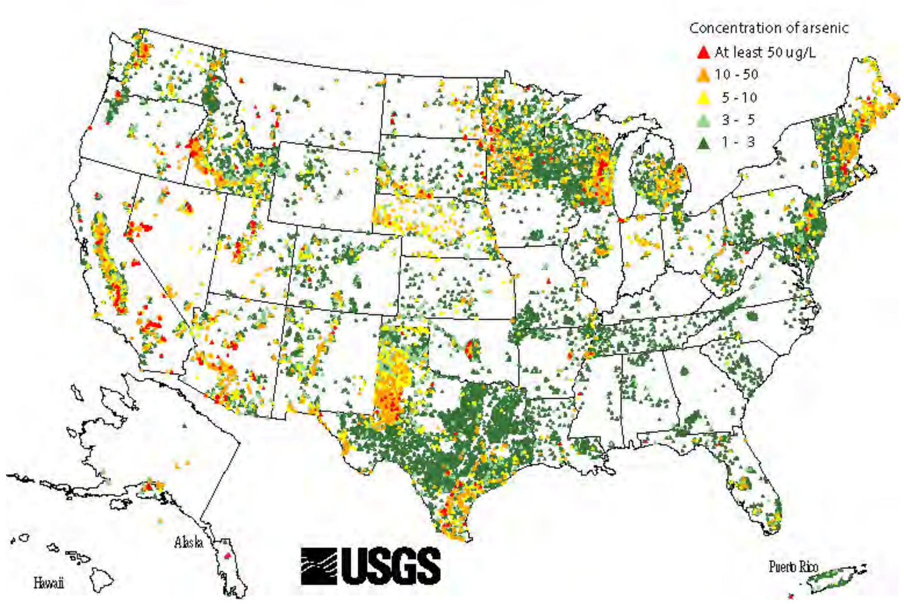


Figure 13: Arsenic Concentration in the United States of America[60]

Case Study: Bangladesh

The threat of arsenic poisoning is perhaps most severe in Bangladesh. In the 1970s, UNICEF began installing tube wells to give the people of Bangladesh an alternative to drinking microbial-contaminated surface water. These wells were not screened for arsenic because, at the time, it was not a known contaminant. There are now over 8 million tube wells in Bangladesh from which 90% of the population receives its drinking water.[25] Increasing awareness of arsenic contamination led to the World Bank screening wells in Bangladesh in 1998. Concentrations as high as 3000 µg/L were found. In 2001, the number of people in Bangladesh drinking contaminated water exceeding 10 µg/L was estimated to be 46 - 57 million.[25] The high levels of arsenic-rich mineral deposits found in Bangladesh results in elevated levels of arsenic in its groundwater. This, coupled with the country's low income and lack of treatment facilities, results in a high risk for contamination. See Figure 14 for arsenic levels across the country; this data was gathered by the British Geological Survey.

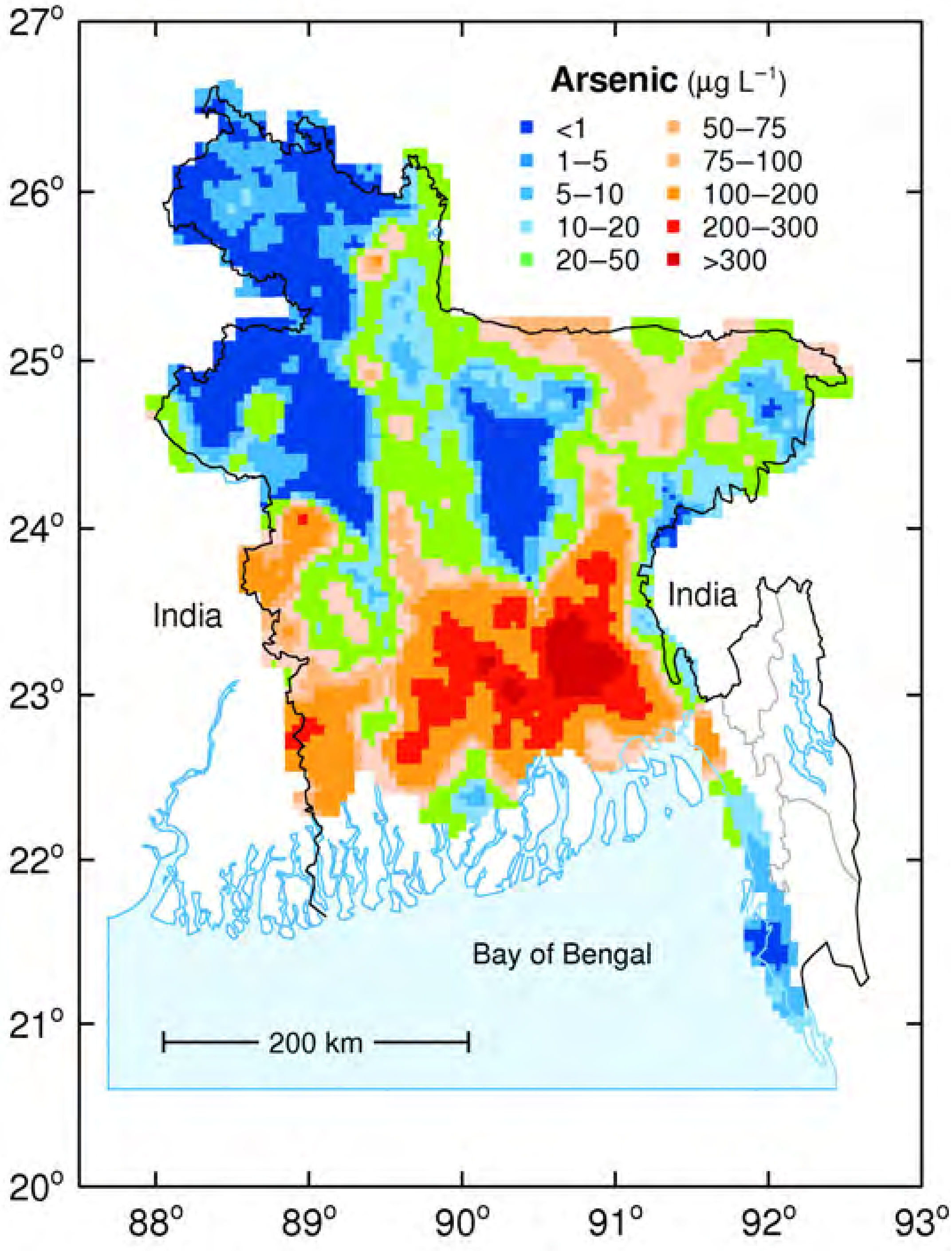


Figure 14: Arsenic Concentrations in Bangladesh[1]

3.2. Removal Media

Arsenic can be removed using one of three methods: membrane filtration, ion exchange, and removal media. The energy required to pressurize an effective membrane filter was not practical for this project. Furthermore, ion exchange was not considered an option due to the limitability of available ion exchange research and necessary distributors. Media-based filtration was the only alternative thoroughly researched due to the wide array of both media types and removal media literature available. In addition, Dr. David Wunder generously provided his research on arsenic-removal media, affirming the selection of arsenic-removal media as the agent of filtration.

There are many arsenic-removal media available, including manufactured media and natural minerals that can be pulverized and created into media. To select media for testing, CLEAR H2O needed to determine what media were available and the criteria needed in the selection and elimination of available media.

3.2.a. Available Media

The EPA splits arsenic removal media into three categories: iron and iron-coated, alumina-based, and other.[27] CLEAR H2O retained these media categories, but redefined the iron and iron-coated media to iron-based: natural minerals and iron-based: engineered media to incorporate the research that was conducted on natural minerals.

Iron-Based: Natural Minerals

Iron oxide media largely consists of pulverized minerals containing iron oxides. The following four minerals contain iron oxides and are used in engineered media: hematite, magnetite, goethite, and akageneite. Chemical formula and media characteristics are highlighted in Table 3.

Table 3: Iron-Based, Natural Minerals

Mineral	Chemical Formula	Appearance/Characteristics
Hematite[29]	Fe_2O_3	black/gray, brownish-red; shiny luster (if specular)
Magnetite[30]	$Fe^{2+}Fe^{3+}O_4$	specular and black; strongly magnetic
Goethite[31]	$FeO(OH)$	black or yellowish-brown
Akageneite[32]	$Fe^{3+}O(OH,Cl)$	brown

Iron-Based Media: Engineered Media

The four minerals detailed in the previous section and other iron oxides/iron hydroxides are the primary components of various manufactured media types. To simplify media research, the team only investigated the following iron-based media that the EPA recommended for arsenic removal: Bayoxide E33, GFH, Media G2, and ARM 200. The manufacturers of these media and their primary constituents are highlighted in Table 4.

Table 4: Iron-Based, Engineered Media

Media	Manufacturer	Primary Constituent
Bayoxide E33[33]	Severn Trent	Goethite
GFH[34]	Siemens	Akageneite
Media G2[35]	Indachem	Ferric-hydroxide
ARM 200[36]	Engelhard	Hematite

Activated Alumina Media

Along with iron-based media, alumina-based media is also widely used in the removal of arsenic in water. The team analyzed four different activated alumina medias recommended by the EPA: AA-400G, AA-FS50, CPN, and AquaBind EP. These media and their manufacturers are displayed in Table 5.

Table 5: Alumina-Based Media

Media	Manufacturer
AA-400G[37]	Delta Adsorbents
AA-FS50[37]	Delta Adsorbents
CPN[27]	BASF
AquaBind[38]	Apyron Tech.

Other Media

One media investigated that is neither iron-based nor alumina-based is MetSorb. Graver Technologies created MetSorb, a titanium dioxide media, to remove arsenic from water.

3.2.b. Existing Media Applications

The following sections look specifically at existing applications of activated alumina and iron-based sorbents in both small- and large-scale operations.

Large-Scale Filtration Systems

Municipalities throughout the United States utilize arsenic removal media to maintain the 10 µg/L MCLG. An example of a municipality incorporating arsenic removal media is Hilltown Township in Pennsylvania. The township had arsenic concentrations exceeding 20 µg/L in its groundwater and thus implemented a 300 gpm SORB 33 system that utilized Bayoxide E33 to remove the arsenic.[40] Like Hilltown Township, Clayton, Delaware also has arsenic concentrations above 10 µg/L in groundwater. To combat the contamination, GFH was added to the existing disinfection system.[41] Yet another example, California wineries recently incorporated MetSorb into a large-scale filtration system that provides water used in processing and irrigation for the wineries.[42]

Point-of-Use Filters

Point-of-use filters are applied in many homes that obtain water with known elevated levels of arsenic. These filters are usually implemented under the sink and contain arsenic-removal media, a filter, and flow control with an automatic shut-off valve. PureEarth Technologies markets household POU filtration systems that incorporate Bayoxide E33 to remove arsenic.[43] One filter system that PureEarth markets is their Model CT-AR (see Figure 15).[43]

Figure 15: Model CT-AR Countertop Arsenic Filter[43]

There are a few unique situations where POU filters have been designed for specific developing regions. Organizations have incorporated large-scale POU filters into wells in villages to provide water free of arsenic to whole communities. An example of a community point-of-use filter is Apyron's integrated system, which has been implemented in rural villages in India and Bangladesh.[44] This community filtration system removes arsenic "from levels exceeding 3,500 µg/L to below 50 µg/L" in up to 17,000 liters per day.

3.2.c. Test Media Selection

CLEAR H2O established a list of criteria to indicate which media out of the thirteen researched would undergo batch testing. Criteria evaluated both media performance and accessibility. A decision matrix was created to assist in the selection and elimination of media based on how well the media fulfilled the established criteria.

Criteria for Media Selection

The first two criteria were removal efficiency and time to breakthrough. To eliminate product biases generated by their respective companies, CLEAR H2O used two EPA presentations as independent sources to compare iron-based, alumina-based, and other media's removal efficiencies and time to breakthrough.

The results of two tests determining media removal efficiencies were found in the EPA's *Media Performance: Laboratory Studies* presentation. The first test tested the removal efficiencies of thirteen different media with varying media masses in solution at an arsenate concentration of 100 µg/L. The second test was with a 100 mg/L media dose and an As(III) concentration of 100 µg/L. The results of these tests were used to quantitatively weigh media's removal efficiencies and can be seen in Figures 16 and 17.

The second criterion was the bed volumes that could be treated prior to breakthrough. Tom Sorg and Darren Lytle of the EPA did breakthrough tests on several of the aforementioned media. The results of their test were included in the *Treatment Options Part 1* presentation, they can be seen in Figure 18. The results of this test were used to quantitatively weigh the media's time to breakthrough.

The final criterion chosen to assess the media was accessibility. The media candidate must have easily accessible information on its website and distributor contact information. The distributor must also respond promptly to either phone or email correspondence. Finally, to ensure a wide variety of media was tested, at least one media from each of the three engineered media categories (iron-based, alumina-based, and other) and at least one natural mineral was selected for testing.

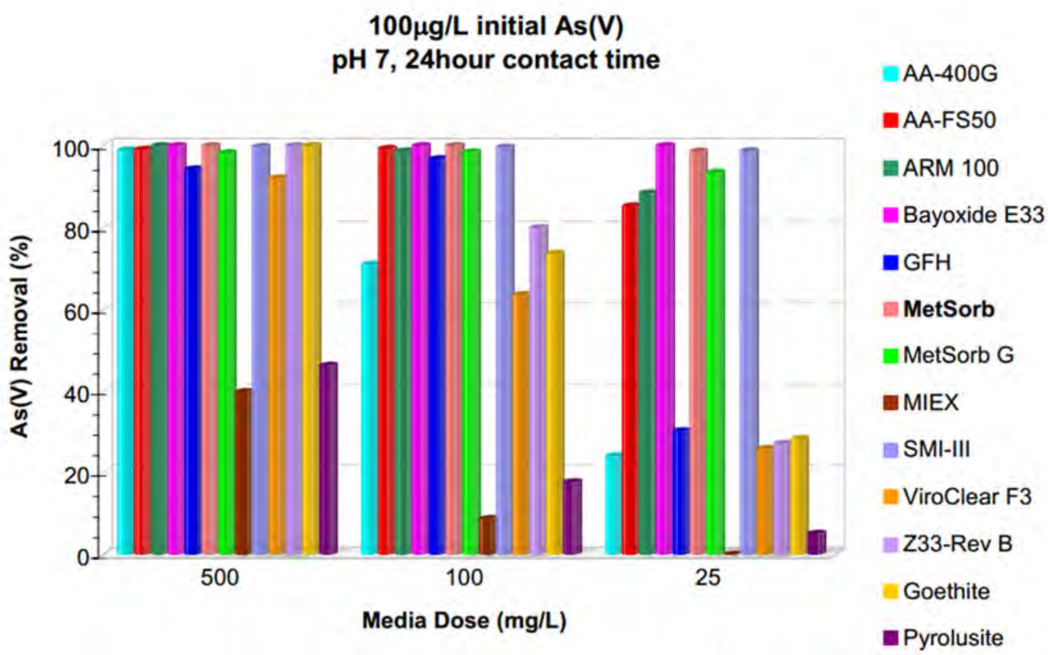


Figure 16: As(V) Removal in Thirteen Adsorption Media[14]

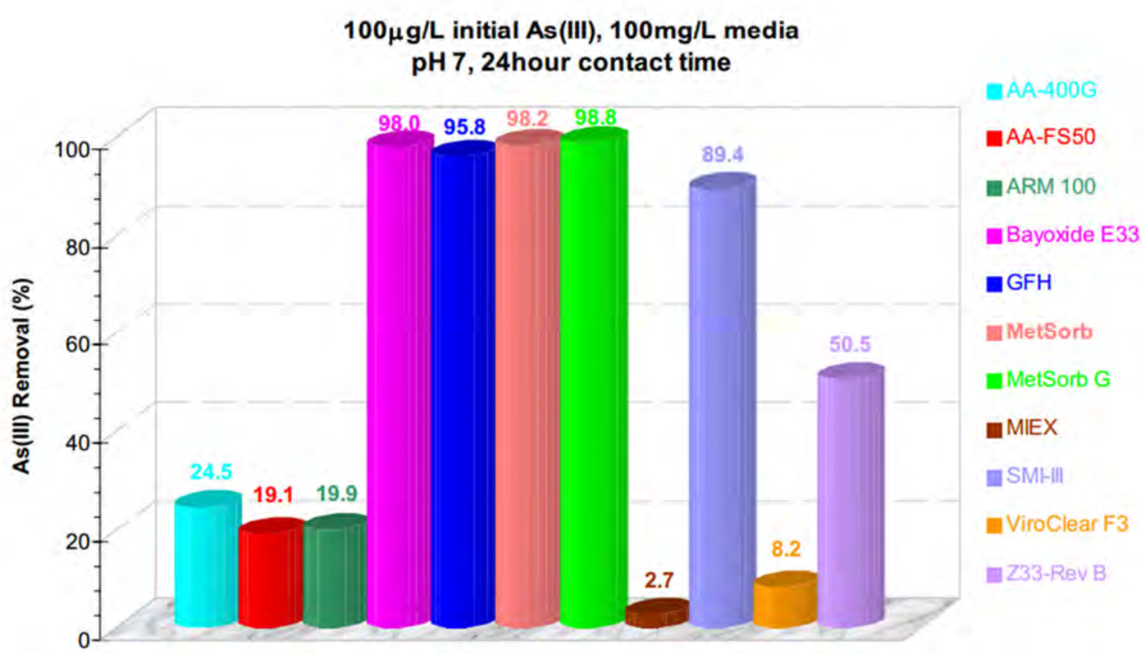


Figure 17: As(III) Removal in Ten Adsorption Media[14]

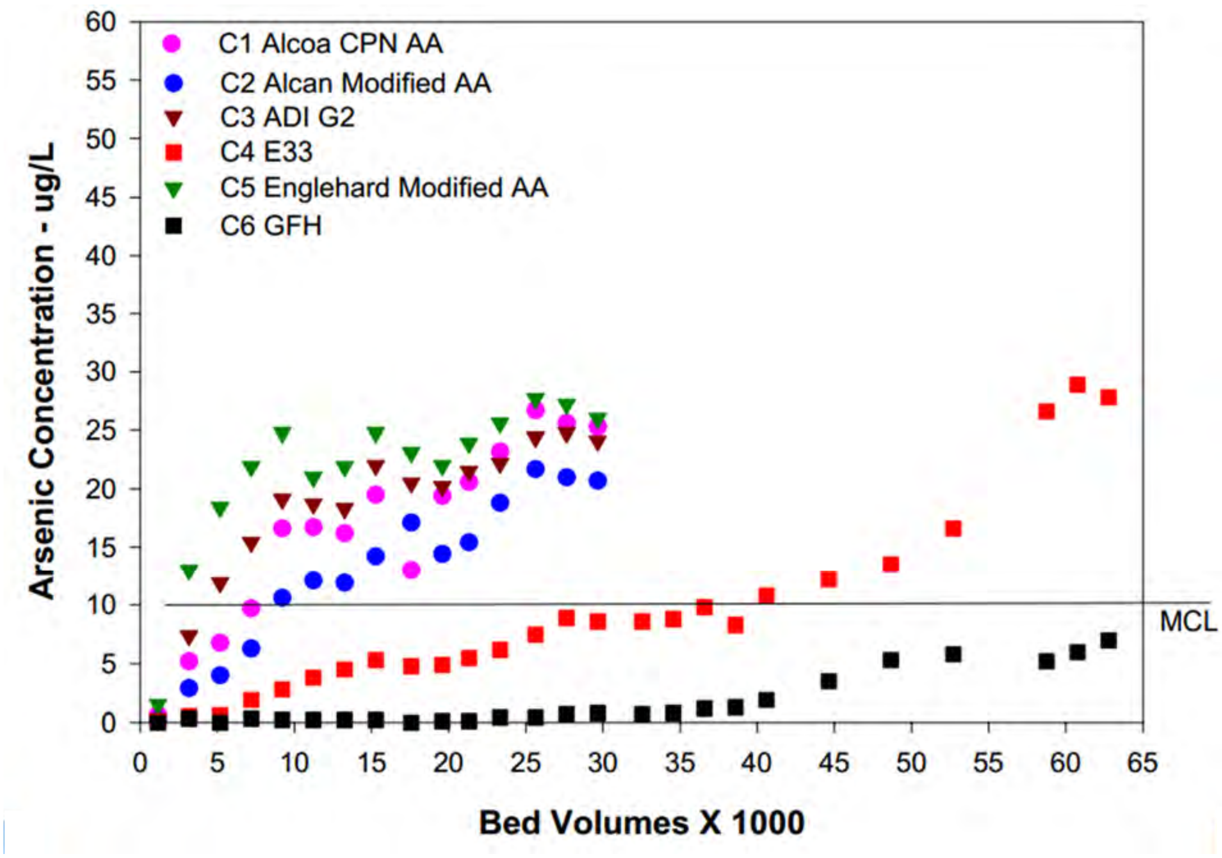


Figure 18: Bed Volumes of Six Different Media[46]

Using the three criteria detailed above, a decision matrix was generated to assist media selection (see Table 6). Removal efficiency was given a weight of 5. The removal efficiencies of both As(III) and As(V) are important; nonetheless, time to breakthrough and accessibility were deemed more important, resulting in a slightly lower weight for removal efficiency. The time to breakthrough criterion was given a weight of 8 because filter media longevity was crucial for the intended application. Finally, accessibility was given a weight of 9. This weight was the highest because CLEAR H2O did not have substantial time to obtain media before testing.

Table 6: Testing Media Selection Decision Matrix

	Weight (1-10):	Media 1	Media 2
Removal Efficiency	5		
Time to Breakthrough	8		
Accessibility	9		
	Total Score:		

Selected Media

Prior to selecting an iron-based natural mineral, the Calvin College Geology Department was consulted to determine whether any of the four minerals (hematite, magnetite, goethite, and akageneite) would be accessible. Professors Ralph Stearley and Gerry VanKooten both indicated that hematite would be easily obtainable in Michigan. The recommended site for hematite collection was Champion Mine (an iron mine located in Michigan's Upper Peninsula). Thus, hematite was selected as the natural mineral for the group to test due to the ease in accessibility (see Table 7).

CLEAR H2O gathered raw specular hematite from Champion Mine in November 2013. The team drove to the Upper Peninsula for a weekend of hematite gathering and Pictured Rocks sightseeing. Hematite of various sizes was gathered, including a large hematite rock and hematite grains that layered the soil in the area. For more on the trip to the Upper Peninsula, visit:
http://www.calvin.edu/academic/engineering/2013-14-team6/gallery.html.

Table 7: Decision Matrix for Iron-Based, Natural Minerals

	Weight (1-10):	Magnetite	Goethite	Akagenite	Hematite
Removal Efficiency	5	N/A	N/A	N/A	N/A
Time to Breakthrough	8	N/A	N/A	4	N/A
Accessibility	9	4	2	2	10
	Total Score:	36	18	32	**90**

Bayoxide E33 was selected as the iron-based mineral because of its high arsenic removal efficiencies for As(III) and As(V) (Figures 16 and 17), its high bed volumes (Figure 18), and accessibility. ARM 200 was eliminated because no information on its bed volumes or removal efficiencies was included in the two EPA documents. Media G2 was eliminated because of its low bed volumes compared to GFH and Bayoxide E33. Bayoxide E33 and GFH were comparable in removal efficiency and bed volumes. Thus, both media manufacturers were contacted to see how accessible their media were. Immediately following initial correspondence, Severn-Trent offered to send a cubic foot of Bayoxide E33 for free. Several attempts were made to contact Siemens for GFH without success. Thus, Bayoxide E33 was selected over GFH (see Table 8).

Table 8: Decision Matrix for Iron-Based, Engineered Media

	Weight (1-10):	GFH	Media G2	ARM 2000	Bayoxide E33
Removal Efficiency	5	8	N/A	N/A	9
Bed Volumes	8	9	2	N/A	8
Accessibility	9	4	N/A	N/A	10
	Total Score:	148	16	N/A	**199**

AquaBind EP was selected as the activated alumina media. CPN, AA-400G, and AA-FS50 had mediocre As(III) removal efficiencies and bed volumes. AquaBind EP was not included in the two EPA presentations; however, it had been used in POU filters in India and Bangladesh. Research by the United Nations University, which used a filter with AquaBind EP media in Bangladesh, confirmed that AquaBind can remove significant concentrations of As(III) and As(V). Finally, Apyron Technologies was contacted and was willing to provide the activated alumina requested; however, after describing the application of the media, Apyron suggested testing two of their other media instead. The two media were AquaBind SP-70, an iron-based engineered media, and AquaBind MP, an alumina-based media. CLEAR H2O accepted Apyron's recommendation and thus, selected AquaBind MP as the alumina-based media (see Table 9). In addition, AquaBind SP-70 was also acquired.

Table 9: Decision Matrix for Activated Alumina

	Weight (1-10):	AA-400G	AA-FS50	CPN	AquaBind MP*
Removal Efficiency	5	4	4	N/A	N/A
Bed Volumes	8	2	2	4	N/A
Accessibility	9	4	4	N/A	10
	Total Score:	72	72	32	**90**

MetSorb was selected due to its high removal efficiencies and MetSorb's uniqueness as the only titanium dioxide media on the market. After contacting Graver Technologies, they agreed to provide free media for testing.

Conclusion

The previous sections detailed the selection process of the five media seen in Figure 19. The media include: AquaBind MP, AquaBind SP-70, Bayoxide E33, Hematite and MetSorb.

Figure 19: Testing Media Selected

3.3. Media Exhaustion Indication

Indicating when the filter is no longer adequately removing arsenic was a constraint of this project. Thus, extensive time was dedicated to researching an effective method for communicating filter exhaustion. Current methods were examined and a variety of potential options were selected for further research.

The researched media exhaustion indication methods were split into three categories: concentration-dependent, volume-dependent, and time-dependent.

3.3.a. Arsenic Concentration Dependent Methods

Three possible methods were researched for indicating exhaustion dependent on the effluent arsenic concentration: field test kits, a quartz crystal microbalance sensor, and the potential for a new undeveloped method for colorimetric indication.

There are many field test kits, such as the *Sensafe Econo-Quick* kit, on the market that effectively indicate concentrations of arsenic to within one colorimetric indicator. The kit requires three reagents and a testing time of 15 minutes. The largest test kits costs greater than $200 for 100 test strips. See Figure 20 for an example of the test strip and reference sheet.

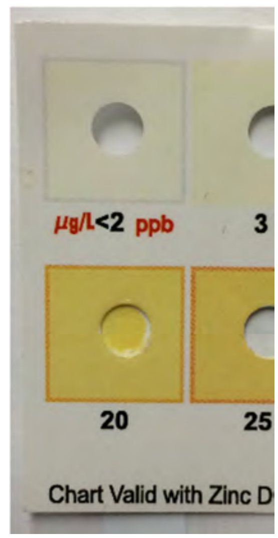


Figure 20: Econo-Quick II Test Kit, Indicator Strips and Reference Sheet

Another indication method researched was a quartz crystal microbalance (QCM) sensor. The QCM sensor uses complex chemical reactions to accurately measure arsenic to levels below 10 µg/L with a cost that exceeds $3,000.[47]

CLEAR H2O hoped to find a method for indicating arsenic concentrations through a colorimetric reaction or method of oxidation indication. There was also discussion about a theoretical design that contained a material that would precipitate when in contact with concentrations of arsenic exceeding 10 µg/L and proceed to plug the filter. However, after a significant amount of research, it was determined that there was no existing method similar to those described.

3.3.b. Volume Dependent Methods

CLEAR H2O evaluated two different volume-dependent exhaustion methods: a volumetric totalizer and a manual counter. The volume-dependent method assumes an influent arsenic concentration and shuts off after a designated volume has flowed through the filter.

The volumetric totalizer method would attach to the filter extension and indicate the volume of water that passes through the filter. A pre-determined minimum bed volume before exhaustion would then be incorporated into the totalizer to result in some form of indication (flashing light, beep, closed valve) that would warn the user that the media is exhausted.

The DigiFlow 8300T-L by Savant Electronics and the Assured Automation Bronze Water Meter - WM2 Series are both volumetric totalizers that could be used to indicate exhaustion; see Figures 21 and 22. The Digiflow flow meter is battery-powered, requires pressurized flow, and has an LCD screen that will indicate to the user when a predetermined volume has passed through the totalizer. Like the Digiflow flow meter, the WM2 requires pressurized flow for operation. Unlike the Digiflow, the WM2 does not require batteries and does not indicate to the user when a certain volume has passed through the totalizer; it merely displays the volume that has passed.

Figure 21: DigiFlow 8300T Flow Meter[48]

Figure 22: Assured Automation Bronze Water Meter[49]

The other method researched was a manual counter. Every time a specified volume, e.g. a full 5-gallon bucket, has passed through the filter, the user would activate the counter. Ideally, after a specified number of counts that corresponds with the exhaustion bed volume, a valve would close either manually or automatically and thus prevent further flow in the system.

3.3.c. Time Dependent Methods

The third method researched for indicating media exhaustion was a time-dependent methodology. This form of indication is based on an anticipated consumption rate and an estimated influent arsenic concentration. Based on these predicted values, a filter life would be established. After the filter life has passed, the indicator would then go off.

Figure 23: Brita® Calendar Minder®[50]

Brita® filters traditionally come with an Electronic Filter Change Indicator; however, they also offer a Calendar Minder® indicator for certain products; see Figure 23. This indicator is a little dial calendar that you set a predetermined time ahead (usually 3 months). When the actual date is the same as that on the dial calendar, filter exhaustion has occurred, and the filter must be replaced.[50]

Tetra implements time dependent filter exhaustion indication methods for their activated carbon filtration cartridges. Specifically, Tetra uses Timestrip® indicators that work by depressing the button at the bottom of the time strip (see Figure 24). After a designed length of time (1 month for Tetra filters) the white area of the strip will fill completely with an opaque dye, indicating filter exhaustion. The user then replaces the filter and time strip, and then repeats the process.[51]

Figure 24: Tetra Timestrip®[51]

3.3.d. Media Exhaustion Method Selection

Criteria for Media Exhaustion Method Selection

Four criteria were used to select the final media exhaustion indication method. The four criteria were cost, accuracy, ease of use, and robustness. A decision matrix including these four different criteria was used to help unbiasedly select a final indication method. Safety was the most important consideration in selecting an indication method, and as such, the safety of the user was imbedded within the evaluation of the final three of the four aforementioned criteria.

The cost criterion includes the cost of the media exhaustion indicator and the additional costs to implement the indication method. It was given a weight of 8 out of 10 (10 being the most important) because the cost of the filter, including the indicator, must be inexpensive for all potential buyers, be competitive with existing filters and encourage bulk donations.

The time-dependent method received the highest score for the cost criterion with a score of 9. The cost of the time-dependent Timestrip® method was fairly negligible, <$1, thus resulting in its high score. Unlike Timestrip®, the flow meters and additional equipment required to pressurize the system for a volume-dependent method cost anywhere from $30-$400, resulting in a lower score of 6. Finally, any concentration-dependent method would incur a cost of over $200, with the most promising technology costing over $3,000. For this reason, concentration-dependent received a cost score of 1.

The accuracy criterion evaluates the precision of the media exhaustion indicator in indicating exhaustion. Of the four criteria, accuracy was given the lowest weight at 5. Although the ideal indicator would be precise at determining exhaustion, the indicator can be designed with a significant safety factor, assuming worst-case conditions. This overdesign would considerably reduce the threat of arsenic exposure due to the under-utilization of the media.

Concentration-dependent methods indicate arsenic breakthrough directly and precisely and for this reason, were awarded the highest score of 9. Both volume-dependent and time-dependent methods do not measure arsenic concentrations at all. However, volume-dependent methods only rely on one assumption, the concentration of the filter influent, whereas time-dependent methods rely on both an assumed concentration and volume. For this reason, volume-dependent methods received a score of 4 and time-dependent methods received a score of 2.

The third criterion was ease of use. Ease of use pertains directly to cultural appropriateness because the design must be easily usable and interpretable by all, regardless of cultural and/or technical background. A likely safety failure of the filter would be the misinterpretation or misuse of the indicator; hence, ease of use was given a weight of 9.

The time-dependent method earned the highest score for the ease-of-use criterion with a score of 9 due to its simple function and its apparent visual indication of exhaustion. Volume-dependent methods require the user to operate mechanical parts and understand the output of the device, both of which increase the complexity of the indication, resulting in a score of 4. The available concentration-dependent methods are exceedingly difficult for an uneducated user to use, resulting in a low score of 2.

The final and most heavily weighted criterion, with a score of 10, was robustness. The most plausible mode of indication failure would be the breakdown of the indicator due to user and distributor negligence, climatic conditions, unavoidable accidents, etc. An indicator failure exposes the user to potential arsenic poisoning and is therefore intolerable.

The time-dependent method was deemed the most robust method with a score of 5. The low-score is due to the potential of time strips failing by not releasing their dye or starting too early during shipping and distributing of the filter. The volume-dependent method received a score of 3 due to the increased potential of failure due to electronic circuitry and moving parts. The electronic circuitry of the QCM indicator and the chemicals of the test kit are also likely to fail in non-room temperature climates, earning a score of 2.

Selected Indication Method – Time-Dependent

The time-dependent method received the highest score on the decision matrix as shown in Table 10, and was chosen as the media exhaustion indicator method. Unfortunately, accuracy received the lowest score with time-dependent methods, but this will be compensated for by assuming a worst-case volume and concentration and the inclusion of a significant safety factor that will reduce the chance of post-exhaustion filter use.

Table 10: Decision Matrix for Media Selection

	Weight (1-10):	Concentration-Dependent	Volume-Dependent	Time-Dependent
Cost	8	1	6	9
Accuracy	5	9	4	2
Ease of Use / Interpretation	9	2	4	9
Robustness	10	2	3	5
	Total Score:	91	134	213

Timestrip® Time-Dependent Indicator

A Timestrip® will be used as the time-dependent indicator. The Timestrip® is the safest option researched and also the most culturally appropriate option because of how easy it is to use and interpret. In addition, Timestrip® has been successfully used in a variety of applications including water filters, cosmetics, healthcare diagnostics, and refrigeration filters.[51] The following case studies illustrate the effectiveness of the Timestrip® indicator.

3M uses the Timestrip® in its water filtration division, Filtrete, to indicate when its Filtrete Water Station (a filter attached to tap water that flows directly into four reusable bottles) has reached exhaustion after three months of usage.[51] Whirlpool uses the Timestrip® to indicate when its Microban Anti-bacterial Filter (which removes mold and bacteria from the circulated air enter a refrigeration) needs to be replaced.[51] Both these applications depend on the Timestrip® to indicate when their filters need to be replaced to ensure that the user is not using the exhausted filter that is no longer safe.

4. Initial Lab Testing

Prior to actual lab testing, research on common laboratory tests used to characterize media filtration effectiveness and the feasibility of testing for arsenic was performed. With this research completed, batch and column lab plans for determining particularly important characteristics of arsenic removal media were developed and completed. Several batch and column tests were then conducted over a seven-month period. The results from these initial tests were used to select the prototype media.

4.1. Feasibility

During the initial project definition, three potential target contaminants – arsenic, fluoride, and pesticides – were considered. Arsenic was the preferred contaminant for removal for both CLEAR H2O and Sawyer®; however, there was uncertainty whether economical testing would be feasible with the limited resources available at Calvin College. Prior to finalizing arsenic as the target contaminant a secure lab location had to be identified, as well as an economical testing method.

4.1.a. Available Laboratory Facilities

Prior to beginning testing, a secure laboratory facility with additional capacity had to be located. The lab had to be equipped with a fume hood and a floor drain to accommodate testing needs. Calvin had two secure facilities that had the needed equipment and space for testing. Both labs were used throughout the project duration.

4.1.b. Laboratory Health and Safety

In addition to finding a laboratory facility, safety precautions were considered prior to testing. CLEAR H2O met with Calvin Environmental Health and Safety (EHS) and discussed necessary safety precautions. EHS provided waste storage containers, personal protective equipment, and safety signs identifying that arsenic was being tested in the lab. A City of Grand Rapids permit for arsenic disposal was also obtained by EHS. The permit allowed arsenic concentrations of up to 700 µg/L to be disposed down the drain. Although no solutions used for testing were near this concentration, the waste was analyzed and the results sent to the City of Grand Rapids' water pollution control officer before disposal.

4.1.c. Available Testing Methods

Prior to any lab testing, a reliable method for testing arsenic concentrations in water had to be determined. Two potential methods were identified: external laboratory testing and field test kits.

External Laboratory Testing

Prein&Newhof, a local engineering consulting firm certified by the Michigan Department of Environmental Quality (MDEQ) for arsenic testing, was the preferred lab identified for sample testing due to its close proximity to, and connection with, Calvin. However, upon initial contact, the quoted cost per test was $10 with a turnaround time of 1-2 weeks. The high cost per test and long turn-around time were initially deemed impractical for testing.

Field Test Kits

Arsenic test kits were also investigated. Many test kits were considered; however, the *Econo Quick II* test kit from *Sensafe* was selected because the kit has been widely used, advertises a practical quantitation limit (PQL) of 2 µg/L, offers 100 tests, and requires a 15 minute testing time. The test kit was ordered for $275, and initial testing occurred to determine the accuracy of the kit. 25 tests of a known concentration of the test solution were conducted to determine the accuracy of the testing kit. Each test was consistently more than one colorimetric scale off, which was determined too inaccurate for laboratory testing purposes. In addition, with the large number of samples required for both batch and column testing, 15 minutes per test would have required an inordinate amount of time.

External Laboratory Testing – Revisited

Since the test kit was more inaccurate than initially anticipated, external laboratory testing was reconsidered. Upon explaining to Sawyer® the difficulties of internal testing, Sawyer® contacted Prein&Newhof and acquired a donation of 250 tests ($4,250 at $17/test) for CLEAR H2O. In addition, Prein&Newhof agreed to decrease their turnaround time to 3-5 days. Thus, all samples were externally tested at Prein&Newhof.

4.2. Batch Testing Theory

Several batch tests were performed with the intent to quantitatively compare media performance. Kinetics and isotherm testing were the two proposed batch tests.

4.2.a. Kinetics Tests

Kinetics tests (equilibrium batch tests) are performed to determine the contact time required to reach a media's adsorption equilibrium. This time to equilibrium dictates time required for future batch tests. A typical kinetics curve is generated by periodically testing the concentration of a solution with a known contaminant concentration after introducing a specified mass of media.[14] An example of a typical kinetics curve can be seen in Figure 25.

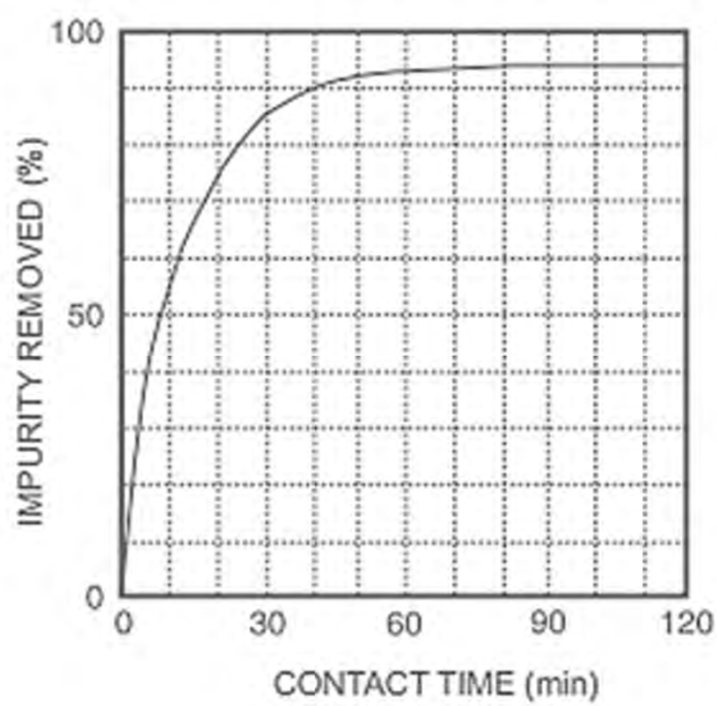


Figure 25: Typical Kinetics Curve[14]

4.2.b. Isotherm Tests

The main purpose of isotherm testing is to determine the adsorptive capacity of media. To generate an isotherm, contact time and contaminant concentration are held constant, and only the media mass is changed. After adsorption equilibrium has occurred, the remaining contaminant in solution is recorded. For adsorptive capacity, the Freundlich isotherm is generally used to relate the contaminant sorbed per mass of media, *q,* with the remaining contaminant in solution, C_{eq}, as shown in Eq. *4.2.1*.

$$q = k * C_{eq}^{\frac{1}{n}} \qquad (4.2.1)$$

The *k* and *n* are experimentally-found constants that change with temperature and are unique to different media, and C_{eq} is the concentration of contaminant remaining in solution. Typical isotherm curves can be seen in Figure 26.

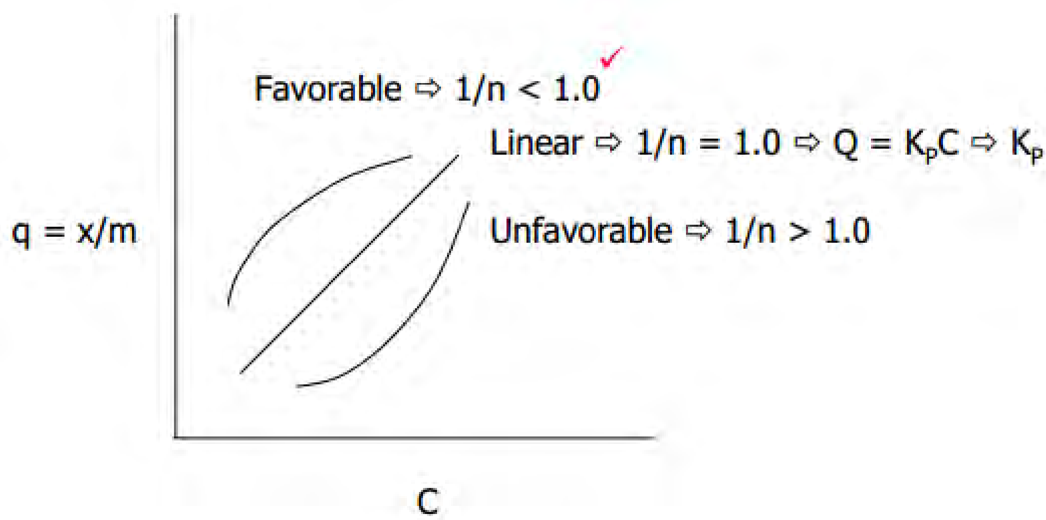


Figure 26: Typical Isotherm Curves[53]

4.3. Stock Solution

The initial step of lab testing was to create a stock solution that contained an elevated concentration of arsenic. By diluting this stock solution, multiple testing batches could be created from the same source, thus reducing storage requirements and variation in testing. The stock solution was created using 17.18 mg of sodium (meta)arsenite ($NaAsO_2$) mixed with 1 liter of distilled water. The intended concentration was 10 mg/L; however, for unknown reasons the actual concentration reported by Prein&Newhof was 7 mg/L. Refer to Appendix A.1 for complete stock solution calculations.

4.4. Kinetics Testing

A kinetics test was performed on all five selected media; however, upon return of the initial isotherm results, flaws in the batch testing method were suspected. Thus, for the sake of preserving both samples and time, the results of the kinetics test were never sent to Prein&Newhof for testing. However, the kinetics information was still valuable for future batch tests; therefore, a similar test performed by the University of Colorado on, among other media, Bayoxide E33, MetSorb and an alumina-based media (much like AquaBind MP) was used to determine future run times. The results of the MetSorb kinetics test can be seen in Figure 27. The results of the other media tests indicated that all four of the engineering media, assuming AquaBind SP-70 is similar to Bayoxide E33 and AquaBind MP is similar to the alumina-based media tested, should reach equilibrium within 24 hours.[45]

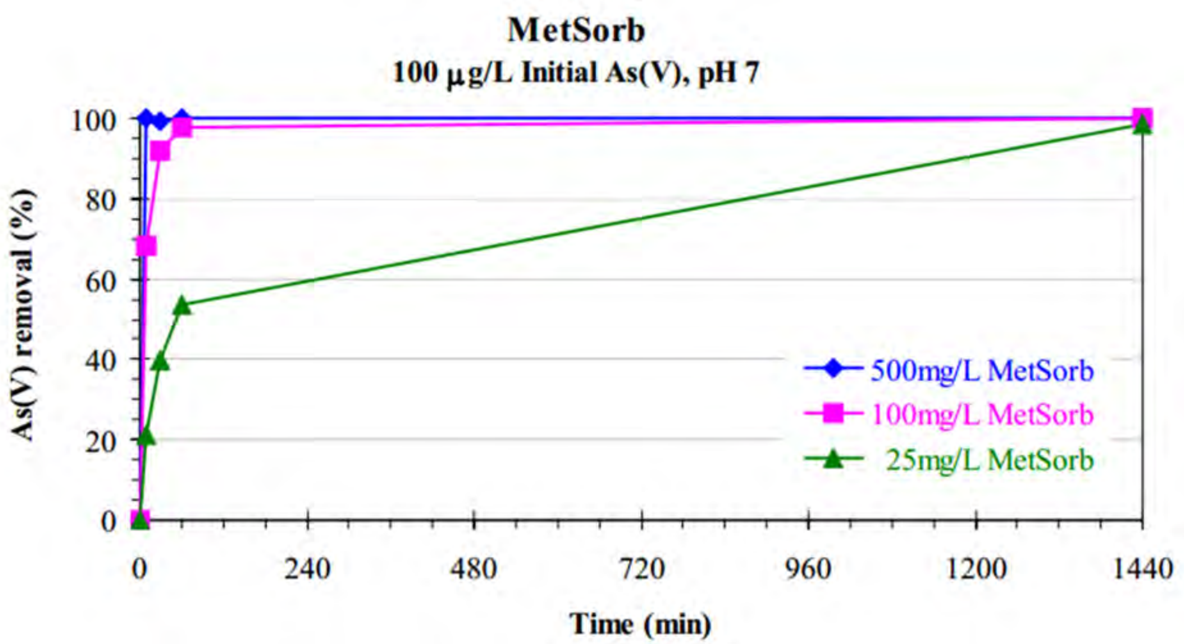


Figure 27: University of Colorado Kinetics Test Results for Various Media[45]

4.5. Isotherm Tests

The following sections describe the testing procedure and results of the three isotherm tests that CLEAR H2O performed.

4.5.a. General Procedure

All tests were conducted with a test solution arsenic concentration of ~100 µg/L. This concentration has been used in several other experiments trying to quantify arsenic-removal media performance and was selected for this reason.[45] The required volume of stock solution was mixed with distilled water and then stirred with a magnetic mixing pill. Different media masses of MetSorb, Bayoxide E33, AquaBind MP and SP-70, and hematite were accurately weighed and added into 100mL of the created test solution. The 100 mL test vials were then placed in a shaker table rotating at 135 rpm and agitated for a set amount of time. After this time had elapsed, the vials were removed and 50mL samples were taken from each vial. Special care was taken to ensure no media was removed while sampling. The samples were then sent to Prein&Newhof for testing.

4.5.b. Isotherm Test #1

The template for this initial test was a similar test performed by the University of Colorado. From this test, the media masses were selected to be approximately 2, 5, 7, 10, and 15 mg.[45] Four liters of test solution was created in a large plastic pitcher. Thirty test vials were then filled with 100 mL of test solution: five vials for each media type, two vials of the stock solution, and three vials of the created test solution. The test vials were agitated for 36 hours to ensure equilibrium.

Results

The isotherms created by the test results deviated far from the predicted isotherms generated for the media. In addition, the stock solution was 7 mg/L and the test solution was approximately 56 µg/L instead of 100 µg/L. Additionally, each media type had near the same arsenic concentration as the controls for every mass except 15 mg. At 15 mg, the results showed miniscule arsenic removal. Figure 28 presents the data generated by this first isotherm testing attempt. Raw experimental data for all of batch testing can be found in Appendix C.1.

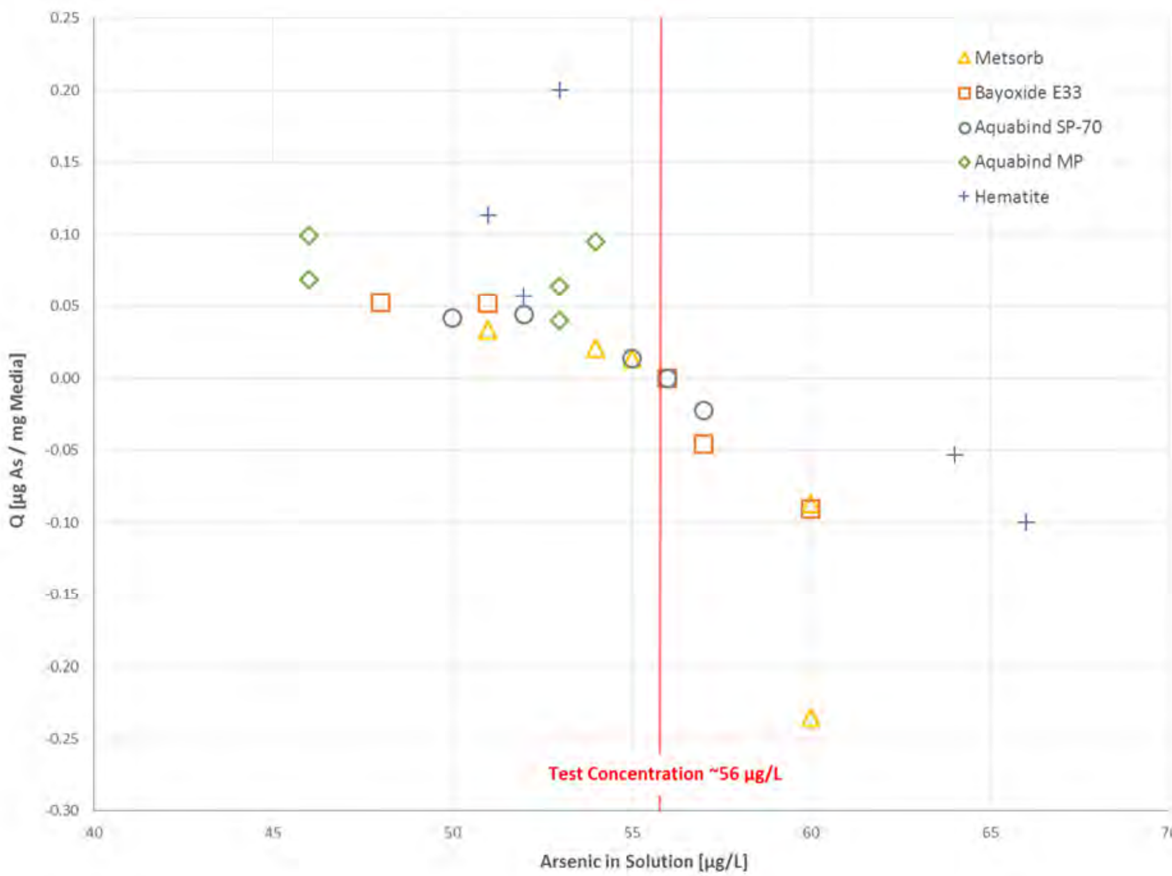


Figure 28: CLEAR H2O Isotherm Test #1 Results

Conclusion

From the results shown above obtained, CLEAR H2O concluded that the media in solution had been under loaded and therefore, even saturated, did not remove an appreciable amount of arsenic. Furthermore, Dr. Wunder speculated that there may be potential adsorption between the arsenic solution and the surface of the plastic jug. CLEAR H2O also speculated that flipping the orientation of the test vial in the shaker table from vertical to horizontal would increase mixing of the media and thus, arsenic removal. Finally, the pH of the test solution was ~5, whereas the pH of the emulated test was ~7.[45] Because pH effects both media surface charge and the speciation of arsenite in solution, the difference in pH may have potentially negated some removal.

4.5.c. Isotherm Test #2

To eliminate the threat of under loading the media again, a second test was run that tested arsenic removal with a large mass of media, 200 mg, and a small mass of media, 20 mg. Both Bayoxide E33 and MetSorb were tested. The premise of the test was to see if an appreciable difference in arsenic removal occurred between the two media masses. If not, the mass would be increased until appreciable removal did occur. In addition to determining appropriate testing masses, the second round of testing also implemented some changes to the specifics of the previous testing method. Namely, the use of Erlenmeyer flasks for solution creation as opposed to a large plastic pitcher, and a horizontal vial orientation in contrast to the vertical orientation used before.

Six control samples were also created. Three controls were held in the Prein&Newhof plastic containers and the other three were placed in the glass vials. This was done to determine if quantifiable arsenic adsorption occurred on the wall of the glass vial. The 7 glass vials were agitated for 12 hours to achieve adsorption equilibrium, see Figure 27. The three controls in the plastic containers were not shaken.

Results

The controls held in the plastic containers had an average arsenic concentration of 116 ug/L and the three glass vial controls averaged 112 ug/L. Appreciable arsenic removal was observed at both media masses. The results of the test can be seen in Table 11.

Table 11: CLEAR H2O Isotherm Test #2 Results

Media Type	Mass [mg]	As Remaining [μg/L]	As Removed [μg/L]	q [μg/mg]
MetSorb	20	23	93	0.46
	200	5	116	0.058
Bayoxide E33	20	16	100	0.5
	200	10	106	0.053

Conclusion

The difference in arsenic concentration between the plastic and glass container was deemed negligible and thus, it was determined that was no sorption with the glass surface. In addition, because an appreciable difference in arsenic removal occurred, the 20-200 mg media mass range was used as a guideline for future batch testing.

4.5.d. Isotherm Test #3

For the third isotherm test, 5, 10, 20, 30, 40, 50, 125, and 250 mg of each media type were tested. In addition, three control samples of the test solution for each media were tested. The procedure mimicked that of the second isotherm test, except an extended equilibrium time of 24 hours was necessary to account for the alumina-based media, which has slower kinetics than the other media.[45]

Results

Four of the five media achieved arsenic removal. Unfortunately, hematite did not remove any arsenic. In addition, rough isotherms were generated for three of the four media that achieved removal. Graphical results of the test can be seen in Figure 29. MetSorb produced the best isotherm curve with an R^2 value of 0.707, and k and n constants of 0.0331 and 1.24 respectively. A summary of the isotherm properties can be seen in Table 12.

Table 12: Isotherm Constants and R^2 Values

Media Type	k	n	R^2
Bayoxide E33	0.0058	0.75	0.489
MetSorb	0.0331	1.24	0.707
AquaBind SP-70	0.0067	1.03	0.129

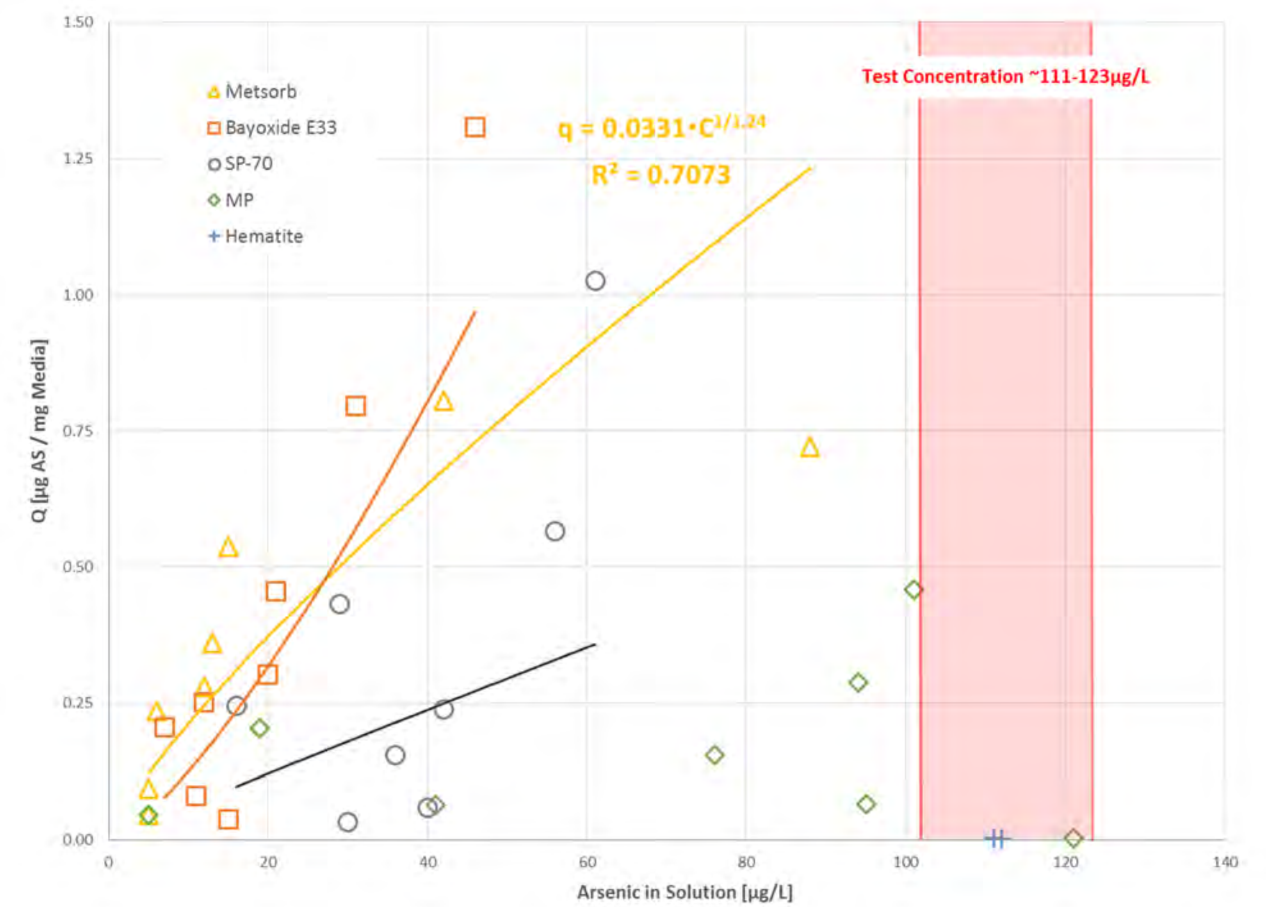


Figure 29: CLEAR H2O Isotherm Test #3 Results

Conclusion

The removal of arsenic relative to media mass was, for reasons unknown, generally inconsistent and could not be used to select a final filtration media. However, from these results both AquaBind MP and hematite were eliminated as potential media for the final prototype. AquaBind MP had extraordinary variation in its removal efficiency and had lower removal per media mass than MetSorb, Bayoxide E33, and AquaBind SP-70. Hematite showed no removal of arsenic.

4.6. Stock Solution – Revisited

Throughout batch testing, there was significant variation in control arsenic concentrations. A large volume of test solution with consistent arsenic concentration was needed for column testing, so a new method for obtaining stock solution was required. A one-liter, 1000 mg/L stock arsenic solution distributed by Environmental Express was obtained as the chosen alternative. Prein&Newhof used a similar solution to create arsenic solutions in their laboratory.

4.7. Column Testing

The second phase of initial laboratory testing was column testing. The purpose of these tests was to determine the volume of contaminated water each media can treat before arsenic breakthrough. The results of these tests provided quantitative data that would be used to select the final media.

4.7.a. Column Testing Theory

Column tests are traditionally used by companies and municipalities to test large scale filtration beds' media performance and removal capacities under operating conditions. Because full-scale pilot plants are resource intensive, mass transfer models are used to scale rapid small-scale column testing (RSSCT) breakthrough results up to full-scale equivalents.[10,54] The difference in size between the final filter extension and the testing columns for this project are not as extreme as seen in RSSCT and therefore mass transfer models are not required to obtain substantial results. However, column testing is still beneficial for this project because it significantly reduces the amount of test solution and time needed to obtain contaminant breakthrough. In addition, the intent of these initial tests is not to simulate real usage, but rather to determine the media that can filter the most contaminated water.

The result of column testing is a breakthrough curve as seen in Figure 18, in section 3.2.c. Typically the y-axis of the breakthrough curve indicates the effluent concentration, and the x-axis is a measure of time or total volume. In Figure 18, bed volumes, see Eq.*4.7.1.*, is the volumetric unit of measure along the x-axis.

$$\#\,of\ Bed\ Volumes = \frac{Volume\ of\ water\ treated}{Volume\ of\ filter\ bed} \qquad (4.7.1.)$$

If several media beds of equal size have solutions with equal arsenic concentrations pumped through them at the equivalent flow rate, then the media that reaches breakthrough last can be reasonably assumed to be the longest lasting media. In the case of Figure 18, this media would be GFH because it has treated the largest volume of water without breakthrough.

4.7.b. General Procedure

The general procedure of column testing involved pumping arsenic-contaminated water through a column with filtration media and testing the effluent water for arsenic concentration to determine how well the media was removing arsenic.

55-gallon drums were used as feed and waste reservoirs throughout column testing. A concentrated NaOH solution was used to buffer the 100 µg/L arsenic test solution to a pH of 6.75 ± 0.25. The ½-inch polycarbonate columns used for testing were packed with glass wool, filtration sand and the different filtration media. Tubing was fed from the feed reservoir through separate peristaltic pump heads (operating under the same pump) and into each column. Effluent tubing was attached to the other end of the column and fed into the waste barrel. The effluent tube could be easily removed from the waste reservoir and used to collect periodic samples. A schematic and picture of the test setup are shown in Figures 30 and 31.

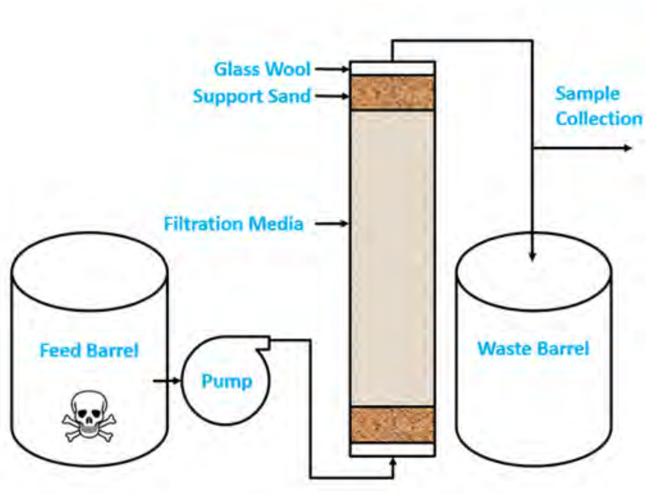


Figure 30: Schematic of Column Testing Setup

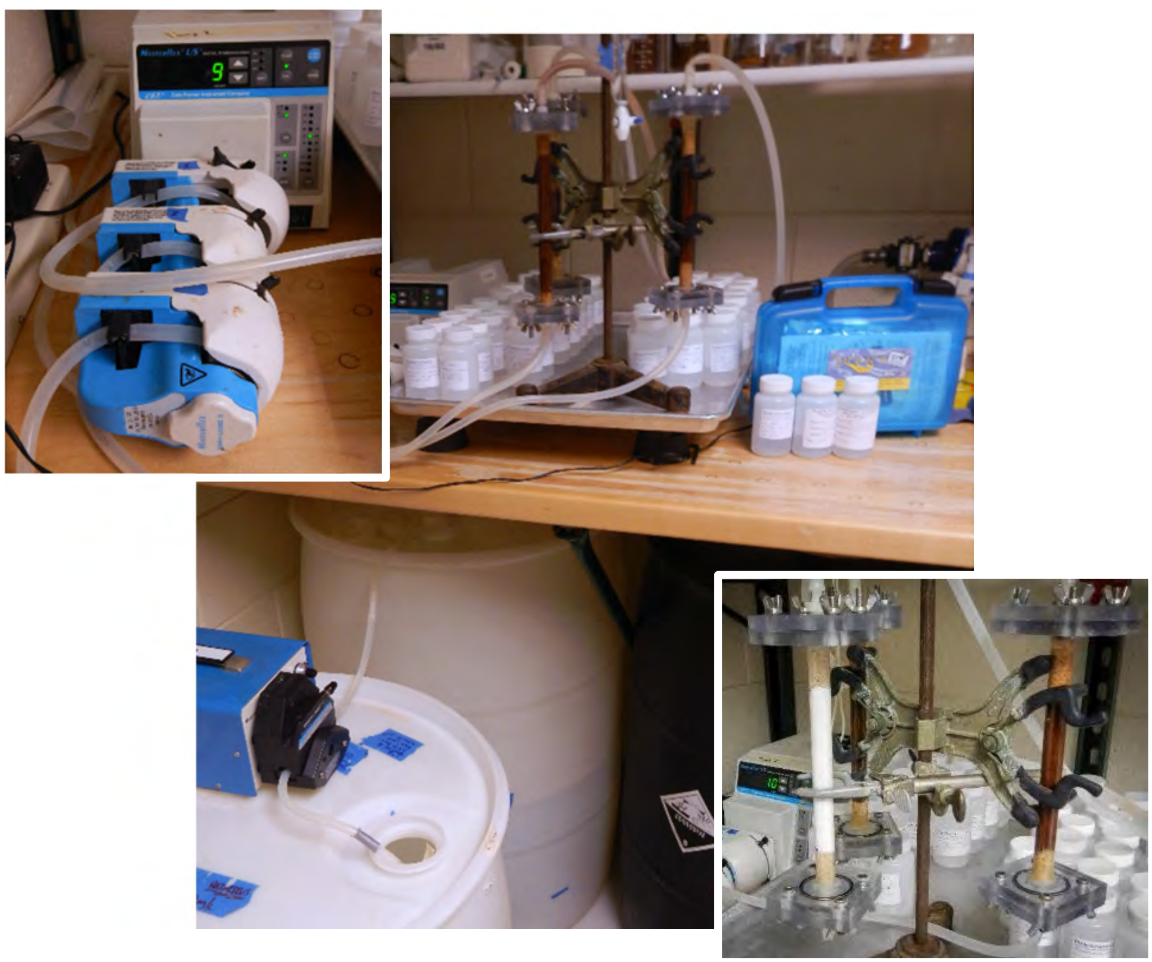


Figure 31: Column Testing Setup

4.7.c. Column Test #1

The first round of column testing was performed with the intent of determining which of the remaining three media (AquaBind SP-70, MetSorb, or Bayoxide E33) would filter the largest volume of water before arsenic breakthrough.

The three filter columns were tightly packed while running water through the filter. Prior to packing the columns, the media was rinsed with distilled water. Each column contained 5 inches of media and the test solution was pumped through at a flow rate of ~10mL/min, resulting in an empty bed contact time (EBCT) of approximately 1.5 min. EBCT is a measure of the amount of time that a contaminated solution is in contact with a removal media (see Eq. 4.7.1).

$$EBCT = \frac{V_{filter}}{Q_{influent}} \qquad (4.7.1)$$

Results and Conclusion

The test results from column test #1 are shown in Table 13 and Figure 32.

Table 13: Average Test Solution Arsenic Concentrations – Column Test #1

Solution Batch #	Solution As Concentration
1	80 µg/L
2	90.7µg/L

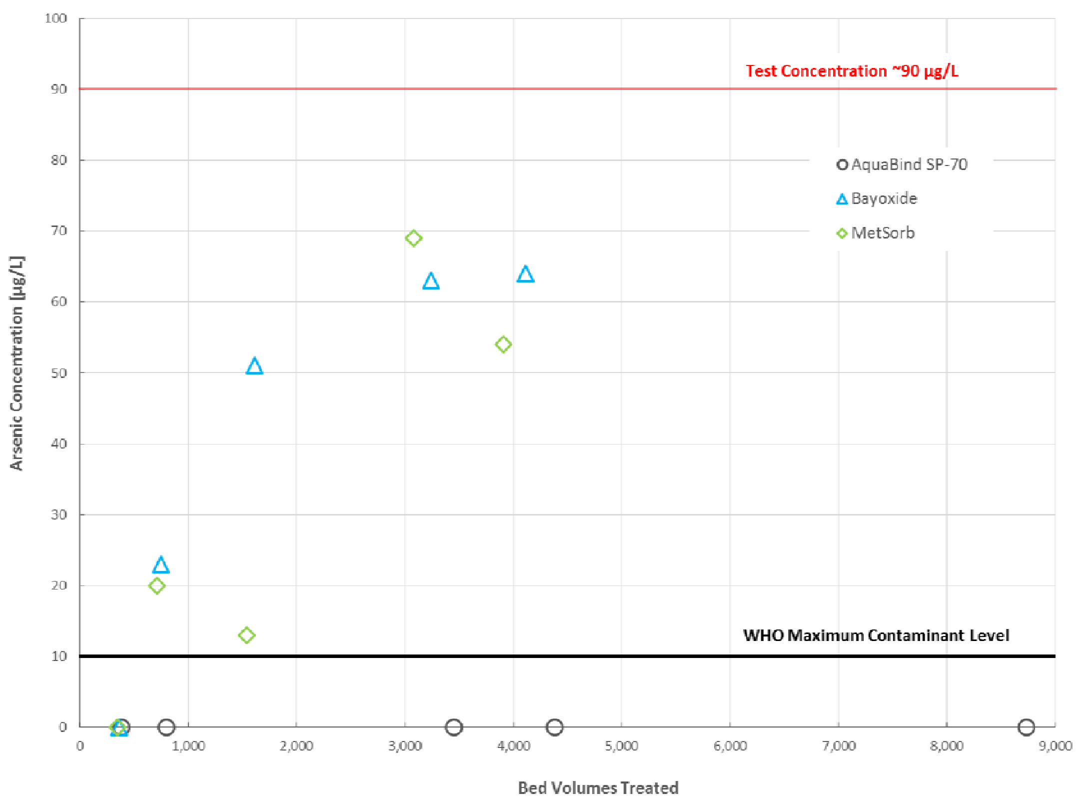


Figure 32: Column Test #1 Results

The variation in test solution concentrations was surprising, especially in lieu of the new stock solution acquired, and the fact that both test solutions were created exactly the same way. However, after consulting Dr. David Wunder, it was speculated that the test solution may contain varying arsenic gradients as a result of insufficient mixing. The concentration of the test solutions will continue to be tracked to validate this speculation.

The results from the media performance were also shocking. Based on initial research, MetSorb and Bayoxide E33 were expected to breakthrough at 10,000 – 20,000 BV's, but breakthrough occurred almost immediately. AquaBind SP-70 had no initial performance information and yet it significantly outperformed MetSorb and Bayoxide E33. CLEAR H2O decided to stop the test before arsenic had broken through AquaBind, even after treating ~9,000 BV's.

A potential cause for the results obtained was that the media beds were packed too well. Surface properties of media are important in the adsorption process, and if these were properties were damaged during the packing of the bed, then the adsorption capacity of the media may have been negatively impacted. It is unlikely, however, that the media capacity would have been impacted so drastically.

4.7.d. Column Test #2

The intent of the second column test was to confirm the unexpected results of the first column test and to address some doubts in the particulars of the procedure. The areas that were addressed were the following: the packing of the columns, the inordinate number of Bayoxide E33 fines, and EBCT. To pack the columns, distilled water was continually run through the columns while introducing the media, thus eliminating voids and still creating a packed bed. The Bayoxide E33 media was sieved to a grain size similar to MetSorb and AquaBind SP-70. Finally, the length of media was increased to 6 inches and the flow rate was decreased to ~9 mL/min, resulting in an EBCT of approximately 2 min.

Results and Conclusion

The test results from column test #2 are shown in Table 14 and Figure 33.

Table 14: Average Test Solution Arsenic Concentration - Column Test #2

Solution Batch #	Solution As Concentration
3	97.7 µg/L
4	86.3 µg/L
5	92.7 µg/L
6	90.0 µg/L

Again, the test solution arsenic concentrations showed significant variation from the intended 100 µg/L. This confirms, to an extent, the aforementioned speculation that there are arsenic concentration gradients in the solution. Multiple samples of the test solution were taken for every batch created throughout all of column testing (every batch was created in the same fashion). The concentrations of all the samples were then averaged to determine a representative testing concentration for all of column testing. The culmination of this data can be found in Appendix C.2. The average solution concentration was 88 µg/L.

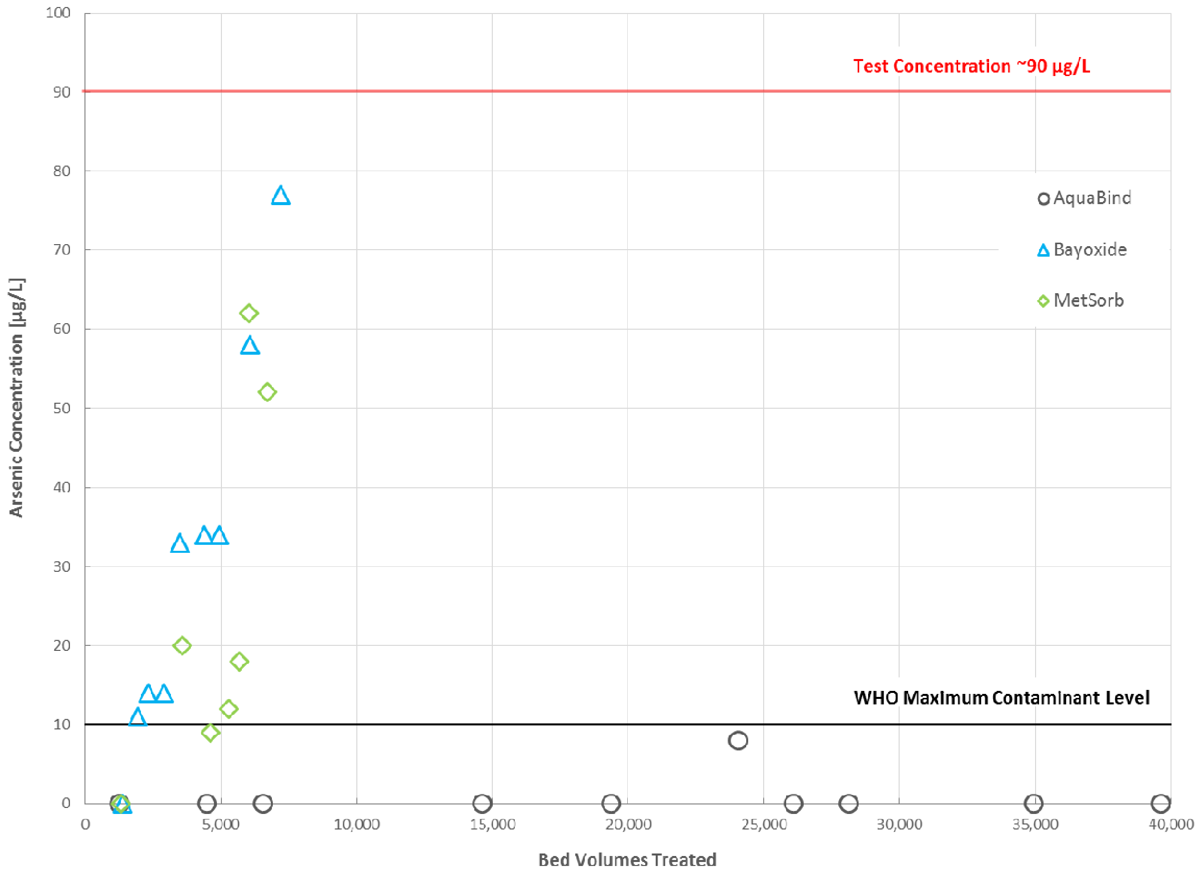


Figure 33: Column Test #2 Results

The second column test delivered better media performance results, assumedly because of the changes in media packing and EBCT. Nonetheless, a similar trend to the first test was observed and that confirmed the results. This is evident in Figure 34, which graphs the combined results from both column tests. Bayoxide E33 broke through near 2000 BV's followed by MetSorb at approximately 5300 BV's. AquaBind once again wholly surpassed Bayoxide E33 and MetSorb in performance, continuing to remove arsenic after 39,000 BV's.

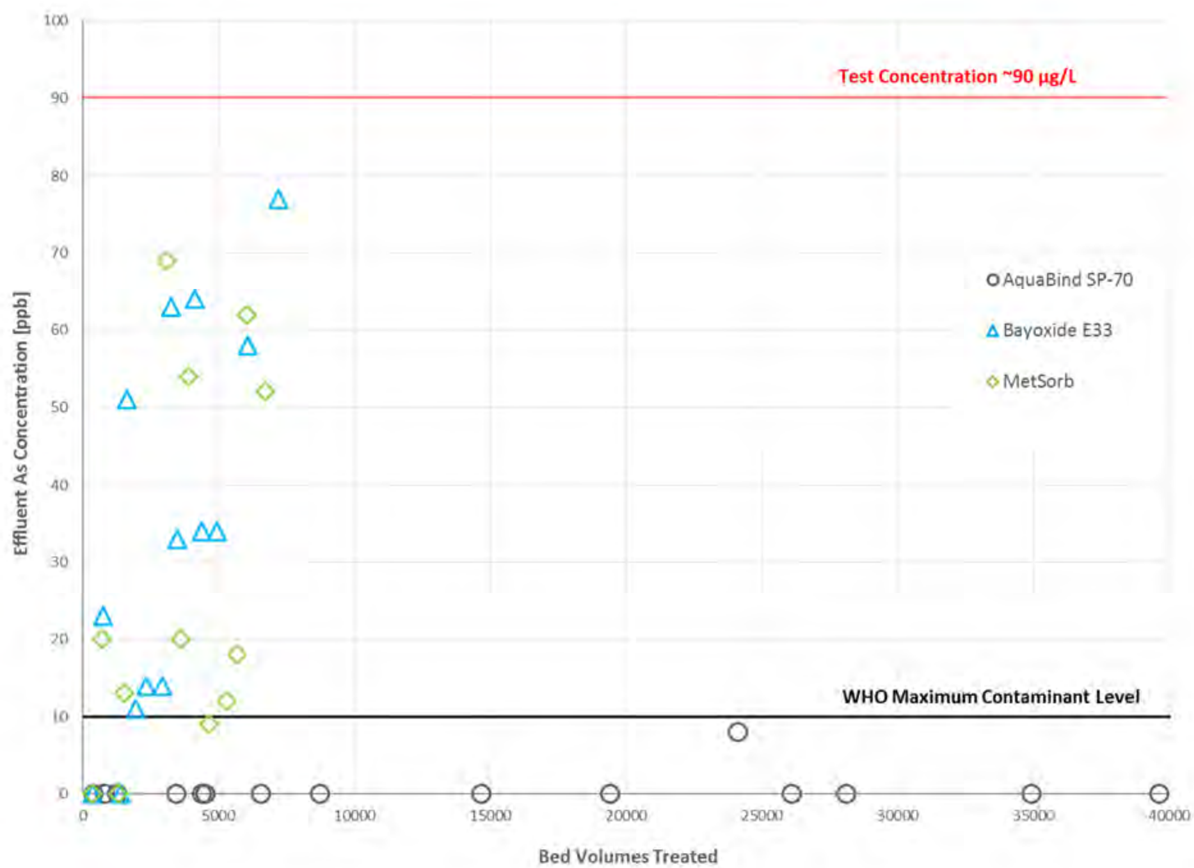


Figure 34: Combined Column Tests Results

4.8. Final Media Selection

The intent of initial lab testing was to select a final media for use in the filter extension prototype. CLEAR H2O had initially hoped to eliminate all but one media after batch testing; however the inconclusive results only eliminated two of the five media, namely hematite and AquaBind MP. Column testing proved more successful in establishing a final media. After two rounds of testing, AquaBind SP-70 clearly outperformed both MetSorb and Bayoxide E33.

The criteria for selecting the final media were filtration capacity and media cost. Column testing provided evidence that AquaBind SP-70 has the highest filtration life, 5-12 times greater than the other two media tested. In terms of cost, Bayoxide E33 is the least expensive per cubic foot and MetSorb is the most expensive, as seen in Table 15.

Table 15: Filtration and Cost Information for AquaBind SP-70, Bayoxide E33, and MetSorb

Media	Filtration Capacity*	Cost/ft^3	Cost/filter
MetSorb	5,000 BV	$285	$4.4
Bayoxide E33	2,000 BV	$185	$2.8
AquaBind SP-70	25,000 BV	$250	$3.8

*Based on CLEAR H2O column test results

Although AquaBind SP-70 is not the most inexpensive media, the cost incurred over the lifetime of the filter, because of its superior filtration capacity, is substantially less than both Bayoxide E33 and MetSorb. In conclusion, because of its outstanding filtration capacity and lowest user lifetime cost, CLEAR H2O selected AquaBind SP-70 as the final filter media. Additional tests were later conducted to determine the specific grain characteristics of the media used in the final prototype.

5. Prototype Development

With the final media selected, work began on developing a final prototype. Extensive lab testing was completed to determine specific operating parameters for the final prototype components and to gather more information about AquaBind SP-70. Tests conducted included a third column test, head loss tests, a pH batch test and a Timestrip® temperature test. Throughout extensive testing, efforts began to construct preliminary prototypes. Simple qualitative tests were completed on the initial prototypes and these tests assisted in final prototype development.

5.1. Extensive Lab Testing

To determine the final operating parameters of the final prototype, additional tests were required, including EBCT testing, head loss testing, pH batch testing, and Timestrip® temperature testing. The following sections detail the four tests that were completed and the means by which they impacted the final prototype design.

5.1.a. Empty Bed Contact Time Test

Following AquaBind SP-70's selection as the removal media for the final prototype, a third column test analyzing the impact of empty bed contact time on AquaBind SP-70's removal capacity was performed. Flowing contaminated solution too quickly through a filter can lower the filter's capacity to remove arsenic. Thus, EBCT column testing was completed to determine the minimum contact time required for appreciable arsenic removal with AquaBind SP-70.

EBCT of a filter can be varied by changing either the volume of the filter or the flow rate flowing through the filter. For this test, CLEAR H2O varied the EBCT by reducing the volume through differing filter bed length. Flow rate was maintained at 9 mL/min. Three different bed lengths were tested: 2 inches, 4 inches, and 6.25 inches. These lengths correlate with an EBCT of 38 seconds, 88 seconds, and 128 seconds, respectively.

EBCT testing immediately began after column test #2. Because the 6.25-inch AquaBind SP-70 column had yet to breakthrough, testing continued on it throughout EBCT. The other two columns were packed with 2 inches and 4 inches of AquaBind SP-70. The testing procedure used for EBCT testing was equivalent to the procedure used for column tests #1 and #2 and can be read in detail in section 4.7.b. General Procedure.

Results

The results from the EBCT test are shown in Figure 35.

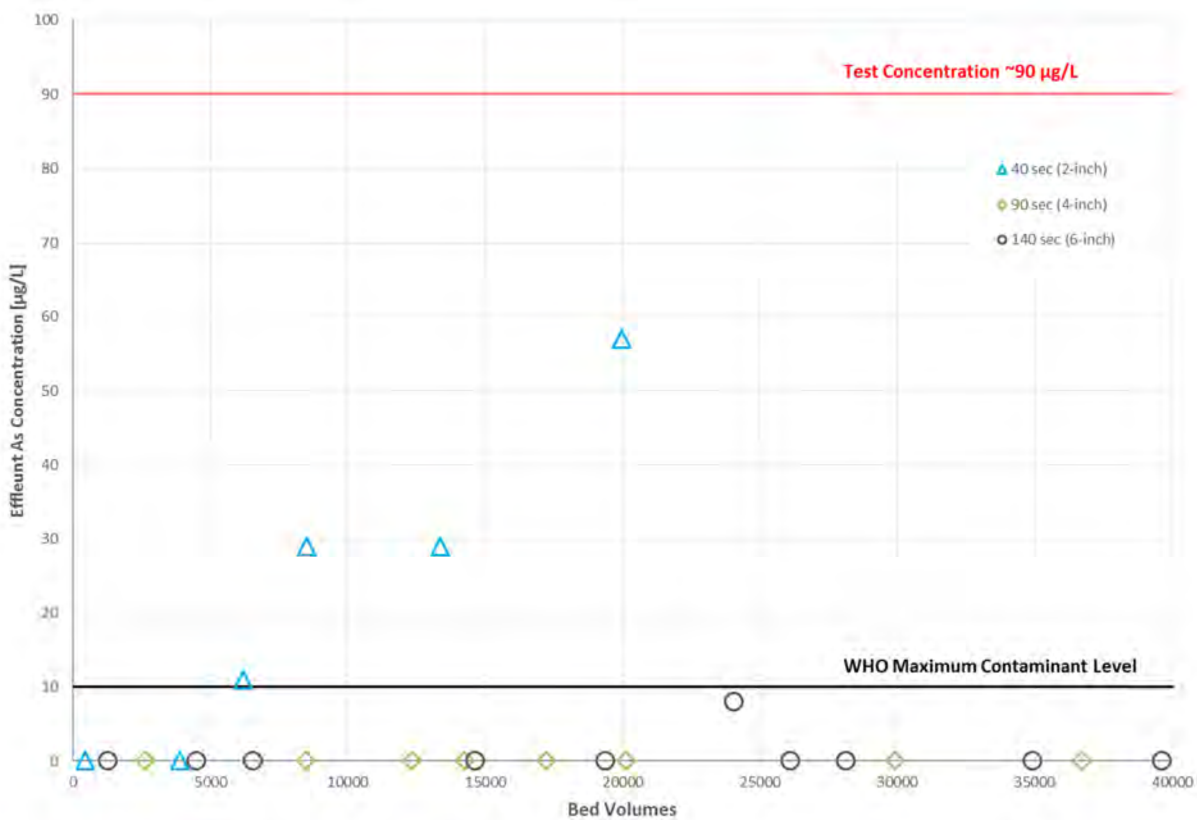


Figure 35: EBCT Test Results

The 38-second EBCT column had breakthrough at approximately 6200 BV. Unfortunately, because of time constraints testing was stopped before breakthrough could occur in the 88-second and 128-second columns. The final samples taken indicated the 88-second EBCT column had surpassed 36000 BV without breakthrough, and the 128-second EBCT column had exceeded 39000 BV.

Conclusion

An EBCT of 38 seconds resulted in breakthrough substantially sooner than an EBCT of 88 seconds and 128 seconds. Thus, for appreciable arsenic removal, the final prototype must have an EBCT exceeding 88 seconds (1.5 minutes) to ensure that the filter is able to have a long usable life.

5.1.b. Head loss Test

To ensure that the final prototype has both sufficient EBCT for removal and a high enough flow rate for practical use, head loss testing was performed. The results of the head loss tests were used to calibrate a MathCAD model that utilized the Kozeny-Carman (KC) equation to assist in the final prototype design.

Head loss is the culmination of all energy losses that occur when water flows through a system. In gravity-fed systems, all energy comes solely from the elevation difference between the water surface and the effluent, or head. Therefore, the head loss through the system cannot exceed the head of the system, else the water will not flow through.

Head loss through a filter media can be calculated using a modified form of the Kozeny-Carman (KC) equation, see Eq. *5.1.1.*, in which μ_w is the dynamic viscosity, ε is the media porosity, v_s is the superficial water velocity entering the media bed, ρ_w is the density of water, g is the gravitational constant, ϕ is the media sphericity, and L is the media bed length.

$$H_L = \left(\frac{150\mu_w (1-\varepsilon)^2 \, v_s}{\rho_w g \varepsilon^3 \left(\phi d_p\right)^2} + 1.75 \frac{(1-\varepsilon)}{\varepsilon^3} \frac{v_s^2}{\phi d_p g} \right) L \qquad \textit{(5.1.1.)}$$

Experimental Setup

Bayoxide E33 was the media selected to be used for head loss testing because of the large volume of media available. AquaBind SP-70 was not tested due to a shortage of on-hand supply. Prior to testing, Bayoxide E33 was sieved to three grain size ranges: 0.5 mm to 0.71 mm (#35-mesh to #25-mesh), 0.71 mm to 0.853 mm (#25-mesh to #20-mesh), and 0.853 mm to 1 mm (#20-mesh to #18-mesh).

A 7/8-inch diameter by 6-inch polycarbonate column was used to house the media. Attached to the top of the polycarbonate column was an 85-inch tall column with the equivalent 7/8-inch diameter. This tall column had marks every inch that were read off during the experiment and corresponded to the head loss through the filter, shown in Figure 36. The effluent hose was configured so it discharged at the height of the top of the media bed in the column, ensuring that the height of water in the column was representative of the head loss through the entire media bed. The media was packed into the column wet.

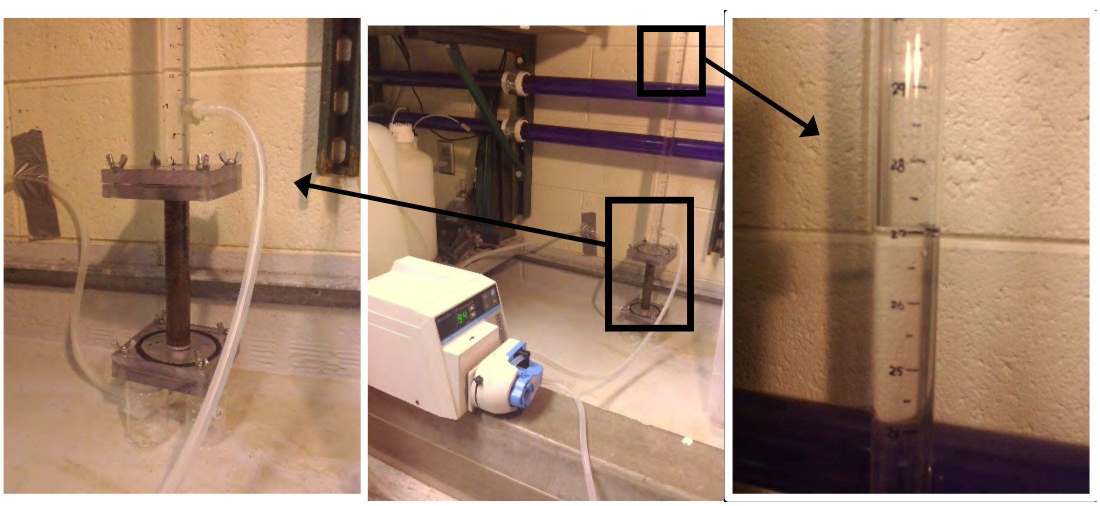


Figure 36: Head Loss Test Apparatus

Varying flow rates were pumped into the filter and the corresponding head loss for each flow rate was recorded for each of the three media grain sizes.

Results

The results of the test can be seen in Figure 37. The results indicate that decreasing the EBCT (or, in effect, increasing the flow rate) greatly increases the head loss through the media bed.

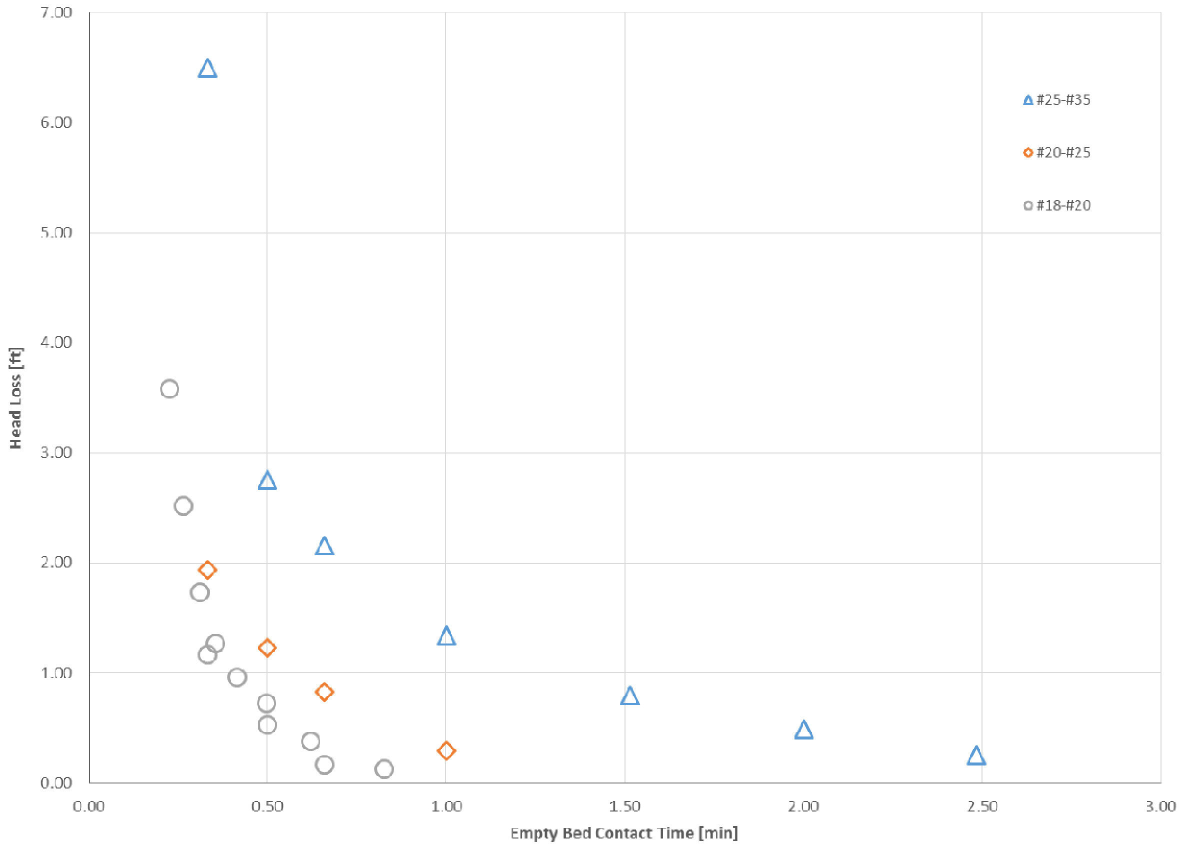


Figure 37: CLEAR H2O Head loss Test Results

Head Loss Model

A media head loss model was created on MathCAD. Porosity (ε) and sphericity (ϕ) were tweaked to "calibrate" the model, so that it best matched the experimental data. For simplification, CLEAR H2O limited the porosity and sphericity to ranges typical to silica sand: 0.25-0.5[55] and 0.7-0.8[56], respectively. Figure 38 shows the calibrated theoretical model and experimental results. The model was calibrated using a porosity of 0.35 and a sphericity of 0.75.

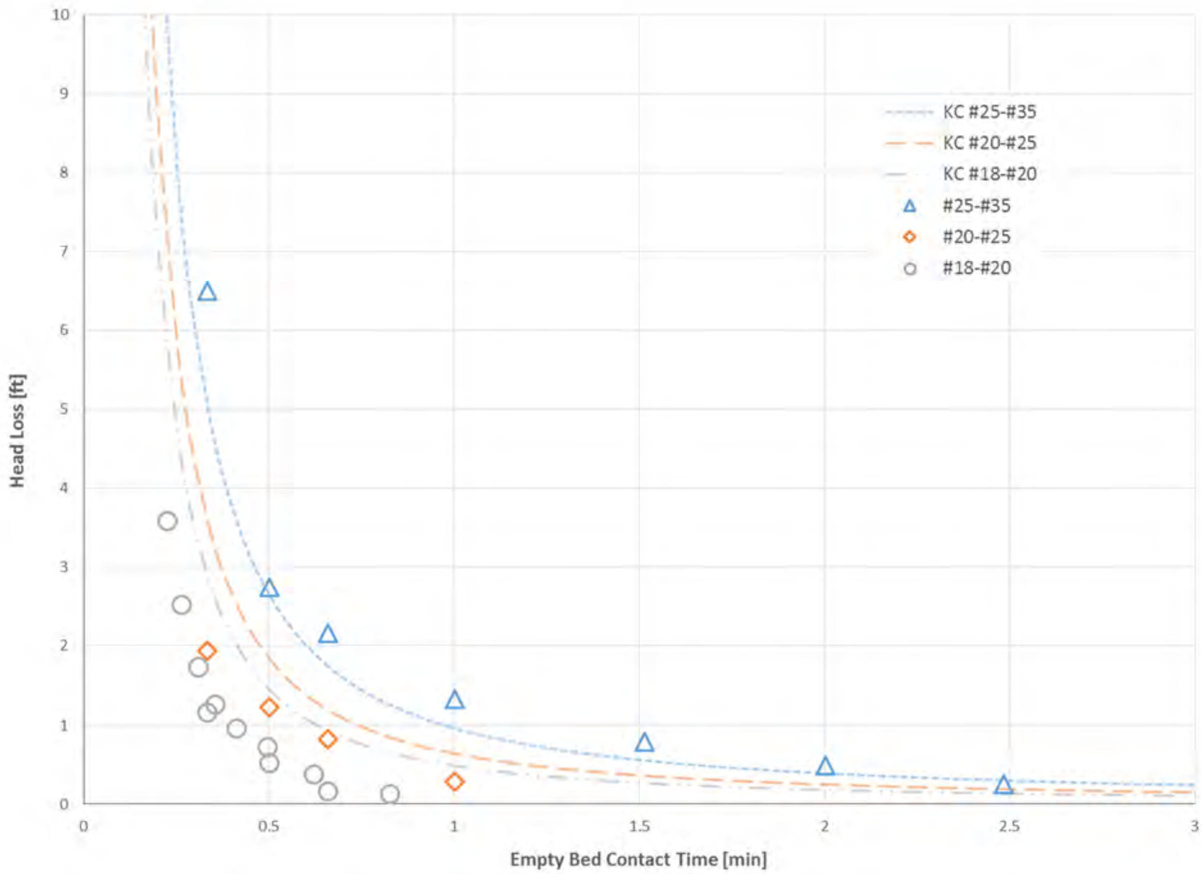


Figure 38: Kozeny-Carman (KC) MathCAD Model with Experimental Data

The KC model is consistent with the head loss experimental data of the #25-#35 sieve size. The correlation between the model and experimental data is not extremely reliable for the other sieve sizes, as the model generally overestimates the head loss. There are several factors that could describe the discrepancies between the theoretical and experimental data. An average grain size was assumed between sieve sizes; however, the true distribution of grain sizes was not known. Since grain diameter has a huge impact on the KC model, having the distribution information for grain sizes would certainly impact the model. Another potential factor would be differences in bed porosity and particle sphericity. The same sphericity and porosity was assumed for all grain sizes and this may not have been the case. Again, like diameter, the slightest variation in sphericity and porosity significantly changes the KC model. The initial MathCAD model with experimental data can be found in Appendix A.2.

Despite its discrepancies, the model was still used to assist in selecting final prototype geometry. The model accurately estimates the head loss for the smallest media grain size, #25-#35, and this was the mesh size selected for the final prototype design.

5.1.c. pH Batch Test

pH batch testing was conducted to determine the impact that varying pH has on AquaBind SP-70's removal efficiency. The equivalent media mass range in isotherm test #3 was used for pH batch testing. pH values of 6.4, 7.11, and 8.14 were created using the test solution used for column testing. The pH of the solution was adjusted using concentrated, aqueous NaOH. In addition to the 8 test vials with media, two controls were created to verify the concentration of the test solution. The test vials were laid on their side in the shaker table and agitated for 48 hours at 135 rpm.

Results and Conclusion

Test results from the pH batch test were inconclusive on the impact that pH had on the removal efficiency of AquaBind SP-70. For all three pH values, the masses between 20 mg and 50 mg had the highest removals of arsenic. For both pH 6.4 and pH 7.11, the masses 75 mg, 125 mg, and 250 mg had nearly equivalent or lower removal than the 5 mg and 10 mg masses. Common sense would indicate that the higher the mass of removal media, the more arsenic would be removed. Thus, no conclusion from the testing can be determined for the masses above 75 mg. For the masses below 75 mg, the test results appear to indicate that pH does not appear to inhibit AquaBind SP-70's ability to remove arsenic, but additional testing is required to determine the impact of pH on removal efficiency. The results from the pH batch test are shown in Figure 39.

Figure 39: pH Batch Test Results

5.1.d. Timestrip® Temperature Test

A test was conducted to evaluate the effect of temperature on the accuracy of the Timestrip® indicator. The strips ordered for this project were labeled "for room temperature use only" and it was determined that the extent to which temperature affects their performance should be analyzed.

Method

Three Timestrip® indicators were placed in a 102°F boiler room, another three were placed in a fridge at 40°F, and the final three were left in a room with an ambient temperature of 68°F. The strips in the boiler room reached the one month mark after approximately 8 days. The strips in the fridge had not yet reached the one month mark after 35 days, and the control strips reached the one month mark on the thirtieth day. Figure 40 shows a comparison of the Timestrip® indicators' display after one week of operation at different temperatures (102, 68, and 40 degrees Fahrenheit, respectively).

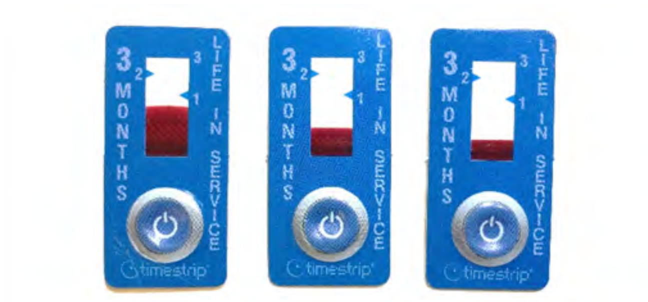


Figure 40: Timestrip® Indicators Operated at Various Temperatures

Conclusions

The fact that Timestrip® indicators are affected by ambient temperature is not ideal for accurately indicating time elapsed in areas where climate and daily temperatures can significantly vary. However, Timestrip® is able to design strips for different temperatures. There are currently Timestrip® indicators on the market that are kept in refrigerators to determine when to dispose of food. The exact temperature range for which Timestrip® can design is unknown, and a company representative would need to be contacted for further information. For use as a method of exhaustion indication, further field testing should be performed to determine the effectiveness of a time strip indicator over its design life when exposed to variations in temperature.

5.2. Prototype 1.0

The first prototype iteration was designed to conduct a series of qualitative tests and to act as a visual aid for the mid-semester project presentation.

5.2.a. Materials Used and Construction

The prototype was constructed with PVC pipe, couplings, and threaded-reducing bushings. Two threaded nylon 3/8-inch hose barbs were also used. The PVC pipe diameter was 1.5-inch, and the total length of the prototype was 12 inches. Two screens were glued on the inside of the couplings to create a 6-inch media bed. The couplings and bushings were glued to the pipe and the hose barbs were threaded in place after the media had been placed inside. The media bed consisted of unsieved, dry-packed Bayoxide E33. The initial prototype can be seen in Figure 41.

Figure 41: Prototype 1.0

Prototype 1.0 was made with materials that could be purchased at a local hardware store. The costs of these parts can be seen in Table 16.

Table 16: Prototype 1.0 Cost Summary

	Cost	Number
PVC Pipe (1.5in x 1ft)	$1.50	1
Couplings	$2.00	2
Reducing bushings	$1.50	2
Male threaded hose barbs	$1.00	2
Media	$1.50	-
	Total Cost:	**$12.00**

5.2.b. Prototype Tests

A couple of qualitative tests were done to determine the pros and cons of the created prototype. The results of these tests dictated what changes would be made for the next prototype iteration.

Sawyer® Compatibility

The prototype was first examined for ease of use in conjunction with the Sawyer® filter. The prototype was placed on the effluent side of the bucket filter and connected with a 3-inch section of MasterFlex tubing. The tubing supported the weight of the prototype, but a more solid connection was needed to increase the robustness of the design. Overall, the size of the prototype was significantly larger and heavier than the Sawyer® filter.

Head loss

A qualitative head loss test was performed on the prototype to see if water would easily flow through it when connected in-line with the Sawyer® filter. About 1/3 of a 5-gallon bucket was filled with water and then the flow through the prototype was evaluated. Water flowed through the prototype very easily, filling a 100 mL beaker in approximately 17 seconds. In comparison, it took about 12 seconds for water flowing through only the Sawyer® filter to fill 100 mL.

5.2.c. Conclusion

Prototype 1.0 was easy to construct and the materials used for construction were relatively inexpensive. In addition, although the size of the prototype was significantly larger than the Sawyer® membrane filter, it was still very portable and relatively lightweight.

Unfortunately, the media inside the prototype cannot be removed and therefore, a new extension would need to be purchased on a regular basis. This would result in significant material waste if the filter must be discarded once it reaches exhaustion. Furthermore, because flow rates were too high through the prototype, head losses through the prototype must be increased to achieve appreciable EBCT. Head losses can be increased easily by increasing the length-to-width ratio of the prototype and/or decreasing the diameter of the filter material.

Pros	**Cons**
Portable	Media cannot be replaced
Inexpensive material	Short EBCT
Lightweight	No direct Sawyer® connection

5.3. Prototype 2.0

Prototype 2.0 was built with the intent to optimize the filter design and to fix some of the issues presented by the first prototype. A high importance was placed on creating a prototype that would enable the user to replace the media and also attach the extension directly to the Sawyer® membrane filter. In addition, the prototype was increased in length to extend the EBCT.

5.3.a. Materials Used and Construction

The prototype was constructed with PVC pipe, couplings, threaded-reducing bushings, and a union. One threaded nylon ½-inch hose barb was also used. The PVC pipe diameter was 1.5-inch and the total length of the prototype was 15 inches. Two screens were glued on the inside to create a media bed of 11 inches. #25-#35 sieved, Bayoxide E33 was used in this prototype iteration. The couplings, union and bushings were then glued to the pipe and the other appurtenances were threaded in place. See Figure 42.

In addition, a custom-made acrylic joint that directly joined the Sawyer® filter with the prototype was designed in SolidWorks and then 3D printed. The part can also be seen in Figure 42.

Figure 42: Prototype 2.0 – Size Comparison with Sawyer® Filter and Custom-made Acrylic Joint

The PVC union allowed the prototype to be unscrewed with the intention of removing the media once it reached exhaustion and replacing it with new media. See Figure 43.

Figure 43: Prototype 2.0 – Replaceable Media Method

The materials for Prototype 2.0 were again purchased at a local hardware store. The increase in size, the addition of the PVC union, and the 3D printed joint increased the cost of the filter substantially. See Table 17 for a cost summary.

Table 17: Prototype 2.0 Cost Summary

	Cost	Number
PVC Pipe (1.5in x 1ft)	$1.50	1
Couplings	$2.00	1
Reducing bushings	$1.50	2
Male threaded hose barbs	$1.00	1
PVC Union	$12.00	1
Media	$3.00	-
3D Printed joint	$6.00	1
	Total Cost:	**$28.50**

5.3.b. Prototype Tests

Some qualitative and quantitative tests were done to determine the pros and cons of the created prototype. The results of these tests dictated what changes would be made for the next prototype iteration.

Sawyer® Compatibility

The prototype was first examined for ease of use in conjunction with the Sawyer® filter. The prototype was placed on the effluent side of the bucket filter and threaded directly into the Sawyer® membrane filter. Prototype 2.0 was significantly larger and heavier than Prototype 1.0. The current bucket filter configuration used by Sawyer® is meant to handle some weight, but the significant weight of Prototype 2.0 might cause structural problems with sustained use.

Head Loss

The flow rate of the second prototype was analyzed to validate the head loss model previously created and to ensure that the #25-#35 sieve size was an appropriate grain size for use in the final prototype. The prototype was first placed in-line with the Sawyer® filter. The bucket was then filled half-full and the flow through the filter was recorded. The flow through the filter was approximately 250 mL per minute, resulting in an empty bed contact time of ~73 seconds. After inputting the parameters of Prototype 2.0—bed length, column diameter, media grain size—the model predicted an EBCT of 80.3 seconds, as seen in Figure 44. Thus, the results of the head loss test validated the effectiveness of the model in predicting EBCT based on filter parameters and affirmed the use of a #25-#35 sieve size in the final prototype.

User Input

Media Parameters

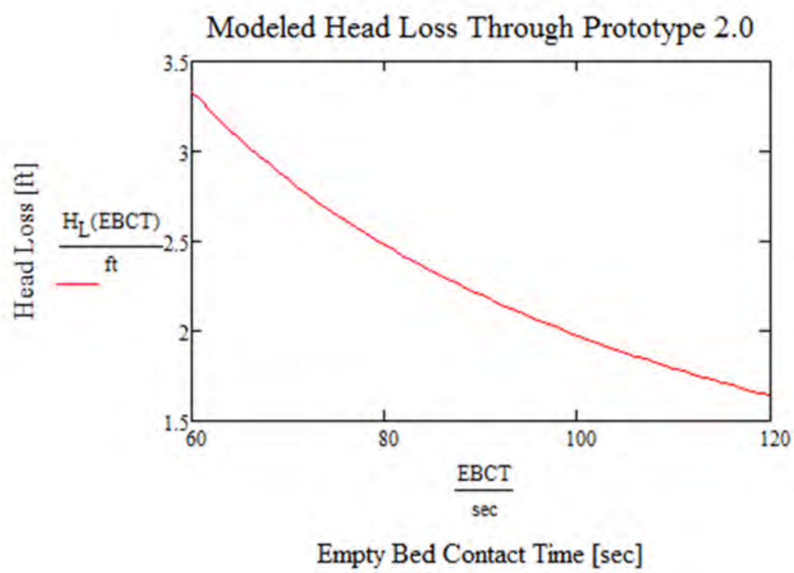
$\varepsilon := 0.35$	Porosity
$\phi := 0.75$	Particle Sphericity
$d_p := 0.602\text{mm}$	Particle Diameter

Filter Parameters

$\text{Length} := 10.5\text{in}$	Depth of Filter Bed Layer
$D_{col} := 1.5\text{in}$	Column Diameter
$EBCT_{ant} := 120\text{sec}$	Anticipated Empty Bed Contact Time
$\text{Head}_{available} := 2.45\text{ft}$	System Head

Model Output

$$\text{Head}_{Loss} := \left[\frac{150\cdot\mu\,(1-\varepsilon)^2\cdot v_{s\_user}}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot(\phi\cdot d_p)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_{s\_user}^{\;2}}{\phi\cdot d_p\cdot g}\right]\cdot\text{Length} = 1.64\cdot\text{ft}$$



$$EBCT_{act} := \frac{\text{Head}_{Loss}}{\text{Head}_{available}}\cdot EBCT_{ant} = 80.31\,\text{s}$$

Actual Empty Bed Contact Time, assuming a linear relationship.

Figure 44: MathCAD Head Loss Model Output for Prototype 2.0

5.3.c. Conclusion

Prototype 2.0 improved upon some of the weaknesses exposed by the first iteration. It was capable of joining directly to the Sawyer® filter, and the increased length allowed for a greater empty bed contact time and thus, increased filtration capacity. With the addition of the PVC union, the prototype was intended to be a permanent housing for the replaceable media.

This prototype was designed with the intent that replacement media bags and Timestrip® indicators would be shipped with the filter. When the media reached exhaustion, the user would then replace the media and start a new Timestrip®. However, this design increases user responsibility as well as the liability of the filter distributor. After consulting both Sawyer® and Dr. David Wunder, it was concluded that the final design should be completely disposable and not dependent on the user to replace media.

Pros	**Cons**
Portable	Increased liability/User responsibility
Inexpensive material	Bulky PVC construction
Direct Sawyer® connection	
Replaceable media	

6. Final Prototype – Prototype 3.0

Prototype 3.0 was constructed as the final prototype iteration for the project. With it, CLEAR H2O hoped to fulfill all constraints and objectives established from the project onset.

6.1. Construction

The construction of Prototype 3.0 was unique in that it was not fabricated in the shop like previous iterations. The prototype was designed in SolidWorks and 3D printed. See Figures 46 and 47 for the SolidWorks rendering and the final product with the Sawyer® filter, respectively. To ensure the final prototype had at least an 88-second EBCT, the original length of the filter was set to 11.5 inches. The head loss model used to accurately predict the flow rate of Prototype 2.0, was also used to predict the EBCT of a final prototype of this length. With a length of 11.5 inches and #25-#35 media grain size, the head loss model predicted an EBCT of 96 seconds, as seen in Figure 45. Unfortunately, due to size restrictions imposed by the 3D printer, the maximum length the prototype could be printed was 10.75 inches. This length only resulted in an EBCT of 84 seconds. In addition, to increase the capacity of the media without increasing head loss, the diameter of the prototype was enlarged to 1.75 inches. The total length of the final prototype is approximately 12.7 inches.

User Input

Media Parameters

$\varepsilon := 0.35$	Porosity
$\phi := 0.75$	Particle Sphericity
$d_p := 0.602\text{mm}$	Particle Diameter

Filter Parameters

$\text{Length} := 11.5 \cdot \text{in}$	Depth of Filter Bed Layer
$D_{col} := 1.75\text{in}$	Column Diameter
$\text{EBCT}_{ant} := 120\text{sec}$	Anticipated Empty Bed Contact Time
$\text{Head}_{available} := 2.45\text{ft}$	System Head

Model Output

$$\text{Head}_{Loss} := \left[\frac{150 \cdot \mu \, (1-\varepsilon)^2 \cdot v_{s\_user}}{\rho_{water} \cdot g \cdot \varepsilon^3 \cdot (\phi \cdot d_p)^2} + 1.75 \, \frac{(1-\varepsilon)}{\varepsilon^3} \, \frac{{v_{s\_user}}^2}{\phi \cdot d_p \cdot g}\right] \cdot \text{Length} = 1.97 \cdot \text{ft}$$

$$\text{EBCT}_{act} := \frac{\text{Head}_{Loss}}{\text{Head}_{available}} \cdot \text{EBCT}_{ant} = 96.481 \text{ s}$$

Actual Empty Bed Contact Time, assuming a linear relationship.

Figure 45: MathCAD Head Loss Model Output for Final Prototype with Ideal Bed Length

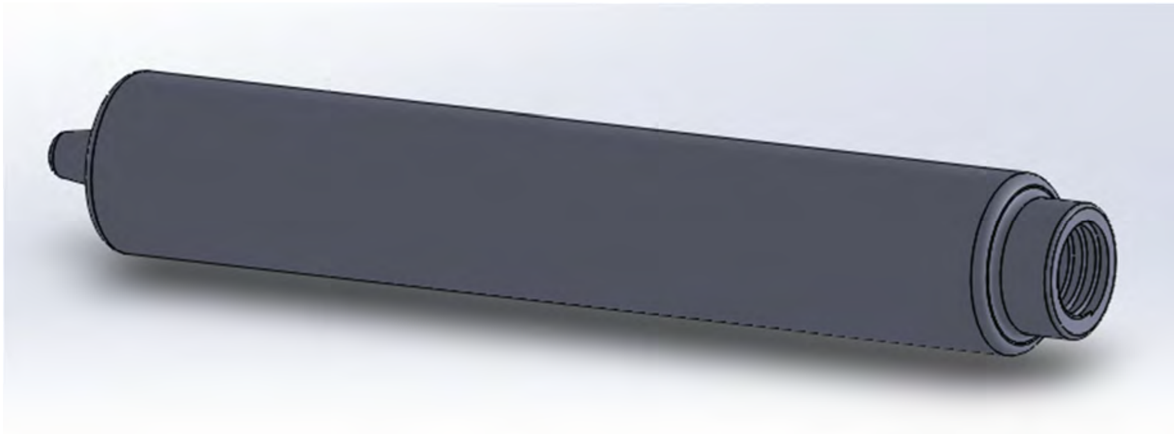


Figure 46: Final Prototype Solidworks Model

Figure 47: Final Prototype

6.1.a. Materials Used

The materials used for the final prototype were 3D-print material, glass wool, steel mesh, an O-ring and AquaBind SP-70. Both the glass wool and mesh were used to prohibit media from exiting the nozzle and the back of the filter, respectively. The filter's design length was meant to use #25-#35 mesh to achieve the desired head loss. Unfortunately, there was insufficient media of this grain size to use in the final prototype and so a mixture of #25-#35 mesh and #14-#18 mesh was used.

6.1.b. Production Method

The final prototype was 3D-printed so that its form might mimic what would be produced in an injection molding process, which is the most likely means to mass produce this product. A second print was deemed necessary because of the handling and display for senior design night and plans for future testing required both a durable model as well as a watertight connection. The second printing increased the wall thickness to improve durability and altered the threaded Sawyer® connection to better hold a watertight seal.

6.2. Tests Conducted

6.2.a. Head loss

The flow rate of the final prototype was also analyzed .The prototype was placed in-line with the Sawyer®© filter. The bucket was filled halfway and a flow rate of 240 mL per minute was measured, resulting in an empty bed contact time of approximately 80 seconds. This is faster than the designed time due to the larger media grain size used.

6.2.b. Pilot Testing

CLEAR H2O wanted to conduct a series of pilot tests to determine how the filter might perform in a scenario that would resemble its designed usage. This would involve gathering water from a local water source and adding a measured amount of arsenic to the collected water. This water would then be filtered with the prototype every day in conjunction with the Sawyer® filter, and every day a sample of the effluent would be sent in to test the arsenic concentration. Unfortunately, the team was unable to perform pilot testing due to time constraints.

6.3 Filter Operation

6.3.a. Backwashing

When testing flow through the filter, backwashing was determined to be a necessary operational component. After prolonged settling the media "cements" and drastically decrease the flow rate. A quick backwash will loosen the media and return flow rates to normal operating conditions. The filter can be backwashed in the same manner as the Sawyer® filter with the syringe provided with their product for backwashing.

6.3.b. First Flush

The initial flow through the filter is discolored with a reddish hue similar to rust, due to the iron oxide composition of the media. The discoloration can be resolved through the implementation of a "first-flush" prior to filter operation. At each use, the user should backwash the filter and then allow the first volume of water to flow out uncollected until the water appears clear.

6.3.c. Filter Disposal

The protocol for disposal of a spent filter is an important aspect of this design. AquaBind SP-70, the adsorbent media, is very resistant to leaching once it has been exhausted. It can be disposed of in a landfill as non-hazardous solid waste and has passed the EPA's Toxicity Characteristic Leaching Procedure (TCLP) test for arsenic removal from drinking water (see Appendix E.1 for AquaBind SP-70 MSDS). However, this does not guarantee that the user will dispose of the filter once exhaustion has occurred. Cultural appropriateness and ease-of-use are very important to the success of this design and its ability to be implemented in developing countries. A simple user manual with pictures and minimal text has been created to describe correct operating and disposal procedure. Appendix F contains the user manual.

User-education does not guarantee that once the filter has been disposed of it will not be picked up by someone else and re-used. CLEAR H2O recognizes that re-use is often central in many developing countries' cultures, and it is easy to imagine a scenario where a filter is unknowingly used far beyond its designed life. Because the filter is designed for "worst-case" scenarios, it is safe to assume the filter will last much longer than its design life. This, along with education and ease-of-use will be important in helping to assure the safety of the user.

6.4. Cost Analysis

6.4.a. Prototype Production Costs

The material cost was almost completely encompassed by the 3D print material which is an acrylic plastic. The cost shown in Table 18 is for the second printing of the final prototype. The first printing cost approximately $150 but the cost increased dramatically due to the increase in material required to increase the wall thickness.

Table 18: Final Prototype Cost Summary

	Cost	Number
3D print material	$240.00	-
Media	$3.75	-
	Total Cost:	**$243.75**

6.4.b. Estimated Full-Scale Production Costs

The full-scale production cost was estimated and a range of values can be seen in Table 19.

Table 19: Estimated Full-Scale Production Costs

	Cost	Number
Injection Molding HDPE	$1.50 - $3.50	-
Media	$2.75 - 3.75	-
Mesh	$0.05 - $0.20	2
Timestrip	$0.10 - $0.50	1
	Total Cost:	**$4.40 - $8.20**

A production model could be produced in the range of $5 to $10. This does not include labor, utilities, or shipping costs.

6.5. Market Analysis

Prior to beginning production of the CLEAR H2O filter, the target market needs to be identified and analyzed. In addition, the CLEAR H2O filter must be competitive when compared to other arsenic filters on the market.

6.5.a. Target Market

The CLEAR H2O filter was designed for a target population who are exposed to high arsenic concentrations in their water and lack necessary water filtration infrastructure. The target market is water filter companies and non-profit organizations who are involved in development work in areas where the target population resides.

6.5.b. Potential Competitors

The following five companies produce arsenic-removing POU filters in developing countries and would be competitors of the CLEAR H2O filter:

Apyron Technologies

Apyron, the makers of AquaBind MP and AquaBind SP-70, implemented a point-of-use system in Adahata, an Indian city that had concentrations of arsenic exceeding 2,000 µg/L in their groundwater. This filter system was connected to the pump of a well and provided 8-12 liters per minute of water with no effluent arsenic.[42] The filer can be seen in Figure 48.

Figure 48: Apyron Competitor Filter[42]

SONO

The SONO Filter uses zero valent iron to remove arsenic in drinking water and provides 100 L/day of clean water to the user.[51] This filtration system was developed to remove arsenic from water by Abul Hussam and Abul K. M. Munir at George Mason University. Over 350,000 SONO filters have been implemented in Egypt, Bangladesh, Nepal, and India since 2001.[51] The current market cost for these filters is $35, with a lifetime expected between 3-5 years.

ALCAN

ALCAN is an activated alumina filter that offers household units and community units to remove arsenic. Household units can treat 11,000 liters of water before reaching exhaustion and cost $52 for the installed unit and $12 for media replacement after exhaustion[52]. Community systems treat 80,000 liters before reaching exhaustion and cost $260 per installed unit and $140 for media replacement after exhaustion. These filters are primarily used in Bangladesh[52].

Sidko

Sidko filters contain GFH media, and are large-scale systems directly connected to community groundwater wells. 121,000 L can be filtered with exhaustion occurring after 6 months. The estimated cost for a filter is $4,300[4].

READ-F

Nihon Kaisui of Japan created the READ-F filter[53]. READ-F incorporates cerium oxide media to remove arsenic, and provides 40,000 L of clean water with media exhaustion occurring after 30 months of usage[4]. The estimated cost for a unit is $80[4].

SONO, ALCAN, Sidko, and READ-F are the only four filters that are commercially approved by the Bangladesh Government to be used for arsenic removal in the country. Pictures of the four filters can be seen in Figure 49.

Figure 49: Four Competitor Filters (from left: Sidko, ALCAN, READ-F, and SONO)[4]

6.5.c. Prototype Competitiveness

Even with four strong competitors, the CLEAR H2O filter has the potential to stand out and become a leader in arsenic filtration. One advantage of the CLEAR H2O filter is that it includes the Sawyer® membrane filter, which is capable of removing biological pathogens, whereas the other filters are not designed for significant pathogen removal. The CLEAR H2O filter is smaller in size and lighter in weight compared to its bulkier and heavier competitors. In addition, none of the available competitor filters have a method of indicating exhaustion, unlike the CLEAR H2O filter which incorporates Timestrip® to indicate exhaustion.

An advantage of two competitor filters (SONO and READ-F) apart from its approval by the Bangladesh Government is its filtration time until exhaustion. The CLEAR H2O filter is expected to last 4-5 months while the SONO filter lasts 3-5 years and the READ-F filter lasts 2.5 years. Thus, in the equivalent time that one SONO filter has become exhausted, a user would need the equivalent of 9 to 15 CLEAR H2O filters. SONO's low cost of $35 over its useful lifetime of 3-5 years is also problematic for the Sawyer® filter, which would likely would have a significantly higher cost (>$100) over the 3-5 year timeframe.

To become a successful competitor to the SONO filter, the Sawyer® would have to significantly market the CLEAR H2O filter's smaller size (relative to the SONO filter), ability to remove pathogens when in conjunction with the Sawyer® filter, and its capability of indicating exhaustion.

6.6. Looking Ahead

6.6.a. Additional Tests

Prior to releasing CLEAR H2O's arsenic-removal filter on the market, many additional tests would need to be conducted. These tests were unable to be completed during the semester due to time constraints and limited lab resources. The additional tests can be divided into three categories: batch, column, and prototype. The batch tests that would be completed are more extensive kinetics and isotherm testing.

In addition to batch testing, extensive column testing also needs to be conducted prior to the distribution of the filter. Additional media should be column tested to confirm the selection of AquaBind SP-70 as the optimal filtration media.

After a final media is selected, CLEAR H2O recommends testing the final media with variations in arsenic concentration, ion presence and acidity. 100 µg/L was used as the standard test concentration; however, globally, concentrations can greatly exceed 100 µg/L, warranting the need for testing at higher concentrations. Ions that interfere with media adsorption include chloride, fluoride, iron, manganese, phosphate, silica, and sulfate.[61] These ions can inhibit the adsorption of arsenic or (in some cases) enhance the adsorption of arsenic, and thus should be analyzed to determine their effects on the selected media. Finally, varying pH affects the surface properties of the media which alters the media's removal capacity.

Following the completion of extensive batch and column testing, prototype testing also needs to be conducted. Prototype testing would involve pilot testing of the prototype in areas with high arsenic concentrations. Multiple filters would be distributed to households and monitored for filter usage trends and effluent arsenic concentrations.

6.6.b. Future Improvements

With proper funding and production equipment, several improvements should be made to the filter cartridge. These improvements are related solely to the durability and user convenience of the final product.

First and foremost, the prototype filter cartridge constructed by CLEAR H2O was 3D printed from very brittle acrylic. This initial prototype served primarily to display the required size and potential design of the filter. In large scale production, the filter cartridge should be injection molded, decreasing cost and improving the durability of the filter.

Another improvement that should be incorporated into the filter cartridge is a method by which the user can manually start and stop water flow through the filter. A solution could be as simple as a push-pull bottle cap, shown in Figure 50, allowing the user to filter water in smaller quantities when needed without having to filter the entire bucket at one time.

Figure 50: Push-Pull Bottle Cap

Improvements are also necessary for the Timestrip® indicator. The filter time strips must be modified from their current state to handle a wide variation in temperature ranges. Additionally, a case or protective cover to keep the time strip attached to the filter would need to be created because the time strip adhesive peals when exposed to excessive moisture.

6.7. Conclusion

Several concluding observations were made about the final prototype, including its adherence to project constraints and objectives, and fulfillment of design norms.

6.7.a. Objective and Constraint Adherence

During the project definition, CLEAR H2O established several project constraints and objectives based on personal goals and client desires. The two constraints were to remove arsenic below the WHO guideline of 10 μg/L and indicate when the media was exhausted. The project objectives pertained to size, ease of use, cost, and robustness.

Project Constraints

The selected media, AquaBind SP-70, effectively removes arsenic below 10 μg/L for at least 39,000 bed volumes with an influent concentration of 100 μg/L.

The Timestrip® indicator was the selected indication method to alert the user when media exhaustion has occurred. It is a proven technology used in other filters.

Project Objectives

Size:	The final prototype has a volume of approximately 0.8 liters, below the size objective of 1 liter.
Cost:	Final prototype production costs are anticipated to be between \$5 and \$10, and after mark-up, would be competitive within the \$35-\$80 cost range of the available arsenic filters on the market.
Ease of Use:	The system is gravity fed, and only requires the user to thread the extension onto the Sawyer® filter and press the time strip button.
Robustness:	The 3D printed prototype was created with a very brittle acrylic. Nonetheless, the production model would be injection molded using high-strength polymers that would substantially increase its durability.

6.7.b. Fulfilment of Design Norms

CLEAR H2O set out to create a filter that would incorporate the design norms of *Caring*, *Justice*, and *Cultural Appropriateness*. The final prototype enacts justice by giving people access to clean water who would otherwise be without. It shows care to those affected by arsenic poisoning by providing a way to treat water and alleviate the detrimental health effects caused by arsenic contamination. Finally, the filter's simple design and ease-of-use is appropriate for people with varying cultural and technical backgrounds.

One issue that was brought about concerning the final design was the excess waste generated by disposable filters. CLEAR H2O wants to design with good stewardship in mind and minimize waste whenever possible. The waste generated by a disposable filter cartridge is unfortunate but deemed necessary, or well worth the benefits of delivering arsenic-free water to those who would otherwise be without one of life's basic needs.

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Appendices Table of Contents

APPENDIX A

MathCAD Calculations

APPENDIX A.1

Stock Solution and Dilution

CLEAR H2O

Required Arsenic and Media For Lab Testing

Batch Tests

Kinetics Tests

$C_{As} := 0.100 \frac{mg}{L}$	Concentration of arsenite in Solution
$V := 100 \cdot mL$	Volume of each batch container
$n_{media} := 5$	Number of media being tested
$n_{tests} := 6$	Number of tests per media
$N := n_{media} \cdot n_{tests}$	Total number of test containers required
$V_{tot1} := N \cdot V = 3\,L$	Total Volume of solution required
$M_{As1} := V_{tot1} \cdot C_{As} = 0.3 \cdot mg$	Total mass of arsenic required

Adsorptive Capacity Tests- Isotherms

$C_{As} = 0.1 \cdot \frac{mg}{L}$	Concentration of arsenite in Solution
$V := 100 \cdot mL$	Volume of each batch container
$n_{media} := 5$	Number of media being tested
$n_{tests} := 6$	Number of tests per media
$N := n_{media} \cdot n_{tests}$	Total number of test containers required
$V_{tot2} := N \cdot V = 3\,L$	Total Volume of solution required
$M_{As2} := V_{tot2} \cdot C_{As} = 0.3 \cdot mg$	Total mass of arsenic required

Stock Solution

$V_{test} := V_{tot1} + V_{tot2} = 6\,L$	Total volume required for the batch tests
$V_{stock} := 1 \cdot L$	Volume of stock solution
$C_{test} := 0.1 \cdot \frac{mg}{L}$	Concentration of arsenic in the test solutions
$C_{stock} := 0.6 \cdot \frac{mg}{L}$	Concentration of arsenic in stock solution (Guess)

Given

$V_{test} \cdot C_{test} = V_{stock} \cdot C_{stock}$

$\text{Find}(C_{stock}) = 0.6 \cdot \frac{mg}{L}$ Concentration of arsenic in stock solution

$m_{as} := C_{stock} \cdot V_{stock} = 0.6 \cdot mg$ Mass of Arsenic required

Minimum Arsenic Required for Batch Testing

$m_{as} = 0.6 \cdot mg$

Total Arsenic Trioxide Required for Batch Testing

The group decided to use a stock solution of 1 mg/L using arsenic trioxide (As2O3). The Following calculations show how much As2O3 must be added to obtain a stock solution of 1mg/L arsenic.

$m_{as} := 1 \cdot mg$ Mass of arsenic desired in solution

$MW_{As2O3} := 197.84 \frac{gm}{mol}$ Molecular Weight of Arsenic Trioxide

$MW_{As2} := 149.84 \frac{gm}{mol}$ Molecular Weight of Arsenic

$M_{As2O3} := m_{as} \cdot \frac{MW_{As2O3}}{MW_{As2}}$ Ratio of arsenic to arsenic trioxide multiplied my desired arsenic in solution.

$M_{As2O3} = 1.32 \cdot mg$ Mass of arsenic trioxide to add to 1 liter of water.

Stock Solution Dilution

Concentration Verification and Test Strip Accuracy

In order to verify the concentration of the stock solution and to see how much the test strips varry per test, the team will dilute the stock solution to 10 ug/L theoretically and each team member will test the concentration using the test kit.

$C_{verify} := 0.01 \cdot \frac{mg}{L}$ Concentration of verification solution

$V_{verify} := 100 \cdot mL$ Volume of verification solution

$V_{stock} := 1L$ Volume of Stock solution (guess)

$C_{stock} := 1 \frac{mg}{L}$ Concentration of stock solution

Given

$V_{verify} \cdot C_{verify} = V_{stock} \cdot C_{stock}$

$\text{Find}(V_{stock}) = 1 \cdot mL$ Volume of stock solution to dilute with 99 ml of water

APPENDIX A.2

Experimental Headloss

Filter Head Loss

I. Parameters and Column Parameters

Media Parameters

$\varepsilon := 0.35$ Porosity

$\phi := 0.75$ Particle Shape Factor (Regular Sand)

Filter Parameters

$L := 6.3 \cdot in$ Depth of Filter Bed Layer

$D_{col} := \frac{7}{8} in$ Column Diameter

Flow Parameters

$\rho_{water} := 1000 \frac{kg}{m^3}$ Density of Water

$\mu := 2.344 \cdot 10^{-5} \cdot \frac{lbf \cdot s}{ft^2}$ Viscosity (60 F)

$Q := 5 \frac{mL}{min}, 10 \frac{mL}{min} .. 200 \frac{mL}{min}$ Volumetric Flow Rate Range

Calculations

1. Velocity of the Fluid Entering the Media

$$v_s(Q) := \frac{Q}{\pi \cdot \left(\frac{D_{col}}{2}\right)^2}$$

Superficial Velocity

2. Column Volume and EBCT

$$V_{col} := \pi \cdot \left(\frac{D_{col}}{2}\right)^2 \cdot L = 2.192 \times 10^{-3} \cdot ft^3$$

Column Volume

$$EBCT(Q) := \frac{V_{col}}{Q}$$

Empty Bed Column Time

II. Experimental Data

A. 25-35 Mesh

$$d_{p35} := 0.605\text{mm} = 1.985 \times 10^{-3} \cdot \text{ft}$$

$$EBCT_{35e} := \begin{pmatrix} 0.50 \\ 0.67 \\ 1.00 \\ 1.50 \\ 2.00 \\ 2.50 \end{pmatrix} \cdot \text{min} \qquad H_{L35e} := \begin{pmatrix} 2.75 \\ 2.16 \\ 1.33 \\ 0.79 \\ 0.48 \\ 0.25 \end{pmatrix} \cdot \text{ft}$$

B. 20-25 Mesh

$$d_{p25} := 0.7815\text{mm}$$

$$EBCT_{25e} := \begin{pmatrix} 0.33 \\ 0.50 \\ 0.67 \\ 1.00 \end{pmatrix} \cdot \text{min} \qquad H_{L25e} := \begin{pmatrix} 1.93 \\ 1.23 \\ 0.83 \\ 0.29 \end{pmatrix} \cdot \text{ft}$$

C. 18-20 Mesh

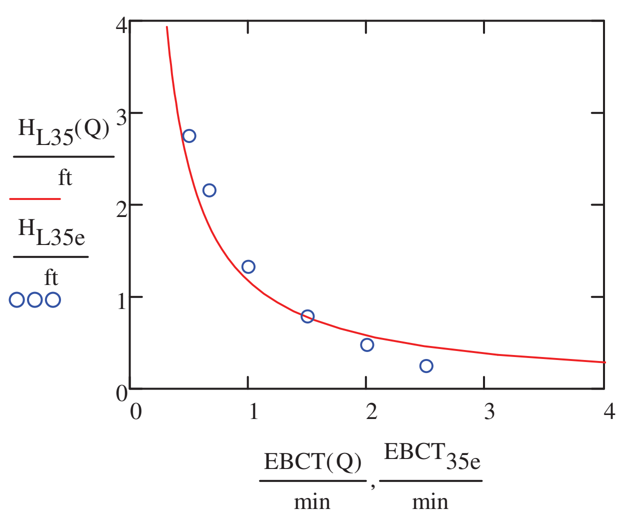
$$d_{p20} := .9265 \cdot \text{mm}$$

$$EBCT_{20e} := \begin{pmatrix} 0.22 \\ 0.26 \\ 0.31 \\ 0.33 \\ 0.35 \\ 0.41 \\ 0.50 \\ 0.50 \\ 0.62 \\ 0.66 \\ 0.83 \end{pmatrix} \cdot min \qquad H_{L20e} := \begin{pmatrix} 3.58 \\ 2.52 \\ 1.73 \\ 1.17 \\ 1.27 \\ 0.96 \\ 0.73 \\ 0.53 \\ 0.38 \\ 0.17 \\ 0.13 \end{pmatrix} \cdot ft$$

III. Calculated Head Loss

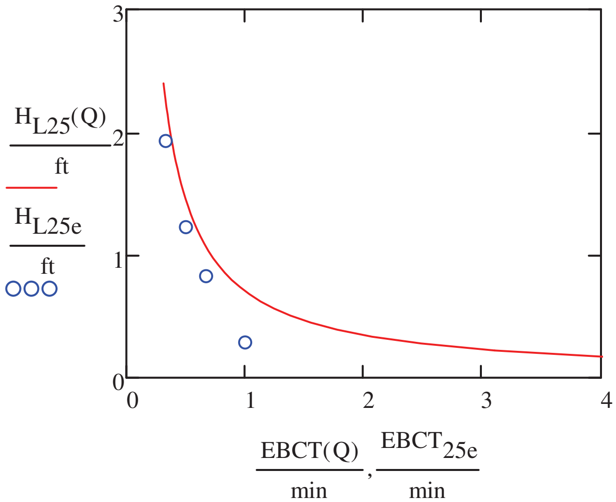
A. 25-35 Mesh

$$H_{L35}(Q) := \left[\frac{150 \cdot \mu (1 - \varepsilon)^2 \cdot v_s(Q)}{\rho_{water} \cdot g \cdot \varepsilon^3 \cdot \left(\phi \cdot d_{p35}\right)^2} + 1.75 \frac{(1 - \varepsilon)}{\varepsilon^3} \frac{v_s(Q)^2}{\phi \cdot d_{p35} \cdot g} \right] \cdot L \qquad \text{Head Loss}$$



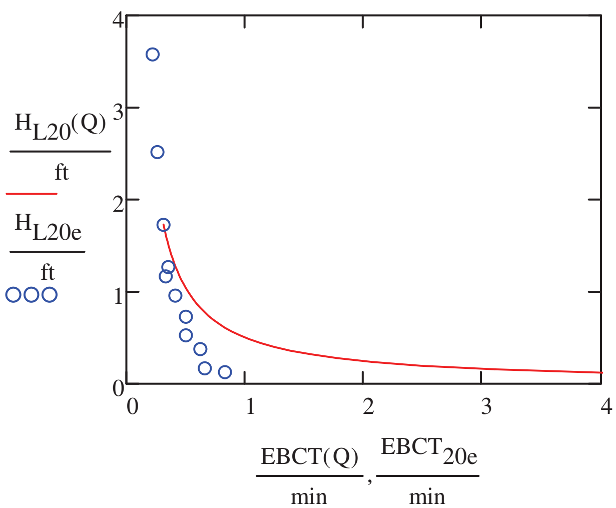
B. 20-25 Mesh

$$H_{L25}(Q) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_s(Q)}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot\left(\phi\cdot d_{p25}\right)^2} + 1.75\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_s(Q)^2}{\phi\cdot d_{p25}\cdot g}\right]\cdot L \quad \text{Head Loss}$$

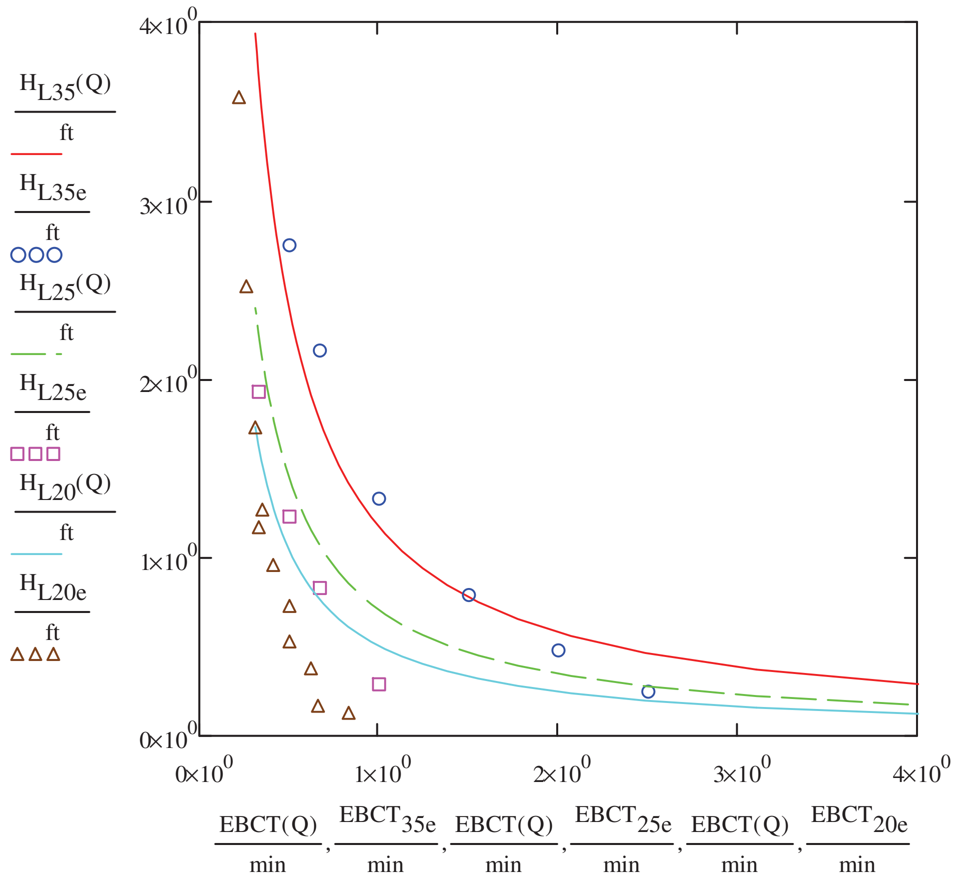


C. 18-20 Mesh

$$H_{L20}(Q) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_s(Q)}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot\left(\phi\cdot d_{p20}\right)^2} + 1.75\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_s(Q)^2}{\phi\cdot d_{p20}\cdot g}\right]\cdot L \quad \text{Head Loss}$$



D. Graphical Comparison



4×10^0
3×10^0
2×10^0
1×10^0
0×10^0
0×10^0
1×10^0
2×10^0
3×10^0
4×10^0
$\frac{H_{L35}(Q)}{ft}$
$\frac{H_{L35e}}{ft}$
$\frac{H_{L25}(Q)}{ft}$
$\frac{H_{L25e}}{ft}$
$\frac{H_{L20}(Q)}{ft}$
$\frac{H_{L20e}}{ft}$
$\frac{EBCT(Q)}{min}, \frac{EBCT_{35e}}{min}, \frac{EBCT(Q)}{min}, \frac{EBCT_{25e}}{min}, \frac{EBCT(Q)}{min}, \frac{EBCT_{20e}}{min}$

APPENDIX A.3

Prototype Headloss and Flow Calculations

Filter Head Loss

I. User Input

Media Parameters

$\varepsilon := 0.35$ Porosity

$\phi := 0.75$ Particle Sphericity

$d_p := 0.602\text{mm}$ Particle Diameter

Filter Parameters

$\text{Length} := 12\text{in}$ Depth of Filter Bed Layer

$D_{col} := 1.75\text{in}$ Column Diameter

$\text{EBCT} := 120\text{sec}$ Empty Bed Contact Time

II. Other Parameters

Flow Parameters

$\rho_{water} := 1000\frac{\text{kg}}{\text{m}^3}$ Density of Water

$\mu := 2.344 \cdot 10^{-5} \cdot \frac{\text{lbf} \cdot \text{s}}{\text{ft}^2}$ Viscosity (60 F)

Variable Parameters

$L := .5\text{in}, 1\text{in} .. 20\text{in}$ Range of bed lengths

$d := .1\text{mm}, .15\text{mm} .. 1.5\text{mm}$ Range of media grain sizes

$\text{EBCT}_{30} := 30\text{sec}$ lower EBCT range

$\text{EBCT}_{120} := 120\text{sec}$ higher EBCT range

Calculations

1. Column Area and Volume

$$A_{col} := \pi\left(\frac{D_{col}}{2}\right)^2 = 2.405 \cdot \text{in}^2$$ Column Area

$$V_{col}(L) := \pi \cdot \left(\frac{D_{col}}{2}\right)^2 \cdot L$$ Variable column volume

$$V_{col\_user} := \pi\left(\frac{D_{col}}{2}\right)^2 \cdot \text{Length}$$

2. Volumetric Flow Rate of Water Entering Media

$$Q\_user := \frac{V_{col\_user}}{EBCT}$$ User defined flow rate

$$Q(L) := \frac{V_{col}(L)}{EBCT}$$ Variable flow rate

$$Q_{30} := \frac{V_{col\_user}}{EBCT_{30}} \qquad Q_{120} := \frac{V_{col\_user}}{EBCT_{120}}$$ High and low range flow rates

3. Superficial Velocity

$$v_s(L) := \frac{Q(L)}{A_{col}}$$ Variable velocity

$$v_{s\_user} := \frac{Q\_user}{A_{col}}$$ User defined flow rate

$$v_{30} := \frac{Q_{30}}{A_{col}} \qquad v_{120} := \frac{Q_{120}}{A_{col}}$$ High and low range superficial velocities

III. Calculated Head Loss

$$H_L(L) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_s(L)}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot\left(\phi\cdot d_p\right)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_s(L)^2}{\phi\cdot d_p\cdot g}\right]\cdot L$$

$$H_{Ld}(d) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_{s\_user}}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot(\phi\cdot d)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_{s\_user}^{\ 2}}{\phi\cdot d\cdot g}\right]\cdot Length$$

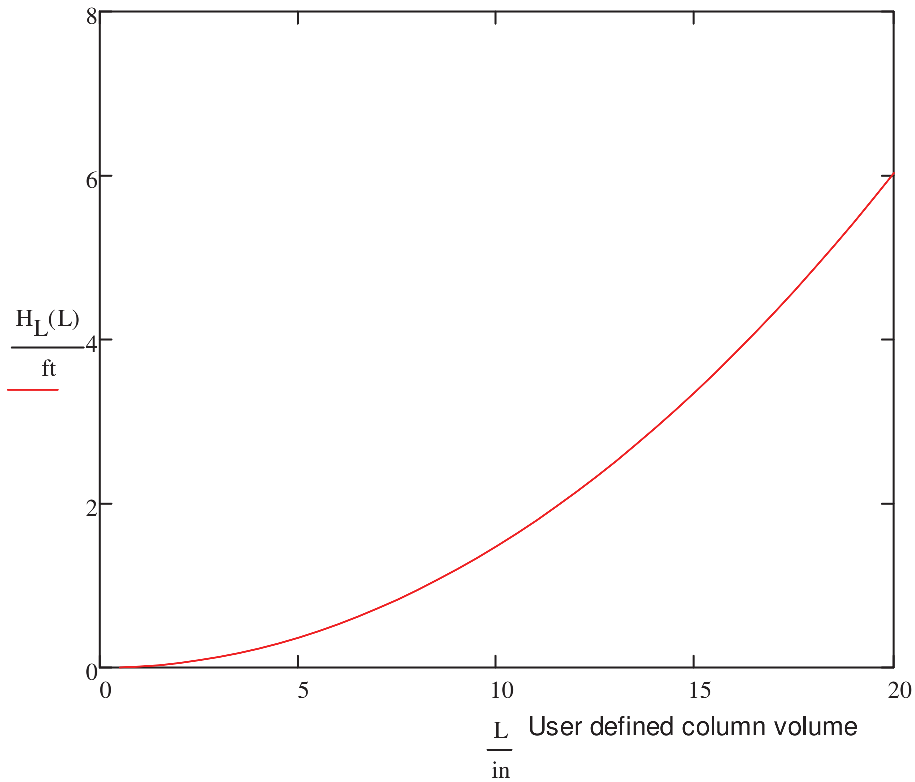
$$H_{L\_30}(d) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_{30}}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot(\phi\cdot d)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_{30}^{\ 2}}{\phi\cdot d\cdot g}\right]\cdot Length$$

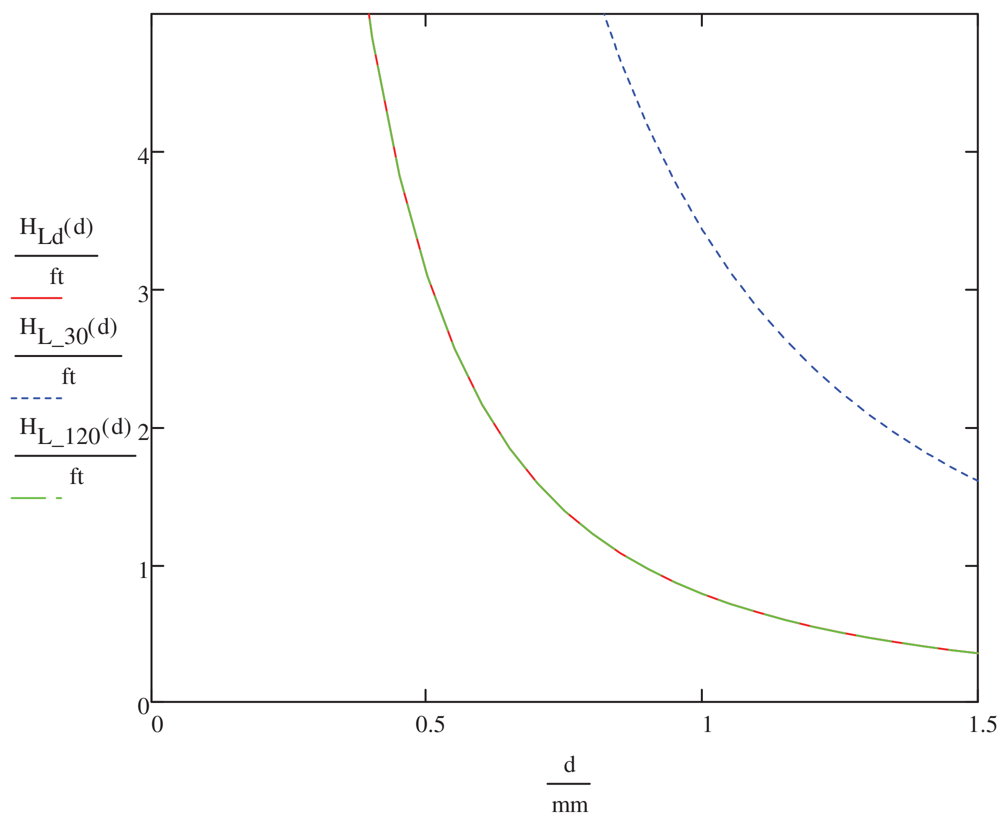
$$H_{L\_120}(d) := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_{120}}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot(\phi\cdot d)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_{120}^{\ 2}}{\phi\cdot d\cdot g}\right]\cdot Length$$

$$\text{Head}_{\text{Loss}} := \left[\frac{150\cdot\mu(1-\varepsilon)^2\cdot v_{s\_user}}{\rho_{water}\cdot g\cdot\varepsilon^3\cdot(\phi\cdot d_p)^2} + 1.75\,\frac{(1-\varepsilon)}{\varepsilon^3}\,\frac{v_{s\_user}^{\;2}}{\phi\cdot d_p\cdot g}\right]\cdot\text{Length} = 2.146\cdot\text{ft}$$

$$Q_{day} := \text{Q\_user}\cdot 6\text{hr} = 85.137\,\text{L}$$

$$\frac{V_{col\_user}\cdot 20000}{Q_{day}} = 111.111 \qquad V_{col\_user} = 0.473\,\text{L}$$





$\frac{H_{Ld}(d)}{ft}$
$\frac{H_{L\_30}(d)}{ft}$
$\frac{H_{L\_120}(d)}{ft}$
0
1
2
3
4
0
0.5
1
1.5
$\frac{d}{mm}$

APPENDIX A.4

pH Testing

AquaBind SP-70 pH Batch Test Calculations

1) NaOH Solution Dilution

$$V_{NaOH} := \frac{0.01\,\frac{mol}{L}\cdot 100mL}{2.8\,\frac{mol}{L}} = 0.357\cdot mL$$

2) pH Calcs

Known:

$$pH_{initial} := 6.05$$

$$pH_{desired1} := 7.2$$

$$pH_{desired2} := 8.2$$

$$M_{initial} := 10^{-pH_{initial}}\cdot\frac{mol}{L} = 8.913\times 10^{-7}\cdot\frac{mol}{L}$$

$$M_{desired1} := 10^{-\left(14-pH_{desired1}\right)}\cdot\frac{mol}{L} = 1.585\times 10^{-7}\cdot\frac{mol}{L}$$

$$M_{total1} := M_{initial} + M_{desired1} = 1.05\times 10^{-6}\cdot\frac{mol}{L}$$

$$V_{NaOH1} := \frac{M_{total1}\cdot 1\cdot L}{0.01\cdot\frac{mol}{L}} = 0.10497\cdot mL$$

$$M_{total2} := M_{initial} + 10^{-\left(14-pH_{desired2}\right)}\cdot\frac{mol}{L} = 2.476\times 10^{-6}\cdot\frac{mol}{L}$$

$$V_{NaOH2} := \frac{M_{total2}\cdot 1\cdot L}{0.01\cdot\frac{mol}{L}} = 0.248\cdot mL$$

Desired Volume

$$V := 1L$$

APPENDIX B

Prein&Newhof Test Results

APPENDIX B.1

Isotherm Test Results

Label Key

S = Stock Solution

C1 or Control 1 = Test Solution Control #
(Typically 3 controls)

A-SP (10) or A-SP-10 = 10 mg of Aquabind SP-70

A-MP (10) or A-MP-10 = 10 mg of Aquabind MP

M (10) or M-10 = 10 mg of Metsorb

B (10) or B-10 = 10 mg of Bayoxide

H (10) or H-10 = 10 mg of Hematite

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Date: *22-Nov-13*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Study

Project No: 2130001

Lab Order: 1311510

Matrix: AQUEOUS

Sampled By: Client

Lab ID: 1311510-001 **Collection Date:** 11/16/2013
Client Sample ID: S-10 **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	7.00	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-002 **Collection Date:** 11/17/2013
Client Sample ID: S-1 **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.685	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-003 **Collection Date:** 11/17/2013
Client Sample ID: A-SP (2) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.056	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-004 **Collection Date:** 11/17/2013
Client Sample ID: A-SP 5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.057	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-005 **Collection Date:** 11/17/2013
Client Sample ID: A-SP (7.5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.055	0.005	mg/L	1	11/20/2013

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Lab ID: 1311510-006 **Collection Date:** 11/17/2013
Client Sample ID: A-SP (10) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.052	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-007 **Collection Date:** 11/17/2013
Client Sample ID: A-SP (15) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.050	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-008 **Collection Date:** 11/17/2013
Client Sample ID: A-MP (2) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.054	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-009 **Collection Date:** 11/17/2013
Client Sample ID: A-MP (5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.053	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-010 **Collection Date:** 11/17/2013
Client Sample ID: A-MP (7.5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.053	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-011 **Collection Date:** 11/17/2013
Client Sample ID: A-MP (10) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.046	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-012 **Collection Date:** 11/17/2013
Client Sample ID: A-MP (15) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.046	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-013 **Collection Date:** 11/17/2013
Client Sample ID: H (2) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.053	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-014 **Collection Date:** 11/17/2013
Client Sample ID: H (5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.051	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-015 **Collection Date:** 11/17/2013
Client Sample ID: H (7.5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.052	0.005	mg/L	1	11/20/2013

Lab ID: 1311510-016 **Collection Date:** 11/17/2013
Client Sample ID: H (10) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.066	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-017 **Collection Date:** 11/17/2013
Client Sample ID: H (15) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.064	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-018 **Collection Date:** 11/17/2013
Client Sample ID: M (2) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.060	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-019 **Collection Date:** 11/17/2013
Client Sample ID: M (5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.060	0.005	mg/L	1	11/21/2013

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Lab ID: 1311510-020 **Collection Date:** 11/17/2013
Client Sample ID: M (7.5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.055	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-021 **Collection Date:** 11/17/2013
Client Sample ID: M (10) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.054	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-022 **Collection Date:** 11/17/2013
Client Sample ID: M (15) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.051	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-023 **Collection Date:** 11/17/2013
Client Sample ID: B (2) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.057	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-024 **Collection Date:** 11/17/2013
Client Sample ID: B (5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.060	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-025 **Collection Date:** 11/17/2013
Client Sample ID: B (7.5) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.056	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-026 **Collection Date:** 11/17/2013
Client Sample ID: B (10) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.051	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-027 **Collection Date:** 11/17/2013
Client Sample ID: B (15) **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.048	0.005	mg/L	1	11/21/2013

Lab ID: 1311510-028 **Collection Date:** 11/17/2013
Client Sample ID: Control 1 **Received Date:** 11/19/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.056	0.005	mg/L	1	11/21/2013

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Date: *02-Dec-13*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Study

Project No: 2130001

Lab Order: 1311717

Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1311717-001 **Collection Date:** 11/25/2013
Client Sample ID: 1.1 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.116	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-002 **Collection Date:** 11/25/2013
Client Sample ID: 1.2 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.115	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-003 **Collection Date:** 11/25/2013
Client Sample ID: 1.3 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.117	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-004 **Collection Date:** 11/25/2013
Client Sample ID: 2.1 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.121	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-005 **Collection Date:** 11/25/2013
Client Sample ID: 2.2 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.109	0.005	mg/L	1	11/29/2013

Project: Arsenic Study **Project No:** 2130001

Lab Order: 1311717 **Matrix:** AQUEOUS

Sampled By: Client

Lab ID: 1311717-006 **Collection Date:** 11/25/2013

Client Sample ID: 2.3 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.108	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-007 **Collection Date:** 11/25/2013

Client Sample ID: B20 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.016	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-008 **Collection Date:** 11/25/2013

Client Sample ID: B200 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.010	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-009 **Collection Date:** 11/25/2013

Client Sample ID: M20 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.023	0.005	mg/L	1	11/29/2013

Lab ID: 1311717-010 **Collection Date:** 11/25/2013

Client Sample ID: M200 **Received Date:** 11/26/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	11/29/2013

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Date: *11-Dec-13*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Study

Project No: 2130001

Lab Order: 1312166

Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1312166-001
Client Sample ID: M-C1
Collection Date: 12/4/2013
Received Date: 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.129	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-002
Client Sample ID: M-C2
Collection Date: 12/4/2013
Received Date: 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.123	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-003
Client Sample ID: M-C3
Collection Date: 12/4/2013
Received Date: 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.118	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-004
Client Sample ID: M-5
Collection Date: 12/4/2013
Received Date: 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.088	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-005
Client Sample ID: M-10
Collection Date: 12/4/2013
Received Date: 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.042	0.005	mg/L	1	12/6/2013

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Lab ID: 1312166-006 **Collection Date:** 12/4/2013
Client Sample ID: M-20 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.015	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-007 **Collection Date:** 12/4/2013
Client Sample ID: M-30 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.013	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-008 **Collection Date:** 12/4/2013
Client Sample ID: M-40 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.012	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-009 **Collection Date:** 12/4/2013
Client Sample ID: M-50 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.006	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-010 **Collection Date:** 12/4/2013
Client Sample ID: M-125 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-011 **Collection Date:** 12/4/2013
Client Sample ID: M-250 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-012 **Collection Date:** 12/4/2013
Client Sample ID: B-C1 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.109	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-013 **Collection Date:** 12/4/2013
Client Sample ID: B-C2 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.104	0.005	mg/L	1	12/6/2013

Lab ID: 1312166-014 **Collection Date:** 12/4/2013
Client Sample ID: B-C3 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.121	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-015 **Collection Date:** 12/4/2013
Client Sample ID: B-5 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.046	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-016 **Collection Date:** 12/4/2013
Client Sample ID: B-10 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.031	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-017 **Collection Date:** 12/4/2013
Client Sample ID: B-20 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.021	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-018 **Collection Date:** 12/4/2013
Client Sample ID: B-30 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.020	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-019 **Collection Date:** 12/4/2013
Client Sample ID: B-40 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.012	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-020 **Collection Date:** 12/4/2013
Client Sample ID: B-50 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.007	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-021 **Collection Date:** 12/4/2013
Client Sample ID: B-125 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.011	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-022 **Collection Date:** 12/4/2013
Client Sample ID: B-250 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.015	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-023 **Collection Date:** 12/4/2013
Client Sample ID: AMP-C1 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.127	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-024 **Collection Date:** 12/4/2013
Client Sample ID: AMP-C2 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.120	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-025 **Collection Date:** 12/4/2013
Client Sample ID: AMP-C3 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.118	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-026 **Collection Date:** 12/4/2013
Client Sample ID: AMP-5 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.101	0.005	mg/L	1	12/9/2013

Lab ID: 1312166-027 **Collection Date:** 12/4/2013
Client Sample ID: AMP-10 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.094	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-028 **Collection Date:** 12/4/2013
Client Sample ID: AMP-20 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.121	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-029 **Collection Date:** 12/4/2013
Client Sample ID: AMP-30 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.076	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-030 **Collection Date:** 12/4/2013
Client Sample ID: AMP-40 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.095	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-031 **Collection Date:** 12/4/2013
Client Sample ID: AMP-50 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.019	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-032 **Collection Date:** 12/4/2013
Client Sample ID: AMP-125 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.041	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-033 **Collection Date:** 12/4/2013
Client Sample ID: AMP-250 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	12/11/2013

Lab ID: 1312166-034 **Collection Date:** 12/4/2013
Client Sample ID: SP-C1 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.111	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-035 **Collection Date:** 12/4/2013
Client Sample ID: SP-C2 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.114	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-036 **Collection Date:** 12/4/2013
Client Sample ID: SP-C3 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.118	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-037 **Collection Date:** 12/4/2013
Client Sample ID: SP-5 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.061	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-038 **Collection Date:** 12/4/2013
Client Sample ID: SP-10 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.056	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-039 **Collection Date:** 12/4/2013
Client Sample ID: SP-20 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.029	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-040 **Collection Date:** 12/4/2013
Client Sample ID: SP-30 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.042	0.005	mg/L	1	12/10/2013

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Lab ID: 1312166-041 **Collection Date:** 12/4/2013
Client Sample ID: SP-40 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.016	0.005	mg/L	1	12/11/2013

Lab ID: 1312166-042 **Collection Date:** 12/4/2013
Client Sample ID: SP-50 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.036	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-043 **Collection Date:** 12/4/2013
Client Sample ID: SP-125 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.040	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-044 **Collection Date:** 12/4/2013
Client Sample ID: SP-250 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.030	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-045 **Collection Date:** 12/4/2013
Client Sample ID: H-C1 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.116	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-046 **Collection Date:** 12/4/2013
Client Sample ID: H-C2 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.119	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-047 **Collection Date:** 12/4/2013
Client Sample ID: H-C3 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.111	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-048 **Collection Date:** 12/4/2013
Client Sample ID: H-5 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.119	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-049 **Collection Date:** 12/4/2013
Client Sample ID: H-10 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.122	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-050 **Collection Date:** 12/4/2013
Client Sample ID: H-20 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.130	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-051 **Collection Date:** 12/4/2013
Client Sample ID: H-30 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.133	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-052 **Collection Date:** 12/4/2013
Client Sample ID: H-40 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.122	0.005	mg/L	1	12/10/2013

Lab ID: 1312166-053 **Collection Date:** 12/4/2013
Client Sample ID: H-50 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.118	0.005	mg/L	1	12/11/2013

Lab ID: 1312166-054 **Collection Date:** 12/4/2013
Client Sample ID: H-125 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.111	0.005	mg/L	1	12/11/2013

Lab ID: 1312166-055 **Collection Date:** 12/4/2013
Client Sample ID: H-250 **Received Date:** 12/5/2013

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.112	0.005	mg/L	1	12/11/2013

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APPENDIX B.2

Column Test #1 Results

Label Key

<u>Controls</u>

Each control was labelled with the word “Control” followed by two numbers. The first number is the barrel number and the second number is the control number.

Control 1.1 = 1 of three controls turned in from barrel #1

<u>Media</u>

Each media test was labelled with a letter for the media type followed by a number that represents the approximate bed volumes.

M 1.0 = 1 bed volume through Metsorb

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Date: *27-Feb-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2130001

Lab Order: 1402525

Matrix: AQUEOUS

Sampled By: Client

Lab ID: 1402525-001 **Collection Date:** 2/25/2014
Client Sample ID: A 1.0 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	2/26/2014

Lab ID: 1402525-002 **Collection Date:** 2/25/2014
Client Sample ID: B 1.0 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.023	0.005	mg/L	1	2/26/2014

Lab ID: 1402525-003 **Collection Date:** 2/25/2014
Client Sample ID: M 1.0 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.020	0.005	mg/L	1	2/26/2014

Lab ID: 1402525-004 **Collection Date:** 2/25/2014
Client Sample ID: Control 1.1 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.073	0.005	mg/L	1	2/26/2014

Lab ID: 1402525-005 **Collection Date:** 2/25/2014
Client Sample ID: Control 1.2 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.098	0.005	mg/L	1	2/26/2014

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Project: Arsenic Testing **Project No:** 2130001

Lab Order: 1402525 **Matrix:** AQUEOUS

Sampled By: Client

Lab ID: 1402525-006 **Collection Date:** 2/25/2014

Client Sample ID: Control 1.3 **Received Date:** 2/25/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.070	0.005	mg/L	1	2/26/2014

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Date: *04-Mar-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing
Project No: 2140001

Lab Order: 1402618
Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1402618-001
Client Sample ID: A 4.00
Collection Date: 2/28/2014 9:05:00 A
Received Date: 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-002
Client Sample ID: A .500
Collection Date: 2/24/2014 8:55:00 P
Received Date: 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-003
Client Sample ID: B 4.00
Collection Date: 2/28/2014 9:05:00 A
Received Date: 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.063	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-004
Client Sample ID: B .500
Collection Date: 2/24/2014 8:55:00 P
Received Date: 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-005
Client Sample ID: M 4.00
Collection Date: 2/28/2014 9:05:00 A
Received Date: 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.069	0.005	mg/L	1	3/3/2014

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Project: Arsenic Testing **Project No:** 2140001

Lab Order: 1402618 **Matrix:** AQUEOUS

Sampled By: Client

Lab ID: 1402618-006 **Collection Date:** 2/24/2014 8:55:00 P

Client Sample ID: M .500 **Received Date:** 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-007 **Collection Date:** 2/27/2014 2:35:00 P

Client Sample ID: Control 2.1 **Received Date:** 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.079	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-008 **Collection Date:** 2/27/2014 2:35:00 P

Client Sample ID: Control 2.2 **Received Date:** 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.087	0.005	mg/L	1	3/3/2014

Lab ID: 1402618-009 **Collection Date:** 2/27/2014 2:35:00 P

Client Sample ID: Control 2.3 **Received Date:** 2/28/2014 11:50:00

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.106	0.005	mg/L	1	3/3/2014

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Date: *11-Mar-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1403146

Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1403146-001
Client Sample ID: A 5.0
Collection Date: 3/1/2014
Received Date: 3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/10/2014

Lab ID: 1403146-002
Client Sample ID: A11.0
Collection Date: 3/6/2014
Received Date: 3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/10/2014

Lab ID: 1403146-003
Client Sample ID: B2
Collection Date: 2/26/2014
Received Date: 3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.051	0.005	mg/L	1	3/10/2014

Lab ID: 1403146-004
Client Sample ID: B5.0
Collection Date: 3/1/2014
Received Date: 3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.064	0.005	mg/L	1	3/10/2014

Lab ID: 1403146-005
Client Sample ID: M2
Collection Date: 2/26/2014
Received Date: 3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.013	0.005	mg/L	1	3/10/2014

Project:	Arsenic Testing	**Project No:**	2140001
Lab Order:	1403146	**Matrix:**	AQUEOUS
		Sampled By:	Client

Lab ID:	1403146-006	**Collection Date:**	3/1/2014
Client Sample ID:	M5.0	**Received Date:**	3/6/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.054	0.005	mg/L	1	3/10/2014

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APPENDIX B.3

Column Test #2 Results

Label Key

<u>Controls</u>

Each control was label with the word “Control” followed by two numbers. The first number is the barrel number and the second number is the control number.

Control 1.1 = 1 of three controls turned in from barrel #1

<u>Media</u>

Each media test was labelled with a letter for the media type followed by a number that represents the approximate bed volumes.

M 1.0 = 1 bed volume through Metsorb

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Date: *20-Mar-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: As Testing

Project No: 2140001

Lab Order: 1403378

Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1403378-001
Client Sample ID: Control 4.1
Collection Date: 3/14/2014
Received Date: 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.084	0.005	mg/L	1	3/18/2014

Lab ID: 1403378-002
Client Sample ID: Control 4.2
Collection Date: 3/14/2014
Received Date: 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.089	0.005	mg/L	1	3/18/2014

Lab ID: 1403378-003
Client Sample ID: Control 4.3
Collection Date: 3/14/2014
Received Date: 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.086	0.005	mg/L	1	3/18/2014

Lab ID: 1403378-004
Client Sample ID: A 6.75
Collection Date: 3/17/2014
Received Date: 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/18/2014

Lab ID: 1403378-005
Client Sample ID: B 6.75
Collection Date: 3/17/2014
Received Date: 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.034	0.005	mg/L	1	3/18/2014

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Project: As Testing | **Project No:** 2140001

Lab Order: 1403378 | **Matrix:** AQUEOUS | **Sampled By:** Client

Lab ID: 1403378-006 | **Collection Date:** 3/17/2014

Client Sample ID: M 6.75 | **Received Date:** 3/17/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.009	0.005	mg/L	1	3/19/2014

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Date: *25-Mar-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing
Project No: 2140001

Lab Order: 1403531
Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1403531-001
Client Sample ID: Control 5.1
Collection Date: 3/20/2014
Received Date: 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.088	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-002
Client Sample ID: Control 5.2
Collection Date: 3/20/2014
Received Date: 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.090	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-003
Client Sample ID: Control 5.3
Collection Date: 3/20/2014
Received Date: 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.100	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-004
Client Sample ID: B 3.25
Collection Date: 3/20/2014
Received Date: 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.014	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-005
Client Sample ID: B 4.75
Collection Date: 3/20/2014
Received Date: 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.033	0.005	mg/L	1	3/24/2014

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Lab ID: 1403531-006 **Collection Date:** 3/20/2014
Client Sample ID: B 9.75 **Received Date:** 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.077	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-007 **Collection Date:** 3/20/2014
Client Sample ID: M 7.75 **Received Date:** 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.012	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-008 **Collection Date:** 3/20/2014
Client Sample ID: M 9.75 **Received Date:** 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.052	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-009 **Collection Date:** 3/20/2014
Client Sample ID: A 9.75 **Received Date:** 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/24/2014

Lab ID: 1403531-010 **Collection Date:** 3/20/2014
Client Sample ID: A 13.0 **Received Date:** 3/20/2014 2:50:00 P

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	3/24/2014

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Date: *04-Apr-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1404035

Matrix: DRINKING WATER

Sampled By: Client

Lab ID: 1404035-001A
Client Sample ID: Control 6.1
Collection Date: 3/21/2014
Received Date: 4/1/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.090**	mg/L	0.005	0.01	Exceeds MCL	SB	4/3/2014	SM3113B

Lab ID: 1404035-002A
Client Sample ID: Control 6.2
Collection Date: 3/21/2014
Received Date: 4/1/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.091**	mg/L	0.005	0.01	Exceeds MCL	SB	4/3/2014	SM3113B

Lab ID: 1404035-003A
Client Sample ID: Control 6.3
Collection Date: 3/21/2014
Received Date: 4/1/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.089**	mg/L	0.005	0.01	Exceeds MCL	SB	4/3/2014	SM3113B

Lab ID: 1404035-004A
Client Sample ID: A21
Collection Date: 4/1/2014
Received Date: 4/1/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**< 0.005**	mg/L	0.005	0.01		SB	4/3/2014	SM3113B

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Date: *09-Apr-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1404111

Matrix: AQUEOUS
Sampled By: Client

Lab ID: 1404111-001 **Collection Date:** 4/3/2014
Client Sample ID: A2 3 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.011	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-002 **Collection Date:** 4/3/2014
Client Sample ID: A4 3 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-003 **Collection Date:** 3/13/2014
Client Sample ID: B 2.75 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.011	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-004 **Collection Date:** 3/18/2014
Client Sample ID: B 825 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.058	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-005 **Collection Date:** 3/14/2014
Client Sample ID: B4 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.014	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-006 **Collection Date:** 3/16/2014
Client Sample ID: B 6.0 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.034	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-007 **Collection Date:** 3/15/2014
Client Sample ID: M5.25 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.020	0.005	mg/L	1	4/7/2014

Lab ID: 1404111-008 **Collection Date:** 3/18/2014
Client Sample ID: M8.25 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.018	0.005	mg/L	1	4/8/2014

Lab ID: 1404111-009 **Collection Date:** 3/19/2014
Client Sample ID: M8.75 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.062	0.005	mg/L	1	4/8/2014

Lab ID: 1404111-010 **Collection Date:** 4/2/2014
Client Sample ID: Control 7.1 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.076	0.005	mg/L	1	4/8/2014

Lab ID: 1404111-011 **Collection Date:** 4/2/2014
Client Sample ID: Control 7.2 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.088	0.005	mg/L	1	4/8/2014

Lab ID: 1404111-012 **Collection Date:** 4/2/2014
Client Sample ID: Control 7.3 **Received Date:** 4/3/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.089	0.005	mg/L	1	4/8/2014

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APPENDIX B.4

EBCT Test Results

Label Key

<u>Controls</u>

Each control was label with the word “Control” followed by two numbers. The first number is the barrel number and the second number is the control number.

Control 1.1 = 1 of three controls turned in from barrel #1

<u>Media</u>

Each media test was labelled with a letter for the media type followed by a number that represents the bed length then a dash and a number that represents the approximate bed volumes.

A6 - 10 = 6 in column of Aquabind after 10 bed volumes

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Date: *15-Apr-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1404238

Matrix: AQUEOUS

Sampled By: Client

Lab ID: 1404238-001 **Collection Date:** 4/8/2014
Client Sample ID: Control 8.1 **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.078	0.005	mg/L	1	4/14/2014

Lab ID: 1404238-002 **Collection Date:** 4/8/2014
Client Sample ID: Control 8.2 **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.078	0.005	mg/L	1	4/14/2014

Lab ID: 1404238-003 **Collection Date:** 4/8/2014
Client Sample ID: Control 8.3 **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.076	0.005	mg/L	1	4/14/2014

Lab ID: 1404238-004 **Collection Date:** 4/8/2014
Client Sample ID: A2-9.0 **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.057	0.005	mg/L	1	4/14/2014

Lab ID: 1404238-005 **Collection Date:** 4/8/2014
Client Sample ID: A4-9.0 **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/14/2014

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Project: Arsenic Testing | **Project No:** 2140001

Lab Order: 1404238 | **Matrix:** AQUEOUS | **Sampled By:** Client

Lab ID: 1404238-006 | **Collection Date:** 4/8/2014
Client Sample ID: A-28 | **Received Date:** 4/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/14/2014

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Date: *17-Apr-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1404457

Matrix: DRINKING WATER
Sampled By: Client

Lab ID: 1404457-001A
Client Sample ID: A4-13
Collection Date: 4/13/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**< 0.005**	mg/L	0.005	0.01		SB	4/16/2014	SM3113B

Lab ID: 1404457-002A
Client Sample ID: A4-16
Collection Date: 4/15/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**< 0.005**	mg/L	0.005	0.01		SB	4/16/2014	SM3113B

Lab ID: 1404457-003A
Client Sample ID: A6-35
Collection Date: 4/15/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.008**	mg/L	0.005	0.01		SB	4/16/2014	SM3113B

Lab ID: 1404457-004A
Client Sample ID: Control 9.1
Collection Date: 4/12/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.106**	mg/L	0.005	0.01	Exceeds MCL	SB	4/16/2014	SM3113B

Lab ID: 1404457-005A
Client Sample ID: Control 9.2
Collection Date: 4/12/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.105**	mg/L	0.005	0.01	Exceeds MCL	SB	4/16/2014	SM3113B

Lab ID: 1404457-006A
Client Sample ID: Control 9.3
Collection Date: 4/12/2014
Received Date: 4/15/2014

Analyses	Result	Units	RPT Limit	M.C.L.		Analyst	Date Analyzed	Method #
Arsenic	**0.107**	mg/L	0.005	0.01	Exceeds MCL	SB	4/16/2014	SM3113B

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Date: *23-Apr-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1404667

Matrix: DRINKING WATER
Sampled By: Client

Lab ID: 1404667-001
Client Sample ID: Control 10.1
Collection Date: 4/21/2014
Received Date: 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.069	0.005	mg/L	1	4/22/2014

Lab ID: 1404667-002
Client Sample ID: Control 10.2
Collection Date: 4/21/2014
Received Date: 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.075	0.005	mg/L	1	4/22/2014

Lab ID: 1404667-003
Client Sample ID: Control 10.3
Collection Date: 4/21/2014
Received Date: 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.070	0.005	mg/L	1	4/22/2014

Lab ID: 1404667-004
Client Sample ID: A4-18
Collection Date: 4/18/2014
Received Date: 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/22/2014

Lab ID: 1404667-005
Client Sample ID: A4-21
Collection Date: 4/21/2014
Received Date: 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/22/2014

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Lab ID: 1404667-006 **Collection Date:** 4/18/2014

Client Sample ID: A4-38 **Received Date:** 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/22/2014

Lab ID: 1404667-007 **Collection Date:** 4/21/2014

Client Sample ID: A4-41 **Received Date:** 4/21/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	4/22/2014

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Date: *12-May-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1405299

Matrix: DRINKING WATER
Sampled By: Client

Lab ID: 1405299-001 **Collection Date:** 3/31/2014
Client Sample ID: A2-0.5 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

Lab ID: 1405299-002 **Collection Date:** 4/2/2014
Client Sample ID: A2-2 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

Lab ID: 1405299-003 **Collection Date:** 5/8/2014
Client Sample ID: A4-38 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

Lab ID: 1405299-004 **Collection Date:** 4/4/2014
Client Sample ID: A2-4.0 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.029	0.005	mg/L	1	5/9/2014

Lab ID: 1405299-005 **Collection Date:** 5/8/2014
Client Sample ID: A6-58 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

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Project: Arsenic Testing **Project No:** 2140001

Lab Order: 1405299 **Matrix:** DRINKING WATER

Sampled By: Client

Lab ID: 1405299-006 **Collection Date:** 4/6/2014

Client Sample ID: A2/6 **Received Date:** 5/8/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.029	0.005	mg/L	1	5/9/2014

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APPENDIX B.5

pH Test Results

Label Key

Controls

Each control was label with the word “Control” followed by two numbers. The first number is the barrel number and the second number is the control number.

Control 1.1 = 1 of three controls turned in from barrel #1

Media

Each media test was labelled with “pH” followed by a number representing the approximate pH followed by another number representing the mass of media.

pH 6 250 = Solution of pH 6 with 250 mg of media

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Date: *09-May-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1405099

Matrix: DRINKING WATER
Sampled By: Client

Lab ID: 1405099-001 — **Collection Date:** 5/1/2014
Client Sample ID: pH 7 Control 1 — **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.075	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-002 — **Collection Date:** 4/29/2014
Client Sample ID: pH 7 Control 2 — **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.081	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-003 — **Collection Date:** 5/1/2014
Client Sample ID: pH 7-5 — **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.056	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-004 — **Collection Date:** 5/1/2014
Client Sample ID: pH 7-10 — **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.043	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-005 — **Collection Date:** 5/1/2014
Client Sample ID: pH 7-20 — **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.021	0.005	mg/L	1	5/7/2014

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Lab ID: 1405099-006 **Collection Date:** 5/1/2014
Client Sample ID: pH 7-35 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.058	0.005	mg/L	1	5/7/2014

Lab ID: 1405099-007 **Collection Date:** 5/1/2014
Client Sample ID: pH 7-50 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.064	0.005	mg/L	1	5/7/2014

Lab ID: 1405099-008 **Collection Date:** 5/1/2014
Client Sample ID: pH 7-75 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.073	0.005	mg/L	1	5/9/2014

Lab ID: 1405099-009 **Collection Date:** 5/1/2014
Client Sample ID: pH 7-125 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.067	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-010 **Collection Date:** 5/1/2014
Client Sample ID: pH 7-250 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.065	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-011 **Collection Date:** 5/2/2014
Client Sample ID: pH 8 Control 1 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.074	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-012 **Collection Date:** 4/30/2014
Client Sample ID: pH 8 Control 2 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.079	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-013 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-5 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.057	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-014 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-10 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.041	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-015 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-20 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.023	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-016 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-35 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.022	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-017 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-50 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.029	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-018 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-75 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.030	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-019 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-125 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.058	0.005	mg/L	1	5/6/2014

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Lab ID: 1405099-020 **Collection Date:** 5/2/2014
Client Sample ID: pH 8-250 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.078	0.005	mg/L	1	5/6/2014

Lab ID: 1405099-021 **Collection Date:** 5/5/2014
Client Sample ID: A6-55 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

Lab ID: 1405099-022 **Collection Date:** 5/5/2014
Client Sample ID: A4-55 **Received Date:** 5/5/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/9/2014

Prein&Newhof
Engineers ▪ Surveyors ▪ Environmental ▪ Laboratory

Date: *05-May-14*

Customer Name: Calvin College
3201 Burton SW
Grand Rapids, MI 49546

Contact Name: Attn: Grant
3201 Burton SW
Grand Rapids, MI 49546

Project: Arsenic Testing

Project No: 2140001

Lab Order: 1405037

Matrix: DRINKING WATER
Sampled By: Client

Lab ID: 1405037-001 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 Control 2 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.080	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-002 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 125 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.050	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-003 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 20 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.044	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-004 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 Control 1 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.073	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-005 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 75 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.050	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-006 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 250 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.051	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-007 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 5 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.043	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-008 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 10 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.025	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-009 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 35 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.037	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-010 **Collection Date:** 4/30/2014
Client Sample ID: pH 6 50 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	0.038	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-011 **Collection Date:** 5/1/2014
Client Sample ID: A6-51 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/2/2014

Lab ID: 1405037-012 **Collection Date:** 5/1/2014
Client Sample ID: A4-31 **Received Date:** 5/1/2014

Analyses	Result	PQL	Units	DF	Date Analyzed
METALS, DRINKING WATER		**SM3113B**			Analyst: **SB**
Arsenic	< 0.005	0.005	mg/L	1	5/2/2014

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APPENDIX C
Excel Spreadsheets

APPENDIX C.1

Batch Testing

Mass Loading Test # 1 - Full Scale Test

Start Date:	11/9/2013
Start Time:	12:00 AM
End Date:	11/11/2013
End Time:	12:00 PM

Description

The purpose of this test is to determine each media's efficiency at removing arsenic. The tests were done with masses 2, 5, 7.5, 10 and 15 mg with 1 control for the entire test. Each test vial contains 100 ml of test solution.

Test Conditions

Stock Solution	1 [mg/L]	
Theoretical test Sol'n	100 [ug/L]	(100 ml of stock solution in 900 ml deionized water)
Actual test Sol'n	56 [ug/L]	

Media Removal Results

Metsorb

Mass [mg]	As Remaining [ug/L]	As Removed [ug]	q [ug/mg]
1.7	60	-0.40	-0.24
4.6	60	-0.40	-0.09
7.4	55	0.10	0.01
9.7	54	0.20	0.02
15.1	51	0.50	0.03

Bayoxide E33

Mass [mg]	As Remaining [ug/L]	As Removed [ug]	q [ug/mg]
2.2	57	-0.10	-0.05
4.4	60	-0.40	-0.09
7.4	56	0.00	0.00
9.6	51	0.50	0.05
15.3	48	0.80	0.05

Aquabind SP-70

Mass [mg]	As Remaining [ug/L]	As Removed [ug]	q [ug/mg]
1.9	56	0.00	0.00
4.5	57	-0.10	-0.02
7.4	55	0.10	0.01
9.1	52	0.40	0.04
14.4	50	0.60	0.04

Aquabind MP

Mass [mg]	As Remaining [ug/L]	As Removed [ug]	q [ug/mg]
2.1	54	0.20	0.10
4.7	53	0.30	0.06
7.5	53	0.30	0.04
10.1	46	1.00	0.10
14.5	46	1.00	0.07

Hematite

Mass [mg]	As Remaining [ug/L]	As Removed [ug]	q [ug/mg]
1.5	53	0.30	0.20
4.4	51	0.50	0.11
7	52	0.40	0.06
10	66	-1.00	-0.10
15	64	-0.80	-0.05

Mass Loading Test # 2

Start Date:	11/25/2013
Start Time:	8:25 PM
End Date:	11/26/2013
End Time:	9:00 PM

Description: This lab test is performed primarily to test the laboratory procedure and to determine if the mass of media was the problem in the first test. This test will be done with Metsorb , bayoxide E33 and two controls. The mass of media will be 20 mg and 200 mg.

Stock Solution:	7	[mg/L]	
Theoretical Test Sol'n:	100	[ug/L]	(14.3 ml of stock and 985.7 ml deionized water)
pH:	5		

	1	2	3	Average		
Control #1:	116	115	117	116	[ug/L]	(Initial Test solution)
Control #2:	121	109	108	113	[ug/L]	(Test solution after 12 hr)

Metsorb

Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
20.4	23	93	0.455882
199.7	0	116	0.058087

	Start Time	End Time	Test Time	
20.4	21:00	9:07	12:07	[hr]
199.7	21:03	9:10	12:07	[hr]

Bayoxide E33

Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
20	16	100	0.5
200.4	10	106	0.05289421

	Start Time	End Time	Test Time	
20	20:55	9:03	12:08	[hr]
200.4	20:58	9:05	12:07	[hr]

Mass Loading Test # 3 - Full Scale Test

A

Start Date:	12/3/2013
Start Time:	9:00 PM
End Date:	12/4/2013
End Time:	11:28 PM

Description

The purpose of this test is to determine each media's efficiency at removing arsenic. The tests were done with masses 5, 10, 20, 30, 40, 50, 125, and 250 mg with 3 controls for each test. Each test vial contains 100 ml of test solution.

Test Conditions

Stock Solution	7	[mg/L]	
Theoretical test Sol'n	100	[ug/L]	(14 ml of stock solution in 986 ml deionized water)
Test Solution pH			
Metsorb	5.11		
Bayoxide	5.09		
SP-70	5.43		
MP	5.18		
Hematite	5.37		
Temperature			
SP-70	23.2	[C]	
MP	25	[C]	

Media Removal Results

Metsorb Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]	Bayoxide E33 Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
4.9	88	35.33	0.72	5	46	65.33	1.31
10.1	42	81.33	0.81	10.1	31	80.33	0.80
20.1	15	108.33	0.54	19.8	21	90.33	0.46
30.6	13	110.33	0.36	30.1	20	91.33	0.30
39.7	12	111.33	0.28	39.4	12	99.33	0.25
49.9	6	117.33	0.24	50.6	7	104.33	0.21
125.4	5	118.33	0.09	124.9	11	100.33	0.08
250.2	5	118.33	0.05	249.7	15	96.33	0.04

Metsorb		Bayoxide E33	
Control 1	129	Control 1	109
Control 2	123	Control 2	104
Control 3	118	Control 3	121
Average	123.3333333	Average	111.3333333

Time

Metsorb Mass	Time Started	Time Removed	Total Time [hr]	Bayoxide E3 Mass	Time Started	Time Removed	Total Time
4.9	21:56	22:06	0:10	5	22:29	22:23	23:54
10.1	21:57	22:08	0:11	10.1	22:32	22:25	23:53
20.1	21:59	22:10	0:11	19.8	22:34	22:26	23:52
30.6	22:02	22:11	0:09	30.1	22:36	22:27	23:51
39.7	22:05	22:13	0:08	39.4	22:38	22:28	23:50
49.9	22:08	22:14	0:06	50.6	22:40	22:29	23:49
125.4	22:10	22:15	0:05	124.9	22:42	22:30	23:48
250.2	22:13	22:16	0:03	249.7	22:45	22:31	23:46
		Average	24.08			average	23:50
Control 1	22:14	22:19	0:05	Control 1	22:47	22:20	23:33
Control 2	22:16	22:19	0:03	Control 2	22:49	22:20	23:31
Control 3	22:18	22:20	0:02	Control 3	22:50	22:21	23:31
			21:55				

quabind SP-70

Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
5.2	61	53.33	1.03
10.3	56	58.33	0.57
19.7	29	85.33	0.43
30.3	42	72.33	0.24
39.9	16	98.33	0.25
50.5	36	78.33	0.16
124.6	40	74.33	0.06
249.5	30	84.33	0.03

Control 1	111
Control 2	114
Control 3	118
Average	114.3333333

Aquabind MP

Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
4.5	101	20.67	0.46
9.6	94	27.67	0.29
19.5	121	0.67	0.00
29.4	76	45.67	0.16
39.9	95	26.67	0.07
50.1	19	102.67	0.20
125.2	41	80.67	0.06
249.3	5	116.67	0.05

Control 1	127
Control 2	120
Control 3	118
Average	121.6666667

Hematite

Mass [mg]	As Remaining [ug/L]	As Removed [ug/L]	q [ug/mg]
4.8	119	-3.67	-0.08
10	122	-6.67	-0.07
19.7	130	-14.67	-0.07
29.6	133	-17.67	-0.06
39.9	122	-6.67	-0.02
50.6	118	-2.67	-0.01
125.8	111	4.33	0.00
250.6	112	3.33	0.00

Control 1	116
Control 2	119
Control 3	111
Average	115.3333333

Aquabind SP-70

Mass	Time Started	Time Removed	Total Time
5.2	23:37	23:03	23:26
10.3	23:39	23:04	23:25
19.7	23:41	23:05	23:24
30.3	23:44	23:06	23:22
39.9	23:45	23:07	23:22
50.5	23:47	23:09	23:22
124.6	23:48	23:10	23:22
249.5	23:50	23:11	23:21
		Average	23:23

Control 1	23:54	23:01	23:07
Control 2	23:55	23:01	23:06
Control 3	23:57	23:02	23:05

Aquibind MP

Mass	Time Started	Time Removed	Total Time
4.5	22:54	22:35	23:41
9.6	22:56	22:36	23:40
19.5	22:58	22:38	23:40
29.4	23:00	22:39	23:39
39.9	23:02	22:42	23:40
50.1	23:03	22:43	23:40
125.2	23:05	22:44	23:39
249.3	23:07	22:45	23:38
		Average	23:39

Control 1	23:08	22:46	23:38
Control 2	23:10	22:46	23:36
Control 3	23:33	22:47	23:14

Hematite

Mass	Time Started	Time Removed	Total Time
4.8	23:15	22:48	23:33
10	23:17	22:50	23:33
19.7	23:20	22:51	23:31
29.6	23:22	22:52	23:30
39.9	23:24	22:54	23:30
50.6	23:25	22:55	23:30
125.8	23:27	22:57	23:30
250.6	23:30	22:59	23:29
		Average	23:30

Control 1	23:32	22:59	23:27
Control 2	23:34	22:59	23:25
Control 3	23:35	23:00	23:25

APPENDIX C.2

Column Testing

COLUMN TEST 1

Constants

Flow Rate [ml/min]		
AquaBind Column		8.99
Bayoxide Column		9.34
MetSorb Column		8.80
Column Diameter [in]		0.5
Start Time		2/24/14 10:15 AM
	Length [in]	Volume [in^3]
AquaBind Column	4.6	0.903207888
Bayoxide Column	5.1	1.001382658
MetSorb Column	5.05	0.991565181

0 indicates <5 ppb

length	5	in
volume	16.08796	ml
flow rate	10	ml/min
EBCT	1.608796	min

	Date	Time	AquaBind		Bayoxide		MetSorb		WHO	
			Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes	Concentration [ug/L]	
0.25	2/24/14 3:42 PM	327		199		186		177	10	0
0.5	2/24/14 8:55 PM	640	0	389	0	364	0	347	10	500
1	2/25/14 8:10 AM	1315	0	798	23	748	20	712	10	1000
1.25	2/25/14 3:37 PM	1762		1070		1003		954	10	1500
1.5	2/25/14 8:30 PM	2055		1248		1170		1113	10	2000
2	2/26/14 9:35 AM	2840		1724	51	1616	13	1538	10	2500
2.25	2/26/14 3:51 PM	3216		1952		1830		1742	10	3000
2.5	2/26/14 9:40 PM	3565		2164		2029		1931	10	3500
3	2/27/14 9:25 AM	4270		2592		2430		2313	10	4000
3.25	2/27/14 2:30 PM	4575		2777		2604		2478	10	4500
3.5	2/27/14 9:10 PM	4975		3020		2832		2694	10	5000
4	2/28/14 9:05 AM	5690	0	3454	63	3239	69	3082	10	5500
4.5	2/28/14 9:43 PM	6448		3914		3670		3492	10	6000
5	3/1/14 10:35 AM	7220	0	4383	64	4109	54	3910	10	6500
6.25	3/2/14 4:18 PM	9003		5466		5124		4876	10	7000
6.5	3/2/14 9:05 PM	9290		5640		5288		5031	10	7500
8	3/3/14 10:31 AM	10096		6129		5746		5468	10	8000
8.5	3/3/14 8:05 PM	10670		6478		6073		5779	10	8500
9	3/4/14 10:03 AM	11508		6986		6550		6232	10	9000
9.5	3/4/14 10:10 PM	12235		7428		6964		6626	10	9500
10	3/5/14 9:26 AM	12911		7838		7349		6992	10	10000
10.5	3/5/14 10:40 PM	13705		8320		7801		7422	10	10500
11	3/6/14 9:58 AM	14383	0	8732		8186		7789	10	11000
11.5	3/6/14 10:40 PM	15145		9194		8620		8202	10	11500
12									10	12000
12.5									10	12500
13	3/8/2014								10	13000
									10	13500
									10	14000
									10	14500

Constants	
Flow Rate [ml/min]	9
AquaBind Column	9.42
Bayoxide Column	9.86
MetSorb Column	8.91
Column Diameter [in]	0.5
Start Time	3/10/14 5:25 PM

0 indicates <5 ppb

	Length [in]	Volume [in^3]
AquaBind Column	6.25	1.22718463
Bayoxide Column	5.95	1.168279768
MetSorb Column	5.75	1.12900986

	Date	Time	AquaBind		Bayoxide		MetSorb	
			Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes
0.25	3/10/14 9:15 PM	230		108		118		111
0.75	3/11/14 10:00 AM	995		466		512		479
1	3/11/14 3:25 PM	1320		618		680		636
1.25	3/11/14 8:40 PM	1635		766		842		787
1.75	3/12/14 9:47 AM	2422		1134		1247		1166
2	3/12/14 2:45 PM	2720	0	1274	0	1401	0	1310
2.25	3/12/14 8:55 PM	3090		1447		1591		1488
2.75	3/13/14 8:34 AM	3789		1774	11	1951		1825
3	3/13/14 5:15 PM	4310		2018		2220		2075
3.25	3/13/14 8:45 PM	4520		2117	14	2328		2177
3.75	3/14/14 10:38 AM	5353		2507		2757		2578
4	3/14/14 3:45 PM	5660		2650	14	2915		2726
4.25	3/14/14 9:08 PM	5983		2802		3081		2881
4.75	3/15/14 10:12 AM	6767		3169	33	3485		3259
5	3/15/14 3:15 PM	7070		3311		3641		3404
5.25	3/15/14 10:00 PM	7475		3500		3850	20	3600
6	3/16/14 3:45 PM	8540		3999	34	4398		4112
6.75	3/17/14 9:39 AM	9614	0	4502	34	4951	9	4630
7.25	3/17/14 9:07 PM	10302		4824		5306		4961
7.75	3/18/14 9:05 AM	11020		5160		5676	12	5307
8.25	3/18/14 9:50 PM	11785		5518	58	6070	18	5675
8.75	3/19/14 10:05 AM	12520		5863		6448	62	6029
9.25	3/19/14 9:03 PM	13178		6171		6787		6346
9.75	3/20/14 10:20 AM	13975	0	6544	77	7197	52	6730
10.25	3/20/14 9:12 PM	14627		6849		7533		7044
10.75	3/21/14 9:03 AM	15338		7182		7899		7386
11	3/22/14 3:25 PM	17160		8035		8838		8263
13	3/24/14 12:12 PM	19847		9294		10222		9557
14	3/25/14 1:06 PM	21341		9993		10991		10277
15	3/26/14 9:45 AM	22580		10573		11629		10873
16	3/27/14 2:40 PM	24315		11386		12523		11709
18	3/29/14 8:47 AM	26842		12569		13824		12926
20	3/31/14 8:30 AM	29705		13910		15299		14304
20.5	3/31/14 9:46 PM	30501		14282		15709		14687
21	4/1/14 10:00 AM	31235	0	14626		16087		15041
21.5	4/1/14 9:00 PM	31895		14935		16427		15359
22	4/2/14 9:50 AM	32665		15296		16823		15730
22.5	4/2/14 9:45 PM	33380		15630		17192		16074
23	4/3/14 9:55 AM	34110		15972		17567		16425
23.5	4/3/14 8:54 PM	34769		16281		17907		16743
24	4/4/14 10:08 AM	35563		16653		18316		17125
25	4/5/14 4:25 PM	37380		17503		19252		18000
26	4/6/14 1:05 PM	38620		18084		19890		18597
27	4/7/14 11:40 AM	39975		18719		20588		19250
28	4/8/14 11:10 AM	41385	0	19379		21314		19929
29	4/9/14 10:01 AM	42756		20021		22020		20589
30	4/10/14 10:10 AM	44205		20699		22767		21287
31	4/11/14 12:45 PM	45800		21446		23588		22055
32	4/12/14 11:10 AM	47145		22076		24281		22702
33	4/13/14 9:30 AM	48485		22703		24971		23348
34	4/14/14 4:31 PM	50346		23575		25929		24244
35	4/15/14 9:22 AM	51357	8	24048		26450		24731
37	4/17/14 12:15 PM	54410		25478		28022		26201
38	4/18/14 10:33 AM	55748	0	26104		28712		26845
39	4/19/14 1:30 PM	57365		26862		29544		27624
41	4/21/14 10:30 AM	60065	0	28126		30935		28924
42	4/22/14 8:25 PM	62100		29079		31983		29904
43	4/23/14 8:45 PM	63560		29762		32735		30607
44	4/24/14 8:15 PM	64970		30423		33461		31286
46	4/26/14 4:15 PM	67610		31659		34821		32557
48	4/28/14 8:50 AM	70045		32799		36075		33730
50	4/30/14 9:00 AM	72935		34152		37563		35121
51	5/1/14 12:30 PM	74585	0	34925		38413		35916
52	5/2/14 12:00 PM	75995		35585		39139		36595
55	5/5/14 8:45 AM	80120		37517		41264		38581
58	5/8/14 12:00 PM	84635	0	39631		43589		40755

Constants

Flow Rate [ml/min]	9	**EBCT [sec]**	
AquaBind - 6	9.42	128.13	
AquaBind - 4	8.68	88.94	
AquaBind - 2	10.24	37.69	
Column Diameter [in]	0.5		
Start Time	3/31/14 5:00 PM		
	Length [in]	Volume [in^3]	
AquaBind - 6	6.25	1.22718463	
AquaBind - 4	4	0.785398163	
AquaBind - 2	2	0.392699082	

0 indicates <5 ppb

	Date	Time	AquaBind - 6 inches* Data Taken from column_data2		AquaBind - 4 inches		AquaBind - 2 inches	
			Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes	Concentration [µg/L]	Bed Volumes
0.5	3/31/14 9:46 PM	286		14177		193	0	455
1	4/1/14 10:00 AM	1020	0	14518		688		1624
1.5	4/1/14 9:00 PM	1680		14825		1133		2674
2	4/2/14 9:50 AM	2450		15183		1653	0	3900
2.5	4/2/14 9:45 PM	3165		15515		2135		5038
3	4/3/14 9:55 AM	3895		15855	0	2628	11	6201
3.5	4/3/14 8:54 PM	4554		16161		3072		7250
4	4/4/14 10:08 AM	5348		16530		3608	29	8514
5	4/5/14 4:25 PM	7165		17375		4833		11406
6	4/6/14 1:05 PM	8405		17951		5670	29	13380
7	4/7/14 11:40 AM	9760		18581		6584		15537
8	4/8/14 11:10 AM	11170	0	19425		7535		17782
9	4/9/14 10:01 AM	12541		20069	0	8460	57	19965
10	4/10/14 10:10 AM	13990		20749		9438		22271
11	4/11/14 12:45 PM	15585		21498		10514		24810
12	4/12/14 11:10 AM	16930		22129		11421		26952
13	4/13/14 9:30 AM	18270		22758	0	12325		29085
14	4/14/14 4:31 PM	20131		23632		13580		32047
15	4/15/14 9:22 AM	21142	8	24106	0	14262		33657
17	4/17/14 12:15 PM	24195		25539		16322		38517
18	4/18/14 10:33 AM	25533	0	26167	0	17225		40647
19	4/19/14 1:30 PM	27150		26926		18315		43221
21	4/21/14 10:30 AM	29850	0	28193	0	20137		47519
22	4/22/14 8:25 PM	31885		29149		21510		50759
23	4/23/14 8:45 PM	33345		29834		22494		53083
24	4/24/14 8:15 PM	34755		30496		23446		55328
26	4/26/14 4:15 PM	37395		31735		25227		59531
28	4/28/14 8:50 AM	39830		32878		26869		63407
30	4/30/14 9:00 AM	42720		34234		28819		68008
31	5/1/14 12:30 PM	44370	0	35009	0	29932		70634
32	5/2/14 12:00 PM	45780		35671		30883		72879
35	5/5/14 8:45 AM	49905		37607		33666		79446
38	5/8/2014 12:00	54420	0	39631	0	36712		86633

Test Solution Feed Barrels

Column Test 1

Barrel #	Date Created	Concentration [µg/L]	NaOH added [mL of 2.8M]	pH
1	2/20/2014	80.3	11.5	6.64
2	2/26/2014	90.7	11.5	6.76

Column Test 2

Barrel #	Date Created	Concentration [µg/L]	NaOH added [mL of 2.8M]	pH
3	3/6/2014	97.7	11.5	6.85
4	3/13/2014	86.3	11.5	6.78
5	3/17/2014	92.7	11.5	6.62
6	3/20/2014	90	11.5	6.75
7	4/2/2014	75.3	11.5	

EBCT Test

Barrel #	Date Created	Concentration [µg/L]	NaOH added [mL of 2.8M]	pH
8	4/5/2014	77.3	11.5	
9	4/11/2014	106	11.5	
10	4/20/2014	71.3	11.5	7

Average Test Concentration [µg/L]	**Average pH**
86.8	6.77

APPENDIX C.3

Budget and Expenses

Team Name CLEAR H2O

Team # 6

Faculty Advisor: Prof. Wunder

Name of student submitting THIS budget and request for reimbursement: Steve Taplin

Email: spt2@students.calvin.edu Student ID No. 2109142

Date	Team member	Vendor/Source	Description	Debit	Credit	Balance
9/30/13			Beginning Balance			$ 500.00
10/18/13	Grant Mathews	Sensafe	Arsenic Econo-Quick II Test Kit	$ (275.00)		$ 225.00
10/31/13	Grant Mathews	-	Hematite Collection Trip to the UP - Gas	$ (400.00)		$ (175.00)
2/6/14	Grant Mathews	Enviro Express	100 ppm Arsenic Soln	$ (66.00)		$ (241.00)
2/10/14	Grant Mathews	US Plastics	Polycarbonate Tubing	$ (11.24)		$ (252.24)
2/10/14	Grant Mathews	Cole Parmer	Masterflex LS 17 Tubing (25')	$ (51.00)		$ (303.24)
3/7/2014	Steve Taplin	Cole-Parmer	4 Outlet Nylon Manifold	$ (56.48)		$ (359.72)
3/18/14	Steve Taplin	Cole-Parmer	Masterflex Tubing Puriflex	$ (61.78)		$ (421.50)
4/1/14	Grant Mathews	Amazon	Timestrip indicators	$ (22.00)		$ (443.50)
4/21/14	Grant Mathews	Calvin	3D print union part #1	$ (6.00)		$ (449.50)
4/24/14	Grant Mathews	Calvin	3D print union part #2	$ (6.00)		$ (455.50)
5/1/14	Grant Mathews	Calvin	3D print final prototype	$ (150.00)		$ (605.50)
5/7/14	Grant Mathews	Calvin	3D print union part # 3	$ (9.00)		$ (614.50)
5/8/2014	Grant Mathews	Calvin	3D print final prototype #2	$ (240.00)		$ (854.50)
5/14/2014	Grant Mathews	Calvin	Senior Design Fund		$ 200.00	$ (654.50)
5/21/14	Grant Mathews	Sawyer	Anticipated Client Donations		$ 654.50	$ -

APPENDIX D

Laboratory Procedures

APPENDIX D.1

Column Test Sampling Procedure

Sampling Procedure:

- Take two empty Prein&Newhof bottles and label them appropriately (see below)
    - Client: Calvin
    - Date: Date sample is taken
    - Time: Time sample was taken, please use military time
    - Sample number: Will be indicated on schedule
    - Tests: Arsenic
    - Project No: Team 6

- Remove bottle cap
- Place the appropriate waste tube into the corresponding bottle.
- Let sit for ~5 minutes
- Remove tube from bottle and replace cap
- Record the time that the sample was taken on the schedule and then sign your initials

Special Notes:

- If feed barrel is completely empty when you come to take a sample
    - Turn off the peristaltic pump
    - Do not bother coming back for more samples
    - Record date of occurrence
- If waste barrel is excessively full
    - A tube specially designed for pumping waste has been labelled and set out for you
    - Use the blue pump labelled “trash pump” in conjunction with the specially marked tube to pump waste from the barrel directly into the trough

If you have any questions or concerns, please contact Steve immediately at (269) 312-3498 or staplin30@gmail.com

APPENDIX E
MSDS Sheets

APPENDIX E.1

Aquabind SP-70

APYRON Technologies, Inc.

Infinitely Better Solutions

MSDS Ref. No: AT1018
Data-Created: 10/23/2013
Ver. No.: 02

MATERIAL SAFETY DATA SHEET

AQUABIND SP70

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: AQUABIND® SP70
PRODUCT DESCRIPTION: Homogeneous Ferric Oxide and Hydroxide
CHEMICAL NAME: Ferric Oxide/Hydroxide

SUPPLIER:

Apyron Technologies
3342 International Park Dr.
Atlanta, GA 30316
Contact: Wade Chen

24 HR. EMERGENCY TELEPHONE NUMBERS

CHEMTREC (U.S.): 800-424-9300
Emergency Phone: 678-904-6600

2. COMPOSITION / INFORMATION ON INGREDIENTS

Ingredient	Wt.%
Proprietary Metal Oxides	~80
Water	~20

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

PHYSICAL APPEARANCE: Brown granules.
IMMEDIATE CONCERNS: Product is not combustible.

POTENTIAL HEALTH EFFECTS

EYES: May cause mechanical irritation which can scratch the cornea.
SKIN: Frequent or prolonged contact may irritate the skin and cause a skin rash (dermatitis).
INGESTION: Ingestion of large quantities may cause stomach and intestinal distress.

INHALATION: Can cause pulmonary system damage by inhalation of dust.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

EYES: Scratch or abrasion, damage to cornea (necrosis).
SKIN: Skin rash, dermatitis, itching.
INGESTION: Upset stomach, intestinal distress.
INHALATION: Obstructive breathing, dry mouth & throat.
ACUTE TOXICITY: Inhalation may cause irritation of eyes and nose
CHRONIC: Chronic inhalation of large quantities of product dust may reduce pulmonary function.
ROUTES OF ENTRY: Inhalation, ingestion, eyes, skin.
TARGET ORGAN STATEMENT: Respiratory system, lungs, skin, eyes, liver, pancreas, kidney.

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4. FIRST AID MEASURES

EYES: Immediately flush eyes with plenty of water. Get medical attention, if irritation persists.
SKIN: Wash with soap and water. Get medical attention if irritation develops or persists.
INGESTION: If swallowed, induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.
INHALATION: Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult give oxygen by trained personnel. Seek immediate medical attention.
NOTES TO PHYSICIAN: Chronic overexposure may cause irritation and lung damage (pneumoconiosis and Shaver's Disease) which is complicated by iron and silica in the air.

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5. FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA: CO_2, foam, dry powder. In case of large fire, water spray should be used

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6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL: With shovel or scoop, place material into clean, dry container; move containers from spill area. Minimize airborne particulates. .
LARGE SPILL: Vacuuming and/or wet methods of cleanup are preferred. Keep airborne particulates to a minimum. Protect against inhalation of dusts. Wear eye protection. place in appropriate containers for disposal. See Section 13 for disposal.

7. HANDLING AND STORAGE

STORAGE: Keep container dry and tightly sealed in a cool and well-ventilated place.
GENERAL PROCEDURES: Avoid contact with eyes, skin, and clothing. Do not breath (dust, vapor, mist, gas). Minimize dust generation and accumulation.

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8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Next page

Experience show that this product can be handled without risk to health if used properly and if usual precautions of industrial hygiene are followed:

ENGINEERING CONTROLS: If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE: Wear safety glasses with side shields or goggles.
SKIN: Wear protective clothing, including long sleeves and gloves, to prevent skin contact. Thoroughly wash clothing before reuse.
RESPIRATORY: Wear NIOSH approved dust respirator with HEPA cartridges in the absence of proper environmental control.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: Granules
ODOR: None
APPEARANCE: Brown solid granules
PERCENT VOLATILE: Less than 20%
MELTING POINT: >1000°C
SOLUBILITY IN WATER: Insoluble
DENSITY: ~75 lb/cu ft (bulk)

10. STABILITY AND REACTIVITY

STABILITY DATA: Stable
HAZARDOUS POLYMERIZATION: No
HAZARDOUS DECOMPOSITION PRODUCTS: metal oxides
INCOMPATIBLE MATERIALS: Strong acids and alkalis.

---

11. TOXICOLOGICAL INFORMATION

Acute toxicity: Not available
IARC: Not listed.
NTP: Not listed.
OSHA: Not listed.

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12. ECOLOGICAL INFORMATION

Environmental Fate: No data available

Ecotoxicological Information: No data available

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13. DISPOSAL CONSIDERATIONS

US EPA Waste Number: Not Regulated
DISPOSAL METHOD: Dispose of this product in accordance with applicable local, state and federal regulations. Recover metal components by reprocessing whenever possible. Dispose as wastes containing metal and metal oxides(testing may be necessary). Passed EPA TCLP and California leaching test for arsenic removal from drinking water.

---

14. TRANSPORT INFORMATION

UN-No Not classified as dangerous in the meaning of transport regulations.

Packing group Not classified as dangerous in the meaning of transport regulations.

Land transport
ADR/RID Not classified as dangerous in the meaning of transport regulations.

Sea transport
IMDG Not classified as dangerous in the meaning of transport regulations.

Air transport
ICAO/IATA Not classified as dangerous in the meaning of transport regulations.

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15. REGULATORY INFORMATION

NO LABELING IS REQUIRED.

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16. OTHER INFORMATION

REVISION SUMMARY

Date – Created and Issued. 07/15/06

MANUFACTURER DISCLAIMER: The information presented herein is believed to be accurate but is not warranted. Recipients are advised to confirm in advance that the information is current, applicable and suitable to their circumstances.

APPENDIX E.2

Aquabind MP

APYRON
Technologies, Inc.
Infinitely Better Solutions

MSDS Ref. No: 001
Data-Revised: 03/18/2005
Revision No: 002

MATERIAL SAFETY DATA SHEET

AQUABINDXP

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: Aqua-Bind® XP, XPL, XPS, XPF, XPW, XPB, XPM, XPT XPV, MP, MPL, MPS, MPF, MPW, MPB, MPM, MPT, MPV, MPG
PRODUCT DESCRIPTION: Heterogeneous catalyst.
CHEMICAL FAMILY: Metal oxides.

MANUFACTURER

Apyron Technologies
3342 International Park Dr
Atlanta, GA 30316
Contact: Wei-Chih Chen

24 HR. EMERGENCY TELEPHONE NUMBERS

CHEMTREC (U.S.): 800-424-9300
Emergency Phone: 678-904-6600

2. COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name	Wt.%	CAS#
Aluminum oxide	75 – 100	1344-28-1
Manganese oxide	0 – 25	1313-13-9

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

PHYSICAL APPEARANCE: Brown powder.
IMMEDIATE CONCERNS: Oxidizing material. Contact with combustible material may cause fire. Overexposure may cause nervous system damage. Overexposure may cause lung damage.

POTENTIAL HEALTH EFFECTS

EYES: May cause mechanical irritation which can scratch the cornea.
SKIN: Frequent or prolonged contact may irritate the skin and cause a skin rash (dermatitis).
INGESTION: Ingestion of large quantities may cause stomach and intestinal distress.
INHALATION: Can cause central nervous system and pulmonary system damage by inhalation of Fumes and dust.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

EYES: Scratch or abrasion, damage to cornea (necrosis).
SKIN: Skin rash, dermatitis, itching.
INGESTION: Upset stomach, intestinal distress.
INHALATION: Chronic manganese poisoning usually begins with complaints of fatigue or sleepiness. This is followed by weakness in the legs, staggering and an expressionless face. The patient speaks with a slow monotonous voice. Muscular twitching and night cramps of the legs appear about the same time.
ACUTE TOXICITY: Inhalation may cause irritation of eyes and nose. Inhalation of fumes may cause metal fume fever (flu-like symptoms: fever, cough, chest pains, muscle weakness, nausea, vomiting, and a high white blood cell count).
CHRONIC: Chronic inhalation of large quantities of manganese compounds may cause central nervous system damage, including symptoms similar to Parkinson's disease, bulbar paralysis, or multiple sclerosis.
ROUTES OF ENTRY: Inhalation, ingestion, eyes, skin.
TARGET ORGAN STATEMENT: Respiratory system, lungs, skin, eyes, liver, pancreas, kidney, nervous system.

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4. FIRST AID MEASURES

EYES: Immediately flush eyes with plenty of water. Get medical attention, if irritation persists.
SKIN: Wash with soap and water. Get medical attention if irritation develops or persists.
INGESTION: If swallowed, induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention immediately.
INHALATION: Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult give oxygen by trained personnel. Seek immediate medical attention.
NOTES TO PHYSICIAN: Chronic overexposure may cause irritation and lung damage (pneumoconiosis and Shaver's Disease) which is complicated by iron and silica in the air. Chronic manganese poisoning symptoms may simulate progressive bulbar paralysis, postencephalitic Parkinsonism, multiple sclerosis, amyotrophic lateral sclerosis, and progressive lenticular degeneration (Wilson's disease).

---

5. FIRE FIGHTING MEASURES

GENERAL HAZARD: Contains a strong oxidizer. Contact with combustible materials may cause a fire.
EXTINGUISHING MEDIA: Use extinguishing agent applicable to surrounding fire.
EXPLOSION HAZARDS: Material is not flammable.
FIRE FIGHTING PROCEDURES: As in any fire, wear self-contained breathing apparatus operated in pressure-demand mode, (MSHA/NIOSH approved or equivalent) and full protective gear.

---

6. ACCIDENTAL RELEASE MEASURES

SMALL SPILL: With shovel or scoop, place material into clean, dry container; move containers from spill area. Minimize airborne particulates. Protect against inhalation of dusts. Wear gloves and long sleeves. Avoid contact with skin. Use eye protection.
LARGE SPILL: Vacuuming and/or wet methods of cleanup are preferred. Keep airborne Particulates to a minimum. Protect against inhalation of dusts or fumes. Wear eye protection. Place in appropriate containers for disposal.

7. HANDLING AND STORAGE

GENERAL PROCEDURES: Avoid contact with eyes, skin, and clothing. Do not breath (dust, vapor, mist, gas). Minimize dust generation and accumulation.

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EXPOSURE GUIDELINES:

OSHA HAZARDOUS COMPONENTS (29 CFR 1910.1200)

		EXPOSURE LIMITS			
		OSHA PEL		ACGIH TLV	
		ppm	mg/m^3	ppm	mg/m^3
Aluminum oxide	TWA	(1)	15		10
Manganese oxide	TWA	(2)		(3)	0.2
	STEL		5		

OSHA TABLE COMMENTS:

1. 5 mg/m3 respirable
2. Ceiling (as Mn)
3. (as Mn)

ENGINEERING CONTROLS: If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE: Wear safety glasses with side shields or goggles.
SKIN: Wear protective clothing, including long sleeves and gloves, to prevent skin contact. Thoroughly wash clothing before reuse.
RESPIRATORY: Wear NIOSH approved respirator with HEPA cartridges in the absence of proper environmental control. Type of respirator depends on level of exposure.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: Solid
ODOR: None
APPEARANCE: Brown powder
PERCENT VOLATILE: Less than 5%
MELTING POINT: Not Determined
SOLUBILITY IN WATER: Insoluble
DENSITY: 45-60 lb/CF (bulk)
MOLECULAR FORMULA: $Al^2O^3 + MnO^2$

10. STABILITY AND REACTIVITY

STABLE: Yes
HAZARDOUS POLYMERIZATION: No
INCOMPATIBLE MATERIALS: Keep away from combustibles, flammables and other easily oxidizable organic materials.

11. TOXICOLOGICAL INFORMATION

EYE EFFECTS: Alumina may cause injury to or disease of the cornea.

CARCINOGENICITY:

IARC: Not listed.
NTP: Not listed.
OSHA: Not listed.

12. ECOLOGICAL INFORMATION

ENVIRONMENTAL DATA: No data available.

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD: Dispose of this product in accordance with applicable local, state and federal regulations. Recover metal components by reprocessing whenever possible.

14. TRANSPORT INFORMATION

DOT (DEPARTMENT OF TRANSPORTATION)
PROPER SHIPPING NAME: Not regulated

15. REGULATORY INFORMATION

UNITED STATES

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)

311/312 HAZARD CATEGORIES: Adverse effect to target organs.
313 REPORTABLE INGREDIENTS: Manganese compounds.

CERCLA (COMPREHENSIVE RESPONSE, COMPENSATION, AND LIABILITY ACT)

CERCLA REGULATORY: Not listed.

TSCA (TOXIC SUBSTANCE CONTROL ACT)

TSCA STATUS: All components are listed on the TSCA inventory.
RCRA STATUS: Not listed.

CANADA

WHMIS (WORKER HAZARDOUS MATERIALS INFORMATION SYSTEM): Listed 1988.

CANADIAN ENVIRONMENTAL PROTECTION ACT: All ingredients are listed on the Canadian Domestic Substances List inventory.

PROPOSITION 65 STATEMENT: This product does not contain chemical(s) known to the state of California to cause cancer, birth defects, or reproductive harm.

COMMENTS: CAA (Clean air Act), Appendix A: Hazardous Air Pollutants (Air Toxics) – Listed.

16. OTHER INFORMATION

REVISION SUMMARY

Date – Issued. 6/1/00
Date – Revised 03/18/05
Rev. No. 1 (Added MPG)

MANUFACTURER DISCLAIMER: The information presented herein is believed to be accurate but is not warranted. Recipients are advised to confirm in advance that the information is current, applicable and suitable to their circumstances.

APPENDIX E.3

Bayoxide E33

Material Safety Data Sheet

LANXESS
Energizing Chemistry

1. Product and company identification

Product name	:	BAYOXIDE E 33 HCF
Supplier/Manufacturer	:	LANXESS Corporation Product Safety & Regulatory Affairs 111 RIDC Park West Drive Pittsburgh, PA 15275-1112 USA For information: US/Canada (800) LANXESS International +1 412 809 1000
<u>In case of emergency</u>	:	Chemtrec (800) 424-9300 International (703) 527-3887 Lanxess Emergency Phone (800) 410-3063.
Material Number	:	56094338
Chemical family	:	Inorganic Metal oxide.

2. Hazards identification

Physical state	:	Solid. [Powder.]
Odor	:	Odorless.
Color	:	Black. Brown.
Emergency overview	:	NOT EXPECTED TO PRODUCE SIGNIFICANT ADVERSE HEALTH EFFECTS WHEN THE RECOMMENDED INSTRUCTIONS FOR USE ARE FOLLOWED. MAY CAUSE MECHANICAL IRRITATION (ABRASION).
Routes of entry	:	Dermal contact. Eye contact. Inhalation. Ingestion.
Medical conditions aggravated by over-exposure	:	Respiratory tract disorders

<u>Potential acute health effects / Over-exposure signs/symptoms</u>

Inhalation	:	Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the nose, throat and lungs. May cause mechanical irritation (abrasion).
Ingestion	:	No known significant effects or critical hazards.
Skin	:	May cause mechanical irritation (abrasion).
Eyes	:	May cause mechanical irritation (abrasion). Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the eyes.

<u>Potential chronic health effects</u>

Chronic effects	:	Repeated or prolonged inhalation of dust may lead to chronic respiratory irritation.
Carcinogenicity	:	No carcinogenic substances as defined by IARC, NTP and/or OSHA.

3. Composition/information on ingredients

There are no ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Name	CAS number	%
No hazardous ingredient		

4. First aid measures

Eye contact : Check for and remove any contact lenses. In case of contact flush eyes with plenty of luke warm water. Get medical attention if symptoms occur.

Skin contact : Wash with plenty of soap and water. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Inhalation : Move exposed person to fresh air. Get medical attention if symptoms occur.

Ingestion : Wash out mouth with water. Do not induce vomiting unless directed to do so by medical personnel. Get medical attention if symptoms occur.

Notes to physician : No specific treatment. Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

5. Fire-fighting measures

Extinguishing media

Suitable : Use an extinguishing agent suitable for the surrounding fire.

Not suitable : None known.

Special exposure hazards : Move containers from fire area if this can be done without risk.

Hazardous thermal decomposition products : Decomposition products may include the following materials:
metal oxide/oxides

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

6. Accidental release measures

Personal precautions : No action shall be taken involving any personal risk or without suitable training.

Spill and Leak Procedures. : Move containers from spill area. Approach release from upwind. Prevent entry into sewers, water courses, basements or confined areas. Vacuum or sweep up material and place in a designated, labeled waste container. Avoid creating dusty conditions and prevent wind dispersal.

7. Handling and storage

Handling : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Avoid breathing dust.

Storage : Store in accordance with local regulations. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10) and food and drink. Keep container tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination.

8. Exposure controls/personal protection

No exposure limit value known.

Consult local authorities for acceptable exposure limits.

Recommended monitoring procedures	:	If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment. Reference should be made to appropriate monitoring standards. Reference to national guidance documents for methods for the determination of hazardous substances will also be required.
Engineering measures	:	Use only with adequate ventilation. If user operations generate dust, fumes, gas, vapor or mist, use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.
Hygiene measures	:	Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Personal protection

Respiratory	:	Although no exposure limit has been established for this product, the OSHA PEL for Particulates Not Otherwise Regulated (PNOR) of 15 mg/m3 - total dust, 5 mg/m3 - respirable fraction is recommended. In addition, the ACGIH recommends 3 mg/m3 - respirable particles and 10 mg/m3 - inhalable particles for Particles (insoluble or poorly soluble) Not Otherwise Specified (PNOS). The following respirator is recommended if airborne concentrations exceed the appropriate standard/guideline. Dust-protection mask.
Hands	:	Gloves.
Eyes	:	safety glasses with side-shields.
Skin	:	Wear cloth work clothing including long pants and long-sleeved shirts. Suitable protective footwear.

9. Physical and chemical properties

Physical state	:	Solid. [Powder.]
Flash point	:	Closed cup: Not applicable.
Color	:	Black. Brown.
Odor	:	Odorless.
Melting/freezing point	:	>1000°C (>1832°F)
Specific gravity	:	4 to 5
Bulk density	:	750 to 950 kg/m³
Viscosity	:	Dynamic (room temperature): Not applicable.
Solubility	:	Insoluble in the following materials: cold water.

10. Stability and reactivity

Chemical stability	:	The product is stable.
Conditions to avoid	:	Excessive temperatures. At temperatures greater than 176 F (80 C), this product may become unstable and slowly auto-oxidize into Fe_2O_3 which generates additional heat. Under certain conditions this heat may be sufficient to cause combustible materials to ignite.
Materials to avoid	:	No specific data.
Hazardous decomposition products	:	Under normal conditions of storage and use, hazardous decomposition products should not be produced.

10. Stability and reactivity

Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

11. Toxicological information

Acute toxicity

No information available.

Irritation/Corrosion

Skin : Non-irritating.

Eyes : Non-irritating.

Carcinogenicity

No carcinogenic substances as defined by IARC, NTP and/or OSHA.

12. Ecological information

Aquatic ecotoxicity

No information available.

Other ecological information

13. Disposal considerations

Waste disposal : Waste disposal should be in accordance with existing federal, state, provincial and/or local environmental controls. The generation of waste should be avoided or minimized wherever possible. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe way.

RCRA classification : If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste. (40 CFR 261.20-24)

14. Transport information

Regulatory information	UN number	Proper shipping name	Classes	PG*	Label	Additional information
DOT Classification	-	-	-	-		Not regulated.
IMDG Class	-	-	-	-		Not regulated.
IATA-DGR Class	-	-	-	-		Not regulated.

PG* : Packing group

RQ : 0 lbs

15. Regulatory information

HAZCOM Standard Status : While this material is not considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200), this MSDS contains valuable information critical to the safe handling and proper use of the product. This MSDS should be retained and available for employees and other users of this product.

SARA Section 311/312 Hazard Categories : None

	Ingredient name	CAS number	Concentration (%)
SARA Title III Section 302 Extremely Hazardous Substances :	None		

	Ingredient name	CAS number	Concentration (%)
SARA Title III Section 313 Toxic Chemicals :	None		

	Ingredient name	CAS number	RQ
US EPA CERCLA Hazardous Subtances (40 CFR 302) :	None		

State regulations

The following chemicals are specifically listed by individual states; other product specific health and safety data in other sections on the MSDS may also be applicable for state requirements. For details on your regulatory requirements you should contact the appropraite agency in your state.

Ingredient name	CAS number	State Code	Concentration (%)
BAYOXIDE E 33 HCF		PA - RTK HS	>= 95
C.I. Pigment Yellow 42	20344-49-4		>= 95

Massachusetts Substances: MA - S
Massachusetts Extraordinary Hazardous Substances: MA - Extra HS
New Jersey Hazardous Substances: NJ - HS
Pennsylvania RTK Hazardous Substances: PA - RTK HS
Pennsylvania Special Hazardous Substances: PA - Special HS

California Prop. 65

Potential exposure to some or all of the California Proposition 65 chemicals in this product have been determined to be below the No Significant Risk Level (NSRL)

To the best of our knowledge, this product does not contain any of the listed chemicals, which the state of California has found to cause cancer, birth defects or other reproductive harm.

U.S. Toxic Substances Control Act : Listed on the TSCA Inventory.

16. Other information

Hazardous Material Information System :

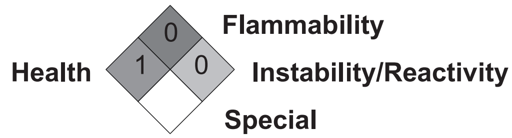
Health	1
Flammability	0
Physical hazards	0

0=Insignificant 1=Slight 2=Moderate 3=High 4=Extreme
***=Chronic**

The customer is responsible for determining the PPE code for this material.

16. Other information

National Fire Protection Association (U.S.A.) :



0= Minimal 1=Slight 2=Moderate 3=Serious 4=Severe

LANXESS' method of hazard communication is comprised of Product Labels and Material Safety Data Sheets. HMIS and NFPA ratings are provided by LANXESS as a customer service.

Contact person : Product Safety and Regulatory Affairs

Date of issue : 12-03-2012

Date of previous issue : 12-03-2012

Version : 1

Indicates information that has changed from previously issued version.

Notice to reader

This information is furnished without warranty, express or implied. This information is believed to be accurate to the best knowledge of LANXESS Corporation. The information in this MSDS relates only to the specific material designated herein. LANXESS Corporation assumes no legal responsibility for use of or reliance upon the information in this MSDS.

APPENDIX E.4

Metsorb

HydroGlobe HMRP **MSDS Effective Date 01/10/05**

1. Product Identification

Synonyms: Titanium (IV) Oxide; Titanium Hydroxide
CAS No.: 13463-67-7 ; 20338-08-3
Molecular Weight: 79.87 116
Chemical Formula: TiO_2 $Ti(OH)_4$

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent
Titanium Dioxide	13463-67-7	30-100%
Titanium Hydroxide	20338-08-3	0-30%

3. Hazards Identification

Emergency Overview

CAUTION! MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT. MAY AFFECT LUNGS.

Potential Health Effects

Inhalation:
May cause mild irritation to the respiratory tract.
Ingestion:
Not expected to be a health hazard via ingestion.
Skin Contact: May cause mild irritation and redness.
Eye Contact: May cause mild irritation, possible reddening.
Chronic Exposure: Long-term exposure to titanium dioxide dust may result in mild fibrosis (scarring of the lungs).
Aggravation of Pre-existing Conditions:
Persons with pre-existing lung disease may be more susceptible to the effects of this substance.

4. First Aid Measures

Inhalation: Remove to fresh air. Get medical attention for any breathing difficulty.
Ingestion: Not expected to require first aid measures. If large amounts were swallowed, give water to drink and get medical advice.
Skin Contact: Immediately flush skin with plenty of soap and water for at least 15 minutes. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention if irritation develops.

Eye Contact: Immediately flush eyes with plenty of water for at least 15 minutes, lifting upper and lower eyelids occasionally. Get medical attention if irritation persists.

5. Fire Fighting Measures

Fire: Not considered to be a fire hazard.

Explosion: Not considered to be an explosion hazard.

Fire Extinguishing Media: Use any means suitable for extinguishing surrounding fire.

Special Information: In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode.

6. Accidental Release Measures

Ventilate area of leak or spill. Wear appropriate personal protective equipment as specified in Section 8.

Spills: Sweep up and containerize for reclamation or disposal. Vacuuming or wet sweeping may be used to avoid dust dispersal.

7. Handling and Storage

Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage.

Containers of this material may be hazardous when empty since they retain product residues (dust, solids); observe all warnings and precautions listed for the product.

8. Exposure Controls/Personal Protection

Airborne Exposure Limits: Titanium Dioxide:- OSHA Permissible Exposure Limit (PEL) is 15 mg/m^3 (TWA).

ACGIH Threshold Limit Value (TLV) - 10 mg/m3 (TWA), A4 - Not classifiable as a human carcinogen.

Titanium Hydroxide: -OSHA PEL and ACGIH TLV do not exist

Ventilation System: A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne

Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, Industrial Ventilation, A Manual of Recommended Practices, most recent edition, for details.

Personal Respirators (NIOSH Approved): If the exposure limit is exceeded, a half-face dust/mist respirator may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest. A full-face piece dust/mist respirator may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. For emergencies or instances where the exposure levels are not known, use a full-facepiece positive-pressure, air-supplied respirator.

WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

Skin Protection: Wear protective gloves and clean body-covering clothing.
Eye Protection: Use chemical safety goggles and/or full face shield where dusting or splashing of solutions is possible. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties
Appearance: White Powder.
Odor: Odorless.
Solubility: Insoluble in water.
Specific Gravity: 4.26
pH: (slurry) ca. 6 - 7
% Volatiles by volume @ 21C (70F): 0
Boiling Point: 2500 - 3000C (4532 - 5432F)
Melting Point: 1855C (3371F)
Vapor Density (Air=1): Not applicable.
Vapor Pressure (mm Hg): Not applicable.
Evaporation Rate (BuAc=1): No information found.

10. Stability and Reactivity
Stability: Stable under ordinary conditions of use and storage.
Hazardous Decomposition Products: No information found.
Hazardous Polymerization: Will not occur.
Incompatibilities: For Titanium Dioxide: A violent reaction with lithium occurs around 200C (392F) with a flash of light; the temperature can reach 900C. Violent or incandescent reaction may also occur with other metals such as aluminum, calcium, magnesium, potassium, sodium, and zinc.
Conditions to Avoid: Dusting and incompatibles.

11. Toxicological Information
Toxicological Data: No LD50/LC50 information found relating to normal routes of occupational exposure. Investigated as a tumorigen and mutagen.
Carcinogenicity: Titanium Dioxide has been classified by the American Congress of Governmental Industrial Hygienists (ACGIH) as an A4 carcinogen- Not Classifiable as a Human Carcinogen.(1999 TLVs and BEIs," p. 67). It has been classified by the International Agency for Research on Cancer (IARC) as group 3- Not Classifiable as to its Carcinogenicity to Humans.

12. Ecological Information
Environmental Fate: No information found.
Environmental Toxicity: For Titanium Dioxide, 96 Hour LC50 for fathead minnows >1,000mg/l

13. Disposal Considerations
Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may

differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.
This is not regulated by RCRA specifically.

14. Transport Information

Not regulated.

15. Regulatory Information

--------\Chemical Inventory Status - Part 1\---------------------------------

Ingredient	TSCA	EC	Japan	Australia
Titanium Dioxide (13463-67-7)	Yes	Yes	Yes	Yes

--------\Chemical Inventory Status - Part 2\---------------------------------

		--Canada--		
Ingredient	Korea	DSL	NDSL	Phil.
Titanium Dioxide (13463-67-7)	Yes	Yes	No	No

--------\Federal, State & International Regulations - Part 1\----------------

	-SARA 302-		------SARA 313------	
Ingredient	RQ	TPQ	List	Chemical Catg.
Titanium Dioxide (13463-67-7)	No	No	No	No

--------\Federal, State & International Regulations - Part 2\----------------

		-RCRA-	-TSCA-
Ingredient	CERCLA	261.33	8(d)
Titanium Dioxide (13463-67-7)	No	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No
SARA 311/312: Acute: Yes Chronic: Yes Fire: No Pressure: No
Reactivity: No (Pure / Solid)
Australian Hazchem Code: No information found.
Poison Schedule: No information found.
WHMIS: This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: 1 Flammability: 0 Reactivity: 0
Label Hazard Warning: CAUTION! MAY CAUSE IRRITATION TO SKIN, EYES, AND RESPIRATORY TRACT. MAY AFFECT LUNGS.

Label Precautions: Avoid contact with eyes, skin and clothing.
Wash thoroughly after handling.
Avoid breathing dust.
Keep container closed.
Use with adequate ventilation.
Label First Aid: In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes. Get medical attention if irritation develops or persists. If inhaled, remove to fresh air. Get medical attention for any breathing difficulty.
Product Use: Laboratory Reagent.
Revision Information: Initial MSDS issue

****

Prepared by Graver Technologies Inc., 200 Lake Drive, Glasgow, DE 19702.   302-731-1700.

APPENDIX E.5

Hematite

MATERIAL SAFETY DATA SHEET
HEMATITE

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

TRADE NAME: HEMATITE

CHEMICAL CLASS: Naturally occuring mineral.

APPLICATIONS: Oil well drilling fluid additive. Weighting agent.

EMERGENCY TELEPHONE: 281-561-1600

SUPPLIER: Supplied by Federal Industrial Products,
A Business Unit of M-I L.L.C.
P.O. Box 42842,
Houston, Texas 77242-2842
TELEPHONE: 281-561-1509
FAX: 281-561-7240

CONTACT PERSON: Sam Hoskin

2. COMPOSITION, INFORMATION ON INGREDIENTS

INGREDIENT NAME:	CAS No.:	CONTENTS :	EPA RQ:	TPQ:
Silica, crystalline, quartz	14808-60-7	0-5 %		
Hematite	1317-60-8	95-100 %		

3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW:

CAUTION! MAY CAUSE EYE, SKIN AND RESPIRATORY TRACT IRRITATION. Avoid contact with eyes, skin and clothing. Avoid breathing airborne product. Keep container closed. Use with adequate ventilation. Wash thoroughly after handling.

This product is a/an red to black powder. May form explosive dust-air mixtures. Slippery when wet. Dike and contain spills. Keep out of sewers and waterways. No significant immediate hazards for emergency response personnel are known.

ACUTE EFFECTS:
HEALTH HAZARDS, GENERAL:

Particulates may cause mechanical irritation to the eyes, nose, throat and lungs. Particulate inhalation may lead to pulmonary fibrosis, chronic bronchitis, emphysema and bronchial asthma. Dermatitis and asthma may result from short contact periods.

INHALATION: May be irritating to the respiratory tract if inhaled.

INGESTION: May cause gastric distress, nausea and vomiting if ingested.

SKIN: May be irritating to the skin.

EYES: May be irritating to the eyes.

CHRONIC EFFECTS:
CARCINOGENICITY:

IARC: Not listed. OSHA: Not regulated. NTP: Not listed.

ATTENTION! CANCER HAZARD. CONTAINS CRYSTALLINE SILICA WHICH CAN CAUSE CANCER. Risk of cancer depends on duration and level of exposure.

IARC Monographs, Vol. 68, 1997, concludes that there is sufficient evidence that inhaled crystalline silica in the form of quartz or cristobalite from occupational sources causes cancer in humans. IARC classification Group 1.

ROUTE OF ENTRY:

Inhalation. Skin and/or eye contact.

TARGET ORGANS:

Respiratory system, lungs. Skin. Eyes.

4. FIRST AID MEASURES

GENERAL: Persons seeking medical attention should carry a copy of this MSDS with them.

INHALATION: Move the exposed person to fresh air at once. Perform artificial respiration if breathing has stopped. Get medical attention.

INGESTION: Drink a couple of glasses water or milk. Do NOT induce vomiting unless directed to do so by a physician. Never give anything by mouth to an unconscious person. Get medical attention.

SKIN: Wash skin thoroughly with soap and water. Remove contaminated clothing. Get medical attention if any discomfort continues.

EYES: Promptly wash eyes with lots of water while lifting the eye lids. Continue to rinse for at least 15 minutes. Get medical attention if any discomfort continues.

5. FIRE FIGHTING MEASURES

AUTO IGNITION TEMP. (°F): N/D
FLAMMABILITY LIMIT - LOWER(%): N/D
FLAMMABILITY LIMIT - UPPER(%): N/D

EXTINGUISHING MEDIA:

Use extinguishing media appropriate for surrounding fire.

SPECIAL FIRE FIGHTING PROCEDURES:

No specific fire fighting procedure given.

UNUSUAL FIRE & EXPLOSION HAZARDS:

No unusual fire or explosion hazards noted.

HAZARDOUS COMBUSTION PRODUCTS:

This material is not combustible. No specific hazardous combustion products noted.

6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS:

Wear proper personal protective equipment (see MSDS Section 8).

SPILL CLEAN-UP PROCEDURES:

Avoid generating and spreading of dust. Shovel into dry containers. Cover and move the containers. Flush the area with water. Do not contaminate drainage or waterways. Repackage or recycle if possible.

7. HANDLING AND STORAGE

HANDLING PRECAUTIONS:

Avoid handling causing generation of dust. Wear full protective clothing for prolonged exposure and/or high concentrations. Eye wash and emergency shower must be available at the work place. Wash hands often and change clothing when needed. Provide good ventilation. Mechanical ventilation or local exhaust ventilation is required.

STORAGE PRECAUTIONS:

Store at moderate temperatures in dry, well ventilated area. Keep in original container.

8. EXPOSURE CONTROLS, PERSONAL PROTECTION

		OSHA PEL:		ACGIH TLV:		OTHER:		
INGREDIENT NAME:	**CAS No.:**	**TWA:**	**STEL:**	**TWA:**	**STEL:**	**TWA:**	**STEL:**	**UNITS:**
Silica, crystalline, quartz	14808-60-7	*		0.1				mg/m3 resp.dust
Hematite	1317-60-8	10 *		5 *				mg/m3

INGREDIENT COMMENTS:

* OSHA PELs for Mineral Dusts containing crystalline silica are 10 mg/m3 / (%SiO2+2) for quartz and 1/2 the calculated quartz value for cristobalite and tridymite. * The PEL given here for Hematite is for Iron Oxide Fume; the TLV is for Iron Oxide dust and fume.

PROTECTIVE EQUIPMENT:

ENGINEERING CONTROLS:

Use appropriate engineering controls such as, exhaust ventilation and process enclosure, to reduce air contamination and keep worker exposure below the applicable limits.

VENTILATION: Supply natural or mechanical ventilation adequate to exhaust airborne product and keep exposures below the applicable limits.

RESPIRATORS: Use at least a NIOSH-approved N95 half-mask disposable or reuseable particulate respirator. In work environments containing oil mist/aerosol use at least a NIOSH-approved P95 half-mask disposable or reuseable particulate respirator. For exposures exceeding 10 x PEL use a NIOSH-approved N100 Particulate Respirator.

PROTECTIVE GLOVES:

Use suitable protective gloves if risk of skin contact.

EYE PROTECTION:

Wear dust resistant safety goggles where there is danger of eye contact.

PROTECTIVE CLOTHING:

Wear appropriate clothing to prevent repeated or prolonged skin contact.

HYGIENIC WORK PRACTICES:

Wash promptly with soap and water if skin becomes contaminated. Change work clothing daily if there is any possibility of contamination.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE/PHYSICAL STATE: Powder, dust.

COLOR:	Red. to Black.	
ODOR:	Metallic.	
SOLUBILITY DESCRIPTION:	Insoluble in water.	
MELT./FREEZ. POINT (°F, interval):	2849	
DENSITY/SPECIFIC GRAVITY (g/ml):	5.24	TEMPERATURE (°F): 68
VAPOR DENSITY (air=1):	N/A	
VAPOR PRESSURE:	N/A	TEMPERATURE (°F):

10. STABILITY AND REACTIVITY

STABILITY: Normally stable.

CONDITIONS TO AVOID:
Not relevant.

HAZARDOUS POLYMERIZATION:
Will not polymerize.

POLYMERIZATION DESCRIPTION:
Not relevant.

MATERIALS TO AVOID:
Strong acids. Strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS:
No specific hazardous decomposition products noted.

11. TOXICOLOGICAL INFORMATION

TOXICOLOGICAL INFORMATION:
No toxicological data is available for this product.

12. ECOLOGICAL INFORMATION

ECOLOGICAL INFORMATION:
Contact M-I Environmental Affairs for ecological information.

13. DISPOSAL CONSIDERATIONS

WASTE MANAGEMENT:
This product does not meet the criteria of a hazardous waste if discarded in its purchased form. Under RCRA, it is the responsibility of the user of the product to determine at the time of disposal, whether the product meets RCRA criteria for hazardous waste. This is because product uses, transformations, mixtures, processes, etc, may render the resulting materials hazardous.
Empty containers retain residues. All labeled precautions must be observed.

DISPOSAL METHODS:
Recover and reclaim or recycle, if practical. Should this product become a waste, dispose of in a permitted industrial landfill. Ensure that containers are empty by RCRA criteria prior to disposal in a permitted industrial landfill.

14. TRANSPORT INFORMATION

PRODUCT RQ: N/A

U.S. DOT:
U.S. DOT CLASS: Not regulated.

CANADIAN TRANSPORT:
TDGR CLASS: Not regulated.

SEA TRANSPORT:
IMDG CLASS: Not regulated.

AIR TRANSPORT:
ICAO CLASS: Not regulated.

15. REGULATORY INFORMATION

REGULATORY STATUS OF INGREDIENTS:

NAME:	CAS No:	TSCA:	CERCLA:	SARA 302:	SARA 313:	DSL(CAN):
Silica, crystalline, quartz	14808-60-7	Yes	No	No	No	Yes
Hematite	1317-60-8	Yes	No	No	No	Yes

US FEDERAL REGULATIONS:
WASTE CLASSIFICATION: Not a hazardous waste by U.S. RCRA criteria. See Section 13.

REGULATORY STATUS: This Product or its components, if a mixture, is subject to following regulations (Not meant to be all inclusive - selected regulations represented):

SECTION 313: This product does not contain toxic chemical subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR Part 372.

SARA 311 Categories:
1: Immediate (Acute) Health Effects.
2. Delayed (Chronic) Health Effects.
The components of this product are listed on or are exempt from the following international chemical registries:

TSCA (U.S.)
DSL (Canada)
EINECS (Europe)

STATE REGULATIONS:
STATE REGULATORY STATUS: This product or its components, if a mixture, is subject to following regulations (Not meant to be all inclusive - selected regulations represented):.
Pennsylvania Right-to-Know.
Illinois Right-to-Know.
New Jersey Right-to-Know.

PROPOSITION 65: This product contains the following chemical(s) considered by the State of California's Safe Drinking Water and Toxic Enforcement Act of 1986 as causing cancer or reproductive toxicity, and for which warnings are now required:
Silica, crystalline

CANADIAN REGULATIONS:

LABELS FOR SUPPLY:

REGULATORY STATUS: This Material Safety Data Sheet has been prepared in compilance with the Controled Product Regulations.

Canadian WHMIS Classification: D2A - Other Toxic Effects: Very Toxic Material

16. OTHER INFORMATION

NPCA HMIS HAZARD INDEX: * 1 Slight Hazard
FLAMMABILITY: 0 Minimal Hazard
REACTIVITY: 0 Minimal Hazard
NPCA HMIS PERS. PROTECT. INDEX: E - Safety Glasses, Gloves, Dust Respirator

USER NOTES: N/A = Not applicable N/D = Not determined

INFORMATION SOURCES:
OSHA Permissible Exposure Limits, 29 CFR 1910, Subpart Z, Section 1910.1000, Air Contaminants.
ACGIH Threshold Limit Values and Biological Exposure Indices for Chemical Substances and Physical Agents (latest edition).
Sax's Dangerous Properties of Industrial Materials, 9th ed., Lewis, R.J. Sr., (ed.), VNR, New York, New York, (1997).
IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Silica, Some Silicates, Coal Dust, and para-Aramid Fibrils, Vol. 68, World Health Organization, Lyon, France, 1997.
Product information provided by the commercial vendor(s).

PREPARED BY: Sam Hoskin

REVISION No./Repl. MSDS of: 1 / February 1993

MSDS STATUS: Approved.

DATE: August 5, 1998

DISCLAIMER:
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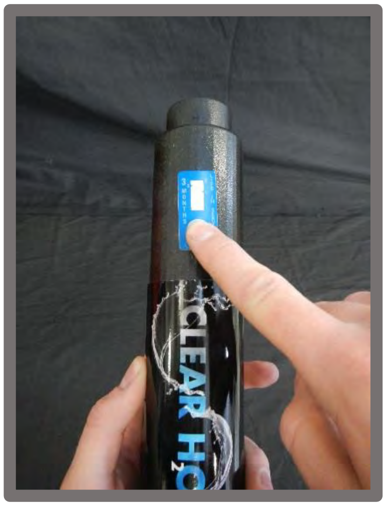
APPENDIX F

User Manual

CLEAR H_2O

Arsenic Filter Instructions

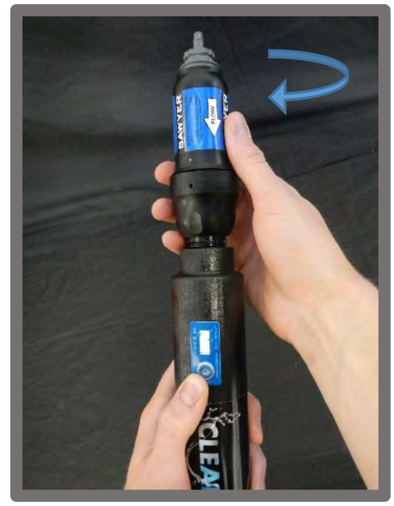


STEP 1

Place the Timestrip® indicator on the filter and firmly press the bubble to start the time.

STEP 2

In a clockwise rotation, thread the CLEAR H_2O filter onto the Sawyer® membrane filter.



STEP 3

Attach the filter unit to the water bucket and pour untreated water into the bucket. Place a clean container at the end of the filter to collect the pure water.

STEP 4

When the Timestrip® on the filter has turned completely red (after several months) the filter is no longer safe to use.

STEP 5

When the Timestrip® has turned red, unscrew the CLEAR H_2O filter in a counter clockwise direction.

STEP 6

Dispose of the CLEAR H_2O filter in a safe location. The filter is safe to discard as nontoxic refuse.