50% Design Report: Low-cost Water Filtration Project

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List of Acronyms/Symbols

As:	Arsenic
BAT:	Best Available Technology
BFA:	Bennett Freeze Area
CFUs:	Colony Forming Units
COC:	Contaminant of Concern
DI:	Deionized Water
DO:	Dissolved Oxygen
GAC:	Granular Activated Carbon
MDG:	Millennium Development Goal
MCL:	Maximum Contaminant Limit
NAU:	Northern Arizona University
NDWR:	Navajo Department of Water Resources
NNEPA:	Navajo Nation Environmental Protection Agency
NTU:	Nephelometric Turbidity Units (a measure of water turbidity)
NTUA:	Navajo Tribal Utility Authority
PWS:	Public Water Supply
TDS:	Total Dissolved Solids
USEPA:	United States Environmental Protection Agency
WHO:	World Health Organization
ZVI:	Zero Valent Iron
U:	Uranium

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1.0 Project Description

1.1 Project Purpose

The purpose of the Low-Cost Water Filtration Project is to provide a design for a low-cost, electricity-free water filtration unit capable of reducing uranium, arsenic, and coliforms to concentrations at or below their Maximum Contaminant Limits (MCLs), as established by the United States EPA (USEPA), in order to provide safe drinking water to the residents of the former Bennett Freeze Area (BFA) of the Navajo Nation.

This project serves the residents of the former BFA and the project client, Forgotten People, which is a non-profit organization that advocates for the well-being of the residents of the former BFA by coordinating with other organizations interested in infrastructure development projects within the region.

1.2 Problem Statement

The 2 million acre area on the Navajo Nation known as the former BFA is occupied by approximately 20,000 individuals residing in an estimated 3,688 homes. Of the 3,688 homes, it is estimated that 2,685 (72.8%) do not have access to a regulated public water supply (Navajo Access Workgroup, 2010). Resident and client testimony support the assumption that most families residing in the former BFA obtain drinking water from unregulated water sources. Unregulated water sources include groundwater wells, surface water deposits, springs, and man-made livestock tanks (U.S. Army Corps of Engineers, 2000). This use of unregulated water supplies presents a problem for residents. Due to a combination of naturally occurring uranium deposits and abandoned uranium mines, many unregulated water sources have concentrations of uranium exceeding the MCL. Extensive uranium mining on the Navajo Nation occurred from the mid to late 1900s, and although these operations have since ceased, a legacy of uranium contamination exists in the area, including the BFA. Two remote wells at Tohatchi Springs and Badger Springs present serious risks, and they are the closest available water sources for residents in the Blackfalls region of the BFA (Ingram, 2011). Unregulated water sources have also shown elevated concentrations of arsenic above the MCL from natural sources and tested positive for coliforms (U.S. Army Corps of Engineers, 2000). Current USEPA MCLs for uranium, arsenic, and total coliform bacteria are 30 µg/L, 10 µg/L, and less than five percent of samples testing positive for coliforms per month, respectively (U.S. Environmental Protection Agency, 2013). Therefore, residents of the BFA are potentially drinking water containing three contaminants of concern (COCs), uranium, arsenic, and coliforms.

There are significant health risks for humans that drink water containing uranium, arsenic, and coliforms above their MCLs. Health risks associated with consuming water with uranium concentrations above the MCL include an increased risk of cancer and kidney toxicity. Health risks associated with arsenic concentrations above the MCL include circulatory system damage, skin damage, and increased cancer risk. Health risks associated with consuming water containing coliforms can vary as the presence of coliforms is utilized as an indicator for the existence of a variety of microbial pathogens. The effects of these pathogens may include acute and/or chronic gastric and respiratory illnesses (U.S. Environmental Protection Agency, 2013). In order to reduce the health risks associated with the drinking of contaminated unregulated water sources in the former BFA, it is necessary to assure the inhabitants of the area have access to water with concentrations of uranium, arsenic, and coliforms below USEPA MCL standards. More information about health risks related to uranium, arsenic and coliforms can be found in section 6.1 Impacts of Final Design, Contribution to Human Health.

1.3 Project Location

The former BFA consists of approximately 1.5 million acres (Navajo Access Workgroup, 2010). The area is named after past Commissioner of Indian Affairs, Robert Bennett. The Navajo and Hopi Settlement Act, Public Law 93-531, defines the borders of the area and the developmental restrictions imposed on its inhabitants. PL 93-531 defines the BFA as: "that portion of the Navajo Reservation lying west of the Executive Order Reservation of 1882 and bounded on the north and south by westerly extensions, to the reservation line, of the northern and southern boundaries of said Executive Order Reservation" (The 93rd Congress of the United States of America, 1966). There are few maps of the BFA in existence. The map in Figure 1 shows the BFA as determined by the U.S. General Accounting Office's Navajo-Hopi Resettlement Program in March 1991. A more detailed map is shown in Figure 2, where the BFA is outlined in red, and a red arrow points to Flagstaff, Arizona.

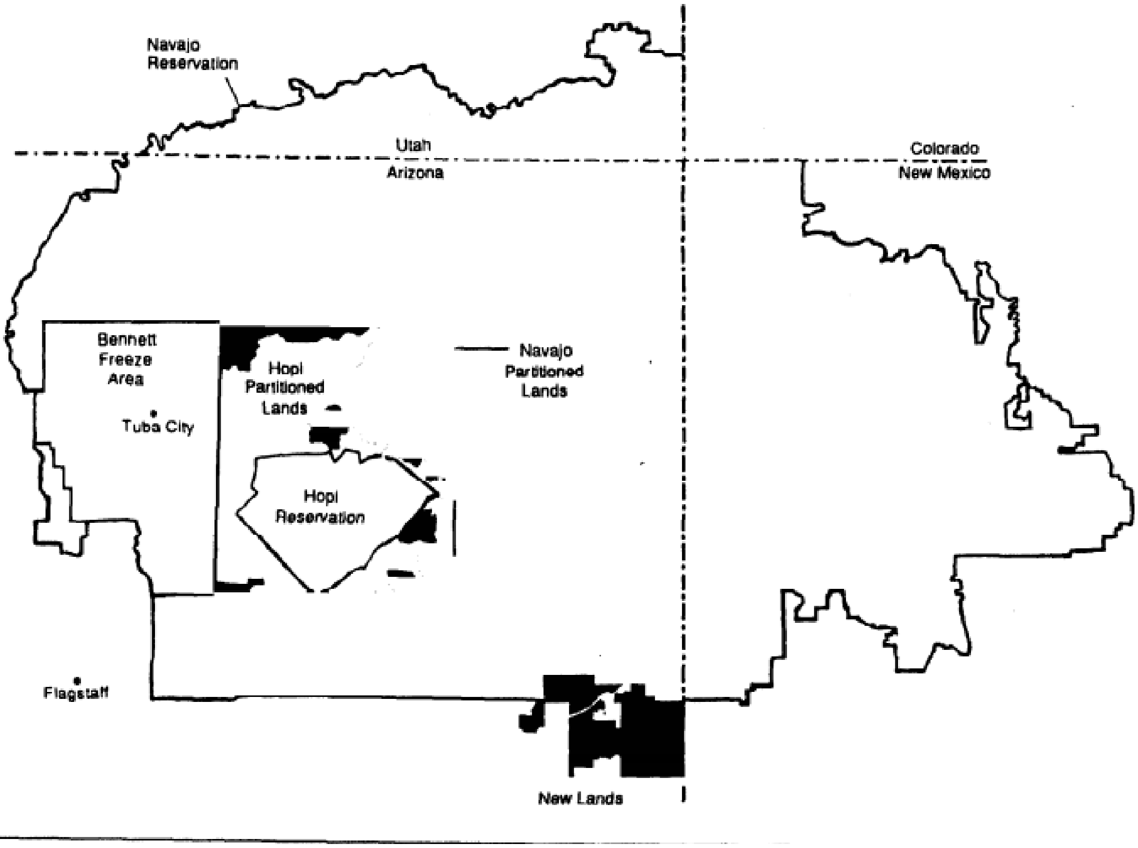


Figure 1: Map of the Bennett Freeze area, as determined by the U.S. General Accounting Office's Navajo-Hopi Resettlement Program *(United States General Accounting Office, 1991)*

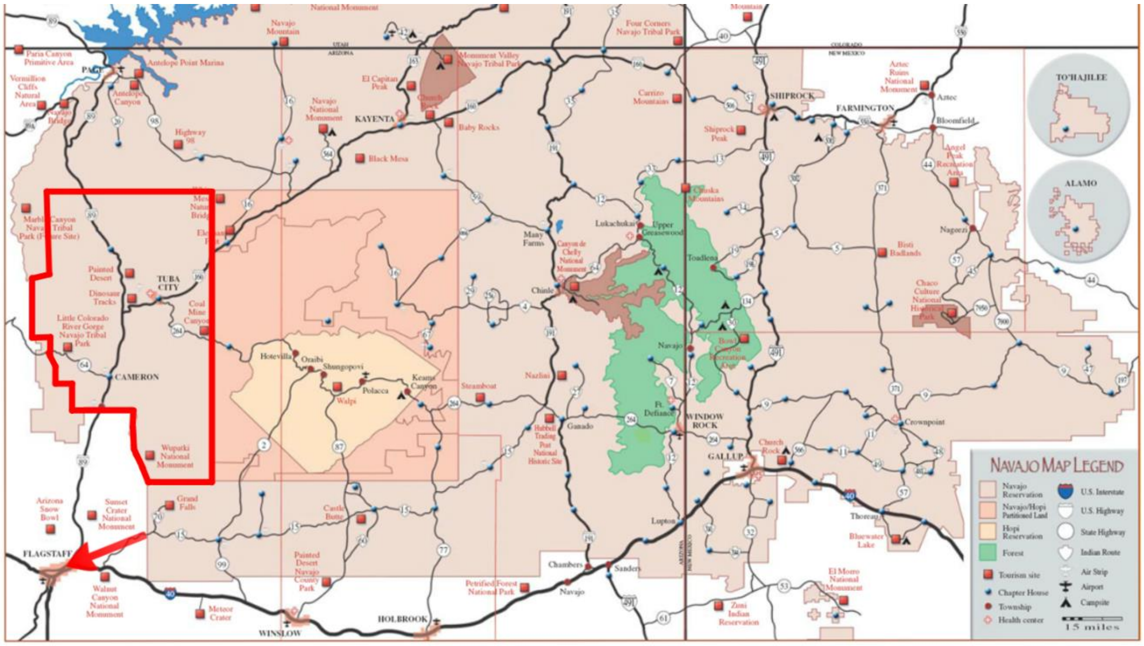


Figure 2: Map of the Bennett Freeze area, as shown by the area outlined in red *(Navajo Nation Map, 2008)*

The developmental restrictions placed on the residents of the BFA prohibited: “any new construction or improvement to the property and further includes public work projects, power and water lines, public agency improvements, and associated rights-of-way” (The 93rd Congress of the United States of America, 1966). The intention of PL 93-531 was to prevent development of the BFA until a land dispute between the Hopi and Navajo Nations could be settled. Unfortunately, the 43 year-long developmental freeze resulted in dire social and economic consequences for residents in the BFA; consequences exacerbated by an absence of infrastructure. Although the land dispute has not been resolved, PL 93-531 section 10(f), which prohibited development was repealed via PL 111-18 in 2009 (The 111th Congress of The United States of America, 2009). The repeal of PL 93-531 10(f) allows for the development of property and infrastructure to resume. Despite this, little progress in terms of drinking water infrastructure has been made.

1.4 Design Constraints and Design Requirements

Taking into consideration the lack of infrastructure and electricity in much of the former BFA as well as the requests of the Forgotten People organization, the following design constraints and requirements were developed for this project. The constraints are imposed restrictions on the design of the water filter, while the requirements indicate what the design must accomplish.

Design Constraints

The device must:

- Function as a point-of-use device
- Operate without electricity
- Minimize cost of construction and maintenance
- Maximize ease of maintenance
- Maximize ease of disposal of used filter materials

Point-of-Use

A point-of-use filter is the most feasible water filtration option for the BFA. This is for several reasons. Residents of the BFA haul their water from community sources to their homes. According to the Program Director of Forgotten People, Marsha Monestersky, installing any form of water treatment at the wellhead would require a lengthy and bureaucratic permitting process from the Navajo Nation. Therefore, a wellhead water treatment system is not advisable. Additionally, residents have been hauling water in large containers, and they are apt to continue using the same containers if a wellhead water treatment system is installed. These containers may contain uranium and arsenic residuals as well as bacteria. Therefore, it is best that a point-of-use water filter is developed for at home use to treat water after it has left the hauling containers.

No Electricity

Many residents in the former BFA do not have access to electricity. Those that do may utilize low-power solar panels or expensive generators. Therefore, the water filtration design should be able to operate without electricity.

Low Cost

Most of the residents of the former BFA live in a state of poverty. Therefore, the final cost for materials and construction of the proposed water filter must be kept to a minimum. In order to keep the cost low, a low-tech solution will need to be developed.

Ease of Maintenance

In order to ensure that the water filter functions for as long as possible, it must be well-maintained. Maintenance time and complexity should be minimized for residents so that the filter is easy to service. The filter life should be maximized so that time between necessary maintenance is minimized. If maintenance is time consuming or difficult, residents may decide it is not worth using in their homes.

Ease of Waste Disposal

The designed water filtration unit will require some form of waste disposal for the collected uranium and arsenic. The design should be able to facilitate easy and safe waste disposal.

Design Requirements

The device must:

- Be capable of reducing uranium and arsenic to concentrations below their MCLs
    - Less than 30 µg/L for uranium
    - Less than 10 µg/L for arsenic
- Be capable of producing coliform-free water
- Operate effectively in a pH range of 7.5-8.4
- Provide filtered water within a reasonable contact time of 0-4 hours

Reduction of COCs and Coliform-Free Water

The main goal of this project is to design a water filter capable of reducing the uranium and arsenic concentration to levels below their MCLs and to provide coliform-free water in order to provide safe water for drinking.

Operational pH Range

The water filter must be able to operate in a pH range of 7.5-8.4, which is the pH range of the water from the wells in the former BFA, as discussed in the section Water Chemistry of the Bennett Freeze Area Wells.

Contact Time

The water filter should be able to produce clean water in less than four hours, so that residents do not have to wait for long-periods of time for water purification.

1.5 Changes to Project Scope

As the Sublime Engineering team conducted research into materials and methods for the removal of U and As to achieve concentrations below the MCLs, it became clear that low-cost, low-tech options are limited. Most of these options are still in the research and development phase, and are being considered by PhD researchers around the world. Furthermore, due to time and budget constraints related to water analysis of U and As, difficulty in acquiring material resources in a timely manner, and the inability to create vast volumes of water needed for testing, the scope of this project has been adjusted. The major change to the scope is the removal of the construction of a bench-scale model and its subsequent laboratory testing. The original scope can be found in Appendix A: Original Scope of Services. The updated scope only affects Task Four, and the major changes are presented below.

TASK FOUR: DESIGN AND DESIGN TESTING

Design and testing of the alternative materials are required. The following subsections detail the subtasks that must be addressed in order to complete the design and testing.

SUBTASK 4.1: DEVELOPMENT OF DESIGN CRITERIA AND CONSTRAINTS

In this subtask, the design criteria and constraints are fully developed. Adherence to the criteria and constraints must occur in subtasks 4.2, Identification of Alternative Methods and 4.9, Final Proposed Design.

SUBTASK 4.2: IDENTIFICATION OF ALTERNATIVE METHODS

This subtask involves the identification of multiple alternative methods to achieve the reduction of arsenic, uranium, and coliforms to concentrations below their respective MCLs. These alternative methods, which may consist of various media or materials, are based upon task three, Literature Review. Any methods or design ideas that would require special permitting from the Navajo Nation are excluded at the request of the client and include any designs that would be implemented at the water source.

SUBTASK 4.3: MATERIAL PURCHASING AND ACQUISITION

Any materials or equipment necessary for testing must be purchased.

SUBTASK 4.4: CONSTRUCTION OF TESTING APPARATUS

A laboratory testing apparatus needed for the testing of the selected alternative methods must be constructed.

SUBTASK 4.5: PREPARATION OF MATERIALS

The materials required for the alternative methods must be prepared for testing following suggested preparation procedures from the literature review. Depending on the material, this may involve cleaning and drying the material, preparing a sand matrix, or crushing the material to provide a greater surface area for removal.

SUBTASK 4.6: TESTING OF ALTERNATIVE METHODS

The selected methods must be tested for their ability to reduce uranium and arsenic. An experimental matrix for water sampling must be determined. Water quality analysis will include uranium and arsenic concentrations. However, testing of the selected method for coliform reduction will be excluded from this project due to known and confirmed procedures from the World Health Organization (WHO). However, the method and calculations for the coliform reduction must be prepared and documented.

SUBTASK 4.7: CONSTRUCTION OF MODULAR DESIGN

A modular design capable of testing the alternative methods in series must be constructed. The selected alternative materials must be capable of being placed into their own individual modules. The modules must be able to be stacked in varying configurations to determine the optimal order of materials in a water filtration unit for the reduction of uranium and arsenic.

SUBTASK 4.8 TESTING OF MODULAR CONFIGURATIONS

Based upon the water quality results from subtask 4.6, Testing of Alternative Methods, decision matrices will be populated to determine the optimal alternative methods. These methods will be tested in various configurations using the constructed modular system from subtask 4.7, Construction of Modular Design. An experimental matrix for water sampling must be determined. Water quality analysis will include uranium and arsenic concentrations. Once again, coliform testing will be excluded.

SUBTASK 4.9: FINAL PROPOSED DESIGN

After receiving results from subtask 4.8, Testing of Modular Configurations, decision matrices are utilized to determine which of the modular configurations best meets the design criteria and constraints established in subtask 4.1. Analysis of the decision matrices leads to the selected final design. The calculations necessary to determine the dimensions of the final design must be computed. If time allows and equipment is procured, these calculations may be based upon additional testing of the hydraulic conductivity of any materials used.

SUBTASK 4.10: ECONOMIC ANALYSIS OF FINAL DESIGN

An economic analysis of the final design is performed using engineering economic principles. The economic analysis shall provide a cost estimate to build, operate, and maintain a full-scale device.

1.6 Project Exclusions

This project does not include the construction of a bench-scale model or an actual full-scale water filtration unit for implementation. Therefore, no laboratory or field testing will be conducted for a bench-scale model or full-scale water filtration device. Rather, a final design will be proposed based on laboratory testing of materials and various configurations of these materials. This exclusion is a result of time constraints for this project. Also as a result of time constraints, reaction kinetics for the materials chosen as alternatives cannot be established.

2.0 Background

Prior to determining alternative water filtration designs, further research of the BFA was conducted. Extensive research of methods for removing arsenic, uranium, and bacteria from drinking water was also conducted. The results of this research are presented in the following sections.

2.1 Bennett Freeze Area Conditions

The development of public water supply (PWS) infrastructure in the former BFA falls under the jurisdiction of the Navajo Nation Environmental Protection Agency (NNEPA), The Navajo Nation Department of Water Resources (NDWR), and the Navajo Tribal Utility Authority (NTUA) (Navajo Access Workgroup, 2010). Development prohibition in the BFA resulted in the inability of these organizations to extend the delivery of PWS infrastructure development projects to the majority of residents in the area (Navajo Access Workgroup, 2010). Due to the lack of access to a regulated PWS and a combination of poor transportation infrastructure, lack of employment opportunities, and high cost of fuel, most residents in the BFA rely on local unregulated water sources for drinking water. Grab samples of unregulated water sources believed to have been utilized for drinking water on the Navajo Nation were analyzed by the U.S. Army Corps of Engineers and the USEPA between 1994 and 2000 (U.S. Army Corps of Engineers, 2000). Samples analyzed during this study exhibited concentrations of uranium and arsenic in excess of the USEPA MCLs.

The former BFA is occupied by approximately 20,000 individuals residing in an estimated 3,688 homes. Of the 3,688 homes, it is estimated that 2,685 (72%) do not have access to a regulated water supply (Navajo Access Workgroup, 2010). According to Thomas Rock, a Navajo PhD student studying bioaccumulation of uranium in sheep on the Navajo Nation under the supervision of Dr. Jani Ingram of the Chemistry Department at NAU, most residents haul their drinking water from unregulated water sources using trucks and a combination of truck-mounted large water tanks, 50 gallon drums, and 5 gallon containers. Some residents purchase drinking water from providers in Flagstaff or Tuba City; however, transportation costs do not favor this alternative.

Water Chemistry of the Bennett Freeze Area Wells

Grab sample water analysis data obtained by the U.S. Army Corps of Engineers and USEPA in 2000 details existing contamination levels of verified unregulated water sources located in the BFA. Total uranium concentrations, a summation of Uranium 234, Uranium 235, and Uranium 238 isotopes, range from 2.55 µg/L to 126 µg/L. Arsenic concentrations range from 0 µg/L to 145 µg/L (U.S. Army Corps of Engineers, 2000). There are three wells of interest in the BFA, as they contain elevated levels of arsenic and uranium, according to a study conducted by Dr. Jani Ingram of the Chemistry Department at NAU in 2011. These wells include well number 5M-74 at Box Springs, an unnumbered well at Tohatchi Springs, and an unnumbered well at Badger Springs. Tohatchi Springs and Badger Springs are within 15 miles of one another, and are located in the remote Blackfalls region of the Navajo Nation (Ingram, 2011). The location of Badger Springs (A, coordinates 35,38,26.7611, -111,11,46.958), Tohatchi Springs (B, coordinates 35, 41,14.0106, -111,6,8.23381), and Box Springs (C, coordinates 35.50, -111.24) can be seen in Figure 3: Map of BFA Wells.

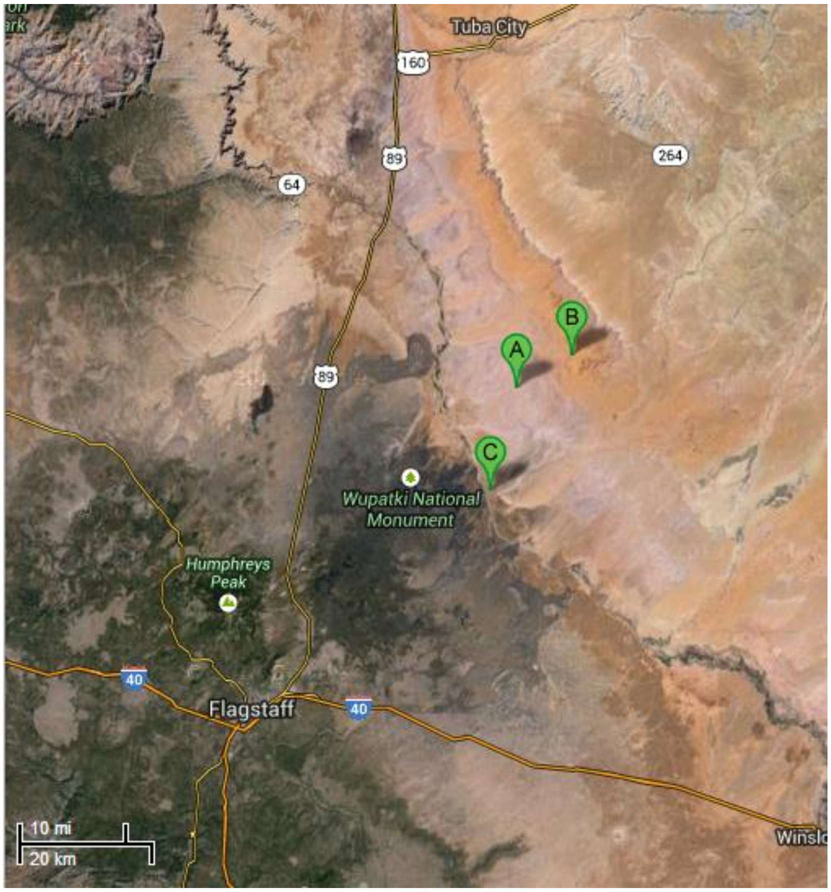


Figure 3: Map of BFA Wells *(Google Maps, 2014)*

Table 1 is a compilation of water chemistry data taken from Dr. Jani Ingram's water quality analysis completed in 2011 and the Navajo Nation Water Quality Project website maintained by Northwestern University that presents water quality data for the Navajo Nation from testing conducted by the U.S. Army Corps of Engineers (Ingram, 2011), (Northwestern University Chemistry Department, Unknown).

Table 1: Water Chemistry for BFA Wells

Well	pH	Elemental U µg/L	As µg/L	HCO_3^- mg/L	Cl^- mg/L	NO_3^- mg/L	SO_4^{2-} mg/L	PO_4^{3-} mg/L	Na^+ mg/L	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L
Box Springs	7.8	Appr. 20-25	N/A	347	24	2.5	195	0.01	156	3.8	13	32
Tohatchi Springs	8.2	Appr. 70	54.8	540	154	1.28	151	0.07	349	2.1	2	5
Badger Springs	8.4	Appr. 20-30	51.1	557	93	1.04	136	0.01	280	1.2	4	7

The relatively high concentrations of bicarbonate (HCO_3^-) at Tohatchi and Badger Springs present an important consideration because it is one of the strongest complexing agents for uranium in an aqueous environment and also has a large role in uranium speciation. The U concentrations shown were determined by the Ingram analysis. The Tohatchi Springs U concentration is listed as approximately 70 µg/L. Large error may be present in this analysis because only two samples were analyzed. In February 2011, the U concentration was found to be 100 µg/L, but it was only 45 µg/L in October 2011. This may be due to a seasonal variation in well water, where the well may have experienced dilution due to runoff from higher seasonal rates of precipitation. It's important to note that data on the U concentrations for the Navajo Nation wells from previous Ingram analyses and the U.S. Army Corps of Engineers provide a wide variation of results. Therefore, no significant, robust study has been conducted to confirm the actual U concentrations. What is presented here is the most recent and best data available. The Ingram report provides further hypotheses on the discrepancies. Regardless, the U concentration at Tohatchi Springs is above the 30 µg/L MCL established by the USEPA. The As concentrations are from the Navajo Nation Water Quality Project.

The water chemistry of the three BFA wells is used to help determine the desired water chemistry for the synthetic water developed for this project, as described in section 4.1 Synthetic Water Development. Details and challenges of the synthetic water development are contained in that section, however the key components of the synthetic water development are the U and As concentrations and the pH. From the data presented in Table 1, the synthetic water goals were determined. The pH should be between 7.8 and 8.4. The U concentration should be 100 µg/L, which is highest measured concentration of U for Tohatchi Springs from February 2011 and the highest U concentration in the BFA. The As concentration should be 70 µg/L, which was selected to be slightly higher than the highest As concentration of 54.8 µg/L. Because As is an increasing problem for water sources across the world, the team elected to increase the As concentration in the synthetic water to attempt to test materials and configurations capable of reducing higher concentrations of As than those found in the BFA.

Arsenic Speciation in Water in the Bennett Freeze Area

Arsenic removal from drinking water is complicated by the fact that As may be present in one of two forms: As(V), which is arsenate with a valence of five, as in $H_2AsO_4^-$ or $HAsO_4^{2-}$, or As(III), which is arsenite with a valence of three, as in $H_2AsO_3^-$ or H_3AsO_3. Most water treatment methods for As removal focus on removing As(V) anion and uncharged As(III) species since they are the most prevalent at a neutral pH as $H_2AsO_4^-$ and H_3AsO_3, respectively. In the Southwestern United States, particularly, As(III) is more common than As(V) (Farrell, Assessing Arsenic Removal Technologies, 2002). As(III) is more toxic and more difficult to remove than As(V), so many large-scale municipal operations utilize a preoxidation step to convert As from the trivalent to the pentavalent form for easier removal (Amin, et al., 2006). Preoxidation is difficult without aeration supplied from an electric device or through chemical means. Because one of the project constraints is to create an electricity-free water filter and the use of chemicals causes additional maintenance and complexity, preoxidation is not suitable for this project.

Uranium Speciation in Water in the Bennett Freeze Area

The potential health effects from drinking uranium contaminated water vary depending on the solubility of the uranium and its speciation in the water, which in turn are dependent upon the pH of the water, water hardness, and concentrations of ligands. Uranium is most commonly found in groundwater in its hexavalent oxidation state, U(VI), as the uranyl ion UO_2^{2+}. Carbonate and phosphate are usually the dominant ligands that affect U(VI) speciation in groundwater (Farrell, Bostick, Jarabek, & Fiedor, 1999). To truly determine the bioavailability and potential toxicity of uranium, the speciation of uranium in water is critical. Unfortunately, Dr. Ingram's 2011 study was not able to determine the exact speciation of U in the water of the BFA wells. However, it was determined that the U was likely present as hexavalent U in the form of a uranyl-hydroxyl or uranyl-carbonate complex (Ingram, 2011).

2.2 Technology Review

Large-scale municipal water treatment systems in the developing world typically employ conventional methods of water treatment such as mechanical separation, coagulation and flocculation, chemical purification, disinfection processes, biological processes, aeration, and membrane technologies. These technologies are often used in combination to increase the effectiveness of water treatment (Mihelcic, Phillips, Barkdoll, Fry, & Myre, 2009).

The following technologies that are described for the removal of arsenic, uranium, or bacteria are evaluated for their efficacy in removing the contaminant of concern, their ability to be obtained and utilized at a low-cost without electricity as a point-of-use filter, and the level of maintenance required. Reasons for excluding or including a technology as an alternative are presented.

Arsenic has become an increasing global concern, especially in places such as Bangladesh and India. For this reason, there is more robust literature available on low-cost and low-tech solutions for arsenic removal from groundwater. On the other hand, research into low-tech methods for uranium removal is less prevalent. In many cases, uranium removal research has been focused on environmental remediation of contaminated sites requiring the reduction of uranium concentrations in the mg/L range rather than the µg/L range. Most of this research does not note whether or not these emerging technologies are capable of removing uranium to concentrations at or below the MCL. Additionally, much of the research is lacking specifics such as detailed results of column tests or recommended contact times for effective removal.

Arsenic and Uranium

The following technologies were evaluated for their capability to remove U, As, or both U and As from water. Only a few of these methods are considered to be fairly well documented, including activated alumina, coagulation/precipitation, ion exchange resins, lime softening, and membranes. Emerging technologies are also being investigated. While less is known about these emerging technologies, many of them have been conceived for use in low-cost, low-tech, and/or rural applications. The emerging technologies include a composite iron matrix, granular ferric hydroxide, hydroxyapatite, orange peels, rice husks, zeolite, and zero valent iron. All of the technologies are presented alphabetically for ease of reference.

Activated Alumina: U and As

Activated alumina is listed as a Best Available Technology (BAT) for both uranium and arsenic, as determined by the US EPA. It is a granulated form of aluminum oxide (Al_2O_3) and is highly porous with a very large surface area over 200 m^2/g. It is best used in packed beds as an adsorbent. The activated alumina process is a physical/chemical process through which As or U ions are removed on the oxide surface. It can also be considered similar to ion exchange resins or adsorption through ligand exchange and chemisorption, although the kinetics of arsenic removal are slower than ion exchange resins. It is more effective for the removal of As(V) than As (III) because the competition for adsorption sites is greater for As(III). If used for the removal of As (III), pre-oxidation is recommended. Activated alumina is also best used at a pH between 5.5 and 6.0, since the efficiency of the activated alumina is decreases at higher pH values due to a net negative charge of the surface that electro-statically repels anions. Activated alumina also requires backwashing, regeneration of the media, or complete disposal as a hazardous waste every one to three years (U.S. Department of the Interior, Bureau of Reclamation, 2010) (Johnson, Heijnen, & Wurzel, 2001). Due to the low pH required and the low efficiency removal of As(III), activated alumina is not a viable option for use in the United States Southwest where As(III) is the dominant form of As. The liquid waste stream generated by activated alumina also may be too acidic, caustic, saline, or As-rich for simple disposal (Johnson, Heijnen, & Wurzel, 2001).

Coagulation/Precipitation: U and As

The most common method to remove As(III) and As(V) is via chemical precipitation using iron and aluminum salts, and it is listed as a BAT for both U and As by the USEPA (Bang, Korfiatis, & Meng, 2005), (Farrell, Assessing Arsenic Removal Technologies, 2002), (Arizona Department of Environmental Quality, 2008). Ferric salts are typically more effective at removing As(III), and are therefore more commonly used. As removal occurs through chemical adsorption and co-precipitation during the formation of ferric hydroxides. Coagulation/precipitation can also remove turbidity, iron, manganese, phosphate, and fluoride, while making improvements to odor and color. Although this is the most efficient method for the removal of As, it has several limitations. It is highly dependent upon the water chemistry, making it difficult to apply general principals to a wide-variety of water sources. Amounts of ferric or aluminum salts are dependent upon the speciation of the As, the pH and ionic composition of the water, and the scale of the treatment operation (Farrell, Assessing Arsenic Removal Technologies, 2002). Additionally, chemical additions of this nature are difficult to control and operate point-of-use, especially because they require a large contact and/or settling basin and a filtration step. For these reasons, coagulation/precipitation is not an appropriate technology for this project.

Composite Iron Matrix (CIM): As

The National Academy of Engineering – Grainger Challenge Prize winner, the SONO filter, utilizes a specially manufactured composite iron matrix for arsenic removal, and was designed specifically for use in Bangladesh and Nepal (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010). The filter has been found to be capable of meeting both WHO and Bangladesh water quality standards for As, reducing As concentrations to less than 10 µg/L in studies of up to four years of use in households in Bangladesh. It can operate at a low-cost without chemical treatment or regeneration of media or the production of toxic waste. The residual material is a non-toxic solid self-contained iron-arsenate cement. The Composite Iron Matrix (CIM) was developed under a proprietary process utilizing food grade acid washes and is composed of 5-10 kg of cast iron turnings (92-94% Fe), 4-5% carbon, 1-2% SiO_2, 1-2% manganese, and 1-2% each of sulfur and phosphorous. The final CIM is porous and lighter than cast iron turnings alone. Additional details about other materials contained in the SONO filter can be found in the referenced article (Hussam & Munir, 2007). While the CIM seems to be an effective method, little else is known about CIM other than the SONO filter. Furthermore, the CIM is produced through a proprietary process. Developing a similar CIM may take years of research and development, and is therefore not appropriate for this project.

Granular Ferric Hydroxide (GFH): As

A granular ferric hydroxide filter is an emerging technology that is found to be operationally simplistic, making it suitable for point-of-use. They are formed from poorly crystalized FeOOH. It is more effective than activated alumina, but does suffer from competitive adsorption of phosphate and silicate. Iron oxides chemically adsorb As(III) and As(V). Once utilized, the GFH media is not intended for regeneration and should be disposed of and replaced (Farrell, Assessing Arsenic Removal Technologies, 2002). GFH is considered to be a proprietary iron-based adsorption material, and has been implemented in full-scale municipal systems in Germany. GFH materials have also been developed in Canada and the United States. Due to the proprietary nature of GFH, compositions and removal mechanisms are not fully known. This also makes GFH promising but expensive with little supporting data (Johnson, Heijnen, & Wurzel, 2001). Thus, GFH is excluded from this project.

Hydroxyapatite/ Synthetic Apatite/ Bone Char: U and As

Hydroxyapatite ($Ca_5(PO_4)_3(OH)$) is a crystal naturally occurring in the deposits of phosphate rock and in the bones and teeth of vertebrates. Synthetic apatite has a very high purity and well-characterized mineral structure. A study of various natural and synthetic apatites and bone char was conducted, with results provided as equilibrium distribution coefficients (K_d) values for a one-hour contact time. Higher K_d values indicate a greater ability of the material to remove U or As from the water. Through these studies, it was found that bone char and Bio-rad hydroxyapatite were best able to remove U at 15,737 mL/g and 48,001 mL/g, respectively. Bone char was not as good at removing As at approximately 18.4 mL/g (Thomson, Smith, Busch, Siegel, & Baldwin, 2009).

Bone from various animals, crushed and charred, has been found to remove heavy metals from water, including As and U. Bone char is both affordable, renewable, and available in most locations in the form of fish bone or from animal processing facilities (Goodier, 2011), (Thomson, Smith, Busch, Siegel, & Baldwin, 2009). However, bone char is eliminated as an option for this project due to opposition from the Navajo culture towards the use of bone remnants. Other forms of hydroxyapatite were eliminated due to limited research on their efficacy for the removal of U and As.

Ion Exchange: U and As

Ion exchange works by strongly attracting the contaminant to a site on the surface of a solid, allowing for a reversible displacement of the ion removed from the water (Johnson, Heijnen, & Wurzel, 2001). Researchers and engineers are increasingly capable of designing ion exchange resins that have more advanced properties that are particularly specific to arsenate, such as copper-doped materials. While ion exchange resins can be highly engineered to remove specific contaminants, their costs are typically high, often eliminating ion exchange as a potential alternative for a low-cost design (Johnson, Heijnen, & Wurzel, 2001). An alternative to the synthetic, highly-engineered ion exchange resin is natural zeolites. Zeolites are naturally occurring materials with crystalline structures with large internal pore spaces and very large surface areas with ion exchange capacities. Natural zeolite minerals such as clinoptilolite and chabazite were found to have a strong affinity for arsenate and arsenite (Johnson, Heijnen, & Wurzel, 2001). While the natural zeolites are less expensive, they are not as effective as the engineered ion exchange resins.

Ion exchange is listed as a BAT for both U and As by the USEPA (Bang, Korfiatis, & Meng, 2005), (Arizona Department of Environmental Quality, 2008). Ion exchange resins, although potentially expensive, are specially designed for the removal of specific contaminants. The resins are easy to regenerate, are applicable over a wide range of pH, and improve overall water quality by removing other potential contaminants such as nitrite and nitrate. They are also operable without electricity. Therefore, ion exchange will be explored as an alternative for this project.

Lime Softening: U and As

This is one of the most common methods for the removal of As, and it is considered a BAT for both U and As removal by the USEPA, (Arizona Department of Environmental Quality, 2008). The process is similar to coagulation/precipitation. Lime ($Ca(OH)_2$) is applied and hydrolyzes and combines with carbonic acid to form calcium carbonate, which acts as a sorbing agent for As or U removal. Lime softening is not feasible for this project because it requires a chemical application that is based highly upon the water chemistry, which varies seasonally and by location. Lime softening also raises the pH of water to a range of 10-12 (Johnson, Heijnen, & Wurzel, 2001). Therefore, this method has been eliminated from further consideration.

Membranes (Microfiltration through Reverse Osmosis): U and As

Numerous synthetic membranes are available and have been designed to be semipermeable so that some molecules are excluded while others are capable of passing through the membrane. Microfiltration and ultrafiltration are considered to be low-pressure membranes with larger pore sizes, requiring pressures of 10-30 psi, while nanofiltration and reverse osmosis are high-pressure membranes with smaller pore sizes requiring pressures of 75-250 psi. High-pressure membranes are advantageous in that they are capable of removing both microbial pathogens and various heavy metals from water, including As and U, as shown in Figure 4: Filterable Materials through Membrane Based on Pore Size (Johnson, Heijnen, &Wurzel, 2001).

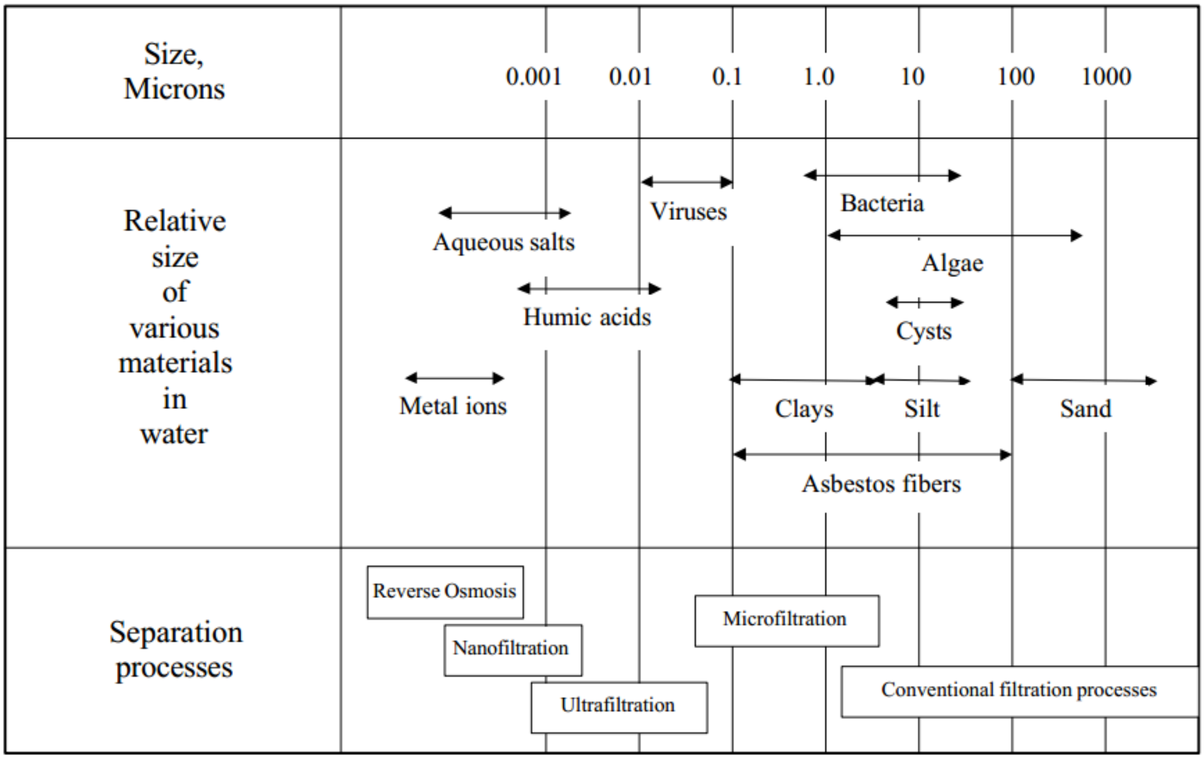


Figure 4: Filterable Materials through Membranes Based on Pore Size *(Johnson, Heijnen, & Wurzel, 2001)*

Membranes require pretreatment of the source water so as to prevent membrane fouling from organics, iron, particulates, manganese, and scale-forming compounds. Unfortunately, the low-pressure systems that are less expensive and less energy intensive are not capable of removing metals ions from water (Farrell, Assessing Arsenic Removal Technologies, 2002) (Johnson, Heijnen, & Wurzel, 2001).

Reverse osmosis (RO) is recommended by the USEPA as a BAT for both U and As (Bang, Korfiatis, & Meng, 2005), (Arizona Department of Environmental Quality, 2008). While RO is capable of reducing As and U to levels below their MCLs, it also removes other ions to very low levels, generating large quantities of brines for disposal (Farrell, Assessing Arsenic Removal Technologies, 2002). Additionally, the electrical requirements, capital costs and operation and maintenance commitments for membrane filtration are high for RO and nanofiltration, making these membranes inappropriate selections for this project (Thomson, Smith, Busch, Siegel, & Baldwin, 2009), (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010) (Raff & Wilken, 1999).

Orange Peels: U

The use of orange peel for the removal of uranium ions from aqueous solutions was recently studied in 2013 by a researcher in Egypt. This is a new uranium treatment technology with little research conducted, but is based on the premise that the orange peels will adsorb the U. The orange peels in the study are cut into small pieces, washed multiple times with distilled water, and dried at 105°C. They are then milled and sieved by a 150-mesh size sieve. High removal efficiency and short contact time make orange peels an attractive option. The optimal contact time is found to be approximately sixty minutes. The disadvantage of orange peels is that the optimal pH for removal occurs at pH 4. At a pH greater than 4, the adsorption of U decreases.

Adsorption is found to be constant over a range of temperatures. At an initial concentration of 25 mg/L of U, the orange peels were able to remove up to 98.16% of the U (Mahmoud, 2013). Although this study was conducted only once at high concentrations of U and as an absorbent in a batch experiment rather than a column or filter, orange peels present a promising option for U uptake. They are a low-cost, natural, and renewable, eco-friendly option. Due to their low-cost and the ease of acquisition, they can be considered an alternative for this project.

Oxidation/Reduction: As

Oxidation is listed as a BAT for As by the USEPA (Bang, Korfiatis, & Meng, 2005), however it cannot be used alone for As treatment. Oxidation merely serves to convert arsenite, the more abundant trivalent form of As, to arsenate, the pentavalent form, in order to facilitate more efficient As removal. Additional treatment, such as coagulation, adsorption, or ion exchange is necessary for actual As removal. Oxidation can be achieved through atmospheric oxidation, artificial oxidation, or chemical oxidation. Atmospheric oxidation is applied simply by allowing water to come into contact with the air. However, oxidation through air contact is a slow process taking weeks. Artificial oxidation can be achieved with electric-powered bubblers. Chemical oxidation can be applied via chlorine, hypochlorite, ozone, permanganate, hydrogen peroxide, or Fenton’s reagent (H_2O_2/Fe^{2+}) (Johnson, Heijnen, & Wurzel, 2001). Oxidation through chemical means requires additional knowledge of the source water’s chemistry to determine the chemical dose, making oxidation a difficult to almost impossible step for this project.

Rice Husks: As

Rice husk, also known as rice hull, has been studied and considered to have tremendous potential for the removal of As from contaminated groundwater. Researchers found that both As(III) and As(V) were completely removed from a water with 100 µg/L of As, a flow rate of 1.7 mL/min and a pH of 6.5 via a single-step column experiment containing 6 g of rice husk with an average particle size of 510 µm. Rice husk is a by-product of the rice milling industry, and is therefore a promising waste reuse product for the removal of As. Rice husk is composed of 49.3% by weight oxygen, 44.6% by weight carbon, and 5.6% by weight hydrogen. Additionally, it is 59.5% by weight volatile, 17.1% by weight ash, and 7.9% by weight moisture. The rice husks were washed and dried before use in the column. No chemicals were added. It was also found that the effectiveness of As removal increased with smaller rice husk grain size and slower flow rates (Amin, et al., 2006). Early research on rice husk found that it has an uptake capacity of 332 mg U per g of rice husk (Khalid, Ahmad, Toheed, & Ahmed, 1998). Similar to orange peels, rice husks are a low-cost, natural, renewable, and eco-friendly option. Due to their low-cost and the ease of acquisition, they can be considered an alternative for this project.

Zero Valent Iron (ZVI): U and As

Zero valent iron is an emerging technology that can often be found as iron filings, shavings, turnings, or pellets. ZVI has been in use for more than 20 years as an in situ treatment for contaminated groundwater, and has recently been employed as an As removal technology in Bangladesh. ZVI filters have been recommended as low-cost, energy efficient systems for the provision of safe drinking water (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010). ZVI has also been investigated by the U.S. Department of Energy (DOE) as a method to remove uranium from contaminated groundwater. Researchers suggest that ZVI is able to remove soluble U through the reductive precipitation of U(VI) to the less soluble U(IV) through the adsorption of uranyl to iron corrosion products (Farrell, Bostick, Jarabek, & Fiedor, 1999).

The majority of ZVI research has been conducted in a laboratory setting, with very few studies taking a field-based approach, and even fewer focusing on long-term use of ZVI filters. While there is much research to be done on ZVI for the removal of As, several laboratory investigations have found that ZVI filings can remove both As(V) and As(III) to levels below 1 µg/L. However, the As removal is limited by the rate of iron corrosion. Fast rates of iron corrosion facilitate the removal of As, even in anaerobic water (Farrell, Assessing Arsenic Removal Technologies, 2002). It is important that the ZVI has the capability to form rust through oxidation, because the removal of As is attributed to adsorption by the iron hydroxides generated from the aerobic corrosion of ZVI. Using ZVI, 82.6% of As(III) and 99.8% of As(V) was removed under aerobic conditions, while less than 4% of As(III) and 9% of As(V) can be removed under anoxic conditions, proving the importance of oxygen and the formation of ferric hydroxide (Bang, Korfiatis, & Meng, 2005).

One negative aspect of ZVI is that the ferrous ion will be produced in the removal process, thus adding to the effluent water, which may be a cause for concern (Johnson, Heijnen, & Wurzel, 2001). Additionally, filter clogging or caking may occur due to the volumetric expansive nature of the iron corrosion process. As iron oxides form, they require more volume than ZVI. To address this issue, ZVI and sand matrices have been researched, and suggestions for incorporating the ZVI as a reactive iron zone within a layer of fine sand have been made. The most effective ZVI to sand ratio was determined to be 40% ZVI: 60% sand by volume, and the ZVI percent by volume should not exceed 52%. Researchers studying the use of ZVI and sand as a low-cost option note that more intensive research is necessary to fully investigate this technology (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010), (Noubactep, Temgoua, & Rahman, 2012).

The Kanchan Arsenic Filter (KAF) was developed by Tommy Ngai at the Massachusetts Institute of Technology for the purpose of water filtration to remove arsenic in Nepal. It makes use of a layer of iron composed of non-galvanized nails, which are placed on top of a sand filter (Ngai & Dangol, 2005). Other researchers have since proven the ineffectiveness of this system, attributing it to the design of iron nails which are not incorporated into a sand matrix. Without the sand matrix, water flowed through the nails too rapidly, therefore not facilitating enough contact time for arsenic removal (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010) (Chiew, Sampson, Huch, Ken, & Bostick, 2009).

The “Three Kolshi Filter” for Bangladesh also utilizes coarse sand and metal iron turnings, as well as other filtration media such as fine sand and wood charcoal. Laboratory tests of this low-tech, low-cost filter have shown that the filter was able to reduce the As concentration to 5 to 30 µg/L from variable initial concentrations of 80 to 1000 µg/L. The World Health Organization states that this filter shows great promise because it is highly effective, low-cost, easy to operate, and is culturally appropriate for its area of proposed use. It employs local materials and traditional, porous water containers (Kolshis). Success of the arsenic removal is partially attributed to the continuous diffusion of air and oxidation facilitated by the porous water containers. While the Three Kolshi Filter is not perfect, the sand and iron filing combination is a high consideration for low-tech As removal (Johnson, Heijnen, & Wurzel, 2001) (Munir, et al., 2001).

A combination of ZVI in the form of mesh iron filings followed by a sand column was found to reduce water samples containing 100 µg/L of As to less than 5 µg/L of As. Testing continued, and no breakthrough occurred after treating 34,000 bed volumes of water. After the water passed through the ZVI column, the iron concentration in the water was found to be between 3 and 6 mg/L, but this was reduced to less than 0.3 mg/L after passing through the sand column (Bang, Korfiatis, & Meng, 2005). These results are indicative of the possibility to create a low-cost filtration process using ZVI and sand for As removal. It is especially effective for water with higher dissolved oxygen (DO) concentrations and lower pH values (at or below neutral pH), as these conditions contribute to the iron corrosion necessary for As removal. For these reasons, ZVI will be considered as an alternative method for As removal for this project.

Bacteria

The following technologies were evaluated for their capability to remove bacteria from water.

Boiling

Although boiling can effectively kill ova, cysts, bacteria, and viruses in water, it is generally not recommended for treatment for several reasons. Boiling requires a large amount of fuel, can give water an unpleasant taste, and may not be executed properly. If a person just heats water without reaching boiling, the water may be falsely considered purified. Additionally, boiling in closed pots may serve to concentrate some volatile organic compounds and other contaminants of concern such as arsenic (Johnson, Heijnen, & Wurzel, 2001). Boiling will not be considered as an alternative.

Chemical Disinfection

There are various ways to chemically disinfect water, including the use of ozone and numerous chlorine containing compounds. In addition to the chlorine compounds used in high-tech treatment plants or lower-tech, rural community-level water treatment plants, there are several chlorine containing compounds used in rural areas that are available for point-of-use. These can include liquid bleach that contains sodium hypochlorite with a range of 1-10% available chlorine, bleaching powder containing calcium hypochlorite that has up to 30% available chlorine, and high-test hypochlorite (often used as a chlorine shock treatment for swimming pools) containing 50-70% available chlorine. Appropriate dosages of chlorine depends on the chemical and physical properties of the water to be treated, and must be able to satisfy the chlorine demand as well as a chlorine residual of 0.5 mg/L. A minimum contact time of 30 minutes is recommended (Johnson, Heijnen, & Wurzel, 2001).

While ozone is not an appropriate technology because it requires an electrical source, chlorine disinfection is included as an alternative for this project. Chlorine disinfection has various advantages in that it’s very effective at reducing pathogens and the chlorine residual provides extra protection for water storage. The USEPA and WHO provide chlorination instructions for rural water sources. The disadvantage of this chemical application is the potential for human error. If too little chlorine is added, pathogens will not be killed. If too much chlorine is used, the water may become unpalatable. Despite this concern, chemical application of chlorine is considered as an alternative for this project due to its low cost, energy-free application, and its demonstrated capability to remove bacteria.

Granular Activated Carbon (GAC)

Although found to be ineffectual for the removal of As and U (Daus, Wennrich, & Weiss, 2004), GAC can be used for the removal of some organic compounds and microbial organisms including viruses and parasites. However, there are still coliform counts observed occasionally. Therefore, this is not the best method for the removal of bacteria (Stanfield, Lechevallier, & Snozzi, 2014).

Membranes (Microfiltration through Reverse Osmosis)

Membranes, as discussed in the technology review for U and As, can also be used for the removal of bacteria through the process of size exclusion. Cysts, bacteria, and viruses can be removed by ultrafiltration, nanofiltration, or ROFigure 4: Filterable Materials through Membranes Based on Pore Size . Once again, the electrical requirements, capital costs and operation and maintenance commitments for membrane filtration are high for RO and nanofiltration, making these membranes inappropriate selections for this project. Additionally, some degree of pre-filtration is necessary prior to any membrane filtration to prevent membrane fouling that causes inefficiencies, requiring an extra step and cost (Stanfield, Lechevallier, & Snozzi, 2014) (Thomson, Smith, Busch, Siegel, & Baldwin, 2009), (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010) (Raff & Wilken, 1999). Therefore, membranes are not eliminated as an alternative method for bacteria removal.

Slow Sand Filtration

The first stage of slow sand filtration is coarse prefiltration through gravel or coconut husk to remove particulate matter. After the coarse prefiltration, water flows through a bed of sand. Slow sand filtration removes pathogens through a combination of physical, chemical, and biological processes. After a sand filter has been in operation for a period of time, a layer of microorganisms forms near the top of the sand bed. This microbial layer is known as the schmutzdecke. It is biologically active and consists of algae, bacteria, diatoms, and zooplankton. It requires two to eight weeks to fully form for effective use. This schmutzdecke ripening period is a major limiting factor for this project due to the time required for formation. Predatory microbes in the schmutzdecke attack and consume pathogens in the water, including *Giardia* and cryptosporidium. Pathogen removal may exceed 99%, but is typically followed by a chlorine disinfection step. Slow sand filters are also capable of reducing turbidity to less than 1 NTU, enterobacteria is removed by 90-99.9%, enteroviruses and *Giardia* cysts are removed by 99-99.9%, and *Cercaria* is removed by 100%. Regardless, the WHO recommends that sand filters are always followed by some form of disinfection (Johnson, Heijnen, & Wurzel, 2001) (Noubactep, Care, Togue-Kamga, Schoner, & Woafa, 2010) (Noubactep, Temgoua, & Rahman, 2012), (Stanfield, Lechevallier, & Snozzi, 2014).

The downside of slow sand filters is that they can become clogged after one to three months of operation, requiring the top two to three centimeters of sand to be scraped off, including the schmutzdecke, therefore decreasing effectiveness until the biolayer forms again. They work best with relatively clear source water, with an influent turbidity of less than 10 NTU recommended unless significant pre-filtration takes place. There can also be a combined multi-stage filtration process that uses a roughing filter of coarse gravel (Johnson, Heijnen, & Wurzel, 2001).

Slow sand filtration technology is not optimal for this project due to the time required for the schmutzdecke to form and the need for a constant flow of water to continually aerate the system allowing for microbial growth. Additionally, it is recommended by WHO that slow sand filters without constant head be followed by a disinfection stage. With this in mind, it is most appropriate to provide a bacterial disinfection stage in lieu of slow sand filtration.

Ultraviolet Radiation

Ultraviolet radiation is an effective technology to kill pathogens. Effective treatment typically requires the use of electric ultraviolet lamps to irradiate water (Johnson, Heijnen, & Wurzel, 2001).

A Swiss research center, EAWAG, has proven that water stored in clear plastic bottles that have been exposed to a minimum of six hours of sunlight can remove over 99% of pathogens due to a synergistic effect of heat and irradiation of the water. It was found that this sunlight method requires water with low turbidity of less than 30 NTU. This method has been termed SODIS, Solar Disinfection, and due to minimal capital and operational costs, seems promising (Johnson, Heijnen, & Wurzel, 2001).

The use of ultraviolet radiation requiring an electric lamp does not meet this project's constraints. The SODIS method is also not feasible due to the long contact time and the need for sunlight. The time of day and weather conditions thus limit the time at which water can be treated.

3.0 Identification of Alternatives

The literature review yields a wide array of technologies available for the removal of arsenic and uranium. These technologies are evaluated for their ability to remove the contaminants of concern from aqueous solutions possessing similar characteristics to those of the contaminated sources in the Bennett Freeze Area as described in Section 2.1 of this report. As the final design is essentially limited to use of gravity and atmospheric pressure, ion exchange and adsorption are identified as the two most viable modes of removal. The efficacy of ion exchange and adsorption of the contaminants of concern are grounded in several parameters:

pH of Influent: The pH of the feed water largely effects the speciation of the arsenic and uranium contained therein. The efficacy of ion exchange and adsorption largely depends on the ionic reduction potential of the contaminants in the aqueous solution (Khandaker, Brady, & Krumhansl, 2009). For neutral compounds, ion exchange and adsorption are much less effective and rely on specific properties of the sorbent. Many ion exchange and adsorption materials are more effective at removing one species of the contaminants. Selection of the technologies discussed in this section is largely based on their demonstrated ability to remove the contaminants of concern in the pH range established in Section 2.1. Typical speciation of arsenic in aqueous solution in regard to pH is shown in Figure 5. Typical speciation of uranium in aqueous solution is shown in Figure 6.

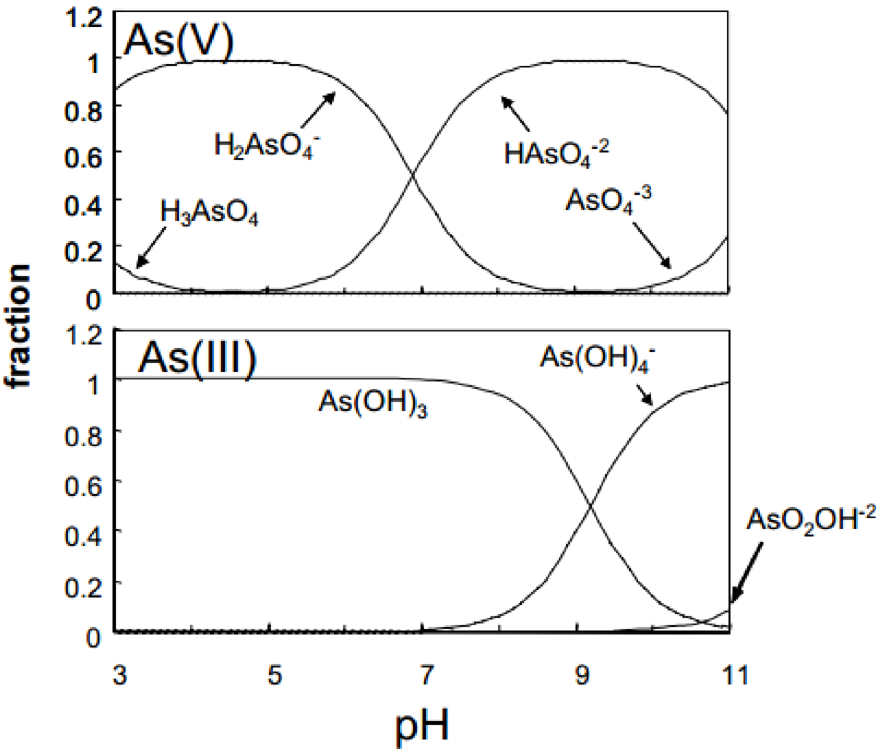
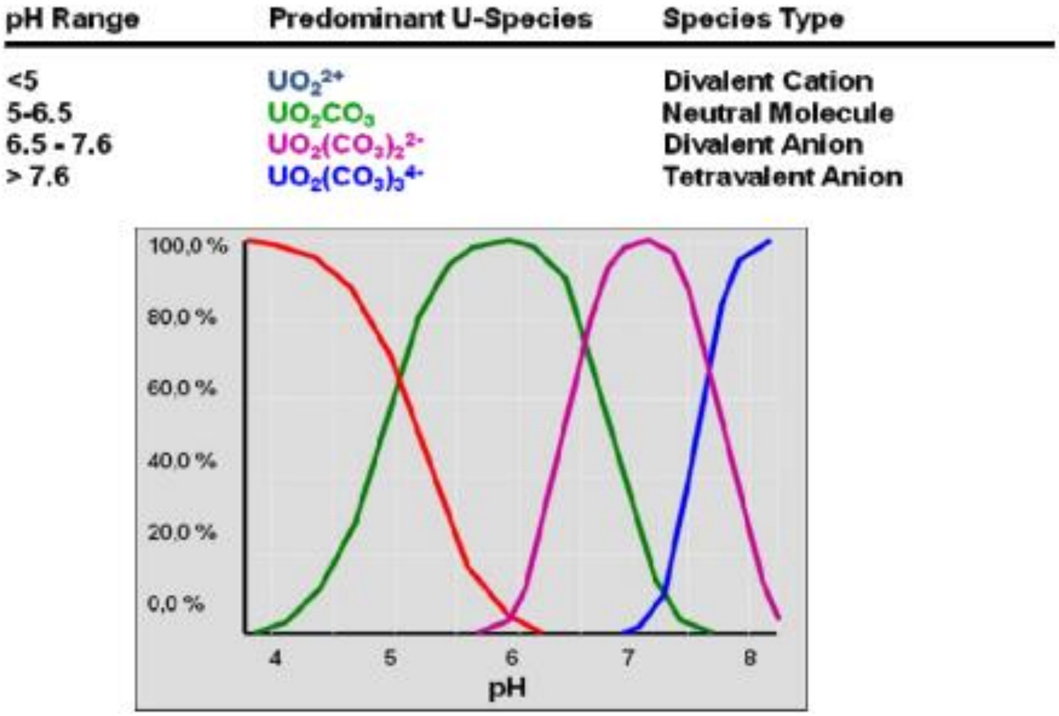


Figure 5: Arsenic Speciation in Aqueous Solutions (Khandaker, Brady, & Krumhansl, 2009)



pH Range	Predominant U-Species	Species Type
<5	UO_2^{2+}	Divalent Cation
5-6.5	UO_2CO_3	Neutral Molecule
6.5 - 7.6	$UO_2(CO_3)_2^{2-}$	Divalent Anion
> 7.6	$UO_2(CO_3)_3^{4-}$	Tetravalent Anion

Figure 6: Uranium Speciation in Aqueous Solutions (Botha, Bester, & Hardwick, 2009)

Removal Efficiency: The literature review largely focuses on the ability of the investigated technologies to remove the contaminants of concern from concentrations similar to those described in Section 2.1 to levels below the MCLs. Most studies concerning ion exchange and adsorption technologies communicate the efficacy of the sorbent as a fraction of removal of the targeted contaminant. Only technologies demonstrating a removal efficiency great enough to reduce the concentrations of the contaminants of concern from those contained in the synthetic water to below the MCLs are considered.

Reaction Kinetics: Out of concern for end-users, and to develop a more practical design the amount of time required to treat water using the technologies is also considered. A maximum contact time of four hours is selected.

The literature review yields several alternatives for the removal of the contaminants of concern which satisfy each of these parameters. The chosen alternatives include ion exchange resin for uranium removal, orange peels for uranium removal, zero-valent iron for arsenic removal, and rice husks for arsenic removal. The following subsections detail the contaminant removal mechanisms and justification for choosing each of these technologies for testing and possible use in the final design.

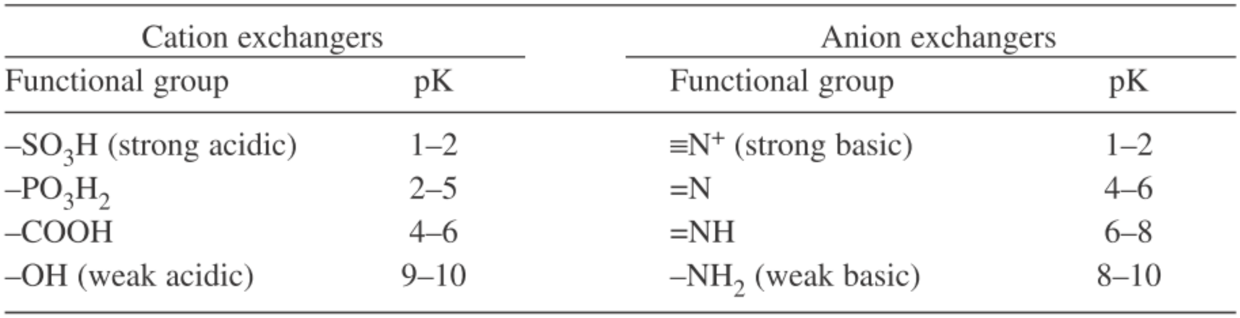
3.1 Ion Exchange Resin for U

Ion exchange resins are highly specialized materials designed to remove specific contaminants from feed water. For this project, a general review of ion exchange alternatives focused on resin selectivity and affinity, ion exchange capacity, and ion exchange kinetics. Selectivity and affinity refer to the ability of a particular ion exchange resin to remove a particular contaminant. Exchange capacity refers to the mass of contaminant which can be adsorbed per mass of resin, and is utilized to gauge maintenance and cost parameters. Exchange kinetics refers to the rate at which ion exchange occurs and relates directly to contact time.

The ion exchange process entails the exchange of ions electrostatically bound to the functional group of a solid matrix for the target contaminant. Ion exchange resins are generally selected for the removal of a particular contaminant. Several factors affect the resin’s affinity to bond with ions in contaminated feed water. These factors include the charge and ionic radii of the ion targeted for removal. The functional group is often an atom for which the resin has the least affinity. Ion affinity also affects sorption kinetics (International Atomic Energy Agency, 2002).

Ion exchange resins are categorized by the type of ion they are designed to remove and the characteristic of their functional group. Resins are designated as cation or anion exchangers and the functional groups are categorized as strongly acidic, weakly acidic, strongly basic, and weakly basic. Table 2 shows some of the most common functional groups of cation and anion exchange resins and their respective negative log pK values.

Table 2: Common Functional Groups of Ion Exchange Resins *(International Atomic Energy Agency, 2002)*



Cation exchangers		Anion exchangers	
Functional group	pK	Functional group	pK
$-SO_3H$ (strong acidic)	1–2	$\equiv N^+$ (strong basic)	1–2
$-PO_3H_2$	2–5	$=N$	4–6
$-COOH$	4–6	$=NH$	6–8
$-OH$ (weak acidic)	9–10	$-NH_2$ (weak basic)	8–10

The following formula illustrates the basic ion exchange reaction between the divalent uranium dioxide ion and a strongly basic ion exchange resin.

$$2(R - N^+) + UO_2\cancel{(CO_3)_2} + \cancel{6H_2O} \leftrightarrow R_2UO_2 + 2N + \cancel{2(CO_3)} + \cancel{6H_2O}$$

Where R represents the solid matrix of the ion exchange resin, and nitrogen is the functional group. The carbonate and water are removed from the equation as they take no part in the ion exchange reaction. It is noted that during this particular ion exchange reaction, nitrogen is added to the treated water. The final selection of a particular ion exchange resin for either uranium or arsenic considers these reactions as mass transfers in order to assure harmful contaminants are not added to the treated water in concentrations greater than those suggested by regulations. It is also noted that the release of charged ions into the feed water may affect pH significantly. This effect is noted in the naming convention of the functional groups of the ion exchange resin. Basic functional groups tend to increase pH while acidic functional groups tend to decrease pH of the treated effluent (International Atomic Energy Agency, 2002).

An extensive review of laboratory studies focusing on the removal efficiencies of anion exchange resins for the treatment of uranium contaminated water yields percent removal in the range of 80-99% (Wilson) (Aieta, Singley, Trussell, Thorbjarnarson, & McGuire, 1987) (Lowry & Lowry, 1988) (Wisser, 2003). For the removal of uranium from solution an anion exchange resin is required. Considering the possible affect the use of a strongly basic anion exchange resin may have on effluent pH, a weakly basic anion exchange resin is preferred. Rohm and Haas, a subsidiary of Dow Chemical Corporation, suggests the use of Amberlite™ PWA8 anion exchange resin for the treatment of uranium contaminated feed water for potable use. It is noted that this anion exchange resin may also remove arsenic from the feed water. No data is available for the removal efficiencies of this particular resin, though it is the particular resin suggested by Rohm and Haas product specialists.

Mass transfer between solution and the active site of the resin takes place in five distinct steps. The order of these steps are diffusion of the ion through the bulk solution, diffusion of the ion through the hydrated film which forms around the resin surface, diffusion of the ion through the thin film, diffusion of the ion through the resin, and finally the actual ion exchange chemical reaction like the one shown above. Reaction kinetics are limited by either diffusion through the thin film or diffusion through the particle. Reaction kinetics are also influenced by other characteristics of the feed water depending on which rate limiting step controls the specific ion exchange resin application (International Atomic Energy Agency, 2002).

Final resin selection is based on a conversation with DOW Chemical Corporation. The selected resin is Amberlite™ PWA8, which is a gel form macroporous weakly basic ion exchange resin specifically designed and demonstrated to effectively remove uranium from feed water. This resin is specifically designed for potable use. A minimum contact time of 30 minutes is suggested but reaction kinetics data supporting this suggestion are unavailable at this time.

Adsorption capacity is well established for uranium removal using ion exchange resins due to their common use in uranium recovery in the uranium mining industry. In general, the capacities of ion exchange resins used in uranium removal are high when the target concentrations of the contaminants in the modeled water used in the testing phase of this project and the target amounts of water to be treated daily by the device, are considered. This means that the final device would likely be able to operate for long periods of time between either replacement or regeneration of the ion exchange resin.

Ion exchange resins are chosen for satisfaction of the design constraints and criteria. This technology has been shown effective in removal of uranium from aqueous solution in the target pH range. Although more costly than the organics considered for this design, ion exchange resins are relatively low-cost when considering the time interval between replacement or regeneration due to their high adsorption capacity. This technology is also selected as it can function in a gravity-fed system

3.2 Orange Peels for U

The use of organic materials for the removal of uranium from aqueous solution is well documented. The use of moss, biomass, and cherry stones have all shown surprising effectiveness in removing large fractions of influent uranium concentrations in concentrated feed streams. One study shows promising results for removing uranium from solution using orange peels (Mohammed , 2013).

Orange peels have shown an adsorption of 75-85% of uranium concentration compared to initial concentrations and a capacity of 12-13 mg of uranium per gram of orange peel in laboratory testing in the pH range of 6-8. Contact time required to achieve this fraction of removal is one hour. The mechanism for removal is a combination of adsorption and ion exchange (Mohammed , 2013).

Orange peels are chosen for their demonstrated ability to remove uranium from aqueous solution. The removal efficiency, pH range of effectiveness, and contact time is considered adequate for application in this design. The widespread availability and general low cost of oranges make this technology an attractive and cost-effective option for use in a low-tech point of use water filter design.

3.3 Zero Valent Iron for As

As ZVI reacts with water with high dissolved oxygen content, insoluble hydrous ferric oxide forms. These oxides have the capability to remove soluble arsenic through adsorption and precipitation processes. When utilizing a ZVI/sand matrix, the precipitate formed through this process can then be contained by the sand, thus removing the arsenic from the water (Chiew, Sampson, Huch, Ken, & Bostick, 2009).

Hydrous ferric oxide is formed under oxidizing conditions, as shown by the following three chemical reactions. Hydrous ferric oxide has a higher adsorptive capacity for As(V) than As(III) at a neutral pH, so more As(V) can be removed from the contaminated water (Bang, Korfiatis, & Meng, 2005).

$2Fe^{0} + O_2 + 4H^{+} \leftrightarrow 2Fe^{2+} + H_2O$

$4Fe^{2+} + 4H^{+} + O_2 \leftrightarrow 4Fe^{3+} + 2H_2O$

$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^{+}$

The prevalence of hydrous ferric oxide is greatly affected by the dissolved oxygen content of the feed water. The ideal condition for application of ZVI for arsenic removal is between 4.3 and 5.5 mg DO/L. The pH of the feed water has also shown to greatly affect removal efficiency. The optimum pH is between 5 and 7, slightly below the pH of the water observed in the contaminated sources considered in this design. Regardless, the removal efficiency of greater than 85% is acceptable for use in this design.

Reaction kinetics have not been adequately established for ZVI in arsenic removal. For a description of the process required to establish reaction kinetics, refer to ion exchange section.

Zero Valent iron is chosen for satisfaction of the design constraints and requirements. ZVI has shown to be effective in completely removing Arsenic from aqueous solution in the target pH range. It is also a low-cost alternative that would work in a low-tech and gravity-fed point of use device.

3.4 Rice Husks for As

Rice husks have been shown effective in completely removing arsenic from aqueous solution in column testing. This technology is shown to be effective in the pH range considered in this design (Amin, et al., 2006).

The mechanism of removal is either affinity adsorption or ion exchange between the arsenic in the feed water and the carbon structure of the rice husk. Carbon contact with water reduces the oxygen to a hydroxyl, causing the carbon to lose electrons and become positively charged, allowing for uncharged Arsenic species prevalent in the target pH range to be removed via ion exchange or affinity adsorption (Amin, et al., 2006).

Rice husks are readily available through online retailers and are relatively inexpensive at $4.00/ lb. Rice husks are a technology considered for the final design as it has been proven to be effective in removing arsenic from aqueous solution in the desired pH range and satisfies the performance criteria. It is an excellent low-cost alternative which can be used in a low-tech point-of-use filtration device.

3.5 Additional Considerations

Granular Activated Carbon

Granular activated carbon (GAC) is considered as a post-treatment option to remove byproducts of the filtration processes. It is observed during initial testing phases that organics like orange peels and rice husks, and inorganics such as ZVI and ion exchange resins, may affect the turbidity, mineral content, taste, and odor of the treated water. GAC will be integrated into the design to clarify and remove byproducts of the filtration process. This technology is the only technology considered for the purpose of making the finished water more aesthetically appealing.

Chlorine Disinfection

Chlorine disinfection is the only technology considered for this design. Chlorine disinfection is the most common, low-cost, and low-tech disinfection treatment commonly employed for in-situ disinfection. Chlorine dose can be calculated based on the free available chlorine content of the specific chemical, the free chlorine contained in the chemical, and the volume of water to be treated.

4.0 Testing and Analysis

Detail all site work. Include sampling, testing, laboratory analyses performed, etc. Complete details of experimental designs/methods/procedures/raw data can be put in an Appendix, but results should be summarized here. Note: This section will be added to after the 50% Report submission.

4.1 Water Quality Analysis Methods

Throughout this project, various water quality parameters were measured in laboratory facilities at NAU and Metropolitan State College of Denver. These water quality parameters include pH, Solids, Turbidity, Coliforms, Hardness, Alkalinity, Dissolved Oxygen, Uranium Concentration, and Arsenic Concentration. The procedures for Coliforms, Hardness, and Alkalinity followed methods established by Standard Methods for the Examination of Water and Wastewater. The Uranium and Arsenic Concentration Testing followed EPA Method 6020. Due to copyright infringement, these methods cannot be attached as appendices. The Standard Methods can be found and purchased from the following website: http://www.standardmethods.org/Store/index.cfm (Standard Methods, 2014). The EPA Method can be found on the following website: http://www.epa.gov/fem/methcollectns.htm (Environmental Protection Agency, 2014).

pH

All pH tests were conducted in the Water Quality Laboratory at NAU. The pH was measured with an Oakton pH/Conductivity/TDS meter, pH/CON 510 series.

Solids

All solids tests were conducted in the Water Quality Laboratory at NAU. Solids were measured as Total Dissolved Solids (TDS) with the HANNA Instruments HI9828 pH/ORP/EC/DO meter, with readings provided as TDS in parts per million (ppm).

Turbidity

All turbidity tests were conducted in the Water Quality Laboratory at NAU. Turbidity measurements were taken using the 2100P Hach Turbidimeter.

Coliforms

All testing for colony forming units (CFUs) was conducted in the Water Quality Laboratory at NAU following Standard Method 9222 B. Standard Total Coliform Membrane Filtration Procedure.

Dissolved Oxygen (DO)

All DO tests were conducted in the Water Quality Laboratory at NAU. DO was measured as with the HANNA Instruments HI9828 pH/ORP/EC/DO meter.

Note: No DO tests have been conducted, but it was recently determined that this should be done.

Hardness

All testing for Total Hardness and Calcium Hardness was conducted in the Water Quality Laboratory at NAU following Standard Method 2340 C. Titration Method.

Alkalinity

All testing for alkalinity was conducted in the Water Quality Laboratory at NAU following Standard Method 2320 B. EDTA Titration Method.

Uranium and Arsenic Concentration

All U and As analysis was conducted by Dr. Michael Ketterer at the Metropolitan State College of Denver. Inductively coupled plasma mass spectrometry (ICP-MS) was used for analysis. ICP-MS uses the basic principle of elemental differentiations based on atomic mass and has been accepted as the most powerful multi-elemental analytical technique. Dr. Ketterer's ICP-MS method is similar to that of the EPA Method 6020.

4.2 Synthetic Water Development

Prior to testing any alternative methods of water treatment, a source of water needed to be identified. Actual well water could not be obtained from any of the BFA wells due to difficulty in securing permits and Navajo Nation Chapter House Resolutions for the sampling and removal of water from the Navajo Nation. For this reason, synthetic water was developed. As discussed in section 2.1 Bennett Freeze Area Conditions, the water chemistry of the three BFA wells was used for the purposes of designing a synthetic water for this project. From the data presented in Table 1: Water Chemistry for BFA Wells, the synthetic water goals are a pH of 7.8-8.4, a U concentration of 100 µg/L, an As concentration of 70 µg/L, and a coliform count of less than 100 CFU/100mL. Additionally, since the BFA water is groundwater, the synthetic water should ideally be sourced from a groundwater well.

Creating the synthetic water involved several steps. This process required the acquisition of a local water source containing coliforms, the acquisition of a local groundwater source with more characteristic water chemistry to better model the BFA groundwater, the determination of the ratio of groundwater to coliform-containing water, the creation of standard U and As solutions from purchased stock solutions, and spiking of the locally sourced water with the U and As standards.

Water Quality Analysis of Upper Lake Mary Water

In order to create a water with these parameters, a combination of groundwater and surface water was used. This was due to the necessity for the presence of coliforms and the desire to create a water most representative of the groundwater in the BFA. Groundwater was obtained from a private residential well in Flagstaff, AZ, but it could not be used alone as it does not contain coliforms. The location of this well is indicated by the letter A in Figure 5.

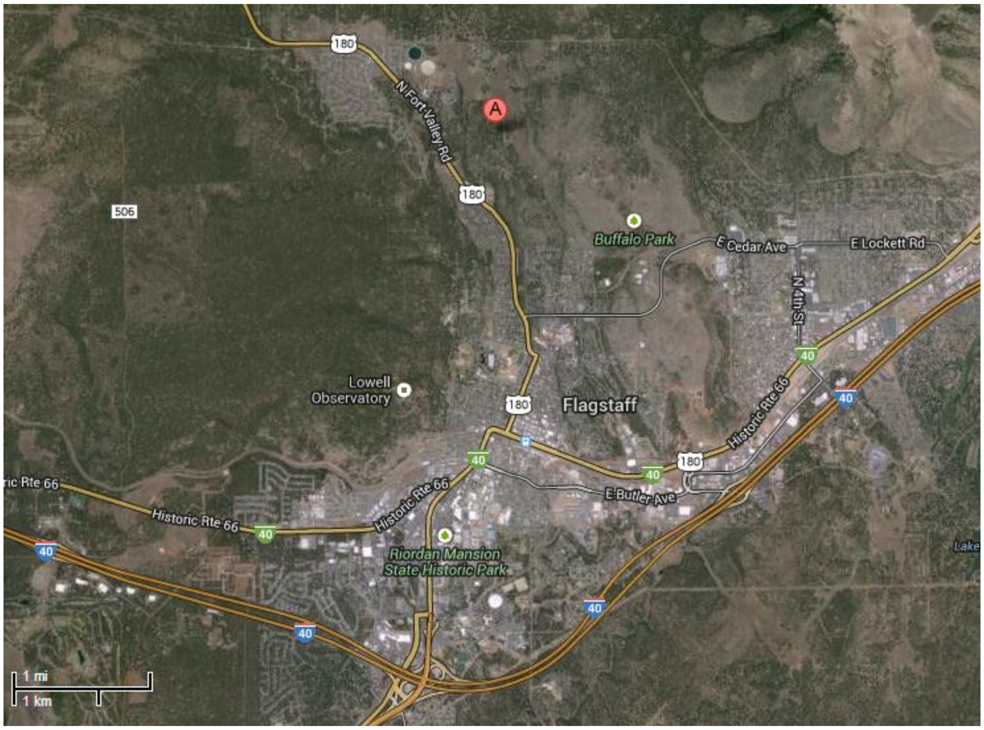


Figure 7: Location of Private Groundwater Well in Flagstaff, AZ *(Map of Flagstaff Groundwater Well, 2014)*

A local water source in Flagstaff, Upper Lake Mary, contains coliforms, but this water is turbid and does not contain as much hardness or alkalinity as typical groundwater sources. The location of this water source is indicated by the letter A in Figure 6(Upper Lake Mary, 2014). The water used in the actual synthetic water creation was taken from a tap at the Lake Mary Water Treatment Plant prior to it receiving water treatment. This tap was easier to access than the actual lake, especially in during the winter months.

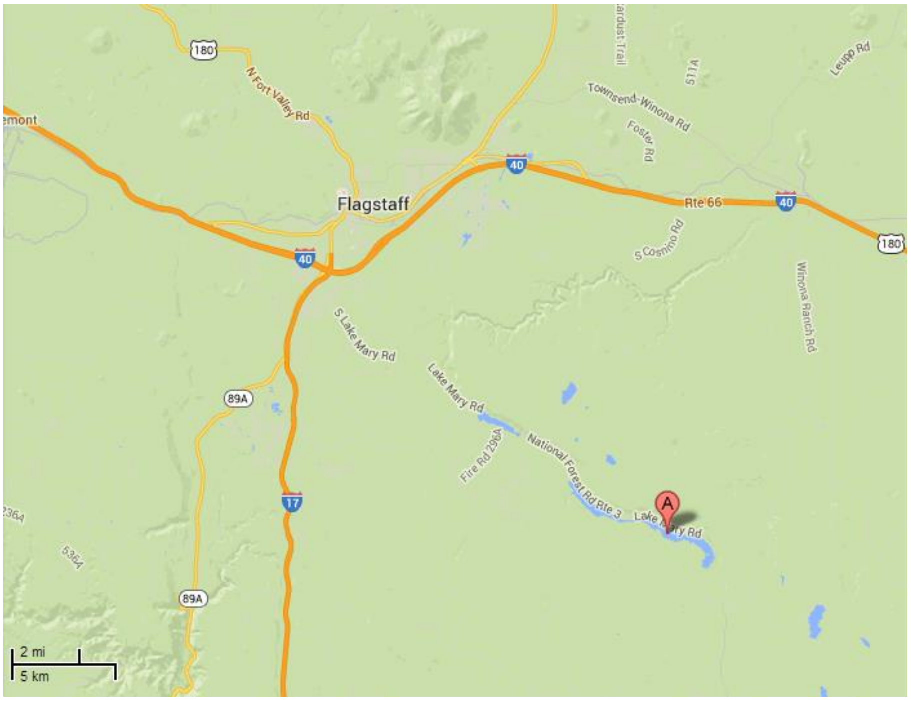


Figure 8: Upper Lake Mary in Flagstaff, AZ *(Upper Lake Mary, 2014)*

A water quality analysis was conducted for Upper Lake Mary in November 2013 in order to determine basic water quality parameters of this source. These tests were limited to those that could be conducted in laboratory facilities at NAU, and therefore excluded testing for background concentrations of U and As. The tests performed included pH, coliforms, turbidity, alkalinity, total hardness, and calcium hardness. A solids test was not conducted. The results of the initial water quality analysis for Upper Lake Mary from November 2013 can be seen in Table 2. The water used in this study was taken directly from surface water at Upper Lake Mary rather than the tap at the Treatment Plant. The full water quality report can be found in Appendix B: Water Quality Analysis for Upper Lake Mary.

Table 3: Water Quality Data for Upper Lake Mary

	pH	Coliforms (CFU/100 mL)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Total Hardness (mg/L as $CaCO_3$)	Calcium Hardness (mg/L as $CaCO_3$)
Average Values for Upper Lake Mary Water	6.25	TNTC	53.6	37.2	35	28

Through this water quality analysis, several issues with the Upper Lake Mary Water were identified. First, the average pH of 6.25 is not within the desired range of 7.8-8.4. The water is also contains a low level of hardness and alkalinity which is not characteristic of groundwater. Additionally, the turbidity is high, which could potential cause problems in any filtration unit. Most importantly the coliform count was too numerous to count (TNTC). Not only was this coliform count not representative of the bacterial contamination of the groundwater wells from the BFA, it was believed that the removal of such a high coliform level would not be possible through a low-cost, electricity-free water filter. Therefore, it was decided that the coliform-containing Upper Lake Mary water should be diluted with the water from the private groundwater well.

Dilution

In order to determine the correct ratio of groundwater to Upper Lake Mary water, a dilution test was performed in February 2014. The method and results of this test can be found in Appendix C: Water Dilution Report. The water used during this dilution test was taken from the tap at the Lake Mary Water Treatment Plant. In this case, the tests found that undiluted, 100% Lake Mary water had an average of 37 CFUs/100mL, which is different from the Lake Mary Water tested in November 2013 that had a coliform count of TNTC. The difference in CFUs may be due to various factors including seasonal changes, location of sampling, and the length of time between taking the water samples and conducting the analysis. Despite a countable amount of CFUs in 100% Lake Mary water, use of groundwater is still desirable in order to better model the groundwater from the BFA. Therefore a ratio of 10% Lake Mary water to 90% groundwater by volume was selected. The 10% Lake Mary water dilution test showed an average of 15 CFUs/100mL.

When creating the synthetic water, 60 gallons of water was produced in a clean, unused 90 gallon plastic trash receptacle secured from the City of Flagstaff Municipal Waste Department. Six gallons of Lake Mary water from the Lake Mary Water Treatment Plant was diluted with 54 gallons of residential groundwater. Due to the large volume of groundwater required, it was added to the container via an electric pump. The flow rate of the pump was established, and 60 gallons of water was transferred to the container based on time requirements and flow rate.

Uranium and Arsenic Spiking

In order to achieve the desired concentrations of 100 µg/L of U and 70 µg/L of As, the blended Lake Mary water and groundwater was spiked with U and As. Stock solutions of U and As were purchased. The chemical information for these U and As stock solutions can be found in Appendix D and Appendix E, respectively.

Due to the highly concentrated nature of the purchased stock solutions, 10,000,000 µg/L for both U and As, two standards were made, one for U and one for As. To create a standard, 100 mL of stock solution was added to a 1 L flask. The 100 mL of stock solution was then diluted to 1 L with deionized (DI) water. This resulted in two 1 L standards, one with a concentration of 1,000,000 µg/L of U and the other with a concentration of 1,000,000 µg/L of As. These standards are able to be stored in their 1 L containers and reduce the margin of error when spiking the synthetic water.

To spike the Lake Mary/Groundwater blend, 22.7 mL of 1,000,000 µg U/L standard and 15.9 mL of 1,000,000 µg As/L were added. Supporting calculations for the creation of the standards and the synthetic water spiking can be viewed in Appendix F.

Water Quality Analysis of Synthetic Water

A water quality analysis was conducted for the synthetic water in February 2014 in the NAU Water Quality Laboratory. The full water quality report can be viewed in Appendix G: Synthetic Water Quality Analysis. Note: Additional synthetic water analysis results for U and As concentrations will be obtained in mid-March. The results of the water quality analysis for synthetic water from February 2014 can be seen in Table 4.

Table 4: Water Quality Data for Synthetic Water

	pH	Coliforms (CFU/100 mL)	TDS (ppm)	Turbidity (NTU)	Alkalinity (mg/L as $CaCO_3$)	Total Hardness (mg/L as $CaCO_3$)	Calcium Hardness (mg/L as $CaCO_3$)
Average Values for Synthetic Water	7.72	2	139	7.85	101.97	102	97

The results in Table 4 show that the pH falls just short of the desired range of 7.8-8.4. As 7.72 is close to 7.8, with a percent difference of 1.03%, no chemical adjustments to alter the pH will be made. The turbidity, alkalinity, total hardness, and calcium hardness are more representative of groundwater sources than the 100% Lake Mary water that was tested in November 2013. The dilution tests showed that a blend of 10% Lake Mary water to 90% groundwater should yield, on average, 15 CFUs/100mL. However, the coliform count of the synthetic water is less than expected, at only 2 CFUs/100mL. This may be a result of changing water quality parameters due to the addition of U and As, or it may be a result of bacteria death as the water sits in the laboratory awaiting use in testing.

4.3 Materials

Ion Exchange for U

Although the Amberlite^{TM} PWA8 Ion exchange resin distributed by DOW Chemical would be an ideal ion exchange resin for U removal, due to cost and time constraints, it could not be acquired. The DOW Chemical Product Data Sheet for Amberlite^{TM} PWA8 can be seen in Appendix H: DOW Chemical Amberlite^{TM} PWA8 Resin Product Data Sheet. However, the Water Quality Laboratory at NAU already possesses Monoplus MP 500 Macroporous Strongly Basic Anion Resin, distributed by Sybron Chemicals, Inc. This resin, as seen in Figure 9, will be tested for the purposes of this project.

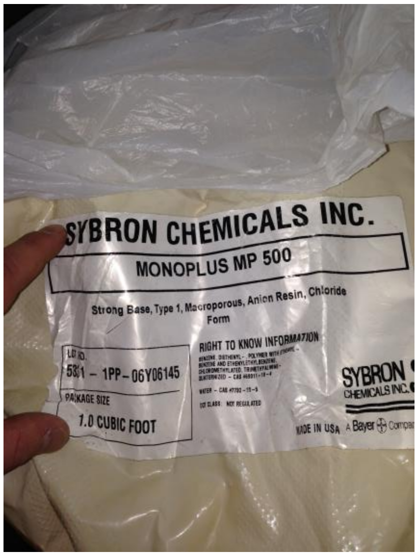


Figure 9: Ion Exchange Resin

To prepare this resin for use, it must be soaked for 24 hours in tap water. It should then be rinsed with up to 200 bed volumes of tap water.

Orange Peels for U

Oranges were purchased at a local grocery store in Flagstaff, AZ. They were then peeled, and the orange peels were dried in an over for a period of 24-36 hours. Initial drying occurred in a convection oven at 105°C for 12 hours. They were then dried overnight for 9-10 hours in open air. They were dried for an additional 3 hours in the water quality laboratory oven at 103°C in a crucible. The orange peels were prepared in a laboratory blender to achieve the diameter size seen in Figure 10. This process for the preparation of orange peels was recommended by the research conducted by M.A. Mahmoud (2013).


Figure 10: Dried and Finely Chopped Orange Peels

Zero Valent Iron for As

Two materials were selected for testing the ZVI alternative. First, steel turnings made from AISI 1020 Cold Rolled Steel, composed of 0.17-0.23% carbon, 99.08-99.53% iron, 0.30-0.60% manganese, less than 0.040% phosphorous, and less than 0.050% sulfur, were provided by the NAU Machine Shop (MatWeb, 2014), and can be seen in Figure 11. The ZVI was coated with APEX 9000 Water Soluble Cutting Oil. The MSDS for this oil can be found here: file:///C:/Users/cd393/AppData/Local/Downloads/A-411_%20APEX%209000%20SOL.pdf. The ZVI turnings were rinsed with tap water and cleaned with a soap solution to remove the cutting oil.

Figure 11: ZVI Turnings

As seen in Figure 11, the ZVI turnings appear to be rusted. This is due to soaking them in tap water. The formation of iron oxide will help facilitate the arsenic removal.

Iron filings were selected as the second ZVI material. Science magnets used for school magnetic experiments were selected for their low cost. They can be seen in Figure 12.

Figure 12: ZVI Filings

Rice Husk for As

Rice husks, distributed by the LD Carlson Company, were purchased from Amazon.com, and can be seen in Figure 13. According to the research of M.N. Amin, et al., to prepare the rice husks, the collected materials should be washed with DI water several times to remove dust and fines. The washing process should be repeated until the color of the wash water was transparent. The washed materials must be dried in an oven at 60 °C for 24 hours. Since the oven in the water quality lab cannot be set to 60 °C, the washed rice husks were kept for 72 hours. However, after 72 hours, the rice husks were still not completely dry. Additionally, during the process of washing the rice husks, no dust or fines were found. The team decided that washing the rice husks was not necessary since it is possible that the obtained rice husks may have been pretreated. Then, the rice husks needed to be sieved. According to Amin et al., 780 µm (0.031in)-sized rice husks are required. Thus, sieve No. 18 and No. 20 were needed to obtain the size between 0.0331 in and 0.0394 in. Using available sieves in the Soils Laboratory at NAU, the No. 10 size sieve was selected. Thus, the final sieved size of the rice husks is between 0.0787 in and 0.0331 in.

Figure 13: Rice Husks from LD Carlson Company

4.4 Experimental Matrix

Experimental matrices are necessary for the testing of the alternative materials and the modular configurations. Dr. Ketterer of Metropolitan State University of Denver is able to analyze up to 125 samples for this project. The experimental matrix for the alternative materials can be seen in Figure 14. It involves testing five DI water blanks, five synthetic water samples, and four effluent samples each from the five materials of interest. This results in a total of 30 samples for the testing of the alternative materials. Each of the materials will be tested with 5 gallons of synthetic water. The four effluent samples will be taken at volume intervals. Samples will be taken at one gallon, two gallons, three gallons, and four gallons. A sample will not be taken at five gallons because some of the water may be adsorbed by the material, so a total effluent of five gallons may not occur for each material. In addition to testing each of the 20 material water samples for U and As, they will be analyzed for pH, turbidity, TDS, and DO. The effluent from the two ZVI materials will also be tested for iron concentration. (Note: The iron concentration testing is pending agreement and price negotiation by Ben Moan at the Colorado Plateau Laboratory at NAU.)

Testing of Alternative Materials

Sample Identifier (Label)	Measured Concentraiton Uranium (ppb)	Measured Concentration Arsenic (ppb)	pH	Turbidity (NTU)	TDS (ppm)	DO (mg/L)	FE (mg/L)	Filtration Media	Notes
B1			N/A	N/A	N/A	N/A	N/A	N/A	DI Blank
B2			N/A	N/A	N/A	N/A	N/A	N/A	DI Blank
B3			N/A	N/A	N/A	N/A	N/A	N/A	DI Blank
B4			N/A	N/A	N/A	N/A	N/A	N/A	DI Blank
B5			N/A	N/A	N/A	N/A	N/A	N/A	DI Blank
B6			N/A	N/A	N/A	N/A	N/A	N/A	Synthetic Water
B7			N/A	N/A	N/A	N/A	N/A	N/A	Synthetic Water
B8			N/A	N/A	N/A	N/A	N/A	N/A	Synthetic Water
B9			N/A	N/A	N/A	N/A	N/A	N/A	Synthetic Water
B10			N/A	N/A	N/A	N/A	N/A	N/A	Synthetic Water
Dilks 1							N/A	IER	IER Gal 1
Dilks 2							N/A	IER	IER Gal 2
Dilks 3							N/A	IER	IER Gal 3
Dilks 4							N/A	IER	IER Gal 4
Dilks 5							N/A	OP	OP Gal 1
Dilks 6							N/A	OP	OP Gal 2
Dilks 7							N/A	OP	OP Gal 3
Dilks 8							N/A	OP	OP Gal 4
Dilks 9								ZVI 1	ZVI Turnings Gal 1
Dilks 10								ZVI 1	ZVI Turnings Gal 2
Dilks 11								ZVI 1	ZVI Turnings Gal 3
Dilks 12								ZVI 1	ZVI Turnings Gal 4
Dilks 13								ZVI 2	ZVI Filings Gal 1
Dilks 14								ZVI 2	ZVI Filings Gal 2
Dilks 15								ZVI 2	ZVI Filings Gal 3
Dilks 16								ZVI 2	ZVI Filings Gal 4
Dilks 17							N/A	RH	RH Gal 1
Dilks 18							N/A	RH	RH Gal 2
Dilks 19							N/A	RH	RH Gal 3
Dilks 20							N/A	RH	RH Gal 4

Figure 14: Experimental Matrix for Testing Alternative Methods

The experimental matrix for the modular configurations has not yet been developed because the testing of the modules will be based upon the results from the alternative materials testing. There will be 95 samples available for modular configuration testing. Of these 95 samples, five will be DI blanks and five will be synthetic water samples.

4.5 Testing of Alternative Materials

Explain experimental procedure. This will be completed after the 50% Report submission.

4.6 Results of Alternative Methods Testing

This section will be completed after the 50% Report submission.

4.7 Testing of Modular Configurations

This section will be completed after the 50% Report submission.

4.8 Results of Modular Configurations Testing

This section will be completed after the 50% Report submission.

5.0 Identification of Selected Design

Detail how the final design was selected. Beginning with the alternatives, show how decision matrices were used to choose the design. Completely explain and justify all weighting and ranking systems developed. Note: This section will be completed after the 50% Report submission.

5.1 Decision Matrices

The criteria used in the decision matrices are based upon the design requirements and constraints, as explained in section 1.4. To reiterate, for the design constraints, the device must:

- Function as a point-of-use device
- Operate without electricity
- Minimize cost of construction and maintenance
- Maximize ease of maintenance
- Maximize ease of disposal of used filter materials

For the design requirements, the device must:

- Be capable of reducing uranium and arsenic to concentrations below their MCLs
  - Less than 30 µg/L for uranium
  - Less than 10 µg/L for arsenic
- Be capable of producing coliform-free water
- Operate effectively in a pH range of 7.5-8.4
- Provide filtered water within a reasonable contact time of 0-4 hours

When devising the decision matrices, some of the constraints and requirements were not used as criteria. All of the materials were capable of the following, and were therefore not included: functioning as a point-of-use device, operating without electricity, and operating in a pH range of 7.5-8.4. Additionally, since the materials and final design were not laboratory tested for bacteria, this design requirement was not included in the decision matrices. Instead, calculations for chlorine disinfection are substituted for this design requirement.

All of the decision matrices utilize weighted criteria. The weights sum to 100. Each alternative is scored for the criteria on a scale of 0 to 2. A score of 0 indicates that the alternative did not meet the criteria or least meets the criteria in comparison to the other alternatives. A score of 1 indicates that the alternative meets the criteria. A score of 2 indicates that the alternative exceeds the criteria or best matches the criteria in comparison to the other alternatives. These raw scores are then multiplied by the criteria's associated weight to obtain the weighted scores. The weighted scores for each criteria are then summed to determine the alternative's total score. The alternative with the highest total score is the best choice.

Decision Matrix for Uranium Removal

The decision matrix for uranium removal is presented in Table 5. The decision matrix is utilized to determine which alternative material, ion exchange or orange peels, is best suited for the removal of uranium. There are four criteria. The most important criteria, which has been given a weight of 50%, is the ability of the alternative material to reduce U below the MCL of 30 µg/L. This is the main purpose of the alternative material, and thus it receives the highest weight. The second criteria is to minimize the cost, and this is given a weight of 30. It is important to the client that the final design is affordable, and thus this is the second most important criteria. A weight of 10 was given to minimizing filter disposal and maintenance and minimizing contact time. These two criteria are the least important for the final design.

Note: This decision matrix has not yet been completed. Results are needed from testing of alternative materials.

Table 5: Decision Matrix for Uranium Removal

Criteria	**Weight**	**Ion Exchange Raw Score**	**Ion Exchange Weighted Score**	**Orange Peels Raw Score**	**Orange Peels Weighted Score**
Able to reduce U below 30µg/L	50		0		0
Cost is minimized	30		0		0
Filter disposal and maintenance is minimized	10		0		0
Contact time is minimized	10		0		0
Total	100	0	0	0	0

Decision Matrix for Arsenic Removal

The decision matrix for arsenic removal is presented in Table 6. The decision matrix is utilized to determine which alternative material, ZVI turnings, ZVI filings, or rice husks, is best suited for the removal of arsenic. The criteria and weights are the same as those discussed for the uranium removal decision matrix with the exception of the first criteria. In this case, the alternative must be able to reduce the As concentration below the MCL of 10 µg/L.

Note: This decision matrix has not yet been completed. Results are needed from testing of alternative materials.

Table 6: Decision Matrix for Arsenic Removal

Criteria	**Weight**	**ZVI Turnings Raw Score**	**ZVI Turnings Weighted Score**	**ZVI Filings Raw Score**	**ZVI Filings Weighted Score**	**Rice Husks Raw Score**	**Rice Husks Weighted Score**
Able to reduce As below 10µg/L	50		0		0		0
Cost is minimized	30		0		0		0
Filter disposal and maintenance is minimized	10		0		0		0
Contact time is minimized	10		0		0		0
Total	100	0	0	0	0	0	0

Decision Matrix for Final Design

The decision matrix for the final design is presented in Table 7. Depending on the results of the testing of the alternative materials, the number of configurations will be determined. This will influence the number of devices listed as alternatives in the matrix. The most important criteria for the final design are the ability to reduce As below 10 µg/L and U below 30 µg/L. These are given equivalent weights of 30. Minimizing cost is the next most important criteria with a weight of 20. Again, minimizing filter disposal and maintenance and minimizing contact time are equivalently weighted at 10, following the same reasoning as that of the decision matrices for arsenic and uranium removal.

Note: This decision matrix has not yet been completed. Results are needed from testing of modular configurations.

Table 7: Decision Matrix for Final Design

Criteria	**Weight**	**Device 1 Raw Score**	**Device 1 Weighted Score**	**Device 2 Raw Score**	**Device 2 Weighted Score**
Able to reduce As below 10µg/L	30		0		0
Able to reduce U below 30µg/L	30		0		0
Cost is minimized	20		0		0
Filter disposal and maintenance is minimized	10		0		0
Contact time is minimized	10		0		0
Total	100	0	0	0	0

6.0 Final Design

Fully details all engineering aspects of the final design. Summary drawings should be included in this section, but detailed supporting engineering calculations should be placed in an Appendix. Note: This section will be completed after the 50% Report submission.

6.1 Modular System

Note: The design for this is not yet determined.

6.2 Uranium Removal

Note: This is unknown at this time.

6.3 Arsenic Removal

Note: This is unknown at this time.

6.4 Adsorptive Layer

Although not tested, a layer of adsorbing material should follow the arsenic and uranium removal layers. This adsorptive layer should consist of granular activated carbon, and would be utilized to trap any particulates or iron that’s possibly exchanged from the ZVI layer, thus improving quality and turbidity of the final effluent (Noubactep, Temgoua, & Rahman, 2012).

6.5 Disinfection

Note: For disinfection, calculations can be completed based on the WHO documents. This will be completed and added after the 50% Report submission.

WHO document, chlorination is on page 3.
http://www.who.int/household_water/resources/emergencies.pdf

Another WHO document.
http://dse.healthrepository.org/bitstream/123456789/88/6/How%20to%20prepare%20chlorine%20stock%20solutionv2.pdf

6.6 Impacts of Final Design

The impacts of this project are incredibly important. The design of a water filter capable of reducing U, As, and removing coliforms makes positive contributions to human health, the natural environment, political systems, economic systems, and culture.

Project Importance

In both the developing world and infrastructure-poor regions of developed countries, such as the Navajo Nation in the United States, the application of low-cost water treatment technology is imperative for the removal of contaminants that have various adverse health effects. In locales where community level water treatment facilities are not economically, politically, or logistically feasible, point-of-use water filtration units are the most practical alternative. Without access to potable water, human health is inevitably impacted, which has much further reaching consequences to be considered.

Conditions of poverty and poor infrastructure affect access to clean water and the prevention of water-borne diseases and illnesses resulting from long-term exposure to contaminated drinking water. More importantly, this situation is cyclical. Without access to clean water and the prevention of water-borne diseases, poverty is exacerbated and continued. The cyclical process makes it difficult for those born in economically depressed regions, especially in the least developed nations, to move out of a state of poverty. In areas of high poverty, especially those that are in developing countries or slums, there is limited economic capacity or might to put forth the financing and effort to prepare and design for access to clean water. Without the access to clean water, a population will inevitably suffer from what are considered to be preventable water-borne diseases or water-related illnesses in wealthy, industrialized countries.

According to the Director-General of WHO, most water-borne illnesses have been eradicated from wealthy countries as living standards improved. Yet, this is not the case for the developing world, which is plagued by water scarcity, poor water quality, and inadequate sanitation. This, in turn, affects food security, health, livelihoods, and education. In many locations where people must travel long distances to haul water back to their homes, time for other activities such as productive businesses, farming, or schooling becomes limited. Additionally, in some communities stricken by poverty where latrines are not common place or are not utilized, open defecation takes place. This adds to the burden of poor sanitation and can cause contamination of drinking water sources. Furthermore, when poor water quality causes human health effects, the full capacity of an individual cannot be used for such activities. In this sense, according to the

Director General of the WHO, the state of sanitation in the world should be regarded as one of the greatest crises facing socioeconomic development (Chan, 2013).

In response to this water and sanitation crisis, the United Nations established the Millennium Development Goals (MDGs), of which there are eight. These eight MDGs were agreed upon by all countries that take part in the United Nations and all of the leading development organizations in the world. The purpose of the eight goals is to meet the needs of the world's poorest citizens by the year 2015, with the overarching goal of eradicating poverty. MDG Seven, to Ensure Environmental Sustainability, has a sub-goal to halve, by 2015, the proportion of the global population without sustainable access to safe drinking water and basic sanitation. By setting a goal for sanitation, water supplies can be better protected. However, there is no specific goal that aims to protect fresh water or groundwater sources from contamination that could cause them to be non-potable and without possibility for remediation. Part of this sub-goal of MDG 7 was met by 2010 when the proportion of people without access to improved sources of water was halved. From the initiation of the MDGs in 1990 until 2010, over two billion people gained access to improved drinking water sources; those using an improved water sources increased from 76% to 89% over this ten year period. However, as of 2011, 768 million people were still without access to improved drinking water sources. In terms of sanitation, more than 240,000 people per day gained access to improved sanitation facilities from the inception of the MDGs until 2011. Unfortunately, there are still 2.5 billion people without access to improved sanitation facilities in developing countries (United Nations, 2014).

Although the written, established goal for water has technically been met, half of the world population has a piped water supply in their homes, and deaths from diarrheal diseases are falling, the target set for sanitation is the most off-track of all the MDGs. Unfortunately, sanitation and access to clean water are inextricably linked. Additionally, the MDGs aren't designed to track the equitable distribution of benefits, as the Director-General of the WHO explains. Rather, progress is based on population averages and not on whether the improvements reach those with the most need. So, while the world met the MDG target overall for access to water, only 61% of the population in sub-Saharan Africa has access. There are gaps in access to clean water in and between countries, and those who are most vulnerable may not actually be experiencing improvements. Of most concern is the fact that the MDGs are not concerned with water quality, which is the most important factor in reducing water-borne illnesses (Chan, 2013). Therefore, while the MDGs focus on access to water, there is no focus on the quality of such water. This should be of the utmost concern, and is the major focus and contribution of this project.

Contribution to Human Health

Note: Add photos. Use articles from CENE 599 on arsenic.

Arsenic

As of 2006, the Arsenic Contamination in the World Report determined that 105 countries in the world suffer from elevated levels of arsenic in their drinking water sources, where approximately 151 million people worldwide are exposed to arsenic contamination with 147 million of these people living in Asia. The countries of most concern are Bangladesh, India, Pakistan, Vietnam, China, Myanmar, Argentina, Cambodia, Chile, Hungary, Taiwan, Vietnam, Japan, New Zealand, Germany, the United States, and Mexico (Murcott, 2013), (Bang, Korfiatis, & Meng, 2005). Elevated levels of arsenic may be present in water as a natural occurrence or due to human influence. Examples of anthropogenic arsenic causing activities include mining, pesticide and herbicide use, industrial effluent, and chemical waste disposal (Bang, Korfiatis, & Meng, 2005). Groundwater is often favored over surface water as the main source of drinking water as it does not contain bacterial contamination in most cases. However, in many parts of the world, including Bangladesh, West Bengal, India, and the Navajo Reservation, arsenic naturally occurs in the water in concentrations several times the MCL, which is set at 50 µg/L in Bangladesh and 10 µg/L by the World Health Organization and the United States Environmental Protection Agency. In Bangladesh, for example, over 10 million tube wells have been installed since the 1970s, exponentially increasing the amount of groundwater consumed by the Bangladeshi population. A nationwide survey in Bangladesh found that one-third of the tubewells are contaminated with arsenic at concentrations about 50 µg/L, while two-thirds have concentrations above 10 µg/L. Avoiding the use of groundwater in arsenic contaminated areas is not feasible due to water scarcity, increasing pollution of surface water, and the inability to provide large-scale removal of microbial pathogens. Other options such as rain water catchment, storage, and use may be promising but inconclusively feasible in arid regions or during the dry season in countries that have wet and dry seasons. Therefore, there is an urgent need for the provision of water filtration units that are capable of removing arsenic to safe drinking levels in developing and rural areas such as Bangladesh and other South Asian countries (Cheng, et al., 2004).

Long-term exposure to arsenic through the ingestion of contaminated water may cause arsenic to become concentrated in liver, kidney, lung, and skin tissues (Bang, Korfiatis, & Meng, 2005). Effects to health include neurological, dermatological, gastrointestinal, and cardio renal diseases. Arsenic is also a suspected carcinogen. Recent research suggests that As may act as an endocrine disruptor even at extremely low concentrations (Amin, et al., 2006).

(Le, 2009)

Uranium

This section still needs to be completed.

Coliforms

This section still needs to be completed.

Contribution to the Natural Environment

All of the U and As removal methods produce some form of U and/or As-rich waste stream, which requires proper and safe disposal. This requires education and training for operators of any point-of-use filter in order to ensure their safety.

Discuss some of the potential negative impacts of this project, including concentrating uranium and arsenic in the filter, causing issues for disposal. Suggest that it may be better to seek other water sources that are not contaminated or are less contaminated so as not to concentrate the uranium and arsenic to severe levels.

Contribution to Political Systems, Economies and Society

This section needs to be completed.

Project Sustainability

Discuss the issues with maintenance, education of the use of the device, and sourcing the materials. Discuss that an alternative water source may be a more sustainable option and that PWS is desperately needed.

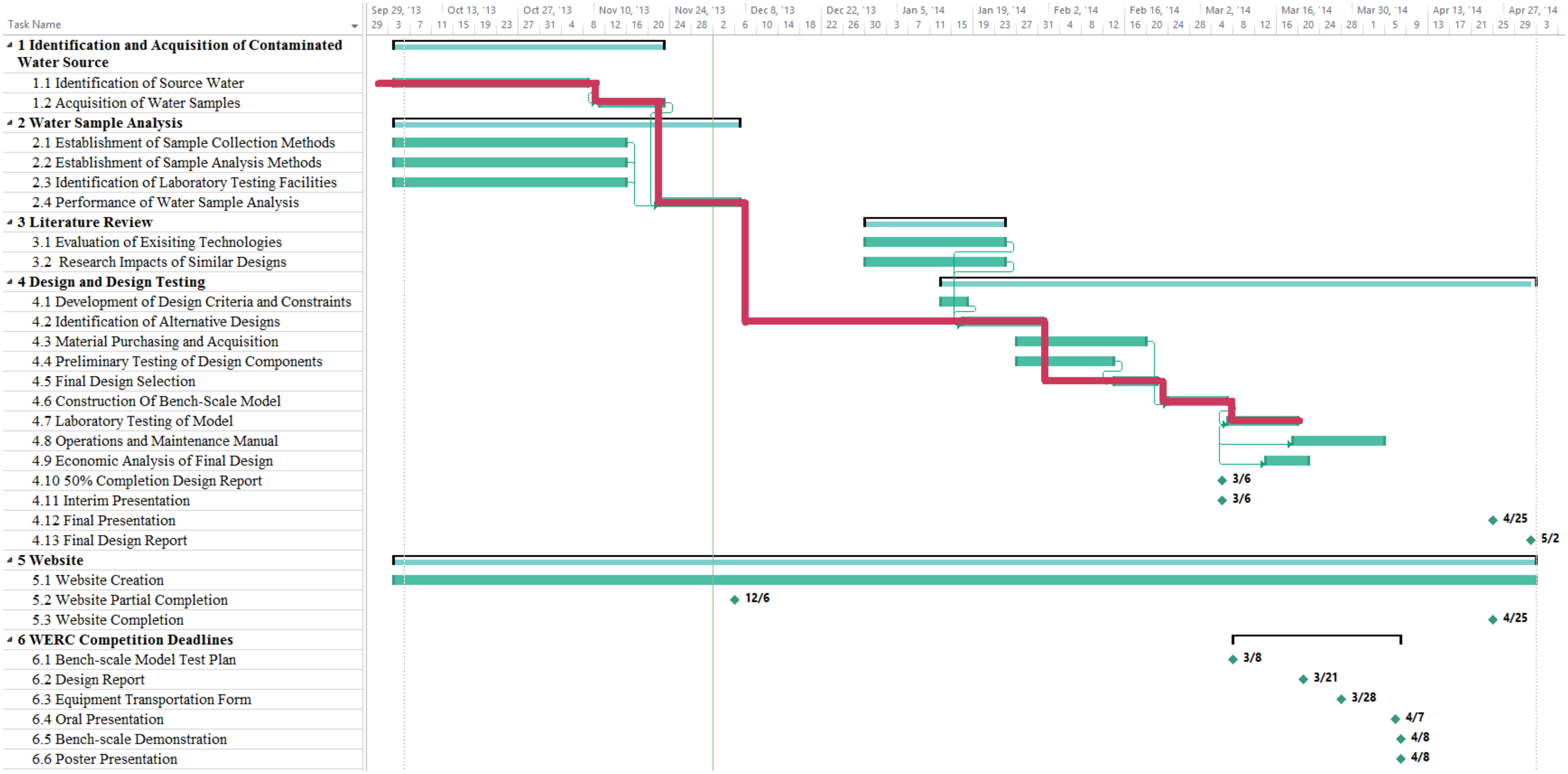
7.0 Cost of Implementing the Design

Provide a complete, detailed breakdown of costs that the client will incur in implementing the design. Note: This section will be completed after the 50% Report submission.

8.0 Summary of Project Costs

Returning to the proposal, summarize how the project was carried out. Show the original Gantt Chart and a Final Gantt Chart, compare the two, and comment on the changes between them. Also show the original cost proposal with time/effort for each employee, and compare to the actual, commenting on any differences. Note: This section will be completed after the 50% Report submission.

Original Gantt Chart



Task Name

1 Identification and Acquisition of Contaminated Water Source
- 1.1 Identification of Source Water
- 1.2 Acquisition of Water Samples

2 Water Sample Analysis
- 2.1 Establishment of Sample Collection Methods
- 2.2 Establishment of Sample Analysis Methods
- 2.3 Identification of Laboratory Testing Facilities
- 2.4 Performance of Water Sample Analysis

3 Literature Review
- 3.1 Evaluation of Exisiting Technologies
- 3.2 Research Impacts of Similar Designs

4 Design and Design Testing
- 4.1 Development of Design Criteria and Constraints
- 4.2 Identification of Alternative Designs
- 4.3 Material Purchasing and Acquisition
- 4.4 Preliminary Testing of Design Components
- 4.5 Final Design Selection
- 4.6 Construction Of Bench-Scale Model
- 4.7 Laboratory Testing of Model
- 4.8 Operations and Maintenance Manual
- 4.9 Economic Analysis of Final Design
- 4.10 50% Completion Design Report
- 4.11 Interim Presentation
- 4.12 Final Presentation
- 4.13 Final Design Report

5 Website
- 5.1 Website Creation
- 5.2 Website Partial Completion
- 5.3 Website Completion

6 WERC Competition Deadlines
- 6.1 Bench-scale Model Test Plan
- 6.2 Design Report
- 6.3 Equipment Transportation Form
- 6.4 Oral Presentation
- 6.5 Bench-scale Demonstration
- 6.6 Poster Presentation

(Cummings, Dilks, Sun, & Weir, 2013)

Original Cost Estimate for Engineering Services

Cost Estimate for Engineering Services

Personnel	Role	Hours	Rate ($/hr)	Cost ($)
	SENG	73	114	8,294
	ENG	223	58	12,952
	LAB	219	44	9,518
	INT	318	21	6,706
	AA	55	38	2,050
	Total Personnel	886		39,520
Travel				
	Local Meetings			
	4 mtgs x 120mi/mtg	$0.40/mi		192
	Water Hauling			
	10 times x 10mi/haul	$0.40/mi		40
Subcontractors				
	Analytical Laboratory Tests			9,800
	200 samples x $49/sample			
Overhead				
				14,673
Total Cost Estimate				
				64,225

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111+11+46.958&sspn=0.001416,0.002422&ie=UTF8&t=h&spn=0.01537,0.029354&z=16

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Appendices

Appendix A: Original Scope of Services

SCOPE OF SERVICES

The scope of services encompasses all tasks necessary to complete the project objective. The scope consists of five primary tasks. The tasks include: identification and acquisition of a contaminated water source, water sample analysis, a literature review, design and design testing, and the creation of a website. Primary tasks may be divided into several subtasks. Details describing each subtask are included.

TASK ONE: IDENTIFICATION AND ACQUISITION OF CONTAMINATED WATER SOURCE

The first task is to identify one or more contaminated water sources in the Bennett Freeze area. The selection of the water source is based on several pre-defined criteria. The criteria include: ease of access, confirmation of use as a drinking water source, and confirmation of contamination by contaminants of concern. The contaminants of concern include uranium, arsenic, and coliform bacteria at levels higher than the MCLs established by the U.S. EPA. The purpose of this task is to assure the water source contains the contaminants of concern as communicated by the client.

SUBTASK 1.1: IDENTIFICATION OF SOURCE WATER

This subtask addresses the establishment of a suitable water source for testing in the designed water treatment device. To complete this subtask, water quality data from research on the Navajo Nation conducted by Dr. Jani Ingram, Associate Professor of Chemistry at Northern Arizona University, may be used to identify a water source in the Bennett Freeze area which satisfies the aforementioned criteria. Due to political boundaries, the location of the source is very important. The location of the source is utilized in subtask 1.2, Acquisition of Water Samples. If water cannot be retrieved from the Navajo Nation, a suitable water source in northern Arizona that contains bacteria must be identified. This water can then be spiked with uranium and arsenic, as described in subtask 1.2.

SUBTASK 1.2: ACQUISITION OF WATER SAMPLES

Permission from political bodies of the Navajo Nation may be necessary to legally procure samples from the source identified in subtask 1.1, Identification of Source Water, for use in analysis, task one, Water Sample Analysis. Water samples may be acquired or created in a variety of ways:

Acquisition of Navajo Nation Water:

Samples are retrieved from the source water identified in subtask 1.1. Sample collection requires permission from one of the Navajo Nation's Chapter houses in the form of a Resolution. The particular Chapter House is dependent on the location of the selected water source. In order to acquire a Resolution to take water samples, the client must attend a Chapter House meeting to request the support of Sublime Engineering in sampling the water and transporting it off of the Navajo Nation.

Acquisition of Non-Navajo Nation Water and Synthetic Water Development:
If a resolution cannot be secured, then water from another source in northern Arizona, such as Upper Lake Mary, can be acquired to create synthetic water containing bacteria, uranium, and arsenic. The creation of synthetic water allows for various concentrations of uranium and arsenic to be tested by creating several different synthetic waters at various concentrations. The alkalinity, hardness, pH, turbidity, and solids of the synthetic water must be analyzed, as will be discussed in task two.

TASK TWO: WATER SAMPLE ANALYSIS

Task two involves a detailed analysis of the acquired water mentioned in subtask 1.2. Testing protocols established in the performance of this task are also necessary for the testing of the treated water from the bench-scale device. These protocols are also utilized in task four, Design and Design Testing. The following subsections detail the subtasks that must be addressed in order to complete the water analysis.

SUBTASK 2.1: ESTABLISHMENT OF SAMPLE COLLECTION METHODS

This task requires research to determine standard of practice sample collection methods. The methods should identify proper water sampling techniques and chain of custody standards for sample collection. The purpose of this task is to establish quality control and quality assurance of experimental results, as well as to ensure the safety of the samplers.

SUBTASK 2.2: ESTABLISHMENT OF SAMPLE ANALYSIS METHODS

This task requires research of procedures that can be utilized to establish the background characteristics of the acquired or synthetic water and background concentrations of the contaminants of concern. The contaminants of concern include uranium, arsenic, and bacteria. Analysis of common water characteristics is also necessary to assure that any physical or chemical processes utilized in the final design consider their effects on performance. The intent is to assure that the final design considers the effects of variations in characteristics of the acquired or synthetic water. Common water characteristics that may be considered include, but are not limited to, solids, turbidity, hardness, alkalinity, and pH. A list of equipment necessary to complete the water analysis is generated and utilized in subtask 2.3, Identification of Laboratory Testing Facilities.

SUBTASK 2.3: IDENTIFICATION OF LABORATORY TESTING FACILITIES

The identification of laboratory testing facilities is required to complete the analysis of water samples. Utilizing the information from subtask 2.2, the equipment required to complete the detailed water analysis should be compared with the capabilities of Northern Arizona University (NAU) facilities. The purpose of this comparison is to identify which NAU facilities are viable for the completion of the water analysis and to determine any necessary radioactive or hazardous waste disposal requirements. Requests for access to the facilities identified during this process are made. If it is determined that a necessary procedure cannot be completed at NAU, it will be outsourced to a capable facility at a minimal cost.

SUBTASK 2.4: PERFORMANCE OF WATER SAMPLE ANALYSIS

This task requires the analysis of acquired or synthetic water samples in accordance with testing methods and guidelines outlined in subtask 2.2. Test results shall be analyzed and interpreted. Water quality reports will be generated.

TASK THREE: LITERATURE REVIEW

Task three involves conducting a literature review to establish existing technologies capable of removing the contaminants of concern. The purpose of the literature review is to assist in the process of generating ideas for the design alternatives of subtask 4.2, Identification of Alternative Designs. Research into potential impacts is also a subtask of the literature review.

SUBTASK 3.1: EVALUATION OF EXISTING TECHNOLOGIES

An investigation of potential physical, biological, and chemical separation processes to remove the contaminants of concern from the untreated water is necessary. An extensive literature review should ensure that a thorough evaluation of technologies is completed. The literature review also includes an examination of the best available technologies (BATs) for each of the contaminants, as suggested by the U.S. EPA or Arizona Department of Environmental Quality (AZDEQ). Any potentially useful technologies from the literature review should be categorized by their level of technological complexity, from low-tech to high-tech. The literature review will help to determine which technologies can be excluded as potential design alternatives. Investigating water treatment technologies utilized by the mining industry may also prove useful.

SUBTASK 3.2: RESEARCH OF IMPACTS OF SIMILAR DESIGNS

Cultural, social, economic and public health implications of a low-cost device that is able to provide water free of uranium, arsenic, and bacteria is researched. These impacts shall be considered for both the Bennett Freeze area and other economically disadvantaged areas that may have similar water contamination.

TASK FOUR: DESIGN AND DESIGN TESTING

Design and testing of the treatment device are required. The following subsections detail the subtasks that must be addressed in order to complete the design and testing.

SUBTASK 4.1: DEVELOPMENT OF DESIGN CRITERIA AND CONSTRAINTS

In this subtask, the design criteria and constraints are fully developed. Adherence to the criteria and constraints must occur in subtasks 4.2, Identification of Alternative Designs, 4.5, Final Design Selection, 4.6, Construction of Bench-Scale Model, and 4.7, Laboratory Testing of Model.

SUBTASK 4.2: IDENTIFICATION OF ALTERNATIVE DESIGNS

This subtask involves the identification of multiple alternative designs to achieve the design objective. These alternatives are based upon task three, Literature Review. Any design ideas that would require special permitting from the Navajo Nation are excluded at the request of the client, including any designs that would be implemented at the water source.

SUBTASK 4.3: MATERIAL PURCHASING AND ACQUISITION

Any materials or equipment necessary for the preliminary testing or for the selected design of the bench-scale model must be purchased.

SUBTASK 4.4: PRELIMINARY TESTING OF DESIGN COMPONENTS

Before decisions are made for the final design, preliminary testing of various alternative designs or sub-components may be necessary. Design ideas are tested and analyzed for their efficacy using sample or synthetic water. Testing procedures follow those determined in task two, Water Sample Analysis.

SUBTASK 4.5: FINAL DESIGN SELECTION

Decision matrices are developed and utilized to determine which of the designs best meets the design criteria and constraints established in subtask 4.1. Analysis of the decision matrices leads to the selected final design.

SUBTASK 4.6: CONSTRUCTION OF BENCH-SCALE MODEL

A bench-scale model for the design selected in subtask 4.5, Final Design Selection, must be constructed. Materials purchased and acquired in subtask 4.3 are utilized. A full-scale model for implementation will not be built. Therefore, full-scale construction and implementation is excluded.

SUBTASK 4.7: LABORATORY TESTING OF MODEL

The bench-scale model constructed under subtask 4.6 must be tested for its efficacy in adherence with the design criteria and constraints developed in subtask 4.1. The testing follows the procedures for water analysis as described in task two, Water Sample Analysis. All testing of the bench-scale model will be completed in a laboratory setting. Field testing is excluded.

If testing shows design failure, adjustments will be made. An iterative design approach will be followed, and the Sublime Engineering team will repeat subtasks 4.4-4.7 if necessary.

SUBTASK 4.8: OPERATIONS AND MAINTENANCE MANUAL

This subtask includes the formulation of an operations and maintenance manual for any potential users of the final device as designed. The operations and maintenance manual shall include:

- Descriptions on how the device should be operated, stored, and cleaned
- Details on the frequency of maintenance required for the device and any removable components such as filters.
- A disposal plan for any radioactive or hazardous waste

SUBTASK 4.9: ECONOMIC ANALYSIS OF FINAL DESIGN

An economic analysis of the final design is performed using engineering economic principles. The economic analysis shall provide a cost estimate to build, operate, and maintain a full-scale device. The potential for mass production may also be considered.

SUBTASK 4.10: 50% COMPLETION DESIGN REPORT

This subtask includes the formulation of the 50% Completion Design Report to be delivered to the client, technical advisor, and Capstone course instructors.

SUBTASK 4.11: INTERIM PRESENTATION

An interim presentation is given, summarizing the 50% Completion Design Report.

SUBTASK 4.12: FINAL PRESENTATION

A final presentation is given summarizing the Final Design Report.

SUBTASK 4.13: FINAL DESIGN REPORT

This subtask includes the formulation of the Final Design Report to be delivered to the client, technical advisor, and Capstone course instructors. This design report is to include an analysis of the potential impacts of the final design. These impacts may concern improvement to public health or may address cultural, social, or economic impacts.

TASK FIVE: WEBSITE

This task involves the creation of a website via the use of Dreamweaver software to present information about the project to the interested observer. The website must include, at a minimum, the following webpages:

- Home Page
- Project Information Page
- Documents Page

Appendix B: Water Quality Analysis for Upper Lake Mary

Introduction

The purpose of the water quality testing is to establish the background characteristics of the water obtained from Upper Lake Mary in Flagstaff, AZ. The intent is to assure that the final design considers the effects of variations in characteristics of the acquired water. Common water characteristics that are considered include turbidity, hardness, bacteria count and alkalinity. In this report, water quality results and data analysis will be presented.

High concentration of suspended solids are associated with warmer water, less light, and less oxygen which makes it harder for some forms of life to survive. Turbidity is associated with the colloidal levels of binding areas for contaminants that may be associated with disease carrying capacity.

Materials

- Graduated cylinder
- Deionized water
- Buret
- Pipette bulb
- Pipette(s)
- Upper Lake Mary water samples
- Turbidimeter (aka Nephelometer)
- Two burette clamps
- 50mL graduated cylinder
- Beaker
- Ring stand
- Stir bar
- Stir plate
- 0.02N EDTA
- Sodium hydroxide
- Ring Stand
- Indicators: BCG-MR, Calcium IND HNB, hardness IND calmagite

- PH meter
- 0.623N H2SO4
- Agar plate
- Flask
- Filters
- M-endo broth
- Filtration units
- Beaker(s)

Methods

Turbidity: The Standard Method 2130 2130 (Standard Method, 2014) will be used for testing turbidity of the samples. The Nephelometer model type used must be documented and calibrated properly according to manufacturer-specific instructions. Since samples can be run very quickly, 5 samples were used.

Hardness: The Standard Method 2340 C. Titration Method 2130 (Standard Method, 2014) will be used for testing hardness of the samples. Only total hardness and calcium hardness will be measured. The end point of titration is the color of the sample water changing from purple to blue. Three trials will be conducted.

Alkalinity: The Standard Method 2320 B. EDTA Titration Method 2130 (Standard Method, 2014) will be used for testing alkalinity of the samples. Three tests will be conducted in order to obtain accurate results. The sample was titrated until reaching a pH of 4.5.

Coliforms: The Standard Method 9222 B. Standard Total Coliform Membrane Filter Procedure 2130 (Standard Method, 2014) will be used for preparing and counting colony form units (CFUs).

Results

Turbidity:

Table 1 outlines the resulting turbidity data for water from Lake Mary Treatment Plant.

Table 1: Turbidity Data

Sample	Turbidity (NTU)
DI	0.12
1	53.4
2	54.4
3	54.1
4	53.2
5	52.7
Average	53.6

Alkalinity:

Table 2 presents the resulting alkalinity data for water from Upper Lake Mary. Lab data used to determine the alkalinity can be found in the Appendix.

Table 2: Alkalinity Data

Titration	Alkalinity (mg $CaCO_3$ /L)
1	36.8
2	44.9
3	29.9
Average	37.2

Hardness:

Table 3 shows the resulting hardness data for water from Upper Lake Mary. Lab data used to determine the hardness can be found in the Appendix.

Table 3: Total Hardness and Calcium Hardness

Trial	Calcium hardness (mg $CaCO_3$ /L)	Total hardness (mg $CaCO_3$ /L)
1	30	44
2	24	30
3	30	30
Average	28	35

CFUs:

Table 4 shows the resulting CFUs for water from Upper Lake Mary.

Table 4: CFUs for Upper Lake Mary

Sample 1	Too numerous to count
Sample 2	Too numerous to count
Sample 3	Too numerous to count
Sample 4	Too numerous to count
Sample 5	Too numerous to count
Sample 6	Too numerous to count
DI	Negative

Conclusion

The coliform tests showed that the total coliforms in the Upper Lake Mary were all too numerous to count. The average calcium hardness was 28 mg/L as $CaCO_3$, and the average total hardness was 35 mg/L as $CaCO_3$, indicating that the calcium hardness contributed to almost all of the total hardness. The alkalinity was determined to be 37.2 mg $CaCO_3$ /L, and the average turbidity was 53.6 NTU.

References

Standard Methods. (2014, February). *Standard Methods Online*. Retrieved from Standard Methods for the Examination of Water and Wastewater: http://www.standardmethods.org/Store/index.cfm

Appendix

Total Hardness Raw Data

Reading (mL)	Added(mL)	Color
1.5	1.5	Pink
2.6	1.1	Pink
3.6	2.1	Purple
3.7	2.2	Blue

Reading (mL)	Added(mL)	Color

6.1	0	Pink
6.5	0.4	Pink
7.0	0.9	Pink
7.4	1.3	Purple
7.6	1.5	Blue

Reading (mL)	Added(mL)	Color
7.6	0	Pink
8.0	0.4	Pink
8.5	0.9	Pink
9.0	1.4	Purple
9.1	1.5	Blue

Calcium Hardness Raw Data

Reading (mL)	Added(mL)	Color
9.1	0	Purple
10.6	1.5	Blue

Reading (mL)	Added(mL)	Color
10.6	0	Purple
11.8	1.2	Blue

Reading (mL)	Added(mL)	Color
11.8	0	Purple
13.3	1.5	Blue

Alkalinity Raw Data

pH	Reading Start(mL)	Added(mL)
6.27	1.20	0
5.55	1.70	0.90
3.54	2.80	1.60

pH	Reading Start(mL)	Added(mL)
6.37	2.80	0
4.50	3.80	1.00
3.00	4.75	1.95

pH	Reading Start(mL)	Added(mL)
6.11	4.75	0
5.70	5.00	0.25

3.78	6.05	1.30

Appendix C: Water Dilution Report

Introduction

The purpose of the water dilution test is to determine the necessary ratio of groundwater to Upper Lake Mary water from Flagstaff, AZ to correctly model the amount of colony forming units per 100 mL (CFU/100mL) in the groundwater wells in the Bennett Freeze Area of the Navajo Nation. In the dilution test, water from Lake Mary Treatment Plant and a private residential groundwater well will be mixed. The methods of the test and the results of the colony forming units (CFUs) will be presented and discussed.

Materials

- 100 mL graduated cylinder
- Deionized water
- Pipette(s)
- Lake Mary Treatment Plant water samples
- Beakers
- M-endo broth
- Sterile absorbent pads
- Filtration units
- Filter
- Agar plates

Methods

In order to determine the proper ratio of groundwater to Upper Lake Mary water, the serial dilution method was utilized. The basic steps of the serial dilution are as follows:

1. Label the 2 sterile test graduated cylinders.
2. The blanks containing deionized water (DI) and the well water will also be tested.
3. Add 10 mL of Lake Mary water to each graduated cylinder.
4. Add 90 mL of the well water into the first graduated cylinder.
5. Mix thoroughly before proceeding to the next step.
6. Use another clean pipette. Withdraw 1 mL of the diluted bacterial suspension from the first graduated cylinder and pipette that into the second graduated cylinder.
7. Add 99 mL of the well water into the second graduated cylinder.
8. The standard method 9222.B (Standard Method Committee, 2014) will be used for putting the samples onto agar plates and counting CFUs.
9. Put the agar plates in a 35 degree incubator for 24 hours.
10. After 24 hours, count CFUs and calculate the amount of bacteria in each plate.

Results

CFUs:

Table 1 outlines the CFUs results. "100%", "10%", and "1%" mean that the water has a dilution factor of 0, 10, and 100, respectively.

Table 1: CFUs Results

Samples	CFUs/100mL
Groundwater #1	Negative
Groundwater #2	Negative
DI #1	Negative
DI #2	Negative
Lake Mary 1%	3
Lake Mary 1%	4
Lake Mary 10% A	20
Lake Mary 10% B	10
Lake Mary 100% A	35
Lake Mary 100% B	39
Average Lake Mary 1%	4
Average Lake Mary 10%	15
Average Lake Mary 100%	37

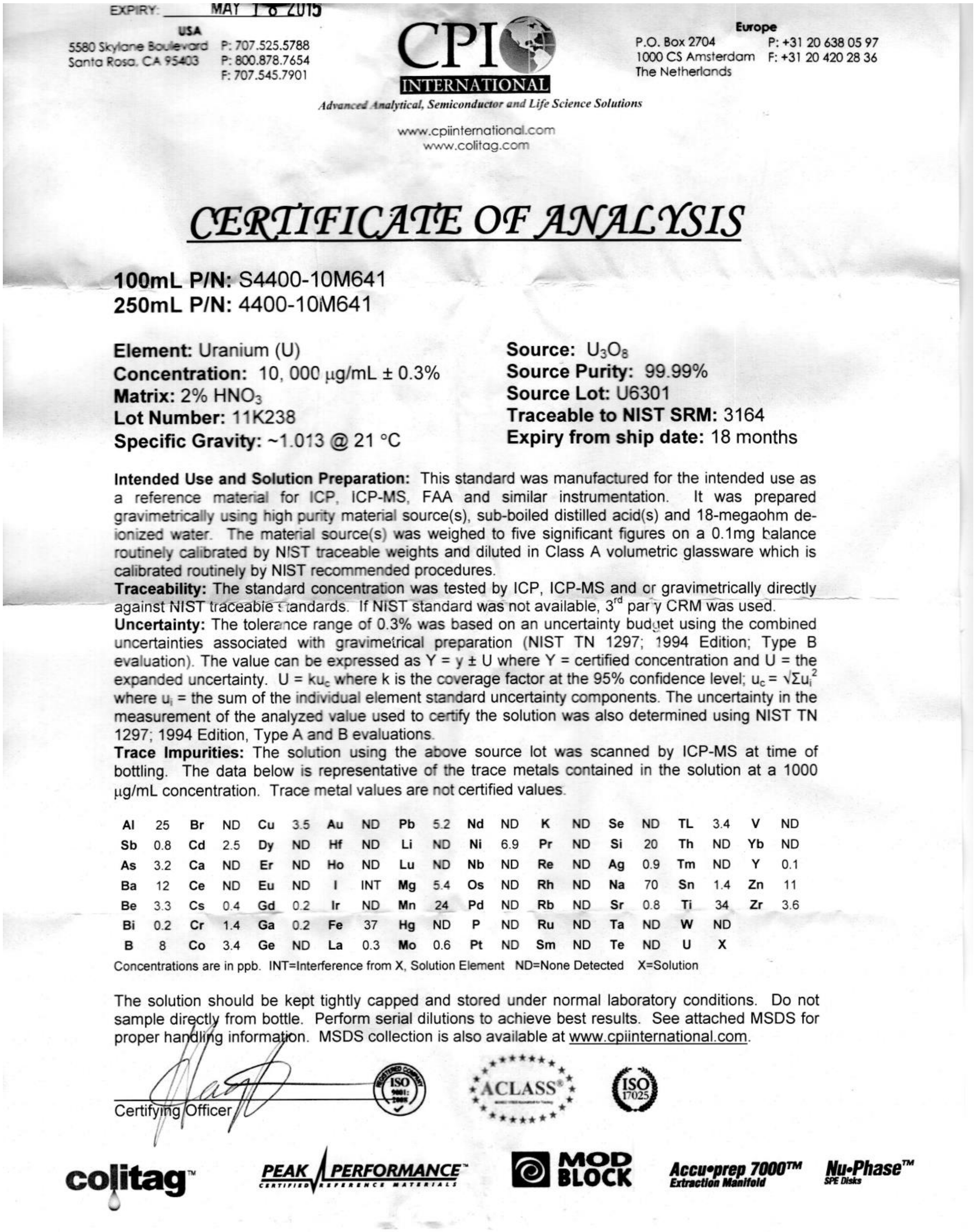
Conclusion

From the dilution test results, Lake Mary 10% was finally determined to be the best option since it contains a level of CFUs/100mL more representative of the Bennett Freeze Area (BFA). Additionally, it contains 90% groundwater, which better models the groundwater wells in the BFA. Lake Mary 1% is an inappropriate choice because the CFUs/100mL is too low for the purposes of this project.

References

Standard Methods. (2014, February). *Standard Methods Online*. Retrieved from Standard Methods for the Examination of Water and Wastewater: http://www.standardmethods.org/Store/index.cfm

Appendix D: Uranium Stock Solution Chemical Information



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CERTIFICATE OF ANALYSIS

100mL P/N: S4400-10M641
250mL P/N: 4400-10M641

Element: Uranium (U)
Concentration: 10, 000 µg/mL ± 0.3%
Matrix: 2% HNO_3
Lot Number: 11K238
Specific Gravity: ~1.013 @ 21 °C

Source: U_3O_8
Source Purity: 99.99%
Source Lot: U6301
Traceable to NIST SRM: 3164
Expiry from ship date: 18 months

Intended Use and Solution Preparation: This standard was manufactured for the intended use as a reference material for ICP, ICP-MS, FAA and similar instrumentation. It was prepared gravimetrically using high purity material source(s), sub-boiled distilled acid(s) and 18-megaohm de-ionized water. The material source(s) was weighed to five significant figures on a 0.1mg balance routinely calibrated by NIST traceable weights and diluted in Class A volumetric glassware which is calibrated routinely by NIST recommended procedures.
Traceability: The standard concentration was tested by ICP, ICP-MS and or gravimetrically directly against NIST traceable standards. If NIST standard was not available, 3rd party CRM was used.
Uncertainty: The tolerance range of 0.3% was based on an uncertainty budget using the combined uncertainties associated with gravimetrical preparation (NIST TN 1297; 1994 Edition; Type B evaluation). The value can be expressed as Y = y ± U where Y = certified concentration and U = the expanded uncertainty. $U = ku_c$ where k is the coverage factor at the 95% confidence level; $u_c = \sqrt{\Sigma u_i^2}$ where u_i = the sum of the individual element standard uncertainty components. The uncertainty in the measurement of the analyzed value used to certify the solution was also determined using NIST TN 1297; 1994 Edition, Type A and B evaluations.
Trace Impurities: The solution using the above source lot was scanned by ICP-MS at time of bottling. The data below is representative of the trace metals contained in the solution at a 1000 µg/mL concentration. Trace metal values are not certified values.

Al	25	**Br**	ND	**Cu**	3.5	**Au**	ND	**Pb**	5.2	**Nd**	ND	**K**	ND	**Se**	ND	**TL**	3.4	**V**	ND
Sb	0.8	**Cd**	2.5	**Dy**	ND	**Hf**	ND	**Li**	ND	**Ni**	6.9	**Pr**	ND	**Si**	20	**Th**	ND	**Yb**	ND
As	3.2	**Ca**	ND	**Er**	ND	**Ho**	ND	**Lu**	ND	**Nb**	ND	**Re**	ND	**Ag**	0.9	**Tm**	ND	**Y**	0.1
Ba	12	**Ce**	ND	**Eu**	ND	**I**	INT	**Mg**	5.4	**Os**	ND	**Rh**	ND	**Na**	70	**Sn**	1.4	**Zn**	11
Be	3.3	**Cs**	0.4	**Gd**	0.2	**Ir**	ND	**Mn**	24	**Pd**	ND	**Rb**	ND	**Sr**	0.8	**Ti**	34	**Zr**	3.6
Bi	0.2	**Cr**	1.4	**Ga**	0.2	**Fe**	37	**Hg**	ND	**P**	ND	**Ru**	ND	**Ta**	ND	**W**	ND		
B	8	**Co**	3.4	**Ge**	ND	**La**	0.3	**Mo**	0.6	**Pt**	ND	**Sm**	ND	**Te**	ND	**U**	X		

Concentrations are in ppb. INT=Interference from X, Solution Element ND=None Detected X=Solution

The solution should be kept tightly capped and stored under normal laboratory conditions. Do not sample directly from bottle. Perform serial dilutions to achieve best results. See attached MSDS for proper handling information. MSDS collection is also available at www.cpiinternational.com.

Certifying Officer

ISO 9001:2008 ACLASS ISO 17025

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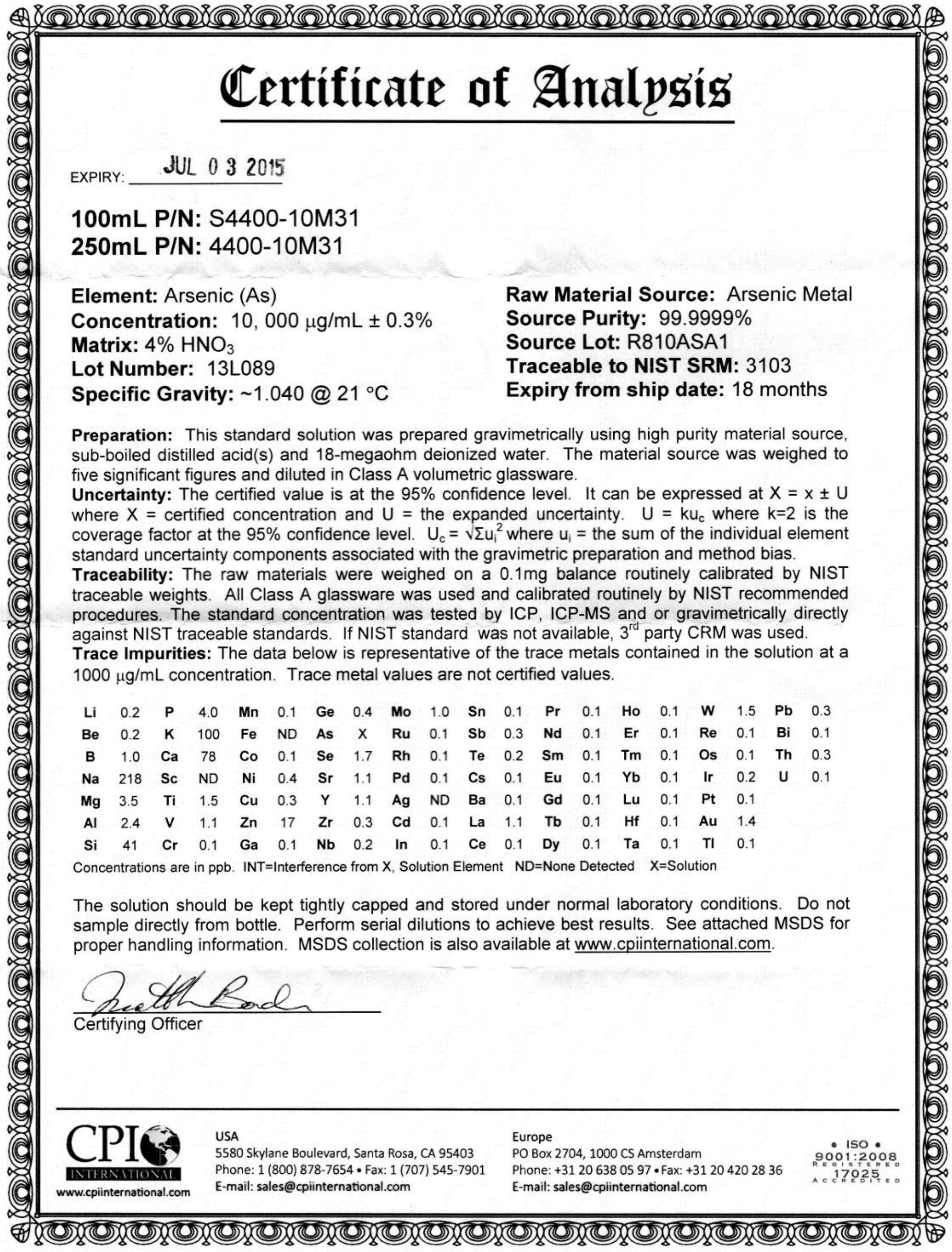
Appendix E: Arsenic Stock Solution Chemical Information



Certificate of Analysis

EXPIRY: JUL 0 3 2015

100mL P/N: S4400-10M31
250mL P/N: 4400-10M31

Element: Arsenic (As)
Concentration: 10, 000 μg/mL ± 0.3%
Matrix: 4% HNO_3
Lot Number: 13L089
Specific Gravity: ~1.040 @ 21 °C

Raw Material Source: Arsenic Metal
Source Purity: 99.9999%
Source Lot: R810ASA1
Traceable to NIST SRM: 3103
Expiry from ship date: 18 months

Preparation: This standard solution was prepared gravimetrically using high purity material source, sub-boiled distilled acid(s) and 18-megaohm deionized water. The material source was weighed to five significant figures and diluted in Class A volumetric glassware.
Uncertainty: The certified value is at the 95% confidence level. It can be expressed at X = x ± U where X = certified concentration and U = the expanded uncertainty. $U = ku_c$ where k=2 is the coverage factor at the 95% confidence level. $U_c = \sqrt{\Sigma u_i^2}$ where u_i = the sum of the individual element standard uncertainty components associated with the gravimetric preparation and method bias.
Traceability: The raw materials were weighed on a 0.1mg balance routinely calibrated by NIST traceable weights. All Class A glassware was used and calibrated routinely by NIST recommended procedures. The standard concentration was tested by ICP, ICP-MS and or gravimetrically directly against NIST traceable standards. If NIST standard was not available, 3rd party CRM was used.
Trace Impurities: The data below is representative of the trace metals contained in the solution at a 1000 μg/mL concentration. Trace metal values are not certified values.

Li	0.2	**P**	4.0	**Mn**	0.1	**Ge**	0.4	**Mo**	1.0	**Sn**	0.1	**Pr**	0.1	**Ho**	0.1	**W**	1.5	**Pb**	0.3
Be	0.2	**K**	100	**Fe**	ND	**As**	X	**Ru**	0.1	**Sb**	0.3	**Nd**	0.1	**Er**	0.1	**Re**	0.1	**Bi**	0.1
B	1.0	**Ca**	78	**Co**	0.1	**Se**	1.7	**Rh**	0.1	**Te**	0.2	**Sm**	0.1	**Tm**	0.1	**Os**	0.1	**Th**	0.3
Na	218	**Sc**	ND	**Ni**	0.4	**Sr**	1.1	**Pd**	0.1	**Cs**	0.1	**Eu**	0.1	**Yb**	0.1	**Ir**	0.2	**U**	0.1
Mg	3.5	**Ti**	1.5	**Cu**	0.3	**Y**	1.1	**Ag**	ND	**Ba**	0.1	**Gd**	0.1	**Lu**	0.1	**Pt**	0.1		
Al	2.4	**V**	1.1	**Zn**	17	**Zr**	0.3	**Cd**	0.1	**La**	1.1	**Tb**	0.1	**Hf**	0.1	**Au**	1.4		
Si	41	**Cr**	0.1	**Ga**	0.1	**Nb**	0.2	**In**	0.1	**Ce**	0.1	**Dy**	0.1	**Ta**	0.1	**Tl**	0.1		

Concentrations are in ppb. INT=Interference from X, Solution Element ND=None Detected X=Solution

The solution should be kept tightly capped and stored under normal laboratory conditions. Do not sample directly from bottle. Perform serial dilutions to achieve best results. See attached MSDS for proper handling information. MSDS collection is also available at www.cpiinternational.com.

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Appendix F: Synthetic Water Standards and Spiking Calculations

Synthetic Water Development - Standard and Synthetic Water Calculations

Definition of Terms

C1	Concentration of stock solution (10,000,000µg/L)
V1	Volume of stock solution needed
C2	Desired concentration for standard (1,000,000µg/L)
V2	Total volume of standard (1L)
C3	Concentration of standard (Equivalent to C2)
V3	Total volume of standard needed to make synthetic water
C4	Desired concentration in synthetic water
V4	Total volume of synthethetic water (60 gallons=227.1L)

Uranium		
C1	10000000	µg/L
V1	0.1	L
C2	1000000	µg/L
V2	1	L
C3	1000000	µg/L
V3	0.02271	L
C4	100	µg/L
V4	227.1	L

Arsenic		
C1	10000000	µg/L
V1	0.1	L
C2	1000000	µg/L
V2	1	L
C3	1000000	µg/L
V3	0.015897	L
C4	70	µg/L
V4	227.1	L

Calculations:

C1V1=C2V2			C1V1=C2V2		
V1=	0.1	L	V1=	0.1	L
	100	mL		100	mL
C3V3=C4V4			C3V3=C4V4		
V3=	0.02271	L	V3=	0.015897	L
	22.71	mL		15.897	mL
Lake Mary/GW Blend =	227.1	L	Lake Mary/GW Blend =	227.1	L
	60.0	gallons		60.0	gallons

URANIUM

Step One: We need ____ of the stock solution. DI water is added up to 1000mL to make the 1L standard

100 mL

Step Two: We need ___ of the standard.

22.7 mL

ARSENIC

Step One: We need ____ of the stock solution. DI water is added up to 1000mL to make the 1L standard

100 mL

Step Two: We need ___ of the standard.

15.9 mL

Appendix G: Synthetic Water Quality Analysis

Introduction

The purpose of the water quality testing is to establish the background characteristics of the synthetic water. The intent is to assure that the final design considers the effects of variations in characteristics of the acquired water. Common water characteristics that are considered include hardness, alkalinity, solids and colony forming units (CFUs). In this report, data analysis, water quality results and discussion will be presented.

Materials

- Graduated cylinder
- Deionized water
- Buret
- Pipette bulb
- Pipettes
- Turbidimeter (aka Nephelometer)
- Two burette clamps
- 50mL graduated cylinder
- Beaker
- Ring stand
- Stir bar
- Stir plate
- 0.02N EDTA
- Sodium hydroxide
- Indicators: BCG-MR, Calcium IND HNB, hardness IND calmagite
- PH meter

Methods

Turbidity: The Standard Method 2130 (Standard Method, 2014) will be used for testing turbidity of the samples. The Nephelometer model type used must be documented and calibrated properly according to manufacturer-specific instructions. Since samples can be run very quickly, 5 samples were used.

Hardness: The Standard Method 2340 C. Titration Method 2130 (Standard Method, 2014) will be used for testing hardness of the samples. Only total hardness and calcium hardness will be measured. The end point of titration is the color of the sample water changing from purple to blue. Three trials will be conducted.

Alkalinity: The Standard Method 2320 B. EDTA Titration Method 2130 (Standard Method, 2014) will be used for testing alkalinity of the samples. Three tests will be conducted in order to obtain accurate results. The sample was titrated until reaching a pH of 4.5.

Coliforms: The Standard Method 9222 B. Standard Total Coliform Membrane Filter Procedure 2130 (Standard Method, 2014) will be used for preparing and counting colony form units (CFUs).

Solids: The amount of Total Dissolved Solids (TDS) in the synthetic water can be determined with a HANNA Instruments HI9828 that has a meter for TDS, measured in parts per million (ppm).

Results

Alkalinity:

Table 1 presents the resulting alkalinity data for the synthetic water. Lab data used to determine the alkalinity can be found in the Appendix.

Table 1: Alkalinity Data

Titration	Alkalinity (mg $CaCO_3$ /L)
1	98.90
2	104.65
3	102.35
Average	101.97

Hardness:

Table 2 shows the hardness data for the synthetic water. Lab data used to determine the hardness can be found in the Appendix.

Table 2: Total Hardness and Calcium Hardness

Trial	Calcium hardness (mg $CaCO_3$ /L)	Total hardness (mg $CaCO_3$ /L)
1	99	106
2	97	101
3	96	99
Average	97	102

Solids:

The solids result is determined using a mode HI 9828 conductivity meter. The TDS is 139 ppm with the conductivity of 265 µs/cm.

CFUs:

The average CFUs of the synthetic water is determined to be 2 CFUs/100mL. Lab data used to determine the CFUs can be found in the Appendix.

Turbidity:

Table 3 outlines the resulting turbidity data for synthetic water.

Table 3: Turbidity Data

Sample	Turbidity (NTU)
DI #1	0.1
DI #2	0.1
Source #1	8
Source #2	7.8
Source #3	7.8
Source #4	7.8
Average	7.85

References

Standard Methods. (2014, February). *Standard Methods Online*. Retrieved from Standard Methods for the Examination of Water and Wastewater: http://www.standardmethods.org/Store/index.cfm\

Appendix

Total Hardness Raw Data

Reading (mL)	Added(mL)	Color
6.35	0	Pink
7.40	1.05	Pink
7.90	1.55	Pink

8.50	2.15	Pink
9.15	2.80	Pink
9.80	3.45	Pink
10.50	4.15	Magenta
11.60	5.25	Blue
11.65	5.30	Blue

Reading (mL)	Added(mL)	Color
11.65	0	Pink
13.90	2.25	Pink
16.50	4.85	Purple
16.60	4.95	Light Blue
16.70	5.05	Blue

Reading (mL)	Added(mL)	Color
17.15	0	Pink
19.98	2.83	Pink
20.95	3.80	Pink
22.00	4.85	Purple
22.10	4.95	Blue

Calcium Hardness Raw Data

Reading (mL)	Added(mL)	Color
22.20	0	Purple
23.15	0.95	Purple
25.90	3.70	Purple
26.85	4.65	Purplish Blue
27.10	4.90	Blue
27.15	4.95	True Blue

Reading (mL)	Added(mL)	Color
27.55	0	Purple
32.40	4.85	True Blue

Reading (mL)	Added(mL)	Color
32.50	0	Purple
37.30	4.80	True Blue

Alkalinity Raw Data

pH	Reading Start(mL)	Added(mL)

7.79	0.95	0
6.79	1.35	0.40
6.52	1.80	0.85
6.25	2.20	1.25
6.05	2.60	1.65
5.78	2.90	1.95
5.61	3.40	2.45
5.38	3.90	2.95
5.18	4.40	3.45
5.12	4.70	3.75
4.85	5.05	4.05
4.46	5.30	4.30

pH	Reading Start(mL)	Added(mL)
7.59	5.30	0
5.65	8.25	2.95
5.44	8.80	3.50
5.33	9.05	3.75
5.18	9.30	4.00
5.14	9.40	4.10
4.99	9.50	4.20

4.81	9.70	4.40
4.27	9.85	4.55

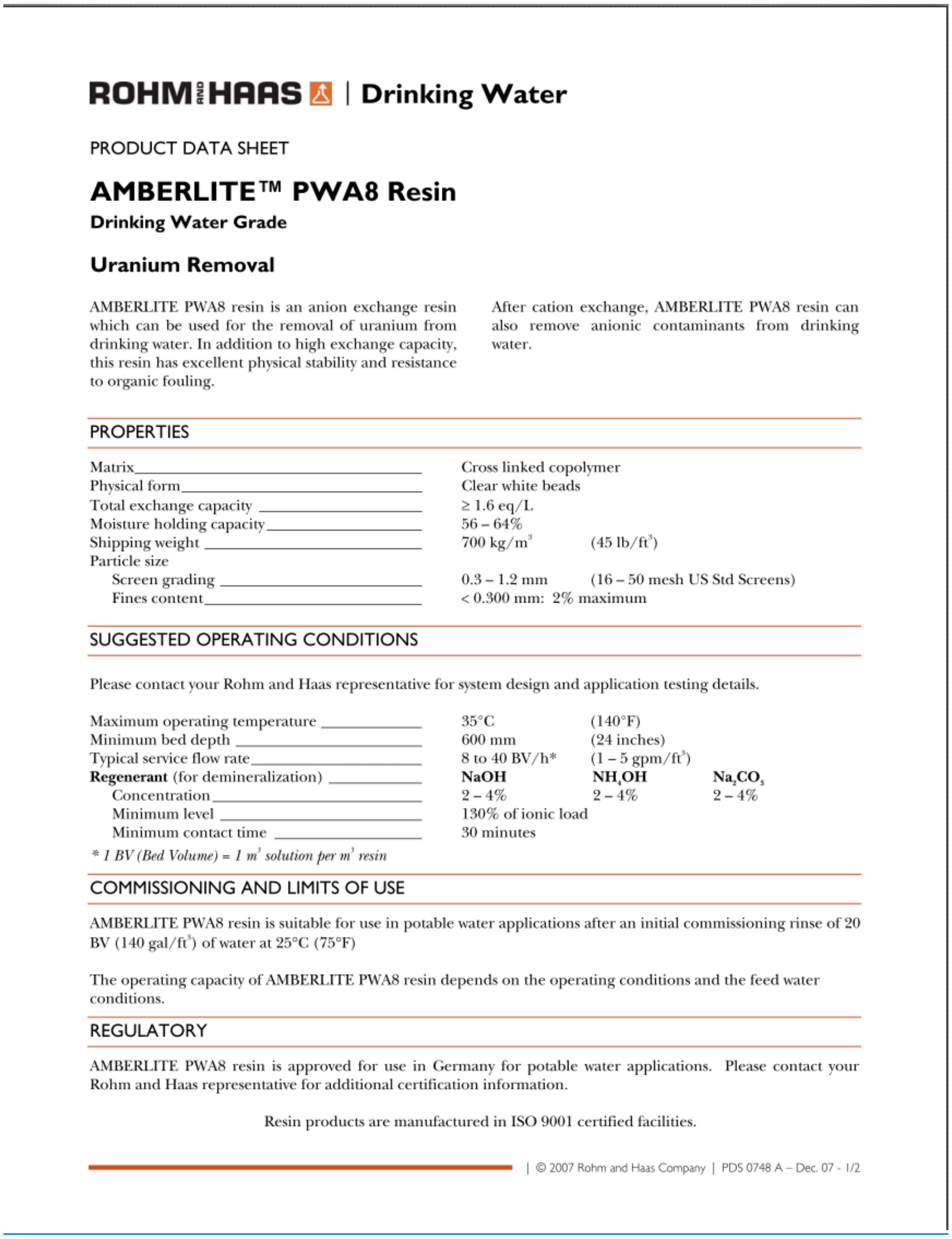
pH	Reading Start(mL)	Added(mL)
7.77	9.85	0
5.50	13.30	3.45
5.20	13.80	3.95
5.01	14.05	4.20
4.71	14.20	4.35
4.49	14.30	4.45

CFUs Raw Data

Results	CFUs/100mL
DI #1	0
DI #2	0
DI #3	0
Sample #1	2
Sample #2	1
Sample #3	3
Sample #4	2
Sample #5	4
Sample #6	0

Appendix H: DOW Chemical Amberlite^{TM} PWA8 Resin Product Data Sheet

Note that Rohm and Haas is a subsidiary of DOW Chemical



ROHM AND HAAS | Drinking Water

PRODUCT DATA SHEET

AMBERLITE™ PWA8 Resin

Drinking Water Grade

Uranium Removal

AMBERLITE PWA8 resin is an anion exchange resin which can be used for the removal of uranium from drinking water. In addition to high exchange capacity, this resin has excellent physical stability and resistance to organic fouling.

After cation exchange, AMBERLITE PWA8 resin can also remove anionic contaminants from drinking water.

PROPERTIES

Matrix	Cross linked copolymer	
Physical form	Clear white beads	
Total exchange capacity	≥ 1.6 eq/L	
Moisture holding capacity	56 – 64%	
Shipping weight	700 kg/m^3	(45 lb/ft^3)
Particle size		
Screen grading	0.3 – 1.2 mm	(16 – 50 mesh US Std Screens)
Fines content	< 0.300 mm: 2% maximum	

SUGGESTED OPERATING CONDITIONS

Please contact your Rohm and Haas representative for system design and application testing details.

Maximum operating temperature	35°C	(140°F)	
Minimum bed depth	600 mm	(24 inches)	
Typical service flow rate	8 to 40 BV/h*	(1 – 5 gpm/ft^3)	
Regenerant (for demineralization)	**NaOH**	**NH_4OH**	**Na_2CO_3**
Concentration	2 – 4%	2 – 4%	2 – 4%
Minimum level	130% of ionic load		
Minimum contact time	30 minutes		

** 1 BV (Bed Volume) = 1 m^3 solution per m^3 resin*

COMMISSIONING AND LIMITS OF USE

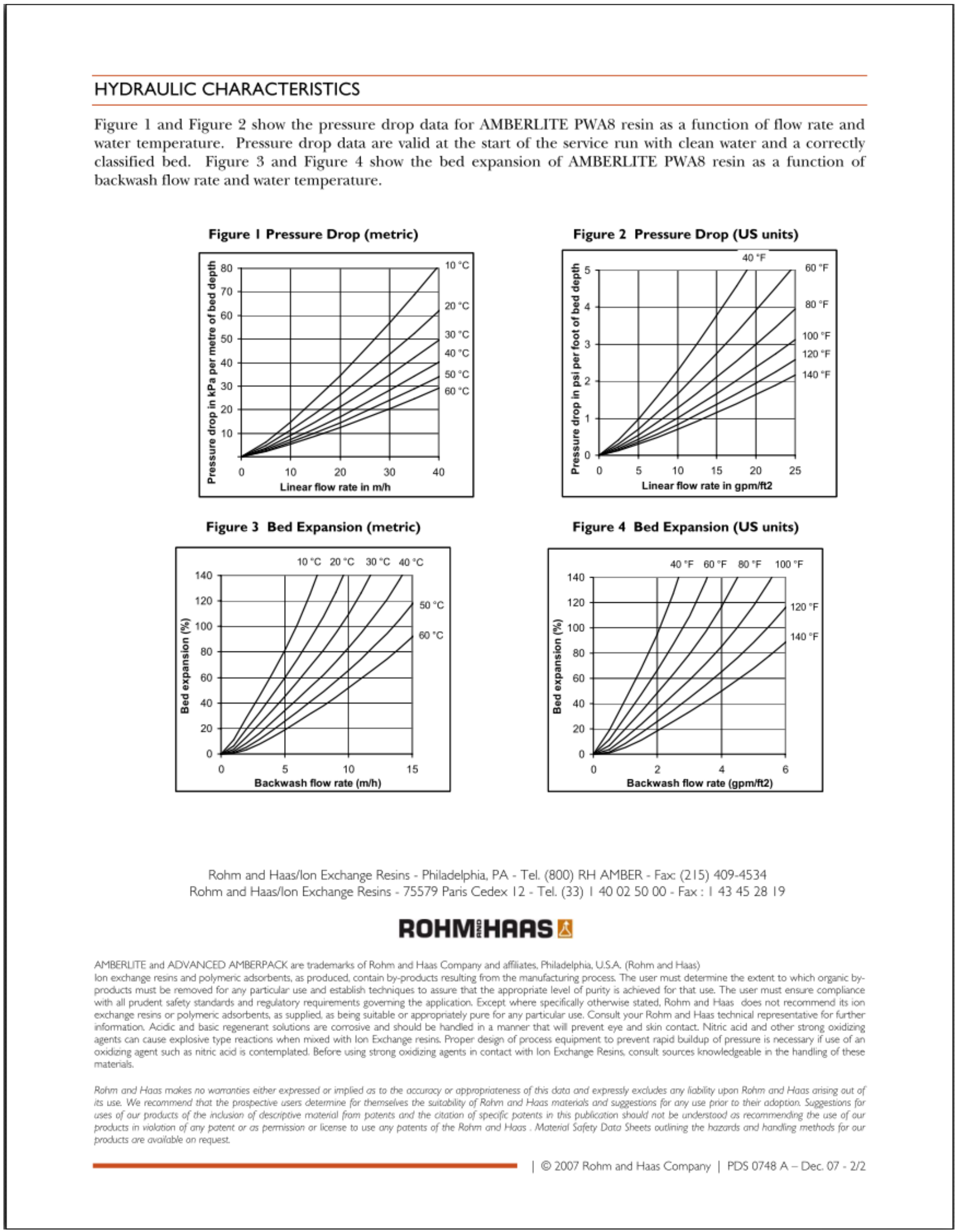
AMBERLITE PWA8 resin is suitable for use in potable water applications after an initial commissioning rinse of 20 BV (140 gal/ft^3) of water at 25°C (75°F)

The operating capacity of AMBERLITE PWA8 resin depends on the operating conditions and the feed water conditions.

REGULATORY

AMBERLITE PWA8 resin is approved for use in Germany for potable water applications. Please contact your Rohm and Haas representative for additional certification information.

Resin products are manufactured in ISO 9001 certified facilities.



HYDRAULIC CHARACTERISTICS

Figure 1 and Figure 2 show the pressure drop data for AMBERLITE PWA8 resin as a function of flow rate and water temperature. Pressure drop data are valid at the start of the service run with clean water and a correctly classified bed. Figure 3 and Figure 4 show the bed expansion of AMBERLITE PWA8 resin as a function of backwash flow rate and water temperature.

Figure 1 Pressure Drop (metric)

Figure 2 Pressure Drop (US units)

Figure 3 Bed Expansion (metric)

Figure 4 Bed Expansion (US units)

Rohm and Haas/Ion Exchange Resins - Philadelphia, PA - Tel. (800) RH AMBER - Fax: (215) 409-4534
Rohm and Haas/Ion Exchange Resins - 75579 Paris Cedex 12 - Tel. (33) 1 40 02 50 00 - Fax : 1 43 45 28 19

Ion exchange resins and polymeric adsorbents, as produced, contain by-products resulting from the manufacturing process. The user must determine the extent to which organic by-products must be removed for any particular use and establish techniques to assure that the appropriate level of purity is achieved for that use. The user must ensure compliance with all prudent safety standards and regulatory requirements governing the application. Except where specifically otherwise stated, Rohm and Haas does not recommend its ion exchange resins or polymeric adsorbents, as supplied, as being suitable or appropriately pure for any particular use. Consult your Rohm and Haas technical representative for further information. Acidic and basic regenerant solutions are corrosive and should be handled in a manner that will prevent eye and skin contact. Nitric acid and other strong oxidizing agents can cause explosive type reactions when mixed with Ion Exchange resins. Proper design of process equipment to prevent rapid buildup of pressure is necessary if use of an oxidizing agent such as nitric acid is contemplated. Before using strong oxidizing agents in contact with Ion Exchange Resins, consult sources knowledgeable in the handling of these materials.

Appendix I: Chlorine Dosage Calculations