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DETERMINING THE FEASIBILITY OF BEST AVAILABLE TREATMENT VERSUS LINE EXTENSION FOR RADIONUCLIDE CONTAMINATION IN THE KICKAPOO TRIBE OF OKLAHOMA JURISDICTION AREA

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DETERMINING THE FEASIBILITY OF BEST AVAILABLE TREATMENT VERSUS LINE EXTENSION FOR RADIONUCLIDE CONTAMINATION IN THE KICKAPOO TRIBE OF OKLAHOMA JURISDICTION AREA

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BY

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I would like to dedicate this thesis to my little brown mama, who is forever my rock; my dad, who makes me a better person every single day; Eden, Graison, and Eibel because they are my biggest fans and best friends; and Lilly Michaela Rose because everything I do is for her. Hesaketvmese liket os.

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ABSTRACT

This project aims to compare best available treatment (BAT) options to a line extension, therefore, presenting residents within the Kickapoo Tribe of Oklahoma (KTO) jurisdictional area with the most effective, in terms of cost and ease of use, option for obtaining potable water. This study also infers hot spots through sampling and geographic information system (GIS) modeling to gauge the extent of necessary treatment or line extension. Residents in this area are currently drawing water from wells with naturally occurring radionuclide contamination. A hydraulic model was completed as a means to design a line extension. Literature was surveyed to review the effectiveness of different BAT options for private well systems and aided the overall comparison to line extension. The BAT solution chosen includes three different sizes of Celpure® P300 diatomite based ceramic depth filter and a strong acid cation exchange unit with DIAION SK1B sodium based resin. The project compares the costs for residential upkeep and the costs of both installation and initial maintenance by Indian Health Service (IHS) for both solutions. These comparisons helped determine cost efficiency. A line extension is the most effective option of potable water for residents, the tribe, and IHS due to a need for longevity of treatment and issues that may arise from the cost of individual upkeep. This is significant because the cost of a BAT solution would far exceed the average income per home per year for residents in this area. Individual treatment systems also leave residents with hazardous wastes that they would be responsible for handling and disposing of properly. A line extension provides minimal cost and maintenance for the homeowner while ensuring that the residents are supplied with safe water. This information provides IHS and the KTO with a feasible recommendation of how to deliver potable water to the residents with naturally occurring radionuclide contamination. Through sampling and GIS modeling, this project also pinpoints areas of

radionuclide contamination in the KTO jurisdictional area for further reference or studies. 49 of the 57 homes in the study area lie within an area at risk for contamination. Two homes are at risk for a higher degree of uranium contamination (45-60 μg/L) and may benefit from immediate chemical testing.

1. INTRODUCTION

In late 2000s, radionuclide groundwater contamination was found among residential wells in northeast McClain, Oklahoma (Becker 2013b). According to the Environmental Protection Agency (EPA, 2016), the current maximum contaminant levels (MCLs) of radionuclides in drinking water consists of radium 226/228 at 5pCi/L, Beta/photon emitters at 4 mrem/yr, gross alpha particles at 15 pCi/L, and Uranium at 30 µg/L. Chronic exposure to this type of radiation can cause serious health concerns such as cancer, benign tumors, cataracts, or other harmful genetic mutations (EPA, 2018a). Approximately five homes in this area (Figure 1) along Hazel Dell Road and Moccasin Trail have wells drawing groundwater that tests above MCLs. One well is currently producing water with Uranium approximately 8 times the recommended level at 241 µg/L, gross alpha particles approximately 15 times the recommended level at 206 ± 11.3 pCi/L, and gross beta/photon emitters approximately 1,554 times the recommended level at 34.0 ± 2.20 pCi/L (or 5,461 to 6,216 mrem/yr, assuming residents spend around 344 days per year at 12 hours per day in their home). The water also tested positive for arsenic at 21.8 µg/L and Selenium at 33.5 µg/L.

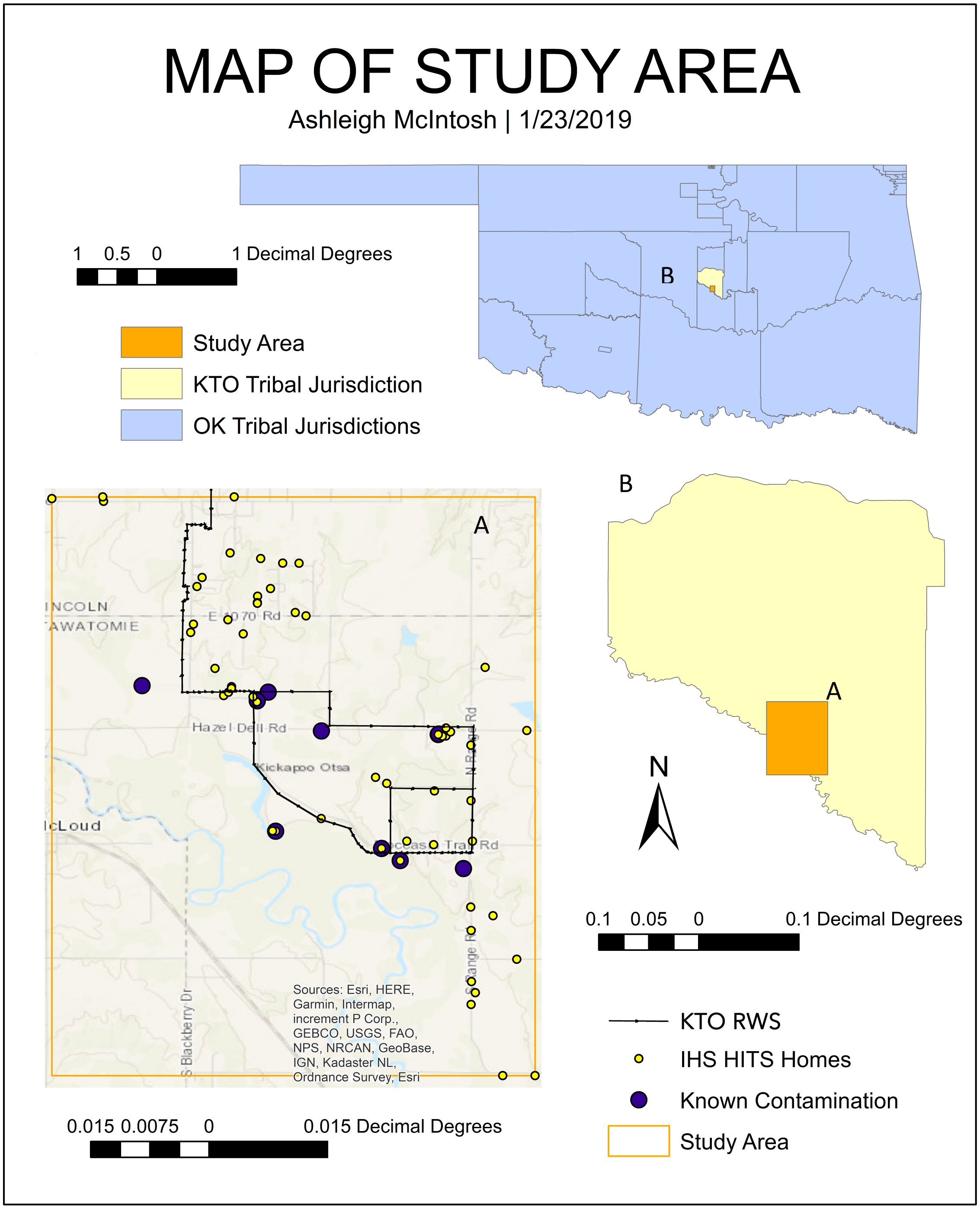

Figure 1: Map of Study Area

The study area for this project (A) is located in the southwest of part of the Kickapoo Tribe of Oklahoma (KTO) Jurisdictional Area (B). This area has a population of around 132 with an Indian population of approximately 40 percent. Residents in this area are drawing well water from the Garber-Wellington Aquifer. The existing KTO Rural Water System is shown in black, existing Indian homes are shown in yellow, and sites with known contamination are shown in blue (A).

1.1 Purpose of Study

Because the contaminated groundwater was being drawn by Indian owned homes in the Kickapoo Tribe of Oklahoma (KTO) Jurisdictional Area, where Indian in this study refers to residents of Native American descent, the Indian Health Service (IHS) decided to determine the feasibility of extending the KTO Rural Water System to reach this area. It is necessary to determine if individual treatment or treatment at the source would be more beneficial than line extension. To assist IHS in this decision-making process, a study was conduction to evaluate the efficiency of treatment at the source compared to a line extension.

1.2 General Overview

This project will analyze the best possible option for the residents by evaluating the economic feasibility, ease of use, and maintenance of best available treatment options versus the proposed waterline extension.

1.3 Current Systems

1.3.1 Individual Systems

Four Indian homes in this area tested positive for naturally occurring radionuclide contamination from their wells. The water used for drinking exceeds EPA MCLs for radium 226/228 at 5pCi/L, Beta/photon emitters at 4 mrem/yr, gross alpha particles at 15 pCi/L, and Uranium at 30 μg/L (EPA, 2016). No individual treatment technology is currently being implemented. One resident is hauling drinking water.

1.3.2 Community System

The system has four wells (known as 1, 2, 3, and 4). These wells are located in close proximity to the storage tank (Figure 2) and constructed with 15.24 cm (6 in) diameter casing to depths ranging from 48-58 m (USDIBR and KTO, 2012). Wells 1, 3, and 4 require chlorine disinfection and are equipped with submersible pumps with 2.54 cm (1 in) diameter discharge connections and sizes unknown. Well 2 is currently offline due to cavitation and the production of white water.

The tribe currently uses LMI chlorinator pumps at the three wells on line in the KTO Housing Authority. The system operator uses approximately 3.785 L of chlorine at 5% for 37.85 m^3 of water to maintain residual Cl_2 levels of 1.10 to 1.60 mg/L of free chlorine. The tribe also uses LMI pumps to add Brennphos polyphosphate to the system to help control the leaching effect of copper. The system operator maintains a level of 3 mg/L. All pumps are rebuilt annually.

The tribe tests for contaminants throughout the system periodically in accordance to EPA regulations. The system is tested at its entry points for Nitrate-Nitrite annually, inorganic contaminates every 9 years, volatile organic contaminates every 3 years, and synthetic organic contaminates every 9 years. The tribe also tests along the distribution system for disinfectant and disinfection byproducts annually, total coliform monthly, and lead and copper biannually.

The system's current water storage tank is an approximately 36.58 m tall welded steel standpipe with a diameter of approximately 3.66 m. The highest allowable water surface level above the base, or when the pumps are signaled to turn off, is 33.83 m or when the tank is holding approximately 355.23 m^3. The lowest allowable water surface level within the tank, or when the pumps are signaled to turn back on, is 21.95 m or when the tank is holding approximately 230.58 m^3. The tank's outflow changes throughout the day with respect to the demand from the system. The tank has a gauge measuring instantaneous pressure, but no meters have been set up to record the outflow of the tank at any given time.

According to the USDI (2012), the system's current distribution system from the storage tank to residents consists of approximately 8.85 km of pipe and appurtenances. This includes approximately 1.62 km of 20.32 cm (8 in) diameter pipe, 6.55 km of 15.24 cm diameter pipe, and 670.56 m of 10.16 cm (4 in) diameter pipe (USDI, 2012). "Appurtenances include fire hydrants, gate valves, air release/vacuum valves, and service connections. Fire hydrants are only for pipe flushing, tank filling, etc. Due to the limited capacity of the system, pumper-type fire trucks cannot be connected to these hydrants," (USDI, 2012).

The peak hourly demand for the original (base) system is approximately 0.003785 m^3/s (60 GPM), accounting for 39 homes with 6.309e-05 m^3/s (1GPM) per home, where 6.309e-05 m^3/s was chosen based on the minimum standard set by the Oklahoma Department of Environmental Quality (ODEQ, 2018) as well as the demands for the tribal complex, Community Childcare Center, and Tribal Health Center. The KTO Casino has its own water supply and storage and does not tie into the KTO Rural Water System. The system adequately delivers water to individual home members online, meeting the minimum water pressure standard of 0.1724 MPa (25 psi) for waterline extensions of municipal water distribution systems as set by the ODEQ (2018).

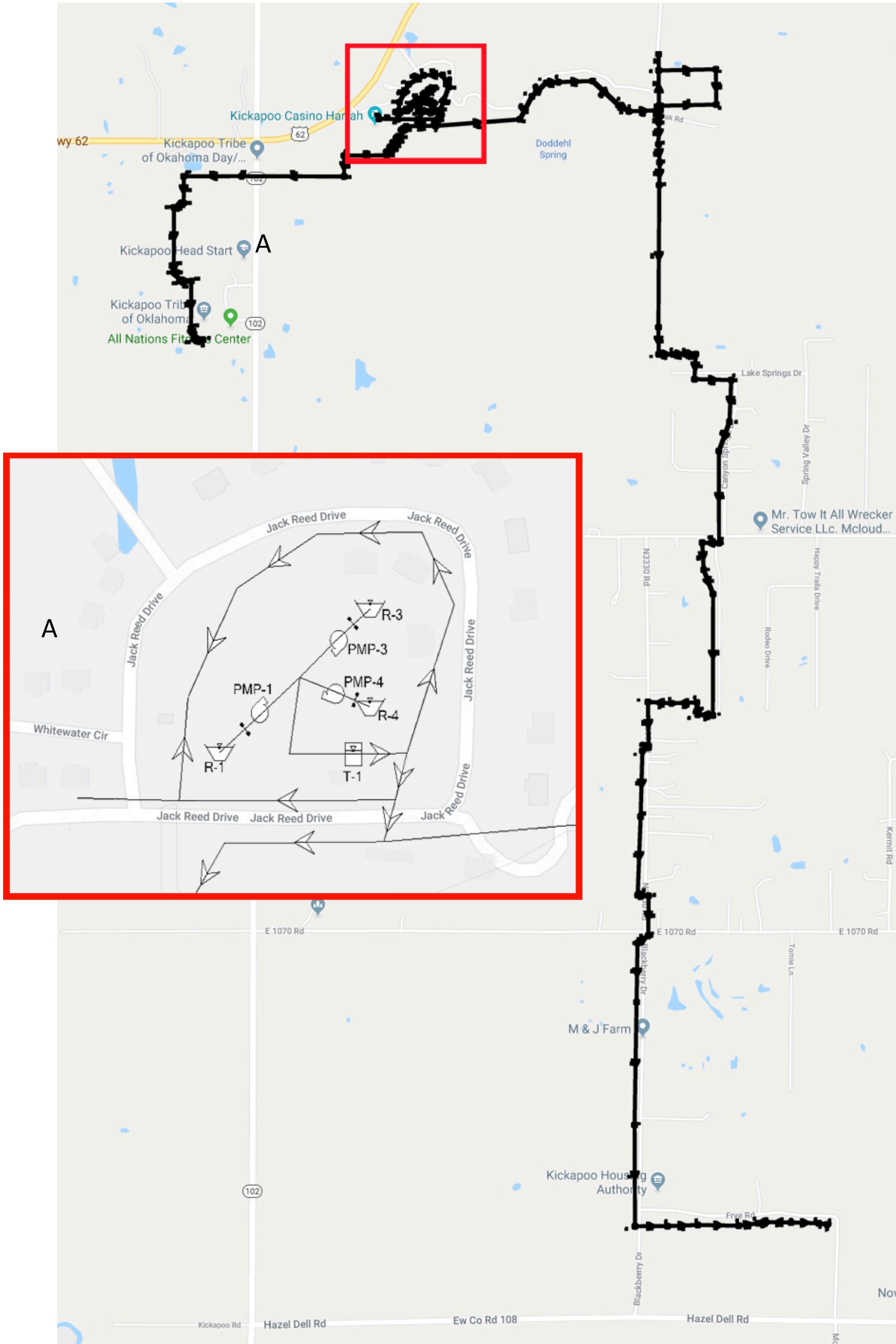

Figure 2: Existing Community System

This figure details the current distribution line, outlined in black, and the surrounding area. The system shown is a visual of the hydraulic model done using WaterCAD. Inset A shows an outline of the well locations with respect to the storage tank.

1.4 Research Conducted

Research conducted for this study investigated the most feasible option to deliver potable water to residents, in terms of cost and efficiency of use. Data was taken from WaterCAD (Bentley, version 10.0.0.55), where the proposed extension was designed, to determine capital investment. The most effective BAT option was chosen from research. Cost and efficiency of use for both options were analyzed in order to determine the most feasible solutions

1.5 Hypothesis, Objective, and Goals

1.5.1 Hypothesis

The hypothesis of this study aims to prove that in comparison to a best available treatment system, a line extension will be the most effective option, in terms of cost and efficiency of use, for residents with contaminated water sources due to a need for longevity of treatment and issues that may arise from costs of individual upkeep, even though BAT would ultimately be more economically feasible for IHS.

1.5.2 Objectives

The first objective of this study is to spatially locate hot spots of naturally occurring radionuclide contamination within the KTO jurisdictional area, based on field sampling and GIS modeling in order to gauge necessary treatment. The second objective of this study is to compare the efficiencies of BAT options versus a total line extension. This will be completed using cost analyses for both residents and IHS, and a literature review will look at the effectiveness of BAT on radionuclide contamination and the sustainability of water supply in American Indian or small, rural, or resource-challenged communities around the world.

1.5.3 Goals

The goal of this research project is to provide IHS and the KTO with a feasible option to deliver potable water to residents with radionuclide contamination as well as to expand the current body of knowledge of where radionuclide contamination can be found in the KTO jurisdictional area.

1.6 Outline of Thesis

This thesis is broken in five sections. Section 1 is the introduction of the problem and need for this study. Section 2 will discuss relevant literature pertaining to the problem and possible solution. Section 3 will review the approach and methods used for this study. Section 4 will include a layout of results and an analysis of the results of this study. Section 5 will be a recommendation for IHS and the KTO for the best possible solution to provide residents with potable water as well as a recommendation for future work using the findings of this study.

2. LITERATURE REVIEW

A literature review was done to gauge the area of possible contamination, to find the potential options for radionuclide treatment through a BAT system, and to gain a perspective on any possible upkeep and feasibility of operation and maintenance for the resident. It was also necessary to review literature to grasp a greater understanding of the sustainability, as far as quality and quantity, of water supply in rural, resource-challenged American Indian communities. Because specific literature is lacking for these smaller communities within the United States, it was necessary to broaden this literature review to include rural, resources-challenged communities in other countries.

2.1 Contaminant Location

Naturally occurring radionuclide contamination of individual well sources in the KTO jurisdictional area was first found in the beginning of the 20th century (Becker 2013a; Becker 2013b). A compilation was done by the United States Geological Survey (USGS) in correspondence with the KTO to gather new and historical data for ground water quality and well water characteristics in the tribal jurisdictional area (Becker, 2013b). The study recorded levels for pH, specific conductance, hardness, major ion concentrations, typical trace elements, and radionuclides (Becker, 2013b). Using this data as a baseline, more testing was done that found a correlation between higher pH values and the occurrence of certain trace elements and radionuclides (Becker, 2013a). These samples were taken from wells within the KTO jurisdictional area that were drawing water from the Garber-Wellington Aquifer. The study showed that pH values above 8.0 could be correlated to high concentrations of arsenic, chromium, selenium, uranium, radon-222, and high gross alpha-particle activity in the well water (Becker, 2013a).

Even though these studies collected data from a total of 155 wells, only 59 private wells were measured for pH and specific conductance (Becker 2013a; Becker 2013b). Of those 59 wells, only 20 wells were sampled for concentrations of major ions, trace elements, and radionuclides (Becker 2013a). This accounts for only 12.9 percent of the wells involved in the studies that were tested for radionuclides. Even though this is a small percentage of the total wells in this area, these studies give a good idea of where contamination lies, and this information can be used to deduce where more sampling is required.

2.2 Effectiveness of Best Available Technology on Radionuclide Contamination

The EPA (2015) provides information on treatment options for radionuclides in drinking water, including a table of technologies categorized as either best available technology (BAT) and/or small system compliance technology (SSCT) along with their specific radionuclide treatment capabilities, source water considerations, and required operator skills. Treatment technologies that could be implemented in an individual home include ion exchange, reverse osmosis (RO), lime softening, and coagulation/filtration (EPA, 2015). According to the EPA (2015), RO treatment is best used for surface water and typically requires pre-filtration. Coagulation/filtration is incapable of treating radium (EPA, 2015). Therefore, research for BATs will start with but not be limited to ion exchange and lime softening. The EPA (2015) defines the operator skill required for ion exchange as “intermediate” and lime softening as “advanced.” It should be noted that the scope of this information by EPA (2015), however, is meant for a municipal system rather than individual BAT and further testing may need to be done on each system for use in a private home.

Lee and Bondietti (1983) conducted an experiment that tested the removal of uranium from contaminated surface water with varying methods of lime softening and coagulation and compared those results to the removal of uranium via strong base anion exchange resin. The contaminated water was taken from a “former low-level radioactive waste settling basin” with a chemical composition similar to that of other natural surface water sources in the region except for its higher levels of uranium of around 83 μg/L (Lee and Bondietti, 1983). It was determined that uranyl carbonates were the dominant uranium species in the water, and these species would be “common in most carbonate dominated surface and well waters,” (Lee and Bondietti, 1983). For the experiments, water samples were adjusted to desired pH levels before varying levels of lime, magnesium carbonate, ferric sulfate, and aluminum sulfate were added (Lee and Bondietti, 1983). Solutions were filtered through a 0.45 μm membrane, and then uranium activity was determined (Lee and Bondietti, 1983).

By experimenting with the lime and magnesium carbonate treatment, Lee and Bondietti (1983) determined that the presence of free carbonate might be the cause of a higher optimum pH range and lower level of uranium removal. It was also determined that since magnesium hydroxide needs a higher pH level to precipitate magnesium than calcium carbonate needs to precipitate calcium, selection of treatment pH depends on magnesium concentration (Lee and Bondietti, 1983). For lime treatment, both pH and magnesium concentrations of the treated water should be high enough so that the uranium-magnesium precipitate is stable (Lee and Bondietti, 1983). Lee and Bondietti (1983) concluded that even radium 226 could be efficiently removed with conventional lime treatment when the pH is 10.5 or higher.

Lee and Bondietti (1983) also went on to test the effectiveness of conventional coagulant treatment using ferric sulfate and aluminum sulfate on the removal of uranium from the contaminated source water. They found that the uranyl complex changes based on change in the charge and stability of the uranyl species at certain pH values and on which “metal hydroxide precipitates at the adjusted pH of the solution," (Lee and Bondietti, 1983). Therefore, the uranium removal efficiency of both ferric sulfate and aluminum sulfate is dependent on dosage and equilibration pH (Lee and Bondietti, 1983). The removal percent increased with increased dosage at pH values of around 6 or 10, but "application of aluminum sulfate is not recommended at a pH greater than 10 because the solubility of the precipitate increases," (Lee and Bondietti, 1983).

Lee and Bondietti (1983) also tested how carbonates affected uranium removal using the coagulants. They found that removal efficiency in a carbonate-free system is influenced by the stability of the coagulants at a given pH (Lee and Bondietti, 1983). It was recommended that the optimum pH range for removal of uranium be around 6 for municipal plants because the optimum pH for turbidity removal can also be expanded to this range (Lee and Bondietti, 1983).

Lastly, Lee and Bondietti (1983) looked at anion exchange as a means to remove uranium from the source water. They found that "strong base anion exchange resin had a large adsorption capacity and selectivity for uranyl carbonates," (Lee and Bondietti, 1983). Adsorption depended on flow rate, pH, and concentrations of uranyl carbonate and other competing anions (Lee and Bondietti, 1983). The uranyl complex had a high negative charge allowing it to adsorb over its competition (Lee and Bondietti, 1983). An increasing flow rate and carbonate concentration caused the loading capacity of the resin to decrease when the influent had higher uranium concentrations (Lee and Bondietti, 1983). From their researcg, Lee and Bondietti (1983) noted that there was a positive correlation between loading capacity and uranium concentration.

Lee and Bondietti (1983) concluded "that a commercially available column containing 2.2 kg of anion-exchange resin could treat 106 L of water containing 83 fig U/L with less than one percent breakthrough in the effluent." Lee and Bondietti (1989) emphasized that strong base anion exchange columns are the recommended treatment for household use and private well water sources. This final recommendation has aided in the decision to focus solely on use of ion exchange resin as the BAT solution of the residential well contamination within the KTO jurisdictional area. Because of the correlation between loading capacity and uranium concentration that Lee and Bondietti (1989) mentioned, it is possible that such high concentration of uranium like those found within the KTO jurisdictional area would require minimal volume due to a lower loading capacity. This would in turn create a more efficient treatment for residential use.

It should be mentioned that Lee and Bondietti (1983) focus primarily on uranium removal using ion exchange methods. Any BAT used for the individual well systems in the KTO study area will need to also take into consideration the removal of other radionuclide contaminants, including radium 226/228, gross alpha particles, and beta/photon emitters. Because of this, further investigation on the efficiency of ion exchange has been done.

Jelinek and Sorg (1988) designed and operated a full-scale ion exchange system with the purpose of removing uranium from groundwater well sources. This study looked at wells with contamination due to gross alpha particle, uranium, U-234 to U-238 ratio, radium 226, and radium 228 (Jelinek and Sorg, 1988). The treatment system consisted of two prefilters and water softeners arranged in series for redundancy, "a brine tank to batch regenerate and facilities to store or transfer regenerate," (Jelinek and Sorg, 1988). Because the turnaround time for a radionuclide analysis took Jelinek and Sorg (1988) approximately two weeks, the second tank also "added a measure of safety."

The concerning aspect of the project by Jelinek and Sorg (1988) was "disposal of the spent ion exchange resin regenerants and rinse waters." Based on the ion exchange column size, water demand, influent water quality, Jelinek and Sorg (1988) found a regeneration frequency of 180 days with a by-product radioactivity of 80 to be 80 μCi. At the time, there were no regulations on the removal processes for radionuclide wastes, therefore a regeneration frequency of once every two months was imposed (Jelinek and Sorg, 1988). Due to cost and safety considerations, disposal of the brine or sludge was carried out by means of "hauling and discharge into a local wastewater facility," (Jelinek and Sorg, 1988).

Ultimately, Jelinek and Sorg (1988) took a deeper look into the operation, maintenance, and costs of only one well source – the Coal Creek Well and the Coal Creek Well treatment system. Coal Creek Well had a raw water composition of 50-60 pCi/L of gross alpha particle activity, 0.024 mg/L of uranium concentration (24 μg/L), U-234 to U-238 ratio of 3.6, and 1.9 pCi/L of radium-226 activity (Jelinek and Sorg, 1988). The system completed a removal or 99.8 percent removal of uranium and up to 94 percent removal of gross alpha particle (Jelinek and Sorg, 1988).

In comparison to the much higher concentrations of uranium and gross alpha particles coming from the wells in the KTO jurisdictional area, it is difficult to gauge the effectiveness of the Jelinek and Sorg system (1988) on the degree of the KTO contamination. Ultimately, specifications regarding how Jelinek and Sorg (1988) detailed costs for the construction, operation, and maintenance of system as well as the disposal of wastes were beneficial in determining the costs of BAT treatment for individual systems in the KTO study area. Capital costs for Coal Creek from Jelinek and Sorg (1988) are detailed in the table below.

Table 1: Capital Costs for Uranium Removal System (Jelinek and Sorg, 1988)

Component	Cost ($)
Prefilter, ion exchange columns, resin, brine tank, manual and automatic valves, pressure gauges, piping and appurtenances	3,800.00
Regenerant wastewater tank, wastewater pump, and hose	1,000.00
District labor for installation (160 h)	2,100.00

Engineering – assist in ordering equipment, observe installation, permitting, record drawings, O&M manual	2,000.00
Total	8,900.00

Operation and maintenance costs, including labor for operation, regeneration, and sample collection, sample analysis, prefilter replacement, resin replacement, regenerant salt, and electrical requirements for uranium removal, were estimated to be \$4.30 per 3.785 m^3 of water treated (Jelinek and Sorg, 1988). Cost for the disposal of the regenerant, including transportation by tanker truck and analysis of the effluent, was estimated to be \$2.40 per 3.785 m^3 of water treated (Jelinek and Sorg, 1988). Any cost comparison done of a BAT system for a residential well in the KTO study area to the work done by Jelinek and Sorg (1988) would have to take into consideration the time value of money, cost of living in Oklahoma versus Colorado, where the original study took place, and the need for reduction of much higher contamination concentrations. Jelinek and Sorg (1988) is a beneficial reference due to the detailing of costs for a small-scale ion exchange system on an individual well, but more research needed to be done on an effective solution to extent of the problem within the KTO study area.

Huang et al. (2012) looked at the ion exchange methods to treat water contaminated by fission product and actinides in the Taiwan Research Reactor's spent fuel pool (TRR SFP). Radionuclides in the TRR SFP included cesium-137, cobalt-57, cobalt-60, americium-241, strontium-90, gross beta, gross alpha, and uranium (Huang et al., 2012). Huang et al. (2012) were concerned about using organic materials to convert the radionuclides in the water to solid media. Organic material has the possibility of being "decomposed by high levels of radioactive energy generated by alpha decay and release of combustible gases," (Huang et al., 2012). For this reason, inorganic material for treatment was the preferred method of this study (Huang et al., 2012).

The first trial of comparison done by Huang et al. (2012) consisted of a sediment filter with 5 μm pores, a diatomite based ceramic depth filter with 0.9 μm pores, and cation exchange resin packed cartridge, and a disposable, hollow fiber filter cartridge with 0.1-0.01 μm pores. The second trial for comparison consisted of diatomite based ceramic depth filters with 5-, 0.9-, and 0.22-μm pore sizes in series (Huang et al., 2012). The extent of contamination in the TRR SFP far exceeded the concentration of radionuclides in the ground water for the KTO study area (Huang et al., 2012). According to Huang et al. (2012), the initial gross beta concentration before treatment was 3,030 Bq/mL (or 81,810,000 pCi/L), gross alpha particle initial concentration was 61.5 Bq/mL (or 1,660,500 pCi/L), and uranium initial concentration was 4.80 mg/L (or 4800 μg/L).

The purification unit in the first trial with the highest removal efficiency for both gross alpha and gross beta was the diatomite based ceramic depth filters with pore sizes of -0.9 μm, while the most efficient unit in the second trial was the diatomite based ceramic depth filter with pore sizes of 0.22 μm (Huang et al., 2012). For uranium, the diatomite based ceramic depth filter in the first trial and the 0.22 μm pore size filter in the second trial both had just over 50 percent removal efficiency (Huang et al., 2012). The most efficient filter for uranium was cation exchange resin in the first trial (Huang et al., 2012).

The strong acid cation exchange resin, classified as DIAION™ SK1B, was a sodium based ionic form with a minimum exchange capacity of 2.0 meq/mL (Huang et al., 2012). The ceramic filters were made up of diatomite, a "natural, amorphous silica formed by the deposition of diatom skeleton," (Huang et al., 2012). The filters were made by sieving diatomite particulates before wetting and shaping them to a cylinder module (Huang et al., 2012). The module was then "sintered at 1100 ^{O}C to provide sufficient mechanical strength," (Huang et al., 2012).

According to Huang et al. (2012), because the filter with the largest surface area has the most adsorption sites, the third filter of the second trial most effectively removed uranium. Even more, as more suspended solids collected on the surfaces of particles in the first and second filters of the second trial, adsorption sites were covered in those filters (Huang et al., 2012). Then, the third filter could filter finer particles with a higher concentration of uranium (Huang et al., 2012). To implement the methods of Huang et al. (2012) as a means to provide residents in the study area with potable water, it might be necessary to take the most efficient aspects of both trials as well as to prefilter any suspended solids.

2.3 Sustainability of Water Supply for Low Income Communities

2.3.1 Health

Gasteyer and Vaswani (2004) state that 1.7 million people within the United States still lack access to adequate water and wastewater facilities in their homes. For any community systems that are put into place to mitigate these issues, there becomes a need to care for the system's infrastructure as it ages and account for the future population distribution and demands (Gastweyer and Vaswani, 2004). Small communities are less likely to have the major funding of a larger system or even the knowledge of how to go about providing for their system (Gastweyer and Vaswani, 2004).

In order to overcome these issues, "the infrastructure investments of the future must combine reinvestment in physical infrastructure with investment in a civic infrastructure. This civic infrastructure must involve improved training of local water operators and water boards and investment of the time and effort to build participatory networks that can create local support for water system maintenance and source water protection. It may involve acceptance of alternative technologies that deliver safe drinking water at lower cost. The soft path should provide opportunities for continual improvement in access to water and sanitation through building human and social capacity," (Gastweyer and Vaswani, 2004).

2.3.2 Supply

Howard and Bertram (2003) reviewed the requirements for water quantity to meet the minimum needs for consumption and hygiene. These two factors ultimately influence the public health. The estimated quantities are meant to surpass the minimum of 5.5 liters per capita per day for hydration that meet the minimum requirements of most people under most conditions because of the extra need for health care, food production, economic activity, or amenity use. Cooking needs require an estimated 2 liters per capita per day. Residents with intermediate access to water with a low level of health concern would likely need to collect around 50 liters per capita per day for hygiene needs.

3. APPROACH AND METHODS

3.1 Tribal Approval

Tribal approval was needed from the KTO to conduct this research. To gain this approval, meetings were conducted between the tribe and Indian Health Service to discuss intentions and clarify goals. IHS data was gathered in order to contact homeowners in regards to having their well sampled. An adequate relationship needed to be established with both the tribe and the homeowners to aid in communication and ease any processes of obtaining information.

3.2 Sampling

To clarify the level of contamination and provide geospatial location of radionuclide hotspots, samples were taken from several wells in the area of interest. A few homes sampled by Becker (2012a; 2012b) were resampled to verify results. Testing parameters, including radium 226/228, beta/photo emitters, gross alpha particles, uranium, pH as well as other trace elements were established based on research by Becker (2012a; 2012b). Sampling standards are based on data provided from ASTM International (2017; 2018) and the Environmental Protection Agency (2011). The process of sampling was consistent for all samples that were taken.

It was preferable to take samples as close to the well source as possible. Samples were taken from the well faucet coming directly from the well, from a sampling faucet coming from a pressure tank, or from a yard hydrants located near the wellhead. If there were no faucets directly in line of the well, the sample would be taken from the outside faucet on the exterior of the home. If samples were taken near the pressure tank, water from the faucet was left to run until the pressure gauge on the water dropped to zero and began rising to ensure that water was being drawn directly from the well. All other faucets were run for approximately three minutes before samples were taken. The sample bottle was filled to within an inch from the top and then immediately closed off with caution taken to not over tighten and cause a broken lid or bottle. Holding times for radionuclides is six months, but all samples for radionuclides were taken same day to labs because samples were collected at the same time as samples for unpreserved classical chemistry constituents that had holding times of six hours (EPA. 2011).

Each sample bottle lid was labeled to match the details on the chain of custody. The chain of custody paperwork was filled out with the IHS HITS home number, the address where the sample was collected, a description of where the sample was taken (e.g. well faucet), the date and time of collection, test required as well as the name, phone number, and email of the IHS supervisory engineer. The name of the resident was not used to protect the homeowner's privacy. All correspondence regarding results of the testing from the laboratory to the homeowner was handled through IHS. Samples were hand delivered that day and chain of custodies were signed at the receiving window of the sample management unit of ODEQ to relinquish custody.

Most results came back within about a week, but radionuclide testing took approximately 3 to 6 weeks. Most homes came back clean, where clean referred to a lack of tested contaminants. Some homeowners had minor contaminants that could be mitigated with disinfection and proper care of the well house. Homeowners that had samples come back with elevated radionuclide contamination were made aware of the results by a letter and a phone call.

3.3 Indian Health Service Home Inventory System

The IHS Home Inventory Tracking System (HITS) is a geospatial inventory of tribal homes used to track the status and plan for the provision of sanitation facilities. In order for IHS to serve a home, the home must be recorded within HITS database. The database allows the IHS Division of Sanitation Facilities Construction (SFC) to create projects for homes that can be seen nationwide by those in SFC. The SFC Program is then able to provide "technical and financial assistance to American Indian tribes for cooperative development and construction of safe water, wastewater, and solid waste systems and related support facilities," (IHS, 2019).

After reviewing the USGS findings, those corresponding to HITS homes were identified based on geospatial coordinates. These data were used to contact homeowners for possible sampling and gauge which home would be included in this project based on IHS eligibility. Any homes identified as Indian owned within the project area that were available to be sampled were also added to IHS HITS database.

3.4 Well Depth Records

Well log data was gathered to better understand any correlation that the depth of the well may have to quality of water. The Oklahoma Water Resources Board provided well log data for various homes in the study area, records were unavailable for the homes that tested positive for radionuclides. Well depths for these homes were taken from USGS data and data stored in the IHS HITS database.

3.5 Geographic Information System Modeling

3.5.1 Geohealth

Modeling had been originally done through the online server, Geohealth through Health and Human Services. Basic points that utilized latitudinal and longitudinal coordinates were plotted to gauge possible trends in degree of contamination. Upon analysis, it could be seen that these results were not focused among any one location. For example, Home A results showed radionuclide contamination, yet all of the neighboring wells of Home A had radionuclide results under the regulated limit set by the EPA. This made it difficult to tell which areas needed further testing. Review of literature published by the USGS illuminated the idea that the wells that tested positive could be pulling "older" water from bedrock that may have had time for radioactive elements to decay (Becker, 2013a). Further modeling using ArcGIS needed be completed after more testing was done to gauge if possible trends existed with respect to depth of well.

3.5.2 ArcGIS Data Collection

To get the outline of the KTO Jurisdictional Area, the "Tribal Jurisdictional Boundaries in Oklahoma" ArcView shapefile was downloaded from the Oklahoma Department of Transportation (2018). The North American 1983 geographic coordinate system was specified. The Select tool was then used to extract the KTO Jurisdiction Area polygon, using the expression, "TRIBAL_ARE" = "KICKAPOO TRIBE OF OKLAHOMA". Data was downloaded from the United States Geological Survey (USGS) website to show the locations of contamination, documented in Becker (2013a). This data was formatted in a spreadsheet before being uploaded to ArcMap. "Display XY Data" was used, specifying the WGS 1984 geographic coordinate system, to display the data. The feature layer was then exported to the default geodatabase using the same coordinate system as the data frame, North American 1983. Location data of Indian homes was downloaded from the IHS online Home Inventory Tracking System (HITS). This data was also formatted in a spreadsheet before it was uploaded. The same methodology was used as done with the USGS data to display and export the feature layer.

3.5.3 ArcGIS Inverse-Distance Weighting

After home location data and sampling results were gathered, a shapefile was created in ArcGIS with USGS data using the Inverse-Distance Weighting tool to create simple risk surfaces based on the degree of contamination values at each known contamination site. Three layers were created based on degree of contamination for uranium, gross alpha particle, and beta/photon emitter, respectively. These simple risk surfaces (Figure 4, Figure 5, and Figure 6 in Section 4) were created to show where further risk of contamination may be located and which homes may be more at risk that others and need more immediate assistance.

One of the layers was exported as a vector in order to use the Clip geoprocessing tool and cut the IHS HITS data to the area of the risk surface. The Clip tool was then used to cut the risk surface IHS HITS point with the KTO Jurisdictional Area layer to show which Indian homes in this risk assessment area within the KTO Jurisdictional Area. Both degree of contamination layers were exported to rasters. Then, the Extract Values to Points tool was used on both the IHS HITS points within the risk assessment area and the IHS HITS points within the risk area and the KTO Jurisdictional Area in order to get a more precise degree of possible contamination for each point. The possible of percent risk of contamination was evaluated with the Field Calculator in each set of points' respective Attribute Table, using the following formula

$$Percent\ Risk\ of\ Contamination = \left(\frac{Possible\ of\ Extent\ of\ Contamination}{Number\ of\ Homes\ in\ the\ Area}\right) * 100$$

Finally, both sets of points were overlaid on top of the risk surface layers. The underlying risk values were used to visualize Indian homes at risk for uranium and gross alpha particle contamination in this area.

3.5.4 ArcGIS Cokriging

The cokriging tool was used to create a geospatial analysis plot of the possible degree of contamination with respect to the known depth of well. The cokriging tool is based on geospatial statistics and allows a value (degree of contamination) to be assigned to a certain space win relation to the values of the spaces around it, while at the same time taking into account another value type (depth of well). In cokriging, the same point data file used to create the risk surfaces with the Inverse-Distance Weighting method was inputted as the source dataset of both Dataset and Dataset 2 in the ArcGIS. The degree of contamination was chosen as the Data Field for Dataset, and well depth was chosen as the Data Field for Dataset 2.

3.6 Hydraulic Model

3.6.1 Base System

A hydraulic model of the existed system had to be completed before the design of the proposed system. This system was meant to model the real conditions of the actual current system and to serve as the base for any extension designs. A hardcopy of the existing system is located in Figure 2.

To make the base system, the as built of the existing system (IHS, 2009) was used as a background layer to show where the line is currently laid out. The AutoCAD drawing of where the line currently lies was traced and home demands were added to nodes that represented homes. The peak hourly demand for the original (base) system is approximately 0.003785 m^3/s, accounting for 39 homes with 6.309e-05 m^3/s per home, where 6.309e-05 m^3/s was chosen based on the minimum standard set by the Oklahoma Department of Environmental Quality (ODEQ, 2018) as well as the demands for the tribal complex, Community Childcare Center, and Tribal Health Center. The KTO Casino has its own water supply and storage and does not tie into the KTO Rural Water System. Elevations for nodes came from Google Maps, and certain locations were checked via survey equipment.

PVC was chosen as the pipe material, but the Hazen-Williams Coefficient was changed to 150 to account for wear over time. Because the original as built was used as a background layer, the WaterCAD layout could stay in the same scale. One inch was equal to one-hundredth of a mile. Distances were checked via Google Maps. Diameters were taken from the technical report by USDIBR and KTO (2012) as well as from the as built of the original system (IHS, 2009).

In order to tell if the system was modeling actual conditions successfully, a calibration was completed. To calibrate the model, pressure readings needed to be taken on the actual water main in different areas of the water system. Two pressure gauges were attached to hydrants at two different location of the water system for a period of two days. The elevation of the base of the tank was gathered in the field, and parameters for the size of the tank were taken from USDIBR and KTO (2012). Assumptions were made regarding the starting elevation of the tank at 43.6 percent of the total volume, and only the volume from 21.95 m to 33.83 m were utilized as per real life conditions (USDIBR and KTO, 2012). Time variables (Tables A1 and A2, Appendix A) were added to the model to represent a change in daily conditions. This would model the change in elevation of the tank as demand changed throughout the day to ensure that storage was adequate.

The specifications for the pumps being used by the system were collected from the Utility Superintendent for the KTO and were entered into the model for each pump (Tables A3 and A4, Appendix A). Reservoirs were used in the model to act as the systems wells and were positioned in the wells' approximate locations. In order to use reservoirs as water sources in the model, an assumption had to be made that an unlimited amount of groundwater would be available to the system. Diameters of the pipes from the reservoir to the pump were entered as 2.514 m (99 in) in order to model a cohesive system and avoid losses.

3.6.2 Proposed Extension

A child system was created in WaterCAD to represent an addition to the base system. A base system contains all of the working data, while a child system inherits data from the base system or other child systems (Bentley, 2018). Child systems allow users to take on the values of the parent system and manipulate those values without changing the parent system or starting a new file. Figure 3 below shows the proposed extension and surrounding area.

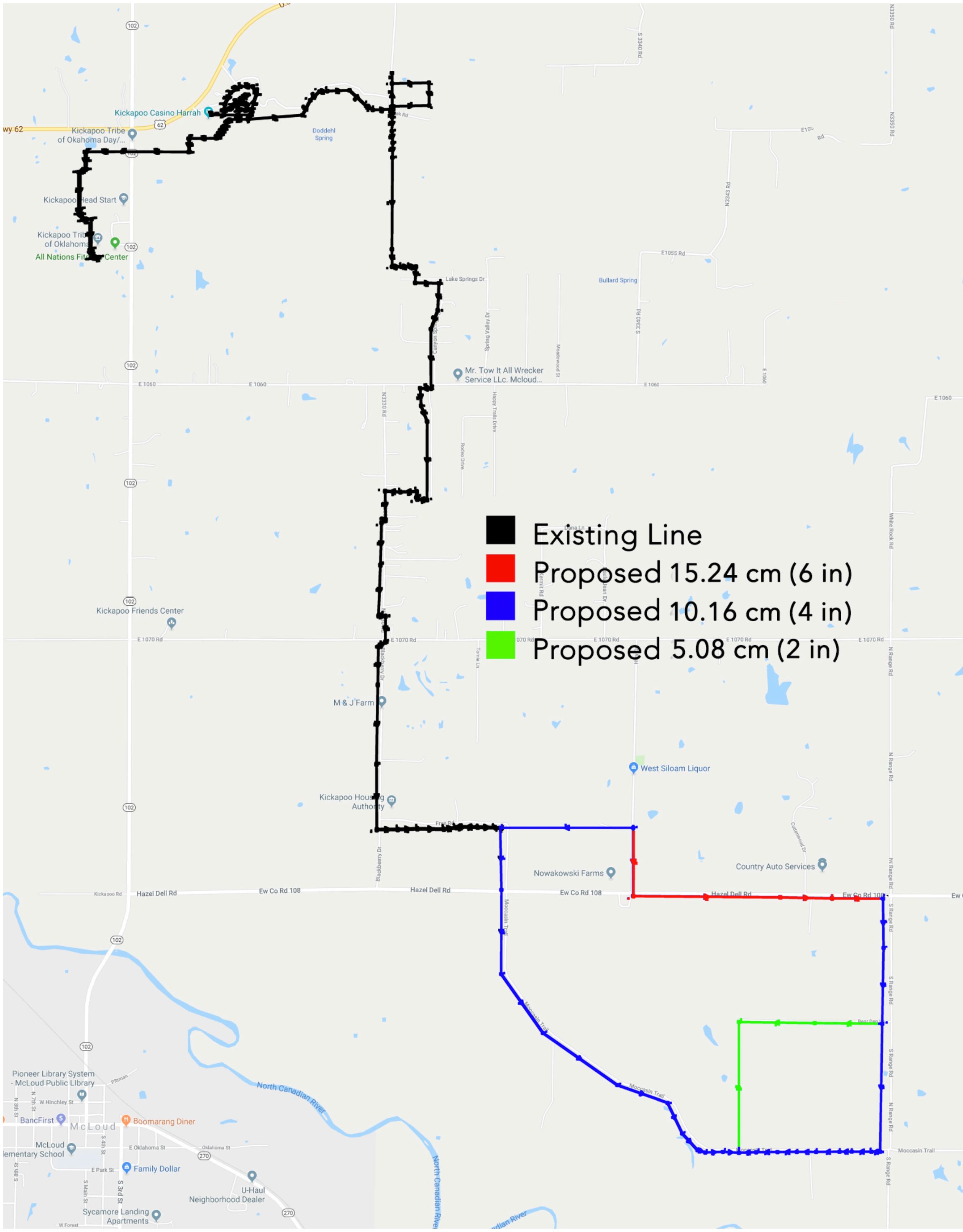

Figure 3: Proposed Extension

This figure details the area surrounding the current distribution line and proposed extension. The system shown is a visual of the hydraulic model done using WaterCAD. The proposed extension is color-coded to distinguish the diameter of pipe, where 15.24 cm (6 in) is red, 10.16 cm (4 in) is blue, and 5.08 cm (2 in) is green.

An AutoCAD drawing of the surrounding area was used as background layer in order to visualize and lay out where the proposed extension would be. Nodes were placed in the approximate locations of homes. Demands were added that remained consistent with the demand conditions of the base system. The same time variable for the base system was also added to this child system. Elevations were gathered using Google Maps.

Pipe diameters were chosen to accommodate any future extensions that the KTO system might need upon growth. A 10.16 cm diameter line would start where the original system ends on Frye Road all the way to HWY Drive. The diameter of the line would become 15.24 cm before going south on HWY Drive then east on Hazel Dell Road (EW Co Road 108) until hitting South Range Road. The diameter would then go back to a 10.16 cm before going south on South Range Road then following Moccasin Trail up to Frye Road, where the proposed extension originally began, to complete a loop. A 5.08 cm diameter line would tee off the 10.16 cm diameter line on the east side of the loop and follow Bear Den Lane going west to the end of the road before turning south to attach back to the 10.16 cm diameter line along Moccasin Trail (Figure 3). Distances were checked via Google Maps.

The system's tank was modeled to utilize more space. Instead of turning the pumps on at 21.95 m and turning off the pumps at 33.83 m, the pumps would be signaled on 1.52 m and turned off at 35.05 m. This would utilize approximately 355 m^3 of space.

3.7 Cost Analyses

3.7.1 Line Extension

A cost estimate of the proposed water line extension was established and included the costs for the standard dimension ratio PVC pipe that would be used for the water main, road boring, any gate valves, bends, or tees needed, flush hydrants, blocking tracer wire, air relief valves, 19 water service line hookups, 19 rural water district metering and membership fees, erosion control, and ODEQ construction permit. Engineering fees would not apply to this project because IHS, in agreement with the KTO, would be responsible for the design. IHS classifies projects entered into the Sanitation Tracking and Reporting System (STARS) based on cost per home as a to justify the projects funded. Therefore, the cost of the line extension would be dived by 19. The project would be 100 percent covered by IHS funding, any grants acquired from the EPA, and/or tribal funding.

3.7.2 Best Available Treatment

Costs were calculated using the predicted upfront costs of the system as well as installation and maintenance for one year. Project costs entered into STARS for an individual system would be formatted differently than that for a line extension. Projects for an individual system would only include the costs for one home. Therefore, to create a reasonable cost comparison the total cost for one individual project would have to be multiplied by 19 to determine feasibility of solution.

The system was designed after the work done by Huang et al. (2012). Huang et al. was able to sufficiently remove radionuclides from a far more concentrated contamination site. Certain removal methods from Huang et al. (2012) were chosen over others because these methods were more effective than others and because it was necessary to meet the needs of the residents in the KTO study area.

Diatomite based ceramic filters with pore sizes of 5.0 µm, 0.9 µm, and 0.22 µm will be used as a prefilters to primarily remove arsenic, gross alpha particles, gross beta particles, and any other suspended solids from individual wells. The effluent of the prefilters would then flow through two 2000 ml strong acid cation exchange columns of DIAION® SK1B sodium based gel resin to primarily remove uranium and radium 226/228. This set up this system is also meant to provide a means of redundancy. The cost estimate for this system consists of depth filter cartridges to be filled with Celpure® P300 in 250 g packages to make diatomite based ceramic filters, empty columns to be filled with DIAION® SK1B (Na) Ion Exchange Resin purchased by the Kg, manual and automatic valves, pressure gauges, tubing for the system, piping and appurtenances, including tees and bends, and the fees for hazardous waste disposal.

This cost estimate assumes that IHS would purchase enough diatomite in the form of Celpure® P300 and resin in the form of DIAION® SK1B to last residents one year as per the typical length of warranty that IHS upholds. The amount of Celpure® P300 needed for one year is based on the percent removal for the diatomite based ceramic filters of the second trial in the Huang et al. (2012) study and the most extreme contamination results from IHS Home No. 10847. Example calculations are provided in Appendix C. The limiting contaminant is assumed to be gross alpha particles because less water is needed for the filters to hit capacity than would be for gross beta particles, and uranium is meant to be primarily removed using ion exchange. Based on the demand assumption of 795 L per home per day (EPA, 2018b), it was found that five cartridges with diameter of 49 mm and length of 248 mm of 5.0 µm pore Celpure® P300, three cartridges of 0.9 µm pore Celpure® P300, and three cartridges of 0.22 µm pore Celpure® P300 would be sufficient to cover the daily needs of residents. In order minimize the storage space of the filters, residents would need to change filtration material daily.

The amount of DIAION® SK1B needed for one year is based on the estimated residual of uranium from the effluent of the ceramic depth filters, the capacity of the resin at 2 meq/L, and the weight of resin at 750 g/L. The residual concentration of uranium from the effluent of the ceramic depth filter was converted to milliequivalents per liter, based on a conservative charge of

4, assuming the dominant uranium species would be a uranyl carbonate of $UO_2(CO_3)_3^{4-}$. This assumption is based on the Lee and Bondietti (1983) deduction that uranyl carbonates are common in groundwater wells where in carbon is prevalent. This value along with the capacity of the resin was used to determine the amount of resin necessary to treat a sufficient quantity of water in a time period of 10 days. The size of column was determined based on the amount of resin to be used within this time period. The order minimize the storage area needed to keep the ion exchange columns, residents would need to change the resin within each column every ten days. Calculations are provided in Appendix C.

It should be noted that this system is based on literature of a very specific scenario that does not completely match the circumstances of contamination within the KTO study area. Because of this, pilot test may be necessary to determine the effectiveness of this treatment setup before implementation. It should also be noted that this system also makes the assumption that the KTO would establish a certified hazardous waste holding place in compliance with the ODEQ and work with a private service to dispose of waste properly.

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 GIS Modeling

Three maps were created to represent the visualizations of Indian homes at risk for uranium, gross alpha particle, and beta/photon emitter contamination in this area, shown in Figure 4, Figure 5, and Figure 6 below. These maps were created using the Inverse-Distance Weighting method and above Percent Risk of Contamination formula. Table A 5 and Table A 6 (Appendix A) were created to show top homes at risk. The tables have data for percent risk values of gross alpha particle and uranium groundwater contamination, respectively.

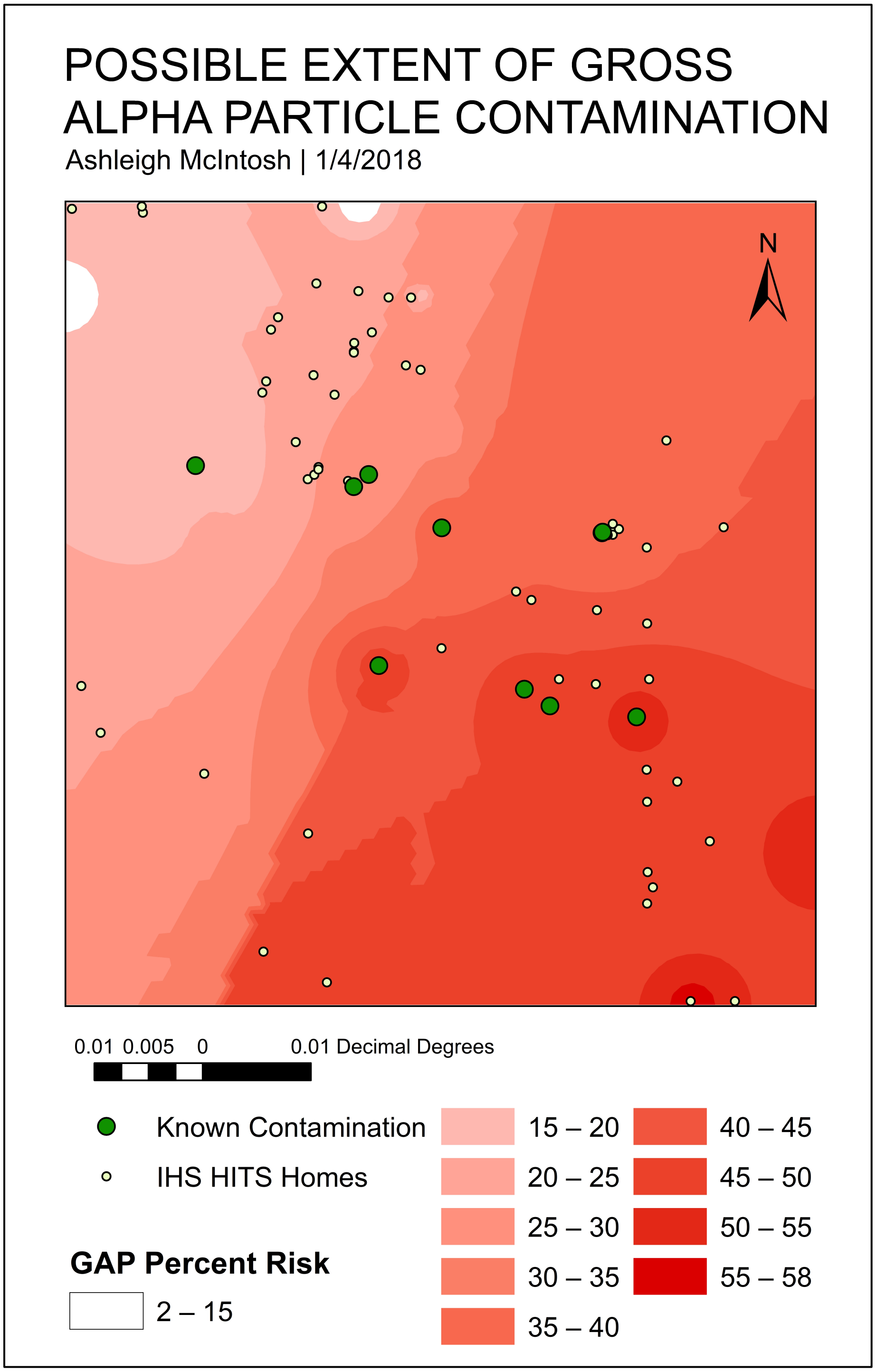

Figure 4: Possible Extent of Gross Alpha Particle Contamination

This map shows the possible extent of gross alpha particle groundwater contamination that exceeds the EPA MCL of 15 pCi/L within the study area with contours units in pCi/L

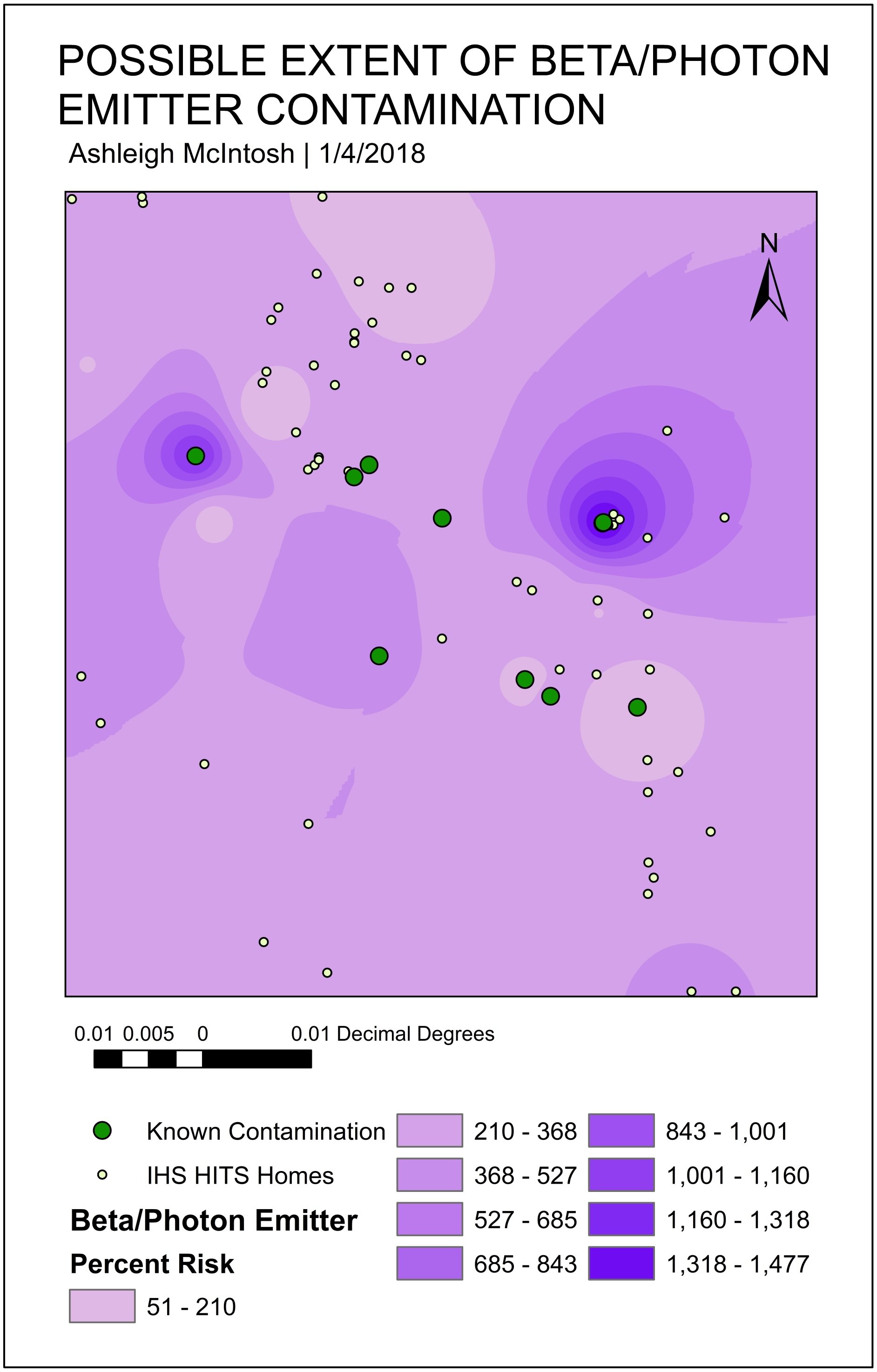

Figure 5: Possible Extent of Beta/Photon Emitter Contamination

This map shows the possible extent of beta/photon emitter groundwater contamination that exceeds the EPA MCL of 4 mrem/yr within the study area with contours in units of mrem/year, assuming residents spend around 344 days per year at 12 hours per day in their home

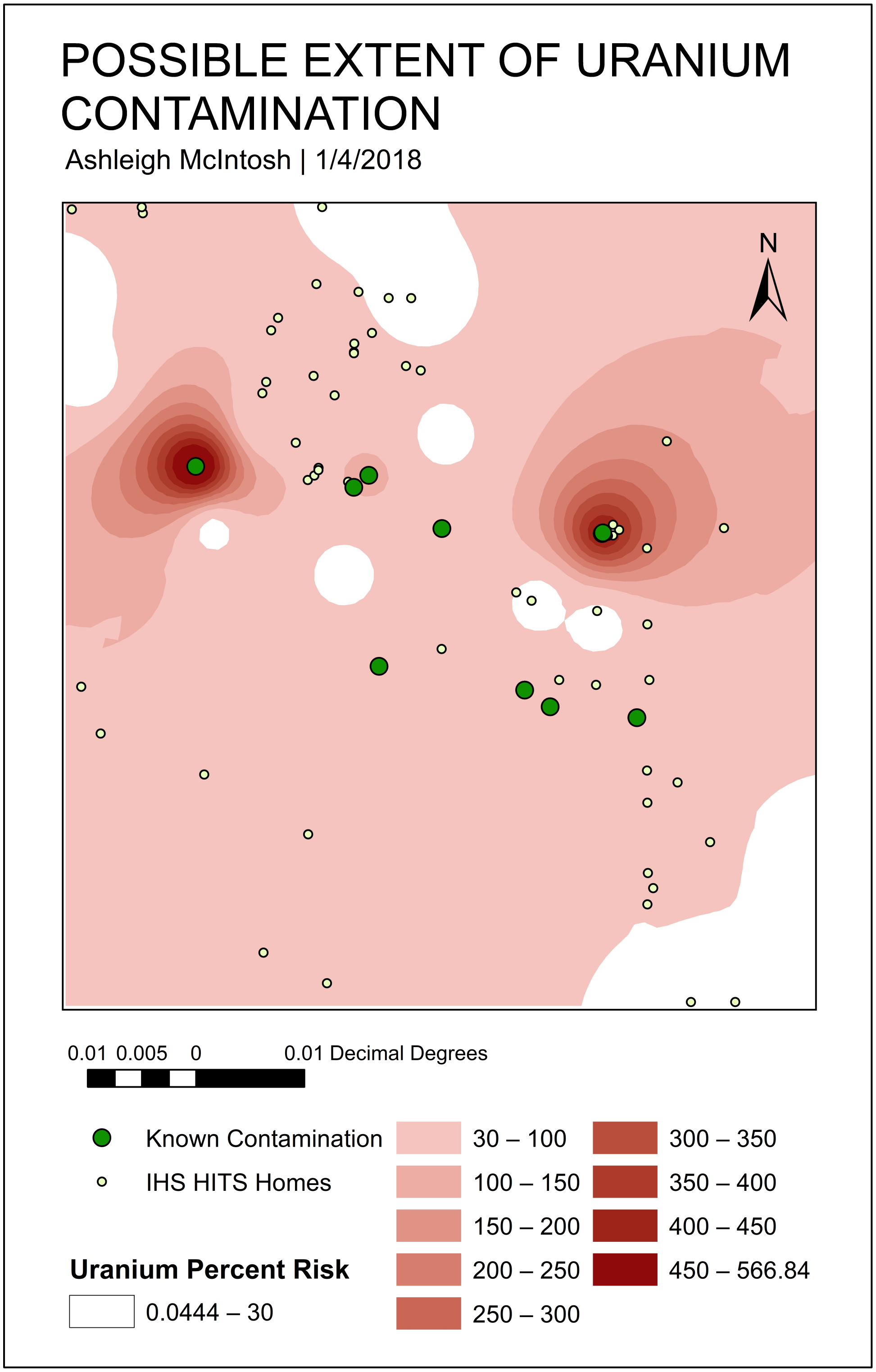

Figure 6: Possible Extent of Uranium Contamination

This map shows the possible extent of uranium groundwater contamination that exceeds the EPA MCL of 30 µg/L within the study area with contours in units of µg/L

The EPA suggests a gross alpha particle MCL of 15 pCi/L, which would lie within the first group in red and any group darker, shown in Figure 4. Therefore, it can be seen that most of the study area is at risk to draw water that surpasses the EPA MCL, but contamination is most likely higher toward the southeast part of the study area. All the homes in this analysis lie where there is possible risk of gross alpha particle contamination.

The EPA MCL for beta/photon emitters is 4 mrem/year, which would lie within any purple color, shown in Figure 5. Therefore, it can be seen that all of the study area is at risk to draw water that surpasses the EPA MCL, but contamination is most likely highest around the Hazel Dell IHS Home No 10847. All the homes in this analysis lie where there is possible risk of contamination due to beta/photon emitter.

The EPA MCL for Uranium is set at 30 µg/L, located within the first group in pink and any color darker, shown in Figure 6. It can be seen that most the study is at risk for uranium contamination. Six of the 63 homes in the study area are not in areas at risk for contamination. Seven homes are located in an area with possible contamination over 177 µg/L.

The tables include a percent risk of specific contaminant for Indian homes within the study area. Each table is organized by descending percent risk. All homes in the study area have some percentage of risk of groundwater contamination, but when disregarding homes not within the KTO Jurisdictional Area, the percent risk for each of the homes left increases due to a decrease in the number of homes included in the study. The six homes added to the study area outside of the KTO Jurisdictional Area are shown in Table A5 and A7 in blue. There are 26 homes that have over a 100 percent risk of uranium groundwater contamination (Tables A7 and A8).

A map was created (Figure 7) to show the risk for uranium contamination within the study site. Homes have been identified with a number 1 through 57. The EPA MCL for Uranium (30 μg/L) is exhibited by the first yellow shade or any shade darker. It can be seen that most the study area is at risk for uranium contamination, but eight of the 57 homes in the study area are in areas not at risk. Two homes are located in an area with possible contamination up to 195 μg/L. These homes were added on to KTO Rural Water System in 2009. Homes labeled 21 and 49 lie in areas with higher possible degree of contamination at 45-60 μg/L. Eight homes lie in areas of white showing that they have very low to zero risk of possible contamination. This includes homes 6, 7, 8, 11, 12, 13, 14, and 56, and these homes do not need further testing for uranium

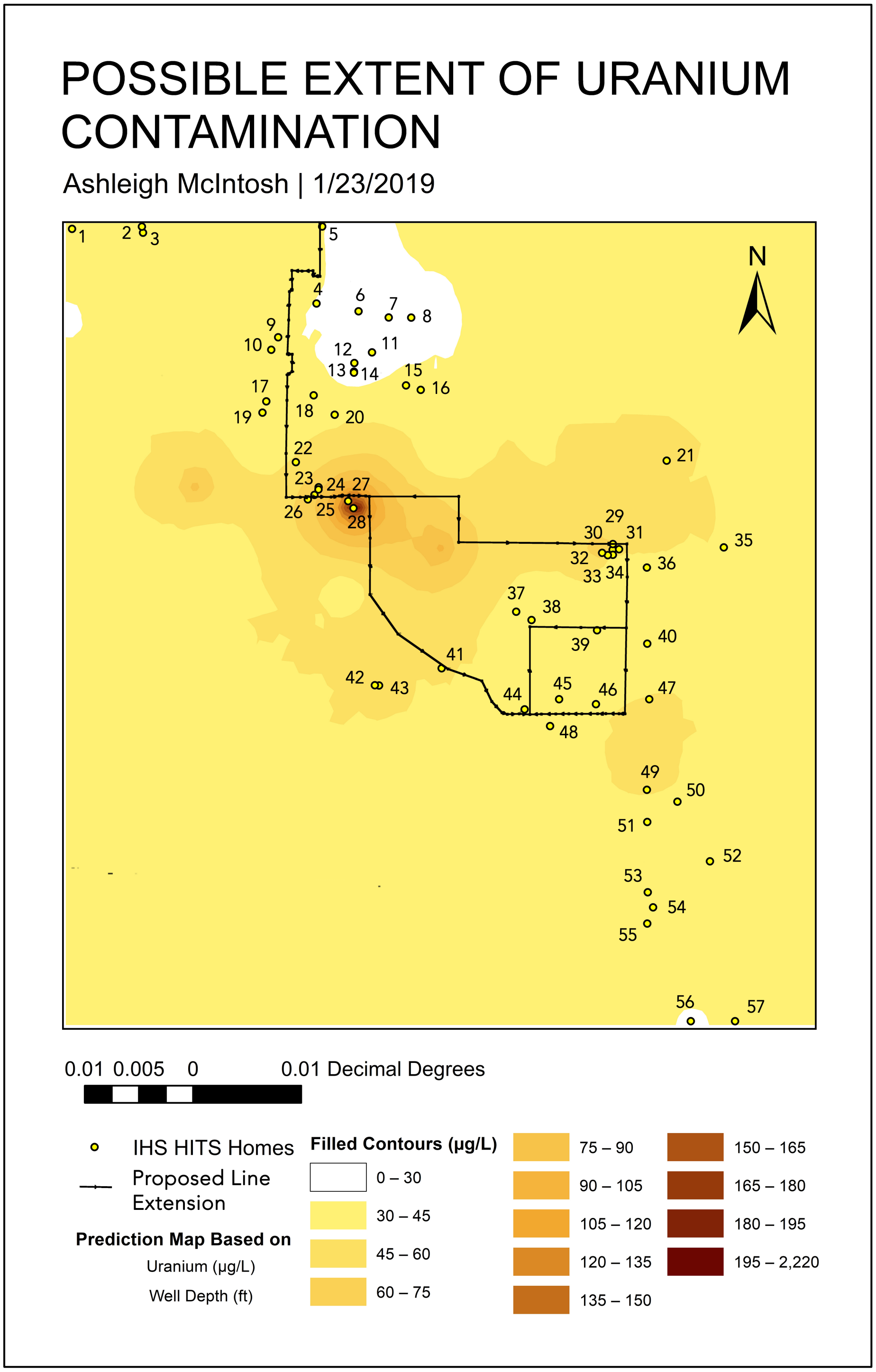

Figure 7: Possible Extent of Radium Contamination

This map shows the possible extent of uranium groundwater contamination within the study area with isoplats in units of µg/L. Homes have been identified with a number 1 through 57.

4.1.2 Hydraulic Model

The hydraulic model was created to gauge the possibility of an extension to the existing KTO water distribution system that would connect 19 Indian homes. Figure 3 gives visual of the proposed extension. The hydraulic model shows to the capacity to add 19 more homes to the current system. The proposed system would adequately deliver water to new and existing homes on line, meeting the minimum water pressure standard of 0.1724 MPa for waterline extensions of municipal water distribution systems as set by the ODEQ (2018).

4.1.3 Cost of Proposed Extension

The cost of extension is detailed in Table 2 below. Costs would include approximately 2,352 m (7,715 ft) of 15.24 cm diameter PVC, 6,847.9 m (22,467 ft) of 10.16 cm diameter PVC, 1899 m (6,231 ft) of 5.08 cm diameter PVC, and 11,099 m (36,413 ft) of tracer wire as well as 3 size 15.24 cm gate valves of, 8 size 10.16 cm gate valves, 2 size 5.08 cm gate valves, and 6 air relief valves for system high points. The project would also lay 19 2.54 cm diameter service lines with shut off valves and include membership and metering fees. The cost would also include approximately 64.0 m (210 ft) of 15.24 cm boring, 18 m (60 ft) of 10.16 cm boring, 9.1 m (30 ft) of 5.08 cm boring, and 64.0 m (210 ft) of 2.54 cm boring for road crossings (all bores with steel casing) as well as a lump sum for all tees, bends, and valves, including blocking. No dead ends are anticipated so flushing hydrants were not included.

Table 2: Cost Estimate for Proposed Extension

The cost estimate of the proposed waterline extension to deliver potable water to 19 residents in the Kickapoo Tribe of Oklahoma Jurisdictional Area was formatted to fit an Indian Health Service project document for the Sanitation Tracking and Reporting System database.

Indian Health Service Sanitation Deficiency System (SDS) Project Cost Estimate					
Project Name:	**Kickapoo/KTO PWS Distribution Loop**				
Service Area:	**Shawnee**				
Sponsor Tribe:	**Kickapoo Tribe of Oklahoma**				
Prepared By:	Ashleigh McIntosh		**Date Prepared:**		1/15/2018
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST
1	15.24 cm (6 in) SDR 21	7,715	LF	$12.00	$92,580.00
2	10.16 cm (4 in) SDR 21	22,467	LF	$8.00	$179,736.00
3	5.08 cm (2 in) SDR 21	6,231	LF	$5.00	$24,924.00
4	Road Bore – 15.24 cm	210	LF	$40.00	$8,400.00
5	Road Bore – 10.16 cm	60	LF	$30.00	$1,800.00
6	Road Bore – 5.08 cm	30	LF	$20.00	$600.00
7	Road Bore – 2.54 cm	210	LF	$10.00	$2,100.00
8	Gate Valve – 15.24 cm	3	EA	$850.00	$2,550.00
9	Gate Valve – 10.16 cm	8	EA	$650.00	$5,200.00
10	Gate Valve – 5.08 cm	2	EA	$450.00	$900.00
11	90° Bend – 15.24 cm	1	EA	$12.00	$12.00
12	90° Bend – 10.16 cm	1	EA	$8.00	$8.00
13	90° Bend – 5.08 cm	1	EA	$4.00	$4.00
14	Tee – 10.16 cm	1	EA	$4.00	$4.00
15	Tee – 15.24 cm x 10.16 cm	2	EA	$12.00	$24.00
16	Tee – 10.16 cm x 5.08 cm	2	EA	$8.00	$16.00
17	45° Bend – 10.16 cm	3	EA	$8.00	$24.00
18	Blocking	11	LS	$2,000.00	$22,000.00
19	Tracer Wire	36,413	LF	$0.15	$5,461.95
20	Air Relief Valves	6	EA	$600.00	$3,600.00
21	WSL	19	EA	$1,000.00	$19,000.00
22	RWD Meter & Membership	19	EA	$700.00	$13,300.00
23	Erosion Control	1	LS	$1,500.00	$1,500.00
24	ODEQ Construction Permit	1	LS	$1,500.00	$1,500.00
				Sub-Total	$385,243.95
				Contingency (10%)	$38,524.40
				Total Construction Cost	$423,768.35
				Project Technical Support (15%)	$64,000.00
				Total Project Cost	**$488,000.00**
				(Round up to Nearest Thousand)	
IHS Eligible Homes Served:		19	**IHS Unit Cost/Home:**		$25,684.21
Engineering fees are not applied to this project, as it will be designed by the IHS/Tribe/Nation.					
PTS is calculated at 15% of the IHS eligible cost with a min. of $5,000 and max. of $100,000.					

The expected design life of the infrastructure is approximately 50 years. The capacity of the proposed system includes the 19 Indian homes with known contamination in the area. With a 10 percent contingency and 15 percent technical support, the estimated total cost for the proposed extension is $488,000.00. This cost would be covered in full by IHS funding, tribal funding, and/or EPA funding. This cost would cover the connection of all 19 homes to the KTO Rural Water System. The cost per home is estimated to be $25,684.21. If more hot spots are located causing the proposed water line to be extended, this cost may need to be updated.

4.1.4 Cost of Best Available Treatment

The estimate for the cost of the BAT solution is detailed in Table 3 below. The total cost per home is $984,000.00. This cost would be fully covered by IHS funding, tribal funding, and/or EPA funding. The total cost for all 19 homes would be $18,753,000. The cost may need to be updated if IHS becomes aware of any more homes with contamination.

Table 3: Cost Estimate for Proposed Best Available Treatment Solution

The cost estimate of the BAT solution for 19 residents in the Kickapoo Tribe of Oklahoma Jurisdictional Area was formatted to fit and Indian Health Service project document for the Sanitation Tracking and Reporting System database.

Indian Health Service Sanitation Deficiency System (SDS) Project Cost Estimate					
Project Name:	**Kickapoo/KTO PWS Distribution Loop**				
Service Area:	**Shawnee**				
Sponsor Tribe:	**Kickapoo Tribe of Oklahoma**				
Prepared By:	Ashleigh McIntosh		**Date Prepared:**		1/23/2019
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST
1	Depth Filter Cartridge	11	EA	$12.00	$132.00
2	Celpure® P300 - 250 g	4,015	EA	$84.69	$340,030.35
3	Ion Exchange Columns	6	EA	$220.00	$1,320.00
4	Diaion® SK1B (Na) Ion Exchange Resin	108	EA	$50.60	$5,464.80
5	Manual and Automatic Valves	55	EA	$15.00	$825.00
6	Pressure Gauge	1	EA	$5.00	$5.00
7	PTFE Tubing, 1.59 mm OD x 0.18mm ID, 25m	1	EA	$58.30	$58.30
8	PTFE Tubing, 2.38 mm ID x 3.97 mm OD, 3.0 m	1	EA	$31.46	$31.46
9	Piping and Appurtenances	1	LS	$300.00	$300.00
10	Wastewater Disposal Fees	1	LS	$455,000.00	$455,000.00
				Sub-Total	$803,166.91
				Contingency (10%)	$80,316.69
				Total Construction Cost	$883,483.60
				Project Technical Support (15%)	$100,000.00
				Total Project Cost	**$984,000.00**
				(Round up to Nearest Thousand)	
IHS Eligible Homes Served:	1		**IHS Unit Cost/Home:**		$984,000.00
Engineering fees are not applied to this project, as it will be designed by the IHS/Tribe/Nation.					
PTS is calculated at 15% of the IHS eligible cost with a min. of $5,000 and max. of $100,000.					

4.2 Discussion

4.2.1 Possible Contaminant Sites

The methodology used to establish the visuals representing the simple risk surfaces using the Inverse-Distance Weighting Tool is questionable due to the fact that depth of well was not taken into account when finding the risk values. Therefore, these visuals were not used as accurate representations of where risk of contamination may be located. Figure 5 identifies homes that remain untested and may be at a higher risk of uranium contamination. Homes labeled 21 and 49 lie in areas at risk for a higher degree of contamination (45-60 µg/L). These homes are not included in the proposed solutions and may benefit from further sampling. Homes labeled 6, 7, 8, 11, 12, 13, 14, and 56 lie in areas a very low to zero risk of contamination, and do not need further testing for uranium. Degree of contamination was only found for uranium because lack of well depth data made it difficult to create an accurate map to show risk of contamination for other contaminants.

4.2.2 Efficiency of Solution

The most efficient solution in terms of cost would be the line extension. Cost per home of the proposed BAT solution is over $958,000.00 more than the cost per home of the proposed line extension. These costs would primarily be covered with IHS funding. The cost estimates for the proposed extension cover the material and construction for an expected life of 50 years. The costs estimated for proposed BAT solution covers constructions of units for the lifetime of the product as well as material needed and removal costs for one year. After one year, residents would be responsible for purchasing the diatomite and resin needed to refill the filter cartridges and ion exchange columns, respectively. For the diatomite, Celpure® P300 – 250 g containers would cost the residents over $340,000.00 per year. DIAION® SK1B resin would cost residents just under $5,400.00. The yearly cost for residents to sufficiently remove radionuclide contamination from their ground water would be approximately $345,400.00.

According to the USCB (2018), the average income per home in this area is $54,985. The cost of $345,400 per year to upkeep the BAT treatment system after one year of use would not be feasible for residents. The most efficient solution in terms of ease of use would also be line extension. Line extension would require occasional maintenance from the tribal operator, but the current operator already has sufficient means to handle the proposed extension. More importantly, no maintenance would be required by the resident for a line extension while the BAT solution would require the residents to change diatomite in the ceramic depth filter daily and the ion exchange resin every 10 days. The residents would then also be responsible for properly disposing of the spent diatomite and resin. The BAT available solution would also require extra costs and commitment from the KTO environmental department to handle waste and contract an outside source to properly dispose of the waste. Therefore, the most feasible solution for residents, the tribe, and IHS would be a line extension.

5. CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

5.1 Conclusions

The study area of this project is located in the southern half of the KTO Jurisdictional Area where various residents were drawing groundwater contaminated with naturally occurring radionuclides. Because these homes lie within a tribal jurisdictional area, the IHS decided to determine the feasibility of extending the KTO Rural Water System to reach the homes. It is necessary to make sure that individual treatment or treatment at the source is not better than line extension to help IHS in making the right decision. Therefore, the purpose of this project was to determine the most feasible option for providing potable water to residents with naturally occurring radionuclide groundwater contamination as well as to establish a means to determine where a potential risk of radionuclide contamination may lie within the study area.

A hydraulic model was completed as a means to design a line extension. The BAT solution was based on the work done by Huang et al. (2012) and included three different sizes of diatomite based ceramic depth filter and a strong acid cation exchange unit with DIAION SK1B sodium based resin. It was found, based on the cost estimates done for both solutions, that line extension would be the most feasible option, in terms of cost and ease of use, for residents, the tribe, and IHS. Individual treatment systems leave residents with hazardous wastes that they would be responsible for handling and disposing of properly. A line extension provides minimal cost and maintenance for the homeowner while ensuring that the residents are supplied with safe water

Work was also done in ArcGIS to a good visualization of where homes could benefit from immediate testing. 49 of the 57 homes in the study area lie within an area at risk for contamination. Two homes, not included in the group of 19 homes to be impacted by this project, are at a higher risk of uranium contamination (45-60 μg/L) and may benefit from further chemical testing.

Limitations of this study include limited testing results as data inputs. The USGS only collected samples from 20 wells in this area to gauge the extent of contamination for an approximate population 132. The results and analysis are also based on limited data for well depths. The cokriging tool was able to make an assumption of where contamination may be located with respect to the depth of well, but the accuracy of this tool is questionable with such limited data.

5.2 Recommendations

It is recommended that the proposed line extension be implemented in order to provide residents with potable water from a stable source. It is also suggested that at least the two homes labeled 21 and 49 in Figure 2 be tested for radionuclide contaminants. If more funding is available, it is recommended that homes labeled 1, 2, 3, 15, 16, 20, 35, 50, 51, 52, 53, 54, 55, and 57 in Figure 2 also be tested for contaminants.

5.3 Future Work

Future work plans include the implementation of this project in the IHS STARS database and further chemical testing for at least the two homes labeled 21 and 49 in Figure 2.

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APPENDIX A: TABLES

Table A 1: Diurnal Time Demand Variables for Hydraulic Model

The time variable demand multipliers used to simulate the change in demand in the span of 24 hours for the WaterCAD model of the proposed line extension

Time from Start (hours)	Multiplier
3.00	0.200
6.00	0.400
9.00	0.600
12.00	0.400
15.00	0.400
18.00	1.000
21.00	0.400
24.00	0.200

Table A 2: 48 Hour Period Time Demand Variables for Hydraulic Model

These time variable demand multipliers were used to simulate the change in demand in the span of 48 hours for the hydraulic model of the proposed extension done in WaterCAD. These values were calibrated using pressure measurements taken from the field.

Time from Start (hours)	Multiplier
3.00	0.200
6.00	0.400
9.00	0.600
12.00	0.400
15.00	0.400
18.00	1.000
21.00	0.400
24.00	0.200
27.00	0.200
30.00	0.400
33.00	0.600
36.00	0.400
39.00	0.400
42.00	1.000
45.00	0.400
48.00	0.200

Table A 3: Pump Definition for Pumps 1 and 3

A standard (3 point) pump definition used to simulate Pumps 1 and 3 in the hydraulic model of the proposed extension done in WaterCAD

	Flow (gpm)	Head (ft)
Shutoff:	0	247.16
Design:	16	230.00
Max. Operating:	20	208.16

Table A 4: Pump Definition for Pump 4

A standard (3 point) pump definition used to simulate Pump 4 in the hydraulic model of the proposed extension done in WaterCAD

	Flow (gpm)	Head (ft)
Shutoff:	0	247.16
Design:	14	230.00
Max. Operating:	18	208.16

Table A 5: Risk of Gross Alpha Particle Contamination for Indian Homes within the study area and the KTO Jurisdictional Area

These percent risk values of gross alpha particle groundwater contamination are for Indian American home locations, based on the Indian Health Service Home Inventory System, located within the study area and the Kickapoo Tribe of Oklahoma Jurisdictional Area.

IHS HITS Home No.	Latitude	Longitude	Percent Risk
38605	35.405287	-97.031649	101.577384
37293	35.405282	-97.027558	90.649755
10812	35.43253	-97.044649	87.698518
162438	35.426641	-97.035709	86.367477
124794	35.435004	-97.035485	85.907096
172148	35.42555	-97.03288	85.028571
112815	35.42368	-97.035669	84.71934
183349	35.435003	-97.043816	84.379123
112716	35.43455	-97.040407	84.246833
172151	35.434074	-97.047005	84.209663
112710	35.42004	-97.029874	83.750086
112624	35.414295	-97.03567	82.897996
19787	35.415793	-97.035134	82.89479
112569	35.417192	-97.035625	82.87207

10755	35.43627	-97.060449	82.443211
155669	35.436294	-97.060837	82.278931
112788	35.44014	-97.035673	75.201764
19227	35.437861	-97.054667	73.880493
35514	35.441372	-97.040305	72.147998
10715	35.442314	-97.046359	71.329425
112723	35.449023	-97.028603	70.178912
25822	35.443083	-97.047778	70.075581
112816	35.447155	-97.0357	68.982583
129387	35.457031	-97.033881	68.564853
112720	35.448852	-97.038269	68.462693
162424	35.449333	-97.038845	68.442381
10753	35.448334	-97.038849	68.44016
10078	35.448806	-97.03887	68.435917
10847	35.448299	-97.039308	68.431212
112715	35.44852	-97.039837	68.421207
162432	35.463558	-97.056592	49.306843
112702	35.463969	-97.057955	48.263985
10721	35.45264	-97.062814	47.650742
19239	35.453297	-97.063301	47.504817
54087	35.454365	-97.066044	43.859803
10539	35.454576	-97.066028	43.776014
35642	35.453867	-97.066414	43.518893
112654	35.461264	-97.064545	42.578399
10900	35.453456	-97.067022	42.547791
112493	35.467016	-97.061094	41.468634
112441	35.465238	-97.06276	41.388652
112494	35.465145	-97.06276	41.388652
10811	35.466035	-97.062728	41.087549
11032	35.470227	-97.057477	40.876435
9642	35.470238	-97.05955	40.415215
9858	35.470819	-97.062341	39.698249
10540	35.45689	-97.068134	39.392247
112691	35.463063	-97.06649	39.289515
33238	35.471528	-97.066222	37.953347
181970	35.46841	-97.069767	36.91598
112448	35.467265	-97.07041	36.451474
10945	35.462497	-97.070863	35.63129
112625	35.461455	-97.07121	35.228348
182302	35.478637	-97.065698	34.054438
128531	35.47863	-97.082348	33.015884

112697	35.478062	-97.082248	32.993979
10674	35.478416	-97.088805	31.745077

Table A 6: Risk of Uranium Contamination of Indian Homes in the Study Area and KTO Jurisdictional Area

Percent risk of uranium groundwater contamination for Indian home locations, based on the Indian Health Service Home Inventory System, located within the study area and the Kickapoo Tribe of Oklahoma Jurisdictional Area

IHS HITS Home No.	Latitude	Longitude	Percent Risk
112715	35.44852	-97.039837	794.1735
10847	35.448299	-97.039308	774.5923
10078	35.448806	-97.03887	764.737
10753	35.448334	-97.038849	759.2382
162424	35.449333	-97.038845	748.4479
112720	35.448852	-97.038269	724.0668
112816	35.447155	-97.0357	433.3876
129387	35.457031	-97.033881	278.4395
112723	35.449023	-97.028603	248.5705
10721	35.45264	-97.062814	180.7732
19239	35.453297	-97.063301	178.7925
10900	35.453456	-97.067022	154.4015
35642	35.453867	-97.066414	153.6658
54087	35.454365	-97.066044	152.9782
10539	35.454576	-97.066028	151.869
112448	35.467265	-97.07041	127.3419
181970	35.46841	-97.069767	118.6282
112654	35.461264	-97.064545	117.9028
112788	35.44014	-97.035673	115.2513
124794	35.435004	-97.035485	113.5194
112691	35.463063	-97.06649	111.5923
162438	35.426641	-97.035709	109.0617
10540	35.45689	-97.068134	106.9747
172148	35.42555	-97.03288	103.3138
10945	35.462497	-97.070863	101.4229
112815	35.42368	-97.035669	100.8386
112441	35.465238	-97.06276	95.84344
112494	35.465145	-97.06276	95.84344
112697	35.478062	-97.082248	90.89265
128531	35.47863	-97.082348	90.70885
19227	35.437861	-97.054667	90.62873

10811	35.466035	-97.062728	89.91836
112716	35.43455	-97.040407	88.1728
112569	35.417192	-97.035625	82.12646
33238	35.471528	-97.066222	79.44947
112702	35.463969	-97.057955	77.00567
19787	35.415793	-97.035134	75.86151
162432	35.463558	-97.056592	75.45022
112625	35.461455	-97.07121	75.1217
112710	35.42004	-97.029874	73.75489
10812	35.43253	-97.044649	73.20202
183349	35.435003	-97.043816	71.97456
112624	35.414295	-97.03567	70.75563
10674	35.478416	-97.088805	68.86777
155669	35.436294	-97.060837	68.52908
10755	35.43627	-97.060449	68.30556
112493	35.467016	-97.061094	66.87096
9858	35.470819	-97.062341	53.70218
25822	35.443083	-97.047778	51.97375
172151	35.434074	-97.047005	51.16478
182302	35.478637	-97.065698	25.03508
9642	35.470238	-97.05955	24.24594
35514	35.441372	-97.040305	19.0298
37293	35.405282	-97.027558	17.1904
10715	35.442314	-97.046359	8.448886
38605	35.405287	-97.031649	4.296197
11032	35.470227	-97.057477	3.127549

APPENDIX B: CALCULATIONS

CALCULATIONS FOR NUMBER DIATOMITE CONTAINERS NEEDED

Capacity

$$Capacity = Volume\ of\ Water\ Before\ Capacity \times Concentration\ of\ Contaminant\ Filtered\ at\ Capacity \times \frac{1\ L}{1000\ mL}$$

where

Volume of Water Before Capacity	is	mL, found in Huang et al. (2012)
Concentration of Contaminant Filtered at Capacity	is	Found in Huang et al. (2012)

Estimated Removal

$$Removal = Concentration\ of\ Contaminant \times \frac{Percent\ Removal}{100}$$

where

Concentration of Contaminant	is	From the chemical analysis of HITS Home No. 10847
Percent Removal	is	Found in Huang et al. (2012)

Volume of Treated Water

$$Volume = \frac{Capacity}{Estimated\ Removal}$$

Diatomite Containers Needed per Day

$$Containers = \frac{Volume\ of\ Treated\ Water}{Demand\ of\ Home\ per\ Day}$$

where

Demand of Home per Day is 795 L/day (EPA, 2018b)

Note:

Number of containers was based on the volume of water needed to remove gross alpha particle. Diatomite has a lower capacity for gross alpha particle than for beta/photon emitters, and ion exchange would be the primary removal method for uranium. The total volume of treated water was calculated from adding the volume of water need to treat gross alpha particle, beta/photon emitters, and uranium.

Diatomite Containers Needed per Year

$$Containers = \frac{Containers}{Day} \times \frac{365\ Days}{Year}$$

CALCULATIONS FOR MASS OF RESIN NEEDED AND TIME PER CYCLE OF RESIN

Equivalent Weight of Uranium

$$EW = \frac{MW}{z}$$

where

MW is Molecular weight of uranium (g/mol)
z is Charge of molecule

$$59.5 = \frac{283\,\frac{g}{mol}}{4}$$

where 4 is a conservative estimate of charge, assuming the dominant uranium species would be a uranyl carbonate of $UO_2(CO_3)_3^{4-}$.

Concentration of Uranium (meq/L)

$$Concentration_{meq} = \frac{Concentration_{mg}}{EW}$$

where

$Concentration_{mg}$	is	The residual concentration of uranium after treatment by diatomite based ceramic depth filters (mg/L)
EW	is	Equivalent weight

$$0.000991597\frac{meq}{L} = \frac{0.059\frac{mg}{L}}{59.5}$$

Total Capacity of Resin (meq)

$$Total\ Capacity = Capacity\ per\ Liter \times Volume\ of\ Resin$$

where

Capacity per Liter	is	Found in the specifications for the resin (2 meq/L)
Volume of Resin	is	Liters

Possible Volume of Treated Water

$$Volume = \frac{Capacity}{Concentration_{meq}}$$

where

Capacity	is	Total capacity of resin (meq)
Concentration	is	meq/L

Note:

Values were found via spreadsheet based on volume of resin. The volume of treated water needed to be closest to but greater than the weekly demand per home (EPA, 2018b) and was chosen to be 6.05 m^3.

Total Mass of Resin Needed (kg; rounded to the nearest whole number)

$$Mass \approx density \times Volume\ of\ Resin \times \left(\frac{1\ kg}{1000\ g}\right)$$

where

Density	is	Found in the specifications for the resin (750 g/L)
Volume of Resin	is	Liters

$$3\ kg \approx 750\ \frac{g}{L} \times 3\ L \times \left(\frac{1\ kg}{1000\ g}\right)$$

Note:

The mass of resin was rounded up to the nearest whole number to accommodate the unit available for purchase. A 3kg mass of resin is actually able to accommodate a 8.07 m^3 volume of treated resin.

Days per Cycle of Resin (based on capacity of 3 kg of resin)

$$Time = \frac{Volume\ of\ Treated\ Water}{Demand\ of\ Home\ per\ Day}$$

where

Volume of Treated Water	is	Found in the specifications for the resin (750 g/L)
Demand of Home per Day	is	795 L/day (EPA, 2018b)

$$10\ days = \frac{8.07\ m^3}{795\ \frac{L}{day}} \times \left(\frac{1000\ L}{1\ m^3}\right)$$

Mass of Resin Needed (per year)

$$Mass = Total\ Mass\ of\ Resin\ \ per\ Cycle \times \left(\frac{36\ ten\ day\ period}{year}\right)$$

$$106\frac{kg}{year} = 3\frac{kg}{cycle} \times \left(36\frac{ten\ day\ period}{year}\right)$$