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Sunflower Seedlings Fail to Remove Uranium Pollution in the Navajo Nation: Participatory Science as a Path to Build Community and Address Environmental Injustice

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Honors Thesis

SUNFLOWER SEEDLINGS FAIL TO REMOVE URANIUM POLLUTION IN THE NAVAJO NATION: PARTICIPATORY SCIENCE AS A PATH TO BUILD COMMUNITY AND ADDRESS ENVIRONMENTAL INJUSTICE

by
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ABSTRACT

SUNFLOWER SEEDLINGS FAIL TO REMOVE URANIUM POLLUTION IN THE NAVAJO NATION: PARTICIPATORY SCIENCE AS A PATH TO BUILD COMMUNITY AND ADDRESS ENVIRONMENTAL INJUSTICE

Zak Webber
Molecular Biology
Bachelor of Science

Mid-20th century mining on Naabeehó Bináhásdzo (Navajo Nation) polluted groundwater with high concentrations of uranium and arsenic. The Navajo Nation and other rural residents of this region use groundwater for drinking, livestock, and irrigation. However, many individuals and communities must purchase and transport treated water from locations that are often hours away. Sunflowers have been shown to preferentially take up heavy metals, including uranium and arsenic, potentially representing a tool to improve water quality through on-site, low-cost phytoremediation. We carried out a collaborative research project with a high school class on the Navajo Nation in 2018 and 2019. The students collected surface water from wells and streams near where they lived, which we analyzed for general chemistry parameters. We then performed a laboratory experiment with sunflower seedlings grown in local soil to assess whether phytoremediation could be effective at removing arsenic and uranium. We found that arsenic concentration did not change over the course of the experiment and uranium concentration increased, potentially associated with weathering of the geologically young

soil in this area. Though it appears phytoremediation is not a feasible solution for heavy-metal contamination in the Navajo Nation, the participatory science approach created meaningful relationships and an important collaboration. Additionally, this project provided experiential learning opportunities for Navajo high school students and the BYU undergraduate students who worked with them.

ACKNOWLEDGEMENTS

This project is the result of many individual's passion for science within their community. Thanks to the community at Brigham Young University, I have had the wonderful opportunity to pursue a question that was important to me. I am grateful for the insight given from many professors and the enthusiasm of the honors advisors. The funding from the honors project allowed me to pursue my thesis question and pay for much of the analysis.

I was extremely fortunate to be connected to Tommy Rock who was instrumental in giving me the initial direction for this project. His research and connection to Navajo Nation greatly impacted the success of our project. I thank him for his patience with me as I tried to approach a project that was in many ways outside of my field.

Sarah Groenwald went above and beyond the expectations of our collaboration. Her students and classes performed the experiments and willing served as our laboratory technicians. Without her collaboration I could not have been successful in this endeavor. I am grateful to her for her hospitality and dedication to the project.

I am grateful to Isaac St. Clair, Rebekah Frei, and other members of the lab who worked to teach me analysis, learn how to acid rinse all sorts of objects. I was amazed by the kindness that both demonstrated to me throughout this process. They were helpful connecting me to lab resources and tools.

Above all I express my gratitude to Ben Abbott who was willing to take on a unique project as I pursued a "what if?". In many moments of discouragement, I felt buoyed up by his interest in the research and his concern for me. He has mentored me in experimental design, writing, and data analysis. Without him this project would not have been possible. I am deeply touched by the energy and investment Dr. Abbott has put into this project.

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Important terms and definitions

Phytoremediation- Restoring an environment using plant life.

Rhizofiltration- Removing a solute or particulate constituent through root processes.

Endemic- Plant or soil that originally comes from the referenced area.

Regolith- Unweathered or poorly weathered rocky material present above bedrock.

Soil matrix- The living and nonliving constituents (soil particles, roots, animals) that make up the solid portion of the soil.

Soil solution- The water and dissolved constituents that exist within and around the soil matrix.

Abiotic interactions- Non-biological relationships such as physical or chemical reactions involving water, regolith, light, etc.

Helianthus annuus- A "mammoth" sunflower species cultivated commonly in many areas of the world.

Participatory science- An approach that involves non-professionals (e.g. community members, students, etc.) in the research process. Participating individuals may contribute to identifying the research question, setting priorities, collecting data, and interpreting and communicating results.

Background

Uranium mining sponsored by the U.S. government in the late 20th century degraded public health, agriculture, and the biosphere of the Four-Corners region[1] of the United States[2]. These effects have directly affected the lifestyle and livelihood of the Diné people, commonly referred to as the Navajo[3]. The hundreds of abandoned mine structures in the Navajo Nation have been linked with the presence of trace heavy metals, such as uranium and arsenic in soils and water[4]. Exposure to uranium causes many adverse health effects including hypertension, renal

Figure 1. Photo of a contaminated well on the Navajo Nation. Groundwater and surface water were polluted with uranium, arsenic, and other heavy metals from widespread mining during the 20th century.

[1]Dashner-Titus, E. J., Hoover, J., Li, L., Lee, J.-H., Du, R., Liu, K. J., Traber, M. G., Ho, E., Lewis, J., & Hudson, L. G. (2018). Metal exposure and oxidative stress markers in pregnant Navajo Birth Cohort Study participants. *Free Radical Biology and Medicine*, *124*, 484–492. https://doi.org/10.1016/j.freeradbiomed.2018.04.579

[2] Navajo Nation: Cleaning Up Abandoned Uranium Mines. (2020, January 14). Retrieved from https://www.epa.gov/navajo-nation-uranium-cleanup

[3] *Uranium Contamination in the Navajo Nation: An Environmental Justice Impact Analysis | Global Ecological Humanities*. (2017). Duke.Edu. https://sites.duke.edu/lit290s-1_02_s2017/2017/03/03/uranium-contamination-in-the-navajo-nation-an-environmental-justice-impact-analysis/

[4] Brugge, Doug, and Rob Goble. "The History of Uranium Mining and the Navajo People." *American Journal of Public Health* 92, no. 9 (September 2002): 1410–19.

failure, and autoimmune disease [5] and is considered unsafe for human consumption in concentrations of 30 µg/L[6]. Arsenic is also commonly found in water sources and even small amounts of arsenic can be toxic and cause vomiting and even death. Many wells have been shut down due to uranium and arsenic concentrations in exceedance of the Environmental Protection Agency (EPA) standards. Despite these measures many Navajo were in the 95th percentile of urine concentrations of U indicating ongoing contamination[7]. The EPA has acknowledged the seriousness of uranium mining contamination, but despite increased scientific investigation[8], a cost-effective solution to resolve this issue has yet to be found.

Many members of the Navajo Nation have limited access to clean water because mine tailings have contaminated their groundwater[2]. Consequently, families must travel to wells that are often hours away to collect water that is safe for consumption, leading to health and resource disparities[9]. This is a classic example of environmental injustice, when the individuals who benefited from environmental degradation are not those who

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[5] US EPA,REG 09. (2016, June 15). *Providing Safe Drinking Water in Areas with Abandoned Uranium Mines | US EPA*. US EPA. https://www.epa.gov/navajo-nation-uranium-cleanup/providing-safe-drinking-water-areas-abandoned-uranium-mines. *See also:* "Health Effects of Uranium" on website.

[6] Table 2. Navajo Nation Contaminated Unregulated Water Sources. (2012). Epa.gov. Retrieved 30 October 2018, from https://www.epa.gov/sites/production/files/2016-06/documents/watersourcestable-with-mcls.pdf

[7] *Evaluation of Water Cistern Contamination and Health Risks in the Navajo Nation*. (2020). https://www.cdc.gov/nceh/hsb/cwh/navajo_nation.htm

[8] US EPA,OA. (2018, September 10). *U.S. EPA awards $429,000 to Diné College for abandoned uranium mine studies. US EPA*. US EPA. https://www.epa.gov/newsreleases/us-epa-awards-429000-dine-college-abandoned-uranium-mine-studies

[9] Fact Sheets, Disparities. (2013). *Disparities. Fact Sheets*. Newsroom. https://www.ihs.gov/newsroom/factsheets/disparities/

bear its cost[10]. In this case, the general U.S. population benefitted from the uranium mining, which enhanced national security and provided energy, but the residents of the sovereign Navajo Nation alone are suffering the environmental consequences of this mining.

I have personally seen the individual and family difficulties caused by groundwater contamination in the Navajo Nation. In 2018, I had the opportunity to teach Navajo students in 7th to 10th grade. When I learned that a third of Navajo still do not have access to potable water at home[2], I felt the urgency of addressing this injustice and decided to focus on this subject for my thesis. Long trips to collect clean water were a part of their life, and I saw how this burden affected students and families. Additionally, while families will travel great distance for personal drinking water, many unregulated wells are used by livestock, despite concentrations of uranium that are considered unsafe for human consumption[3]. It is unknown whether uranium is bioaccumulating in the meat or milk of the livestock drinking contaminated water or in the tissues of crops watered with contaminated water in the Navajo Nation, though this is a potential vector for human harm[11]. To my knowledge, there is no testing of livestock or crops produced in the Navajo Nation, though these are widespread food sources[7]. The local community has gone to great lengths to solve water contamination. They have dug new wells, trucked water to aquifers, and investigated wells which are contaminated. However, many of these solutions are costly and require specialized equipment.

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[10] Daniels, Brigham, Michalyn Steele, and Lisa Grow Sun. "Just Environmentalism." SSRN Scholarly Paper. Rochester, NY: Social Science Research Network, May 1, 2018. https://papers.ssrn.com/abstract=3178353.

[11] Corlin, L., Rock, T., Cordova, J. et al. Health Effects and Environmental Justice Concerns of Exposure to Uranium in Drinking Water. Curr Envir Health Rpt 3, 434–442 (2016). https://doi.org/10.1007/s40572-016-0114-z

In the past few decades, phytoremediation (using plant growth to reduce soil pollutants) has been applied in other areas with heavy-metal contamination. This approach has substantial benefits because of its low cost and relatively simple infrastructure requirements[12]. Several different processes are involved in phytoremediation, including rhizofiltration, where plant roots accumulate contaminants through passive or active uptake (Fig. 1). When active uptake occurs, the plant preferentially removes the contaminant from the soil solution faster than it takes up water for transpiration. This has been shown to work for many heavy metals, including arsenic[13]. Until recently, few plants had been tested for their ability to remediate uranium-contaminated water[14]. However, Lee and Yang recently discovered that, in a hydroponic environment, H*elianthus annuus* (the common sunflower) successfully removes uranium with a peak removal of 90% in less than 10 hours[15]. Their research

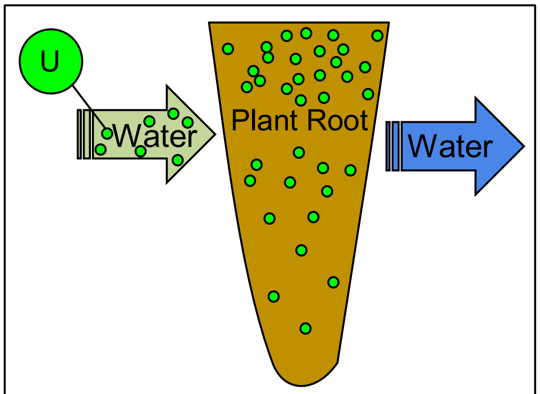

Figure 1. Conceptual drawing of rhizofiltration. As the plant root interacts with water in the soil solution, it takes up pollutants (in this case the solute uranium) and accumulates them in the plant biomass, improving the water quality.

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[12] Lone, M. I., He, Z. L., Stoffella, P. J., & Yang, X. E. (2008). Phytoremediation of heavy metal polluted soils and water: progresses and perspectives. Journal of Zhejiang University. Science. B, 9(3), 210-20.

[13] Abbas, Ghulam et al. "Arsenic Uptake, Toxicity, Detoxification, and Speciation in Plants: Physiological, Biochemical, and Molecular Aspects." International Journal of Environmental Research and Public Health 15.1 (2018): 59. PMC. Web. 10 Oct. 2018.

[14] "Memorandum: May 16, 2005. Phytoremediation Pilot Study at the Monument Valley UMTRA site". Madeline Roanhorse. Navajo AML/UMTRA Department. Accessed Oct. 24 2018. file:///home/chronos/u-6be40415b559bbcfc34ed78cf14fa8eac8d27c89/Downloads/MON000033.pdf

[15] Lee M, Yang M. "Rhizofiltration using sunflower (Helianthus annuus L.) and bean (Phaseolus vulgaris L. var. vulgaris) to remediate uranium contaminated groundwater". J Hazard Mater. 2010 Jan 15;173(1-3):589-96. Doi:10.1016/j.jhazmat.2009.08.127. Epub 2009 Sep 1. PubMed PMID: 19783370.

suggests that sunflowers and related species could be effective in the removal of uranium from contaminated water.

The discovery of sunflower rhizofiltration of uranium raises several questions with scientific and societal implications. Would this method be effective at removing uranium from contaminated water in a soil matrix, rather than only in a hydroponic environment? Specifically, does the filtration work in the arid soil of Navajo Nation as effectively as in a hydroponics system without mineral interactions? How might differences in chemistry and soil organisms increase or decrease the filtration rate? Is this method scalable to a rural area with many end consumers and no centralized water distribution system? To address these questions, I initiated a project with my faculty adviser to collaborate with high school students in the Navajo Nation and undergraduate students from BYU. Using this participatory approach, we evaluated the efficacy of phytoremediation in a laboratory incubation using soil from the Navajo Nation.

Methods

Initiating the collaboration

We undertook this project from a framework of environmental justice and community collaboration. This approach, which is commonly referred to as citizen science or participatory science, can increase the relevance and quality of scientific research, particularly when the area of scientific inquiry has implications for society[16]. As opposed to a "scientist-only" approach, which may or may not respond to external input and priorities, a community centered approach seeks input from community collaborators and other stakeholders. A community centered approach seeks to determine the relevance of the research by integrating the input of non-professionals in the scoping, implementation, and interpretation of the work. While there has been some resistance to and criticism of participatory approaches for potential issues in data quality and control, these methods have effectively been implemented in many fields of research including environmental hydrology[17]. Because they involve the community in the whole scientific process, the benefit of science is more apparent and can deliver valuable experiences to local participants before the sometimes-long time lags between data collection and peer-reviewed publication of results[16].

We began our project by identifying collaborators within the Navajo Nation. We

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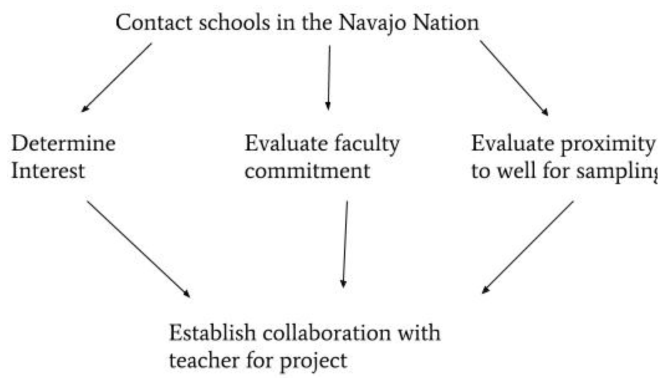
[16] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., De BiÃ¨vre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D. M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., … Zhumanova, M. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, *2*. https://doi.org/10.3389/feart.2014.00026

[17] Abbott, Benjamin W., Florentina Moatar, Olivier Gauthier, Ophélie Fovet, Virginie Antoine, and Olivier Ragueneau. "Trends and Seasonality of River Nutrients in Agricultural Catchments: 18 Years of Weekly Citizen Science in France." *Science of The Total Environment* 624 (May 15, 2018): 845–58. https://doi.org/10.1016/j.scitotenv.2017.12.176.

contacted high schools to gauge interest and considered the research objectives in discussion with potential collaborators within the Navajo Nation prior to formulating the full scope of our project. We identified a list of schools and contacted administrators via phone and email. We made additional contacts through social media platforms such as LinkedIn ©. Schools were selected based on interest and proximity to well data provided by our collaborator Tommy Rock (Ph.D.) who sampled well data for the Navajo Nation Environmental Protection Agency. Of eight schools contacted, two expressed interest and one had an environmental science teacher (Ms. Groenwald) who readily committed to the project. For these reasons, we worked with Chinle high school as our collaborating school (Fig. 2).

Figure 2. Method of establishing high school collaboration:



Once we had established a collaboration with Ms. Groenwald, we arranged a visit on April 5, 2019 to meet the students at Chinle High School and review the experimental design. Dr. Rock presented us to the class who would be participating in the research project.

In addition to the engagement at the high-school level, we contacted the Navajo Nation Environmental Protection Agency and inquired whether they were interested in collaborating. Members of the Navajo Nation Protection Agency felt the project was important and should be presented to the tribal chapters for approval. They expressed interest in the project and provided information about the history of uranium problems in the Navajo Nation water supply. An appointment was made with the Many Farms Tribal Chapter. We prepared and informational packet and proposal that requested approval from the council of elders. We provided these materials to Ms. Groenwald who presented them to the chapter on April, 8 2019 explaining the goals of the project. The elders were very accommodating and provided the location of wells for sampling and offered additional assistance if necessary.

Experimental design

The collaboration consisted of two major components: 1. collection of surface-water by students and 2. a student-led phytoremediation experiment. I describe both of these below.

During our first visit to Chinle High School, we initiated a sample collection project to catalyze reflection in students of the causes of water quality. We invited each student to select a location from surface-water sources and wells near where they lived (Table 1). Prior to departing, we taught students the procedure for collecting a water sample and distributed 125 mL and 60mL high-density polyethylene (HDPE) bottles, syringes, and filters. We left a detailed protocol with images and illustrations of the process for each student.

Table 1. Outline of procedure for sample collection used by citizen scientists.

Step	Process
1. Locate site	Find site, note weather conditions, note temperature, record bottle ID and any other observations.
2. Fill the 250 mL bottle	Fill bottle with unfiltered water. Avoid solid things, leaves, floating objects, etc. If possible, find an area where the water is flowing.

3.	Fill the 30 mL bottle with filtered water	Using syringe, suck up water using the same guidelines as step 2. Next, place the filter on the syringe end and gently expel the water through into the bottle. Be careful not to push too hard or the filter could break.
4.	Preserve the sample	When returning to class have the teacher place 1 drop of HCl in the filtered bottle. Keep samples cool.

We analyzed the student-collected samples for several parameters to help students think about the water quality in the area they live. From the unfiltered bottle, we used a field-deployable spectrophotometer (s::can Messtechnik GmbH, Vienna) to quantify nitrate, total organic carbon, dissolved organic carbon, and turbidity, common water quality parameters. We also used an ion chromatography system (Thermo Scientific Dionex, Sunnyvale) to quantify major anions and cations (dissolved constituents in the water that vary with water source and other conditions). We shared these data with students (Table 2) and invited them to compare the concentrations with the notes they took about the conditions of the sites from which they sampled.

For the phytoremediation experiment, we needed endemic (site-specific) soil and water to test if rhizofiltration could be effective in the Navajo Nation. During our first visit to Chinle, we collected 40 L of soil from the school yard to be used as endemic (site-specific) soil in the phytoremediation experiment. Soil was gathered using trowels and was stored in buckets until the experiment (details below). With input from the tribal chapters, we selected livestock well 10T-254 (36.4409, -109.6385) for collection of water. This well is an artesian well that flows from a spring that has been contained in a spring box. This well had lower levels of uranium than expected previously. During our second visit to Chinle High School on May 20, 2019, we collected the water and soil for the experiment. At the time of water collection from the livestock well, there were many cattle and a decomposing cow carcass near the site. We collected the water on May 20, 2019 with a temperature of about 20°C. We collected 8L of sample in acid-rinsed, 2-L HDPE bottles. The water was stored in the bottles until use in the experiment two hours later with young student collaborators.

Phytoremediation experimental conditions

We purchased seeds for mammoth sunflowers (*Helianthus annuus*) from a local greenhouse. Students planted the seeds in 13 plastic cups (500 mL) during our initial visit to Chinle. Sprouting the plants with the students accomplished two important goals. First, it verified that they would grow in the endemic soil and conditions. Second, it increased the involvement and engagement of the students by extending the contact time and providing an opportunity to develop relationships during the cultivation. For example, students chose the plant ID names, assigning humorous and personal names, that we used throughout the experiment.

In case the local seedlings failed to sprout, we grew additional plants for 16 days in the Brigham Young University (BYU) greenhouse using soil collected from the first visit to Chinle. For both sets of seedlings (Chinle and BYU), we followed the same procedure. Two seeds were buried ~1 cm deep in plastic cups that were filled two-thirds with noncompacted soil using a small trowel. We prepared 7 control cups without seedlings to account for the effects of soil alone on the uranium concentrations. The plant containers were perforated to allow water to seep through the bottom for collection and analysis. To allow the seedlings to develop, plants and controls were kept at ~24°C and watered daily for 16 days. Plants used for the experiment were from the greenhouse at BYU. Chinle plants were donated to the high-school community garden.

Figure 4. Photo of Chinle, the town where the high school we collaborated with was located.

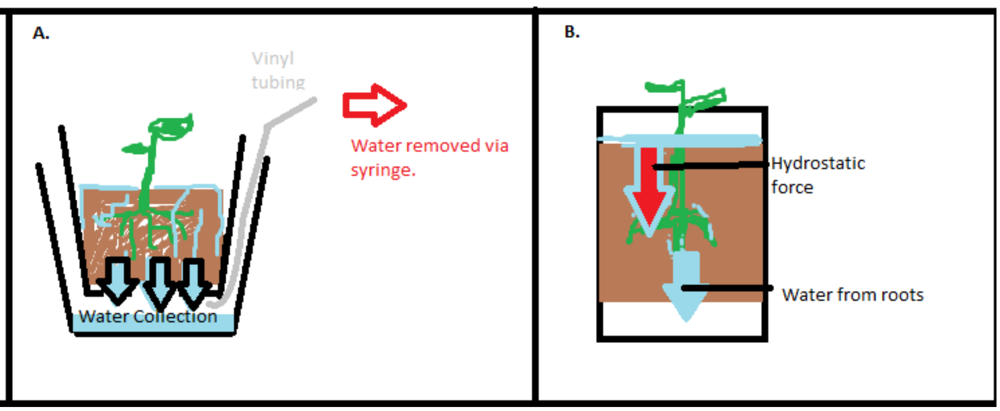
During the experiment itself, we placed each perforated cup into an overlapping cup that had a section of 9-mm inner diameter vinyl tubing laying in it. This design allowed the collection of the water which had infiltrated through the soil matrix, including plant roots for the cups with seedlings (Fig. 5). The other end of the tubing fit on a syringe to collect water at the bottom of the container. A collection container ensured that the plant roots were fully submerged in water and allowed for water collection.

We conducted the experiment at the high school working directly with the teacher and students. First, we added 150 mL of water to each sample at the beginning of the experiment (0 hours). We removed water samples 0, 2, 4, and 12 hours after beginning.

To ensure the water was representative of what was in contact with the soil, the water from the bottom of the collecting cup via syringe and placed on the top of the plant to force all the water below to descend via hydrostatic pressure. Hydrostatic pressure is created by the force of gravity on the water layer above, which forces the water below to exit into the collection duct (Fig. 5). At this point we vacuumed the water and filtered through a glass-fiber filter paper with an effective pore size of 0.7 µm. The filter removes solids, allowing analysis of the solute fraction. We placed filtered samples in acid-rinsed 5 ml polystyrene containers labeled with the plant ID and corresponding time interval. Students performed this portion of the experiment under supervision of the instructor and investigators.

Figure 5. The design of the apparatus used to collect water.

Before collecting a sample the water must be moved on top of the plant in order to use hydrostatic pressure to move the water off the roots.



For the 13 plants and 7 controls, we collected water at the different time steps to calculate uptake rate and test if there were nonlinearities due to saturation kinetics. Many plants in excess water show reduced transport efficiency as the plant absorbs more water and becomes more saturated relative to the solution outside the root[18]. For this reason, the

[18] Welch, R. M. (1973). Vanadium Uptake by Plants. *Plant Physiology*, *51*(5), 828–832. https://doi.org/10.1104/pp.51.5.828

active uptake of water and solutes by the plant roots may decrease through time (Fig. 6). One plant and two controls were excluded because they were labeled improperly or not sampled at the correct time.

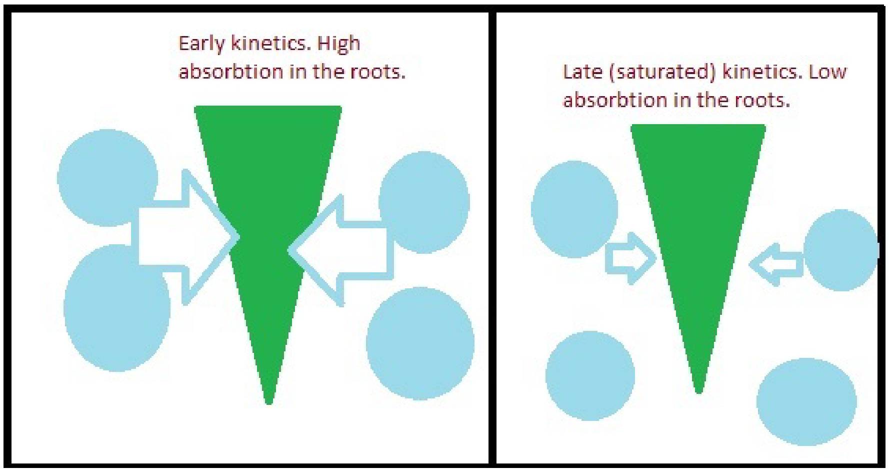


Figure 6. Saturation kinetics in the roots.

Working with the students, we hypothesized that the plants would have lower concentrations of Uranium (U) and arsenic (As) at the end of the experiment compared to the controls due to the active uptake of the roots, as suggested by the experiments used by Lee et al[11]. Antimony (Sb) was also included as a control as it is not an element we expected to be present in the water. Furthermore, we hypothesized that due to the saturation kinetics the roots would demonstrate less active uptake over time as the experiment proceeded.

All collected samples were analyzed for U, Sb, and As concentrations using inductively coupled plasma mass spectrometry (ICP-MS) at the University of Utah. This technique dissociates individual elements dissolved in a water sample. The element concentration is quantified by comparing the mass of each element in the sample to a known standard.

Statistical analysis

We used the open-source statistical software package R to analyze the data and create figures[19]. In order to test for changes in concentration through time, we calculated linear regressions. Given the moderate number of comparisons relative to our sample size, we used a decision criterion of $\alpha = 0.05$, which reduces the probability of a false positive to 5% for each statistical test. To compare concentrations in plant and control treatments, we calculated the smoothed conditional means over the course of the experiment as well as the 95% confidence intervals around those means. When the confidence intervals overlapped between the two treatments, we concluded there was not a significant difference (i.e. we rejected the hypothesis that presence of sunflower seedlings altered concentration of the various heavy metals).

Results

Mapping of uranium concentration in groundwater

Based on the Navajo EPA data provided by Dr. Rock, we plotted concentration of U in wells across the Navajo Nation (Fig. 7). Approximately 47 % of tested wells were above the recommended level of 30 µg per liter. The highest levels of contamination appeared to be near abandoned mines, though we did not have enough data to quantitatively test for a spatial correlation.

[19] R Core Team. "R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing," 2016. http://www.R-project.org/.

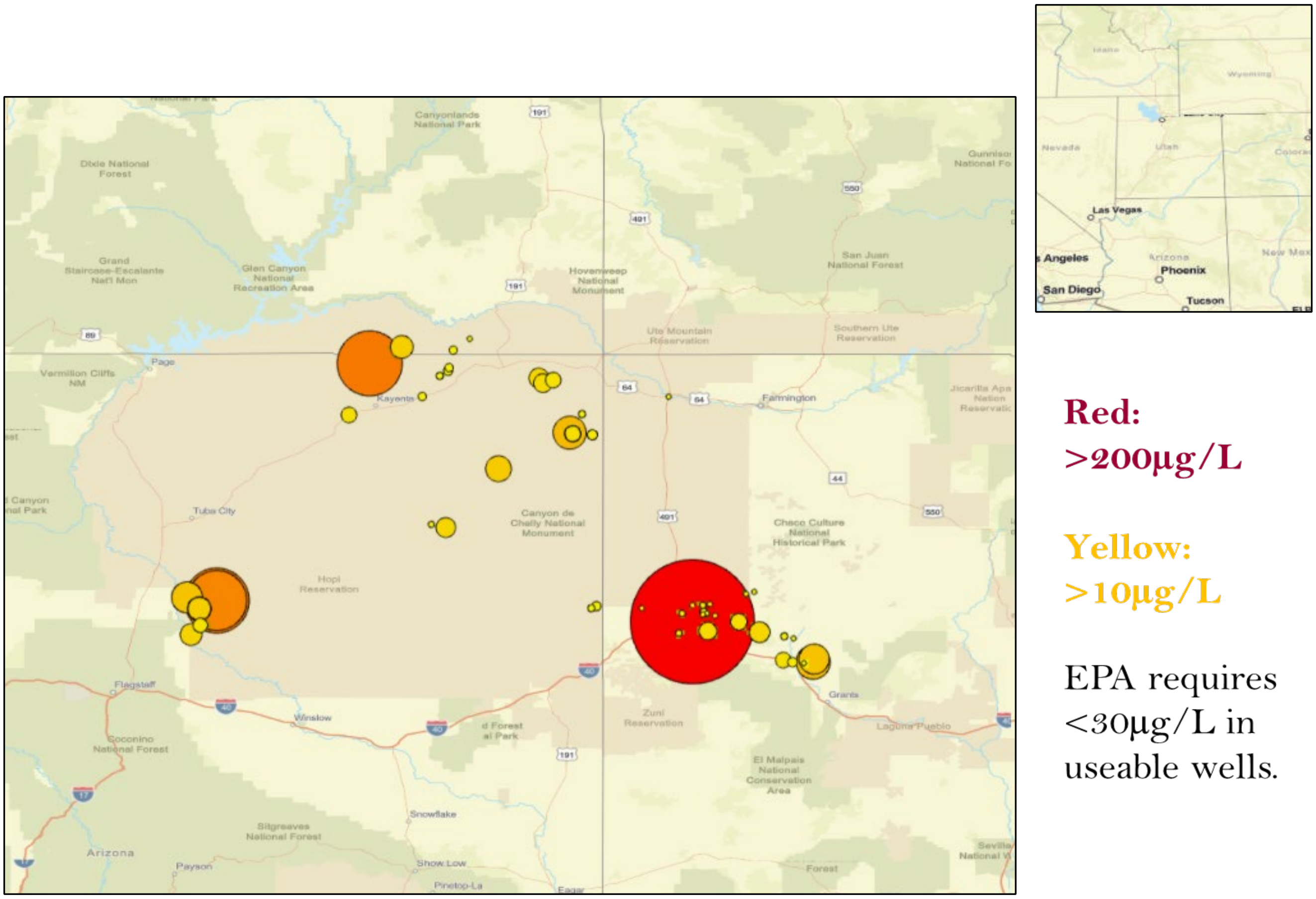


Figure 7. Uranium concentration in wells on the Navajo Nation. Color and size of circle denote concentration, with light yellow representing 10 µg/L and red representing 200 µg/L. Data provided by the Navajo Environmental Protection Agency.

Results from student sampling of surface water

Surface-water chemistry sampled by the students was highly variable across parameters (Appendix, Table 2). Some concentrations of nitrate, nitrate, and phosphate far exceeded water quality standards. However, this could be highly local contamination rather than a systemic problem because the students collected samples primarily from isolated pools that could be experiencing evaporation or direct contamination from livestock or people.

Sunflower uptake of uranium and arsenic

During the 12-hour rhizofiltration experiments outlined above, we observed no change in arsenic (As) concentration (Fig. 8). This suggests there was no preferential uptake in As, or that the release rate of As from the soil exceeded the uptake rate. The control and plant treatments were statistically identical throughout the experiment, based on the overlap in the 95% confidence intervals (Fig. 8A). This further suggests that abiotic processes in the soil and soil solution overwhelmed any potential activity in or around the roots.

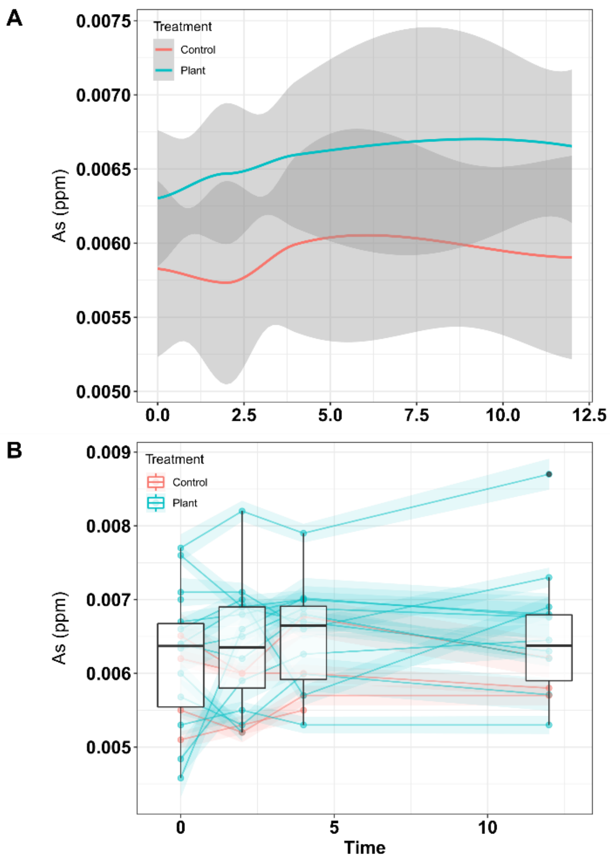


Figure 8. Arsenic concentrations through time. The control incubations (without seedling) are shown in pink and the plant incubations (with seedling) are shown in green. A: The smoothed conditional mean and standard error of the mean for each treatment. As the standard error overlapped over the whole range, we failed to reject the null hypothesis of no difference in the means. B: Individual incubation results and distribution of all results as the control and plant means were not different. The shading around the lines shows the standard deviation of repeat injections (i.e. the analytical error). The boxplots show the distribution of observed values across both treatments, representing the median, quartiles, 1.5-times the interquartile range (IQR), and points beyond 1.5-times the IQR. Linear regressions between concentration and time were not significant ($p = 0.68$ and 0.26 for control and plant treatments, respectively).

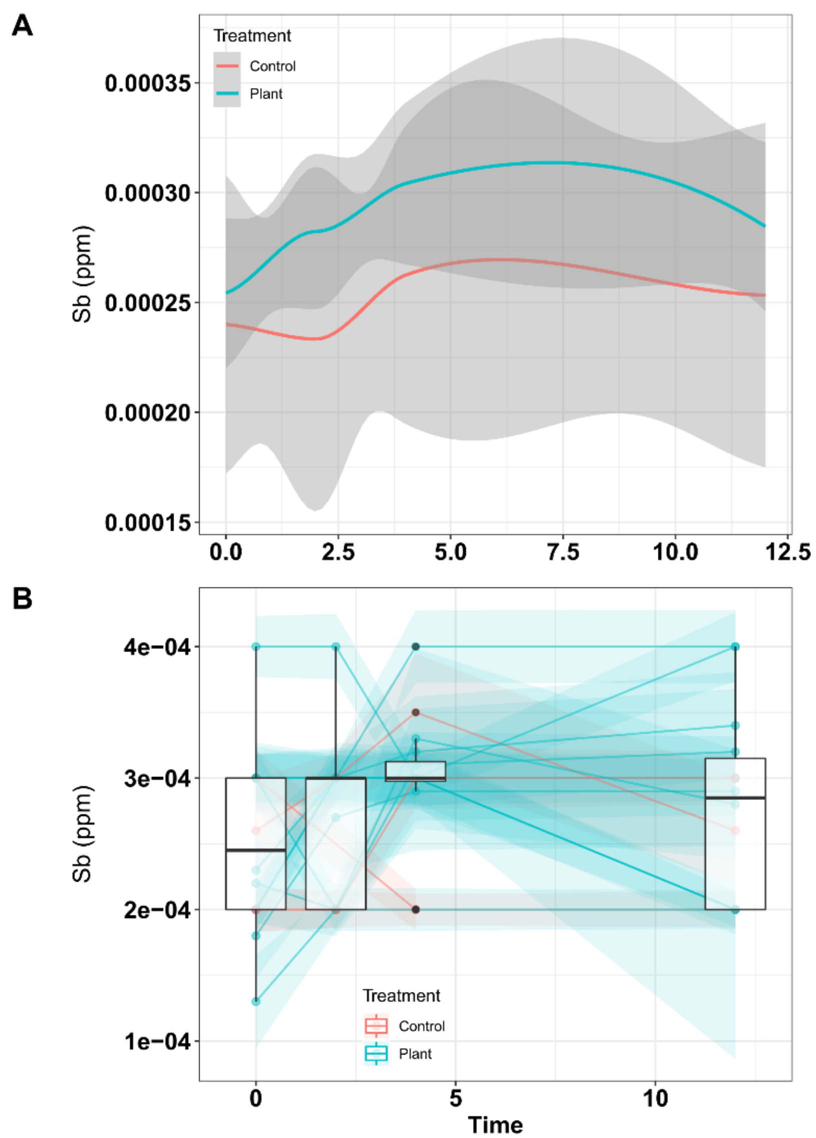


Figure 9. Antimony concentration through time. Symbology is the same as for Fig. 1. Linear regressions between concentration and time were not significant (p = 0.60 and 0.13 for control and plant treatments, respectively).

Antimony (Sb) showed the same pattern as As: no change in concentration through the experiment and no significant difference between control and plant treatments (Fig. 9). This further suggests that active uptake may not have been appreciable when compared to the effects on the roots exerted by the heterogenous solution from the soil.

However, uranium (U) showed significant increases over the course of the experiment (Fig. 10). For both plant and control treatments, U concentration increased by approximately 20% over the first two hours of the experiment, and then increased more slowly through 12 hours (Fig. 10). The plant treatment was statistically indistinguishable from the control treatment, based on the 95% confidence intervals of the smoothed means.

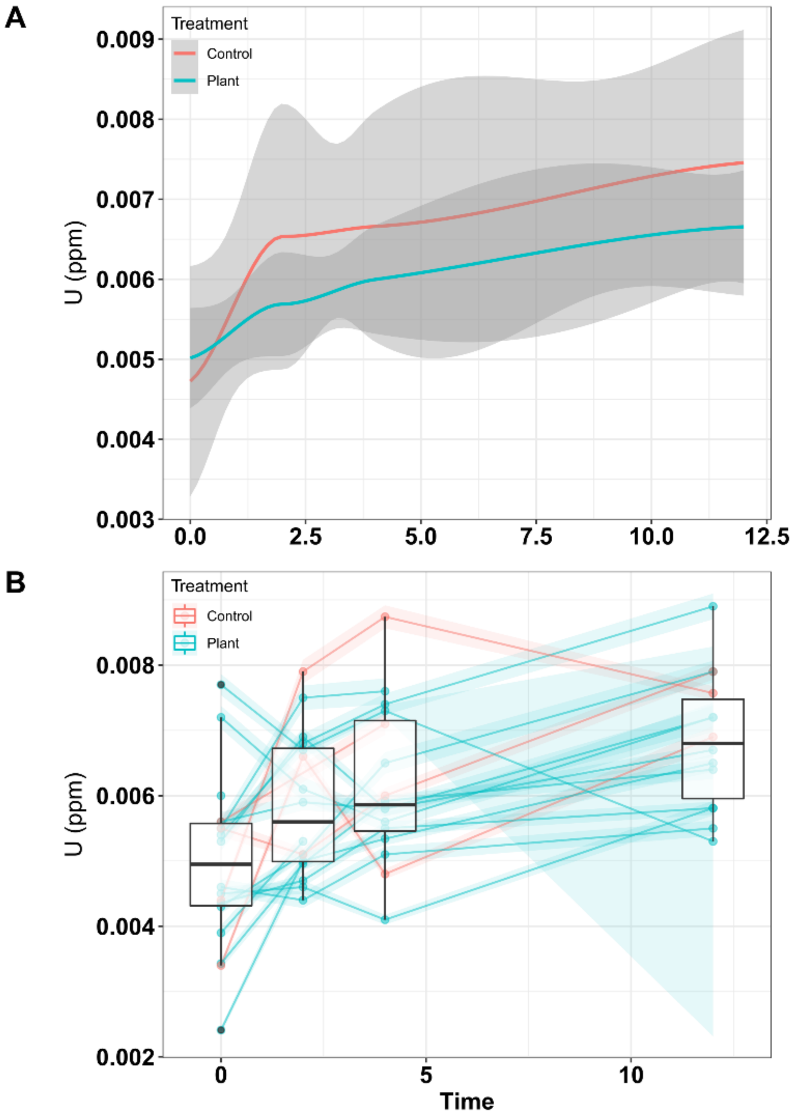


Figure 10. Uranium concentration through time. Symbology is the same as for Fig. 1. Linear regressions between concentration and time were significant ($p = 0.01$ and 0.001 for control and plant treatments, respectively). Time is in hours.

Discussion

The nonlinear increase in U concentration fits observations of rapid abiotic dissolution (i.e. weathering) of soil and regolith soon after wetting[20] [21]. The relatively dilute water stimulates release of soluble elements from the soil matrix, rapidly moving towards equilibrium. The continued increase of U concentration through the 12-hour experiment (Fig. 10) demonstrates that the soil is geologically young and unmodified, which is what we expected for such an arid and geologically active area as the Navajo Nation.

There are several potential explanations for our findings. First, the lack of a difference between plant and control treatments across the three heavy metals could be due to the seedlings having too low of root density in the soil matrix. Second, previous rhizofiltration experiments have been carried out in hydroponic environments with uranium dissolved in solution (i.e. in a nutrient solution devoid of the soil) to allow assessment of the root-solution interactions. However, controlled, hydroponic environments are poor analogues for actual soils, where multiple processes can enhance or impede root activity.

[20] Jean Marçais, Alexandre Gauvain, Thierry Labasque, Benjamin Abbott, Gilles Pinay, et al.. Dating groundwater with dissolved silica and CFC concentrations in crystalline aquifers. Science of the Total Environment, Elsevier, 2018, 636, pp.260-272. ff10.1016/j.scitotenv.2018.04.196ff. ffinsu-01779877f

[21] Alam, M. S., & Cheng, T. (2014). Uranium release from sediment to groundwater: Influence of water chemistry and insights into release mechanisms. *Journal of Contaminant Hydrology*, *164*, 72–87. https://doi.org/10.1016/j.jconhyd.2014.06.001

We chose to conduct our experiment to test specifically the potential efficacy of rhizofiltration in an actual soil from a contaminated area. The age of the seedlings and the volume of the soil solution were comparable to other laboratory tests[22], so we reject the conclusion of a failed experiment. Instead, we hypothesize that because soils on the Navajo Nation are arid and relatively undeveloped, when they are exposed to water flow, they rapidly weather, releasing trace elements, including heavy metals, which are present in low quantities in these parent materials. When surveyed in many sites the soil profile was loose, gravelly, and had large amounts of carbonate[23] and were generally alkaline. Studies with rice plants have correlated increased pH with reduced metal uptake [24]. We suspect that the increased alkali properties of the soils near Chinle could predict the ineffectiveness observed in this study. Consequently, our data suggests that rhizofiltration is unlikely to be an effective remediation technique on the Navajo Nation, at least not if the sunflowers are planted in soils which are alkaline. A hydroponic setup could be effective at reducing U concentration in small-scale wells[25] but given the material and maintenance costs of such systems, it may not be a feasible solution. A more effective method would be a hydroponic filtration system to reduce adverse effects from the soil.

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[22] Jain, R., Peräniemi, S., Jordan, N., Vogel, M., Weiss, S., Foerstendorf, H., & Lakaniemi, A.-M. (2018). Removal and recovery of uranium(VI) by waste digested activated sludge in fed-batch stirred tank reactor. *Water Research*, *142*, 167–175. https://doi.org/10.1016/j.watres.2018.05.042

[23] *United States Department of Agriculture Natural Resources Conservation Service*. (n.d.). Retrieve March 3, 2020, from https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/arizona/chinleAZ_NM2011/CHINLE%20AREA%20SOIL%20SURVEY.pdf

[24] Zeng, F., Ali, S., Zhang, H., Ouyang, Y., Qiu, B., Wu, F., & Zhang, G. (2011). The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. *Environmental Pollution*, *159*(1), 84–91. https://doi.org/10.1016/j.envpol.2010.09.019

[25] Magwaza, S. T., Magwaza, L. S., Odindo, A. O., & Mditshwa, A. (2020). Hydroponic technology as decentralised system for domestic wastewater treatment and vegetable production in urban agriculture: A review. *Science of The Total Environment*, *698*, 134154. https://doi.org/10.1016/j.scitotenv.2019.134154

Further studies should be done to investigate the mechanism by which plants actively uptake heavy metals. To understand the nature of the regolith present in many regions of the Navajo Nation, these studies should be compared to geospatial mapping of wells to observe the trends of well data in the solution. In future experiments a soil matrix plant analysis of uranium may have many confounding factors and make it difficult to determine the efficacy of rhizofiltration of U. The initial pH of the soil and root diameter can greatly affect the absorption of uranium by the roots. The presence of other ions in the soil and water can also affect the uptake by the plant[26].

Although the results may have rejected our hypothesis, this project led to important collaboration with members of the Navajo Nation through citizen science. Using a community centered approach to research we succeeded in raising awareness of scientific issues and allowing young collaborators to participate in scientific research[27]. Many of our collaborators actively took notes in their sampling of wells and documented the growth of the seedlings in endemic soil internalizing scientific skills. This suggests that with further mentoring high school aged students could participate in additional research projects. Furthermore, the project instilled an excitement of scientific inquiry in the community. Students, tribal leaders, Navajo Nation EPA members, and teachers became interested in a research question that was relevant to their community. Consequently, this project could lead to more research questions based on the findings and data gathered in this endeavor.

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[26] *A Model of Uranium Uptake by Plant Roots Allowing for Root-Induced Changes in the soil*. (2018). Environmental Science & Technology. https://pubs.acs.org/doi/10.1021/acs.est.7b06136

[27] Yurth, Cindy. *The Sunflower Project - Navajo Times*. Navajo Times. (2019, May 9). https://navajotimes.com/ae/community/the-sunflower-project/

An obstacle in our research process was the geographic distance between us and our collaborators in Chinle, Arizona. While we began the process with the vision of providing closely supervised hands-on experimentation the 400-mile distance to our collaborators made it difficult to make frequent trips and develop relationships with our collaborators. Future recommendations would be a temporary residence in the community where collaborators are found in order to have frequent connections with them. Furthermore, we would have liked students to take part in the dissemination of the project; however, since many graduated before the completion of the project it was difficult to remain in contact. We recommend that parties interested in high-school collaborative projects begin their research early in the school year in order to have more time to gather data and conduct experiments.

Regarding experimentation with rhizofiltration, further studies should include multiple plants at different stages of growth to control growth mediated variables in active uptake. Hydroponic solutions should not be associated with a plant's ability as a phytoremediator in soil conditions. Since soil matrices may exhibit complex dynamics due to the dissolved heterogenous mixture of components found within[26]. Given this information ongoing studies would be prudent to include soil analysis with filtration rate data. Recent studies have also investigated age specific root dynamics. There is also evidence to support that age of the root is negatively correlated with root uptake[28]. This supports the rejection of our hypothesis since our plants were relatively young. Future research would provide greater insight to the soil-specific effects of soils on plant root

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[28] COMAS, L. H., BAUERLE, T. L., & EISSENSTAT, D. M. (2010). Biological and environmental factors controlling root dynamics and function: effects of root ageing and soil moisture. *Australian Journal of Grape and Wine Research*, *16*, 131–137. https://doi.org/10.1111/j.1755-0238.2009.00078.x

dynamics. Although many factors could be considered when analyzing root dynamics our data clearly demonstrates that the compilation of these factors make sunflowers an ineffective rhizofilter of U and As in soil conditions of the Chinle region.

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Advisors Credentials:

Ben Abbott- Ecohydrologist. Experienced in biogeochemistry and hydrology. Led and organized multiple citizen science projects in France and Utah.

Abbott, Benjamin W., Florentina Moatar, Olivier Gauthier, Ophélie Fovet, Virginie Antoine, and Olivier Ragueneau. "Trends and Seasonality of River Nutrients in Agricultural Catchments: 18 Years of Weekly Citizen Science in France." *Science of The Total Environment* 624 (May 15, 2018): 845–58. https://doi.org/10.1016/j.scitotenv.2017.12.176.

Additional materials:

Bulletin sent to potential collaborators:

Mentored High School Student Research Opportunity

Aims

- Help High school students participate in academic research.
- Engage in environmental science project within the local community.
- Help students communicate in Navajo.

Summary

Mining in the Navajo nation has caused heavy metal contamination of water sources. New evidence suggests that plants effectively remove contaminants from water. We will try to look into new ways of removing heavy metal contaminants from water using sunflower plants.
Student from the community will learn to collect water samples, cultivate sunflowers, and analyze data. Students can use this experience in their college applications and will have the opportunity to help share the findings of this project at conferences in their communities.
This will be a competitive opportunity for students as they prepare for college. Students will be mentored and present the data to their communities. Students will also have the opportunity to advance their Navajo language skills by creating posters and presentations that connect with a traditional audience.

Collaborators:

Students will work with undergraduate college students, local community leaders, and professional researchers.

Locations:

This project will take place in schools across the Navajo Nation.

Timeline:

The project will begin in April 2019 and data will be presented in Fall of 2019. Some time may be required during summer months for students to meet and work on projects.

Costs:

No cost will be required of students. Students will be provided transportation from their school to the research locations. Students will also be covered for the costs of conferences and posters.

Contact:

Zak Webber

Well samples collected by students in April 2019

Name	Bottle #	Location	Latitude	Longitude	Time Sampled	Notes on weather	Other Notes	Turbidity NTU	NO3 mg/L	TOC**Total org	DOC **Dissolved	Lithium	Sodium	Ammonium	Potassium	Floride	Chloride	Bromide	Nitrate	Sulfate	Phosphate
Dawson	2018-7472	Nazlini Well	35.939145	-109.509762	12:00 PM		well water	11.64	3.39	12.26	9.48	1.6958	123.3438	4.7085	33.2444	1.6066		0.7795	50.4228	74.4455	5.2145
Anaegnan	2018-7492	Del Muerto	36.1920418	-109.4225063	9:00 PM	clear	sink water	0.66	0.09	1.57	1.34					18.6527		1.515	0.2951	310.1344	2.0953
Antonio	2018-7536	Durango	37.262556	-107.881533	9:31 AM	clear	downstream fm	0.8	2.84	0.45	0.2										
Naldane	2018-7217	"Home"		-109.544831	7:40 PM	breezy	Livestock water														
Lorinda	2018-7532	Low Mountain	35.819468	-110.154644	7:08 PM	clear, breezy															
Irwin	2018-7472	Sink, April 5	36.21361	-109.1319	4:30 PM	clear, very wind	may be garbage, 7200' elevation														
Wyatt	2018-7531	Del Muerto	36.184789	-109.432983	7:32 AM	cloudy		3.02	0.32	1.46	1.05										
Cindy	2018-7535	Chinle	36.150857	-109.508243	4:32 PM	clear	tap water from	0.76	-0.01	4.13	3.84										
Coy	2018-7519	Chinle	36.15472	-109.5794				0.8	-0.06	3.31	2.97										
Gerall	2018-7520	Many Farms	36.26795	-109.58618			Old Valley Store	38.63	0.35	15	6.79										
Cheyenne	2018-7530	Chinle	36.165074	-109.58017	2:26 AM	cold, clear, bre	tap water	1.41	0.02	2.48	2.03										
Da'ml	2018-7515	Chinle	36.121566	-109.448458	7:30 PM	clear	Canyon De Chel	114.39													
2- Well 10T-258	2018-7512	Many Farms	36.417068	-109.619504	2:00 PM	sunny, hot	Windmill	123.66				17.6524	26459.7136		232.7159		11.6933			11.2255	

Bottle #	Site #	Site Type	Location	Latitude	Longitude	Time Sampled	Notes on weather	Source	Other Notes	Lithium (μM)	Sodium (μM)	Ammonium (μ	Potassium (μ	Floride	Formate	Acetate	Chloride	Nitrite	Bromide	Nitrate	Sulfate	Phosphate
2018-7464	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	pooled water	dead cow, gras	16.7584	11154.5528	n.a.	1234.0254	n.a.	n.a.	n.a.	n.a.	1575.1621	4.4138	290.7468	3331.6977	0.3041
2018-7533	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	water trough	dead cow, rust	4.0266	1509.945	n.a.	192.5463	38.6282	n.a.	n.a.	n.a.	10.236	2.2488	9.5785	1420.7156	
2018-7458	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	water trough	corpse of dead cow nearby, hazardous water?													
2018-7459	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	pooled water	dead cow in water													
2018-7499	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	pooled water	dead cow, cow poo, algae, trash, spider													
2018-7475	1-Well 10T-254	Artesian Well	Old Pipe Springs	36.440682	-109.636389	9:30 AM	clear, sunny	water trough	algae, dead cow nearby													
2018-7497	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	1:45 PM	sunny, windy	pipe into trough	collected from p	10.5205	14319.3415	n.a.	55.4376	27.7349	n.a.	n.a.	6960.8312	n.a.	4.057	0.4455	6624.1737	0.245
2018-7518	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	sunny, clouds	pooled water by	fertilizer?													
2018-7525	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	sunny, windy	pooled water by	muddy													
2018-7512	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	sunny, hot	pooled water by windmill		17.6524	26459.7136	n.a.	232.7159	n.a.	n.a.	n.a.	11.6933	n.a.	n.a.	n.a.	11.2255	n.a.
2018-7534	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	sunny, windy	water trough	muddy , animal poop													
2018-7489	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	windy, hot	pooled water by	muddy, yellow splotches near the water													
2018-7487	2-Well 10T-258	Windmill	Many Farms	36.417068	-109.619504	2:00 PM	sunny, windy	pooled water by	unfiltered water	n.a.	n.a.	156137.074	741.5149	n.a.	n.a.	n.a.	17265.6715	15.9253	4.22	9.3451	329.8533	3.6854

*missing Jayden and Breandrea

	[illegible]	[illegible]	[illegible]	[illegible]	Livestock. Cattle corpse.
[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]		Dead cows. Second spring. rusted pipes. Animal waste.
	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]		Spider, algae, trash, animal waste.
[illegible]	[illegible]	[illegible]			
		[illegible]	[illegible]		

No.	Name	CD Lithium	Sodium	Ammonium	Potassium			Floride	Formate	Acetate	Chloride	Nitrite	Bromide	Nitrate	Sulfate	Phosphate	
1	BLANK	n.a.	0.6212	0.8533	0.6905	µ-molar											
2	0.1 cation std	1.3646	21.4821	0.1694	1.5297	µ-molar	BLANK	6.4414	n.a.	n.a.	n.a.	46.7045	n.a.	n.a.	n.a.	n.a.	µ-molar
3	1.0 cation std	1.6593	2.4199	1.0484	1.0648	µ-molar	0.1 anion std	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	8076.2787	µ-molar
4	10 cation std	7.6677	6.5062	10.203	6.8665	µ-molar	10 anion std	10.5952	n.a.	n.a.	14.8266	10.8677	9.9569	11.9749	13.6478	n.a.	µ-molar
5	100 cation std	118.518	86.4427	112.3666	115.4912	µ-molar	100 anion std	104.7444	n.a.	n.a.	96.7758	100.4305	98.2655	98.0966	97.0997	92.5561	µ-molar
6	BLANK	n.a.	0.34	0.1658	0.5781	µ-molar	BLANK	n.a.	n.a.	n.a.	2.0669	n.a.	n.a.	n.a.	7.332	1.6815	µ-molar
7	7487	n.a.	n.a.	156137.074	741.5149	µ-molar	7487	n.a.	n.a.	n.a.	17265.6715	15.9253	4.22	9.3451	329.8533	3.6854	µ-molar
8	7519	3.0699	705.763	n.a.	161.7704	µ-molar	7519	19.8245	n.a.	n.a.	n.a.	21.0746	0.6679	0.7033	394.578	2.9724	µ-molar
9	7533	4.0266	1509.945	n.a.	192.5463	µ-molar	7533	38.6282	n.a.	n.a.	n.a.	10.236	2.2488	9.5785	1420.7156	n.a.	µ-molar
10	7497	10.5205	14319.3415	n.a.	55.4376	µ-molar	7497	27.7349	n.a.	n.a.	6960.8312	n.a.	4.057	0.4455	6624.1737	0.245	µ-molar
11	7512	17.6524	26459.7136	n.a.	232.7159	µ-molar	7512	n.a.	n.a.	n.a.	11.6933	n.a.	n.a.	n.a.	11.2255	n.a.	µ-molar
12	7525	9.8238	14008.2848	n.a.	49.9327	µ-molar	7525	35.8845	n.a.	n.a.	7661.7499	n.a.	4.248	0.2158	6561.1072	0.2639	µ-molar
13	7475	3.8605	1684.4878	n.a.	201.2854	µ-molar	7475	30.7354	n.a.	n.a.	4936.6163	24.4719	1.9434	9.8688	1408.7109	n.a.	µ-molar
14	7539	4.1135	1635.3766	n.a.	193.3095	µ-molar	7539	37.7124	n.a.	n.a.	n.a.	26.5905	2.6084	11.4557	1410.2673	n.a.	µ-molar
15	7536	2.4726	480.5828	0.0794	82.4119	µ-molar	7536	16.457	n.a.	n.a.	n.a.	n.a.	0.1764	0.2934	401.3925	0.4261	µ-molar
16	7535	4.2661	929.6852	n.a.	172.8056	µ-molar	7535	20.4766	n.a.	n.a.	n.a.	16.6057	0.4691	0.5464	378.9505	3.0618	µ-molar
17	7515	n.a.	19.5771	n.a.	0.6607	µ-molar	7515	2.4898	n.a.	n.a.	5.3599	n.a.	n.a.	0.0734	0.2319	0.8374	µ-molar
18	7517	5.9682	1427.8592	n.a.	45.0083	µ-molar	7517	22.0594	n.a.	n.a.	n.a.	n.a.	2.6778	12.3174	175.3249	n.a.	µ-molar
19	7518	n.a.	26045.6151	n.a.	0.5796	µ-molar	7518	n.a.	n.a.	n.a.	n.a.	75222.7768	11.8492	3.9762	n.a.	2.6049	µ-molar
20	7532	4.6516	4754.5643	n.a.	9.5243	µ-molar	7532	16.9151	n.a.	n.a.	5859.1754	5.1847	0.7396	76.5991	380.6688	2.1048	µ-molar
21	1.0 cation std	1.7793	33.8341	0.7835	1.3739	µ-molar	10 anion std	10.7879	n.a.	n.a.	25.7698	11.0775	10.4386	10.9883	12.7058	5.23	µ-molar
22	10 cation std	7.8334	35.6834	10.0013	7.5259	µ-molar	100 anion std	95.1233	n.a.	n.a.	101.1646	99.375	101.6949	101.6671	102.265	99.8447	µ-molar
23	BLANK	1.3501	26.679	0.128	0.7223	µ-molar	BLANK	n.a.	n.a.	n.a.	1.5579	n.a.	n.a.	0.0576	0.2575	9.12	µ-molar
24	7484	16.7584	11154.5528	n.a.	1234.0254	µ-molar	7484	n.a.	n.a.	n.a.	n.a.	1575.1621	4.4138	290.7468	3331.6977	0.3041	µ-molar
25	7458	5.1407	1669.2372	n.a.	202.1401	µ-molar	7458	37.8278	n.a.	n.a.	5534.3278	26.5118	2.1347	11.4749	1413.4672	n.a.	µ-molar
26	7520	2.9903	n.a.	n.a.	n.a.	µ-molar	7520	n.a.	n.a.	n.a.	n.a.	49861.0299	n.a.	0.0753	310.8586	0.0804	µ-molar
27	7509	17.5634	n.a.	50093.9329	239.8545	µ-molar	7509	n.a.	n.a.	n.a.	2159.7867	6.9855	7.5727	2.0688	n.a.	1.0581	µ-molar
28	7530	4.1206	731.0059	n.a.	n.a.	µ-molar	7530	11.4541	n.a.	n.a.	n.a.	n.a.	1.4658	0.2008	364.8823	5.4647	µ-molar
29	7472	1.6958	123.3438	4.7085	33.2444	µ-molar	7472	1.6066	n.a.	n.a.	n.a.	n.a.	0.7795	50.4228	74.4455	5.2145	µ-molar
30	7489	12.338	28968.3508	n.a.	n.a.	µ-molar	7489	55.0565	n.a.	n.a.	4858.2795	n.a.	10.8263	4.6658	n.a.	44.758	µ-molar
31	7492	3.555	723.2968	0.0567	129.6341	µ-molar	7492	18.6527	n.a.	n.a.	n.a.	n.a.	1.515	0.2951	310.1344	2.0953	µ-molar
32	7531	3.6002	721.2783	0.2577	147.1048	µ-molar	7531	21.3301	n.a.	n.a.	5959.157	n.a.	0.8616	0.4687	323.5633	6.1688	µ-molar
33	7499	n.a.	44667.0108	n.a.	n.a.	µ-molar	7499	n.a.	n.a.	n.a.	n.a.	103156.471	76.0635	3.9377	4002.6671	27.1101	µ-molar
34	7534	10.2477	25224.2847	n.a.	596.6852	µ-molar	7534	58.6335	n.a.	n.a.	10620.5287	6.9457	8.0799	1.0234	n.a.	6.1156	µ-molar
35	7485	4.2566	1188.9279	n.a.	n.a.	µ-molar	7485	n.a.	n.a.	n.a.	6097.1627	n.a.	3.2784	0.7906	2175.6046	0.2499	µ-molar
36	7469	15.6877	2586.8555	n.a.	68.7243	µ-molar	7469	13.8695	n.a.	n.a.	3649.0435	13.0289	2.0984	n.a.	315.4849	n.a.	µ-molar
37	0.1 cation std	1.4628	47.6569	0.532	3.2874	µ-molar	0.1 anion std	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	µ-molar
38	100 cation std	81.9149	110.9268	87.6141	85.0605	µ-molar	100 anion std	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	µ-molar
39	BLANK	1.3727	38.0889	0.2269	2.3927	µ-molar	BLANK	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	µ-molar

Cation
Anion NevNas
studio/double click peaks show elements.
7515 looks weird

Sums:		393.303	212149.622	206460.202	5017.499
Average:		11.918	5893.045	11470.011	147.574

ID # / Name				*Total organic c	*Dissolved Organic Carbon		
Name	Bottle #	Turbidity NTU	NO3 mg/L	TOC	DOC	Time	
Dawson	2018-7472	11.64	3.39	12.26	9.48	11:38 AM	May 7, 2019
Anaegnan	2018-7492	0.66	0.09	1.57	1.34	11:45 AM	May 7, 2019
Antonio	2018-7536	0.8	2.84	0.45	0.2	12:10 AM	May 7, 2019
Naldane	2018-7217^ missing						May 7, 2019
Lorinda	2018-7532						May 7, 2019
Irwin	2018-7472						May 7, 2019
Wyatt	2018-7531	3.02	0.32	1.46	1.05	11:41 AM	May 7, 2019
Cindy	2018-7535	0.76	-0.01	4.13	3.84	11:50 AM	May 7, 2019
Coy	2018-7519	0.8	-0.06	3.31	2.97	12:26 AM	May 7, 2019
Gerall	2018-7520	38.63	0.35	15	6.79	11:57 AM	May 7, 2019
Cheyenne	2018-7530	1.41	0.02	2.48	2.03	11:59 AM	May 7, 2019
Da'ml	2018-7515	114.39	NaN	NaN	NaN	12:01 AM	May 7, 2019
	2018-7517	0.55	0.74	1.42	1.18	12:05 AM	May 7, 2019
?	2018-7509	19.98	1.11	21.33	14.07	12:15 AM	May 7, 2019
?	2018-7485	3.6	0.19	4.89	3.9	12:18 AM	May 7, 2019
	2018-7464	56.86	NaN	NaN	NaN	11:48 AM	May 7, 2019
	2018-7533	3.47	NaN	37.84	36.75	12:03 AM	May 7, 2019
	2018-7458	0.85	1.63	2.78	2.52	12:08 AM	May 7, 2019
	2018-7459^ missing						May 7, 2019
	2018-7499	NaN	NaN	NaN	NaN	11:22 AM	May 7, 2019
	2018-7475	0.65	8.2	7.82	7.17	12:06	May 7, 2019
	2018-7497	7.97	0.49	7	4.21	11:31 AM	May 7, 2019
	2018-7518	NaN	NaN	NaN	NaN	11:29 AM	May 7, 2019
	2018-7525	NaN	NaN	NaN	NaN	11:51 AM	May 7, 2019
	2018-7512	123.66	NaN	NaN	NaN	11:25 AM	May 7, 2019
	2018-7534	NaN	NaN	NaN	NaN	11:55 AM	May 7, 2019
	2018-7489	NaN	NaN	NaN	NaN	11:53 AM	May 7, 2019
	2018-7487	29.82	NaN	NaN	NaN	11:27 AM	May 7, 2019
	2018-7539	NaN	NaN	NaN	NaN	11:30 AM	May 7, 2019
	2018-7469	0.61	0.09	0.43	0.2	11:33 AM	May 7, 2019

*NaN indicates too much of a value, usually turbidity, interfering with the light able to pass through
This mostly just says there is too much in the water to get an accurate measurement. We will get better results for them when we do the metal analysis.

Time-Dependent Filtration Experiment

Overview

1. Label tubes, name each plant.
2. Pour well-water into each of the samples.
3. Collect samples after 15 minutes and 4 hours.
5. Analysis of filtration.

Labeling

We are going to label each tube before starting. We also will name each cup of dirt. This allows us to organize and keep track of the samples.

1. Write a fun name on tape for each plant and put it on the plant.
2. Using tape label 4 bottles for each plant with the same plant name in quotation marks.
3. Label each bottle the date and T-1, T-2, T-3, T-4

Setting up the experiment

We need to measure the water that is in contact with the roots the most. For this reason we will need to transplant the sunflowers in buckets to smaller cups so they can be used next week for the same experiment.

1. Carefully dig a plant out from the ground. Keep all the roots intact and use gloves. If the roots have grown together keep the plants together. Place the plant in a cup and burry with dirt until it is mostly upright. Disturbing the roots can cause the plant to change its behavior.
2. Lightly water the soil using school tap water.

To test the filtration rate on 3-week old plants we will use plants in the red cups. Each cup has had holes poked in it so that water can drain into the bottom and be collected through the tube and syringe.

1. For each plant (or cup of dirt) measure 150mL of well-water into a graduated cylinder. It is important that this is as precise as possible.
2. Pour the water gently onto the plant. Take care to avoid pouring it to quickly and causing an indent in the dirt.

Taking water samples

Water samples will be taken four times after 0 hours, 4 hours, 20 hours, and 40 hours. Twice during school. The next sample will be taken by Mr. Webber after 20 hours and again after 40 hours.

1. Gently vacuum all the water by pulling the syringe back slowly. When it's full, gently twist it off the tube (without removing the tube) and expel the water into the cup with the soil. This will force out water that is in contact with the roots.
2. Set a timer for 5 minutes. Relax, listen to some good music, talk about how you think "End Game" should have ended.
3. Vacuum 10mL water using the syringe and tube. Detach it gently from the tube and using gloved hands screw on the filter. Gently push the water into the bottle labeled T-#
4. Push gently, hard force can break the filter and ruin the sample. If the filter gets clogged get Mr. Webber's attention.
5. Once the sample is collected take the sample to the teacher with HCl. Have them add 1-2 drops. Keep gloves on until done with step 6.
6. Seal the bottle tightly and label the time it was sampled on the data sheet.

Analysis

Data can take some time to analyze. We always need more scientists and often scientists are balancing many projects at once. It will take 3 weeks or more before the data samples can be analyzed using a machine that will measure concentrations of Uranium, Arsenic, Copper and other water contaminants.

Once the data has been run it takes additional time to write the entire project in a way that is professional and able to be interpreted by all. If the sunflowers are effective there are many future research questions that could be asked. How could sunflowers benefit the Navajo Nation? What effect would this have on drinking water? While science often does not give us quick answers I hope you know you have participated in research and a project that helps benefit the community you live in. It may not have seemed that you did much but in science every drop of counts.

Email me if you have questions, comments, or ideas: Zak Webber (fransisco.webber@gmail.com)

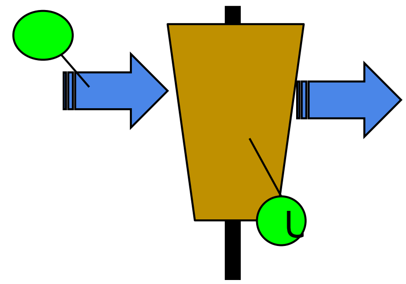
Project outline shared with students April 5, 2019

Project: Water Filtration via Sunflowers

Overview

We're going to see if Sunflowers are effective in removing Uranium from the water we give them. We will do this by testing the content of the water before and after we use it to water the plants.

If this works then we will know whether sunflowers would make a useful crop for areas affected by high amounts of uranium in the water or soil. This project will allow us to not only investigate the quality of the water, but do something about it.

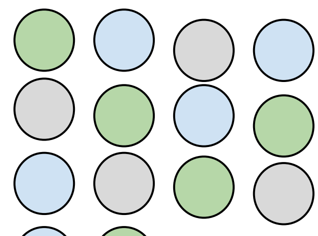


Experimental Procedure

a. Growing Sunflowers

Sunflowers will need to be sprouted to seedling size before planting in the affected areas. We will need to record any factors that may contribute to their growth. Only the healthy seedlings should be planted.

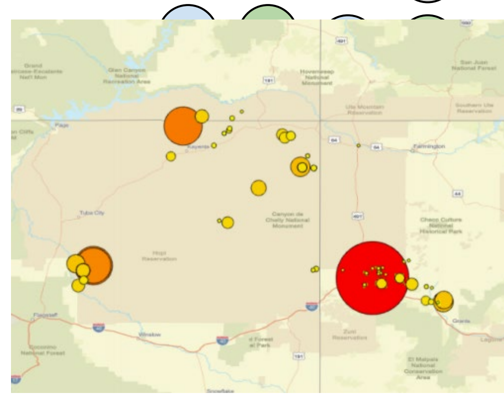
To keep good track of the plants we will plant sunflowers in per each bucket so that the roots are sufficiently dense. These plants will be watered with water collected from designated sources. In addition, 4 buckets will be left empty in random locations. No other treatments should be made to the plants. This will ensure that the experiment is not affected by unaccounted variables.



b. Measuring Water Quality

Using water from the source we will measure 5 samples of each source. One source will be industrial water from the school, and the other source will be one known to contain heavy metals.

We will also map the areas the water is sampled from. If it is a well, this will be labeled with the well identification. The mapping can easily be done using excel and arcGIS.



e. **Drying the Sunflowers**

At the conclusion of the experiment sunflowers must gently be removed from the buckets to measure the content in the plants. They can be placed in ziplock bags after removing the dirt. Isolating them for assessment will help us know where the sunflowers retain different materials, such as Uranium.

f. Student Presentations

Students will create posters describing what they learn and the experimental design. With each action careful recording should be taken so we know exactly what happens during the experiments. Student groups should also research academic articles and cite their sources in their presentation. The final presentation should be prepared in Navajo.

Poster presentation for Spring Run-Off conference, presented March 26 2019