**Project Title**: Arsenic in All Seasons

**School**:  College of the Atlantic

**Grade Level**: Undergraduate (four-year)

**Your Name**: Dr. Sarah R. Hall

**Project Partners**: My teacher partner for the 2021-2022 academic year was middle school teacher, Lynn Hanna at Conners-Emerson School in Bar Harbor, Maine. I also worked on aspects of the project with Dr. Jane Disney (Associate Professor of Environmental Health) at the MDI Biological Laboratory and Brian Jackson (Research Professor) Dartmouth College Toxic Metals research group.

**Teacher/Scientist Partner Profile**:
I am a geoscientist with an expertise in landscape shaping processes (geomorphology) such as rivers, glaciers, and active tectonics. I completed my PhD at the University of California, Santa Cruz, where I studied the rates of processes shaping the landscapes of Pervuian Andes and coastal regions. Currently, I am the Anne T. and Robert M. Bass chair of GeoScience and Earth Systems at the College of the Atlantic located in Bar Harbor Maine. I teach a wide range of geoscience courses to undergraduate students who are working towards a B.A. in Human Ecology. Some of the classes I teach include: Climate and Weather, Geology of MDI, Rocks and Minerals, Watersheds, The Anthropocene, Geology and Humanity, and Geology of National Parks. Many of my classes have a field component enabling my students to experience “reading” the rocks and landscape to make interpretations about the processes at work. I got involve in the All About Arsenic project in 2016 to provide my undergraduate students a local research opportunity that focused on a societally relevant problem. Through the years my students have worked on many aspects of a subproject of the greater AAA project: Arsenic in All Seasons. Students have assisted with data analysis, community water sample collection, curricular resource development, advocacy, and scientific communication of our findings.

**Summary**:
I engage my undergraduate students in the AAA project through independent study projects and within curricular materials such as class lectures and homework problem sets. During 2021-2022 the Town of Bar Harbor was interested in offering water testing to residents. Along with Jane Disney (MDIBL), Lynn Hanna (teacher partner) and her students, and some current COA students, we assisted the town with this additional sampling. Lynn’s students made informational material and advertised the event. My students visited residents’ houses to enable sampling. Also, during the academic year, I worked with a few undergraduates on independent study projects to analyze, interpret, and disseminate data. Work-study student and MDIBL summer fellow alum, Isi Muñoz Segovia, assisted in writing up a summary of our work to eventually share with the local paper. An excerpt that summarizes our work and findings follows (italicized text):

*Here on Mount Desert Island our public water is sourced from pristine lakes, most, surrounded by protected National Park lands. Unfortunately, most of us living on MDI are not connected to the public water systems. Due to the extensive near-surface bedrock and small population, it’s not economically possible to run access pipes throughout the island, so only the residents closest to the downtown centers drink the lake water, the rest of us rely on private well water. Today we have complex drilling technology that allows us to drill wells over 600’ deep and even “frack” the rock to open more cracks and allow more water to flow into our wells. This deep old water resides in our fractured bedrock aquifers and can take on chemical characteristics of the surrounding rock.*

*To give you some scientific insights: when water resides in rock for a while, moving very slowly and, often under very low-oxygen conditions, the pH of the water might go down (become a bit acidic) and the water can begin to dissolve some minerals, taking on chemical characteristics of the rock. Metals, such as arsenic, iron, magnesium, uranium and more can be leached from the rock and remain dissolved in the water as it continues to move slowly along the fracture network and into your well. It turns out that our iconic pink granites of our region tend to contribute uranium and radon gas to our bedrock groundwater sources. And the sparkly and foliated Ellsworth Schist of western MDI and the dark layered Bar Harbor Fm of eastern MDI provide arsenic to the deep water. It doesn't matter which rock you live on, if you have a private well, you need to test (and potentially treat) your water to ensure you are not regularly ingesting carcinogens.*

*Arsenic especially has been shown to be toxic at very low chronic doses. Other states that have naturally high arsenic levels in their groundwater, and many residents relying on private well water, have slightly higher drinking water standards than ME. For example, in both NH and NJ the Maximum Contaminant Level (MCL) for As is 5ppb while in Maine it is double that. During the last few years, the All About Arsenic program grew out of an initial Data Literacy and Public Health initiative hosted at MDI Biological laboratory. Through this program middle and high school students in Maine and New Hampshire have been testing their drinking water and then visualizing, analyzing, and then communicating their findings to their communities. For example, here on MDI, Lynn Hanna's 8th-graders at Conners-Emerson school assisted in facilitating a town-sponsored free well testing event last November. Sarah Dunbar's seventh graders attended a public testimony at a recent Maine legislative session in support of a bill that will provide funding and access for more private well owners to test and treat their water. College of the Atlantic students have supplemented the sampling effort to offer testing in the broad MDI area. Thanks to many voluntary community participants, we have collected samples from hundreds of local wells during that last ~7 years. Below we share some of our initial findings and insights:*

- *COA students Gaby Moroz ('20) and Gemma Venuti ('18) identified regional spatial correlations in groundwater quality. Often the higher uranium values were found in wells located on granite while the higher arsenic values were found in wells located on metasedimentary and iron/magnesium-rich igneous rocks. However, this is not a strict rule – the fracture network can allow water to move beyond the bedrock units, so all residents of MDI on private well water should test for both constituents as well as for radon gas in the water and air.*

- *Ben Capuano ('23) and Madalyn Adams ('22) found that well water quality can change with changing well water level, such as after a rain event. We also found seasonal variations in well water quality through the year. Thanks to ~30 dedicated participants who collected a sample every month for one year during 2020-2021 and a few extra samples on either side of a rain event, we identified changing arsenic, uranium, and other elemental concentrations in local wells. In general, it seems that the short- and long-term variations in chemistry are on the same scale: for example, an elevated post-rain arsenic concentration may be about the same as the wet season maximum value. In some cases, arsenic values went from below the Maine MCL of 10ppb to above the MCL in just a few days following rain. This suggests to us that well owners should consider sampling their wells at least twice a year in different seasons to get a view of potential well water variability with changing water levels.*

- *Ludwin Moran Sosa ('24) considered how the many different water system components (water softener, particulate filter, reverse osmosis filter, UV filter, etc.) influence the arsenic concentration in drinking water. He found that particulate filters may take out a bit (10%) of arsenic that likely is stuck to the sides of small grains trapped by the filter, however this is not enough to reduce arsenic to safe levels. Reverse Osmosis filters are most reliable for removing all of the arsenic (from well over 50ppb to under 1ppb). They work even under variable water level conditions, such as during rain events, as long as they are properly maintained. In some cases, we found Reverse Osmosis systems failing to remove* *arsenic when the user did not change the filter. It is possible with changing water use, the filter replacement schedule may need to be adjusted.*

- *Since arsenical pesticides were used widely in Maine during the late 1800s through late 1900s, Lenka Slamova ('24) investigated arsenic abundance in local soils, particularly focusing on small orchards and farmland. She found that most soil arsenic concentrations are quite similar to the Maine "background" levels established in a United States Geological Survey Study, except for a few cases with slightly elevated arsenic levels from soil on top of metasedimentary bedrock and located directly under an apple tree or blueberry bush. Adam Feher ('23) considered pathways of uptake of arsenic through consumption of produce grown at regional farms in locations with either high arsenic levels in groundwater or a high likelihood of past arsenical pesticide use (mainly from sites not on MDI) and found very low levels of arsenic in sampled kale and arugula, well below the advisable maximum suggested by the World Health Organization. Ingesting water with arsenic is a much more likely and a more direct pathway of consuming this toxin in this region. We note that this was a very preliminary study and there is much more work to be done in this area (pathways of arsenic ingestion).*

- *Isi Munoz ('24) has contributed to many aspects of the project through the years, first serving as a project intern at the MDI Biological lab and then as a work study student at College of the Atlantic. She worked with folks at Defend Our Health, a Portland based organization, to develop an Advocacy Toolkit for teachers, parents, students, or community members to use as they consider how to bring their "data to action". In fact, her toolkit assisted in writing this piece…to communicate our work and findings with the community that helped build the dataset! You can find her toolkit featured on the allaboutarsenic.org website.*

*During the last few years, we have collected over 450 well water samples in the MDI area. From these data we find 7% have arsenic levels above the Maine MCL and 15% have arsenic levels above the NH/NJ MCL. Nearly half of the wells have some arsenic (>1ppb) and arsenic is a toxin at any level. Further, some wells that have relatively low arsenic levels have elevated uranium levels. About 4% of sampled wells have uranium concentrations above the Maine MCL of 30ppb. These data suggest that all well owners of MDI and nearby regions should be testing their wells regularly and taking steps to remove arsenic and other toxins.*

*As lead investigator, Jane Disney likes to say: each has their own "well story" requiring specific attention and understanding. While it takes time and money to get to know your well story, it is worth it given the multitude of potential negative health outcomes related to ingesting toxins: many types of cancer, cognitive and developmental issues in children, and complications during pregnancy. We are exposed to many risks every day. There are likely many carcinogens that we have no specific awareness of our exposure to and no obvious means of defense against them, however, our drinking water should not be one of them. Water consumption is one of the most direct pathways for putting something into our bodies. We are fortunate to have technology available and state assistance programs in place to help ensure we are all drinking clean water.*

**Project Details**:

- How many students were in the class that was involved in this project?
  About 7 current COA students conducted research this year. ~30 COA students were exposed to the project through in-class lectures and/or problem sets.
- Detail specific curricular items such as questions, articles, books, YouTube videos, and labs. It's helpful if you provide links.
  - We developed some Digital Interactive Notebooks (DINs) for teachers to use with their students. To date there is one about private well water and one about public policy available on the All About Arsenic website. We continue to update the Story Map.

- How did you use Tuva, both for the arsenic data and for other datasets?
    - I used Tuva with my undergraduate work study student to make a demo worksheet that middle school and high school teachers might use with their students (pasted below).
- How did you plan your community outreach?
    - I worked with my teacher partner and town government to offer free private well testing. I assisted middle school students in preparing their pamphlets and posters by preparing a document on talking points and doing two rounds of editing with students. Along with a few of my students, I participated as a witness in a state legislative session.
- Include any data analyses your students did.
    - Five of my students presented the findings of their independent study projects at that Maine Sustainability and Water Conference in Augusta and the Geological Society of Maine Spring Meeting. You can see their poster presentations here and references are listed below.
    - One student has been very active in the advocacy portion of this work. She shared her work during office hours and was a co-author on a recent publication (Farrell et al., 2021).

**Discussion and Conclusion:**

My independent study students were able to participate in many aspects of the study including data collection, analysis, interpretation, and dissemination. As their posters hang outside the geoscience classroom at COA, they have generated great discussion among our campus community. Their work helped inspire a campus-wide tap testing event in spring 2022. Conferences have been a great way for my students and I to network and engage with others around the state who are working on drinking water quality projects.

**References**: star denotes student author


Capuano, B.*, Adams, M.*, Hall, S.R., Disney, J., 2022. Precipitation-mediated fluctuations in well water arsenic in Hancock County, ME, Maine Sustainability and Water Conference, Augusta, Maine, March 31, 2022.

Feher, A.*, Hall, S.R, Disney, J.E., and Jackson, B.P., 2022. Arsenic abundance in arugula and kale, Maine Sustainability and Water Conference, Augusta, Maine, March 31, 2022.

Slamova, L.*, Hall, S.R., Feher, A.*, Disney, J.E., and Jackson, B.P., 2022. Do the orchard soils of Mount Desert Island region harbor residuals of historical arsenical pesticide use? Maine Sustainability and Water Conference, Augusta, Maine, March 31, 2022. Won honorable mention for poster presentation.

Moran, L.*, Hall, S.R., Farrell, A., and Disney, J., 2022. Influence of different water treatment systems on arsenic concentrations in private well groundwater: A view from MDI, ME.

Farrell, A., Buckman, K., Hall, S.R., Muñoz, I.*, Bieluch, K., Zoellich, B., and Disney, J., 2021. Adaptations to a secondary school-based citizen science project to engage students in monitoring well water for arsenic during the Covid-19 pandemic. Journal of STEM Outreach 4(2), doi: 10.15695/jstem/v4i2.05.



**Acknowledgement**: The work reported in this publication was supported by the National Institute of General Medical Sciences of the National Institutes of Health under Award Number R25GM129796. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

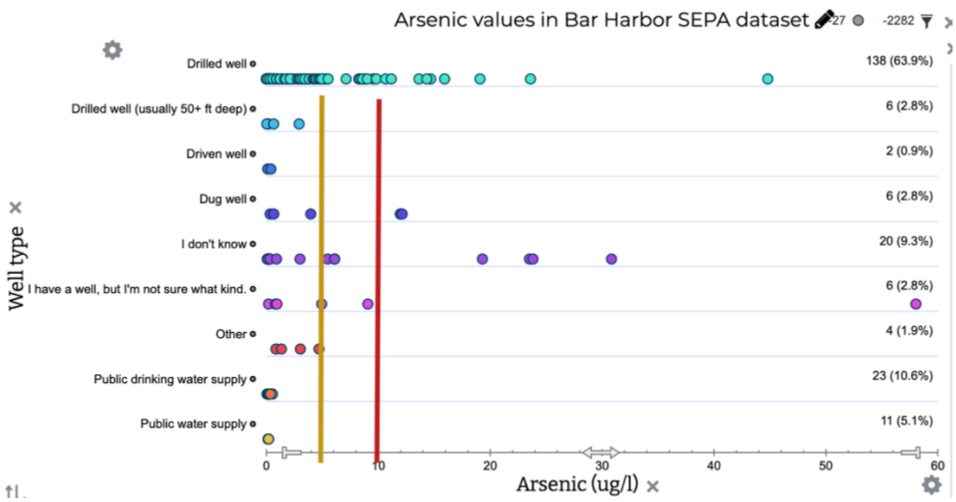

**Appendix:** Demo data worksheet using Tuva (below)

**IDEAS FOR DATA ANALYSIS WORKSHEET:**

**STEP 1: Find the data!**
Find your town/county's dataset(s) on Tuva. This may include just your school or other schools in your town/county. Write the name of the datasets (which town/county/schools) included here:

**STEP 2: Make the graph!**
Plot the data to make the graph shown below:
1) Arsenic on the x-axis, Type of well on the y-axis by dragging the dataset to each axis.
2) Drag the 'well type' dataset to the far right axis to color code the different well types.
3) Add a title that describes your graph: "Arsenic values by well type in NAME OF TOWN"
4) Add a vertical line at 10ppb and add a textbox near it that says "ME MCL"
5) Add a vertical line at 5ppb and add a textbox near it that says "NH MCL"

**STEP 3: Analytics!**
1) Add statistics to your graph by including "Count" and "Percent" for each well type (EXPLAIN HOW TO DO THIS HERE). Now your graph should look something like the one below:




2) Looking at your graph, fill out the table below:

| Row | Well Type | Count | Percent |
|---|---|---|---|
| 1 | Drilled Well | | |
| 2 | Drilled Well (usually 50' deep) | | |
| 3 | Driven Well | | |
| 4 | Dug Well | | |
| 5 | I have a well but I'm not sure what kind | | |
| 6 | I don't know | | |
| 7 | Other | | |
| 8 | Public drinking water supply | | |
| 9 | Public water supply | | |
| | **TOTAL:** | | |

Great! Now you can answer the questions below:
1) How many total data points (N) are in your study? (HINT: add up all the numbers in the count column.)
2) How many of your data points come from wells (W)? (HINT: add up rows 1-5)
3) What percent of samples in your study comes from wells? (HINT: W/N *100)

**Follow the same process in questions 2 and 3 to answer the following questions:**

4) What percent of samples in your study come from public drinking water supply?
5) What percent of samples in your study come from “Other” or “I don’t know” sources?
6) Looking at all of the different well types together, what are the minimum and maximum arsenic values?

**With the calculations you made in questions 1-7 to fill out the Summary Table:**

| Row | Well Type | Count | Percent | Minimum As Value | Maximum As Value |
|---|---|---|---|---|---|
| 1 | All Wells | | | | |
| 2 | All Public Water | | | | |
| 3 | All Other/Unknown | | | | |

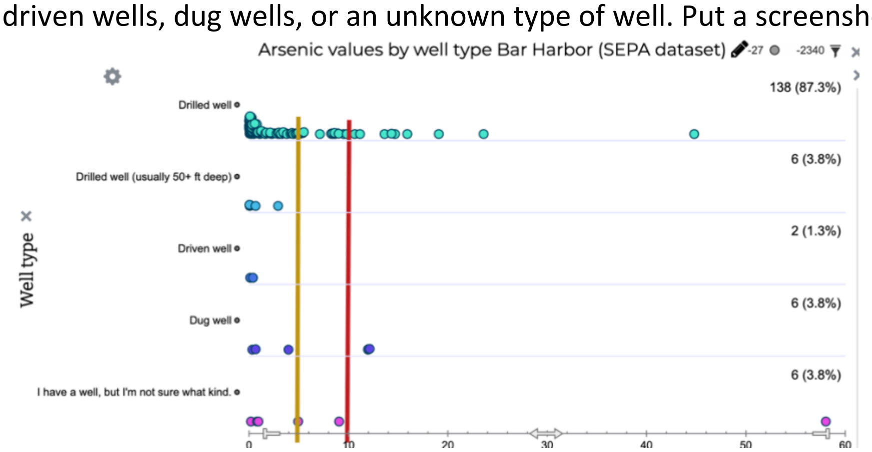
**STEP 4: Interpretation Part 1!**

Already you can start making interpretations about your dataset.

7) Write a sentence or two summarizing where the data in your dataset come from: what was measured and in what type of well. For example, something like: “Of the ### participants in the Bar Harbor SEPA study, ##% use private well water as their drinking water source, ##% use public water as their drinking water source, and ##% don’t know where their water comes from.”
8) Looking at the graph and your summary table, write a few sentences where we tend to see arsenic in the dataset. Perhaps try to answer the following questions:
    a. Which water source has the highest maximum values?
    b. Which water source has the lowest maximum values?
    c. Which water source has the greatest range of values?
    d. Are the maximum values above the ME and/or NH MCL?
9) Given your statement written in #8, write one final interpretive statement about which water source(s) tends to contain arsenic at levels at or above the ME/NH MCL.

**STEP 5: Subsetting the dataset**

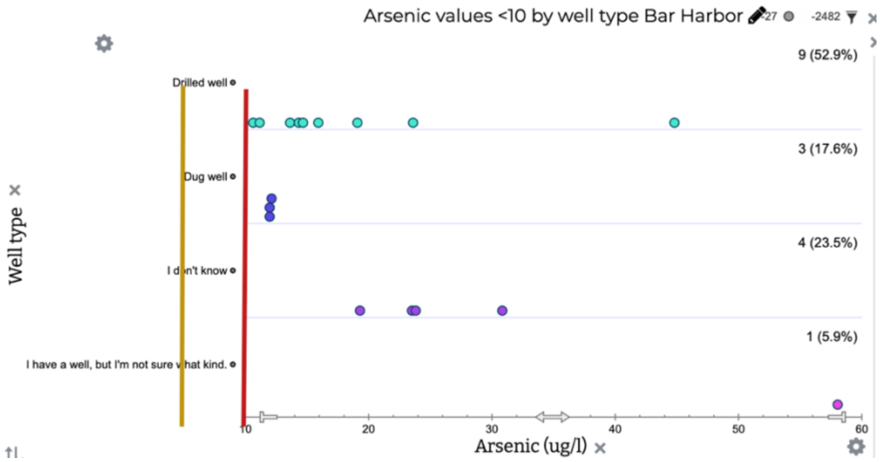
Now we will break the dataset up a bit to look at a few specific things. You can open up any of the variables, such as Well Type, in the data panel on the left (EXPLAIN THIS). Open up the Well Type data and uncheck everything that isn’t a well. You should be left with data on your graph that only comes from drilled wells, driven wells, dug wells, or an unknown type of well. Put a screenshot of your graph below:




10) Using your first table and your new plot answer the following questions:
    a. What percent of wells are drilled wells?
    b. What percent of wells are driven or dug wells?
    c. What percent of wells are of an unknown type?

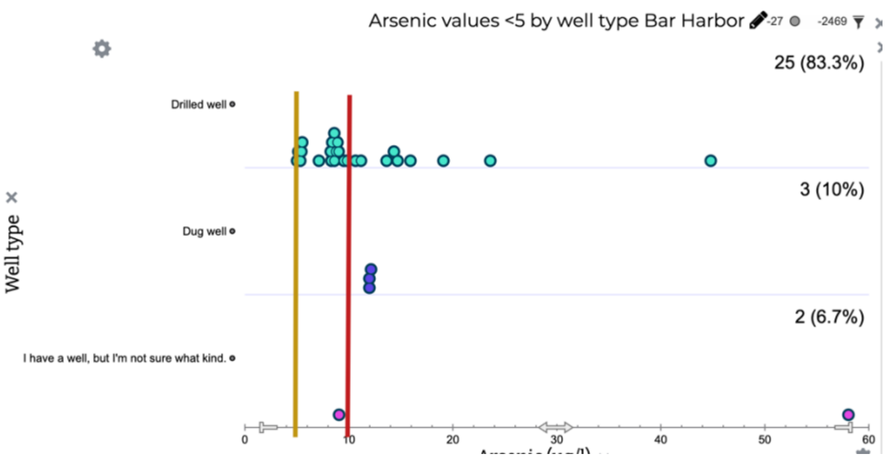
Now let's subset the data to see how many data points are above the ME MCL. Open the Arsenic variable panel and uncheck all values below 10ppb. Now your graph should only show the data that is greater or equal to 10ppb.

11) Put the screenshot of your graph with arsenic values >10ppb below:




Do the same thing for the NH MCL: uncheck all As values below 5ppb so that your graph only shows data great than or equal to 5ppb.

12) Put the screenshot of your graph with arsenic values >5ppb below:




13) Let's add our new observations to our first table. You already have the number of each type of well (Count). Re-enter them here. Then, fill in the number of samples above the ME MCL (10ppb) and the number of samples above the NH MCL (5ppb) for each well type below.

| Row | Well Type | Count | # > 10ppb | # > 5ppb |
|---|---|---|---|---|
| 1 | Drilled Well | | | |
| 2 | Drilled Well (usually 50' deep) | | | |
| 3 | Driven Well | | | |
| 4 | Dug Well | | | |
| 5 | I have a well but I'm not sure what kind | | | |
| 6 | I don't know | | | |
| 7 | Other | | | |
| 8 | Public drinking water supply | | | |
| 9 | Public water supply | | | |
| | **TOTAL:** | | | |

14) Using the data on your table above, calculate the percent of wells that has an arsenic value over 10ppb and over 5ppb for each well type. Remember, to calculate a percent, use the form (# of specific part/# of total elements * 100)

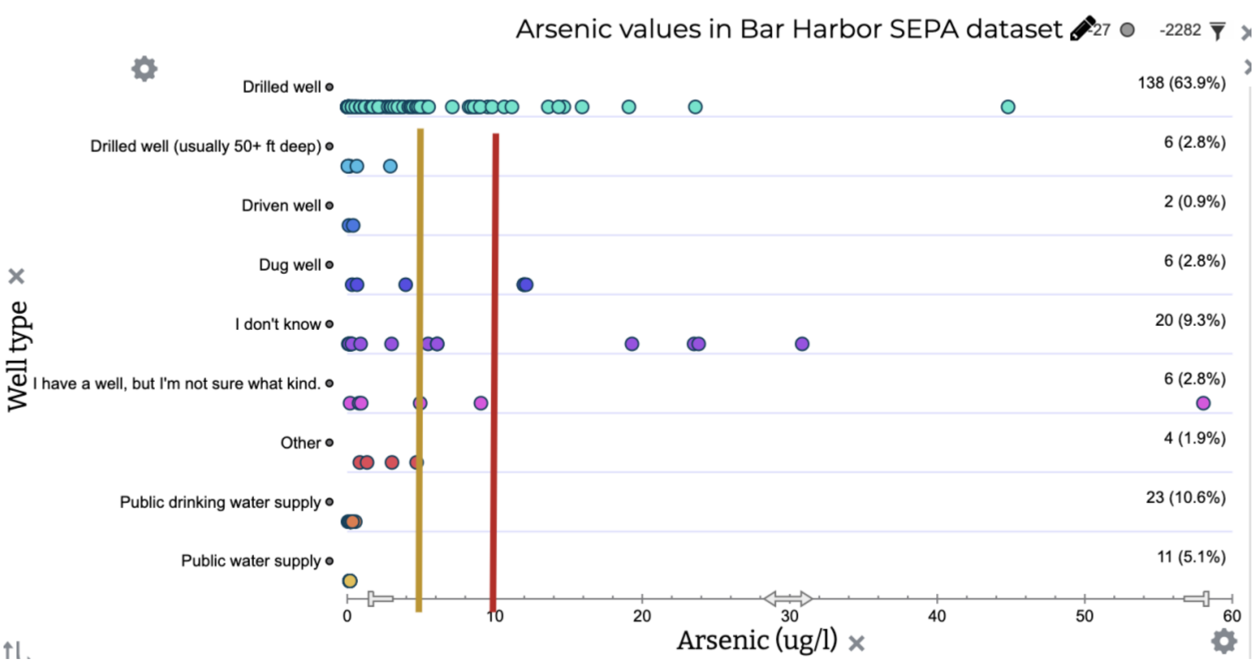
| Row | Well Type | Count | # > 10ppb | % > 10ppb | # > 5ppb | % > 5ppb |
|---|---|---|---|---|---|---|
| 1 | Drilled Well | | | | | |
| 2 | Drilled Well (usually 50' deep) | | | | | |
| 3 | Driven Well | | | | | |
| 4 | Dug Well | | | | | |
| 5 | I have a well but I'm not sure what kind | | | | | |
| 6 | I don't know | | | | | |
| 7 | Other | | | | | |
| 8 | Public drinking water supply | | | | | |
| 9 | Public water supply | | | | | |

**STEP 6: Interpretation Part 2!**

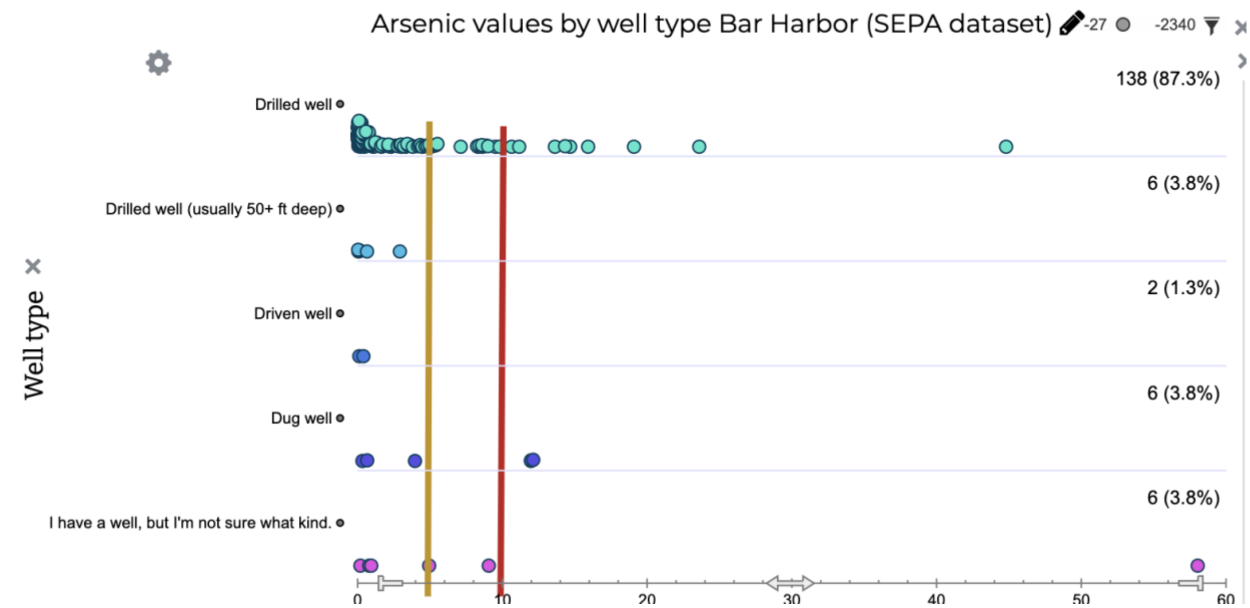
Given your calculations on your table above, write a few statements about which wells tend to have levels of arsenic above the ME/NH MCL. Possible questions to answer:

a) Do you see any evidence that people who don't know what their water source is are drinking elevated levels of arsenic?
b) What advice might you suggest based on these data?
c) Given the total number of wells in BH (1400?), how many of them might have As levels above 10ppb given the percent of wells that have As levels above 10ppb? 5ppb?

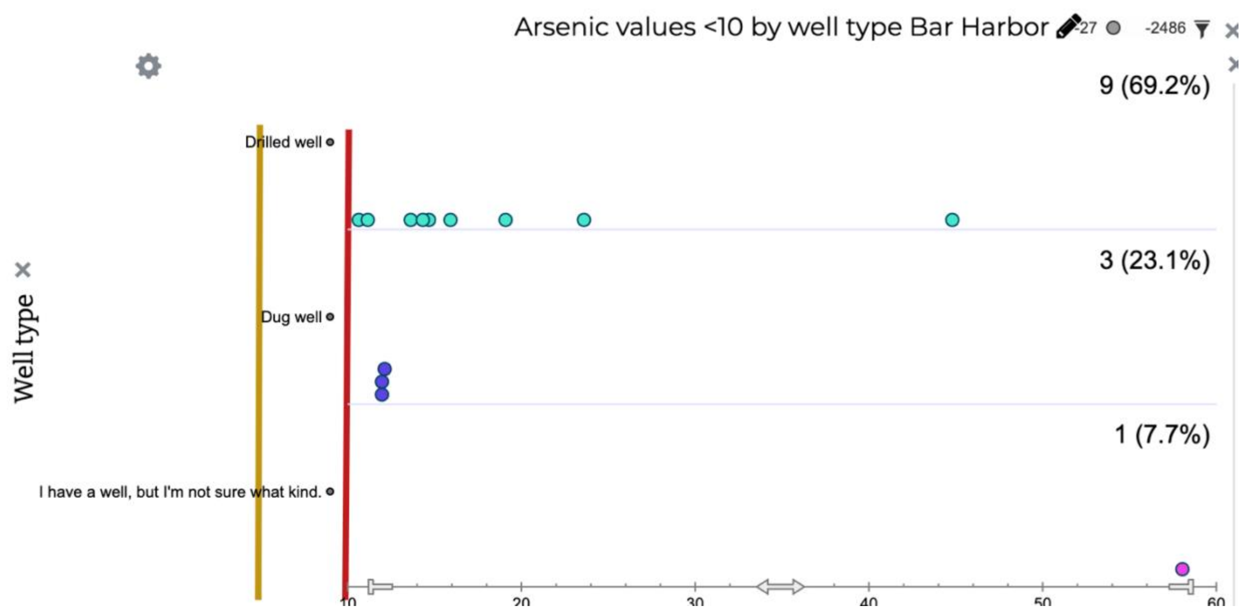
**Subset to Bar Harbor SEPA data**: from this we can see that As is mainly in private well water and that the total number of data points is: 216, 158 are known to be wells, 44 are known to be public drinking water sources, and 24 are "I don't know" or "other". Some of the "I don't know" samples have high As! Overall, we can calculate that 73% of the data points come from wells or private groundwater sources (like springs).



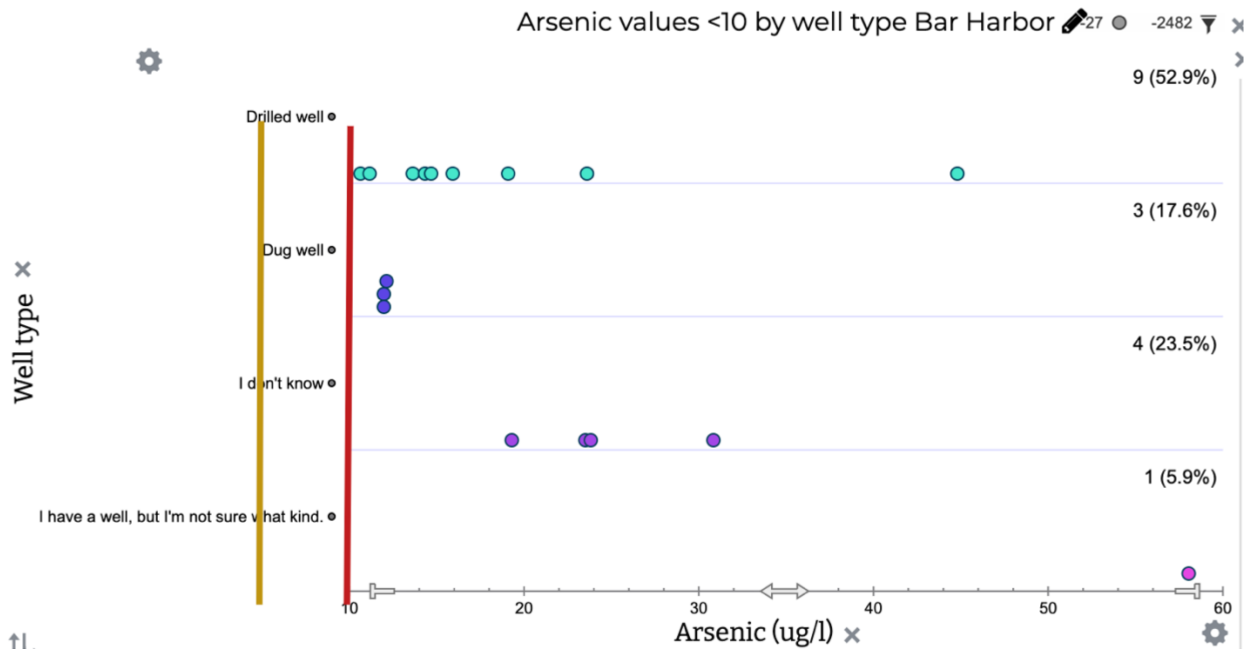

**Subset again to only include data from wells**: exclude public water, I don't know, and other. Then plot well type vs arsenic abundance and turn on the count or percent: From this we can see that most of the wells are drilled and that some people don't know what kind of well they have. Of the 158 wells, 138 of them are drilled (this is 87% of the wells in the dataset).



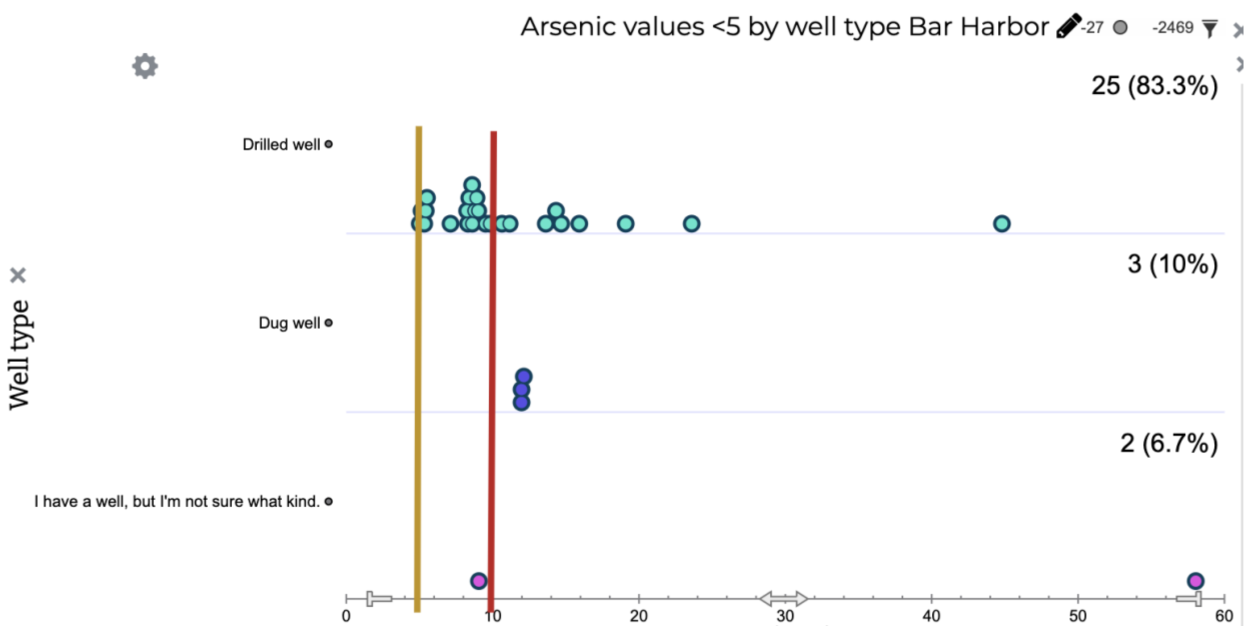

**Set the minimum As value to 10ppb**: From this we can see that of the total wells in this study, 13 of them have As over 10ppb (accidentally used the < instead of > sign in the title!). This is 8% of all wells studied (13/158*100).



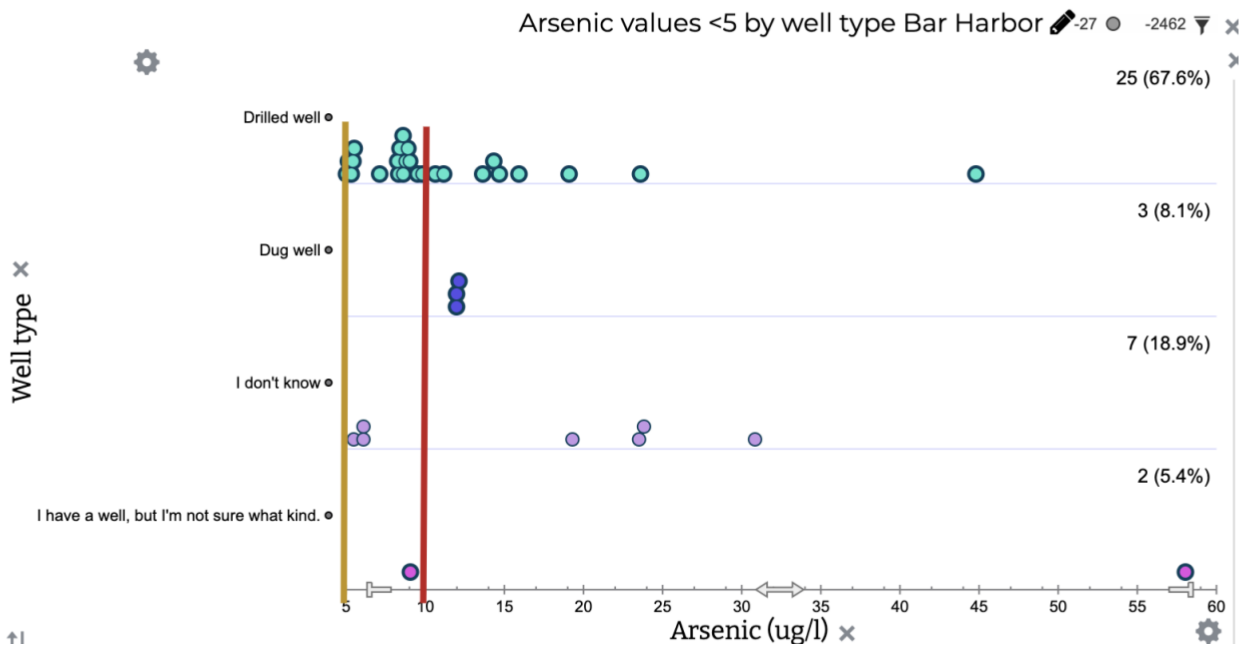

If we kept the "other" and "I don't know" samples included, the number of samples with As over (accidentally used the < instead of > sign in the title!) 10ppb is 17 which is 7.8% of all the samples in the study (including public water; 17/216*100).




**Now set the minimum arsenic value to 5ppb:** from this we can see that 30 wells have As greater than 5 ppb (accidentally used the < instead of > sign in the title!) which is 19% of all of the wells in the study.




Again, if we include the rest of the data, you can see that 37 samples have As over 5ppb (accidentally used the < instead of > sign in the title!) which is 17% of the total dataset. Note that this plot will only show the data if the value of As is 5 or greater, so none of the public water samples have that much As so that type of sample doesn't even show up on the y-axis.




**Take home message:**

About 8% of samples in the BH SEPA dataset have As values over the ME MCL of 10ppb. Most likely these all come from private water sources (a few are "I don't know).

About 18% of samples in the