Understanding the Prevalence of Uranium in Groundwater Wells in Glastonbury, CT - June 2021

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Executive Summary

The Glastonbury Health Department has been conducting an ongoing investigation on the quality of private well water since 2018. They have found that uranium, a naturally occurring metal, has appeared in higher concentrations than federal and state regulatory criteria. The Town of Glastonbury has encouraged private groundwater well owners to share their own well water samples with the Glastonbury Health Department. Of the 821 wells tested in Glastonbury, CT, approximately 35% had uranium concentrations greater than the United States Environmental Protection Agency's maximum contaminant level of 30 ppb. Please note, wells located within two areas of interest were more heavily sampled than other areas of town. We, the authors of this report, looked at geology, water quality and availability, and groundwater well characteristics to better understand the occurrence of uranium in groundwater.

1. **Geology:** After comparing maps of the bedrock and surface geology with the locations of uranium-containing groundwater wells, the presence of uranium was found to be primarily associated with the Glastonbury Gneiss. The original source of uranium in the groundwater wells in Glastonbury is likely the granitic gneiss and similar igneous rocks. Over time, the geology and geochemical environment changed, allowing for uranium to dissolve into groundwater in the area.
2. **Water quality:** Uranium was especially present in areas where the surficial geology is a thin till. Due to the fractured nature of the geology coupled with the overlying thin till, water can move easily from the surface and through the ground. Since the subsurface is inconsistent, it is challenging to predict water quality and availability for individual wells.
3. **Groundwater well characteristics:** After comparing the prevalence of uranium with groundwater well characteristics, we found that 70% of the wells with uranium concentrations greater than 30 ppb are deeper than 400 ft.

Due to the potential health impacts of uranium exposure to residents, we, the preparers of this report, have detailed actions citizens can take now. However, data is limited and we provide suggestions for future studies and investigations. In the meantime, the Town of Glastonbury has established an action plan to promote a safe and healthy Glastonbury and help protect its citizens.

What is causing uranium contamination in drinking well water?

Bedrock Geology

Glastonbury Gneiss and Schist (also labeled as Collins Hill Formation) are the primary geologic and bedrock features under and around Glastonbury, CT, as shown in Figure 1. When igneous rocks are formed, they differentiate into different types at various stages from their source magma. The Glastonbury Gneiss was originally granodiorite (similar to granite, an igneous rock) before being metamorphosed (subjected to high pressures and temperatures). These source igneous rocks (e.g. granodiorite, syenite, and granite) all formed during late-stage differentiation from magma, are reported to be uranium-rich containing 2 to 6 ppm of uranium[45]. In Glastonbury, uranium-rich minerals have been found and studied since the early 20th century[7–12]. Samples of stream sediments around Glastonbury had median uranium concentrations of 6.5 ppm (range 3.4-12.7 ppm), which is high compared to the average concentration in the upper crust (~2.7 ppm), and implies that the area is relatively uranium-rich terrain[13,14]. Figure 2 shows a map of this same bedrock geology and locations of the groundwater wells with measured uranium, illustrating the potential that uranium-rich magmatic minerals in the Glastonbury Gneiss are the possible primary source of uranium in groundwater and surface water in this area.

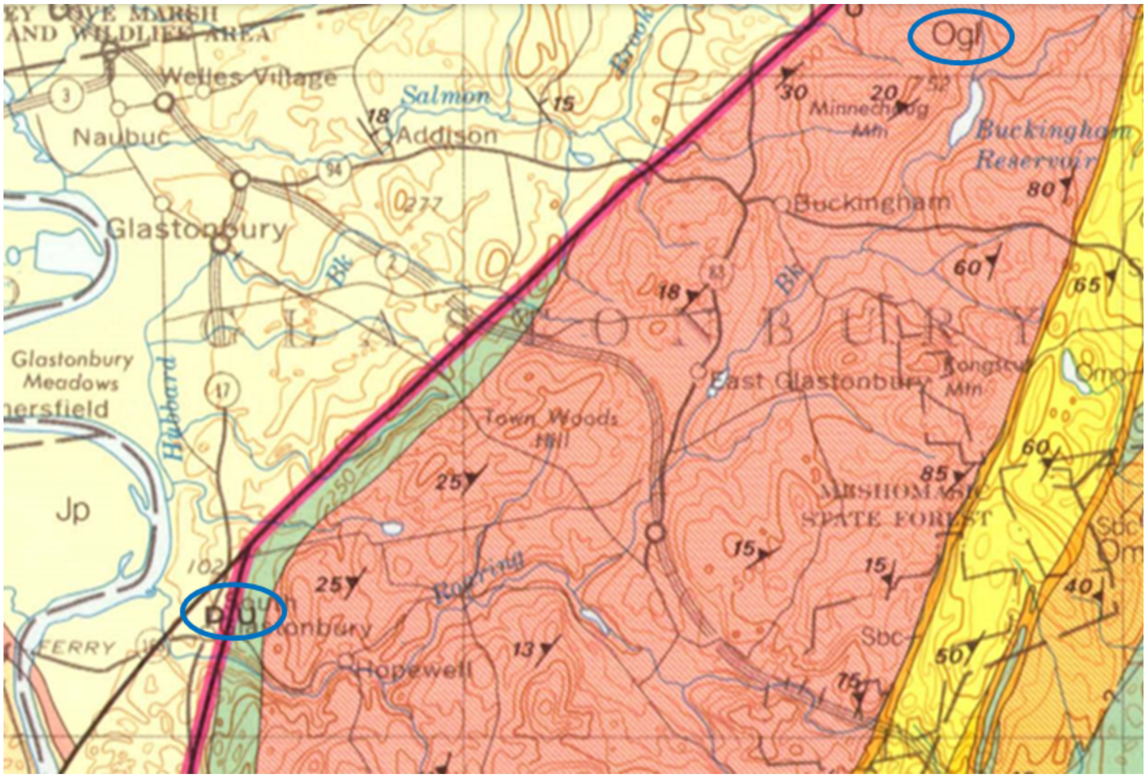

Figure 1: Bedrock geologic map of Connecticut showing Glastonbury portion. "Ogl" is the Glastonbury Gness unit, "U" is the upthrown block of high-angle fault, and "D" is the downthrown block of high-angle fault.

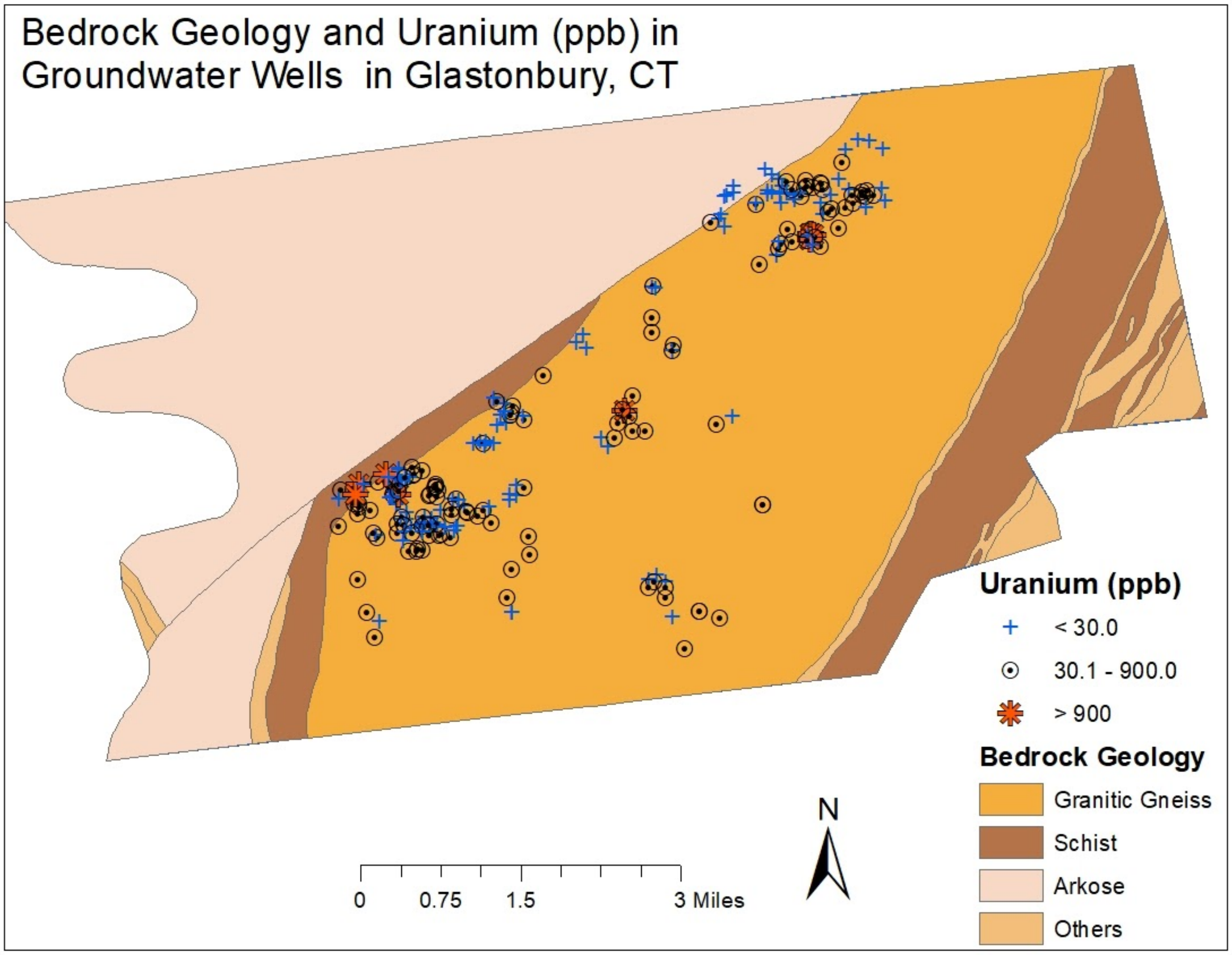

Figure 2: Bedrock geology map of Glastonbury town overlain by recently mapped well water uranium. [43,47] **Please note: not all tested wells are shown here.**

Faulting

Faults are the planes of movements of rock blocks that create fractured-rock aquifers, which are conduits for the movement of groundwater. Faulting also disturbs the subsurface geology by throwing deeper rocks up towards the oxygenated surface (as indicated by "U" in Figure 1 on the previous page). This leads to a change in the geochemical conditions, which may favor uranium dissolution, discussed in more detail later. The fault plane is present at the contact zone between the granitic gneiss, schist, and arkose rock, and the other rock units incline towards the fault (Figures 1 and 2). This indicates a significant structural discontinuity between these geologic layers and the presence of rock fractures dipping towards the faulted area. The presence of geologic structures, such as faults and folds in the Glastonbury area may have enhanced the exchange between the surface and subsurface, which in turn could promote uranium dissolution into water sources.

Most of the wells in Glastonbury are connected to a fractured rock aquifer. Water movement in fractured aquifers is very complex, which presents significant challenges in predicting water quantity and quality. Since the amount and quality of water transmitted by fractures can vary significantly over a small geographic area, wells situated close to each other are not necessarily connected to the same fractures. As a result, uranium concentrations can vary between wells, as illustrated in Figure 3.

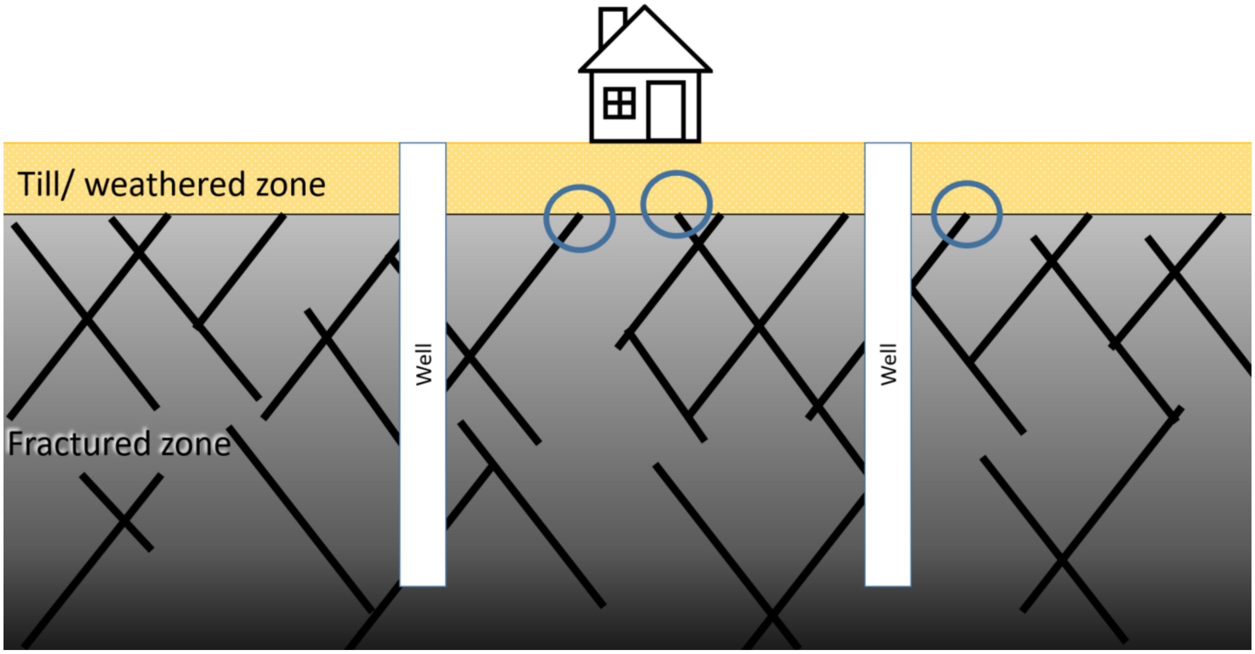

Figure 3. Simplified illustration of a fractured-rock aquifer system. Notice how there is no overlap in the fractures connected to the two wells. The blue circles indicate areas where water can move quickly from the surface to the well, bringing with it potential contamination.

Surface - Subsurface Interactions

Of the groundwater wells measured in this study, wells with high concentration of uranium are located where 1) the surficial material is thin till, 2) is in the contact zone between the thin till and the Roaring Brook (in the east/southeast), or 3) in the contact zone between the thin till with thick till (in the north). As shown on the map in Figure 4, till is the most extensive surficial deposit in the Glastonbury area.

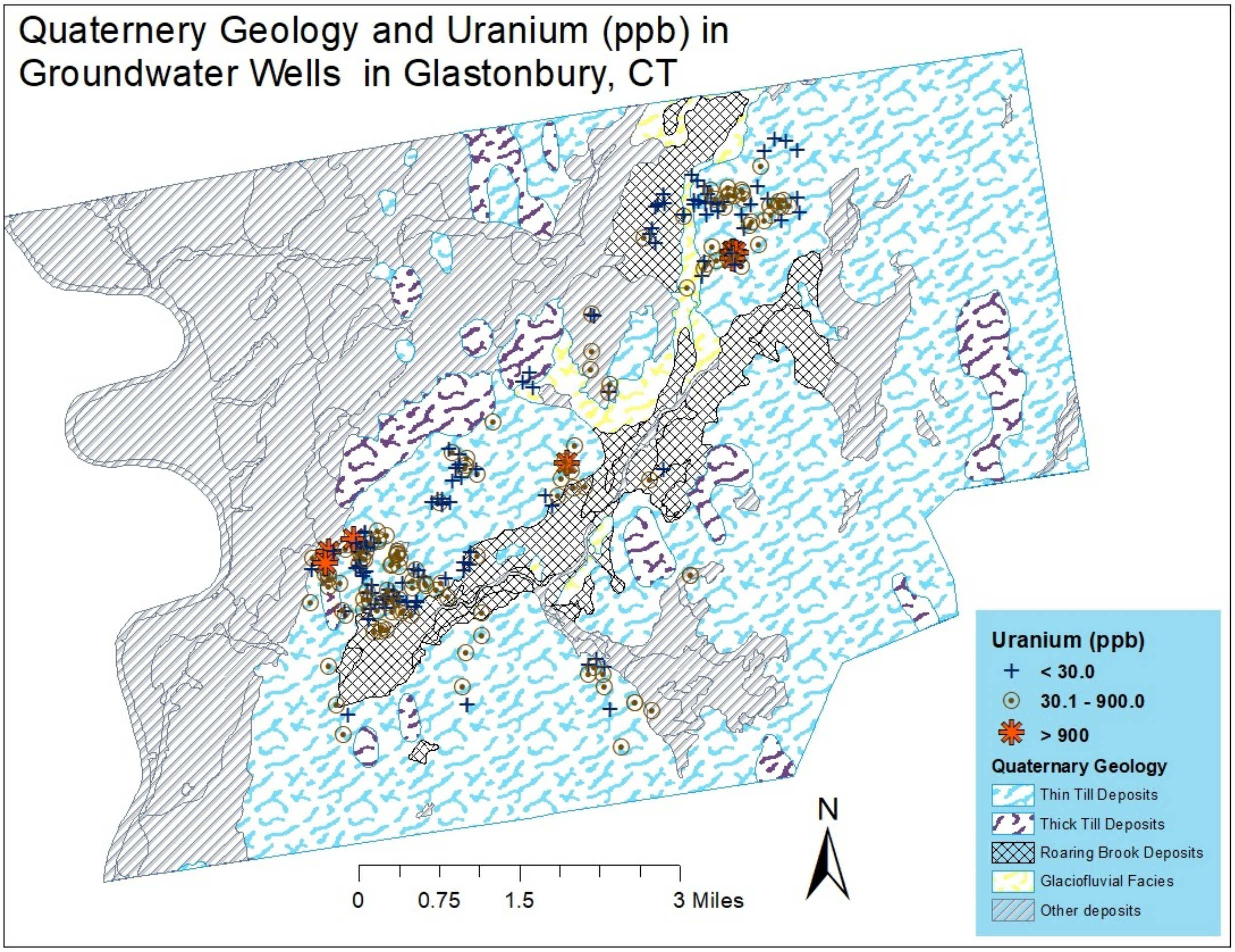

Figure 4: Quaternary geology map of Glastonbury town overlain with recently mapped well water uranium[44,47]

Tills are weathered zones that are made up of silt-sand and sandy or silty sediment matrix containing 5 to 40% of pebbles, cobbles, and boulders, and is illustrated in the simplified Figure 3. These tills can lead to substantial hydraulic conductivity (or groundwater flow). Thin till is less than 4 - 5 meter thickness, whereas the thickness of thick till typically exceeds 4 - 5 m. The tills under Glastonbury are likely a product of local bedrock weathering because rock shearing and breakage zones have been observed in the shallow part of the thin till, and the thin till characteristics (i.e., color, texture, composition) are closely related to the surrounding bedrock[42]. The shallow part of the lower till shows an oxidized zone next to the Roaring Brook that is likely a result of weathering, resulting in frequent occurrences of closely-spaced joints (open fractures without measurable movement) and iron and manganese oxide minerals. These surficial deposits and geologic characteristics indicate that the primary rock types in the area have undergone substantial geologic and geochemical changes over time.

Since water can move easily from the surface through the thin till, fractured rock aquifers are more susceptible to inputs from surface land-use activities, such as nitrate. Since the presence of nitrate reduction can be coupled with uranium oxidation, additional geochemical processes can impact uranium solubility, and thereby, availability in water. In areas with groundwater contamination (i.e. contamination coming from aquifer rocks), it can be difficult to predict which wells will be affected, because individual wells are connected to their specific network of fractures.

Geochemical Influences on Uranium in Groundwater

Granitic aquifers, similar to those in Glastonbury, are commonly known to contain groundwater with high concentrations of uranium[1–6]. One way uranium can be leached into groundwater from aquifer materials is by dissolution minerals containing uranium. In certain environmental conditions dependent on factors like pH and the lack of dissolved oxygen, the uranium may adsorb (or reattach) back onto mineral surfaces in the aquifer over time. Desorption from these surface sites when water conditions favor uranium solubility is the second way that uranium may get into groundwater from aquifer solids.

Uranium is most soluble in water under oxidizing conditions, which in groundwater often means water with dissolved oxygen concentrations >0.5 mg/L. Carbonate alkalinity (the amount of carbonate + bicarbonate in water) can also play an important role in controlling uranium in groundwater through the formation of highly soluble complexes. Increased salinity and slightly alkaline pH also promote uranium desorption.

In Glastonbury, *deeper wells tend to have higher concentrations of uranium (p-value < 0.001, Figure 5).* This is somewhat counterintuitive, as shallow groundwater in most systems is usually more oxygenated, which would lead us to expect higher concentrations of uranium. However, fractures can quickly transport young oxygenated water from the surface to depth, affecting redox conditions, and thus expected uranium concentrations. Additionally, higher uranium concentrations at depth may be more influenced by the surrounding geology than aquatic chemistry. Studies in similar formations from Massachusetts have shown consistent increases in groundwater electrical conductivity with increasing depth from individual wells[15]. Electrical conductivity is a field proxy for salinity, which may be correlated with increased groundwater uranium concentrations. There are a few instances in the Glastonbury dataset of two wells drilled in very close proximity, but at different depths. Site 551 has a well drilled to 520 ft with 48 ug/L measured uranium, but at site 252, which is 330 ft away, a well drilled to 750 ft was measured as having 22,300 ug/L uranium. Additionally, site 1662 has two wells, one at 405 ft and one at 505 ft, drilled 245 ft apart. When the two wells were measured for uranium on the same day, the deeper well had a higher uranium concentration, 26.5 µg/L compared to 16 µg/L. While anecdotal, these examples could indicate that there is more soluble uranium in deeper fractures. This has implications for the exploitation of deeper groundwater reserves and may be worth investigating further.

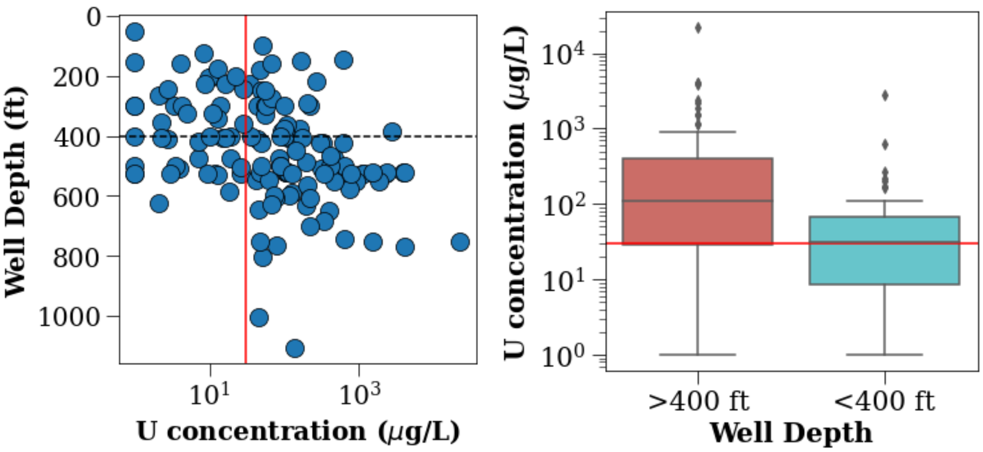

Figure 5. Uranium concentration and well depth. On the left, a scatterplot shows the plotted data from Glastonbury with a red line for a uranium concentration of 30 ug/L and a dotted black line indicating the median well depth from the Glastonbury data (~400 ft). On the right, two boxplots show the distribution of measured uranium concentrations in wells less than 400 ft deep and well greater than 400 ft deep.

The groundwater well chemistry dataset contains a few wells for which more than one uranium measurement was made. For some wells, concentrations of uranium were vastly different between samplings. One possible explanation for this is seasonal changes in water levels. We used USGS water level data from Marlborough, CT, and data from the two wells with at least 3 observations for uranium as representative groundwater data. In both well 510 and well 10 there were very large differences between the highest and lowest uranium concentrations measurements, 105 vs. 4050 µg/L and 1130 vs 2215 µg/L respectively. Both also showed trends with water level fluctuations, though in opposite directions (Figure 6). This could be consistent with different formations being watered or dewatered due to seasonal changes, but more detailed information would be needed to confirm. The dataset contains other wells which were measured at two different times throughout the year, with different measured uranium concentrations. The data implies that there can be large fluctuations in uranium concentrations over time, which homeowners should be mindful of.

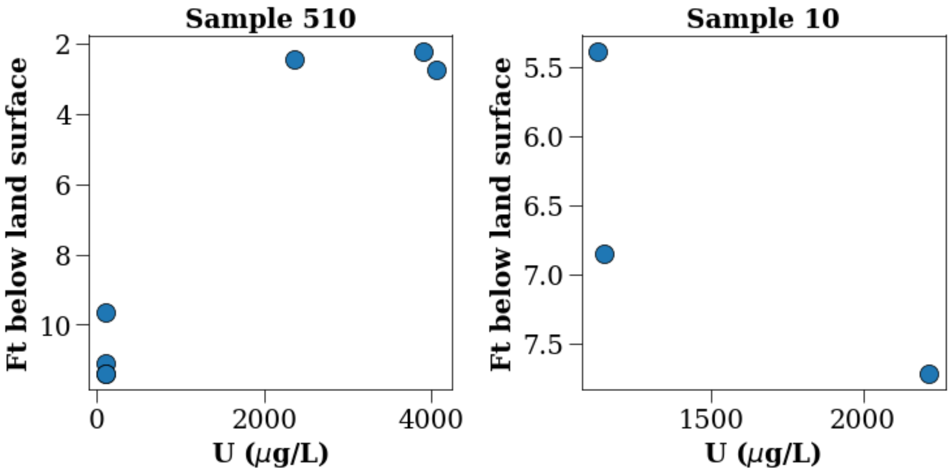

Figure 6. Results of multiple uranium concentrations measurements in two wells from the Glastonbury dataset. These measurements were taken at different times and plotted against the water level measurement at a nearby monitoring site. The changes tend to cluster with times of different water levels, which may imply that uranium concentrations at the wells may change as the water table fluctuates.

Calcium concentrations and pH are weakly correlated with uranium concentrations. This may reflect calcium complexation with uranium, which forms compounds that are very stable and do not adsorb to aquifer materials easily, or may be an indicator of silicate weathering taking place in the aquifer. The association with pH could reflect a tendency of uranium to desorb at higher pH, though the correlation with pH is not significant in the small subset of samples (n=35) for which pH and U were measured at the same time. More comprehensive data measuring uranium simultaneously with other chemical well parameters is important for understanding what determines uranium concentrations in well water, as well as potentially devising cost-effective methods for homeowners to assess the likelihood that their groundwater contains concentrations of uranium greater than 30 ug/L.

How can uranium impact health?

Ingestion of natural uranium is not a health threat because of its radioactivity, but rather because of its chemotoxicity as a heavy metal[16]. Roughly 95% of ingested uranium is excreted in urine within one week of ingestion[17], and that which is retained is incorporated into the bones, kidneys, and liver[18]. Uranium has no known essential biological function in humans, but assessing its exact toxicity is difficult due to ethics constraints and thus most literature relies on animal models and field studies of exposed communities. There are limitations to nearly all epidemiological studies; sometimes uranium exposure is not well quantified, uranium speciation is usually not considered, and it can be difficult to control for confounding environmental factors. In 2020, Ma et al published a review of the uranium toxicology literature, which goes through the epidemiological literature from the past 20 years and covers proposed explanations of mechanisms of toxicity[19]. The following sections describe existing literature related to different body systems.

Nephrotoxicity

Uranium has been broadly studied for its nephrotoxicity, or kidney toxicity. There is some evidence from community-based studies that long-term consumption of drinking water with elevated uranium concentrations can cause kidney problems, especially proximal tubular damage, but the clinical significance of the biomarkers used (urinary levels of glucose, calcium, and various low-molecular-weight proteins) are not always clear[20–23].

Bone Toxicity

Uranium is chemically similar to calcium and, thus, incorporates into the skeleton. Uranium has been shown to impair normal bone metabolism and function in animal studies, and increase the risk of osteosarcoma and osteogenesis[24–27]. One study in humans suggested an association between increased bone turnover and drinking water uranium exposure in men, but not in women[28]. Another study involving veterans hit with depleted uranium shrapnel fragments during the first Gulf War showed that individuals with higher urine uranium concentrations also had lower bone mineral density[29].

Reproductive Toxicity

Animal and in vitro studies have shown that reproductive organs and germ cells are sensitive to uranium[30–33]. One study has found that in utero exposure to high uranium concentrations may increase the risk of orofacial clefts in humans[34]. Two very large studies found associations between high parental urine uranium concentrations and earlier gestational age at delivery, greater risk of preterm birth, and lower birth size[35,36].

Hepatotoxicity and neurotoxicity

Little to no epidemiological data exists regarding the direct toxicity of uranium to the liver, brain, or lungs, but there are some studies in rats. For the liver, studies have linked the ingestion of high concentrations of uranium to altered liver detoxification function, dysfunctions of steroidal hormone metabolism, and increased cholesterol. Uranium exposure may increase neuroinflammation, impair neurological function, locomotion, sleep-wake cycle, and cerebral development in rats[37–39].

Other

A few epidemiological studies have looked at uranium exposure and cancer, with a study from South Carolina concluding there may be an association between total cancer, and specifically colorectal, breast, and kidney cancer, with the use of uranium-contaminated groundwater[40]. A study in Kuwaiti children suggested that salivary biomarkers for uranium are related to obesity in children[41]. Uranium exposure was not measured directly in either of these studies.

As a Glastonbury citizen who may be impacted, what can I do? Options to address uranium in drinking water

Connection to a public water system provides a drinking water supply that is routinely tested and treated for a variety of contaminants and water concerns, including uranium. Expansion of public water into areas currently not served can take years. If public water is not available, there are two methods of treatment commonly used to remove uranium from drinking water: reverse osmosis (RO) and anion exchange (AE).

Reverse Osmosis

Reverse osmosis (RO) can be installed for point-of-use or can treat the whole house. Point-of-use treatment (usually at the kitchen sink) is best for lower concentrations of uranium. RO systems require relatively clean water to prevent premature fouling of the filter membrane, so pretreatment may be necessary. RO systems remove uranium, different salts, iron, nitrate, lead, fluoride, sulfate, potassium, manganese, aluminum, silica, chloride, total dissolved solids, chromium, orthophosphate, some detergents, some pesticides, as well as some taste, color, and odor-producing chemicals. Point-of-use RO systems generally cost less than $1,000 installed, and a whole house RO system is currently estimated at $30,000.

RO systems generate backwash wastewater, and the backwash from a point-of-use system may be discharged to a sanitary sewer or your home septic system. Due to the volume of wastewater generated, the backwash from a whole house RO system must be discharged into the sanitary sewer or a separate, dedicated leaching structure. This wastewater cannot be discharged into your home septic system. The most efficient RO systems generate at least one gallon of wastewater for every gallon of treated water. Over one day, a whole-house system may produce hundreds of gallons of wastewater. Since RO systems remove almost all of the minerals, the water becomes very corrosive. Minerals may have to be added back into the RO-treated water to protect the home's plumbing.

Anion Exchange

Anion exchange (AE) systems use a salt-recharged filter media to remove negatively charged ions. Chloride is released into the water as part of the treatment process. Recharging the media generates wastewater that is then discharged either into the sanitary sewer (if available) or into an appropriately sized dedicated leaching system. The backwash from an AE system may not be discharged into the home's septic system. Source water that is turbid or has elevated concentrations of iron may foul the treatment system. Anion exchange systems will reduce the pH of the water, so a pH neutralizer may be needed to prevent corrosion of the home's plumbing. In addition to uranium removal, AE systems remove nitrates, bicarbonate, sulfate, selenium, some forms of arsenic, and some organics that affect odor, taste, and color. The filters cost from $1,200 to $2,000 as well as an additional $2,500 to $4,000 for the backwash leaching system.

What is the Town of Glastonbury doing to address concerns surrounding uranium in well water?

The Town of Glastonbury is working with consulting engineering firm Tighe & Bond on a preliminary report to identify an opportunity to extend public water service to areas of high uranium concentration in residential wells. The areas under review are served by the Manchester Water Company, (Minnechaug Mountain), and the Metropolitan District (generally the Chestnut Hill Road corridor.) The preliminary report was presented to the Glastonbury Town Council at its meeting on April 27, 2021. Legislation is currently pending for a state-wide analysis of uranium in well water. Subject to state legislative approval, the report will be issued in early 2022. The Town is also exploring federal funding opportunities for infrastructure projects, and working with the state and Department of Public Health to identify potential funding, grant, and loan eligibility for this project.

In the interim, and as part of its ongoing efforts, the Glastonbury Health Department is continuing to receive uranium test results for residential wells, and plotting the data to a community map. This map is available to community members and will help guide any potential future extension of public water service.

Suggestions for Potential Future Investigations

There are outstanding questions about the uranium in Glastonbury's groundwater that could be investigated. In particular, it would be helpful to understand the connections between well depth, hydrology, geology, land use, easy-to-measure water quality parameters (i.e., pH, calcium concentrations), and groundwater uranium concentrations.

One approach to answering these questions could be the installation of multilevel monitoring wells with detailed geological, hydrological, and infrastructure information for interpreting the data. Geotechnical samples can be taken during the drilling process for these wells to provide site-specific geological information related to uranium occurrence (i.e. sorbed vs. mineral uranium forms, changes in available uranium with depth). These wells would also enable convenient depth discretized sampling to explore the relationship between uranium and other physicochemical parameters in the groundwater, such as pH, oxidation state, and bicarbonate. These wells may also be used to monitor water level fluctuations, which is useful both from a uranium investigation standpoint, but also as a practical matter as Glastonbury doesn't have a water level monitoring station.

Since installing monitoring wells can be expensive, higher frequency sampling of existing pumping wells is a possible alternative to better understand environmental trends across Glastonbury that may impact public health, land use, and land value. As part of this public health study, a more robust sampling program with existing infrastructure is a low-barrier option to resolve dissimilarities in the existing data that may not be fully captured by the currently limited monitoring well set up.

Regardless of the collection approach, the inclusion of data for all major elements (Na, Ca, Mg, Cl, SO_4^{2-}, NO_3^-, HCO_3^-), dissolved oxygen, pH, and temperature in addition to uranium would be important for determining geochemical controls on uranium occurrence and possible effects of human activities. A monitoring approach that collects this data at multiple points throughout the year (along with water levels if possible), will clarify how common uranium fluctuations are in groundwater, and if they are indeed a result of water table fluctuations. By addressing current knowledge gaps, the public will be better served and the potential harm can be mitigated from a better-informed response plan.

Going Forward

For additional resources, please refer to the Town of Glastonbury's website: www.glastonburyct.gov/uranium. Here, you will find information regarding where to direct any questions, guidance, and protocols for collecting and submitting results from well water tests for uranium, and information on possible next steps one can take if uranium is detected in a sample. This dedicated web page will also have the most up-to-date information about ongoing plans and actions taken by the Town of Glastonbury.

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