Evaluation of Arsenic Contamination in Groundwater from Historical Agricultural Practices in the Northeastern United States

Recent studies by the USGS and our research team have indicated that arsenic contamination of domestic wells is widespread across Connecticut and other states within the northeast (USA). Although the source of the arsenic has been thought to be geogenic, our work has shown that a statistically significant spatial correlation exists between contaminated wells and former orchards which were likely sprayed with a lead arsenate pesticide prior to the 1970's. Field work in Connecticut confirmed that orchards sprayed with lead arsenate can still retain elevated levels of arsenic which can continue to act as a source of groundwater contamination. The USGS has identified Weston as having the highest occurrence of arsenic contaminated wells than any other town in the State. Thus, in cooperation with several local and state agencies, we have conducted a detailed hydrogeologic study of the arsenic contamination in Weston. Our study assessed the relationship between arsenic contamination and historical orchards while accounting for hydrogeologic conditions. The study entailed the compiling, digitizing, and analyzing of well completion reports (1600), water quality reports for arsenic (481), historical imagery on the location and extent of orchards, and existing synthesized hydrogeologic information. Our analyses show there is a correlation of arsenic contaminated bedrock wells with nearby orchard sites and wells having shallow depth to groundwater and shallow depth to bedrock. With respect to the bedrock lithology, one rock type had a higher frequency of contaminated wells, but this rock formation also had a much higher prevalence of historic orchards. Results of this work suggest that regulatory authorities and local health officials should develop a plan to address the risk of arsenic contamination in relation to property history and location and begin a dialogue among stakeholders (including the public) to determine how current and former orchard sites can be treated to help mitigate the problem.

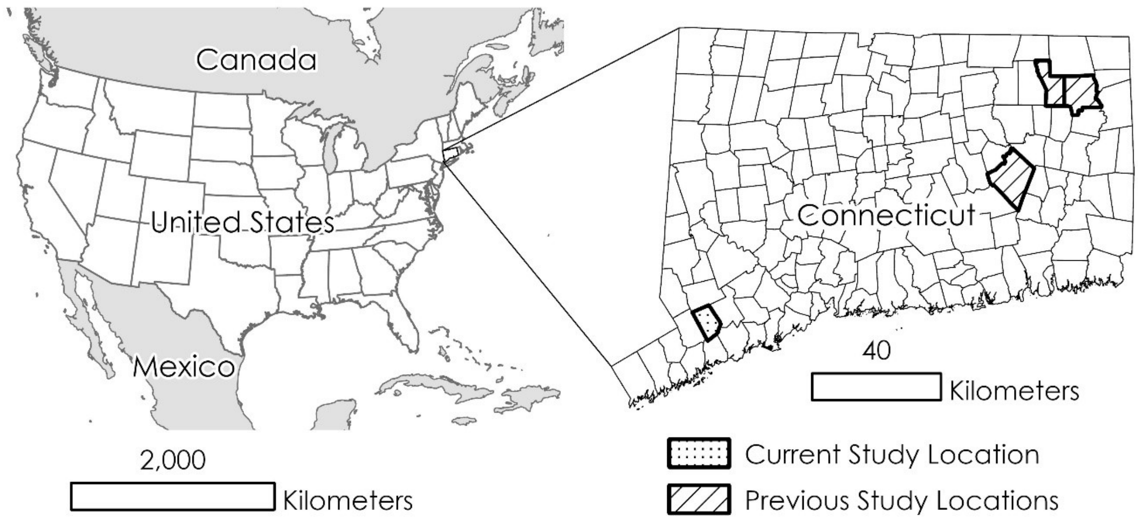
Keywords: *Arsenic, orchards, groundwater, bedrock wells*

Introduction

Groundwater derived from crystalline bedrock is a vital source of water in rural and urban areas of Connecticut which is located in southern New England of the

United States (Figure 1). The prevalence of arsenic in domestic well water has been known to be a concern in New England (Peters et al., 1999; Ayotte et al., 2003; Ayotte et al., 2017) but a recent testing of bedrock wells has revealed that arsenic is a prevalent contaminant in the bedrock groundwater of Connecticut. A study conducted by the United States Geological Survey (Gross and Brown, 2020) to evaluate risk of arsenic contamination assumed there was a relationship between arsenic and the underlying lithology in Connecticut. In this study, we evaluated this assumption at several locations. We present an alterative hypothesis to the source of arsenic and suggest that the source is due to the legacy of historical applications of lead arsenate on orchards. For almost 60 years, lead arsenate was used as a pesticide to prevent the loss of trees due to spongy (gypsy) moth infestations (Peryea & Creger, 1994; Schooley et al., 2008; U.S. Bureau of the Census, 1936). Lead arsenate was sprayed in unknown quantities multiple times per growing season on over somewhere between 35,000 and 47,000 orchards across the State (Peryea & Creger, 1994; Schooley et al., 2008; U.S. Bureau of the Census, 1936). Although the amounts sprayed varied, reported rates varied up to 71 pounds of arsenic per acre per year (Peryea & Creger, 1994; Schooley et al., 2008; U.S. Bureau of the Census, 1936). To evaluate the relationship between groundwater contamination and lead-arsenate application on orchards, we conducted several investigations across the state focused on 1) the occurrence of lead arsenate in soils at former orchards, 2) the prevalence of groundwater contamination in proximity to orchards, 3) the relationship between groundwater flow paths and observed arsenic contamination, and 4) the frequency of contaminated wells associated with underlying rock types.

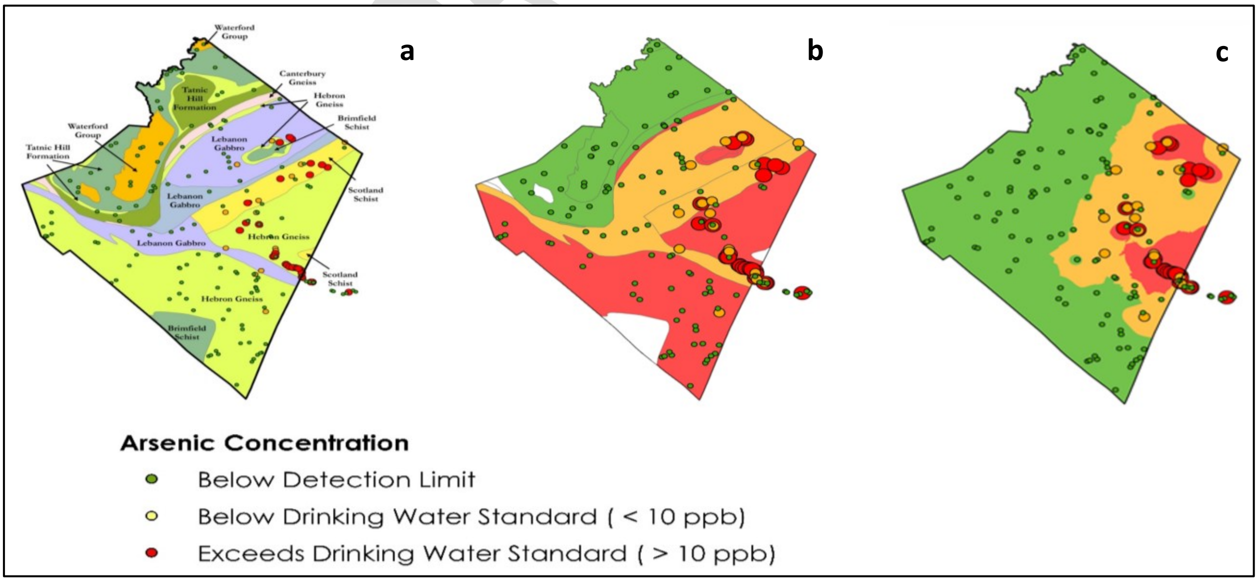
Figure 1. *Location of study areas, historical and present, where arsenic contaminated bedrock wells were examined with respect to lithology and historical orchards*



Eastern Connecticut Arsenic Contamination

Over two hundred groundwater samples were collected from wells within a rural town in eastern Connecticut. Figure 2a shows the distribution of the wells sampled for arsenic with respect to the underlying geology. Figure 2b is a risk assessment map of arsenic contamination assuming there is a relationship between arsenic occurrence in the groundwater and the geology. However, in evaluating Figure 2b with respect to the lithological units shown in Figure 2a, the distinct patterns in arsenic concentrations observed in the bedrock wells do not correspond to the aerial distribution of the bedrock. For example, the Hebron Gneiss has the largest aerial extent and the greatest number of contaminated wells. Despite the uniformity of the lithology, the contamination is concentrated in only specific areas. Figure 2c was generated by interpolating arsenic concentrations observed in bedrock wells creating a concentration topography. Figure 2c also shows how different a risk assessment can be when considering the contamination itself without assuming there's a relationship to the underlying geology.

Figure 2. *Distribution and arsenic concentration of bedrock wells examined (a) to create a risk assessment map assuming a lithological relationship exists (b) and not assuming a lithological relationship (c)*



Given these previous observations, a farm with known arsenic groundwater contamination in another town in eastern, Connecticut with the presence of historical orchard trees was studied. Despite the lack in the use of lead-arsenate on the property for more than 50 years, the soil contained excess arsenic and lead. Others have observed the longevity of arsenic contamination elsewhere (Schooley et al., 2008). At a nearby site with a former orchard, levels of arsenic contamination the frequency of occurrence of contaminated wells increased with proximity to the orchard (Higgins, Metcalf, and Robbins, 2022).

Current Area of Study

In the US Geological Study (Gross and Brown, 2020), the town of Weston was identified as the community with the highest frequency of contaminated wells. Thus, we commenced a study to examine the sources of contamination in Weston given our previous knowledge. This study followed the approach by Metcalf and Robbins (2013) and involved digitizing more than 1,600 well reports that provided information on well location, well depth, water levels, and depth to rock (Figure 3a) and digitizing more than 480 water quality reports which provide information on groundwater quality including arsenic (Figure 3b). Locations of former orchards were identified using historical imagery as described by Higgins, Metcalf, and Robbins (2022). The incorporation of well characteristics, groundwater flow patterns, groundwater quality, and historical orchards resulted in the evaluation of the relationship of historical orchards as a potential source of arsenic in groundwater in consideration of underlying hydrologic conditions.

Figure 3. *Distribution of well completion reports (a) and water quality reports (b) used in this study to evaluate groundwater conditions*

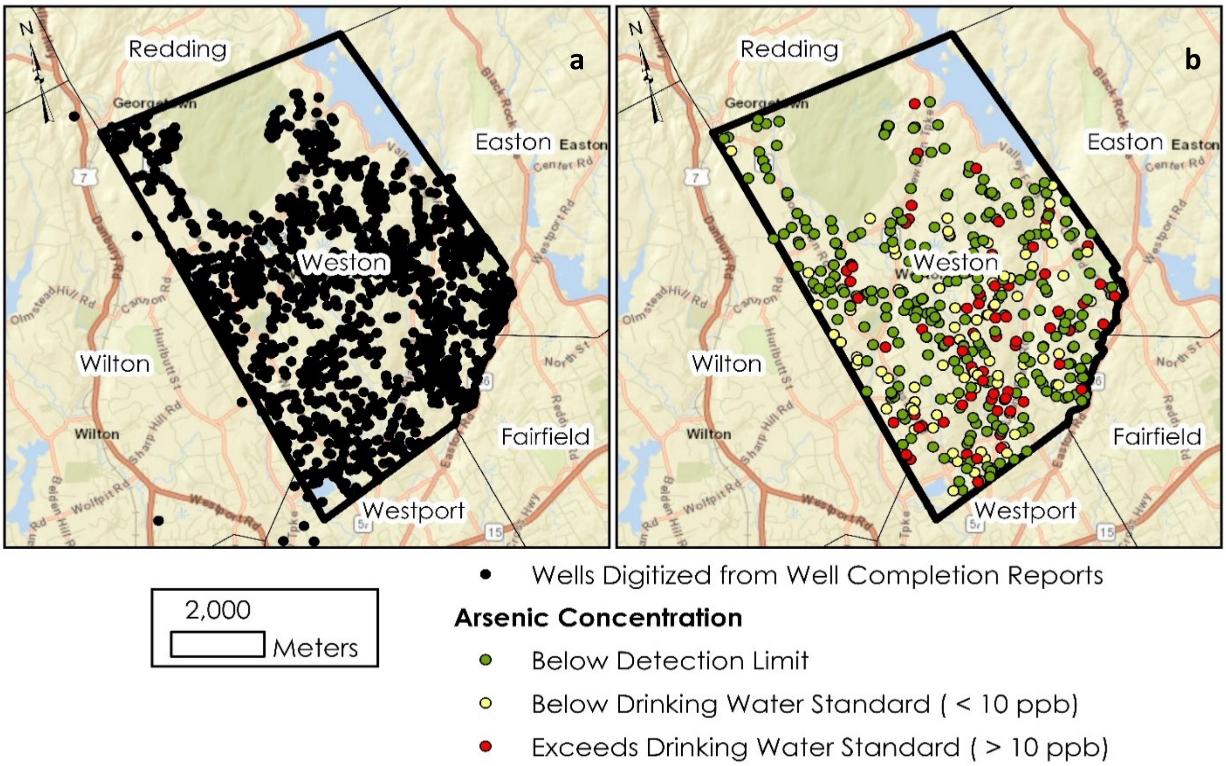


Figure 4 shows the distribution of domestic wells with respect to the four underlying lithological units. Again, we observed no relationship between the average arsenic concentration of wells and each rock type. In Weston, there are four rock types. Figure 5 shows that the average arsenic concentration in wells for each rock type are relatively the same. Table 1 provides detailed information regarding the wells within each underlying rock formation. The most striking aspect is that the rock formation with the highest percentage of wells with arsenic concentrations exceeding the EPA drinking water standard is the rock formation with the highest percentage of orchard area to total area.

Figure 4. *Underlying bedrock geology within the study area (a) and the observed arsenic concentrations (b)*

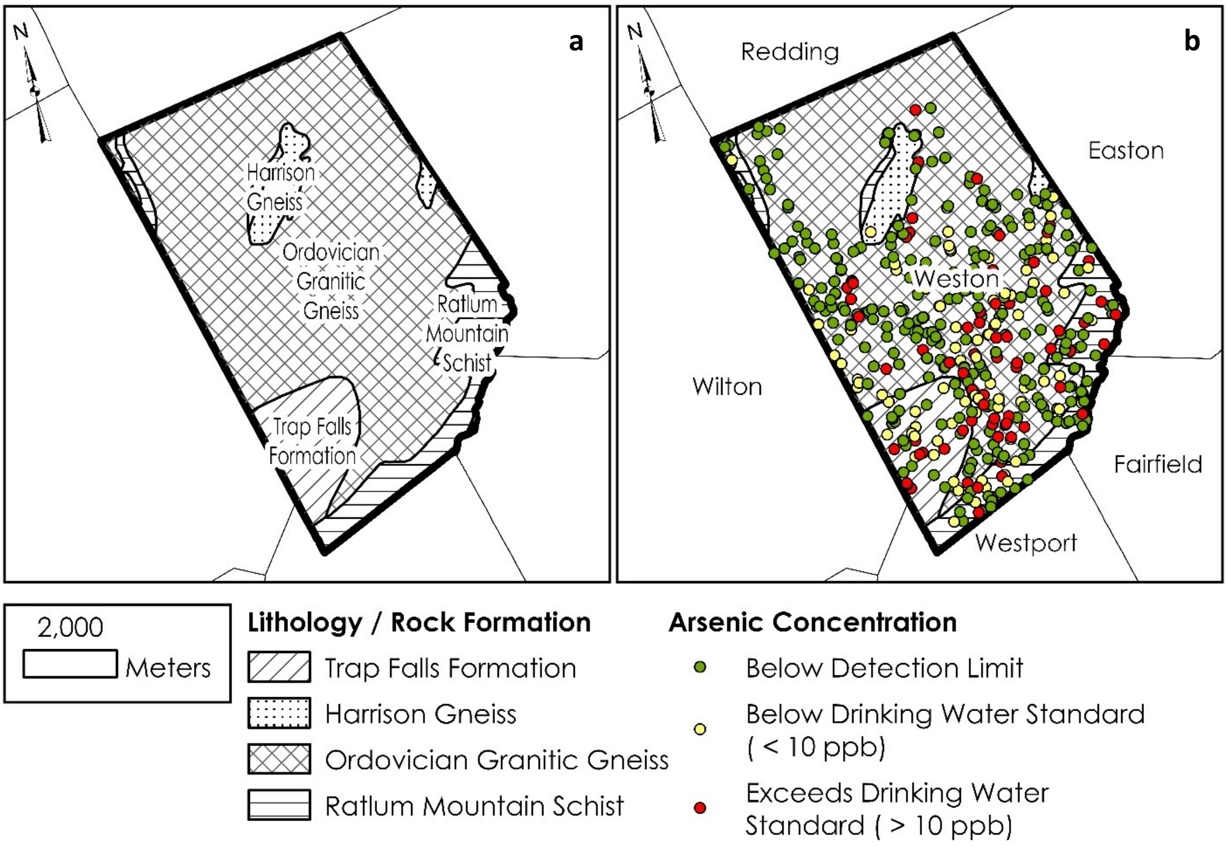


Figure 5. *Average arsenic concentrations of bedrock wells within each of the lithological units for the study area*

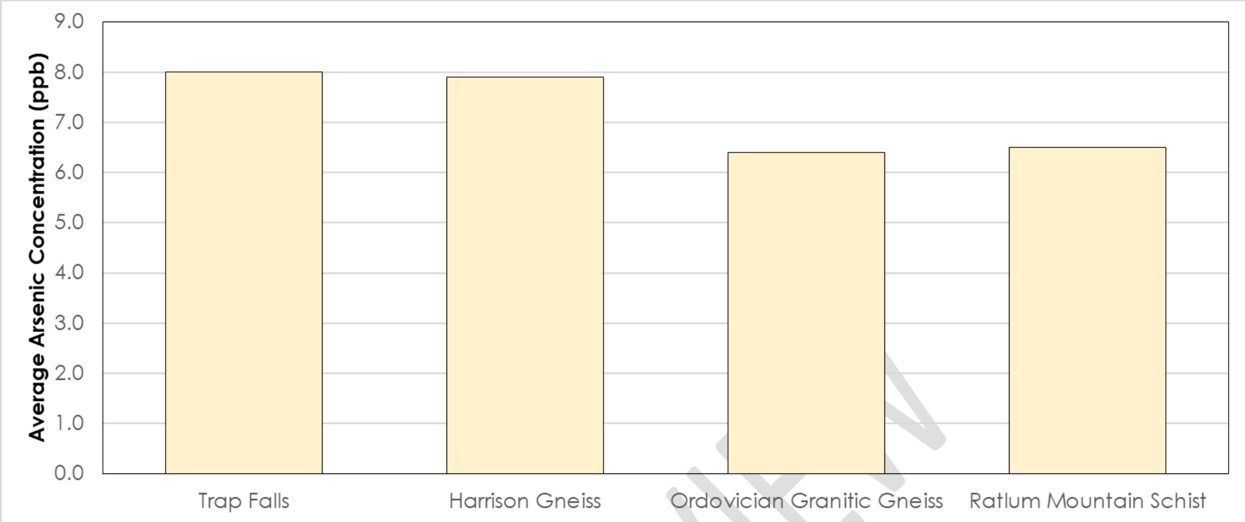


Table 1. *Spatial statistics for each of the lithological units (formations) within the study area associated with contaminated wells and relationship to orchard area*

Formation	**Total Number of Wells**	**Percent of Wells with Arsenic Present**	**Percent of Wells with Arsenic Conc. > 10 ppb**	**Percent of Orchard Area to Total Area**
Trap Falls	45	56	33	7.3
Harrison Gneiss	10	30	20	0.0
Ordovician Granitic Gneiss	358	32	17	2.0
Ratlum Mountain Schist	68	32	18	1.2

Figure 6a shows the distribution of former orchards across the town of Weston which were identified using historical imagery from the period in which lead arsenate was used in Connecticut. Figure 6b shows the groundwater flow lines developed from water level measurements from well report data (superimposed on map). Figure 6c shows the orchard, flow lines, and the distribution of arsenic contaminated wells. As shown, majority of contaminated wells are located on historical orchards or in the direction of groundwater flow from historical orchards.

Figure 6. *Relationship of the locations of historical orchards (a), groundwater flow paths from orchards (b), and wells contaminated with arsenic (c)*

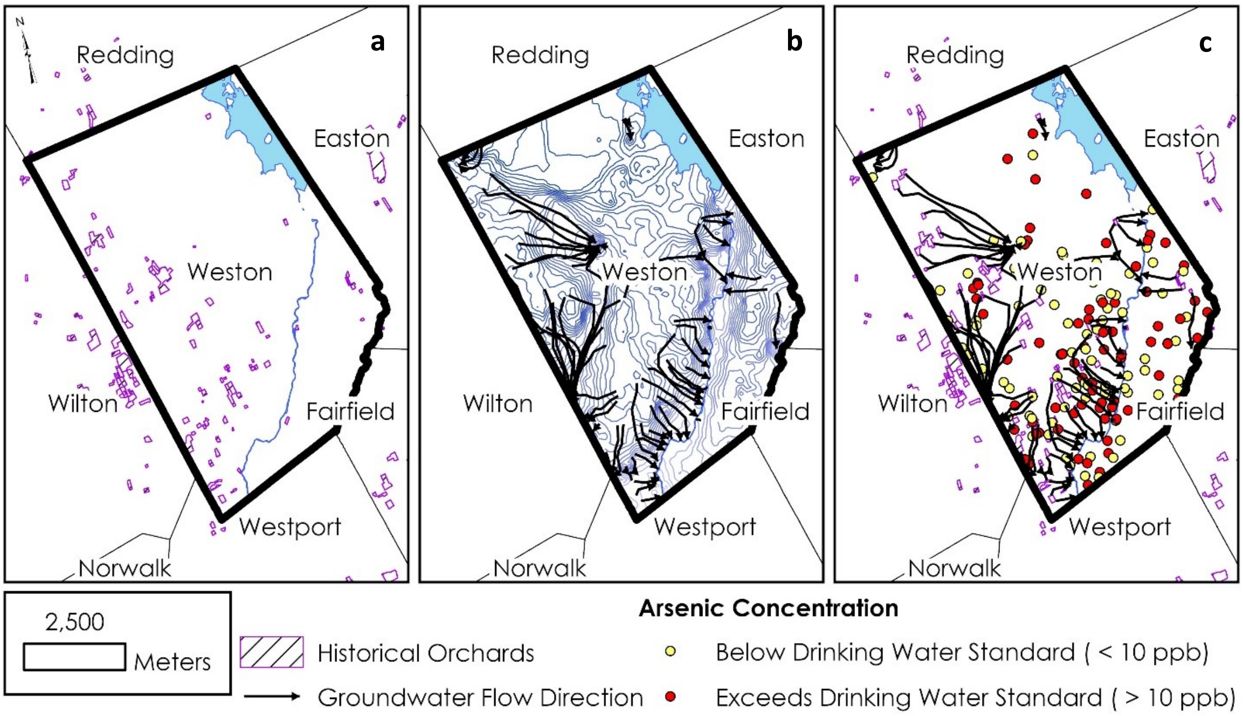


Figure 7 further demonstrates that the average arsenic concentration in wells decreases as the distance from orchards increases. Additionally, the depth to bedrock (thickness of the soil above the rock) plays a role in contaminating wells as shown in Figure 8. Arsenic emanating from the surface from the application of pesticides, such as lead arsenate, can infiltrate faster and at higher concentrations when the soil overlying the rock is thin.

Figure 7. *Average arsenic concentrations of wells within corresponding distances from historical orchards*

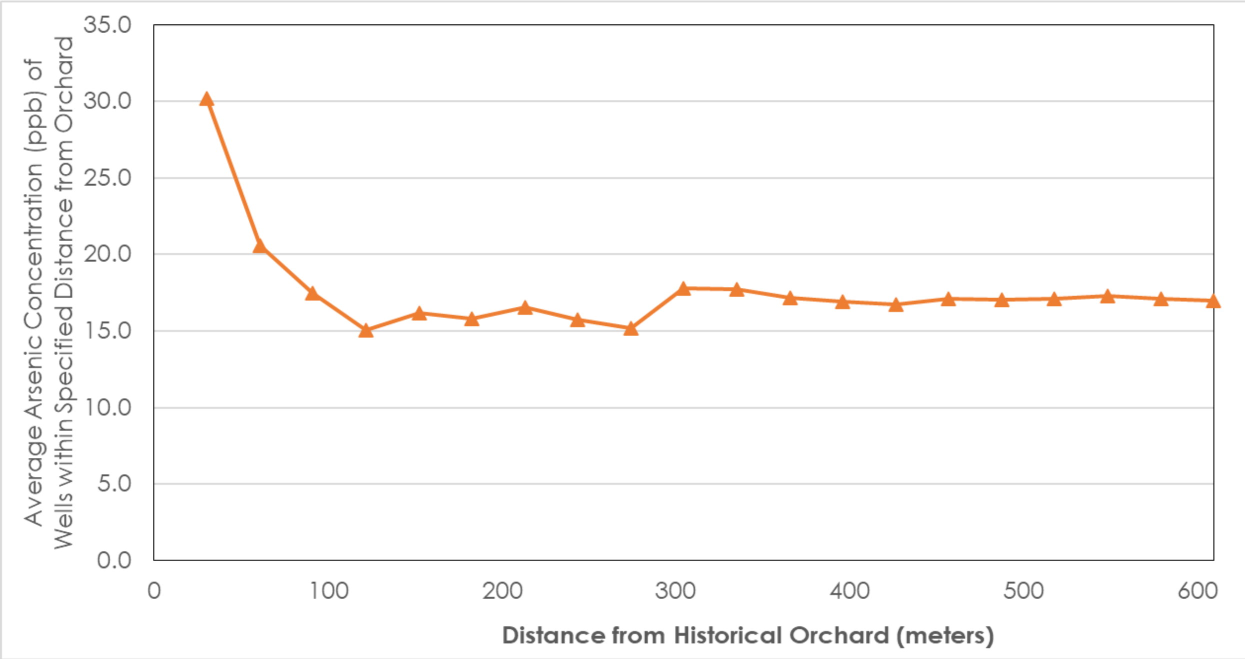
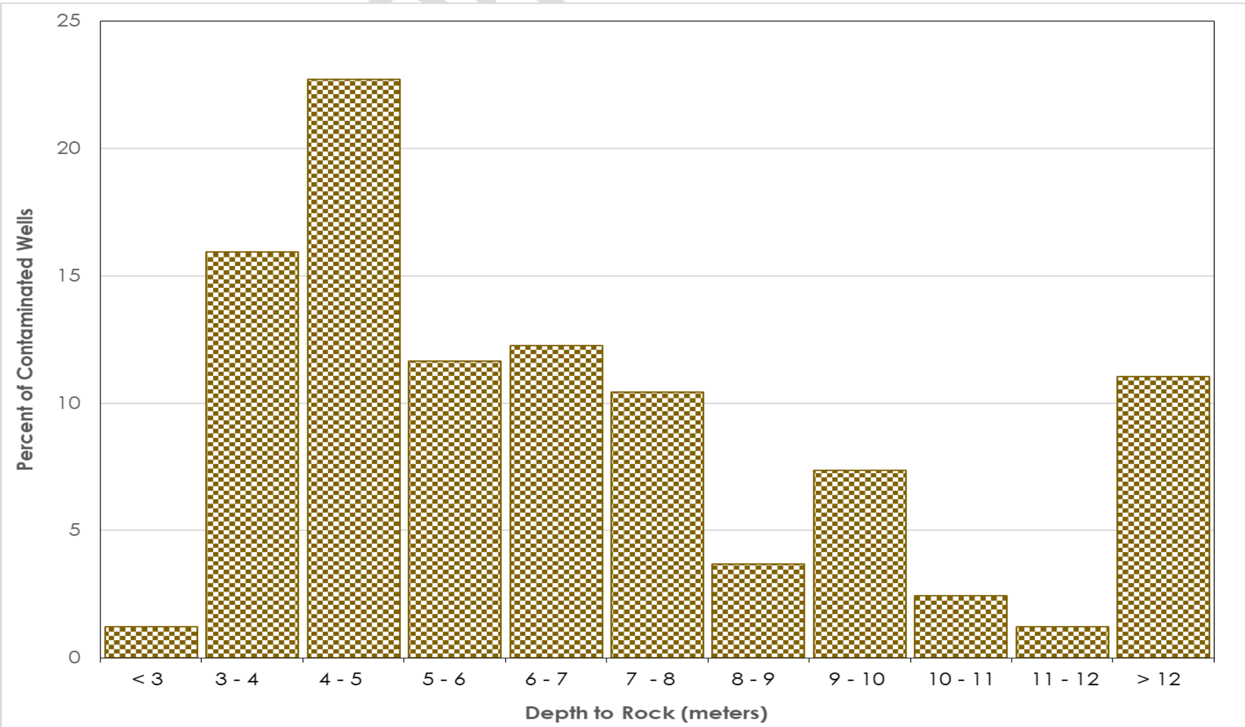


Figure 8. *Percent of contaminated wells with respect to the depth of the rock (obtained from well completion reports)*



Complicating Factors

Deriving quantitative correlations between groundwater quality, such as arsenic concentrations, and any other variable is complicated due to sampling related factors that are likely to influence observed concentrations as shown by Higgins, Metcalf, and Robbins (2020). These factors include:

- The use and condition of sediment filters on domestic water systems.
- Sampling methods which includes timing for purging of well or the amount of water purged.
- Water levels achieved in the well during sampling which effect flow from water bearing fractures and varying amounts of water mixing.

Conclusions

This study finds no evidence that would suggest the use of bedrock distributions for assessing risk from arsenic contamination in Connecticut. Rather we have found evidence for the use of lead arsenate contamination on orchards as the principle source of arsenic contamination in bedrock wells. The use of geologic maps as a risk assessment can be highly misleading both in terms of over or under risk. Thus, such maps should not be used for this purpose without a clear correlation between the bedrock and arsenic in the groundwater. What we have found to be useful for assessing risk of arsenic contamination is the use of aerial photographs for mapping historical orchards and the use water level data for mapping groundwater flow conditions.

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