Use of GIS to Assess Ground Water Vulnerability to Fuel Releases

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PRIVATE DOMESTIC WELL LOCATIONS

Introduction

Approximately 15% of the US population gets their drinking water from a private domestic well (PDW), roughly 50 million people. These wells are not subject to the Safe Drinking Water Act, unlike municipal drinking water systems. PDWs are susceptible to contamination by natural and anthropogenic contaminants. For developing contaminant management strategies and protecting drinking water supplies and public health, the locations of PDWs and their relationship to contaminant sources needs to be determined.

There is no national inventory of PDW locations. While most states maintain a record of newly drilled well locations, the quality of these state databases vary state by state. This makes it difficult to compare state PDW use to one another. It also limits researchers from conducting PDW vulnerability assessments since the locations of many wells are unknown.

In 2017 the US EPA developed a national estimate of PDW locations on the Census block, block group, and tract scale. Figure 1 shows the estimated PDWs for the United States by Census block. Figure 2 depicts the 10 states with the most PDWs. The granularity (census blocks are on average roughly 100 acres) of this undertaking allows for the US EPA to better understand the spatial heterogeneity of well density across the United States, conduct risk assessment research, and hypothesis on the causal links between well location and water quality.

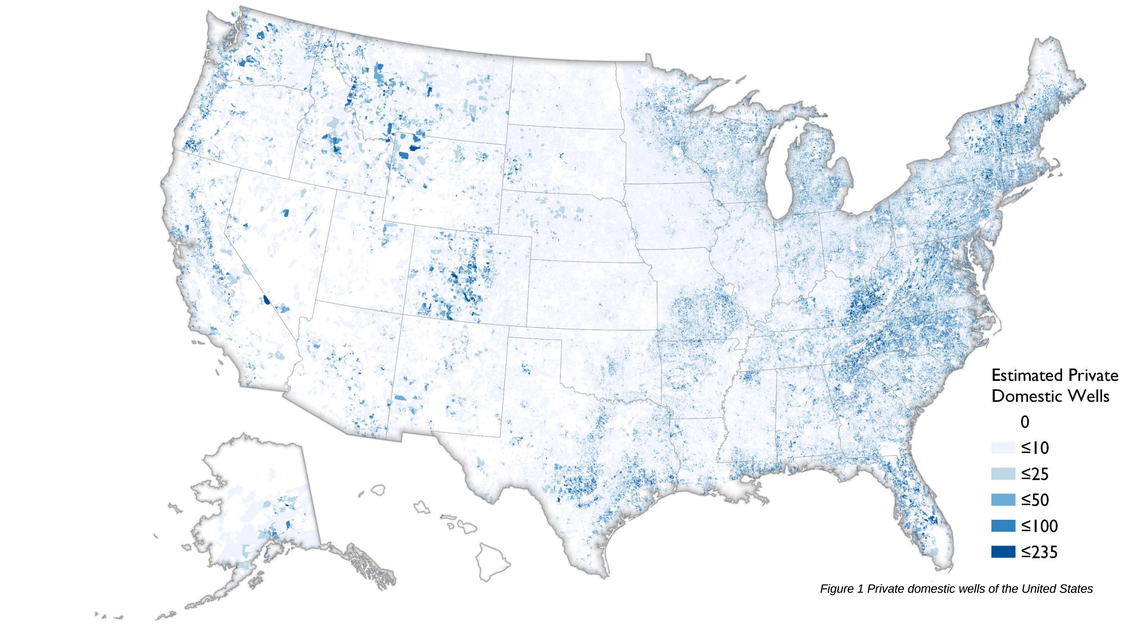

Figure 1 Private domestic wells of the United States

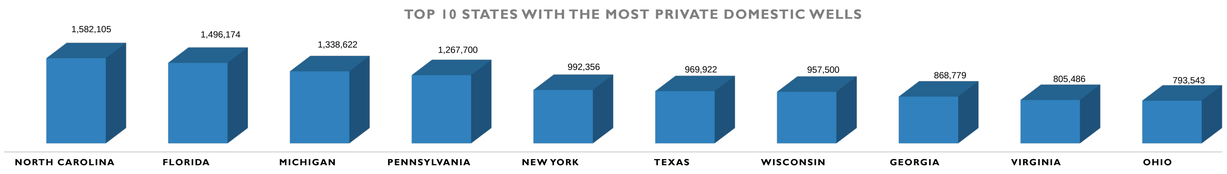

Figure 2 States with the most private domestic wells

Methods

Two statistical methods were used to estimate 2010 private domestic wells at the Census tract, block group, and block level: 'Net Housing Unit' (NHU) methods and 'Reported Wells (RW) method). In both approaches the 1990 Census estimates of household reliance on PDWs was used to generate a baseline of domestic well use for all Census block groups in the US. 1990 was the last time the US Census asked whether a house was reliant on well water. This analysis updates these results to better reflect 2010 PDW use.

'Reported Wells' Method

This method is based on the number of reported wells added and housing units lost from 1990 to 2010. The formula:

$$\rho_{pdw-est} = \rho_{pdw-init}\left(\frac{A_{init}}{A_{new}}\right) + \Delta\frac{N_w}{A_{new}} - f_{pdw}\frac{N_{HU-lost}}{A_{new}}$$

where $\rho_{pwd-est}$ is the well density estimate over an area of A_{new}, $\rho_{pwd-init}$ is the initial well density over the area A_{init}, N_w is the number of wells, f_{pdw} is the fraction of well use to total water supply, and $\frac{N_{HU-lost}}{A_{new}}$ is the number of housing units lost per unit area. The initial well density and f_{pdw} are inferred from the 1990 census results. The method is applied in two increments corresponding to census years: 1990 to 2000, and 2000 to 2010.

The quantity f_{pdw} is updated after each incremental calculation is made, allowing for changing spatial patterns of well use. Including the loss of housing units accounts in part for the loss of wells, as the well records may only indicate wells added.

'Net Housing Unit' Method

The second method is based only on the net change in housing units (NHU):

$$\rho_{pdw-est} = \rho_{pdw-init}\left(\frac{A_{init}}{A_{new}}\right) + f_{pdw}\,\Delta\frac{N_{HU}}{A_{new}}$$

where $\Delta\frac{N_{HU}}{A_{new}}$ is the net change in housing units per unit area. The fraction of private well use f_{pdw} is determined from the 1990 census results. Any estimates which produced negative well density for either method were replaced with a value of zero (Weaver et. al. 2017).

The RW method accounts for shifts in private domestic well usage based on its reliance on actual well drilling logs containing locations and drill dates. However, due to the incomplete availability of well log data for every state (e.g., varying reporting requirements by state, legality of disclosure of well locations, compliance of drillers, insufficient locational accuracy), the NHU method is used to expand well estimates to all states with insufficient well log data. Thus two results were generated and a hybrid was uses which reflected the best method for a given state (either RW or NHU), seen in figure 1.

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PRIVATE DOMESTIC WELL VULNERABILITY TO USTs

Introduction

Numerous examples of private domestic well contamination demonstrate the potential risks for people who drink from private wells. One such source of contamination are leaks from underground storage tanks. Gasoline constituents, such as BTEX, can find their way into a PDW from leaking underground storage tanks (USTs). As of March 2018 there have been ~541,000 confirmed UST releases in the US (US EPA). The most common UST facility are gas stations. The research discussed in this section seeks to assess the vulnerability of PDWs from LUST sites.

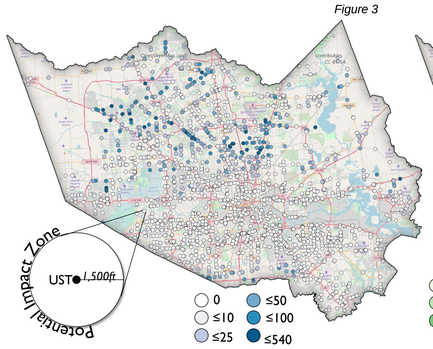
Methods

Since no national inventory of UST locations exist, gas station locations were used as a proxy. 2017 gas station data was provided by the navigation concern NAVTEQ. Water well estimates at the Census block level were used to estimate the number of PDWs within 1,500 ft. of a gas station, an approximation of the area of potential impact. The number of wells (by block) within each gas station's buffer area was estimated using spatial analysis tools in ArcGIS. Vulnerability is determined by the number of wells within 1,500 ft. as well as gas station density. The more gas stations within 1,500 ft. of a well, the more vulnerable a well is to contamination. Density was determined by calculating the maximum sum of buffer unions intersecting a gas station. When the total number of wells and gas station density are estimated for each gas station, a vulnerability index is calculated by simply multiplying both the two variables.

Case study: Harris County, TX

PDWs within 1,500 ft. of a UST

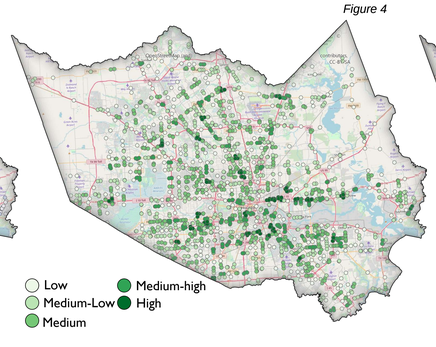
Figure 3



Harris County, TX, home of Houston, has an estimated 23,595 private domestic wells within 1,500 ft. of its ~2,000 gas stations. With ~80,000 PDWs located within the county, 30% of these PDWs are within 1,500 ft. of at least one gas station. It is estimated that half (2 million) of Harris County's population is within this distance of a gas station. Visible from Figure 3 above, most of the private domestic well use around gas stations occurs in the Northern suburbs of Houston where municipal water infrastructure is unavailable.

UST Density

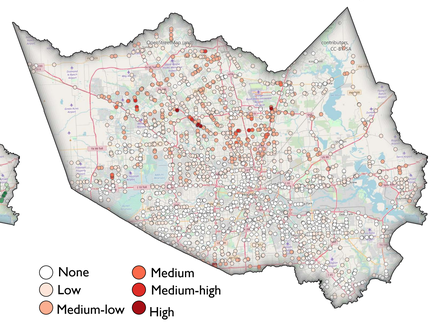
Figure 4



Texas has more gas stations than any other state. There are just over 12,000 gas stations in Texas, 30% more than 2nd highest state, California. Harris County contains 1,884 gas stations (Figure 4 above), twice the amount as Dallas County, TX—the county with the second most gas stations in Texas. To get a sense of gas station density, there are, on average, three gas stations within 1,500 ft. of a given gas station. The higher the UST density the higher the PDW vulnerability.

PDW Vulnerability

Figure 5



Harris County is the most vulnerable county in the United States in terms of PDW vulnerability to potential fuel releases. The high proportion of residents within Houston and its (mostly Northern) suburbs on well water combined with the high density of gas stations makes Harris County's well water vulnerable to petroleum hydrocarbon contamination. Central and Southern Houston are less vulnerable to fuel releases simply because there are much fewer PDWs. State highway 249 and the 169 corridor contain the highest areas of PDW vulnerability (Figure 5 above).

Discussion

Every estimated PDW within 1,500 ft. of every gas station UST was assessed for potential vulnerability to a potential fuel release. Most gas stations USTs do not have private domestic wells near them, so no potential for contaminated drinking water exists. However, of the 21 million estimated PDWs in the United States, 7% (1.6 million) are within a 1,500 ft. radius of at least one UST. 270,000 PDWs are estimated to be within a 1,500 ft. radius of two or more USTs. Figure 6 shows the cumulative vulnerability of all wells near USTs by county. The black pins identify the 10 most vulnerable counties, also shown in Figure 7. Four out of the ten most vulnerable counties are located in Florida. While Florida has the second most PDWs, it has the highest number of wells within 1,500 feet of a UST—over 125,000, followed by North Carolina (90,000). Due to Florida's large population, relatively easy accessibility to its water table, and the large number of gas stations (3rd most), Florida's well water is the most vulnerable to potential fuel releases, followed by North Carolina, Texas, and California. The most vulnerable counties are primarily coastal—located in the Pacific Northwest, California, New England and Florida counties. In the country's interior, PDWs in counties containing the Chicago area are notably vulnerable to UST fuel releases, as well as Troy County (MI) and Marion County (IN).

Future work: : Gas stations are not the only facilities with USTs. Most states have a complete UST inventory including precise locations, the number of tanks at facilities, and reported releases locations. The US EPA is working with several of these state databases to get a more complete representation of PDW vulnerability to all USTs.

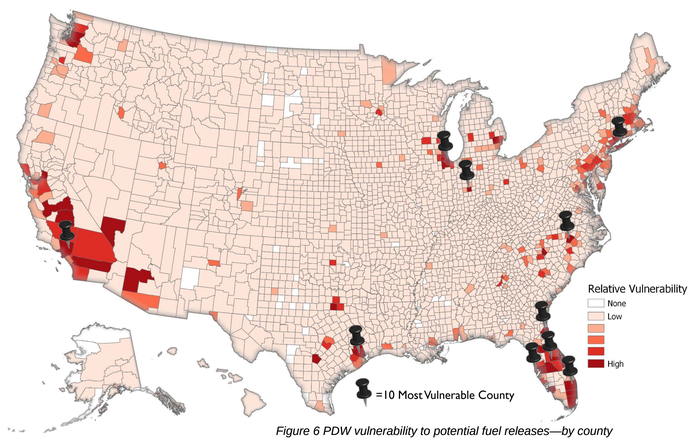


Figure 6 PDW vulnerability to potential fuel releases—by county

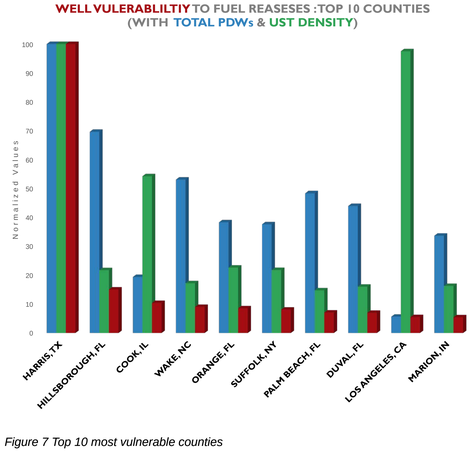


Figure 7 Top 10 most vulnerable counties