Estimating Private Domestic Well Use in the United States: A Pilot Study in Oklahoma

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Abstract

Private domestic wells are not subject to the testing requirements of the Safe Drinking Water Act and are susceptible to contamination by natural and anthropogenic contaminants. For public health and planning purposes, the locations of high density of private domestic well (PDW) use need to be determined. A key resource is the 1990 U.S. Census where the source of water was a survey question, which led to a nationwide estimate of PDW usage. In this paper, methods are developed to estimate the areal density of PDW use in later years using readily accessible data including the 1990 census results. Because of abundant data on PDW locations and public water supplies, Oklahoma was used for a pilot project. Well logs reported to the Oklahoma Water Resources Board and the addition of housing units provide the means to update the 1990 census estimates. Census results and housing unit data are available on the county, census tract, and census block group level. PWD density estimates were consistent among these scales, as were estimates based on wells added and net housing units. The completeness of reported well logs was tested by counts from neighborhoods with known reliance on PDWs. The results showed that a significant undercounting of logs exists, and the small scale of subdivisions relative to even census block groups causes the method estimates to be lower than subdivision PDW densities. The estimates, however, indicate locations where high densities of PDWs are expected.
Introduction

The Safe Drinking Water Act (SDWA) regulates public water systems in the U.S. and uses source water protection, treatment, distribution integrity, and public information as barriers between contamination and safe drinking water. Testing is required for a list of natural and anthropogenic contaminants (U.S. EPA, 2004). Private wells, which serve less than 25 persons, are not regulated by the SDWA, nor are public systems with fewer than 15 service connections and serve less than 25 people per day for 60 days of the year. USGS estimated that 14% of the U.S. population provided their own domestic water in 2010 (Maupin et al., 2014). Fresh ground water accounted for 98% of the estimated withdrawal of 3,600 Mgal/d. For Oklahoma, the population using self-supplied domestic water was an estimated 316,000, or 8% of the population.

Earle et al. (2011) used results from the 1990 U.S. census and gas station business data to estimate the potential for contamination of private domestic wells by leaking underground storage tanks. Use of private domestic wells was inferred from 1990 census, and commercially available data on gas stations.

The purpose of this work was to develop a method to update 1990 estimates of private domestic well usage from publically-available data. Because the state of Oklahoma freely distributes required data, Oklahoma was selected for study. From U.S. Census, USGS, and Oklahoma Water Resources Board (OWRB) data, two approaches were developed for estimating the density of private well usage. To address scale and zoning issues, the results are compared at the county, census tract and census block group administrative levels and underlying neighborhood scale. Several unique locations within the state were used for evaluating the rate for well log reporting and for the PDW density estimates.
Methods

The Oklahoma Water Resources Board (OWRB) distributes compiled data from well logs reported under the state’s well driller registration requirements (OK OACR, 2015). Well locations are either estimated by location within the U.S. public land survey system township-section system or, since 2009, reported as latitude-longitude. The Oklahoma reporting requirements went into effect in the early 1980s, which spurred an increase in the number of reported wells (Figure 1).

Figure 1. Cumulative number of domestic wells reported to the Oklahoma Water Resources Board.

Private wells were used for domestic water supply before statehood (e.g., Caton, 1954, Hoig, 1987, Wright, 1926), so the number of private domestic wells in use is likely higher than the number of reported wells. National data on well use were developed in response to the U.S. Congress authorization of a survey of housing in 1939. Beginning in 1960, the source of water supply was added to the long form census and continued as a question through 1990 (U.S. Department of Commerce, 2009). (Figure 2).
In 1960 and later the question was asked: “Do you get water from

- A public system (or private company)?
- An individual well?
- Some other source?

Figure 2. Housing units using PDW inferred from 1990 Census on a census block group spatial basis.
The number of wells added since 1990 were determined in two ways:

The first method is based on the number of reported wells added (denoted WA) and housing units lost during a specified time period:

Equation (1): \[ \rho_{pwd-est} = \rho_{pwd-init} + \frac{\Delta N_w}{A} - f_{pwd} \frac{N_{HU-lost}}{A} \]

where \( \rho_{pwd-est} \) is the PDW density estimate, \( \rho_{pwd-init} \) is the initial PDW density,

\( \Delta N_w \) is the change in the number of wells, \( N_w \), and \( A \) is the area for analysis,

\( f_{pwd} \) is the fraction of PDW use to total water supply, and

\( \frac{N_{HU-lost}}{A} \) is the number of housing units lost per area.

The initial PDW density and \( f_{pwd} \) are inferred from the 1990 census results. The quantity \( f_{pwd} \) is updated after each incremental calculation is made, allowing for differences in patterns of PDW use. Including the loss of housing units accounts for the loss of PDWs, as the state well records only indicate wells added.

The second method is based only on the change net change in housing units (denoted NHU) and is intended for use when state-agency records are unavailable:

Equation (2): \[ \rho_{pwd-est} = \rho_{pwd-init} + f_{pwd} \frac{\Delta N_{HU}}{A} \]

where \( \Delta \frac{N_{HU}}{A} \) is the net change in housing units per area.

The fraction of private well use \( f_{pwd} \) is taken as the fraction inferred from the 1990 census.
Results

County-Level Projections for 2000 and 2010

The results show the high density of PDW in the center of the state and along the border with Arkansas (Figure 3). The highest density occurred in Oklahoma County, which contains the extensive public water system of Oklahoma City (OKC, 2014). Many independent cities and towns, and unincorporated areas either border Oklahoma City or are contained within. These include two cities with no water systems (Forest Park, 2010 pop 998, and Nicoma Park, 2010 pop 2,393) and cities with water systems which do not serve their entire populations (i.e., Edmond (City of Edmond, 2009), and Choctaw (OWRB, 2015b)).

Figure 3. Wells-added estimate of private domestic well density for 2010.
In Northeastern Oklahoma, the highest PDW density was found in Delaware County, with a 2010 population of 41,487 and a number of small cities and towns, which had a combined 2010 population of 12,384. Rural water districts covered around 24% of the county (in 1995, the latest year data are available, OWRB, 2015b), which, coupled with the large fraction of rural residents, suggests reliance on PDW throughout the county. Both the WA and NHU methods generated similar estimates of domestic well density in 2010 throughout the state (Figure 4).

![Figure 4. County-level predicted PDW for 2010 use from housing unit increase compared against predicted PDW use from wells reported to the OWRB.](image)

**Census Tract Level Estimates for 2000 and 2010**

At the census tract level, both the WA and NHU methods show similar results, where the areas of highest PDW density fall near the center of the state and in the northeastern corner (Figure 5, left). Both methods produce similar distributions of PDW density across the state when using a factor of ten color scale. The census tracts with the highest PDW density are located in the center of the state and in the northeast, as were the county-level estimates. High PDW density is localized in areas smaller than counties as the smaller spatial scale of the census tracts allows sub-county heterogeneity to appear. Census tracts revealed high PDW density in some areas of moderate county-level density.
The NHU method produced higher PWD densities than did the WA method for 42% of the census block groups without \( f_{pdw} \) updating, and 43% with \( f_{pdw} \) updated to 2000. Given that the data are not normally distributed, Mann-Whitney Test results showed no statistically significant difference between the two approaches (\( P = 0.9037 \)).

Census Block Group Level Estimates for 2000 and 2010

At the census block group level, more small-scale variability and higher maximum PDW densities were found (Figure 5, right). The WA method generated lower estimates than the NHU in about 40% of the census block groups. Higher NHU results are evident by both the visible higher densities and more widespread distribution of NHU results (Figure 5). The estimated difference between the 1990 inferred PDW density and the 2010 estimate shows large areas of the state with 10% to 100% increases (Figure 6). From 1990 to 2010, the fraction of PWD use increased in many areas of the state including the Panhandle, Cimarron, Canadian, and Washita River Basins, central and northeastern Oklahoma (Figure 7). In the Oklahoma City area, some census block groups showed both strong increases and strong decreases. These are associated with expansion of cities surrounding Oklahoma City relying on both public and private water.
Figure 6. Percent change in estimated well density 1990 to 2010 using the WA method.

Figure 7. Estimated change in fraction of PWD to total water supply from 1990 to 2010 on a census block group level.
High density of private well use was found in satellite cities of Oklahoma City and several other locations within the state: Enid, Sand Springs, Delaware County. Maps of public water systems overlain on city limits show that many of the satellite cities adjoining Oklahoma City have not extended their water systems throughout their territories: Edmond (Edmond, 2009), Choctaw, Del City, and El Reno as examples (OWRB, 2015b). Cities adjoining Oklahoma City to the east, use public wells to tap the Garber-Wellington Aquifer, as well as provide surface water. Despite their public supplies, these cities have some residents reliant on PDWs, which tap the upper part of the Garber-Wellington aquifer with wells approximately 60 m deep. Three communities were identified where all residents rely on PDWs: Nicoma Park, Forest Park, and Lake Aluma.

Central Oklahoma is situated above alluvial terraces, formations of the Hennessey Group, the Garber Sandstone and the Welling formation, which yield small to moderate amounts of fair quality water (Bingham and Moore, 2004) and are considered major aquifers. Oklahoma City developed a public water system by purchasing 14 private wells in 1908. Surface water supplies were completed in 1918, 1945, and 1961, which are still the main sources of water for the city (Mashburn et al., 2013). Contrarily, Tulsa did not exhibit similar density of private domestic well use. Tulsa is situated over the shale, sandstone, and thin coal beds of the Seminole formation, which yield small amounts of poor quality water. Arkansas River terrace deposits yield moderate amounts of fair to good quality water (Marcher and Bingham, 1989). Historically, Tulsa developed a water system early in its history, as water from springs and the Arkansas River were insufficient or of poor quality (Clinton, 1945, Engineering and News Record, 1924). Higher quality ground water is available 25 to 30 km east of Tulsa and in other areas of Eastern Oklahoma, including Delaware County (Marcher and Bingham, 1989). For the most part, public supplies dominate in the areas around Tulsa, with the exception of an area in Sand Springs, Oklahoma, which has no public supplies (OWRB, 2015b) and is situated along the Arkansas River where terrace deposits supply good quality water.

Testing of Approximations

Cities without Water Supply Systems

Three locales in Oklahoma County have no water supply systems and residents rely on PDWs: The City of Forest Park, population 998, Lake Aluma, population 88, and the City of Nicoma Park, population 2,393 (Figure 8). Both of the cities are contained within one census tract, but they each contain all or parts of several census block groups. Lake Aluma is contained within one census block group. Estimated densities of PDWs based on neighborhood counts of reported wells and existing residences differ in PDW density from the corresponding census block group 2010 estimates for the WA method for two reasons. First, houses were built in Forest Park and Nicoma Park prior to the well-reporting requirement, so few reported wells were expected here giving neighborhood-count estimates that were less than estimated by the 2010 WA method. Despite also using the reported well data, the WA method estimated high PDW density because of its basis in the 1990 census results, which had already established these areas with high density of PDW (Figure 2). Secondly, the neighborhoods have higher housing unit density because they do not include undeveloped parts of the county, census tracts, and census block groups, so the neighborhood estimates result in higher PDW density.
Enid, Oklahoma

Enid, Oklahoma is situated over the Enid Isolated Terrace Deposit which supplies moderate amounts of fair to good quality water (Bingham and Bergman, 1980) for the public water system and private wells. Parts of Enid show high density of private wells within an area covered by the city’s public water supply. Many of the wells are shallow with depth of 15 to 18 m. After the August 2012 imposition of a complete ban on the use of city water for outdoor lawn watering, drilling of private wells went up dramatically (Figure 9) and well drillers reported many requests for new wells (Enid News, 2012). As for other urban areas with public water supply systems, private well use coexists with public supply, although the purpose of the private wells may not always be as discernable.

Figure 8. Comparison of neighborhood-count estimates of private well density with the wells-added method results for 2010. The neighborhood-count estimates are based on the sizes of the neighborhood (median size of 0.62 km$^2$, approximately ¼ section). The wells-added method estimates are based on the census block group size.
Oklahoma Subdivisions

Oklahoma land was divided into sections under the public land survey system (PLSS). Because of the patterns developed under Indian land allotments and land runs, current development in Oklahoma follows PLSS boundaries and often occurs in 160 ac (0.65 km²) quarter-section plots (Gates and Swenson, 1968). Neighborhoods without public water supplies and recently-constructed homes were used independently to estimate PWD usage and to evaluate the completeness of well reports. Comparing PDW density based on housing-unit and reported-well counts shows that the number of reported wells is less than housing units. OWRB (2014) recognized the failure among some drillers to file required well completion reports. The results also show that neighborhood-count estimate densities (median area size 0.62 km²) are greater than block group estimates (median area size 2.65 km²), because the neighborhoods contain only housing areas and not open space.

Figure 9. Wells Drilled in Garfield County Oklahoma in 2011 and 2012.
Conclusions

• The 1990 U.S. Census results provide a baseline estimate of private domestic well usage on the census block group level.

• Updates made by either well logs reported to state agencies or by the net addition of housing units give similar results.

• The methods provide a guide to areas of high private domestic well use, but do not replicate estimates on an areal basis smaller than the census block group.

• The next step is to extend the net housing unit method to generate an estimate of private well use for the whole U.S.

Draft journal paper describing these results:

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