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Private wells near municipal landfills: a national groundwater vulnerability screen for the United States

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Research Article

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Abstract

Leachate from municipal solid waste landfills can contaminate groundwater, and households on private domestic wells are the least protected receptors, because their water falls outside federal drinking-water regulation and is rarely tested. No national estimate exists of how many private-well users live near US landfills. This study combined three open datasets: 2265 landfills in the conterminous United States from the Environmental Protection Agency Landfill Methane Outreach Program database, a US Geological Survey 1 km grid of the population served by domestic wells in 2010, and the US Geological Survey principal aquifer map. About 343,000 private-well users lived within 2 km of at least one landfill and about 2.29 million within 5 km, counted without double counting. Exposure was highly skewed: the median landfill had 65 well users within 2 km, but 926 landfills had at least 100 and 35 had more than 1000. Closed landfills had a higher median than open landfills (100 vs 42), and landfills opened before the 1993 federal liner and monitoring criteria had more than twice the median of newer sites (80 vs 34). Rankings were stable across buffer radii (Spearman correlation 0.88 to 0.90). A total of 213 priority landfills in 31 states opened before 1993, overlie unconsolidated sand-and-gravel or carbonate-rock aquifers and have at least 100 private-well users within 2 km. The counts measure proximity only and say nothing about whether any well is contaminated.

Introduction

Municipal solid waste landfills generate leachate that can carry dissolved organic carbon, ammonium, chloride, metals and synthetic organic compounds into groundwater (Kjeldsen et al., 2002). Below a landfill, leachate forms plumes in which redox zones, attenuation of organic compounds and the mobility of metals and ammonium have been described in detail (Christensen et al., 2001). Groundwater contamination near municipal landfills has been documented in many settings, from field studies of leachate and nearby wells (Mor et al., 2006) to national reviews (Han et al., 2016). Landfill leachate also carries per- and polyfluoroalkyl substances (PFAS) (Lang et al., 2017), which have been traced from legacy landfills into groundwater (Hepburn et al., 2019).

Landfills built before the US federal criteria for municipal solid waste landfills (40 CFR Part 258) took effect in October 1993 were generally not required to have composite liners, leachate collection or groundwater monitoring, so older sites carry the greatest legacy risk. Field monitoring shows that groundwater chemistry near a landfill depends on its age and on whether it has been closed (Abiriga et al., 2020). The same problem is acute at open dumpsites in Nigeria, where the author's unpublished B.Sc. survey of the unlined Awotan dumpsite in Ibadan imaged low-resistivity zones interpreted as leachate migrating away from the waste body. That survey led to the present study, which asks the same question at national scale for the United States, where the necessary data are public.

Whether landfill leachate matters for people depends on who draws groundwater nearby. Public water systems are regulated and monitored, but households on private domestic wells are not covered by federal drinking-water standards, and testing is left to the owner. Contaminants above health

benchmarks are common in these wells (DeSimone et al., 2009), yet many households never test them (Zheng & Flanagan, 2017), and voluntary testing programmes reach only part of the population (Lade et al., 2024). Johnson et al. (2019) estimated the population served by domestic wells across the conterminous United States on a 1 km grid, and national studies have used this surface to assess private-well exposure, for example to arsenic during drought (Lombard et al., 2021). A pilot study counted private wells near underground storage tanks in Oklahoma (Weaver et al., 2017), but no comparable national screen exists for landfills.

The aims were to count the private-well users living within 1, 2 and 5 km of each US municipal landfill in the LMOP database, to compare these counts by landfill status, age and aquifer type, and to list the landfills where many well users live near an older landfill on a permeable aquifer. The output is a ranked list for screening. It does not estimate the probability that any well is contaminated.

Materials and methods

Landfills

The EPA Landfill Methane Outreach Program (LMOP) Landfill and Project Database, landfill-level file of September 2024 (US Environmental Protection Agency [US EPA], 2024), lists 2641 municipal solid waste landfills with status, opening and closure years and waste in place. It does not include every municipal landfill in the country, nor industrial or hazardous waste landfills. After removing landfills without coordinates and those outside the conterminous United States, 2265 landfills remained (1223 open, 1032 closed, 10 of unknown status).

Private-well users

The US Geological Survey (USGS) dataset of domestic well locations and populations served in 2010, road-enhanced method (Johnson & Belitz, 2019; Johnson et al., 2019), gives the number of people served by domestic wells in each 1 km × 1 km cell of the conterminous United States. The grid sums to 37.2 million people.

Aquifers

The USGS map of principal aquifers (US Geological Survey [USGS], 2003) assigns each area to one of six rock types: unconsolidated sand and gravel, semiconsolidated sand, sandstone, carbonate rock, sandstone and carbonate rock, and igneous and metamorphic rock. About one third of the landfills lie outside any mapped principal aquifer.

Well users near each landfill

Landfill points were projected to the equal-area projection of the well-population grid (USA Contiguous Albers Equal Area). For radii of 1, 2 and 5 km, the population of every grid cell whose centre lies within that distance of the landfill point was summed. The 2 km radius is the main measure; the 1 km radius is

coarse relative to the 1 km grid, and 5 km gives a regional view. Population counts near point sources are sensitive to the choice of buffer (Czolowski et al., 2017), so all three radii are reported. Because neighbouring landfills can share the same wells, national totals were computed from the union of all buffers so that no person is counted twice; per-landfill values are not de-duplicated.

Context flags and priority landfills

Each landfill was assigned the principal aquifer at its location and two flags: opened before 1993, and located over an unconsolidated sand-and-gravel or carbonate-rock aquifer, the two types in which contaminants can travel fastest through intergranular or solution porosity. A landfill was classed as priority when it was opened before 1993, lay over one of those aquifer types and had at least 100 private-well users within 2 km. This is a deliberate simplification of hydrogeologic-setting methods such as DRASTIC (Aller et al., 1987), which require depth to water, recharge and soil data at a finer scale. The flags are not weighted into a single score, so that the reason each site is listed remains visible.

Sensitivity, software and use of a large language model

Rankings across radii were compared with Spearman rank correlation and with the overlap of the top-100 lists. All analyses used Python (pandas, GeoPandas, rasterio); the code is archived with the results (see Data availability). A large language model, Claude (Anthropic), was used to assist with writing analysis code and drafting text. The author designed the study, chose the data and screening criteria, checked all code and results, and takes full responsibility for the content.

Results

National totals

About 343,000 people on private wells lived within 2 km of a landfill in the database, and about 2.29 million within 5 km (Table 1). Summing per-landfill values without removing overlaps would overstate these totals by about 3% at 2 km and 7% at 5 km. The distribution is strongly skewed (Fig. 2): the median landfill had 65 well users within 2 km, the upper quartile 208 and the maximum 1848. The largest values are in the Northeast, the Great Lakes states, the Piedmont of the Carolinas and Virginia, Florida and northern California (Fig. 1).

Table 1
Private-well users near US municipal landfills (2010 population). Unique well users are counted once even where buffers overlap

Radius	Unique well users	Landfills with any users	Landfills with ≥ 100 users	Landfills with ≥ 1000 users
1 km	73,556	1710	202	0
2 km	342,911	2021	926	35
5 km	2,287,862	2224	1849	863

Status, age and aquifer setting

Closed landfills had a median of 100 well users within 2 km, against 42 for open landfills (Fig. 3). Landfills opened before 1993 had a median of 80, against 34 for those opened in 1993 or later, and the 1714 older landfills accounted for 83% of the summed 2 km total. Landfills opened since 1993 are, on average, farther from households that rely on wells.

Landfills over igneous and metamorphic rock and over carbonate rock had the highest medians (190 and 130; Table 2, Fig. 4). The igneous and metamorphic result reflects the rural Piedmont and New England, where household wells in fractured crystalline rock are common. Landfills over unconsolidated sand and gravel had the lowest median (30), although they are the most numerous group within principal aquifers.

Table 2
Private-well users within 2 km by principal aquifer type at the landfill

Aquifer type	Landfills	Median	Mean	Sum
Outside principal aquifers	746	41	135	100,303
Unconsolidated sand and gravel	483	30	128	62,017
Semiconsolidated sand	263	63	148	38,940
Sandstone	257	63	158	40,693
Igneous and metamorphic rock	207	190	244	50,586
Carbonate rock	176	130	219	38,590
Sandstone and carbonate rock	133	97	168	22,399

Highest-ranked and priority landfills

Of the twenty landfills with the most private-well users within 2 km, all but two are closed and most opened between 1940 and 1990; the highest is a closed Ohio landfill opened in 1940 with about 1850 well users within 2 km (full list in the archived data). Rankings were consistent between radii: Spearman correlation was 0.90 between 1 and 2 km and 0.88 between 2 and 5 km, and 63 landfills appeared in the top 100 at both 2 and 5 km.

Applying the three criteria gave 213 priority landfills in 31 states (Fig. 5), with about 74,600 private-well users within 2 km (summed per landfill). Of these, 134 are closed and 79 open; 119 overlie unconsolidated sand and gravel and 94 carbonate rock. The largest numbers are in California (39), Florida (26), Illinois (19), Washington (17) and Indiana (16).

Discussion

What the screen shows

The totals count people who drink from private wells near landfills. They do not count people drinking contaminated water. Whether leachate reaches a given well depends on liner performance, waste type, groundwater flow direction, depth to water and well construction, and none of these is available nationally. What the screen can do is rank landfills by how many well users live nearby and flag the sites where landfill age and aquifer type make leachate migration more likely.

Older and closed landfills

Landfills opened before the 1993 federal criteria have more than twice as many nearby well users as newer sites and account for most of the national total. Many are now closed, which can reduce attention to them, yet closure does not end leachate production: leachate composition evolves over decades, ammonium in particular remains a long-term concern, and leachate volume can increase again if the cover deteriorates (Kjeldsen et al., 2002). Field records show that groundwater near closed landfills can remain affected long after closure (Abiriga et al., 2020), and legacy landfills are a source of PFAS that conventional monitoring was not designed to detect (Hepburn et al., 2019; Lang et al., 2017).

Hydrogeological setting

Sand-and-gravel and carbonate aquifers transmit contaminants quickly, through intergranular porosity and solution conduits respectively, which is why they define the priority list. Landfills over igneous and metamorphic rock had the highest median well-user counts, which needs a different interpretation. Groundwater in these rocks moves mainly through fractures, so where a fracture connects a landfill to a well, contaminants may travel along it with limited dilution; whether such connections exist cannot be resolved at the scale of a national aquifer map.

Implications for private-well testing

Few households test their wells regularly (Zheng & Flanagan, 2017), and voluntary programmes in Iowa reached only part of the eligible population (Lade et al., 2024). State and county programmes that offer free or subsidised testing could use the 213 priority landfills, or the full ranked table archived with this study, to decide where to send test kits first. Near older landfills, ammonium, chloride, metals and PFAS would be the obvious analytes.

Transferability

The same three-layer approach (landfill locations, well-user population and aquifer type) could be applied wherever those layers exist. In Nigeria, open dumpsites such as Awotan in Ibadan lie close to communities that rely on hand-dug wells and boreholes, and a comparable screen would be a useful first step once dumpsite locations and groundwater-use data are compiled.

Limitations

The LMOP database is incomplete for municipal landfills and excludes industrial and hazardous waste sites, so the national totals are lower bounds. Well-user population is for 2010 and is modelled rather than counted (Johnson et al., 2019). Landfills are represented by a single point rather than their footprint, so for large sites the distance to the waste boundary is smaller than the distance to the point. The 1 km grid makes the 1 km radius coarse. Distances are straight-line and ignore groundwater flow direction, so users upgradient of a landfill are counted alongside those downgradient. Aquifer type is assigned only at the landfill point, and the principal aquifer map is a national generalisation intended for use at 1:2,500,000 or smaller scales.

Conclusions

About 343,000 private-well users lived within 2 km of a US municipal landfill in the EPA LMOP database, and about 2.29 million within 5 km (2010 population, without double counting). Exposure is concentrated: the median landfill had 65 well users within 2 km, but 926 had at least 100 and 35 more than 1000. Closed landfills and those opened before the 1993 federal liner and monitoring criteria have about twice the median nearby well-user population of open and newer sites. A total of 213 landfills in 31 states combine pre-1993 construction, a sand-and-gravel or carbonate aquifer and at least 100 well users within 2 km. Testing private wells around these sites would give the most information for the effort spent.

Declarations

Competing interests

The author has no relevant financial or non-financial interests to disclose.

Ethics approval

and consent

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Author Contribution

P.O.O. conceived and designed the study, acquired and analysed the data, prepared all figures and tables, and wrote and revised the manuscript.

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Data Availability

All input data are public: EPA LMOP landfill-level data (September 2024, https://www.epa.gov/lmop/landfill-technical-data), USGS domestic-well population for 2010 (https://doi.org/10.5066/P9FSLU3B) and USGS principal aquifers (https://doi.org/10.5066/P9Y2HOUJ). The code, the ranked landfill table and the figures are available at https://github.com/Oladipopreserve-19/LandfillPrivateWellsUS and archived at https://doi.org/10.5281/zenodo.24399764.

References

1. Abiriga, D., Vestgarden, L. S., & Klempe, H. (2020). Groundwater contamination from a municipal landfill: Effect of age, landfill closure, and season on groundwater chemistry. *Science of the Total Environment*, *737*, 140307. https://doi.org/10.1016/j.scitotenv.2020.140307
2. Aller, L., Bennett, T., Lehr, J. H., Petty, R. J., & Hackett, G. (1987). *DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings*(EPA/600/2–87/035). US Environmental Protection Agency.
3. Christensen, T. H., Kjeldsen, P., Bjerg, P. L., Jensen, D. L., Christensen, J. B., Baun, A., Albrechtsen, H.-J., & Heron, G. (2001). Biogeochemistry of landfill leachate plumes. *Applied Geochemistry*, *16*(7–8), 659–718. https://doi.org/10.1016/S0883-2927(00)00082-2
4. Czolowski, E. D., Santoro, R. L., Srebotnjak, T., & Shonkoff, S. B. C. (2017). Toward consistent methodology to quantify populations in proximity to oil and gas development: A national spatial analysis and review. *Environmental Health Perspectives*, *125*(8), 086004. https://doi.org/10.1289/EHP1535
5. DeSimone, L. A., Hamilton, P. A., & Gilliom, R. J. (2009). *The quality of our Nation's waters: Quality of water from domestic wells in principal aquifers of the United States, 1991–2004: Overview of major findings*(U.S. Geological Survey Circular 1332). https://doi.org/10.3133/cir1332
6. Han, Z., Ma, H., Shi, G., He, L., Wei, L., & Shi, Q. (2016). A review of groundwater contamination near municipal solid waste landfill sites in China. *Science of the Total Environment*, *569–570*, 1255–1264. https://doi.org/10.1016/j.scitotenv.2016.06.201
7. Hepburn, E., Madden, C., Szabo, D., Coggan, T. L., Clarke, B., & Currell, M. (2019). Contamination of groundwater with per- and polyfluoroalkyl substances (PFAS) from legacy landfills in an urban re-development precinct. *Environmental Pollution*, *248*, 101–113. https://doi.org/10.1016/j.envpol.2019.02.018

8. Johnson, T. D., & Belitz, K. (2019). *Domestic well locations and populations served in the contiguous U.S.: Datasets for decadal years 2000 and 2010*[Data set]. U.S. Geological Survey. https://doi.org/10.5066/P9FSLU3B
9. Johnson, T. D., Belitz, K., & Lombard, M. A. (2019). Estimating domestic well locations and populations served in the contiguous U.S. for years 2000 and 2010. *Science of the Total Environment*, *687*, 1261–1273. https://doi.org/10.1016/j.scitotenv.2019.06.036
10. Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long-term composition of MSW landfill leachate: A review. *Critical Reviews in Environmental Science and Technology*, *32*(4), 297–336. https://doi.org/10.1080/10643380290813462
11. Lade, G. E., Comito, J., Benning, J., Kling, C., & Keiser, D. (2024). Improving private well testing programs: Experimental evidence from Iowa. *Environmental Science & Technology*, *58*(33), 14596–14607. https://doi.org/10.1021/acs.est.4c02835
12. Lang, J. R., Allred, B. M., Field, J. A., Levis, J. W., & Barlaz, M. A. (2017). National estimate of per- and polyfluoroalkyl substance (PFAS) release to U.S. municipal landfill leachate. *Environmental Science & Technology*, *51*(4), 2197–2205. https://doi.org/10.1021/acs.est.6b05005
13. Lombard, M. A., Daniel, J., Jeddy, Z., Hay, L. E., & Ayotte, J. D. (2021). Assessing the impact of drought on arsenic exposure from private domestic wells in the conterminous United States. *Environmental Science & Technology*, *55*(3), 1822–1831. https://doi.org/10.1021/acs.est.9b05835
14. Mor, S., Ravindra, K., Dahiya, R. P., & Chandra, A. (2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment*, *118*(1–3), 435–456. https://doi.org/10.1007/s10661-006-1505-7
15. Oladipo, P. O. (2026). *Private wells near municipal landfills: A national groundwater vulnerability screen for the United States: Code and results*(Version 1.0.0) [Computer software]. Zenodo. https://doi.org/10.5281/zenodo.24399764
16. US Environmental Protection Agency. (2024). *LMOP landfill and project database, landfill-level data (September 2024)*[Data set]. Retrieved November 20, 2026, from https://www.epa.gov/lmop/landfill-technical-data
17. US Geological Survey. (2003). *Principal aquifers of the 48 conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands*[Data set]. https://doi.org/10.5066/P9Y2HOUJ
18. Weaver, J. W., Murray, A. R., & Kremer, F. V. (2017). Estimation of the proximity of private domestic wells to underground storage tanks: Oklahoma pilot study. *Science of the Total Environment*, *609*, 1589–1599. https://doi.org/10.1016/j.scitotenv.2017.06.124
19. Zheng, Y., & Flanagan, S. V. (2017). The case for universal screening of private well water quality in the U.S. and testing requirements to achieve it: Evidence from arsenic. *Environmental Health Perspectives*, *125*(8), 085002. https://doi.org/10.1289/EHP629

Figures

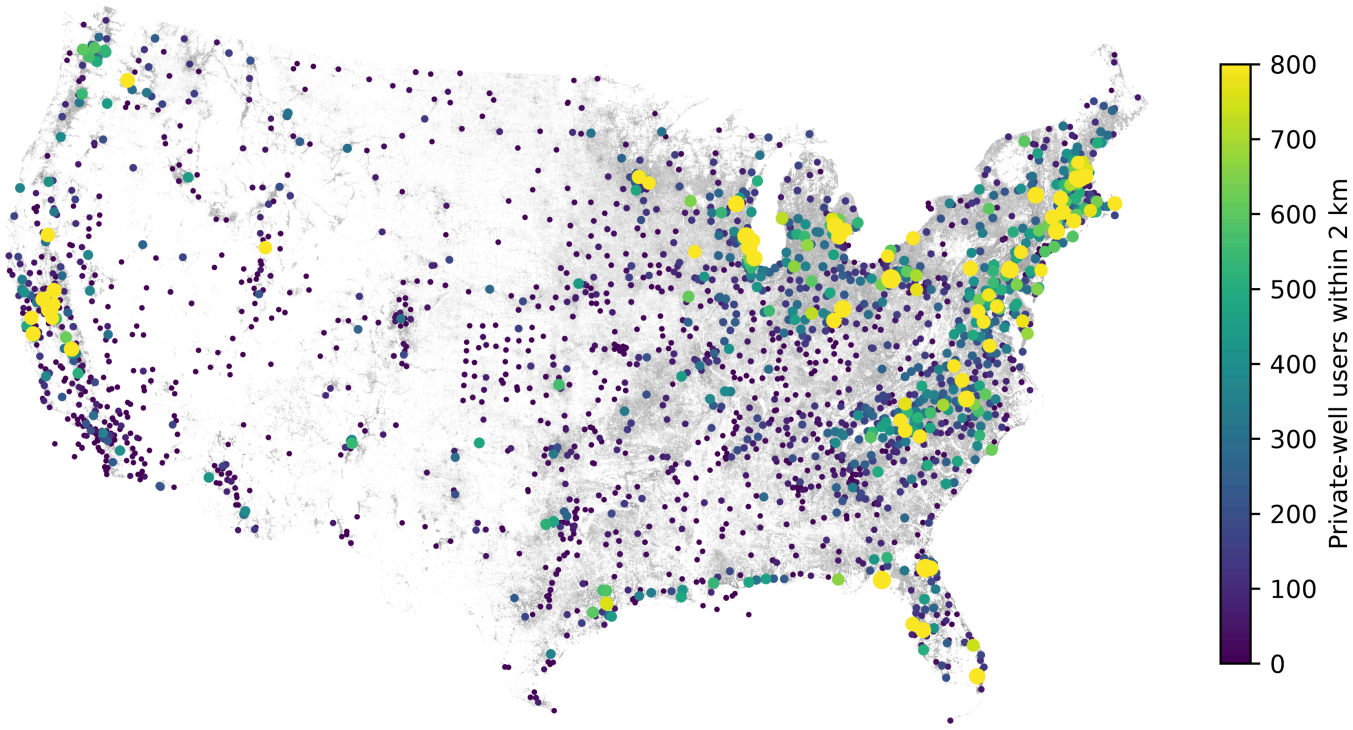

Figure 1

US municipal landfills in the EPA LMOP database, coloured and sized by the number of private-well users within 2 km, over the USGS 2010 domestic-well population grid (grey)

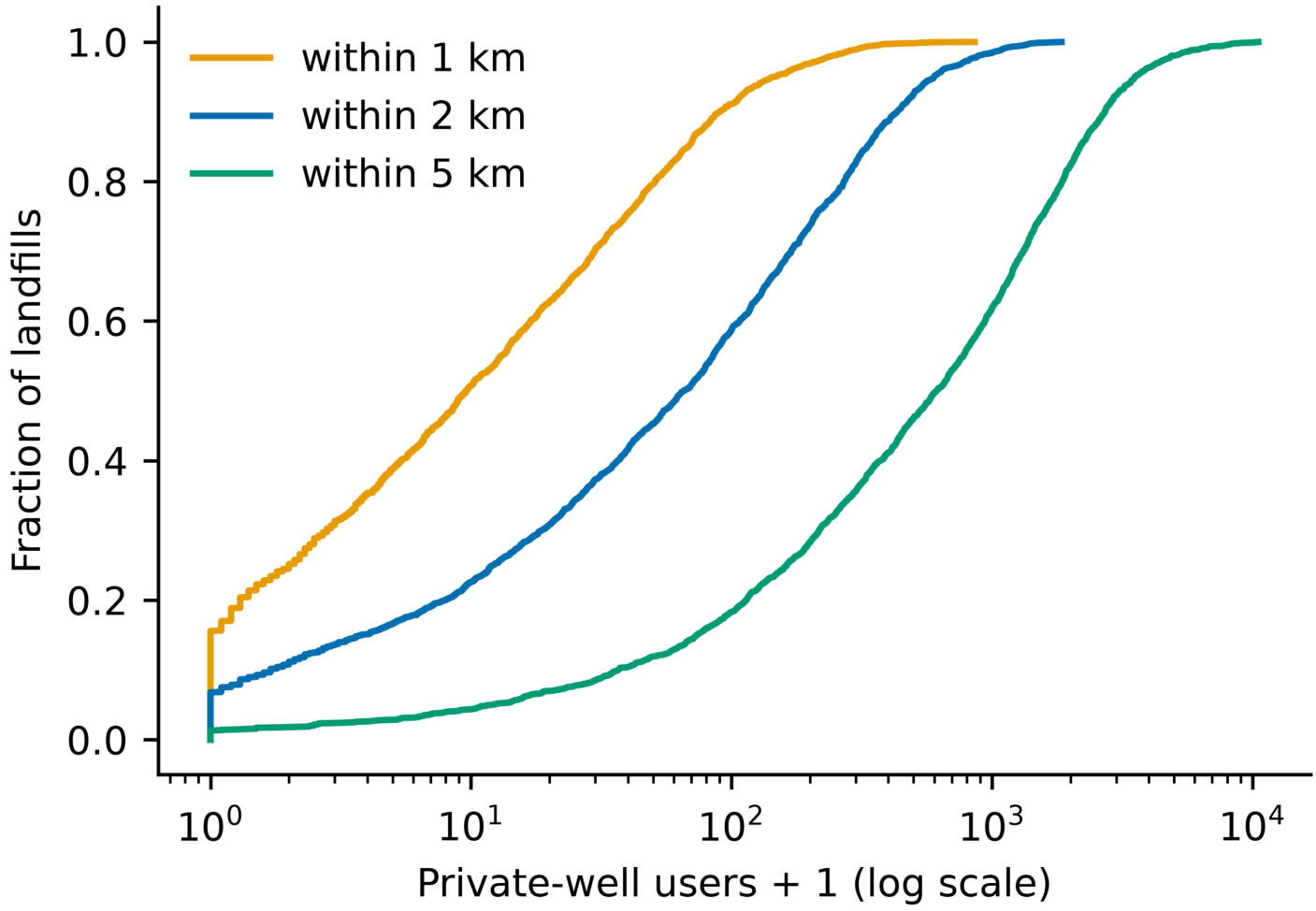

Figure 2

Cumulative distribution of private-well users within 1, 2 and 5 km of each landfill

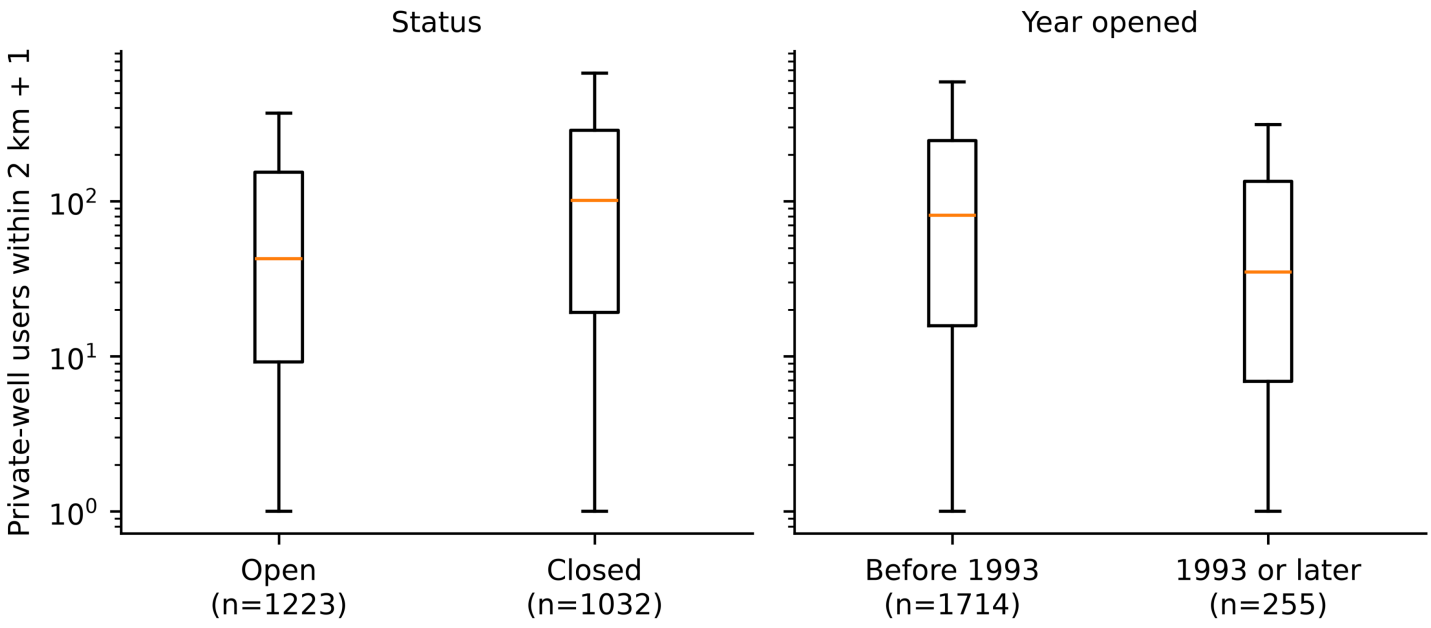

Figure 3

Private-well users within 2 km by landfill status (left) and opening year (right). Boxes show the interquartile range; outliers not shown

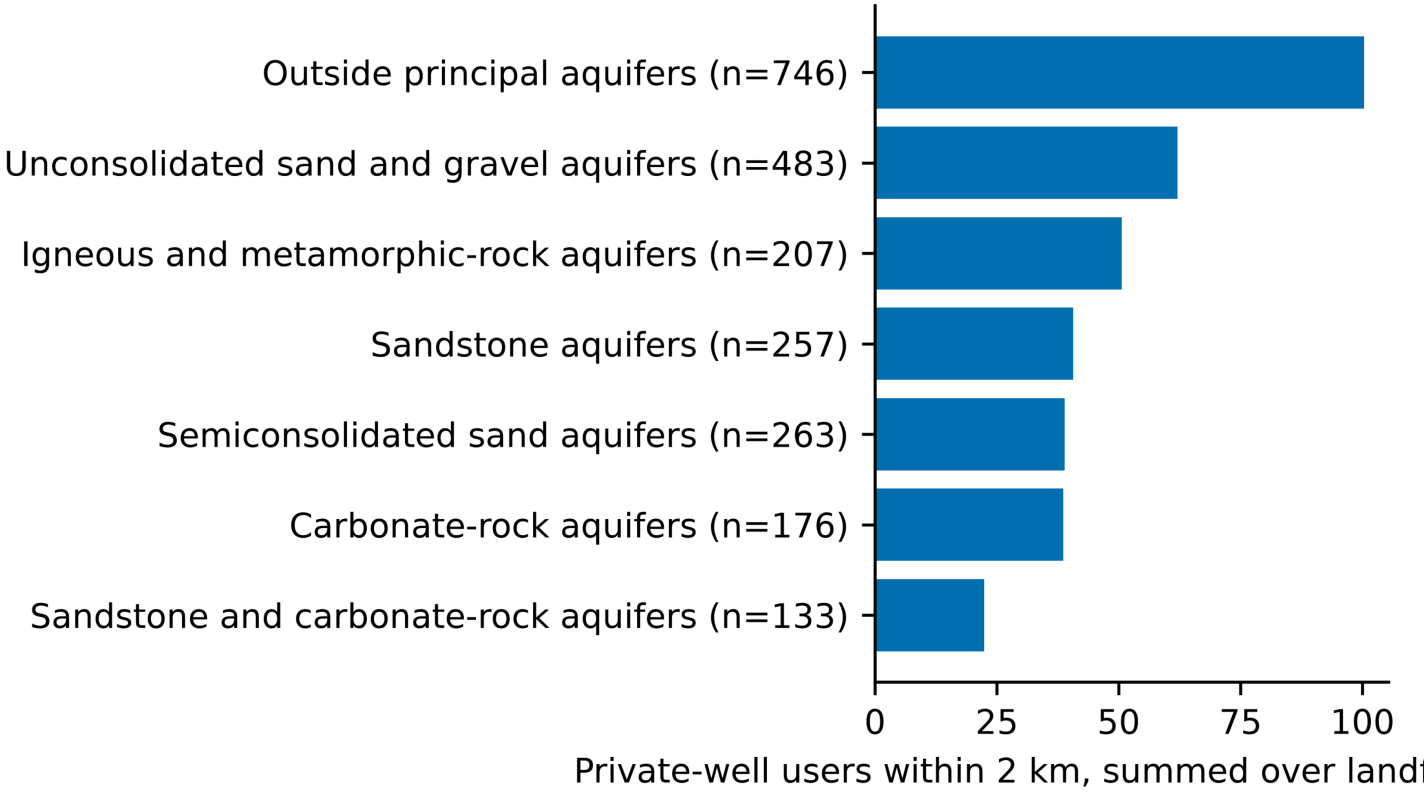

Figure 4

Private-well users within 2 km, summed over landfills, by principal aquifer type at the landfill

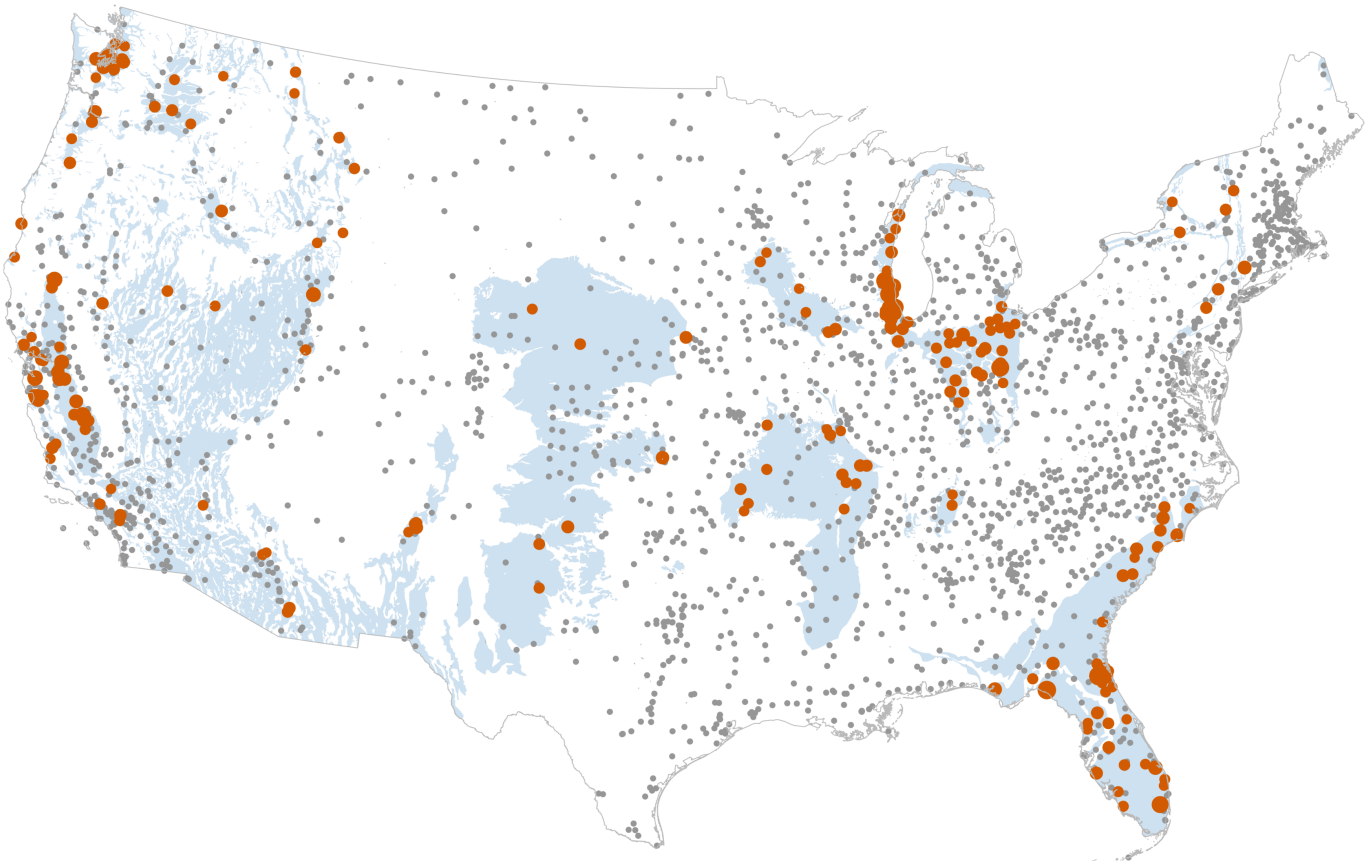

Figure 5

The 213 priority landfills (orange) and all other landfills (grey). Blue: unconsolidated sand-and-gravel and carbonate-rock principal aquifers