PFAS Contamination and Residential Property Values

A Study of Five US Sites within the Assessment Stage of the Remediation Lifecycle

by Orell C. Anderson, MAI, Chris Yost-Bremm, PhD, Stephen G. Valdez, Jason Borras, and Tara Harder

Abstract

This article presents the findings of an empirical study of residential property sales from 2005 through 2019 in areas surrounding five source sites known to be polluted with per- and polyfluoroalkyl substances (PFAS). The five sites are located in Georgia, Alaska, Wisconsin, California, and Arizona. By controlling for property and market characteristics, the hedonic regression model isolates the impact of PFAS awareness on sale prices. This allows for observation of any consistent pattern of diminution across geographies. Little to no evidence of diminution was found. The results are mixed and vary with local market, property, and environmental considerations.

Introduction

Per- and polyfluoroalkyl substances (PFAS), a family of thousands of synthetic compounds with a wide array of applications, are currently being studied as potential health hazards. The discovery of PFAS in public and private water supplies has led to increased media attention, regulation, and litigation throughout the United States and abroad. For example, on July 22, 2020, the Michigan Department of Environment, Great Lakes, and Energy announced new drinking water standards for seven types of PFAS. To date, the Michigan standards are some of the most stringent any state has applied to this class of substances. The day after the Michigan standards were announced, the governor of New Hampshire signed a bill regulating four types of PFAS in drinking water in that state. In February 2020, the Australian federal government reached a $212.5 million settlement for three class action lawsuits resulting from PFAS contamination[1] of residential water supplies surrounding military bases in Australia.[2]

While there has been considerable research into the environmental presence and health effects of different types of PFAS, there has been no systematic analysis of the potential influence of PFAS contamination on residential real estate values. This article examines five residential real estate markets in the United States where there is public knowledge of PFAS contamination. A hedonic regression model is used to measure the effect of this contamination on real estate markets surrounding known source sites in Georgia, Alaska, Wisconsin, California, and Arizona. By controlling for property and local market characteristics, the analysis isolates effects on value attributable to general public awareness—but not specific market participant actual knowledge or disclosure of PFAS—while in the assessment

1. The definition of *contamination* in USPAP Advisory Opinion 9 (AO-9) is not instructive here, as at the date of this study, PFAS was not classified as a hazardous substance nor were there enforceable levels for remediation.

2. The authors were retained as experts in the class action litigation in Australia.

phase of the remediation lifecycle.[3] The results of the hedonic model reveal variation in the effects of PFAS contamination on local real estate values across the five studied geographies.

This article begins with an overview of PFAS contamination and regulation in the context of real estate valuation practice. The next section includes a brief review of the relevant empirical literature. The research methodology and data sources are then described, followed by brief environmental histories of the five source sites. The results of the study are then presented.

Per- and Polyfluoroalkyl Substances (PFAS)

The family of chemicals collectively referred to as PFAS includes thousands of synthetic compounds. Two of the most common PFAS, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), were produced in the United States for industrial, military, and commercial purposes beginning in the 1940s and continued until their domestic production was phased out during the early 2000s. PFAS repel both water and oils and are resistant to high temperatures, making them suitable for many applications in industrial and consumer products, such as waterproof clothing, food packaging, carpet materials, firefighting foam, and nonstick cookware. Studies in the 1990s that revealed the ubiquity of PFAS in exposed workers and the general population led to investigations into their potential health effects in the early 2000s. Unfortunately, the qualities that make PFAS effective in industrial and consumer applications also make them persistent in the environment. PFAS migrate readily through groundwater, do not degrade, and bioaccumulate in animal tissues.[4]

Regulatory Limits

In the authoritative appraisal literature, most of the definitions of *environmental contamination* closely align with the definition from USPAP Advisory Opinion 9 (AO-9):

> Adverse environmental conditions resulting from the release of hazardous substances into the air, surface water, groundwater or soil. Generally, the concentrations of these substances would exceed regulatory limits established by the appropriate federal, state, and/or local agencies.[5]

PFAS exist in an uncertain regulatory environment. There is currently no enforceable federal regulation of any PFAS in drinking water. Though the US Environmental Protection Agency (EPA) is in the process of determining appropriate regulations for PFOS and PFOA under the Safe Drinking Water Act, the only relevant federal drinking water standards for over ten years have been the non-enforceable EPA health advisories established in 2009 and 2016.[6] In January 2009, the EPA established a Provisional Health Advisory for PFOS and PFOA in drinking water.[7] The 2009 advisories for PFOA and PFOS were 0.4 and 0.2 parts per

3. Appraisal Standards Board, Advisory Opinion 9 (AO-9), "The Appraisal of Real Property That May Be Impacted by Environmental Contamination," in *USPAP Advisory Opinions*, 2020–2021 (Washington, DC: Appraisal Foundation, 2020), defines the *remediation lifecycle* as "a cycle consisting of three stages of cleanup of a contaminated site: before remediation or cleanup; during remediation; and after remediation. A contaminated property's remediation lifecycle stage is an important determinant of the risk associated with environmental contamination. Environmental risk can be expected to vary with the remediation lifecycle stage of the property." (Lines 93–96) The before-remediation stage of the lifecycle is often referred to by the more descriptive term *assessment stage*. See, for example, Orell C. Anderson, "Environmental Contamination: An Analysis in the Context of the DC Matrix," *The Appraisal Journal* 69, no. 3 (2001): 322–332.

4. Interstate Technology Regulatory Council, "Regulations, Guidance, and Advisories for Per- and Polyfluoroalkyl Substances (PFAS)," April 2020, https://bit.ly/37Jnzd1; US Environmental Protection Agency (EPA), "Per- and Polyfluoroalkyl Substances (PFAS)," https://www.epa.gov/pfas; EPA, "Our Current Understanding of the Human Health and Environmental Risks of PFAS," https://bit.ly/3wlyl3p.

5. Appraisal Standards Board, Advisory Opinion 9 (AO-9), Lines 74–76.

6. EPA, "EPA Releases PFAS Action Plan: Program Update," News Releases, February 26, 2020, https://bit.ly/3ih5qFp.

7. EPA, "Drinking Water Health Advisories for PFOA and PFOS," https://bit.ly/36czRKn. "EPA's health advisories are non-enforceable and non-regulatory and provide technical information to state agencies and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination. EPA's health advisory level for PFOA and PFOS offers a margin of protection for all Americans throughout their life from adverse health effects resulting from exposure to PFOA and PFOS in drinking water."

billion (ppb), respectively.[8] In May 2016, the EPA released a Lifetime Health Advisory for combined concentrations of PFOS and PFOA of 70 parts per trillion (ppt).[9] Thus, on a federal level, the current EPA standards are non-enforceable health advisories and only apply to PFOS and PFOA.

In the absence of federal action, multiple states are in the process of establishing their own standards and regulations.[10] The five sites in the case study are in Alaska, Arizona, California, Georgia, and Wisconsin. None of these states currently have—or had at any point during the 2005–2019 study period—an enforceable regulation for any PFAS in drinking water. Each of the five states has enacted different combinations of advisories, standards, and guidelines; these are subject to change. Currently, Georgia and Arizona have no state-level standards. Alaska has a November 2016 regulatory cleanup level for PFAS in groundwater or soil and a non-regulatory advisory guideline for drinking water. California has non-regulatory notification and response levels for drinking water supplies set in 2018 and lowered in February 2020. Wisconsin is the only state of the five that is actively in the process of establishing regulatory levels for PFAS in drinking water. On June 21, 2019, the Wisconsin Department of Health Services recommended groundwater enforcement standards (a more stringent requirement for cleanup) and preventive action limits for PFOS and PFOA individually or combined.[11] In Wisconsin, there is currently a groundwater advisory, a fish and wildlife consumption advisory, and regulations for soil.

But even as state-level standards are set, they are sometimes rolled back or suspended from enforcement by litigation. For example, in 2019 the governor of Alaska rolled back regulations for five PFAS, deferring instead to the EPA.[12] In New Hampshire, a 2019 injunction in a lawsuit brought by potentially responsible parties stopped the regulatory process only to have the regulations established in a 2020 bill.[13]

The concept of a single, or central, regulatory limit is further complicated by the fact that PFAS is an umbrella term that refers to thousands of related compounds. For example, soil and groundwater cleanup levels in Alaska are set for PFOS and PFOA individually, while a proposed regulation in Massachusetts applies to the summed concentrations of six PFAS. In Vermont, meanwhile, the standards apply to five PFAS.

Market Perception

It is not the role of the real estate appraiser to determine whether a property is contaminated. From a valuation perspective, the question of whether a property is physically contaminated is not as important as whether there is an observable market perception of environmental risk. This is acknowledged within the USPAP Advisory Opinion 9 definition of *environmental risk*:

> The additional or incremental risk of investing in, financing, buying, or owning property attributable to its environmental condition. *This risk is derived from perceived uncertainties* concerning:
> 1) the nature and extent of the contamination;
> 2) estimates of future remediation costs and their timing;
> 3) potential for changes in regulatory requirements;
> 4) liabilities for cleanup (buyer, seller, third party);
> 5) potential for off-site impacts; and
> 6) other environmental risk factors, as may be relevant. (Emphasis added.)[14]

The hypothesis of the study presented in this article is that residential properties within a 1.5-mile radius of the source of PFAS contam-

8. EPA, "Provisional Health Advisories for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS)," January 8, 2009, https://bit.ly/36bnoGP.

9. EPA, "Drinking Water Health Advisories for PFOA and PFOS."

10. Michigan has been in the lead adopting regulations establishing maximum contaminant levels (MCLs) for PFAS chemicals in drinking water; see https://bit.ly/3qj2s7X.

11. Wisconsin Department of Health Services, "Groundwater Standards," April 6, 2020, https://bit.ly/351jaBg.

12. Dan Bross, "State Dials Back PFAS Response Standard," Alaska Public Media, April 16, 2019, https://bit.ly/3qlK2U2.

13. Adrianne Appel, "New Hampshire Judge Suspends State's New PFAS Restrictions," Bloomberg Law, November 26, 2019, https://bit.ly/3L0XeoX.

14. Appraisal Standards Board, AO-9, Lines 77–84. See also "Guide Note 6: Consideration of Hazardous Substances in the Appraisal Process," *Guide Notes to the Standards of Professional Practice* (Appraisal Institute, 2020), https://bit.ly/2RLm8mN.

ination are impaired either with environmental contamination (as non-source properties) or with environmental risk (as adjacent or proximate properties). These properties are hereinafter referred to as the "impaired subject areas." The unimpaired control areas are those properties within a 10-mile radius of the point-source, excluding the central 1.5-mile radius subject area. Though groundwater contamination does not radiate out from a central point, the literature discussed in the next section provides evidence that, under certain circumstances, buyers may pay for distance from a perceived environmental disamenity. Incorporation of contamination plume maps and zones of potential environmental risk established by qualified environmental experts—which were not available for this study but may be required under certain assignments—would therefore enhance the accuracy of the analysis.[15]

Literature Review

The measurement of any observable impacts of contamination on property values has been an active area of economics and appraisal research since the mid-1980s. This research has found that point-source contamination can impact nearby real estate values. There are several extensive literature reviews that provide an in-depth treatment and essentially find mixed results. There is consistent evidence that elevated health risks due to contamination may be capitalized into surrounding property values, but there is disagreement about the extent and duration of any impacts. Some studies find no impacts whatsoever.[16] Perhaps because valuation professionals are trained to think carefully about the relationship between time and value, the appraisal literature, much of it published in *The Appraisal Journal*, often focuses on the question of market resiliency in the time period following remediation.[17] For the last thirty years, scholars and practitioners in the appraisal profession have grappled with how to classify and measure what is commonly referred to as *stigma* (environmental risk and market resistance are more precise terms) in the post-remediated, ongoing stage of the remediation lifecycle.[18] *The Appraisal of Real Estate*, fifteenth edition, describes *stigma* as

> an adverse public effect on property value produced by the market's perception regarding a property, commonly the identification of increased risk. This risk is derived from perceived uncertainties surrounding a detrimental condition such as environmental contamination ... which penalizes the marketability of the property and may also result in a diminution in value. ... The negative perception of a particular site may be short-term or long-term, depending on the source of the stigma and changing market reactions to the nature of the event.[19]

The text notes that "the three significant factors in the analysis of stigma are the real or imagined cause of the stigma, the duration of the effect of the stigma, and the geographical extent of the influence of the stigma."

Since the primary pathway that exposes residential properties—and the occupants—to PFAS is groundwater and municipal water systems, the research into the impacts of contaminated groundwater is of importance. Much of the groundwater-specific research that does exist finds that groundwater contamination has little

15. The 1.5-mile radius was selected because it represented the most consistent tradeoff across the various markets studied in terms of the number of sales close to the site versus those that were farther away. As a sensitivity analysis, the analysis was re-run for alternative thresholds, ranging the cutoff from 0.75 through 2.0 miles away, in increments of 0.25 miles. Adjusting the threshold within this range of alternatives did not qualitatively alter the findings.

16. For in-depth reviews of the empirical literature, see Stephen Farber, "Undesirable Facilities and Property Values: A Summary of Empirical Studies," *Ecological Economics* 24, no. 1 (January 1998): 1–14; Melissa Boyle and Katherine A. Kiel, "A Survey of House Price Hedonic Studies of the Impact of Environmental Externalities," *Journal of Real Estate Literature* 9, no. 2 (2001): 117–144; Thomas O. Jackson, "The Effects of Environmental Contamination on Real Estate: A Literature Review," *Journal of Real Estate Literature* 9, no. 2 (2001): 93–116.

17. Richard J. Roddewig, "Temporary Stigma: Lessons from the Exxon Valdez Litigation," *The Appraisal Journal* (January 1997): 96–101; Richard J. Roddewig, Charles T. Brigden, and Anne S. Baxendale, "A Pipeline Spill Revisited: How Long Do Impacts on Home Prices Last?" *The Appraisal Journal* 86, no. 1 (Winter 2018): 23–47; and Thomas O. Jackson, "Evaluating Environmental Stigma with Multiple Regression Analysis," *The Appraisal Journal* (Fall 2005): 363–369.

18. Orell C. Anderson, "Environmental Contamination: An Analysis in the Context of the DC Matrix," *The Appraisal Journal* 69, no. 3 (2001): 322–332.

19. Appraisal Institute, *The Appraisal of Real Estate*, 15th ed. (Chicago: Appraisal Institute, 2020), 184.

or no impact on residential real estate; this is especially true for earlier research. In a 1993 study, Page and Rabinowitz find no impacts in six of seven residential case studies—and a rebound after two years where there was an impact.[20] Dotzour in a 1997 paper in *The Appraisal Journal* finds no impacts to residential properties following discovery of groundwater contamination, though this study used a sample that was entirely reliant on a public water supply.[21] Boyle, Poe, and Bergstrom find small and temporary impacts due to highly publicized arsenic contamination in two towns in Maine.[22]

On the other hand, in a 2015 article Muehlenbachs, Spiller, and Timmins report declines of up to 16.5% for groundwater-dependent homes within 1.5 km of newly drilled shale gas wells.[23] In a series of individually published studies and collaborations between 2012 and 2018, Guignet attempted to introduce the role of media and property-specific awareness metrics into the residential groundwater contamination data—often using data sets related to leaking underground storage tanks. For example, Zabel and Guignet find that the most highly publicized leaking underground storage tank sites experienced small price effects following discovery, and these effects increased along with the duration of the environmental investigation, with impacts as high as 12.4% up to 1 km away for a particularly notorious site.[24] Thus, the development of richer data sets incorporating geospatial methods and property-specific contamination, exposure, and publicity measures has allowed for more nuanced results. Despite the addition of techniques for better data gathering, work remains in the study of how long any impacts last after discovery.

Valuation of Contaminated Real Estate

In the context of property valuation, contamination falls under the umbrella term of *detrimental conditions*. Although detrimental conditions can significantly complicate a valuation assignment, the presence of a detrimental condition does not necessarily result in property value diminution. This distinction is central to the valuation of contaminated real estate. The question the appraiser attempts to answer is not whether the detrimental condition exists, but rather how much weight the market gives to that detrimental condition relative to the aggregate of other factors that influence value.[25] It is possible that the detrimental condition is so great that markets may consider a property "no-go" until it has been remediated, but likewise, it is possible that markets may ascribe little, if any, discount to environmental contamination. Whatever the outcome, an appraiser's analysis and determination of this price of risk, if present, must be based on the analysis of relevant transactional market data and not simply an assumption.[26]

The appraisal profession in the United States has developed a system of methodologies for valuing real estate affected by contamination. Previously, the potential value impact of contamination was either disregarded or estimated by subtracting remediation costs from the unimpaired market value. The technique used may be considered suitable in some places or circumstances but not others. For example, guidelines of the International Valuation Standards, the Australian Property Institute, and the Royal Institution of Chartered Surveyors have not yet set out comprehensive valuation methodologies for environmentally contaminated real estate.

20. G. William Page and Harvey Rabinowitz, "Groundwater Contamination: Its Effects on Property Values and Cities," *Journal of the American Planning Association* 59, no. 4 (December 31, 1993): 473–481, https://bit.ly/3wvjqUm.

21. Mark Dotzour, "Groundwater Contamination and Residential Property Values," *The Appraisal Journal* 65, no. 3 (July 1997): 279–285.

22. Kevin J. Boyle, Gregory L. Poe, and John C. Bergstrom, "What Do We Know about Groundwater Values? Preliminary Implications from a Meta Analysis of Contingent-Valuation Studies," *American Journal of Agricultural Economics* 76, no. 5 (December 1994): 1055–1061, https://bit.ly/3JO2hJz.

23. Lucija Muehlenbachs, Elisheba Spiller, and Christopher Timmins, "The Housing Market Impacts of Shale Gas Development," *American Economic Review* 105, no. 12 (December 2015): 3633–3659, https://bit.ly/3qqsHt7.

24. Jeffrey E. Zabel and Dennis Guignet, "A Hedonic Analysis of the Impact of LUST Sites on House Prices," *Resource and Energy Economics* 34, no. 4 (November 2012): 549–564, https://bit.ly/3IspejR.

25. Randall Bell, *Real Estate Damages*, 3rd ed. (Chicago: Appraisal Institute, 2016).

26. Appraisal Standards Board, AO-9, Lines 170–171.

The standards and methods for appraising contaminated real estate in the United States can be found in peer-reviewed literature, authoritative texts of the valuation and economic professions, professional training courses, organizational guide notes, and codified federal and state valuation laws. The fundamental valuation framework focuses on characterizing contaminated sites as source, non-source, adjacent, or proximate properties (SNAP) and the stage a property falls into within the remediation lifecycle (before, during, and after cleanup), while considering any market-supported cost, use, and risk issues.[27] Cost, use, and risk are the three value elements of property value diminution. The foundational prerequisites of a reliable analysis include adherence to the Uniform Standards of Professional Appraisal Practice competency requirements, the use of acceptable methodology and relevant terminology, and consideration of relevant property characteristics.[28]

Methods typically accepted by the real estate market and the US judicial system include the cost, sales comparison, and income approaches to value. Supporting techniques include impaired comparable adjustment grids, case study analysis, unimpaired and impaired paired data testing, before and after sales assessment, literature review, market trending, regression analysis, and in situations where insufficient market transactions are available, contingent valuation. These methods are employed to varying degrees to express property value diminution as a percentage of unimpaired value. These methods can be supplemented with market questionnaires, interviews, or surveys as support.

Case Study Methodology

The methodology used in the case study presented here is hedonic regression analysis. Hedonic regression analysis is a form of regression analysis used by real estate experts to quantify various property characteristics into meaningful component parts and to isolate each part's economic contribution to observed prices. One benefit of a regression analysis for determining property value impacts is that it can simultaneously control and estimate for multiple property influences. For example, regression allows the analyst to identify the contributory value of an additional bathroom, while controlling for the incremental value effect from the additional square footage provided by that bathroom.

Another benefit of regression analysis is the ability to quantify the reliability of its output. For example, looking at the statistical significance of various factors can provide an appraiser with a sense of whether a particular property value adjustment is warranted.

Whether with regression analysis or another generally accepted method, the use of relevant data is a critical component to measuring property value effects from contamination, if any. USPAP Advisory Opinion 9, for example, emphasizes that "analysis of the effects of increased environmental risk and uncertainty on property value (environmental stigma) must be based on market data, rather than unsupported opinion or judgment."[29] As in all appraisal methods, comparable sales should be relevant to the subject property. In the current regression analysis, efforts are made to ensure compatibility by limiting each study area to several specific comparable factors, such as geography and property type. We therefore caution that hedonic effects found in a specific region of the United States or for a specific property type may not be applicable elsewhere.

Data

The data in the study come from ATTOM Data Solutions, a vendor of property data extracted from county recorder offices. The data include property characteristics (e.g., square footage, type of property, acreage) as well as information on recorded sales, including sale price, sale type (e.g., arm's-length, REO), and sale date. Each observation used in the analysis is an individual, single-family residential property sale. The study focuses on five localities where there is a history of local media coverage surrounding nearby PFAS sites. These five sites are Dalton, Georgia; Fairbanks, Alaska; Madison, Wisconsin; Mather, California; and Mesa, Arizona. The residential sales data span 2005 through 2019. Sales infor-

27. Appraisal Standards Board, AO-9, Lines 97–100; Anderson, "Environmental Contamination," 325–330.

28. Competency Rule, *Uniform Standards of Professional Appraisal Practice*, 2020–2021 ed., Lines 298–341.

29. Appraisal Standards Board, AO-9, Lines, 170–171.

Exhibit 1 Summary Statistics by Area

Area	Count	Mean ($)	Std. Dev. ($)	Min. ($)	Max. ($)
Dalton, GA	12,310	158,804	233,078	25,500	12,400,000
Fairbanks, AK	1,456	254,887	119,317	26,889	1,047,375
Madison, WI	35,517	315,403	381,012	25,392	18,300,000
Mather, CA	159,970	311,390	452,496	25,500	90,900,000
Mesa, AZ	25,462	447,294	786,594	26,135	22,200,000

mation for these data is summarized in the summary statistics, organized according to area, in Exhibit 1. The mean sale prices ranged from Dalton with generally lower-priced homes (mean $158,804), to Madison, Mather, and Mesa with higher-priced homes.

Discussion of Variables Used

The dependent variable used is sale price. There are two versions of sale price: one is logged and one is sale price raw, as appraisers typically view it ("unlogged"). A log transformation is sometimes used for the dependent variable to control for statistical issues that can occur, such as heteroskedasticity.[30]

A number of independent variables are used to explain the dependent variable(s). Many of these are control variables, designed to capture common influences on real estate value. Selection of control variables is critical in a regression analysis, because the exclusion of any important control variables could inadvertently bias any measurement of contamination found. This issue is known as an "omitted variable bias."[31] Control variables included square feet (interior living area), bedrooms, total baths, building age (in years), and lot size (in square feet). In addition, the analysis included binary variables corresponding to the year in which each sale occurred (known as "fixed effects"). These Sale Year variables control for general changes in real estate values over time (e.g., the 2008–2009 downturn), regardless of whether a sale was impacted by proximity to contamination. All of these independent variables are unlogged.

The main independent variable of interest is designed to measure differences in values between the areas affected by contamination (the Subject) and the areas nearby but unaffected by such contamination (the Control). In particular, a value of \`1\` for the Subject variable was coded if a sale was in the affected area, and \`0\` otherwise. Similarly, a value of \`1\` was coded if the sale took place after the discovery of contamination (regardless of Subject or Control status) and was coded \`0\` otherwise. The intersection of these two variables is the main variable of interest: of whether the sale took place in the affected area, *after* the discovery of contamination. By comparing how Subject properties performed relative to their Control counterparts, in the "After" period relative to the "Before" period, any changes in trend between the two after the discovery of contamination can be quantified. The use of these two binary (\`0\` or \`1\` valued) "Subject" and "After" variables in this way is what is known as a "difference-in-difference" regression.[32] This difference-in-difference approach can control for variability in housing prices over time as well as general differences between Subject and Control areas.

30. "Regression Analysis and Statistical Applications," Appendix B in *The Appraisal of Real Estate*, 15th ed., 14, supplementary content available at https://bit.ly/3wxsZll.

31. "Regression Analysis and Statistical Applications," 11–16.

32. For a description and illustration of a difference-in-difference approach to measuring effects from environmental contamination on real estate values, see, for example, Thomas O. Jackson and Chris Yost-Bremm, "Environmental Risk Premiums and Price Effects in Commercial Real Estate Transactions," *The Appraisal Journal* (Winter 2018): 48–67; and Richard J. Roddewig, Charles T. Brigden, and Anne S. Baxendale, "A Pipeline Spill Revisited: How Long Do Impacts on Home Prices Last?" *The Appraisal Journal* (Winter 2018): 23–47.

Case Study of Five PFAS Sites

The case study involves areas surrounding five source sites known to be polluted with per- and polyfluoroalkyl substances (PFAS) located in Georgia, Alaska, Wisconsin, California, and Arizona. At the time the study was conducted, the sites were within the assessment stage of the remediation lifecycle.

Environmental Timelines and Dates of Awareness

The hedonic method assumes that the buyer is aware of the factors—such as bedrooms, square footage, or contamination—included as independent variables. Buyer awareness of contamination in a market could arise from testing activities, community outreach, film, television, print media, or any other means. The dates of awareness chosen in this study are based on the fact patterns described for each location. After establishing a date of awareness for each subject test area, transactions of impaired sales were compared to unimpaired Control Area sales.

Dalton, Georgia

The identified source of PFAS contamination in Dalton, Georgia, is the Dalton Utilities Loopers Bend Wastewater Treatment Plant (Appendix Figure 1). Dalton is a global center of carpet manufacturing, an industry that has made heavy use of PFAS compounds for carpet protection and stain resistance. Following a 2008 study that showed elevated levels of PFAS in the Conasauga River downstream from the Loopers Bend facility, the EPA tested the municipal drinking water in Dalton and other towns near the wastewater treatment plant.[33] In 2009, tests found that levels in these municipal water supplies did not exceed the then-current 2009 EPA health advisories.[34] The EPA then requested that Dalton Utilities test the effluent, groundwater, and compost at the Loopers Bend facility. This testing found elevated levels of PFOS and PFOA in soils, groundwater, fresh sludge, and compost.[35] In late 2009, subsequent testing of 110 private wells within one mile of the facility revealed one well with concentrations of PFOS above the EPA advisory. Dalton Utilities connected this property to the public water supply.[36] In August 2010, Dalton Utilities provided the EPA with reporting showing the results of this testing. Given this environmental timeline, we consider the *after period* for measuring potential property impacts as any time after August 10, 2010, the date of the Dalton Utilities report.[37]

Fairbanks, Alaska

The Fairbanks region of Alaska has several PFAS sites where elevated levels of PFAS have been detected in both private and public water supplies. In this study, the impact PFAS contamination on real estate transactions within 1.5 miles of the Fairbanks International Airport (Appendix Figure 2) is examined. In October 2017, the airport notified the Alaska Department of Environmental Conservation (DEC) of on-site PFAS levels exceeding the EPA health advisory and the DEC cleanup levels. Subsequent testing of downgradient drinking water wells began in November 2017 and continued through April 2018. Initial sampling results showing wells over the EPA advisory levels were provided to the airport in late November 2017. A public meeting was held at a local hotel on December 18, 2017, with presentations by the DEC, the Fairbanks International Airport, and the Alaska Department of Health and Social Services. This stakeholder meeting is used as the date of public awareness for the PFAS contamination in the Fairbanks real estate market.

Madison, Wisconsin

In April 2018, the Wisconsin Department of Natural Resources (DNR) notified the Madison Water Utility that shallow groundwater near

33. Brad J. Konwick, Gregg T. Tomy, Nargis Ismail, James T. Peterson, Rebecca J. Fauver, David Higginbotham, and Aaron T. Fisk, "Concentrations and Patterns of Perfluoroalkyl Acids in Georgia, USA Surface Waters Near and Distant to a Major Use Source," *Environmental Toxicology and Chemistry* 27, no. 10 (2008): 2011–2018.

34. EPA, "Region 4: Water Protection—Release of Perflourochemicals (PFCs) from the Dalton Utilities Loopers Bend Wastewater Treatment Plant (Dalton Utilities) in Dalton, Georgia," February 20, 2016.

35. Dalton Utilities, "Analytical Report for Fluorochemical Characterization of Aqueous and Solid Samples, MPI Report No. L0018099," July 20, 2009.

36. EPA, "Perfluorochemical (PFC) Contamination in Dalton, GA: Statement and Background Prepared by US Environmental Protection Agency (EPA)," October 8, 2009.

37. Dalton Utilities, "Dalton Utilities Data Summary," August 10, 2010.

one of the municipal wells in Madison contained PFAS (Appendix Figure 3).[38] In 2018, the Wisconsin Air National Guard declared responsibility for cleanup of the PFAS contamination, suspected to be from the Truax Air National Guard Base.[39] Testing revealed that one of the water utility's municipal wells contained PFAS, though at levels below the EPA advisory. The utility shut off the affected well. Later testing has confirmed the presence of PFAS at levels below the EPA health advisories and the stricter Wisconsin standards proposed to the DNR by the Wisconsin Department of Health Services. The local utility held a community meeting on March 6, 2019, in which representatives explained the potential for PFAS contamination in municipal water. The date of this community meeting is used as the date marking public awareness of PFAS contamination in the Madison study area.

Mather, California

The source of PFAS contamination in Mather, California, is the Mather Airport, formerly called the Mather Military Base (Appendix Figure 4). PFOS, PFOA, and several other contaminants (TCE, hydrocarbons, antifreeze, and hazardous metals) have been discovered at the site.[40] The site was listed by the EPA on the National Priorities List in 1987.[41] EPA investigations identified a total of 89 areas of contamination, including multiple groundwater plumes and soil contamination sites. Sources of human exposure have been eliminated, but soil vapor extraction and groundwater pump-and-treat systems continue.[42] In 2016, PFAS compounds were found within a well near Mather. A remediation system was operable by September 2017. Following a March 2018 study that identified the US Air Force (USAF) as the responsible party for the PFAS contamination, the site became the subject of a cost recovery and property damage suit against the USAF and the federal government. The USAF conducted an environmental site assessment in March 2019, but details were not publicly released.[43] Since PFAS contamination was found on January 1, 2016, that date is used as the most conservative date of awareness of contamination in Mather.

Mesa, Arizona

The suspected source of PFAS contamination in Mesa, Arizona, is the former Williams Air Force Base (Appendix Figure 5). The 4,043-acre site was placed on the National Priorities List in 1989 and is the current site of the Phoenix-Mesa Gateway Airport, the Arizona State University Polytechnic Campus, and Chandler-Gilbert Community College. Though the site was listed in 1983 primarily for its contamination with benzene and other gasoline components and additives, the USAF began testing for PFAS in March 2018. PFAS were found in groundwater near the landfill, the fire training area, a fuel spill site, and the fire station.[44] Groundwater characterization for PFAS is ongoing, and testing results are not expected to become public information until the US Department of Defense and the EPA finalize regulatory thresholds.[45] On October 16, 2018, a meeting was held at the airport administration building with stakeholders and USAF representatives. This meeting is used in this study as the date of awareness of PFAS contamination in Mesa.

38. City of Madison, "Discovering PFAS in Madison—A Timeline," accessed July 21, 2020, https://bit.ly/3D37MS1.

39. Chris Hubbach, "Dane County, Madison Water Utility Sued for Withholding PFAS Records," Wisconsin State Journal, March 17, 2020, https://bit.ly/3wAioq6.

40. We include Mather and Mesa as study areas but caution in interpretation of the results here on account of their preexisting status as Superfund sites.

41. "The National Priorities List (NPL) is the list of sites of national priority among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The NPL is intended primarily to guide the EPA in determining which sites warrant further investigation." EPA, "Superfund: National Priorities List (NPL)," https://bit.ly/3upEZ6e.

42. EPA, "Mather Air Force Base (AC&W Disposal Site) Mather, CA: Cleanup Activities," Superfund Site Information, accessed July 21, 2020, https://bit.ly/3IzFSxU.

43. Evan Jacobs, "PFAS in Sacramento," (PowerPoint presentation, California America Water Spring Conference, Sacramento, CA, May 23, 2019), https://bit.ly/3ubGjcI.

44. EPA, "Williams Air Force Base Chandler, AZ: Cleanup Activities," Superfund Site Information, accessed July 22, 2020, https://bit.ly/36FUIpg.

45. Arizona Department of Environmental Quality, "Superfund Site—Former Williams Air Force Base," April 8, 2021, https://bit.ly/3wxBAou.

Exhibit 2 Proximity to Environmental Contamination—Hedonic Effect Summaries

	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
Log Model	Neutral	Neutral	Positive	Negative	Neutral
Linear Model	Neutral	Neutral	Neutral	Negative	Negative

Results

The results of the hedonic regression indicate a varied range of outcomes. Measuring the hedonic effects by comparing price trends before and after the date of public awareness of the potential contamination, the precise outcomes differ across localities. However, most market responses to public awareness of PFAS are nonexistent and, in one case, significantly positive. No consistent pattern of diminution was found across the regions and model specifications. These results are described in more detail in the paragraphs that follow. A more concise summary is displayed in Exhibit 2.

Log Model and Linear Model Results

Homes in Dalton, Georgia, proximate to the PFAS site sold at a higher average price after public awareness, relative to homes that were located farther away. While the model coefficients for these proximate homes are positive, they are not statistically significant at any conventionally accepted threshold. This suggests that for these proximate homes, there is no identifiable divergence in price after public announcements regarding contamination, relative to homes farther away.

Why might there be no effect in Dalton? It may be that, as homes nearby were connected to municipal water, exposure concerns were mitigated. Other influences may have also outweighed PFAS concerns, such as the fact that the surrounding residential properties and the buyers that located to this market prioritized property-specific characteristics over environmental factors.

Similarly, the log specification (Exhibit 3) for homes in Fairbanks, Alaska, shows negative but statistically insignificant price impacts for homes more proximate to the source site. This means that no difference can be identified between homes close to the PFAS site and homes further away. Evidence for a negative effect becomes somewhat more apparent when looking at the linear specification (Exhibit 4); however, this effect is only observable at the 10% level of significance. This higher significance threshold suggests a healthy degree of caution in interpreting whether price discounts truly exist in this market.

Taking the two models together, it appears that any price diminution for Fairbanks would be weak or nonexistent. This may be attributable to the fact that the site is in a mixed-use area, with many homes already near other industrial uses. The location of homes near preexisting industrial uses may render any incremental PFAS effects more difficult to isolate. Analysis of the area is further complicated by the presence of two known PFAS plumes and a chlorinated solvents plume as well as separate plumes in the nearby populated areas of North Pole and Moose Creek. Given the geographic isolation of Fairbanks in central Alaska, a lack of substitution for housing also may have impacted sensitivity to environmental considerations.

No observable impact was found for homes proximate to PFAS in Madison, Wisconsin. In the linear model (Exhibit 4), the most-proximate homes experienced no statistically significant differences in growth rates, relative to homes more distant. However, for the log specification (Exhibit 3), proximate homes experienced relatively higher prices in the period after the assumed awareness date—a finding which is statistically significant at better than the 5% level.

The positive outperformance of price trends for the proximate homes in Wisconsin is surprising, but it is notable that in the annual year coefficients (which are designed to capture broader market time trends, regardless of proximity) display some of the strongest rebounds after the awareness date when compared to the other areas studied. In other words, it is possible that strong positive trends in the market can outweigh concerns about environmental contamination. Put simply, a heated seller's market may lead to a pool of buyers who are less sensitive to such issues. However, testing this hypothesis is beyond the scope of this study.

Mather, California, is the exception to the lack of diminution found in the other areas. In both the linear and logarithmic models, prices of homes within 1.5 miles of the source point of contamination sold at discounts compared to homes between 1.5 miles and 10 miles away. While these measured discounts were not large (about 3.4% of property value), both were statistically significant at better than 1% level. Yet, as mentioned previously, other environmental factors complicate the analysis for Mather, as this source site was already a Superfund site (listed in 1987) and affected by airport noise prior to the discovery of PFAS.

Finally, findings in Mesa, Arizona, were mixed. While the linear model suggests a negative and statistically significant pricing effect, the log model shows no difference whatsoever between proximate and distant properties. Generally (though not always) results from logarithmic models tend to be more robust to outliers than linear ones. The contrasting effects between linear and log models may signify extreme sales in the data. While all the linear models excluded any outlier observations that exhibited absolute residuals of greater than three standard deviations (thus excluding approximately the most extreme 5% of sales in the data), it is still possible that substantial variation of property characteristics in the area are driving differences between the two specifications.

Reconciling the differences between logged and non-logged versions of the model for each area, the results were generally found to be similar. Dalton, Mesa, and Fairbanks, for example, had insignificant effects for either specification. Madison had positive effects under both specifications, although only one of these (the log specification) was statistically significant. Mather, meanwhile, was statistically significant and negative for both. Specifications involving logged dependent variables are often perceived as being more robust to the presence of outliers. The consistency in results between log and non-logged specifications suggests that individual sale outliers for any of these areas are not a concern.

If so, such dissimilar findings may indicate a lack of credibility of aggregate regression modeling for this area. This would imply a need for a more geographically focused study for Mesa—that is, a more careful delineation of the various submarket areas within Mesa via personal inspection of the affected area(s), with the advice of a local expert appraiser informing this process. Alternatively, it may indicate that PFAS effects are specific to the region impacted, as well as other event-specific information, such as the extent of contamination and method of conveyance. At the least, these results indicate the need for any analyses and conclusions regarding environmental risk from PFAS to be specific to the region studied and not applied as a one-size-fits-all opinion about diminution or lack thereof.

Alternative Considerations: Subject and Control Area Buffer Zones

While the Subject and Control Area boundaries are clearly delineated, they may not necessarily correspond to the area that is truly impacted. A more credible analysis of the market area would likely involve delineation according to a recognized zone of contamination, such as a plume map. The lack of any mapping is a limitation of this study.

One approach to ameliorating this concern is to define a buffer area between the Subject and Control Areas. This helps to eliminate sale observations that may exhibit "bleed-through," or ambiguity about whether the home is impacted or not.[46] To that end, the regressions were reestimated but excluded any sales that were in a buffer zone or a specific circular region between Subject and Control. Three alternative buffer zones were used with a 0.25 (1.50–1.75 miles), 0.50 (1.50–2.00 miles), and 0.75 (1.50–2.25 miles) radius. Sales within these radial regions were removed from the analysis, and the regressions reestimated. These effects, presented in Exhibit 5, indicate that bleed-through in the precise definition between Subject and Control does not impact the previously summarized results. Decreased property values for Subject Area sales relative to Control Area sales in Mather, for example, remain consistent at between approximately 2.4% and 2.5%, regardless of the choice of cutoff distance for the buffer zone.

46. We thank an anonymous referee for this suggestion.

Exhibit 3 Log Model Regression of Sale Prices

Characteristic	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
Living Area (SF)	0.000***	0.000***	0.000***	0.001***	0.000***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Bedrooms	–0.003	–0.017**	–0.043***	–0.053***	—
	[0.496]	[0.015]	[0.000]	[0.000]	
Total Baths	0.178***	0.150***	0.045***	0.064***	0.170***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Building Age	–0.005***	–0.007***	–0.000***	0.002***	0.001***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]
Lot Size (SF)	0.000***	0.000	–0.000***	0.000***	0.000***
	[0.000]	[0.540]	[0.000]	[0.000]	[0.000]
Subject Sale	–0.073**	–0.223	–0.192***	–0.009*	–0.318***
	[0.019]	[0.165]	[0.000]	[0.096]	[0.000]
After	0.089***	–0.738**	0.116***	–0.050***	0.099***
	[0.000]	[0.011]	[0.000]	[0.000]	[0.000]
Subject, After	0.023	0.191	0.033**	–0.023***	0.017
	[0.486]	[0.252]	[0.046]	[0.001]	[0.805]
2006.SaleYear	–0.007	0.040	0.305***	–0.023***	0.098***
	[0.749]	[0.505]	[0.005]	[0.000]	[0.000]
2007.SaleYear	–0.075***	–0.213	0.302***	–0.181***	0.037*
	[0.000]	[0.114]	[0.006]	[0.000]	[0.057]
2008.SaleYear	–0.181***	–0.388***	0.275**	–0.681***	–0.279***
	[0.000]	[0.000]	[0.012]	[0.000]	[0.000]
2009.SaleYear	–0.327***	–0.455***	0.234**	–0.830***	–0.465***
	[0.000]	[0.001]	[0.032]	[0.000]	[0.000]
2010.SaleYear	–0.338***	0.204***	0.238**	–0.821***	–0.517***
	[0.000]	[0.000]	[0.029]	[0.000]	[0.000]
2011.SaleYear	–0.472***	–0.647***	0.202*	–0.933***	–0.580***
	[0.000]	[0.000]	[0.064]	[0.000]	[0.000]
2012.SaleYear	–0.474***	–0.451***	0.198*	–0.852***	–0.406***
	[0.000]	[0.000]	[0.070]	[0.000]	[0.000]

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Exhibit 3 (*continued*)

Characteristic	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
2013.SaleYear	–0.429***	–0.815***	0.242**	–0.540***	–0.262***
	[0.000]	[0.000]	[0.027]	[0.000]	[0.000]
2014.SaleYear	–0.313***	–0.177**	0.282***	–0.415***	–0.212***
	[0.000]	[0.025]	[0.010]	[0.000]	[0.000]
2015.SaleYear	–0.253***	–0.686***	0.312***	–0.325***	–0.134***
	[0.000]	[0.000]	[0.004]	[0.000]	[0.000]
2016.SaleYear	–0.176***	–0.135	0.374***	–0.171***	–0.200***
	[0.000]	[0.419]	[0.001]	[0.000]	[0.000]
2017.SaleYear	–0.137***	0.364	0.455***	–0.080***	–0.136***
	[0.000]	[0.248]	[0.000]	[0.000]	[0.000]
2018.SaleYear	–0.035***	0.987***	0.504***	–0.015***	–0.059***
	[0.009]	[0.001]	[0.000]	[0.000]	[0.000]
2019.SaleYear	—	1.052***	0.441***	—	—
		[0.000]	[0.000]		
Constant	10.970***	11.801***	11.455***	11.952***	11.857***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Observations	11,448	1,350	37,936	149,554	24,016
Adjusted *R*-squared	0.684	0.658	0.598	0.722	0.787

Note: An additional year fixed effect (2019) was dropped from the analysis in three of the specifications, because of collinearity between year fixed effects and the "After" categorical fixed effect. High Variance Inflation Factor (VIF) scores for Mesa meant that the number of bedrooms variable was dropped for this model. (For the other areas, all VIF scores were below 10.)

This table regresses the natural log of sale prices of residential arm's-length home sales on various property and sale characteristics, as well as variables to identify PFAS proximate (Subject) hedonic effects. Sale outliers, as measured by an absolute standardized residual of greater than 1.96, are excluded from the analysis. Robust standard errors are included.

***, **, and * represent (two-tailed) significance at greater than a 1%, 5%, and 10% significance level, respectively.

Exhibit 4 Linear Model Regression of Sale Prices

Characteristic	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
Living Area (SF)	67.151***	78.194***	135.146***	200.602***	69.329***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Bedrooms	–207.716	–2,567.396	–15,111.321***	–28,538.729***	—
	[0.766]	[0.137]	[0.000]	[0.000]	
Total Baths	27,089.232***	40,049.164***	5,145.110***	18,211.914***	48,012.449***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Building Age	–28.693	–1,496.425***	–10.390***	1,337.064***	1,540.335***
	[0.158]	[0.000]	[0.000]	[0.000]	[0.000]
Lot Size (SF)	0.034**	0.008	0.167	0.718***	1.663***
	[0.011]	[0.752]	[0.166]	[0.000]	[0.000]
Subject Sale	–9,926.426**	36,069.242	–42,818.305***	–3,873.818***	–25,015.756*
	[0.043]	[0.149]	[0.000]	[0.003]	[0.070]
After	32,630.029***	–98,419.328***	28,648.922***	–7,596.232***	67,092.086***
	[0.000]	[0.000]	[0.000]	[0.001]	[0.000]
Subject, After	6,061.518	–51,384.328*	1,734.006	–11,842.152***	–91,976.180***
	[0.240]	[0.056]	[0.795]	[0.000]	[0.000]
2006.SaleYear	12,018.277**	9,198.382	95,016.789***	–4,592.858	75,994.523***
	[0.019]	[0.464]	[0.002]	[0.125]	[0.000]
2007.SaleYear	–16,662.770***	–17,744.205	97,783.398***	–52,539.406***	16,135.470
	[0.000]	[0.373]	[0.001]	[0.000]	[0.201]
2008.SaleYear	–28,045.125***	–24,140.479	93,631.805***	–166,139.719***	–75,431.344***
	[0.000]	[0.125]	[0.002]	[0.000]	[0.000]
2009.SaleYear	–42,956.531***	–5,143.450	84,013.477***	–192,889.219***	–137,263.562***
	[0.000]	[0.754]	[0.006]	[0.000]	[0.000]
2010.SaleYear	–42,561.309***	40,499.590***	84,984.992***	–195,469.109***	–158,165.344***
	[0.000]	[0.000]	[0.006]	[0.000]	[0.000]
2011.SaleYear	–60,563.473***	–131,034.109***	78,874.820**	–213,133.828***	–169,909.609***
	[0.000]	[0.000]	[0.010]	[0.000]	[0.000]
2012.SaleYear	–62,210.305***	–49,190.941***	75,128.336**	–202,762.984***	–128,159.570***
	[0.000]	[0.000]	[0.014]	[0.000]	[0.000]

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Exhibit 4 (*continued*)

Characteristic	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
2013.SaleYear	–50,474.754***	–79,863.766***	86,297.969***	–140,698.359***	–78,137.766***
	[0.000]	[0.000]	[0.005]	[0.000]	[0.000]
2014.SaleYear	–42,910.801***	–38,764.969**	97,836.414***	–115,466.266***	–69,474.086***
	[0.000]	[0.018]	[0.001]	[0.000]	[0.000]
2015.SaleYear	–36,542.023***	–126,627.812***	104,434.586***	–92,281.133***	–39,650.410***
	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]
2016.SaleYear	–28,764.400***	6,461.496	117,659.641***	–59,917.734***	–90,935.109***
	[0.000]	[0.791]	[0.000]	[0.000]	[0.000]
2017.SaleYear	–24,688.930***	81,859.773***	142,441.031***	–31,237.049***	–56,546.207***
	[0.000]	[0.007]	[0.000]	[0.000]	[0.000]
2018.SaleYear	–7,221.327***	158,420.281***	149,905.938***	–3,597.406***	–19,993.586***
	[0.003]	[0.000]	[0.000]	[0.010]	[0.000]
2019.SaleYear	—	175,542.547***	135,290.188***	—	—
		[0.000]	[0.000]		
Constant	37,612.191***	81,941.016***	–24,367.633	63,943.363***	18,129.969
	[0.000]	[0.000]	[0.427]	[0.000]	[0.190]
Observations	11,898	1,374	39,436	158,384	25,018
Adjusted *R*-squared	0.645	0.623	0.520	0.639	0.605

Notes: An additional year fixed effect (2019) was dropped from the analysis in three of the specifications, because of collinearity between year fixed effects and the "After" categorical fixed effect. High Variance Inflation Factor (VIF) scores for Mesa meant that the number of bedrooms variable was dropped for this model. (For the other areas, all VIF scores were below 10.)

This table regresses dollar market sale prices of residential (arm's-length) home sales on various property and sale characteristics, as well as variables to identify PFAS proximate (Subject) hedonic effects. Sale outliers, as measured by an absolute standardized residual of greater than 1.96, are excluded from the analysis. Robust standard errors are included.

***, **, and * represent (two-tailed) significance at greater than a 1%, 5%, and 10% significance level, respectively.

Exhibit 5 Regression Sensitivity Analysis—Increasing the Control Buffer Zone

Radius (Mi.)	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
1.75	0.017	0.199	0.029	-0.024***	0.017
	[0.603]	[0.231]	[0.204]	[0.001]	[0.801]
2.00	0.01	0.191	0.032	-0.025***	0.018
	[0.761]	[0.255]	[0.172]	[0.000]	[0.795]
2.25	0.007	0.189	0.032	-0.025***	0.018
	[0.838]	[0.261]	[0.175]	[0.000]	[0.793]

Radius (Mi.)	Dalton, GA	Fairbanks, AK	Madison, WI	Mather, CA	Mesa, AZ
1.75	3,188.96	-48,351.949*	1,552.517	-12,031.614***	-91,989.820***
	[0.449]	[0.072]	[0.872]	[0.000]	[0.000]
2.00	2,408.49	-50,413.914*	1,286.06	-12,241.225***	-91,751.539***
	[0.556]	[0.062]	[0.895]	[0.000]	[0.000]
2.25	651.674	-51,556.160*	384.181	-12,328.850***	-91,753.219***
	[0.872]	[0.059]	[0.969]	[0.000]	[0.000]

***, **, and * represent (two-tailed) significance at greater than a 1%, 5%, and 10% significance level, respectively.

Alternative Considerations: Narrowing the Control Area Boundary Cutoff

One additional consideration is the size of the Control Area; at 10 miles, the Control Area is quite large. A truly credible study would likely devolve the control area into separate components, each matched to distinct but comparable regions of the subject area. This is where an appraiser's expertise comes into play—for the comparables to truly be apples-to-apples an appraiser needs to use their local market knowledge as well as knowledge regarding the boundaries of potential contamination. Delineating Subject Area boundaries for each of the subject areas in this way is beyond the scope of this article, but one potential way to alleviate concern about difference in property characteristic variation within the Control Area is to tighten the range of what is defined as control. To that end, the analysis was reconducted considering alternatives to the 10-mile radius cutoff previously used. The Control Area is defined as at first, being within 1.5 and 4.0 miles outside of the center point of the contamination. Then the models are reestimated and diminution (if any) is recorded. This process is then repeated, each time extending the definition of the Control Area boundary by one mile. This process is repeated iteratively, each time recording the result for each Subject Area, all the way up to the original 10-mile radius.

The results are presented in Exhibit 6, and they are generally consistent across different definitions of what it means to be considered "control"—in particular, Mather remains statistically significant and negative. Notably, Fairbanks has, under the log specification, a positive effect for the Subject Area sales, when using shorter cutoff regions, which provides indication that not only is there no effect as a result of the PFAS discovery, but that potentially other amenities immediately within the Subject Area make it a more highly valued location relative to its immediate surroundings. Dalton has a slightly similar effect, although it is not statistically significant. Overall, though, the alternative Control Area definitions do not change substantively the conclusions of the analysis, either for any one of the areas

Exhibit 6 Regression Sensitivity Analysis—Reducing Control Area Distance Radii Boundaries

	Subject After (Log)				
Radius (Mi.)	**Dalton, GA**	**Fairbanks, AK**	**Madison, WI**	**Mather, CA**	**Mesa, AZ**
4.0	0.060*	0.288*	-0.002	0.043***	-0.011
	[0.087]	[0.053]	[0.943]	[0.000]	[0.794]
5.0	0.039	0.645***	0.013	0.068***	0.098***
	[0.244]	[0.000]	[0.568]	[0.000]	[0.001]
6.0	0.031	0.122	0.024	0.090***	-0.042
	[0.353]	[0.401]	[0.301]	[0.000]	[0.597]
7.0	0.026	0.164	0.018	0.081***	0.086***
	[0.424]	[0.253]	[0.459]	[0.000]	[0.004]
8.0	0.019	0.227	0.027	0.046***	0.024
	[0.570]	[0.129]	[0.265]	[0.000]	[0.630]
9.0	0.022	0.219	0.032	0.002	0.018
	[0.514]	[0.141]	[0.182]	[0.781]	[0.776]

	Subject After (No Log)				
Radius (Mi.)	**Dalton, GA**	**Fairbanks, AK**	**Madison, WI**	**Mather, CA**	**Mesa, AZ**
4.0	7,374.97	8,518.45	-1,929.88	-7,936.59***	-11,077.80
	[0.272]	[0.825]	[0.818]	[0.009]	[0.838]
5.0	10,476.32*	12,028.95	4,177.23	-12,563.44***	-28,572.40
	[0.071]	[0.752]	[0.655]	[0.000]	[0.620]
6.0	10,400.77*	-47,528.15*	5,706.96	-8,674.79***	-38,674.67
	[0.063]	[0.078]	[0.574]	[0.001]	[0.497]
7.0	9,466.79*	-44,959.39*	-6,827.10	-8,707.96***	-51,490.10
	[0.081]	[0.091]	[0.366]	[0.001]	[0.383]
8.0	5,540.52	-53,804.39*	2,978.11	-9,993.19***	-4,131.12
	[0.304]	[0.051]	[0.773]	[0.000]	[0.937]
9.0	5,490.80	-51,711.43*	2,619.22	-10,753.10***	-23,134.14
	[0.295]	[0.054]	[0.782]	[0.000]	[0.677]

***, **, and * represent (two-tailed) significance at greater than a 1%, 5%, and 10% significance level, respectively.

individually, or overall. Again, the property effects associated with PFAS discovery in an area are highly individualized to the specific region and circumstances of that market, and any conclusion about effects on home values from PFAS in one real estate market are not a one-size-fits-all conclusion for another.

Conclusions

PFAS are of concern to many parties in the real estate process as well as government agencies. Despite this, little to no research has questioned whether public awareness of PFAS has any measurable effects on property value, and, if so, how much. The case study results reported here find that the answer to this question is nuanced. Property value effects depend on market conditions, location, property characteristics, or some combination thereof.

Sellers and brokers are required to disclose adverse material facts and generally required to disclose environmental problems or adverse environmental conditions, with some exceptions. The five states studied in this research have seller disclosure laws that include environmental contamination, even if such knowledge can be gleaned broadly from market awareness via the media. Given the increased media exposure and frequency and intensity of discussions in the United States over PFAS and PFOA, it is expected that disclosure rules for these chemicals would be included within requirements over general contamination disclosure.[47]

Real estate damage theory argues that with mandatory seller disclosure and informed market participants, decreases in demand for non-source properties may ensue, causing downward pressure on price. Even if the science remains inconclusive as to PFAS and direct causality to various diseases, community outrage may still prevail. Location has always been the value driver, but with exotic contaminants, perception and politics can defy the science and adversely affect real estate markets. However, an appraiser is cautioned to rely on market evidence—as measured by relevant sales transactions—on whether perceptions of risk drive any differences in real estate value. For a credible opinion of value, any analysis of market transactions must take place using generally accepted appraisal methodology.

For the market transactions studied in this research, there was little quantitative evidence to support the idea that public awareness of PFAS in a community causes widespread declines in property value. In areas where diminution was found, preexisting environmental conditions complicate the analysis, and caution should be exercised in interpreting results; effects may depend on considerations such as characterization and the actionable level of contamination, approved and financed remedial action plans, the real estate market, assumptions, or previously documented environmental disamenities in the area.

Variation in the empirical effects of PFAS on house prices serves as a useful reminder that no single uniform conclusion can be drawn when it comes to contamination and real estate values. The results of this study should not be generalized across geographies or stages in the remediation lifecycle. Instead, the real estate expert needs to consider the environmental and real estate facts and community awareness that are specific to each market. Analysis of these or other factors may influence how PFAS pollution within the assessment phase of the remediation lifecycle can impact sale prices, necessitating analysis of local sales data, whenever possible.

47. The Biden Administration has refocused on environmental concerns. Pending legislation calls for the EPA to move the compounds from the category of "Contaminants or Chemicals of Emerging Concern (CECs)," to designate the constituents as hazardous substances. With the establishment of the EPA Council on PFAS, a commitment for PFAS limits in wastewater discharges, a long list of proposed stand-alone legislation on both the federal and state levels, and announcements of targeted cleanups of contaminated groundwater and soils, there will be increased market awareness of PFAS, especially on a state level. See discussion at EPA, "PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024," https://bit.ly/3D3Wywq.

About the Authors

Orell C. Anderson, MAI, FRICS, ASA, is president of Strategic Property Analytics Inc., and specializes in real property damage economics. As a forensic appraiser and expert consultant, he has worked on some of the largest climate, environmental, and terrorist cases in recent times. He is co-chair of the American Bar Association's Litigation Subcommittee on Environmental Damages and Eminent Domain. His research on environmental contamination has been published by the International Right of Way Association, the American Bar Association, and the Appraisal Institute; he also is the coauthor of *Real Estate Damages: An Analysis of Detrimental Conditions* and *Real Estate Damages: Applied Economics and Detrimental Conditions* (second edition). **Contact: orell@strategicpropertyanalytics.com**

Chris Yost-Bremm, PhD, is an assistant professor of finance at San Francisco State University, and he has significant experience, both academic and professional, in analyzing the impacts of environmental contamination. Yost-Bremm has published real estate and financial valuation work in numerous academic journals, including *The Appraisal Journal*, *The Journal of Behavioral Finance*, *Cities*, *The North American Journal of Economics and Finance*, *The Review of Behavioral Finance*, and *The Journal of Computer Information Systems*. His 2018 study that measured the impacts of environmental contamination on income capitalization rate risk premiums and sale prices for commercial properties in Southern California received *The Appraisal Journal*'s Richard U. Ratcliff Award for the most outstanding original academic article. Yost-Bremm holds a PhD in finance from Texas A&M University, an MBA from California State University (with distinction), and undergraduate degrees in management, engineering, and international economics (with honors). **Contact: cyb@sfsu.edu**

Stephen G. Valdez is the president of Delta Valuation Inc., an appraisal and consulting firm with a specialty in complex property valuation and real estate damages. His practice is international, including iconic properties, highly publicized disasters, and an array of detrimental conditions. He is the coauthor of the *Valuation of Environmentally Contaminated Real Estate* course for the International Right of Way Association. He has published several articles in legal and valuation journals and is a noted contributor to authoritative texts on the valuation of detrimental conditions in real estate. **Contact: steve@valueofdelta.com**

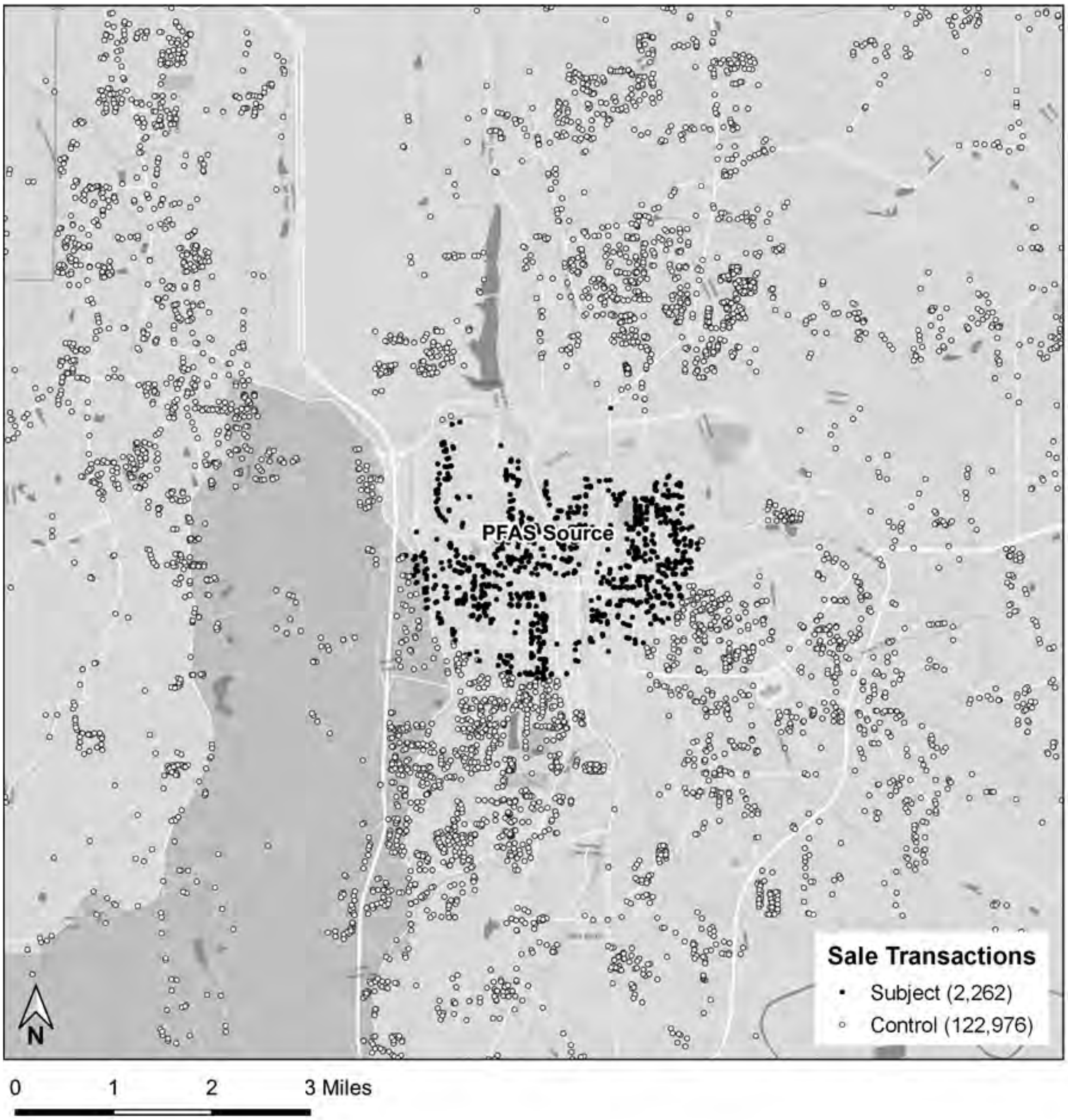
Jason Borras has provided appraisal-related consulting, research, and analysis for litigation or negotiations concerning environmental contamination and eminent domain, including single-family residential, residential subdivisions, mobile home parks, vacant land, industrial, commercial, and special-use properties. **Contact: jsn_borras@yahoo.com**

Tara Harder began her career mapping glacial velocities in Greenland before focusing full time on providing research for litigation support. In 2018, she started Pinpoint GIS Specialists and has been working on geospatial projects ever since. Harder holds a BA in environmental science from the University of California, Irvine, and a professional GIS certificate from Michigan State University. **Contact: tara@pinpointgis.com**

SEE NEXT PAGE FOR APPENDIX >

Appendix PFAS Case Study Areas

Figure 1 Dalton, Georgia

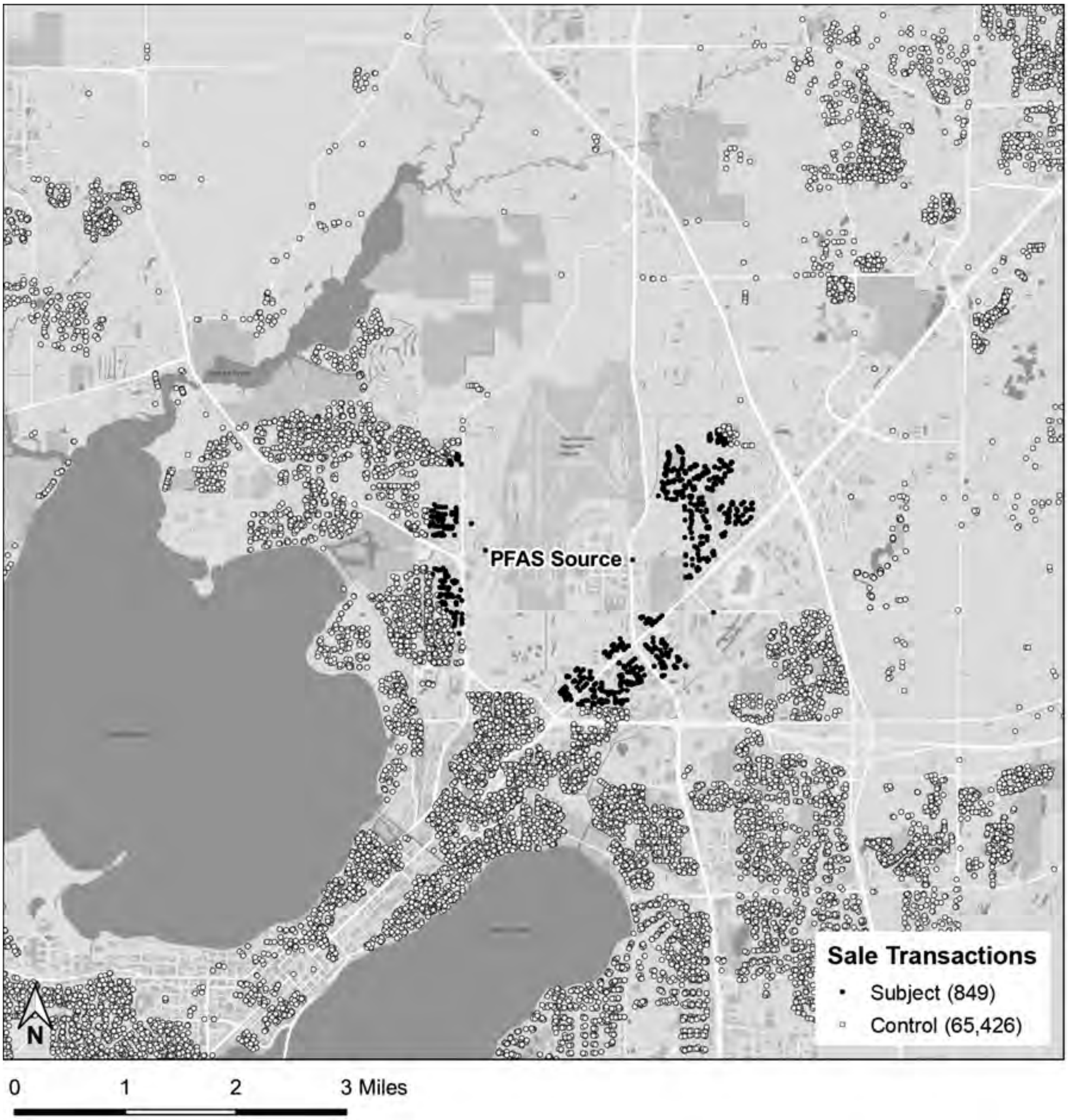


Appendix (*continued*)

Figure 2 Fairbanks, Alaska

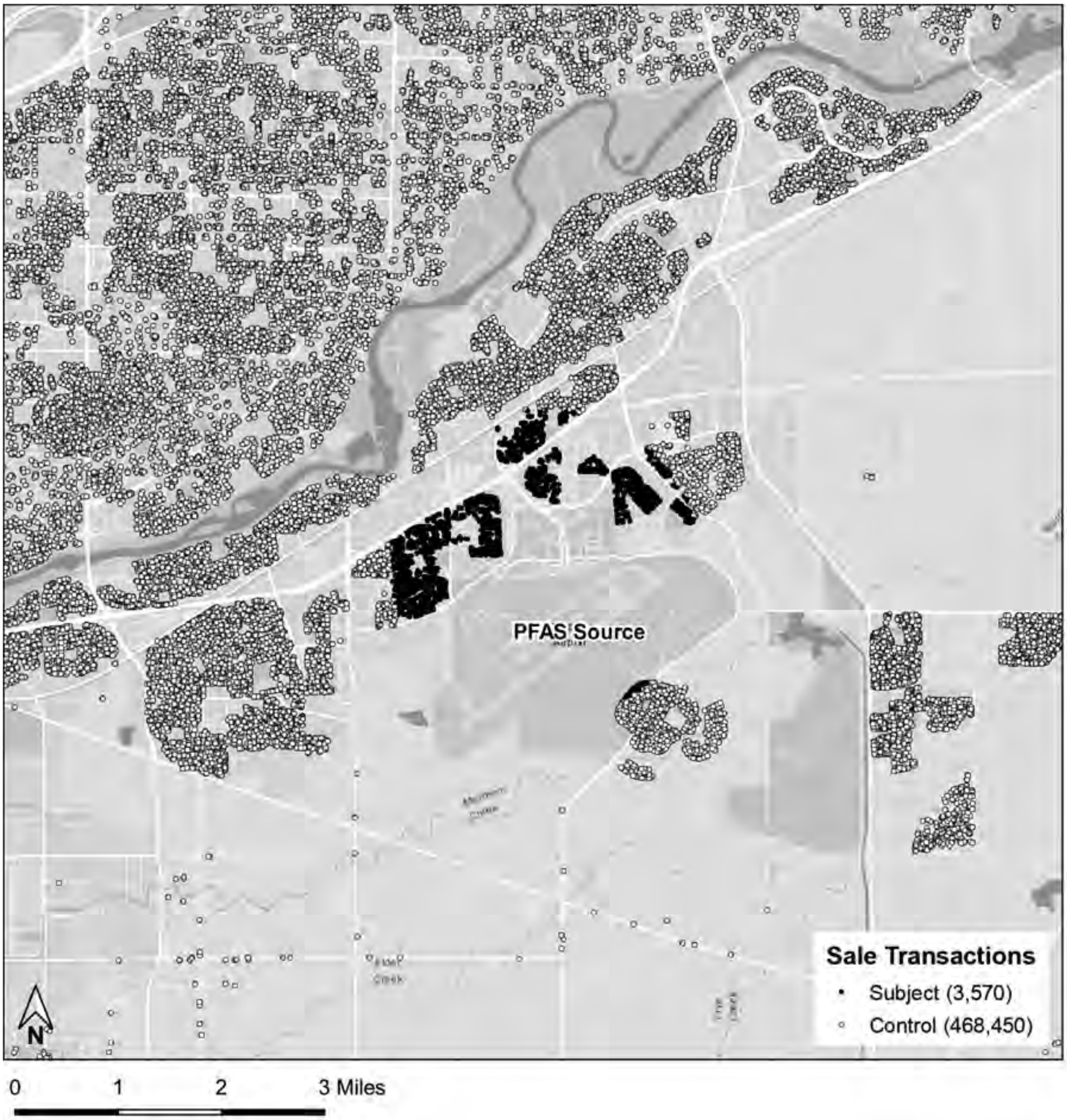
Appendix (*continued*)

Figure 3 Madison, Wisconsin



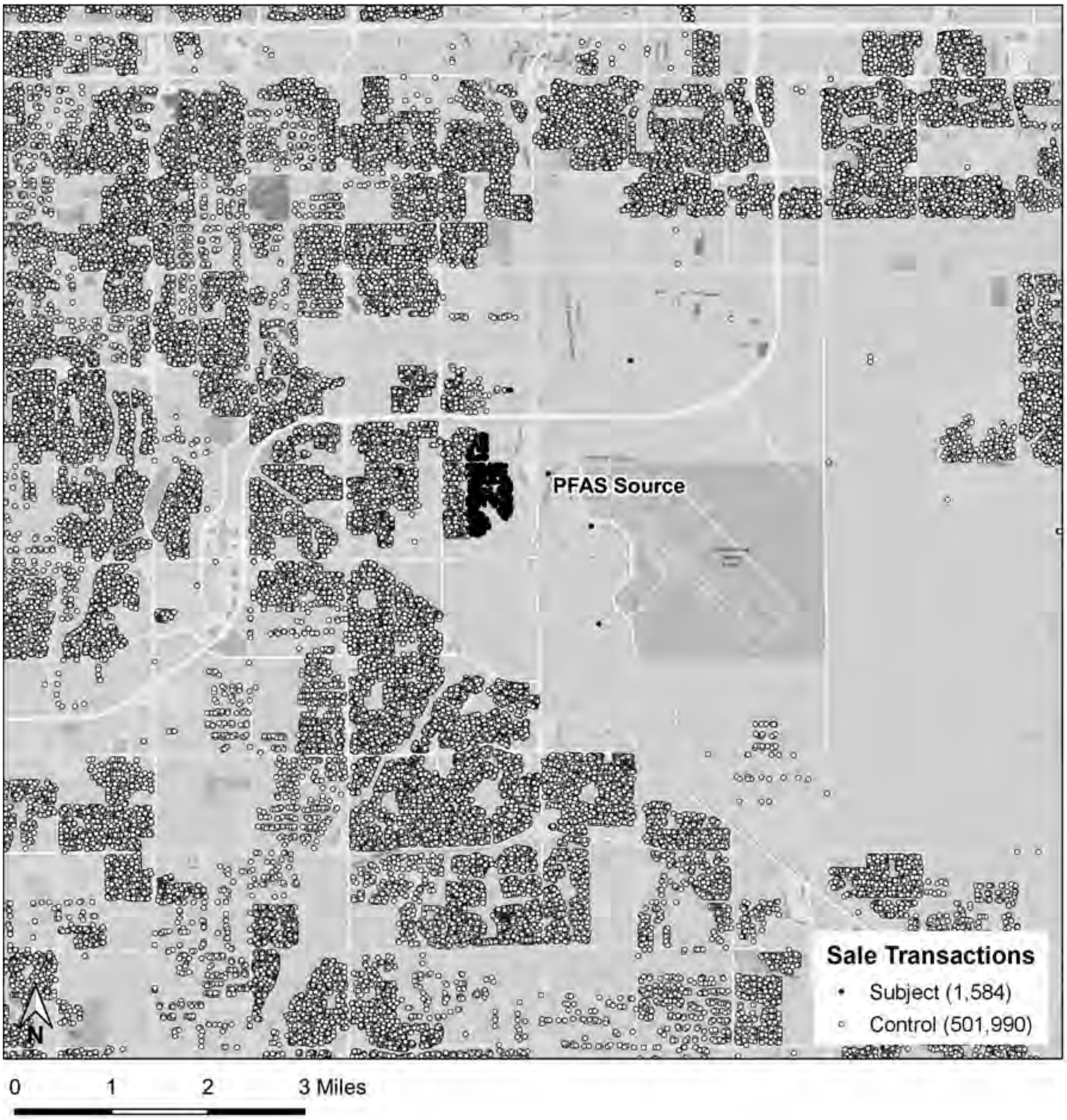
Appendix (*continued*)

Figure 4 Mather, California



Appendix (*continued*)

Figure 5 Mesa, Arizona



Additional Resources

Suggested by the Y. T. and Louise Lee Lum Library

Appraisal Institute

- ***The Appraisal of Real Estate*, 15th ed., Chap. 12 "Land and Site Description"**
- **Guide Note 6: "Consideration of Hazardous Substances in the Appraisal Process"**
- **Lum Library [Login required]**
  - Knowledge Base Information Files—Real estate damages
  - *Diminution Valuation Assignments: Enhance the Importance of Highest and Best Use* (Conference presentation, 2019)

US Environmental Protection Agency

- **"PFAS Explained"**
  https://www.epa.gov/pfas/pfas-explained
- **"PFAS Resources, Data and Tools"**
  https://www.epa.gov/pfas/pfas-resources-data-and-tools
- **"US State Resources about PFAS"**
  https://www.epa.gov/pfas/us-state-resources-about-pfas