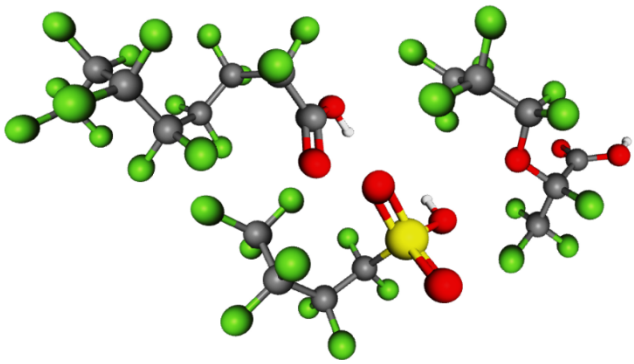
Groundwater Fact Sheet
PFAS



Constituent of Concern

Per- and poly – fluoroalkyl substances (PFAS)

Synonym

"Forever chemicals"

Compounds Include

PFOA, PFOS, PFNA, HFPO-DA (or GenX Chemicals), PFHxS, PFBS, etc.

Chemical Formula

PFOA	$C_8HF_{15}O_2$
PFOS	$C_8HF_{17}O_3S$
PFNA	$C_9HF_{17}O_2$
HFPO-DA	$C_6HF_{11}O_3$
PFHxS	$C_6HF_{13}O_3S$
PFBS	$C_4HF_9O_3S$
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CAS Number

PFOA	335-67-1
PFOS	1763-23-1
PFNA	375-95-1
HFPO-DA	13252-13-6
PFHxS	355-46-4
PFBS	375-73-5
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Summary

On March 14, 2023, the U.S. Environmental Protection Agency (EPA) announced the proposition of Maximum Contaminant Levels (MCL) in drinking water for six per- and polyfluoroalkyl substances (PFAS) including perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as GenX Chemicals), perfluorohexane sulfonic acid (PFHxS), and perfluorobutane sulfonic acid (PFBS). The EPA is also proposing to use a 'Hazard Index' for mixtures of PFHxS, HFPO-DA, PFNA, and PFBS since their known co-occurrence toxic effects in drinking water. The California State Water Resources Control Board (State Water Board) issued Notification (NL) and Response Levels (RL) for four PFAS in drinking water (PFOA, PFOS, PFHxS, and PFBS) based on their toxicity for human consumption. NL and RL are non-regulatory advisory levels for chemicals without MCL. Public water systems (PWS) are required to notify customers of the PFAS detection, notify governing bodies of the PFAS NL exceedance, and notify customers of the RL exceedance if the water source is not removed from service (or provided treatment).

The EPA defines PFAS as a class of over 12,000 man-made fluorinated organic compounds containing at least one fully fluorinated carbon atom. They have been widely used in industry and consumer products since the 1940s and are long lasting chemicals, meaning they break down very slowly over time or only under extreme conditions (e.g., over 900 ?C). PFAS can be used in many consumer products, including cleaners, textiles, leather, paper, paints, fire-fighting foams, and wire insulation. Groundwater contamination by PFAS is often associated with fire response sites, industrial/manufacturing sites, and secondary receivers of PFAS (e.g., landfills and wastewater treatments plants). Certain PFAS can accumulate and stay in the human body for long periods of time. There is evidence that exposure to PFAS can lead to adverse health outcomes in humans.

Based on State Water Board data from 2018 to 2023, 654 active PWS had at least one detection of a PFAS compound above the NL (of 2,558 wells tested, 937 detections). PFAS detections above a NL in PWS were primarily found in Los Angeles (193 wells), Orange (80 wells), and Riverside (69 wells) counties.

Revised January 2024

REGULATORY WATER QUALITY LEVELS[1] PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)			
Compound	**Type**	**Agency**	**Concentration**
PFOA	Proposed MCL[2]	EPA[3]	4 ng/L (nanograms per liter)
	Proposed MCLG[2]	EPA[3]	Zero
	Cancer risk factor (1/10[6])[4]	OEHHA[5]	0.1 ng/L
	State NL[7]	State Water Board[6]	5.1 ng/L
	State RL[8]	State Water Board[6]	10 ng/L
PFOS	Proposed MCL [b]	EPA[3]	4 ng/L
	Proposed MCLG [b]	EPA[3]	Zero
	Cancer risk factor (1/10[6])[4]	OEHHA[5]	0.4 ng/L
	State NL[7]	State Water Board[6]	6.5 ng/L
	State RL[8]	State Water Board[6]	40 ng/L
PFHxS	State NL[7]	State Water Board[6]	3 ng/L
	State RL[8]	State Water Board[6]	20 ng/L
PFBS	State NL[7]	State Water Board[6]	500 ng/L
	State RL[8]	State Water Board[6]	5000 ng/L
PFNA, PFHxS, PFBS, and HFPO-DA	Proposed Hazard Index (HI)[9] MCL	EPA[3]	1.0 (unitless)

[1]These levels are generally related to drinking water. Other water quality levels may exist.

[2]MCL (Maximum Contaminant Level) and MCLG (Maximum Contaminant Level Goal) are proposed enforceable levels in drinking water and health-based, non-enforceable levels, respectively.

[3]EPA - United States Environmental Protection Agency.

[4]Cancer risk factors represent concentrations in drinking water that would not pose more than a one in one million cancer risk over a lifetime.

[5]OEHHA - California Office of Environmental Health Hazard Assessment.

[6] State Water Resources Control Board.

[7]The NL (Notification Level) is the level of a drinking water contaminant that does not pose a significant health risk but, when exceeded, warrants notification to a water system's governing body and other specified entities. NL are only for the ingestion of drinking water and do not take into consideration possible dermal or inhalation exposures resulting from typical household uses of water containing a specific constituent of concern.

[8]The RL (Response Level) is established in conjunction with NL and represents the concentration of a drinking water contaminant where additional steps, beyond notification, are recommended to reduce public exposure. For contaminants with cancer risk, the RL is calculated as 10 times the cancer risk factor. For contaminants with noncancer health risks or when data are insufficient to determine the cancer risk factor, a response level up to 10 times the NL is consistent with an acceptable margin of safety.

[9]EPA is proposing a Hazard Index MCL to limit any mixture containing one or more of PFNA, PFHxS, PFBS, and/or GenX Chemicals. The Hazard Index considers the different toxicities of PFNA, GenX Chemicals, PFHxS, and PFBS. For these PFAS, water systems would use a hazard index calculation to determine if the combined levels of these PFAS in drinking water pose a potential risk and require further action for that water system.

PFAS DETECTIONS IN PUBLIC WATER WELL SOURCES[10]	
Number of active public water wells with at least one NL exceedance[11]	654 of 2,558 wells tested (937 detections)
Top 3 counties with PFAS detections in public wells above the NL	Los Angeles (193 Wells), Orange (80 Wells), Riverside (69 Wells).

[10]Based on 2018-2023 data collected by the State Water Board at active PWS (groundwater sources). Data from private domestic wells are not regulated and not available. Data from PWS with less than 15 service connections are available if the PWS consistently serves 25 people daily for at least 6 months, or 25 people for at least 60 days, per year.

[11]The establishment of NL and RL does not require PWS to monitor for the contaminant. Some PWS, however, will sample constituents in addition to those contaminants for which there are MCL, and if those monitoring results indicate that a NL has been exceeded, the PWS must notify the governing body of the local agency.

ANALYTICAL INFORMATION			
Approved EPA methods		533[12]	537.1
Detection limit (ng/L)	PFOA	3.4	0.53
	PFOS	4.4	1.1
	PFNA	4.8	0.7
	HFPO-DA	3.7	1.9
	PFHxS	3.7	1.4
	PFBS	3.5	1.8
Notes		Extracts are analyzed by Liquid Chromatography with tandem mass spectrometry (LC-MS/MS).	
Known Limitations to Analytical Methods		Method interferences may be caused by contaminants in solvents, reagents (including reagent water), sample bottles and caps, and other sample processing hardware. All items such as these must be routinely demonstrated to be free from interferences by analyzing laboratory reagent blanks.	
Public Drinking Water Testing Requirements		The State Water Board Division of Drinking Water (DDW) can require active PWS to monitor and report state NL and RL exceedances for PFAS. If NL are exceeded, the PWS must comply with the statute's notification requirements[13].	

[12]Method 533 performance is represented by detection limits in terms of Lowest Concentration Minimum Reporting Levels (LCMRL). LCMRL is the lowest concentration for which the instrument recovery is predicted to fall between 50 and 150% with high confidence (99%). The LCMRL that laboratories can obtain depends on the instrumentation used.

[13]Exceedance of a RL is determined by a quarterly running annual average (QRAA) for PFOA, PFOS, PFBS, and PFHxS. The QRAA is the average of sample results taken at an individual source during the previous four calendar quarters; it is re-calculated each quarter using the most recent four quarters of results. If any sample would cause the QRAA to exceed a RL, the water source would exceed the RL. In the latter case, the PWS is required to provide treatment.

PFAS Occurrence

Anthropogenic Sources

PFAS are a class of manmade chemicals that contains over 12,000 compounds. A non-exhaustive evaluation of the uses of PFAS identified more than 200 use categories and subcategories for more than 1,400 individual PFAS. PFOA and PFOS are the most extensively produced and studied of these compounds and are very persistent in both the environment and human body. These compounds are used to make materials waterproof, non-stick, and resistant to stains. Examples include non-stick cookware, furniture, carpets, mattresses, clothing, paper, cleaning products, pesticides, pharmaceuticals and medical devices, coatings, rubber, plastics, and food packaging. Additional uses include fire suppression and friction modifiers for the aerospace, automotive, construction, and electronic industries. PFAS can also form as a degradation byproduct from other types of PFAS. Some PFAS, including PFOA and PFOS, have no longer been manufactured in the United States since the 2000s (voluntary phase-out program), except in some accepted industrial processes such as in semiconductors, printed circuits, aviation equipment, defense, pesticides, and solar panels. Although most of these compounds are no longer manufactured in the United States, other countries still produce PFOA and PFOS and products that contain them may be imported.

PFAS are commonly found in ground and surface water near facilities that use PFAS and in products that contain PFAS. Many contaminated areas are near facilities that use PFAS fire-fighting foam (known as Aqueous Film-Forming Foam or AFFF) for training, such as military bases, airports, and fire-fighting training centers. Also, PFAS can contaminate ground and surface water when products that contain PFAS are disposed of into landfills. As the products break down, PFAS linger in the soil and may seep into nearby water sources.

Natural Sources

PFAS are human made substances and are not found naturally in the environment.

History of Occurrence

PFAS were first synthesized in the late 1930s. Since the 1950s, many products commonly used by consumers and industry have been manufactured with or from PFAS, with peak production from 1970 to 2002.

In 2006, the EPA invited eight companies producing PFAS to join a global stewardship program with a purpose to:

- Achieve a 95 percent reduction in facility emissions, encompassing PFOA, precursor chemicals capable of transforming into PFOA and other related substances, as well as the levels of these chemicals present in products.
- Commit to working toward the elimination of these chemicals from emissions and products by 2015.

According to the EPA, all eight companies have met the program goals.

Manufacturers have also been developing replacement technologies, including reformulating longer-chain PFAS, or substituting them with nonfluorinated chemicals or shorter-chain PFAS. Some alternate PFAS include, but are not limited to, compounds produced with electrochemical fluorination and fluorotelomerization, such as fluorotelomer alcohols, PFBS, per- and polyfluoroalkylether acids (for example, HFPO-DA), and other types of PFAS.

Consistent sampling for PFAS in public supply wells started in 2013 after the introduction of the third Unregulated Contaminant Monitoring Rule (May 2012) by EPA. Since 2019, the DDW ordered mandatory PFAS testing for hundreds of water system sites near airports, landfills, chrome platers, bulk fuel terminals, refineries, and Department of Defense sites in California. Additionally, the U.S. Geological Survey Groundwater Ambient Monitoring and Assessment (USGS GAMA) Priority Basin Project began the analysis of 28 PFAS compounds in 2019, in both public and domestic supply wells across California.

Contaminant Transport Characteristics

There is a large variation in published data on chemical and physical properties of PFAS.

PFAS typically have a carbon-fluorine "tail" and a nonfluorinated "head" consisting of a polar functional group. The tail is hydrophobic and lipophobic, while the head groups are polar and hydrophilic. Because the head and the tail compete, partitioning to interfaces of environmental media such as soil/water, water/air, and water/organic co-contaminants (Non-Aqueous Phase Liquids, NAPL) can occur and affect their transport and fate in groundwater.

Studies have found that sorption to soil generally increases with increasing perfluoroalkyl tail length, while solubility increases with decreasing tail length. Other factors that affect PFAS mobility include pH, which varies by PFAS according to specific electrostatic charges.

Together with solubility, the resistance of most PFAS to biotic or abiotic degradation makes them environmentally mobile and persistent chemicals and can therefore be found world-wide and in all environmental media. PFAS have indeed been found from the Arctic to urban rainwater worldwide. Atmospheric transport has been shown to play an important role in global PFAS distribution. Once deposited, higher molecular weight PFAS show lower mobility but tend to bioaccumulate more. In different environments (landfills, oceans, and soils) different PFAS break down at different rates, creating various terminal end-products.

Remediation and Treatment Technologies

Resistance to chemical and biochemical degradation makes PFAS difficult to remove from soil and groundwater. The most frequently used cleanup techniques are still excavation and off-site disposal, and pump and treat systems. Other remediation technologies involving degradation techniques are currently being studied and have proven to be effective in destroying fluorochemicals, such as photocatalytic and photochemical oxidation and reduction, thermally induced reduction, and sonochemical pyrolysis.

The effectiveness of these methods depends upon the initial concentration of the constituent, background water chemistry, and PFAS physicochemical properties. PFAS remediation technologies are currently in a phase of rapid development.

Drinking Water and Wastewater Treatment

It is recognized that removing PFAS from drinking water can be an expensive proposition. Currently, three treatment processes can be very effective for PFAS removal (up to or above 99% removal): granular activated carbon (GAC), ion exchange resins, and high-pressure membrane systems. The exact percentage removal with a given technology will be dependent upon a variety of factors, including source water quality and water system characteristics. To prevent contaminant

breakthroughs, these technologies require periodical replacements or reactivation of the media used.

Processes found to be ineffective for the removal of PFAS (low or negative removal percentages) were biological treatment, chloramines, conventional treatment (comprised of the unit processes coagulation, flocculation, clarification, and filtration), hydrogen peroxide, ozone, ozone plus hydrogen peroxide, slow sand filtration, UV photocatalysis using titanium dioxide, and UV irradiation plus ozone. Negative removal values indicate that a study found a higher concentration in effluent water than in influent water, possibly due to the analytical uncertainties or the oxidation of PFAS compounds within the process.

Health Effect Information

Currently, much of the toxicity data available for PFAS are for PFOA and PFOS. Epidemiological studies have revealed associations between exposure to specific PFAS and a variety of health effects, including altered immune and thyroid function, liver disease, lipid and insulin dysregulation, kidney disease, adverse reproductive and developmental outcomes, and cancer. Concordance with experimental animal data exists for many of these effects. Research is ongoing to determine how different levels of exposure to different PFAS can lead to a variety of health effects. Research is also underway to better understand the health effects associated with low levels of exposure to PFAS over long periods of time, especially in children.

Additional research may change our understanding of the relationship between exposure to PFAS and human health effects.

Key Resources

1. Drinking Water Treatability Database https://tdb.epa.gov/tdb/findcontaminant
2. Evich, M.G., Davis, M.J.B., McCord, J.P., Acrey, B., Awkerman, J.A., Knappe, D.R.U., Lindstrom, A.B., Speth, T.F., Tebes-Stevens, C., Strynar, M.J., et al. Per- and Polyfluoroalkyl Substances in the Environment. Science 2022, 375. https://doi.org/10.1126/science.abg9065
3. Fenton S. E., Ducatman A., Boobis A., DeWitt J.C., Lau C., Ng C., Smith J.S., Roberts S.M. Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research. Environ. Toxicol. Chem., 2021. https://doi.org/10.1002/etc.4890
4. Glüge J., Scheringer M., Cousins I. T., DeWitt J. C., Goldenman G., Herzke D., Lohmann R., Ng C. A., Trier X., Wang Z. An overview of the uses of per- and polyfluoroalkyl substances (PFAS). Environ Sci Process Impacts. 2020 Dec 1;22(12):2345-2373. doi: 10.1039/d0em00291g. Epub 2020 Oct 30. https://pubs.rsc.org/en/content/articlelanding/2020/em/d0em00291g
5. Interstate Technology Regulatory Council (ITRC) - Fate and Transport of Per- and Polyfluoroalkyl Substances (PFAS), 2020. https://pfas-1.itrcweb.org/wp-content/uploads/2020/10/f_and_t_508_2020Aug.pdf
6. National Environmental Methods Index (NEMI). https://www.nemi.gov/home/
7. National Institute of Environmental Health Sciences – PFAS. https://www.niehs.nih.gov/health/topics/agents/pfc/index.cfm
8. State Water Board - GAMA GIS online tools. http://www.waterboards.ca.gov/water_issues/programs/gama/geotracker_gama.shtml
9. State Water Board - Per- and Polyfluoroalkyl Substances (PFAS) Investigation Sites, 2022. https://gispublic.waterboards.ca.gov/portal/home/item.html?id=a41fef8cff674ac8b5f2cf1844df543e
10. State Water Board - PFBS Notification Level Issuance, 2021. https://www.waterboards.ca.gov/drinking_water/programs/documents/pfbs_nl_issuance_03052021_final_signed.pdf
11. State Water Board - PFHxS Notification Level Issuance, 2022. https://www.waterboards.ca.gov/drinking_water/programs/documents/PFHxS-issuance.pdf
12. State Water Board – PFOA and PFOS Notification Level Issuance, 2020. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/pfos_and_pfoa/pfoa_nl_issuance_jan2020.pdf
13. State Water Board - Testing in California drinking water. https://www.waterboards.ca.gov/pfas/drinking_water.html#:~:text=In%20August%202019%2C%20DDW%20revised,PFOA)%20remained%20at%2070%20ppt.
14. State Water Board - Drinking Water Notification Levels https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/NotificationLevels.html
15. EPA – Contaminated Site Cleanup Information – PFAS, 2023. https://clu-in.org/contaminantfocus/default.focus/sec/Per-_and_Polyfluoroalkyl_Substances_(PFAS)/cat/Remediation_Technologies/
16. EPA - PFAS National Primary Drinking Water Regulation Rulemaking, 2023. https://www.federalregister.gov/documents/2023/03/29/2023-05471/pfas-national-primary-drinking-water-regulation-rulemaking#h-79
17. EPA - Proposed PFAS National Primary Drinking Water Regulation, 2023. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

18. EPA - Third Unregulated Contaminant Monitoring Rule, 2012 https://www.epa.gov/dwucmr/third-unregulated-contaminant-monitoring-rule
19. EPA - Understanding the PFAS National Primary Drinking Water Proposal Hazard Index, 2023. https://www.epa.gov/system/files/documents/2023-03/How%20do%20I%20calculate%20the%20Hazard%20Index._3.14.23.pdf
20. EPA – Master List of PFAS Substances https://comptox.epa.gov/dashboard/chemical-lists/PFASMASTER
21. USGS - Sampling for Per- and Polyfluoroalkyl Substances (PFAS) by the GAMA-PBP, 2021. https://pubs.er.usgs.gov/publication/fs20213028

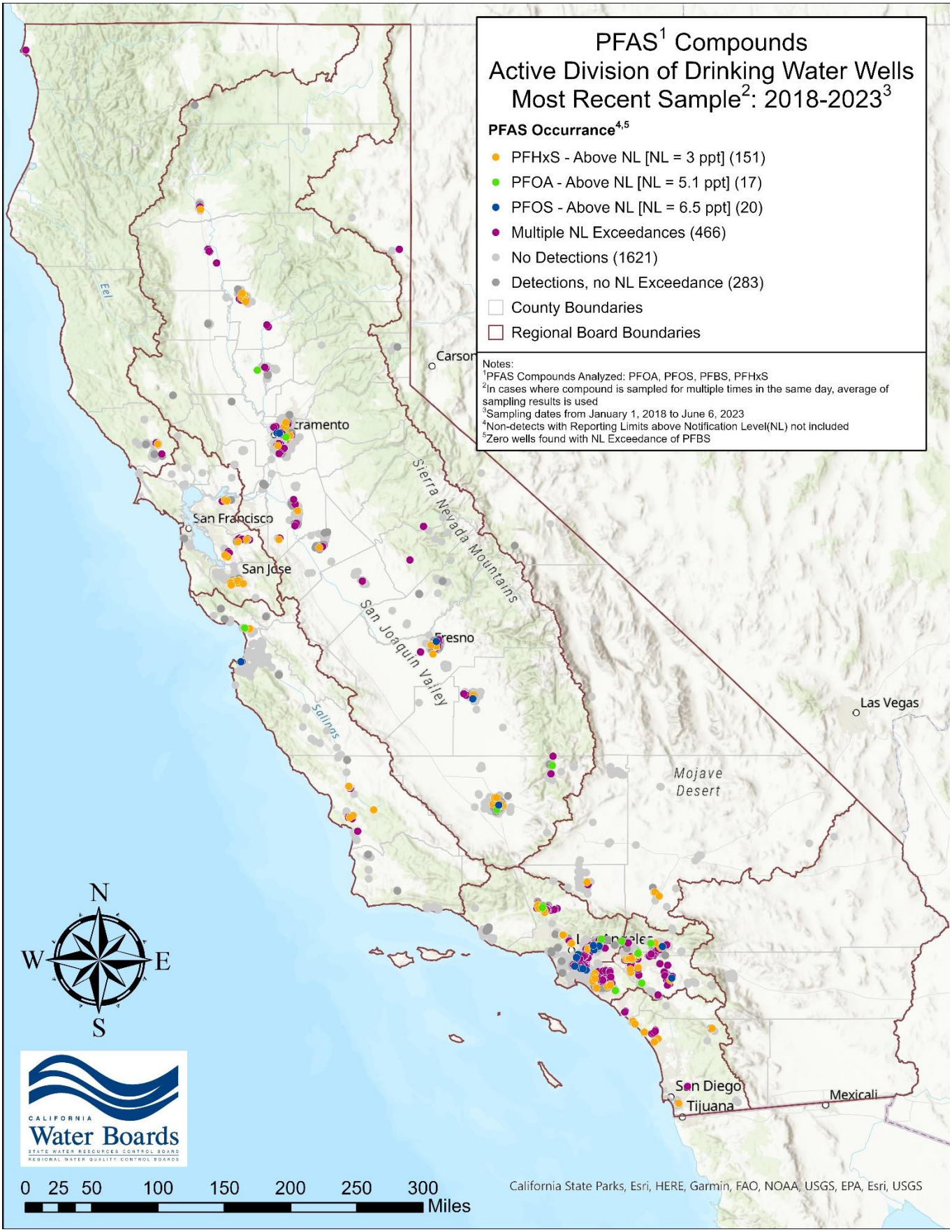

Figure 1. Active public drinking water wells with NL exceedances for PFOA, PFOS, PFBS, and PFHxS'. Most recent sampling (2018-2023) shown; 654 of 2,558 wells tested (937 detections). Data source: GAMA GIS.

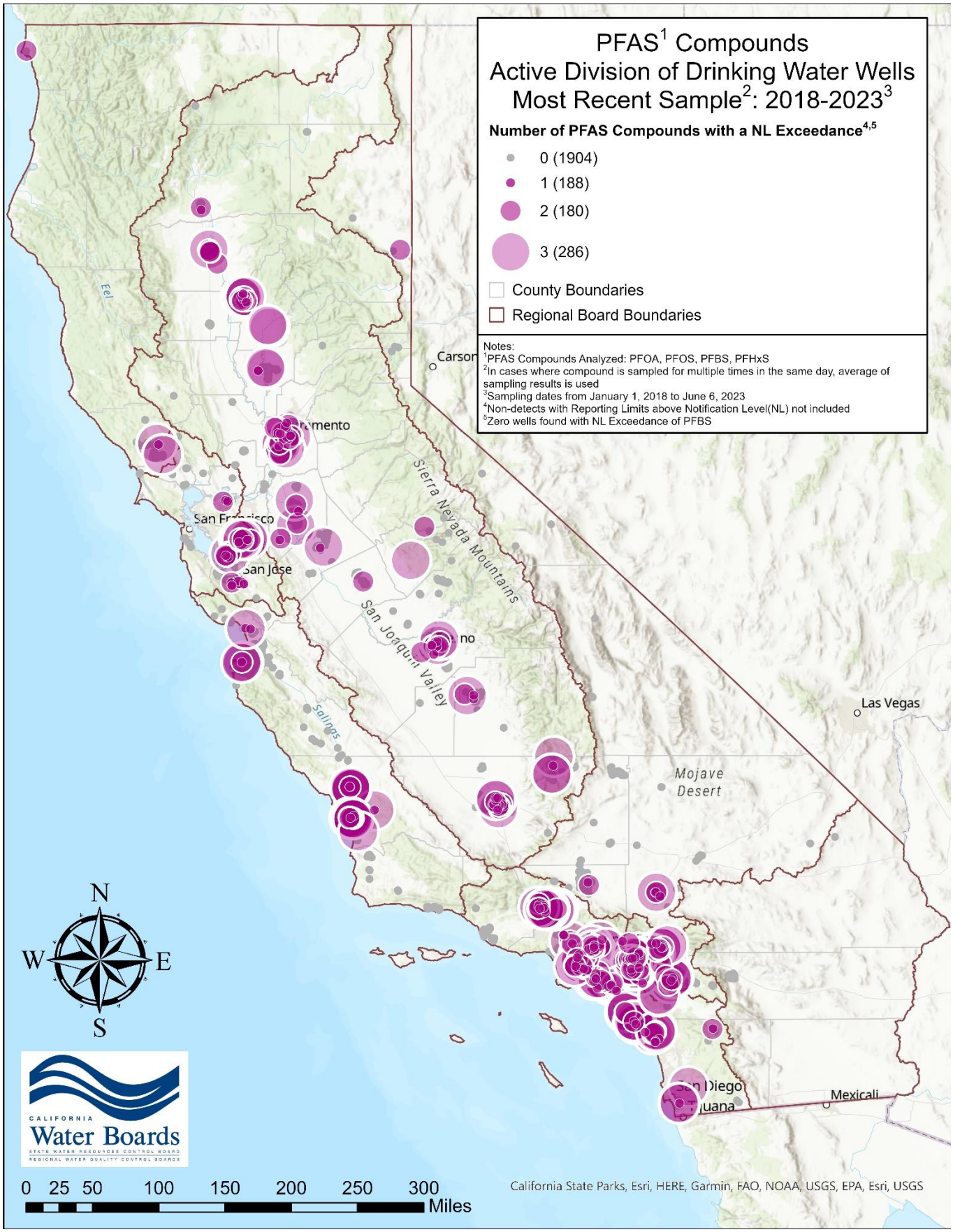

Figure 2. Active public drinking water wells with number of NL exceedances for PFOA, PFOS, PFBS, and PFHxS' per well. Most recent sampling between 2018-2023 shown. Data source: GAMA GIS.