# GROUNDWATER INFORMATION SHEET

# Radionuclides

*The purpose of this groundwater information sheet is to provide general information regarding a specific constituent of concern (COC). The information provided herein relates to wells (groundwater sources) used for public drinking water, not water served at the tap.*

| GENERAL INFORMATION | |
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| **Constituents of Concern** | Radionuclides: Uranium, Radon, Tritium, Strontium, Radium, Gross Alpha, Gross Beta. |
| **Aliases** | None |
| **Chemical Formula** | U, Ra, $^{3}$H, Sr-90, Rd, proton-neutron (α), electron (β) |
| **CAS Nos.** | Uranium-234/235/238 - 13966-29-5/15117-96-1/7440-61-1<br>Radon-222 - 14859-67-7<br>Radium-226/228 - 13982-63-3/15262-20-1<br>Gross Alpha - 12587-46-1<br>Gross Beta - 12587-47-2<br>Tritium - 10028-17-8<br>Strontium-90 - 10098-97-2 |
| **Storet Nos.** | Uranium - #28012<br>Radon-222 - #82303<br>Radium (226+228) - #11503<br>Gross Alpha - #01501<br>Gross Beta - #03501<br>Tritium - #82126<br>Strontium-90 - #13501 |
| **Summary** | There are many radioactive elements present in the environment. Radionuclides outlined in this Information Sheet include Uranium, Radon, Strontium, Radium, Tritium, and particles (e.g., gross alpha and beta) emitted from unstable (radioactive) elements. Maximum Contaminant Levels (MCLs) have been established by the California Department of Public Health (CDPH)[1] for uranium, strontium, radium, gross alpha, gross beta particle activity and tritium. The United States Environmental Protection Agency (US EPA) has established MCLs different from California for uranium, radon, strontium, tritium and gross beta (adopted by California) particle activity. EPA's MCLs for strontium and tritium are covered by gross beta activity.<br><br>Some level of radiation exposure is due to natural background sources (e.g., cosmic radiation, terrestrial, food, etc.). According |

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| **Summary (cont.)** | to the U.S. Nuclear Regulatory Commission the average natural background radiation dose in the United States is approximately 310 mrem/year. Different radioactive constituents will interact and damage biologic activity differently. As a result, some constituents have greater or lower MCLs than others. The most common radionuclides in California's groundwater are uranium and gross alpha.<br><br>**Uranium:** Between 2006 and 2016 (GeoTracker) uranium was detected above the MCL of 20 pCi/L in 280 public water wells with a maximum concentration of 378 pCi/L. MCL exceedances were most common in San Bernardino (56), Madera (34), Kern (27) and Fresno (27) counties.<br><br>**Gross alpha:** Between 2006 and 2016 gross alpha radioactivity was detected above the MCL of 15 pCi/L in 558 public water wells with a maximum concentration of 920 pCi/L. MCL exceedances were most common in San Bernardino (90), Kern (72), and Fresno (58) counties. |

[1]The California Department of Public Health Drinking Water Program was transferred to the State Water Resources Control Board Division of Drinking Water in July 2014.

| REGULATORY AND WATER QUALITY LEVELS[2] | | | |
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| **Constituent** | **Type** | **Agency** | **Concentration[3]** |
| Gross Alpha | MCL | US EPA & SWRCB-DDW[4] | 15 pCi/L |
| | DLR[5] | SWRCB-DDW | 3 pCi/L |
| Gross Beta | MCL (official) | US EPA & SWRCB-DDW | 4 mrem/year (dose) |
| | MCL[6] (trigger) | US EPA | 50 pCi/L |
| | DLR | SWRCB-DDW | 4 pCi/L |
| Radium (combined) | MCL | US EPA | 5 pCi/L |
| | DLR | SWRCB-DDW | 1 pCi/L |
| | PHG[7] (Ra-226) | SWRCB-DDW | 0.05 pCi/L |
| | PHG (Ra-228) | SWRCB-DDW | 0.019 pCi/L |
| Radon | MCL[8](advisory) | US EPA | 4,000 pCi/L |
| | DLR | SWRCB-DDW | 100 pCi/L |
| Uranium | MCL | US EPA | 30 μg/L |
| | MCL | SWRCB-DDW | 20 pCi/L |
| | DLR | SWRCB-DDW | 1 pCi/L |
| Tritium | MCL | SWRCB-DDW | 20,000 pCi/L |
| | DLR | SWRCB-DDW | 1,000 pCi/L |
| Strontium-90 | MCL | SWRCB-DDW | 8 pCi/L |
| | DLR | SWRCB-DDW | 2 pCi/L |
| | PHG | SWRCB-DDW | 0.35 pCi/L |

[2]These levels generally relate to drinking water. Other water and air quality levels may exist. For further information, see *A Compilation of Water Quality Goals* (Marshack, 2016).

[3]Concentrations are reported in milirems (mrem) per year and in picocuries per liter (pCi/L). A 'rem' is a unit of measure describing how a specific type of radiation damages biologic tissue. A milirem is one thousandth of a rem. A curie is a standard unit of radioactivity, where 1 curie is the radioactivity associated with 1 gram of radium. A picocurie is one trillionth of a curie. There is no simple conversion between a curie and a rem.

[4]SWRCB-DDW –State Water Resources Control Board, Division of Drinking Water

[5]DLR = Detection Limit for Purposes of Reporting

[6]This MCL is no longer an official regulatory level, but is still in use as a trigger for EPA and SWRCB-DDW. If the trigger level is exceeded additional testing is required to determine the source of beta radiation and if the MCL has been exceeded.

[7]PHG = Public Health Goal

[8] MCL advisory level; there is no established requirement for radon monitoring. Level listed here represents proposed level by the US EPA for states that are taking action to reduce radon levels in indoor air by developing an enhanced indoor air program. California currently has an EPA-approved indoor air program.

| SUMMARY OF DETECTIONS IN PUBLIC GROUNDWATER SOURCES[9] | |
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| **Radionuclide Detection Type** | **Number of Active and Standby Public Sources** |
| Gross Alpha activities >15 pCi/L | 558 of 12,114 sources tested |
| Gross Beta activities >50 pCi/L | zero of 12,114 sources tested |
| Radium-226 activities >5 pCi/L<br>Radium-228 activities >5 pCi/L | 13 of 12,114 sources tested<br>7 of 12,114 sources tested |
| Radon activities >4,000 pCi/L | 6 of 12,114 sources tested |
| Uranium activities >20 pCi/L | 280 of 12,114 sources tested |
| Tritium activities > 20,000 pCi/L | zero of 12,114 sources tested |
| Strontium-90 activities > 8 pCi/L | zero of 12,114 sources tested |

[9]Based upon Division of Drinking Water data collected from 2006-2016 (GeoTracker).

| ANALYTICAL INFORMATION[10] | | |
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| **Method** | **Detection Limit** | **Note** |
| **Gross Alpha**: US EPA methods 900.0, 00-02 (drinking water), others | 1 pCi/L minimum detectable level | Detection limit may vary depending on sample volume, solids concentrations, counting system and time. |
| **Gross Beta**: US EPA methods 900.0 (drinking water), others | 0.5 pCi/L minimum detectable level | Detection limit may vary depending on sample volume, solids concentrations, counting system and time. |
| **Radium**: US EPA 903.0, 903.1, others | 0.1 pCi/L and up, 1 pCi/L minimum detectable level | Detection limit may vary depending on sample size, reagent used, instrument counting efficiency and time. |
| **Radon**: ASTM D5072, SM-7500 series | 1 pCi/L or less | Gas extraction method (D5072) is more accurate but more difficult and requires specialized equipment. |
| **Uranium**: US EPA 908.0, 908.1, others | 1 pCi/L to 0.03 pCi/L<br>1 pCi/L minimum detectable level | Roughly 15 methods are approved by the US EPA. Type of method selected depends on need. |
| **Tritium**: US EPA Method 906.0, others | 300 pCi/L minimum detectable level | There are eight total US EPA approved methods. |
| **Strontium-89** and **Strontium-90**: US EPA Method 905.0, others | 0.5 pCi/L minimum detectable level | A total of nine methods are approved by the US EPA. Some modifications may be required to measure for Sr-89. |

[10]The analytical methods here are only a partial list. For a full list of US EPA-approved analytical methods please see the references 10 and 11.

## OCCURRENCE

Radionuclides are naturally occurring elements of the Earth, and are present (usually at very low levels) in every substance and material on the planet, and may sometimes include several different isotopic version of the same element. Isotopes are atoms of an element with differing atomic masses (specifically, different numbers of neutrons). Different isotopes will have different radioactive decay properties. As a result, some isotopes may have established health regulatory levels, while others do not. An example is tritium, or $^{3}H$. Tritium is an isotope of hydrogen, with three neutrons. The SWRCB-DDW established a regulatory level of 20,000 pCi/L for this isotope. However, the most common isotope of hydrogen is $^{1}H$, with one neutron. This isotope of hydrogen is the most abundant element (and isotope) in the universe, is not radioactive, and poses no health risk.

Exposure to naturally occurring radioisotopes is caused by "background radiation". Some background radiation even comes from space. Most radiation detected in groundwater is the result of interactions with natural geologic materials that contain trace levels of radioactive isotopes. Radioactivity is a function of the abundance of radioisotopes and of the decay-rate of that radioisotope.

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| **Radium-226, 228** | Radium is a naturally occurring, silvery white metal formed by decay of uranium and thorium. Multiple isotopes occur at very low levels in virtually all rocks, soil, water, plants and animals. Ra-226 is an alpha emitter and has a half-life of about 1,600 years. Ra-228 is a beta emitter and has a half-life of 5.76 years. Radium decays to form isotopes of radioactive radon and stable lead. Before the risks of radium exposure were understood, mixtures of light emitting radium salts and phosphors were widely used in luminescent paints for clock dials and gauges. |
| **Radon-222** | Radon is a naturally occurring gas, and is a product of uranium decay. Radon occurs in groundwater and easily moves into the air. A radon concentration of 10,000 pCi/L in water results in a concentration of 1 pCi/L in the air. Radon is naturally present wherever uranium and radium concentrations in geologic materials are high, and tends to be abundant in granitic terrains and certain types of sedimentary deposits. Radon may accumulate in basements and enclosed areas where gases are trapped and air circulation is low. |
| **Uranium** | Uranium is a naturally occurring radioactive element in rocks, soil, water, plants, animals and humans. There are three main isotopes of uranium (U-234, U-235, and U-238). U-238 is a weakly radioactive metal, and contributes to low-level background radiation in the environment. U-238 has a very long half-life of 4.47 billion years. Enriched U-235 is used as fuel in nuclear reactors and in nuclear weapons. Depleted uranium, which is poor in U-235 but rich in U-238, is used by the military in tank armor, bullets, and missiles for its strength and density. Uranium is common in specific types of igneous, metamorphic, and sedimentary rocks. Recent research indicates that increased concentrations of uranium in groundwater are caused by mobilization of uranium present in soil with irrigation waters containing bicarbonates. Also, nitrate can mobilize |

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| | uranium through a series of bacterial and chemical reactions. |
| **Gross Alpha** | Alpha particles (α-particles) are a type of radiation emitted by some radionuclides. They consist of two protons and two neutrons. Their travel range is only a few centimeters. Once alpha particles loose energy, they pick up electrons and become helium. U-238, Ra-226 and Rd-222 are examples of alpha particle emitters. Alpha emitters are used to treat cancer, as a static eliminator in paper mills and other industries, and in smoke detectors. |
| **Gross Beta** | Beta particles (β-particles) are a type of radiation emitted by some radionuclides. Beta particles are equivalent to electrons, and can travel a few meters in air. After losing their energy, they are picked up by positively charged ions. There are numerous sources of beta particles, including tritium, strontium-90, cesium-137, and products of radium decay. Beta emitters have many uses, especially in medical diagnosis, imaging, and treatment. They can also be used as tracers in agricultural studies (strontium-90), luminous aircraft and commercial exit signs (tritium), drug metabolism studies (tritium), dating organic matter (carbon-14), and in a variety of industrial instrumentation. |
| **Tritium** | Tritium ($^{3}H$) is a naturally occurring isotope of hydrogen (H) that is widely found in all water, although usually at very low concentrations. Tritium is used commercially as an illuminating agent in exit signs and other devices. Tritium is also used in metabolism and new drug studies. While the majority of natural tritium forms as a result of bombardment of the upper atmosphere by cosmic background radiation, significant quantities of tritium are produced in nuclear reactors and in maintenance of thermonuclear devices. Large quantities of Tritium were released into the atmosphere during aboveground nuclear testing in the 1950s and early 1960s. The short half-life (12.32 yrs.) of Tritium is useful in age-dating of young groundwater. |
| **Strontium-90** | Strontium-90 is a byproduct of thermonuclear fission between uranium and plutonium. There are several other naturally occurring isotopes of strontium as well. Large quantities of strontium-90 were produced in the 1950s and 1960s by testing of nuclear devices. This strontium was rapidly distributed in the atmosphere throughout the world. The 1986 Chernobyl accident in Ukraine also released large amounts of strontium-90 into the atmosphere. Strontium-90 is used as a tracer in agricultural and medical studies, and as a long-term power source for remote buoys, satellites, and other objects. |

## REMEDIATION & TREATMENT TECHNOLOGIES

In general, mitigation of drinking water that exceeds a state or federal radionuclide standard is complicated, since traditional water treatment processes and disposal methods cannot be routinely implemented. Residuals and wastewater derived from the treatment process for these types of contaminants cannot be easily disposed of. Water systems with sources that exceed drinking water standards for radionuclides may consider implementing the measures summarized below to comply with drinking water quality regulatory requirements.

1. Mixing Solution: Interconnect with other non-impacted water systems in the area. This option often may be the most cost-effective approach to resolving water quality problems for the long-term. Depending on the water quality and yield of each source, water from different sources may be blended to meet drinking water standards, or new sources may be developed.
2. Geologic solution: determine if certain water bearing zones can be isolated to improve water quality and comply with radionuclide regulatory requirements.

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| **Radium** | The most inexpensive treatment method is synthetic zeolite ion exchange similar to home water softeners, which removes roughly 90% of the radium. Other possible treatment methods include lime-soda ash softening and reverse osmosis. Comparatively high start-up and operating costs may make these options impractical for most affected systems. Technologies being tested include an adsorptive media where water is passed through columns for treatment, and oxidation-coagulation flocculation-filtration method. |
| **Radon** | Granular activated carbon filters (GAC) uses activated carbon to remove the radon. Aeration devices, which bubble air through the water and carry radon gas out into the atmosphere through an exhaust fan, are another alternative. |
| **Uranium** | Processes include reverse osmosis, anion exchange, special adsorbent media, distillation, or lime softening. |
| **Gross Alpha** | The presence of alpha particles in water usually indicates radium-226, U-235 and Rd-222 as the source. As shown in the attached maps (Figs. 1, 2) distribution of uranium and gross alpha activities above MCL levels is closely related. Water should be tested for a source of radioactivity and treated appropriately. |
| **Gross Beta** | Presence of beta particles in water usually indicates radium-226 and tritium as the source. Water should be tested for a source of radioactivity and treated appropriately. |
| **Tritium** | Mixing or geologic solutions are most effective. |
| **Strontium** | Reverse osmosis and activated charcoal is effective. Mixing and geologic solutions may also be appropriate. |

| HEALTH EFFECT INFORMATION | |
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| **Radium** | Radium is known to cause bone cancer when consumed in high doses. The National Academy of Sciences (NAS) has concluded that a long-term exposure to elevated levels of radium in drinking water poses a higher risk of bone cancer for those exposed. In the 1920s, radium paint was used to make watch dials luminescent. The workers who painted the watch dials would touch the paintbrush tips to their tongues, and inadvertently swallowed high doses of radium. In the decades since, this group of occupationally exposed workers (approximately 4,000) has developed an extremely high rate of death from bone cancer. This effect of radium has also been documented in laboratory animals. |
| **Radon** | Breathing radon in indoor air can cause lung cancer. Radon inhalation is the second leading cause of lung cancer, behind smoking, and causes approximately 21,000 deaths a year in the U.S. Most radon that enters indoor spaces comes from degassing of natural geologic deposits. Only about 1-2 percent of radon in the air comes from drinking water. Drinking water that contains radon also presents a risk of developing internal organ cancers, primarily stomach cancer. Based on a NAS report, the US EPA estimates than radon in drinking water causes about 168 cancer deaths per year: 89% from lung cancer caused by breathing radon released to indoor air from water and 11% from stomach cancer caused by consuming water containing radon. |
| **Uranium** | Exposure to uranium can result in both chemical and radiological toxicity. Natural uranium consists primarily of the U-238, which is very weakly radioactive and it is not a hazardous radioactive substance. However, uranium is a weak chemical poison than can seriously damage the kidneys at high blood concentrations. This damage is dosage dependent and somewhat reversible. The uranium ion (uranyl) can also deposit on bone surfaces and may be detected in the bone matrix for several years following exposure. |
| **Gross Alpha** | The health effect of alpha particles depends upon how exposure takes place. External exposure is far less of a concern than internal exposure, because alpha particles lack the energy to penetrate the outer dead layer of skin. If alpha emitters have been inhaled, ingested, or absorbed into the blood stream, living tissue may be exposed. Exposure of living tissue to alpha radiation is associated with an increased risk of cancer, in particular lung cancer (inhalation). The greatest exposure to alpha radiation comes from the inhalation of radon and its decay products, several of which also emit potent alpha radiation. |

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| **Gross Beta** | Beta radiation can cause both acute and chronic health effects. Contact with a strong beta source from an abandoned industrial instrument may result in acute exposure. Chronic effect results from low-level exposure over a long period (approximately 5-30 years). The main chronic health effect from radiation is cancer. When taken internally beta emitters can cause tissue damage, which increase the risk of developing cancer. Some beta emitters, such as carbon-14, distribute widely throughout the body. Others accumulate in specific organs; iodine-131 in the thyroid gland, strontium-90 in bone and teeth. |
| **Strontium-90** | Strontium is similar chemically to calcium, and tends to accumulate in bones, where calcium is normally deposited. Increased exposure to strontium-90 has been linked to bone cancer, cancer near bones, and leukemia. |
| **Tritium** | Tritium is a beta-emitter, and like all beta emitters it contributes to an increased risk of cancer. However, tritium rapidly exits the body and overall is one of the least-dangerous radionuclides. Tritium is naturally found in very low levels in all water. |

## KEY REFERENCES

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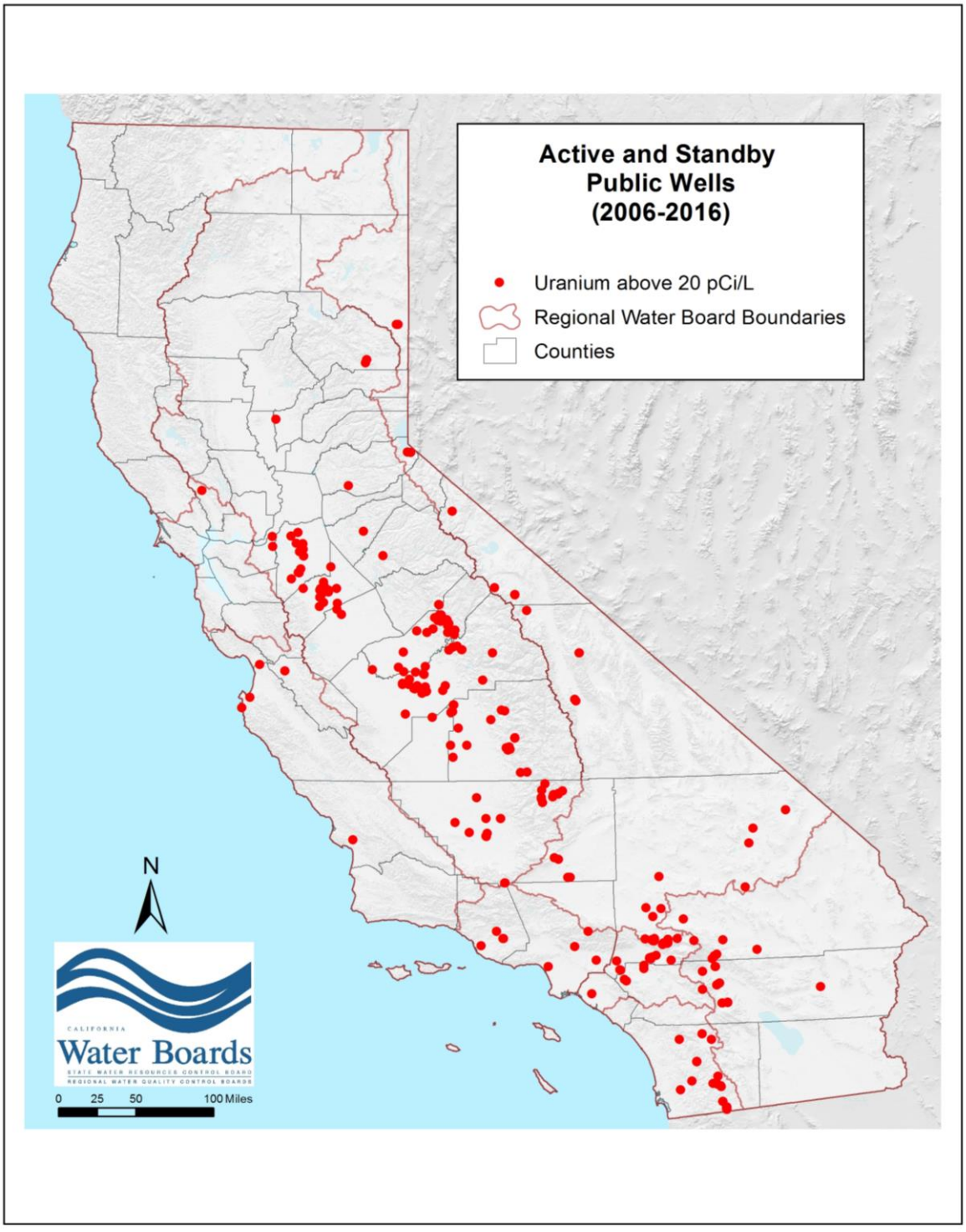
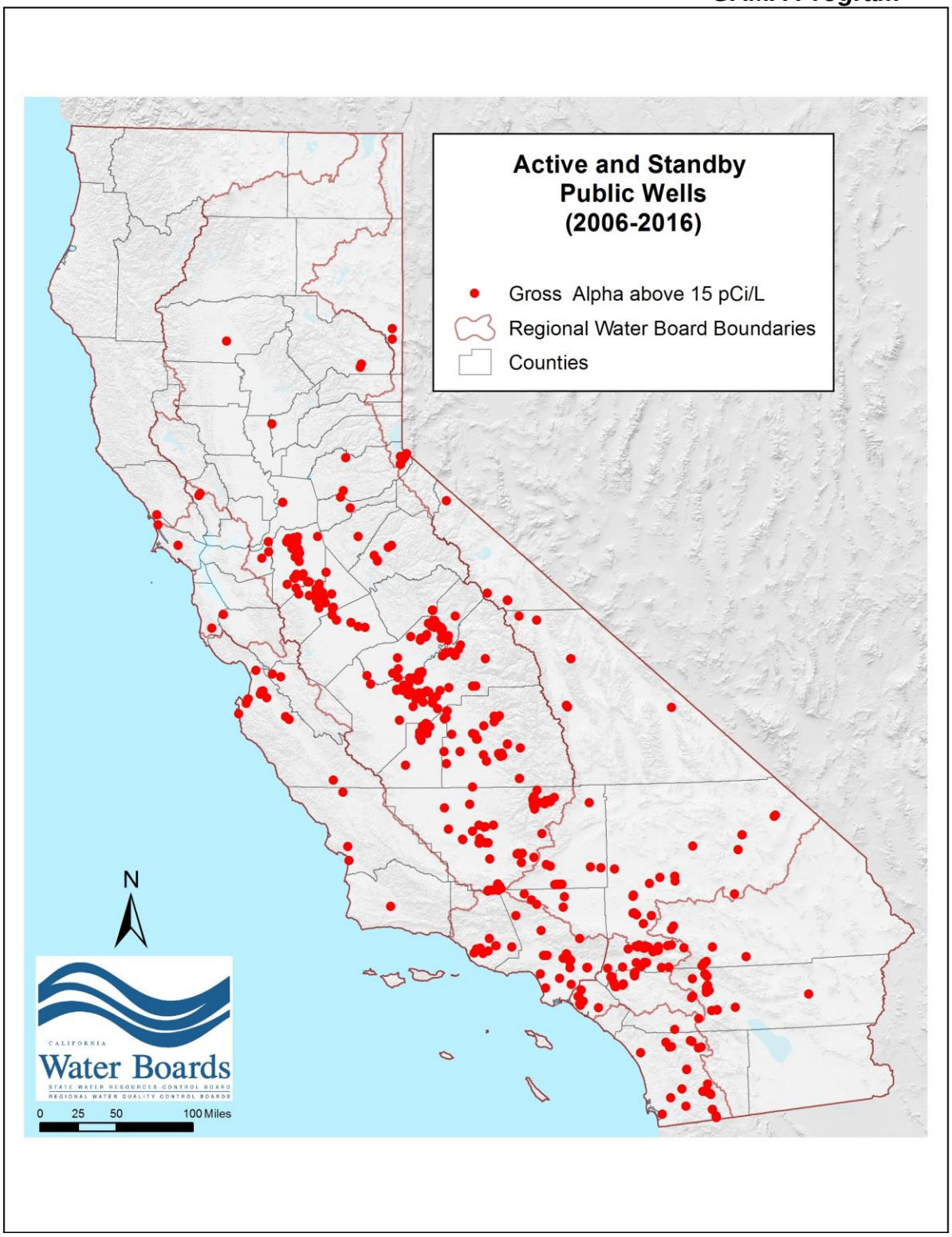



Active and Standby Public Wells with at least one detection of Uranium above the MCL of 20 pCi/L (280 wells). (Source: Public Well data using GeoTracker-GAMA).




Active and Standby Public Wells with at least one detection of gross alpha activity above the MCL of 15 pCi/L (558 wells). (Source: Public Well data using GeoTracker-GAMA).