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Study 182/228: Trend Analysis of Regulated Agricultural Pesticide Concentrations in Groundwater in Fresno and Tulare Counties

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SUMMARY

In this report, a trend analysis was performed on measured concentrations in groundwater of six pesticide active ingredients (atrazine, simazine, prometon, bromacil, diuron, norflurazon) listed in regulation on the Groundwater Protection List (Title 3 California Code of Regulations [3CCR] Section 6800[a]) and four degradation products (degradates) of these pesticides (DEA, ACET, DACT, DSMN). The groundwater was sampled under Studies 182 and 228 between 1999 and 2022 from a network of 75 domestic wells (Well Network) located in Fresno and Tulare counties along the eastern side of the San Joaquin Valley. The six pesticides were initially detected in groundwater in many areas of California from the early 1980s through the 1990s. Formal reviews of these pesticides subsequently conducted in accordance with the Pesticide Contamination Prevent Act (PCPA) concluded that these pesticides had all contaminated groundwater and therefore required regulation as a condition for their continued agricultural, outdoor industrial, and outdoor institutional use. The six pesticides were initially regulated in Pest Management Zones (PMZs) between 1989 and 2003 under 3CCR Sections 6486 and 6802. These regulations were later revised and superseded in 2004 by 3CCR Section 6487, where the six pesticides were then regulated in Groundwater Protection Areas (GWPAs). The initial and revised regulations both imposed restrictions on agricultural and non-agricultural use of the pesticides to mitigate their potential to further contaminate groundwater. Under Studies 182 and 228, the six pesticides and four degradates were therefore measured to assess whether the use restrictions imposed by the revised regulations were effective in mitigating further contamination of groundwater by these chemicals and ultimately reducing their concentrations in the aquifer system.

The trend analysis was performed on the measured pesticide and degradate concentrations in each of the Well Network wells using the Akritas-Theil-Sen (ATS) nonparametric regression method. For each time series of chemical concentrations measured in each well, the ATS method estimates a linear trendline through the plotted data (i.e., chemical concentration versus time). The ATS method is uniquely developed to handle left-censored environmental data, such as measured pesticide concentrations in groundwater. For Studies 182 and 228, the reporting limit from 1999 to 2020 used by the California Department of Pesticide Regulation's (DPR) Groundwater Protection Program (GWPP) for all laboratory-measured pesticide and degradate concentrations in analyzed groundwater samples was 0.05 parts per billion (ppb). Measured concentrations greater than or equal to 0.05 ppb are therefore referred to as 'detections' and those below 0.05 ppb are 'non-detects'. Non-detects of the six pesticides and four degradates are treated as left-censored data by the ATS method. Starting in 2021, however, the reporting limit was updated to be analyte-specific and ranged from 0.01 to 0.03 ppb for the six pesticides and four degradates. Since the updated analyte-specific reporting limits were only applicable to laboratory measurements for the last two years (2021 and 2022) of the 24-year study period, to achieve consistency in the trend analysis the measured concentrations of the six pesticides and four degradates below 0.05 ppb in samples collected in 2021 and 2022 were also treated as left-censored data. From the trend analysis, the estimated trendlines of the measured concentrations over time of each pesticide and degradate in each well by the year 2022 were characterized as either: 1) below 0.05 ppb, 2) trending downward but still above 0.05 ppb, 3) trending sideways, or 4) trending upward. A trend of measured concentrations of a particular chemical in a well characterized as 'below 0.05 ppb' includes both a time series consisting entirely of non-detects (i.e., no detections of the chemical in the well from any sampling event between 1999 and 2022) and a time series of measured concentrations (i.e., detections) in the well whose values eventually trended below the 0.05 ppb reporting limit by 2022.

Overall, 61 of the 75 original wells enlisted in the Well Network in 1999 had measured concentration datasets for the six pesticides and four degradates over the 1999 to 2022 sampling period that were complete enough to be analyzed by the ATS method. A summary of well counts of estimated trend directions for the six pesticides and four degradates in the 61 wells is summarized in Tables S1 and S2, respectively.

Table S1. Summary of well counts of estimated trend directions for measured concentrations of six regulated pesticides in Well Network wells in Fresno and Tulare counties.

Trend Direction	Number of Wells					
	Atrazine	**Simazine**	**Prometon**	**Bromacil**	**Diuron**	**Norflurazon**
Below 0.05 ppb	60	44	61	47	61	52
Downward	0	13	0	5	0	0
Sideways	1	4	0	8	0	8
Upward	0	0	0	1	0	1
Total Wells	61	61	61	61	61	61

Table S2. Summary of well counts of estimated trend directions for measured concentrations of four major degradates of the regulated pesticides in Well Network wells in Fresno and Tulare counties.

Trend Direction	Number of Wells			
	DEA (degradate of atrazine)	**ACET** (degradate of simazine)	**DACT** (degradate of simazine)	**DSMN** (degradate of norflurazon)
Below 0.05 ppb	59	27	23	39
Downward	0	22	16	5
Sideways	2	12	20	13
Upward	0	0	2	4
Total Wells	61	61	61	61

In addition to the estimated trendlines by the ATS method, the trend analysis also considered changes in regional use of the six regulated pesticides from 1990 to 2021. A summary of the trend analysis for each of the six pesticides and four degradates is provided as follows:

1. For atrazine, 60 of 61 wells analyzed had concentration trendlines below 0.05 ppb by 2022. Actual detections of atrazine were found in only three wells over the sampling period. Only one well had concentrations of atrazine that were still trending sideways by 2022; however, no local atrazine use in the vicinity of the well was reported to corroborate these detections. For DEA, the major degradate of atrazine, 59 of 61 wells had concentration trendlines below 0.05 ppb by 2022. Overall, the almost complete lack of atrazine detections in the Well Network is consistent with its minor and infrequent use in the study area from 1990 to 2021.

2. For simazine, 44 of 61 wells analyzed had concentration trendlines below 0.05 ppb by 2022; 13 wells were trending downward; and four wells were trending sideways. As a major degradate of simazine, changes in the trend direction of ACET concentrations in wells lagged behind those of simazine. Specifically, 27 of 61 wells had ACET concentration trendlines below 0.05 ppb by 2022; 22 wells were trending downward; and 12 wells were trending sideways. As the major degradate of ACET, DACT concentrations in individual wells similarly lagged behind those of ACET. Specifically, 23 of 61 wells had DACT concentration trendlines below 0.05 ppb by 2022; 16 wells were trending downward; 20 wells were trending sideways; and 2 wells were trending upward. Overall, downward trending concentrations or concentration trendlines below 0.05 ppb for simazine, ACET, and DACT in most of the wells are consistent with the long-term decline in simazine use in the study area from the late 1990s to present.
3. For prometon, all 61 wells had concentration trendlines below 0.05 ppb by 2022. Actual detections of prometon were found in only two wells over the sampling period. The complete lack of prometon detections in the other 59 wells is consistent with the fact that no use of prometon was reported in the study area from 1990 to 2021.
4. For bromacil, 47 of 61 wells analyzed had concentration trendlines below 0.05 ppb by 2022; five wells were trending downward; eight wells were trending sideways; and one well has been trending upward in the last few years. Downward trending concentrations or concentration trendlines below 0.05 ppb for bromacil in most wells are consistent with its long-term decline in use in the study area from 1990 to 2021.
5. For diuron, all 61 wells analyzed had concentration trendlines below 0.05 ppb by 2022. Prior to 2022, detections had been found in 24 wells in various sampling years. Concentration trendlines below 0.05 ppb for all 61 wells are consistent with the long-term decline in diuron use in the study area from 1990 to 2021.
6. For norflurazon, 52 of 61 wells analyzed had concentration trendlines below 0.05 ppb by 2022; eight wells were trending sideways; and one well has been trending upward since the early 2000s. As the major degradate of norflurazon, changes in the trend direction of DSMN concentrations in wells generally lagged behind those of norflurazon. In particular, 39 of 61 wells had DSMN concentration trendlines below 0.05 ppb by 2022; five wells were trending downward; 13 wells were trending sideways; and four wells were trending upward. Similar to simazine, bromacil, and diuron, decreasing concentrations or non-detects of norflurazon in the majority of wells are consistent with its long-term decline in use in the study area from the early 2000s to present.

The major conclusions of the trend analysis are the following:

1. Measured concentrations of the six regulated pesticides and four degradates have been generally decreasing in the Well Network since monitoring began in 1999. However, use

of all these pesticides has also been steadily declining since the early 2000s. Current use of atrazine, bromacil, and norflurazon is almost nonexistent in both Fresno and Tulare counties. Prometon has had no reported use between 1990 and 2021 and currently there are no registered prometon products in California. Simazine and diuron still have some low reported agricultural use in the study area but their use continues to decrease each year. It is possible that one effect of the use restrictions imposed by the initial and revised regulations from 1990 to present was to reduce the popularity of 3CCR Section 6800(a) pesticide products for agriculture use in Fresno and Tulare counties with growers choosing other non-regulated herbicides (i.e., that do not require use permits) for their weed management programs.

2. Most of the mitigation measures required under the revised regulations (i.e., 3CCR Section 6487) involve implementation of efficient irrigation methods during and after applications of the regulated pesticides. Many of these efficient irrigation methods required by the pesticide use permits were already starting to be adopted by growers in the study area and elsewhere in the state during the mid-1980s to early-1990s (i.e., when the PCPA was passed and the initial regulations were enacted) in response to long-term droughts that were affecting agricultural surface water supply availability and groundwater pumping costs. As noted, reported use of the six regulated pesticides has also declined significantly from 1990 to 2021. Consequently, it is not possible to determine whether any of the observed decreases in pesticide and degradate concentrations in the Well Network are due to implementation of the pesticide use restrictions or whether those decreases resulted from the combined effect of diminished use of the regulated pesticides in the study area and widespread adoption of efficient irrigation methods due to water supply and cost concerns.

3. If reportable use of the regulated pesticides in the study area diminishes completely, then concentrations of these pesticides in groundwater would eventually decrease below their respective laboratory-achieved reporting limits, as has been the case with atrazine, prometon, and diuron. Despite the appearance of declining use of all six of the regulated pesticides to low or seemingly negligible levels, a single application of a regulated pesticide to a field under conditions that violate the requirements of the use permit can result in detectable concentrations of that pesticide in a nearby well that can persist for years thereafter. Consequently, the GWPA-based regulations remain important for protecting groundwater in regions of the state where they are defined in the event that use of these regulated pesticides increases in the future or if other pesticides found to contaminate groundwater under the Detection Response Process are added to the Groundwater Protection List (3CCR Section 6800[a]).

INTRODUCTION

Pesticide Contamination Prevention Act (PCPA)

The Pesticide Contamination Prevention Act (PCPA) is defined in Sections 13141-13152 of the California Food and Agricultural Code (FAC). The PCPA was originally enacted in 1985 under Assembly Bill 2021 and was significantly revised in 2014 under Senate Bill 1117. Section 13149 of the PCPA mandates that when a laboratory-confirmed detection of a pesticide active ingredient or other specified ingredient or degradation product of a pesticide is found in groundwater and the detection is determined to be due to legal agricultural use of the pesticide, then DPR is required to conduct a formal review (Detection Response Process) to determine if use of the pesticide should continue and, if so, under what conditions.

Detection Response Process

The Detection Response Process consists of three steps: 1) issuance of a Notice of Detection to all product registrants that the pesticide has been found in groundwater; 2) subsequent request by the registrant(s) for a public hearing in front of a three-person subcommittee of the DPR Pesticide Registration and Evaluation Committee (PREC); and 3) report of findings from the public hearing and a recommendation by the subcommittee to the DPR Director concerning the future agricultural use of the pesticide in the state. The three-person subcommittee consists of a representative from DPR, the State Water Resources Control Board, and the Office of Environmental Health Hazard Assessment. During the public hearing, oral and written testimony is presented to the subcommittee by DPR staff, representatives of the product registrants, expert witnesses, and the public concerning the environmental, economic, and public health impacts of the agricultural use of the pesticide in question. The subcommittee evaluates the totality of the evidence and makes a recommendation to the DPR Director based on three possible findings: 1) that the ingredient found in groundwater has not polluted and does not threaten to pollute the groundwater of the state and subsequently use of registered agricultural products containing the pesticide can continue without additional regulation; 2) that use of registered agricultural products containing the pesticide should be modified (i.e., regulated) to mitigate the threat of polluting groundwater; or 3) that modification of agricultural use or cancellation of the pesticide will cause severe economic hardship on the agricultural industry, and that no alternative products or practices can be used so that there is a high probability that pollution of the groundwater of the state will not occur. For this third finding, the subcommittee recommends a level of the pesticide concentration in groundwater that does not significantly diminish the margin of safety recognized by the subcommittee to not cause adverse health effects. The subcommittee presents their finding as a recommendation to the DPR Director who decides one of the following: 1) to accept the subcommittee's recommendation; 2) to determine their own level of the pesticide concentration in groundwater that does not significantly diminish the margin of safety recognized by the subcommittee to not cause adverse health effects; or 3) to determine, contrary to the finding of the subcommittee, that no pollution or threat to pollution exists. Alternatively, registration of the pesticide shall be cancelled for any of the following reasons: 1) the registrant(s) do not request or fail to request in a timely manner a public hearing with the PREC; 2) the registrant(s) fail to demonstrate that the pesticide does not threaten to pollute and has not polluted groundwater according to the terms under which it is registered; or 3) the subcommittee is unable to make a recommendation of the three possible findings to the DPR director based on the totality of evidence presented during the public hearing.

Initial Regulations for Restricted Use Pesticides: 1989-2003

To date, 12 pesticides registered for agricultural use in California have been formally reviewed under the Detection Response Process (Table 1). Eight of the 12 pesticides were determined by the DPR Director at the time to require regulation as a condition for their continued agricultural use in the state (Table 1). These regulated pesticides (in order of regulation over time) are atrazine, simazine, prometon, bromacil, diuron, aldicarb, bentazon, and norflurazon (see Table 2 for common and Chemical Abstracts [CAS] names of the eight regulated pesticides and four major degradates). Regulations for the eight pesticides were in the form of restrictions on the timing and place of agricultural use of products containing them. Use restrictions for aldicarb and bentazon were distinctly different than those adopted for the other six pesticides (atrazine, simazine, bromacil, prometon, diuron, norflurazon). Regulations for aldicarb were enacted in 1990 under 3CCR Section 6458 and included restrictions on the amount of aldicarb that could be applied to the following crops: cotton, potatoes, sugar beets, dried beans, citrus, and ornamentals. Use of pesticides containing aldicarb was also not allowed on these crops between September 1 and March 1 of each year. Regulations for bentazon (3CCR Section 6486.6) were enacted in 1991 and included the following use restrictions: 1) bentazon shall not be applied in Del Norte or Humboldt counties; 2) bentazon shall not be used in the production of rice; 3) bentazon shall not be applied prior to April 1 or after July 31 of each year; and 4) irrigation of sites following treatment with bentazon shall be applied only by sprinklers through December 31 of that year.

Initial regulations restricting the use of atrazine, simazine, prometon, bromacil, diuron, and norflurazon were enacted between 1989 and 2001 and were based on the concept of a "Pest Management Zone" (Goh, 1992). A Pesticide Management Zone (PMZ) was originally defined in regulation under 3CCR Section 6802 as "a geographical area of approximately one square mile which is sensitive to ground water pollution and which corresponds to a section as defined by base meridian, township, range and section, or which is defined by latitude and longitude or other generally accepted geographical coordinates". More formally, a section is a 1-mile^2 area of land defined by the Public Lands Survey Coordinate System (Davis et al., 1966). A section of land was identified as a PMZ if a drinking water well in it was sampled and found to contain a residue of one or more of the six regulated pesticides (atrazine, simazine, prometon, bromacil, diuron, norflurazon) determined to have reached groundwater by legal agricultural use of product(s) containing them (Oshima, 1987; Weaver, 1996). A section of land was designated as a PMZ for each regulated pesticide detected in that section. As such, a section could be defined as a PMZ for multiple regulated pesticides if detections of those pesticides were found in that section. Use of pesticides regulated in a PMZ was prohibited for the agricultural, outdoor industrial, and outdoor institutional uses listed in Table 3. In sections designated as a PMZ for prometon and diuron, for example, all uses of prometon would be prohibited and uses of diuron in certain non-crop areas and rights-of-way would also be prohibited (Table 3).

The number of PMZs defined statewide for each of the six regulated pesticides between 1989 and 2001 is presented in Table 4 (Troiano et. al, 2013). For example, the first PMZs were defined for atrazine in 1989 and consisted of 62 sections throughout the state in which atrazine was found in well water and determined to have reached groundwater by legal agricultural use (Table 4). As seen in Table 3, all agricultural, outdoor industrial, and outdoor institutional uses of atrazine were prohibited under 3CCR Section 6486.1 in the 62 atrazine-specific PMZs defined in regulation in 1989. Additional PMZs for atrazine were added to 3CCR Section 6802 in 1990, 1992, and 1999 (Table 4). Norflurazon is the most recent pesticide determined by the DPR Director to require regulation under the Detection Response Process (Table 1). Under 3CCR Section 6486.8, norflurazon use was prohibited in areas managed or designed to recharge groundwater as well as inside canal and ditch banks in 11 norflurazon-specific PMZs enacted in regulation in 2001 under 3CCR Section 6802 (Table 3).

California Vulnerability (CALVUL) Model

During the 1990s, the continual demand to identify new sections that had detections of the six regulated pesticides and subsequent designation of them in regulation as PMZs became a burdensome process for DPR with respect to time and staff resources. Consideration was therefore given to shift from a detection-based process for identifying new sections to a process based on common geographic features of sections that had historical detections of the regulated pesticides. To investigate this possibility, DPR staff developed the CALVUL (CALifornia VULnerability) model (Troiano et al., 1994; Troiano et al., 1997; Troiano et al., 1999). Data input to the CALVUL model included various soil and hydrogeologic characteristics of sections with detections of the six regulated pesticides. The CALVUL model then applied a statistical methodology to identify specific soil and hydrogeologic properties of the sections that correlated with the occurrence of the pesticide detections. Very generally, detections were found to commonly occur in sections with coarse-textured soils and in other sections with low-permeable soils overlying a hardpan layer. Historical detections were also frequently found in sections where the depth to the water table was 70 feet or less below the ground surface.

In addition to common geographic properties, the CALVUL model analysis also identified two major pathways for pesticide movement to groundwater. The first pathway was leaching of pesticides in applied irrigation through the coarse-textured soils. The second pathway was the offsite movement of pesticide-laden runoff from agricultural fields characterized by low-permeable surface soils underlain by a shallow hardpan layer. The runoff from these fields was then redirected into dry wells, water storage structures (e.g., percolation ponds), or water conveyance structures (e.g., canals, ditches). Redirection of runoff into dry wells resulted in pesticides directly entering the water table. Redirection of runoff into various water storage and conveyance structures resulted in pesticides leaching through the underlying sediments and eventually reaching groundwater. The CALVUL model then classified existing PMZs and other sections with historical detections of regulated pesticides as being vulnerable to groundwater contamination by pesticides via either the "leaching", "runoff", or "leaching/runoff" pathway (i.e., a section classified as "leaching/runoff" was vulnerable to groundwater contamination via both pathways). In addition, the CALVUL model also identified sections in which detections of regulated pesticides had not yet been found or sampled for, and classified them as being vulnerable to groundwater contamination by pesticides via either the leaching, runoff, or leaching/runoff pathway based on their soil and hydrogeologic properties that were common to sections with historical detections of regulated pesticides.

As well as providing a classification scheme for the vulnerability of sections to groundwater contamination by pesticides, the CALVUL model was meant to be used for several other purposes (Troiano et al., 1999):

1. To improve planning of well monitoring studies required by the PCPA to detect residues of pesticides that have not yet been found in groundwater (i.e., pesticides listed on 3CCR Section 6800[b] of the Groundwater Protection List).
2. To identify and delineate areas where mitigation measures should be implemented to reduce the potential of pesticides to contaminate groundwater.
3. To aid in the development of specific mitigation measures for sections classified as vulnerable to groundwater contamination by the leaching, runoff, or leaching/runoff pathway.
4. To aid in the fulfillment of a United States Environmental Protection Agency requirement (around the time the CALVUL model was developed) to create a Pesticide Management Plan that would include a statewide vulnerability assessment of groundwater contamination by regulated pesticides.

Study 182: Monitoring the Concentration of Detected Pesticides in Wells Located in Highly Sensitive Areas

During the 1990s, well water sampling was conducted by DPR for three main purposes: 1) to look for pesticides determined to have the potential to contaminate groundwater but that had not yet been found in groundwater (Ground Water Protection List Monitoring); 2) to help determine if pesticides recently found in groundwater were due to legal agricultural use of those pesticides (Four-section Survey Monitoring); and 3) to identify new sections with wells containing pesticides that were adjacent to sections with previously detected pesticides (i.e., PMZs) (Adjacent Section Monitoring). The objective of Adjacent Section Monitoring was to sample wells in 10% of the sections surrounding each PMZ. Adjacent sections with wells found to contain residues of regulated pesticides were submitted for designation as new PMZs. As the number of PMZs increased, the number of adjacent sections to sample grew rapidly and the goal of sampling 10% of the adjacent sections became untenable (Troiano et al., 2001).

As described in the previous section, the CALVUL model was developed to identify sections of land vulnerable to groundwater contamination by pesticides as a function of their soil and hydrogeologic properties. Given the expanding sampling demands of Adjacent Section Monitoring, that effort was made to replace the detection-based process for identifying new vulnerable sections with one based on common geographic features of sections with previous pesticide detections. If identification of vulnerable sections by the CALVUL model proved to be a viable method for predicting where pesticide contamination of groundwater could potentially occur, then Adjacent Section Monitoring could be reduced or eliminated.

In the fall of 1999, Study 182 was initiated with the objective to measure temporal changes in regulated pesticide concentrations in groundwater by conducting biannual sampling over an initial 5-year period from a network of domestic wells located in vulnerable sections in Fresno and Tulare counties along the eastern side of the San Joaquin Valley. The monitored chemicals consisted of the six regulated pesticides (atrazine, simazine, prometon, bromacil, diuron, norflurazon), four major degradates of these regulated pesticides (DEA, ACET, DACT, DSMN), and the unregulated pesticide hexazinone. The initial sampling period from 1999 to 2004 was chosen because five years was estimated from a groundwater age-dating study as the minimum time a pesticide might take to migrate from the ground surface where it was applied to a water well where it would be detected (Spurlock et al., 1992). Under Study 182, 75 domestic wells were chosen for inclusion in the Well Network where each selected well had at least one previous detection of simazine, bromacil, or diuron. As such, nearly all 75 wells chosen were located in existing PMZs in Fresno and Tulare counties (see Tables 5a and 5b). A map showing the locations of the 75 wells in the Well Network and all the PMZs defined in that area by 2001 is displayed in Figure 1. The CALVUL model was used to classify the sections containing the 75 wells as vulnerable to groundwater contamination by either the leaching or runoff pathway.

Thirty three of the 75 wells were subsequently located in sections vulnerable to the leaching pathway and 42 wells were located in sections vulnerable to the runoff pathway.

Regulations were also proposed in 1999 to more comprehensively reduce the potential for agricultural use and certain non-crop agricultural, outdoor industrial, and outdoor institutional uses of atrazine, simazine, bromacil, diuron, prometon, norflurazon, and bentazon to contaminate groundwater. The proposed regulations were intended to revise and supersede the initial regulations for the six pesticides under 3CCR Sections 6486.1-6486.5 and 6486.8 (Table 3) and 3CCR Section 6802, and would also modify the initial regulations for bentazon. The proposed regulations included the requirement of a use permit for products containing the regulated pesticides and enforcement of grower implementation of mitigation measures listed on the permit that were intended to reduce the potential for the regulated pesticides to contaminate groundwater. Study 182 was conducted in anticipation of enactment of the proposed regulations that would occur in 2004.

Overall, four major objectives were achieved with the development and monitoring of the Well Network under Study 182. First, regular monitoring of pesticides in a consistent network of wells had not been conducted by DPR or other agencies at that time. Therefore, repeated sampling of the Well Network over the initial 5-year period would demonstrate whether measurable changes in pesticide concentrations in groundwater could be observed by this kind of monitoring program. Second, monitoring of the regulated pesticides in the Well Network from 1999 to 2004 would provide a baseline of their concentrations in groundwater from which to measure the effectiveness of the proposed regulations after enactment. Third, monitoring from 1999 to 2004 would also measure any changes in regulated pesticide concentrations in the PMZs where the network wells were located that may have resulted over that 5-year period due to the initial regulations that were enacted nearly 10 years prior. Finally, the Well Network would continue to be sampled beyond 2004 to assess the impact of the revised regulations on regulated pesticide concentrations in groundwater and to monitor for other non-regulated agricultural pesticides (e.g., pesticides listed on 3CCR Section 6800[b] of the Groundwater Protection List) that may be reaching groundwater.

Revised Regulations for Restricted Use Pesticides: 2004-present

In 2004, the proposed regulations were enacted to protect groundwater from contamination by products registered for agricultural, outdoor industrial, and outdoor institutional use that contained pesticides listed on 3CCR Section 6800(a) of the Groundwater Protection List. The revised regulations are listed under 3CCR Section 6487.1-6487.5 and summarized in Table 6. Sections of land classified by the CALVUL model as vulnerable to groundwater contamination by pesticides via the leaching, runoff, and leaching/runoff pathways were defined as Groundwater Protection Areas (GWPAs) in the revised regulations. Specifically, sections identified as vulnerable to groundwater contamination via the leaching pathway were designated as ‘Leaching GWPAs’; sections vulnerable to the runoff pathway were designated as ‘Runoff GWPAs’; and sections vulnerable to the leaching/runoff pathway were designated as ‘Leaching/Runoff GWPAs’. Regulations 3CCR Sections 6487.1 and 6487.2 restrict use of the regulated pesticides in artificial recharge basins and inside canal and ditch banks located throughout the entire state. Regulations 3CCR Sections 6487.3-6487.5, on the other hand, restrict use only in GWPAs. A map displaying GWPAs in the Well Network study area is displayed in Figure 2. The major land uses and cropping patterns in the study area are also displayed against the Well Network in Figure 3.

Use of the restricted pesticides listed in Table 6 in regulated areas requires a permit. Each permit includes mitigation measures that must be implemented during and sometimes after the application of the pesticide. The mitigation measures are designed to ultimately reduce the potential for the pesticides to move offsite from the area of application and contaminate groundwater. As will be described later in the report, the majority of regulated pesticide use occurs as applications to agricultural fields. Regulations 3CCR Sections 6487.4 and 6487.5 pertain to pesticide applications to agricultural fields located in Runoff GWPAs and Leaching GWPAs, respectively. Mitigation measures designed to reduce offsite movement in Runoff GWPAs typically involve pesticide and water management practices intended to minimize runoff from fields or to properly manage runoff from fields to offsite structures (e.g., percolation ponds) to prevent groundwater contamination. Mitigation measures in Leaching GWPAs are designed to minimize leaching of pesticides below the soil root zone or shallow surface soil. Mitigation measures for both Runoff and Leaching GWPAs generally include adoption of efficient irrigation methods, restrictions on pesticide application areas relative to irrigation placement, and restrictions on the timing of pesticide applications relative to forecasted rainfall or scheduled irrigation events.

Study 228: Monitoring the Concentration of Detected Pesticides in Wells Located in Highly Sensitive Areas (Well Network Sampling)

As described previously, the Well Network was sampled under Study 182 for an initial 5-year period from 1999 to 2004. To measure the long-term effectiveness of the revised regulations for reducing regulated pesticide concentrations in the study area, annual sampling of the Well Network was continued from 2005 to present under Study 228 (Davalos, 2021). In addition to the six regulated pesticides, four major degradates, and hexazinone, groundwater samples collected under Study 228 were also analyzed for a large number of other non-regulated pesticides listed on 3CCR Section 6800[b] of the Groundwater Protection List.

Initial Trend Analysis of Regulated Pesticide Concentrations in Groundwater

A trend analysis of measured concentrations of four of the regulated pesticides (simazine, bromacil, diuron, norflurazon) and three of the degradates (ACET, DACT, DSMN) in the Well Network for sampling conducted from 1999 to 2012 was performed by Troiano et al. (2013). (As described later in this report, this initial trend analysis was not conducted for atrazine, DEA, and prometon since relatively few detections of these chemicals were found over the 1999 to 2012 sampling period.) Monitoring of the Well Network began in 1999 when the initial regulations were still in effect and five years before the revised regulations were enacted in 2004. During this 5-year period, Troiano et al. (2013) noted that downward trends in simazine, ACET, diuron, and bromacil were already occurring in wells that initially contained detections of these four chemicals and these downward trends were potentially attributable to the effects of the initial regulations. Downward trends in concentrations of simazine, ACET, DACT, and diuron continued from 2004 to 2012 in both Leaching and Runoff GWPAs and for bromacil in Runoff GWPAs.

In contrast, upward trends in norflurazon and DSMN concentrations in well water were observed in Runoff GWPAs from 2004 to 2012. Norflurazon is an alternative herbicide to simazine and diuron and wasn't regulated until 2001 (Table 3). As discussed later in this report, very few norflurazon-specific PMZs were designated in the study area where the Well Network is located. As such, Troiano et al. (2013) speculated that prior to 2004, growers may have switched use from the more highly regulated simazine and diuron herbicides, which were both regulated in 1990, to the less regulated norflurazon. Overall, it was unclear whether downward trends in the regulated pesticides and their degradates (except norflurazon and DSMN) were due to the revised regulations enacted in 2004, to the long-term decline in agricultural use of these pesticides by growers in the region, or to the ongoing adoption of more efficient irrigation methods (e.g., drip, micro-sprinkler) by growers in response to drought impacts on surface water supply availability and groundwater pumping costs (Tindula et al., 2013). Troiano et al. (2013) concluded their study by commenting that continued monitoring of the Well Network was necessary to further evaluate potential impacts of the revised regulations on regulated pesticide concentrations in groundwater in the study area.

Report Objectives

More than a decade has passed since the initial trend analysis was performed by Troiano et al. (2013). The objective of this study is to update the trend analysis for the period from 1999 to 2022. The trend analysis here is performed on measured concentrations of the six regulated pesticides (atrazine, simazine, prometon, bromacil, diuron, norflurazon) and four major degradates (DEA, ACET, DACT, DSMN) in each domestic well in the Well Network for which a sufficiently complete dataset of measurements is available. Trends of each chemical are evaluated with respect to spatial and temporal use patterns of the regulated pesticides, timelines for which the initial and revised regulations were in effect, crop patterns in the study area, and regional changes in irrigation methods.

WELL NETWORK SAMPLING AND LABORATORY ANALYSIS

The Well Network originally established under Study 182 consisted of 75 domestic wells located in rural agricultural areas of Fresno and Tulare counties along the eastern side of the San Joaquin Valley. As seen in Figure 1, nearly all 75 wells were located in existing PMZs. A summary of location and sampling information for each of the wells is provided in Table 7. Under Study 182, each well was planned for sampling twice per year (i.e., during the spring and fall seasons) beginning in the fall of 1999 for a minimum of five years (Garretson, 1999). The Well Network ended up being sampled in the fall of 1999, 2000, 2001, and 2002, and in the spring of 2000, 2001, 2002, 2003, and 2004. Under Study 228, monitoring of the Well Network continued with sampling occurring only once per year in the late-spring or early-summer.

Participation in the monitoring program by well owners is purely voluntary. Permanent discontinuation of sampling of individual wells was typically the result of the owner opting out of the study, the well going dry, or the well being abandoned and not replaced by another elsewhere on the property. In other cases, sampling of individual wells did not occur for various reasons in certain years but then resumed in other years. By the spring of 2022 (i.e., the ending year of the study period for this trend analysis), 57 of the original 75 wells were still participating in the monitoring program and 51 wells had been sampled every year since the study began in 1999 (Table 7). Overall, 61 of the original 75 wells were determined to have measured concentration datasets complete enough over the study period to be analyzed by the statistical method described in the next section.

As noted in Table 7, seven wells in the network during the monitoring period from 1999 to 2022 were replaced by new wells on their respective properties by the well owners. For all seven wells, groundwater sampling continued in the new (replacement) wells once these wells were completed and accessible. For this study, the measured concentrations of the six pesticides and four degradates from the original well on each property were combined with those of the replacement well to form a single time series of measurements representative of that residence. It is important to note that even though a new well is constructed on the same property (presumably nearby) as the original well, measured concentrations of pesticides and degradates in the two wells may differ significantly from each other. Differences in measured concentrations are often due to differences in well construction details (e.g., screen depths and lengths) and the spatial variation of pesticide and degradate concentrations in the aquifer encountered by each well. The impact of well replacement on measured concentrations of different regulated pesticides in Well Nos. 59 and 59A, for example, is described later in the bromacil trend analysis section of this report.

Chemical analysis of groundwater samples collected from the Well Network was performed by the California Department of Food and Agriculture's (CDFA) Center for Analytical Chemistry (CAC). Concentrations of the six regulated pesticides and four degradates in groundwater samples were measured by the CDFA CAC using the 'Triazine Screen' analytical method (EMON-SM-62.9; CDFA, 2009). At the start of Study 182 in 1999, the Triazine Screen analytical method included analysis of the six regulated pesticides, three of the major degradates (DEA, ACET, DACT), and the unregulated pesticide hexazinone. Analysis for DSMN was added to the Triazine Screen method in 2004. The method detection limit (MDL) for each chemical was 0.05 ppb from 1999 to 2004 and varied by chemical from 2005 to 2022 (Table 8). The laboratory reporting limit (RL) for each chemical was also 0.05 ppb from 1999 to 2020 and varied by chemical from 2021 to 2022 (Table 8). For consistency in the trend analysis, all laboratory-measured pesticide and degradate concentrations below 0.05 ppb in analyzed groundwater samples collected from 1999 to 2022 are treated as left-censored data.

STATISTICAL METHOD FOR TREND ANALYSIS

The trend analysis was performed on the measured pesticide concentrations using the Akritas-Theil-Sen (ATS) nonparametric regression method programmed in R software (Helsel, 2012). The ATS method was applied to the measured concentrations of each of the 10 chemicals (six pesticides and four degradates) in 61 of the original 75 wells in the Well Network. The ATS method was developed to handle both singly-censored and doubly-censored data. As mentioned previously, all laboratory-measured pesticide and degradate concentrations below 0.05 ppb in analyzed groundwater samples collected from 1999 to 2022 are treated as left-censored data. For each time series of measured chemical concentrations in each well, the ATS method calculates a p-value and a Kendall's tau correlation coefficient (Helsel, 2012). The p-value is a statistical measure used to test the null hypothesis that the measured chemical concentrations in a well are randomly distributed (in time) about a mean value and therefore do not exhibit an upward or downward trend. Generally, a p-value less than 0.05 would result in rejection of the null hypothesis that an upward or downward trend in the measured data over time does not exist. In other words, rejection of the null hypothesis means that the measured data are not randomly distributed (in time) about a mean value, but instead exhibit an upward or downward trend. If the null hypothesis is rejected, the upward or downward direction and strength of the trend is determined by interpretation of the Kendall's tau correlation coefficient. A positive Kendall's tau indicates an upward trend and a negative Kendall's tau indicates a downward trend. The following rule-of-thumb guideline is useful for interpreting the absolute value of Kendall's tau as a measure of trend strength:

- Strong trend when absolute value of tau > 0.45
- Moderate trend when absolute value of tau > 0.27
- Weak trend when absolute value of tau is > 0.09

Interpretation of the p-value and Kendall's tau can be illustrated by application of the ATS method to the measured concentrations of the six pesticides and four degradates in Well No. 4. The measured concentrations of the 10 chemicals versus time are plotted in Figure 4 and the calculated p-values and Kendall's tau values by the ATS method are listed in Table 9. The p-values for bromacil and DACT, for example, are both greater than 0.05 indicating that no statistically significant upward or downward trend in the measured data exists (i.e., the null hypothesis is not rejected). The associated Kendall's tau for bromacil and DACT are both less than 0.27 and negative, indicating that the two chemicals have weak downward trends at best or more appropriately are "trending" sideways. Atrazine, DEA, simazine, ACET, and diuron all have p-values less than 0.05 and large negative Kendall's tau values, suggesting statistically significant moderate to strong downward trends for their measured concentrations over time in Well No. 4. Alternatively, norflurazon and DSMN have p-values less than 0.05 and large positive Kendall's tau values, suggesting statistically significant moderate to strong upward trends for their measured concentrations over time (Figure 4). It should be stressed that the ATS method estimates only a linear trendline for each set of concentrations and doesn't account for any changes in trend direction or provide any measure of temporal non-linearity. For this study, interpretation of chemical concentrations over time in the wells are made by evaluation of calculated p-values and Kendall's tau values, visual inspection of plotted data, and consideration of other factors such as the spatial distribution of pesticide use, temporal changes in pesticide use, possible impacts of regulations, and proximity of trending concentration values relative to the 0.05 ppb reporting limit. For example, plots for atrazine, DEA, and diuron in Figure 4 show that measured concentrations have trended downward below the 0.05 ppb reporting limit whereas measured concentrations for simazine and ACET are also trending downward but are still greater than 0.05 ppb.

TREND ANALYSIS OF REGULATED PESTICIDE CONCENTRATIONS IN GROUNDWATER

Trend analysis of measured concentrations of the six pesticides and four degradates in 61 of the network wells from 1999 to 2022 is performed in this section. For Studies 182 and 228, the DPR reporting limit for all laboratory-measured pesticide and degradate concentrations in analyzed groundwater samples was 0.05 ppb. Measured concentrations greater than or equal to 0.05 ppb are referred to as 'detections' and those below 0.05 ppb are 'non-detects'. As mentioned previously, non-detects of the six pesticides and four degradates are treated as left-censored data by the ATS method. From the trend analysis, the estimated trendlines of measured concentrations over time for each pesticide and degradate in each well by the year 2022 were characterized as either: 1) below 0.05 ppb, 2) trending downward but still above 0.05 ppb, 3) trending sideways, or 4) trending upward. A trend of measured concentrations of a particular chemical in a well characterized as 'below 0.05 ppb' includes both time series consisting entirely of non-detects (i.e., no detections of the chemical in the well from any sampling event between 1999 and 2022) and time series of measured concentrations (i.e., detections) in the well which eventually trended below the 0.05 ppb reporting limit by 2022. This convention for classifying trend direction was applied to all six pesticides and four degradates analyzed in this study.

Atrazine and DEA

Atrazine is a chlorotriazine herbicide (Table 2). It provides pre- and post-emergent selective control of annual grasses and broadleaf weeds in agricultural crops such as corn, sorghum, grapes, and citrus, and in non-agricultural areas such as fallow fields, recreational turf, and rights-of-way. The first atrazine product was registered in California in 1971 and currently there are four products with active registrations (DPR, 2026).

Atrazine was entered into the Detection Response Process in July 1986 and a decision to regulate its use was issued by the DPR Director in June 1987 (Table 1). Use restrictions for atrazine in atrazine-specific PMZs were enacted in 1989 (Table 3). As defined in 3CCR Section 6486.1, all agricultural, outdoor industrial, and outdoor institutional uses of atrazine were prohibited in the atrazine-specific PMZs defined in 3CCR section 6802 (see map of atrazine-specific PMZs in the study area in Figure 5). By 2001, a total of 177 atrazine-specific PMZs were designated statewide (Table 4) with 32 PMZs located in Fresno County (Table 5a) and 27 PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.1 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted atrazine use in GWPAs (see Table 6 and Figure 5).

Annual agricultural and non-agricultural use of atrazine in Fresno and Tulare counties from 1990 to 2021 is charted in Figures 6a and 6b, respectively. Total agricultural use of atrazine over this period at the section scale in the study area is mapped in Figure 7 and summarized by site for Fresno and Tulare counties in Tables 11a and 11b, respectively. From 1990 to 2003, when the initial regulations for atrazine use in PMZs were in effect, atrazine use in the study area was quite low with most use occurring in non-agricultural sites (see Figures 6a and 6b). Similarly from 2004 to 2020, when the revised regulations for atrazine use in GWPAs were in effect, atrazine use in the study area remained low with applications made mostly to corn and sorghum fields in Fresno County (see Figure 6a and Table 11a). During 2021, no atrazine use occurred in Fresno County while one pound of use was reported in Tulare County (DPR, 2024).

Trend analysis of measured atrazine concentrations in 61 of the network wells from 1999 to 2022 was performed. Trend directions of atrazine concentrations in the Well Network are plotted with the spatial distribution of total agriculture use of atrazine in Figure 7. Similarly, atrazine trend directions in the wells are plotted against the GWPAs in Figure 8. Well counts of atrazine concentration trend directions in the network are summarized in Table 10a. Of the 61 wells analyzed by the ATS method, 60 wells were characterized as below 0.05 ppb (Table 10a). In fact, actual measured concentrations of atrazine greater than 0.05 ppb were found in only three wells (Well Nos. 4, 59/59A, 90) over the study period. In particular, atrazine concentrations trended sideways in Well No. 90 and trended below 0.05 ppb by 2022 in Well Nos. 4 and 59/59A (Figure 9).

DEA is a major degradate of atrazine, whereas ACET and DACT are degradates of both atrazine and simazine (Table 2). As described later, detections of ACET and DACT in the Well Network over the study period were quite numerous in comparison to detections of DEA. Historical simazine use in the study area, at least between 1990 and 2021, was also significant whereas atrazine use over the same period was comparatively minimal. Consequently, although ACET and DACT are technically degradates of both simazine and atrazine, detections of ACET and DACT in the Well Network are presumed to occur from degradation of simazine rather than from atrazine. For this reason, trend analyses of ACET and DACT concentrations in the Well Network are discussed in the section concerning simazine.

Trend directions of DEA concentrations in the Well Network are plotted against the GWPAs in Figure 10. Well counts of DEA concentration trend directions in the Well Network are summarized in Table 10b. Of the 61 wells analyzed, 59 wells were characterized as below 0.05 ppb (Table 10b) and two wells (Well Nos. 47 and 90) had concentrations trending sideways (Figure 11). Well No. 90, in particular, was the only well to display a sideways trend for both atrazine and DEA, whereas Well Nos. 4 and 59/59A both had downward trends of atrazine and DEA concentrations that eventually fell below 0.05 ppb during the study period (Figures 9 and 11).

Interestingly, none of the wells with identified atrazine or DEA concentration trends (i.e., Well Nos. 4, 59/59A, 47, or 90) were located inside or near sections with reported agricultural use of atrazine between 1990 and 2022 (see Figure 7). While low levels of non-agricultural use of atrazine (e.g., rights-of-way) in Fresno County was reported between 1990 and 1993 (Figure 6a), non-agricultural pesticide use is aggregated to the county scale (rather than the section scale) when reported to DPR. Consequently, the reported non-agricultural use of atrazine cannot be disaggregated to the actual sections where it was applied and used to corroborate detections of atrazine or DEA in specific wells, such as Well No. 90.

Overall, measurable concentrations of atrazine and DEA were found in only three and four wells in the Well Network, respectively, over the study period. The lack of detections in the Well Network is consistent with low and infrequent use of atrazine in the study area from 1990 to 2021. Although the initial regulations effectively prohibited all use of atrazine in atrazine-specific PMZs from 1989 to 2003, these PMZs covered only a small fraction of the study area to which those restrictions would apply. Inspection of atrazine use from 1990 to 2021 in Figures 6a and 6b suggests that atrazine was not heavily used in the study area in the years preceding its regulation in 1989. The effects of the initial regulations on historical use of the other regulated pesticides (e.g., simazine, diuron, bromacil) were more pronounced and are discussed in the following sections.

Simazine, ACET, and DACT

Simazine is a chlorotriazine herbicide (Table 2). It provides pre-emergent control of grasses and broadleaf weeds for a variety of agricultural crops including grapes, citrus, deciduous stone fruit and tree nuts, olives, pome fruits, and asparagus, and for non-agricultural uses such as outdoor buildings and structures, aquatic areas, industrial sites, and rights-of-way. The first simazine product was registered in California in 1958 and currently there are six products with active registrations (DPR, 2026).

Simazine was entered into the Detection Response Process in August 1986 and a decision to regulate its use was issued by the DPR Director in August 1987 (Table 1). Use restrictions for simazine in the simazine-specific PMZs were enacted in 1990 (Table 3). As defined in 3CCR Section 6486.2, simazine use was prohibited in various non-cropped and rights-of-way areas in simazine-specific PMZs defined in 3CCR section 6802 (see map of simazine-specific PMZs in the study area in Figure 12). By 2001, a total of 383 simazine-specific PMZs were designated statewide (Table 4) with 104 PMZs located in Fresno County (Table 5a) and 167 PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.2 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted simazine use in GWPAs (see Table 6 and Figure 12).

Annual agricultural and non-agricultural use of simazine in Fresno and Tulare counties from 1990 to 2021 is charted in Figures 13a and 13b, respectively. Total agricultural use of simazine over this period at the section scale is mapped in Figure 14 and summarized by site for Fresno and Tulare counties in Tables 12a and 12b, respectively. From 1990 to 2003, when the initial regulations for simazine use in PMZs were in effect, simazine use fluctuated annually in both Fresno and Tulare counties reaching a maximum annual use around 1998. Simazine use in both counties has declined significantly since the early 2000s to its present-day low level (Figures 13a and 13b). The major use sites of simazine in Fresno and Tulare counties are listed in Tables 12a and 12b, respectively. Simazine use in both counties occurred mostly in grape vineyards, and citrus, tree nut, and stone fruit orchards, all commonly located along the eastern side of the San

Joaquin Valley in the study area (compare simazine use map in Figure 14 with land use map in Figure 3).

Trend directions of simazine concentrations in the Well Network are plotted with the spatial distribution of total agriculture use of simazine in Figure 14. Similarly, simazine trend directions in the wells are plotted against the GWPAs in Figure 15. Well counts of simazine concentration trend directions in the network are summarized in Table 10a. Of the 61 wells analyzed, 44 wells were characterized as below 0.05 ppb; 13 wells were trending downward; and four wells were trending sideways. No wells were trending upward (Table 10a).

ACET and DACT are major degradates of simazine, with ACET forming from the degradation of simazine and DACT forming from the degradation of ACET (Table 2). As mentioned previously, ACET (and therefore DACT) are also degradates of atrazine. However, low atrazine use in the study area from 1990 to 2021 and a lack of atrazine and DEA detections in 57 of the 61 wells analyzed suggests that detections of ACET and DACT likely occur from degradation of simazine (rather than atrazine) which had significant use in the study area over the same period.

Trend directions of ACET and DACT concentrations in the Well Network are plotted against the GWPAs in Figure 16 and 17, respectively. Well counts of ACET and DACT concentration trend directions in the network are summarized in Table 10b. More than half of the 61 wells exhibit either downward or sideways trends for ACET and DACT concentrations (Table 10b). Plots of simazine, ACET, and DACT concentrations over the study period in Well Nos. 22, 35, and 61 are displayed in Figure 18. Trend directions of the three chemicals in each well in Figure 18 generally reflect the sequence of degradation with simazine concentrations trending downward or sideways, ACET trending mostly sideways, and DACT trending upward. The sequence of degradation is also reflected in the concentrations of the three chemicals in each well where [simazine] < [ACET] < [DACT] (compare vertical axis of plots in Figure 18).

Overall, the majority of the analyzed wells have simazine concentrations that are either below 0.05 ppb or trending downward towards this level. Despite the dissipation of simazine, detections of ACET and DACT are still found in at least half of the Well Network due to the high historical use of simazine from at least 1990 to the mid 2000s (see Figures 13a and 13b). Restrictions on simazine use imposed by PMZ- or GWPA-based regulations from 1990 to present may have reduced the popularity of simazine products for agriculture use in Fresno and Tulare counties with growers choosing other herbicides that do not require use permits for their weed management programs. Nevertheless, current detections of ACET and DACT in a large number of wells necessitates continued sampling of simazine and these degradates in the future under Study 228.

Prometon

Prometon is a triazine herbicide (Table 2). It provides control of annual and perennial broadleaf weeds, brush, and grass in non-agricultural areas on industrial sites, non-cropped areas on farms, and under asphalt. The first prometon product was registered in California in 1967 and currently there are no prometon products with active registrations (DPR, 2026).

Prometon was entered into the Detection Response Process in February 1986 and a decision to regulate its use was issued by the DPR Director in September 1987 (Table 1). Use restrictions for prometon in prometon-specific PMZs were enacted in 1990 (Table 3). Under 3CCR Section 6486.5, all prometon use was prohibited in prometon-specific PMZs defined in 3CCR section 6802 (Figure 19). By 2001, a total of 25 prometon-specific PMZs were designated statewide (Table 4) with four PMZs located in Fresno County (Table 5a) and eight PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.5 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted prometon use in GWPAs (see Table 6 and Figure 19).

Prometon has had no reported agricultural or non-agricultural use in Fresno and Tulare counties from 1990 to 2021 (DPR, 2024). A map displaying trend directions of prometon concentrations in the Well Network against the GWPAs is displayed in Figure 20. Overall, prometon concentrations in all 61 wells were below 0.05 ppb by 2022. Prometon concentrations in Well No. 35 were measured at detectable levels early in the study period but had decreased to below 0.05 ppb by 2011 (Figure 21). Detectable levels were also measured in Well No. 54 in some years between 2014 and 2021 but had also fallen to below 0.05 ppb by 2022 (Figure 21). The occurrence of relatively recent detections in Well No. 54 over the last decade is somewhat surprising given the complete lack of reported prometon use in the study area between 1990 and 2021. Nevertheless, as of 2022 no detections of prometon were found in the Well Network.

Bromacil

Bromacil is a uracil herbicide (Table 2). It provides non-selective control of grasses and broadleaf weeds for a variety of citrus crops including oranges, tangerines, lemons, and grapefruit, and for non-agricultural uses such as rights-of-way and uncultivated non-cropped areas. Products can be formulated with either the acid or lithium salt form of bromacil. The earliest instance of a registered bromacil product in California is 1968. At present, there are 15 bromacil products with active registrations in California (DPR, 2026).

Bromacil was entered into the Detection Response Process in July 1986 and a decision to regulate its use was issued by the DPR Director in September 1987 (Table 1). Use restrictions for bromacil in bromacil-specific PMZs were enacted in 1990 (Table 3). Under 3CCR Section 6486.3, bromacil use was prohibited in various non-cropped and rights-of-way areas in bromacil-specific PMZs (Figure 22). By 2001, a total of 138 bromacil-specific PMZs were designated statewide under 3CCR section 6802 (Table 4) with 27 PMZs located in Fresno County (Table 5a) and 92 PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.3 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted bromacil use in GWPAs (see Table 6 and Figure 22).

Annual agricultural and non-agricultural use of bromacil in Fresno and Tulare counties from 1990 to 2021 is charted in Figures 23a and 23b, respectively. Total agricultural use of bromacil over this period at the section scale is mapped in Figure 24 and summarized by site for Fresno and Tulare counties in Tables 13a and 13b, respectively. In the study area, most bromacil use occurred in citrus orchards (e.g., oranges, lemons, tangerines) predominantly located in Tulare County along the eastern edge of the San Joaquin Valley (see Figures 4 and 24). From 1990 to 2003, when PMZ-based regulations were in effect, bromacil use in Tulare County decreased significantly (Figures 23a and 23b). After enactment of the GWPA-based regulations in 2004, use rebounded until about 2011 and then decreased again in both counties to current low levels (Figures 23a and 23b).

Trend directions of bromacil concentrations in the Well Network are plotted with the spatial distribution of total agriculture use of bromacil in Figure 24. Similarly, bromacil trend directions in the wells are plotted against the GWPAs in Figure 25. Well counts of bromacil concentration trend directions in the network are summarized in Table 10a. Of the 61 wells analyzed, 47 wells were characterized as below 0.05 ppb; five wells were trending downward; eight wells were trending sideways; and one well was trending upward (Table 10a).

All wells trending sideways or upward were located in runoff GWPAs with significant citrus production (see Figures 4 and 25). By contrast, most wells in the network with no or few detections of bromacil were located in areas not traditionally cropped in citrus (Figure 4) and where historical bromacil use was nonexistent or low (Figure 24). Example plots of bromacil concentrations over time for Well Nos. 12, 61, 75/75A, and 84 are shown in Figure 26. Although the overall trendlines for Well Nos. 12, 61, and 75/75A have been upward since 1999, bromacil concentrations in those wells have been trending sideways and slightly downward over the last 10 to 15 years (Figure 26). In contrast, a “flat” trendline was estimated for Well No. 84 by the ATS method despite recent high bromacil concentrations in that well after years of non-detectable or low concentrations dating back to 1999 (Figure 26). Well No. 84 is the only well with bromacil concentrations characterized as trending upward.

Similar to simazine, the majority of the analyzed wells have bromacil concentrations that are either below 0.05 ppb or trending downward towards this level. The overall decrease in measured bromacil concentrations in the Well Network is consistent with the long-term decrease in agricultural use of bromacil in the study area from 1990 to 2021. It is worth noting that the highest measured concentrations of bromacil were significantly greater than the highest measured concentrations of the other five regulated pesticides and four degradates. For example, measured concentrations of bromacil in Well Nos. 4, 48, 71, 84, and 90 at times were greater than 2 ppb and as high as 6.7 ppb, whereas concentrations for the other five pesticides were typically significantly less than 1 ppb. As such, continued sampling of bromacil in the Well Network is necessary under Study 228 to monitor its presence in groundwater.

As noted previously, seven wells in the network during the monitoring period from 1999 to 2022 were replaced by new wells on their respective properties by the well owners (Table 7). For example, Well No. 59 was replaced by Well No. 59A in 2015 (Table 7), and the measured concentrations of the six regulated pesticides and four degradates were combined for the trend analysis and are plotted (except for prometon) in Figure 27. For bromacil, a distinct upward shift in measured concentrations occurs in 2015 when Well No. 59 was presumably replaced (for sampling) by Well No. 59A. For atrazine, an apparent downward shift in measured concentrations also occurs in 2015 (Figure 27). From 1999 to 2014, atrazine concentrations in this well appear to be trending sideways but are measured as non-detectable from 2015 to 2022. A change in trend direction for DACT in 2015 is also apparent in Figure 27. For the other measured chemicals (simazine, ACET, DEA, diuron), however, no apparent change in trend occurs in 2015. Although replacement wells on the same property as the original well are valuable for continued sampling at that location, noticeable shifts in measured concentrations seen for some measured analytes in Well No. 59/59A emphasize that care should be taken when interpreting measurement data combined from two different wells, even if those wells were in close proximity to one another.

Diuron

Diuron is a phenylurea herbicide (Table 2). It provides control of herbaceous weeds and annual and perennial grasses in a variety of agricultural crops including deciduous stone fruit and tree nuts, citrus, grapes, alfalfa, cotton, olives, and asparagus, and in non-cropland such as airports, utility rights-of-way, fence rows, barrier strips, and sewage disposal areas. The earliest instance of a registered diuron product in California was 1971. At present, there are 39 diuron products with active registrations in California (DPR, 2026).

Diuron was entered into the Detection Response Process in July 1986 and a decision to regulate its use was issued by the DPR Director in October 1987 (Table 1). Use restrictions for diuron in diuron-specific PMZs were enacted in 1990 (Table 3). Under 3CCR sections 6486.4, diuron use was prohibited in various non-cropland and rights-of-way areas in diuron-specific PMZs defined in 3CCR section 6802 (Figure 28). By 2001, a total of 239 diuron-specific PMZs were designated statewide (Table 4) with 58 PMZs located in Fresno County (Table 5a) and 147 PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.4 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted diuron use in GWPAs (see Table 6 and Figure 28).

Annual agricultural and non-agricultural use of diuron in Fresno and Tulare counties from 1990 to 2021 is charted in Figures 29a and 29b, respectively. Diuron use peaked around 1998 and has steadily declined ever since. Total agricultural use of diuron from 1990 to 2001 at the section scale is mapped in Figure 30 and summarized by site for Fresno and Tulare counties in Tables 14a and 14b, respectively. Citrus (e.g., oranges, lemons, tangerines) has the highest diuron use in Fresno and Tulare counties although significant use also occurs in other crops grown on the east side of the valley including grapes, olives, and walnuts. Similar to bromacil, diuron use in the study area was highest in Tulare County along the eastern edge of the San Joaquin Valley where citrus orchards are located (see Figure 3). Diuron-specific PMZs were therefore designated predominantly in sections of Fresno and Tulare counties where citrus was grown (see Figures 3 and 30). When the revised regulations were enacted in 2004, most of the diuron-specific PMZs were converted to runoff GWPAs since offsite movement of spring-applied pre-emergent herbicides in runoff from citrus orchards had been identified as a significant source of groundwater contamination based on field experiments and CALVUL modeling.

Trend directions of diuron concentrations in the Well Network are also plotted with the spatial distribution of total agriculture use of diuron in Figure 30. Similarly, diuron trend directions in the wells are plotted against the GWPAs in Figure 31. Well counts of diuron concentration trend directions in the network are summarized in Table 10a. Overall, diuron concentrations had fallen below 0.05 ppb in all 61 wells by 2022. In particular, 37 wells had diuron concentrations initially measured at detectable levels in 1999 but had trended downward and fallen below 0.05 ppb by 2022. The other 24 wells either had no measured detections of diuron over the study period or too few detections to identify a clear trend. Overall, concentration trendlines below 0.05 ppb for all 61 wells is consistent with the long-term decline in diuron use in the study area from 1990 to 2021.

Norflurazon and DSMN

Norflurazon is a pyridazinone herbicide (Table 2). It provides control of grass and broadleaf weeds in a variety of agricultural crops including deciduous stone fruit and tree nuts, citrus, grapes, alfalfa, cotton, and asparagus, and in non-cropland areas such as fence lines, equipment lots, ditch banks above the high waterline, driveways, on-farm roads, and turn rows. The first norflurazon product was registered in California in 1977 and currently there are three products with active registrations (DPR, 2026).

Norflurazon was entered into the Detection Response Process in May 1998 and a decision to regulate its use was issued by the DPR Director in April 1999 (Table 1). Use restrictions for norflurazon in norflurazon-specific PMZs were enacted in 2001 (Table 3). Under 3CCR sections 6486.8, norflurazon use was prohibited in areas managed or designed for the recharge of groundwater and inside canal and ditch banks in norflurazon-specific PMZs (Figure 32). By 2001, a total of 11 norflurazon-specific PMZs were designated statewide under 3CCR section 6802 (Table 4) with 4 PMZs located in Fresno County (Table 5a) and 7 PMZs in Tulare County (Table 5b). In 2004, 3CCR Sections 6486.8 and 6802 were superseded by 3CCR Sections 6487.1-6487.5 which restricted norflurazon use in GWPAs (see Table 6 and Figure 32).

Annual agricultural and non-agricultural use of norflurazon in Fresno and Tulare counties from 1990 to 2021 is charted in Figures 33a and 33b, respectively. Norflurazon use peaked around 1999 to 2000 and decreased significantly thereafter following enactment of the initial regulations for its restricted use in 2001 (Table 3). Regional norflurazon use continued to decrease after enactment of the revised regulations in 2004 (Table 6). Since 2016, norflurazon use in both counties has diminished to extremely low levels (Figures 33a and 33b). Total agricultural use of norflurazon from 1990 to 2001 at the section scale is mapped in Figure 34 and summarized by site for Fresno and Tulare counties in Tables 15a and 15b, respectively. As seen in Table 15a, norflurazon use in Fresno County was highest in grapes followed by citrus and deciduous stone fruit and tree nuts. In Tulare County, norflurazon use was highest in citrus followed by deciduous stone fruit and true nuts and grapes (Table 15b).

Trend directions of norflurazon concentrations in the Well Network are also plotted with the spatial distribution of total agriculture use of norflurazon in Figure 34. Similarly, norflurazon trend directions in the wells are plotted against the GWPAs in Figure 35. Well counts of norflurazon concentration trend directions in the network are summarized in Table 10a. Of the 61 wells analyzed, 52 wells were characterized as below 0.05 ppb by 2022. In particular, 12 of those 52 wells had norflurazon concentrations initially measured at detectable levels in 1999 but had trended downward and fallen below 0.05 ppb by 2022. The other 40 wells either had no measured detections of norflurazon over the study period or too few detections to identify a clear trend. Eight of 61 wells had norflurazon concentrations that were trending sideways (see plots for Well Nos. 71 and 94 in Figure 36). Finally, Well No. 4 was the only well with norflurazon concentrations trending upward since the early 2000s (Figure 4).

Trend directions of DSMN concentrations in the Well Network are plotted against GWPAs in Figure 38. Overall, DSMN concentrations in 39 of 61 wells had fallen below 0.05 ppb by 2022 (Table 10b). For the other 22 wells, five wells had DSMN concentrations trending downwards; 13 wells were trending sideways; and four wells were trending upward. One well (Well No. 4) had upward trends for both norflurazon and DSMN (Figure 4). Two wells (Well Nos. 71 and 94) with upward trending DSMN concentrations had norflurazon concentrations that were trending sideways (Figure 36). Finally, Well No. 35 did not have any detections of norflurazon but did have measured DSMN concentrations trending upward (Figure 37).

Overall, wells with sideways and upward trending concentrations of norflurazon and DSMN were located in both leaching and runoff GWPAs (Figures 35 and 38). The decline of measured norflurazon concentrations in the Well Network is consistent with its long-term decrease in agricultural use in the study area since the early 2000s. If negligible use of norflurazon continues, then measured concentrations of norflurazon and DSMN should continue to decline as these chemicals dissipate in groundwater. As the major degradate of norflurazon, DSMN is expected to persist longer in the aquifer system than norflurazon. Continued sampling of norflurazon and DSMN in the Well Network is necessary under Study 228 to monitor their presence in groundwater.

CONCLUSIONS

The major conclusions of the trend analysis are the following:

1. Measured concentrations of the six regulated pesticides and four degradates have been generally decreasing in the Well Network since monitoring began in 1999. However, use of all these pesticides has also been steadily declining since the early 2000s. Current use of atrazine, bromacil, and norflurazon is almost nonexistent in both Fresno and Tulare counties. Prometon has had no reported use between 1990 and 2021 and currently there are no registered prometon products in California. Simazine and diuron still have some low reported agricultural use in the study area but their use continues to decrease each year. It is possible that one effect of the use restrictions imposed by the initial and revised regulations from 1990 to present was to reduce the popularity of 3CCR Section 6800(a) pesticide products for agriculture use in Fresno and Tulare counties with growers choosing other non-regulated herbicides (i.e., that do not require use permits) for their weed management programs.

2. Most of the mitigation measures required under the revised regulations (i.e., 3CCR Section 6487) involve implementation of efficient irrigation methods during and after applications of the regulated pesticides. Many of these efficient irrigation methods required by the pesticide use permits were already starting to be adopted by growers in the study area and elsewhere in the state during the mid-1980s to early-1990s (i.e., when the PCPA was passed and the initial regulations were enacted) in response to long-term droughts that were affecting agricultural surface water supply availability and groundwater pumping costs. As noted, reported use of the six regulated pesticides has also declined significantly from 1990 to 2021. Consequently, it is not possible to determine whether any of the observed decreases in pesticide and degradate concentrations in the Well Network are due to implementation of the pesticide use restrictions or whether those decreases resulted from the combined effect of diminished use of the regulated pesticides in the study area and widespread adoption of efficient irrigation methods due to water supply and cost concerns.

3. If reportable use of the regulated pesticides in the study area diminishes completely, then concentrations of these pesticides in groundwater would eventually decrease below their respective laboratory-achieved reporting limits, as has been the case with atrazine, prometon, and diuron. Despite the appearance of declining use of all six of the regulated pesticides to low or seemingly negligible levels, a single application of a regulated pesticide to a field under conditions that violate the requirements of the use permit can result in detectable concentrations of that pesticide in a nearby well that can persist for years thereafter. Consequently, the GWPA-based regulations remain important for protecting groundwater in regions of the state where they are defined in the event that use of these regulated pesticides increases in the future or if other pesticides found to contaminate groundwater under the Detection Response Process are added to the Groundwater Protection List (3CCR Section 6800[a]).

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Table 1. List of 12 pesticides subjected to formal review (Detection Response Process) since enactment of the Pesticide Contamination Prevention Act (PCPA) in 1985.

Pesticide	DPR Chemical Code	Notice of Detection Issuance	Director's Decision Issuance	Director's Decision	Year Regulation Enacted
Atrazine	45	July 1986	June 1987	Regulate by imposing use restrictions	1989
Simazine	531	August 1986	August 1987	Regulate by imposing use restrictions	1990
Prometon	499	February 1986	September 1987	Regulate by imposing use restrictions	1990
Bromacil	83	July 1986	September 1987	Regulate by imposing use restrictions	1990
Diuron	231	July 1986	October 1987	Regulate by imposing use restrictions	1990
Aldicarb	575	October 1988	September 1989	Regulate by imposing use restrictions	1990
Bentazon	1944	March 1989	June 1990	Regulate by imposing use restrictions	1991
Norflurazon	2019	May 1998	April 1999	Regulate by imposing use restrictions	2001
Hexazinone	1871	November 2010	September 2011	Allow continued use without regulation	N/A
Metolachlor/ S-metolachlor	384/5133	September 2016	July 2017	Allow continued use without regulation	N/A
Chlorthal dimethyl	179	March 2018	December 2018	Allow continued use without regulation	N/A
Imidacloprid	3849	September 2021	June 2022	Allow continued use without regulation	N/A

Table 2. Common name (reference) and Chemical Abstracts (CAS) name of regulated pesticides and their major degradation products.

Common Name (Reference)	Chemical Abstracts (CAS) Name	Chemical Classification
Atrazine	6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine	Chlorotriazine herbicide
Deethylatrazine (DEA)	4-amino-2-chloro-6-ethylamino-s-triazine	Degradation product of atrazine and propazine; triazine substance
Simazine	6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine	Chlorotriazine herbicide
Deethylsimazine/ Deisopropylatrazine (ACET)	2-amino-4-chloro-6-ethylamino-*s*-triazine	Degradation product of atrazine and simazine; triazine substance
Desethyldesisopropylatrazine (DACT)	2,4-diamino-6-chloro-*s*-triazine	Degradation product of atrazine, simazine, and propazine; triazine substance
Prometon	6-methoxy-N,N'-bis(1-methylethyl)-1,3,5-triazine-2,4-diamine	Methoxytriazine herbicide
Bromacil	5-bromo-6-methyl-3-(1-methylpropyl)-2,4(1H,3H)-pyrimidinedione	Uracil herbicide
Diuron	N'-(3,4-dichlorophenyl)-N,N-dimethylurea	Phenylurea herbicide
Aldicarb	2-methyl-2-(methylthio)propanal *O*-[(methylamino)carbonyl]oxime	Oxime carbamate acaricide, insecticide, and nematicide
Bentazon	3-(1-methylethyl)-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide	Benzothiadiazinone herbicide
Norflurazon	4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2H)-pyridazinone	N-phenyl heterocycle herbicide
Desmethylnorflurazon (DSMN)	5-amino-4-chloro-2-[3-(trifluoromethyl)phenyl]-3(2H)-pyridazinone	Degradation product of norflurazon; pyridazinone substance

Table 3. Summary of initial regulations under 3CCR Sections 6486.1-6486.5 and 6486.8 enacted between 1989 and 2001 to protect groundwater from contamination by regulated pesticides in PMZs.

Regulation 3CCR Section	**Regulated Pesticide**	**Years Regulation in Effect**	**Prohibited agricultural, outdoor industrial, and outdoor institutional uses in PMZs**
6486.1	Atrazine	1989-2003	All uses prohibited in PMZs.
6486.2	Simazine	1990-2003	(a) In non-crop areas including, but not limited to, petroleum tank farms, lumberyards, storage areas, industrial sites, parking lots, fence lines, driveways, and around buildings and equipment. (b) On rights-of-way including, but not limited to, utility lines, pipelines, railroads, highways, roadsides, and roadways.
6486.3	Bromacil	1990-2003	(a) In non-crop areas including, but not limited to, petroleum tank farms, lumberyards, storage areas, industrial sites, parking lots, fence lines, railroad sidings, loading ramps, and around buildings and equipment. (b) On rights-of-way including, but not limited to, utility lines, pipelines, railroads, highways, roadsides, roadways, and irrigation ditch banks.
6486.4	Diuron	1990-2003	(a) In non-crop areas including, but not limited to, petroleum tank farms, lumberyards, storage areas, industrial sites, parking lots, fence lines, and around buildings and equipment. (b) On rights-of-way including, but not limited to, utility lines, pipelines, railroads, highways, roadsides, roadways, and irrigation and drainage ditches.
6486.5	Prometon	1990-2003	All uses prohibited in PMZs.
6486.8	Norflurazon	2001-2003	Areas managed or designed to recharge groundwater and inside canal and ditch banks.

Table 4. Year and number of PMZs statewide enacted into regulation under 3CCR Section 6802 for the six regulated pesticides (atrazine, simazine, bromacil, diuron, prometon, norflurazon).

	Number of sections statewide designated as PMZs							
Year	**Atrazine**	**Simazine**	**Bromacil**	**Diuron**	**Prometon**	**Norflurazon**	**Total**	**Distinct**
1989	62	0	0	0	0	--	62	62
1990	1	66	11	20	7	--	105	41
1992	14	48	13	18	0	--	93	55
1999	100	260	114	201	18	--	702	330
2001	0	0	0	0	0	11	11	1
Total	177	383	138	239	25	11	973	489

Table 5a. Total number of PMZs in Fresno County by 2001 for regulated pesticides in Groundwater Protection List (3CCR Section 6800[a]) and the total number of GWPAs that replaced them in regulation in 2004.

Regulated Pesticide	**Total No. PMZs**	**Total No. Leaching/Runoff GWPAs**	**Total No. Leaching GWPAs**	**Total No. Runoff GWPAs**	**Total No. All GWPA Types**
Atrazine	32	9	371	210	590
Bromacil	27	9	371	210	590
Diuron	58	9	371	210	590
Norflurazon	7	9	371	210	590
Prometon	4	9	371	210	590
Simazine	104	9	371	210	590

Table 5b. Total number of PMZs in Tulare County by 2001 for regulated pesticides in Groundwater Protection List (3CCR Section 6800[a]) and the total number of GWPAs that replaced them in regulation in 2004.

Regulated Pesticide	**Total No. PMZs**	**Total No. Leaching/Runoff GWPAs**	**Total No. Leaching GWPAs**	**Total No. Runoff GWPAs**	**Total No. All GWPA Types**
Atrazine	27	11	72	557	640
Bromacil	92	11	72	557	640
Diuron	147	11	72	557	640
Norflurazon	4	11	72	557	640
Prometon	8	11	72	557	640
Simazine	167	11	72	557	640

Table 6. Summary of revised regulations enacted in 2004 to protect groundwater from contamination resulting from the use of pesticides registered for agricultural, outdoor industrial, and outdoor institutional use containing pesticide active ingredients listed on the Groundwater Protection List (3CCR Section 6800[a]).

Regulation 3CCR Section	Regulated Areas of Use	Use Restrictions and Permit Requirement Types
6487.1	Artificial recharge basins statewide	Restrictions on areas of application in recharge basins and timing of application relative to planned recharge events
6487.2	Inside canal and ditch banks statewide	Restrictions on areas of application inside canals and ditch banks; acceptable infiltration rates in canals and ditches; and timing of application relative to water storage in canals and ditches
6487.3	Engineered Rights-of-way in Groundwater Protection Areas	Requirements for management of runoff from treated rights-of-way on non-crop vegetated areas, on unenclosed fallow fields, and subject to storm water provisions per the Clean Water Act
6487.4	Runoff Groundwater Protection Areas	Requirements for soil incorporation, area of application, timing of application relative to irrigation events and time of year; acceptable infiltration rates and size of cropped fields, fallow fields, and retention/holding ponds that receive irrigation or precipitation runoff from treated fields
6487.5	Leaching Groundwater Protection Areas	Requirements for area of application in furrows or beds relative to irrigation water levels, timing of application relative to irrigation events, and application efficiency of the irrigation method

Table 7. Location and sampling information for 75 domestic wells in the original Well Network.

Well ID	Well Address	County	GWPA Type	Years Sampled	Notes
1	13S21E-01	Fresno	Runoff	1999-2022	
2	13S22E-33	Fresno	Leaching	1999-2022	
3	13S23E-28	Fresno	Runoff	1999-2022	
4	13S23E-32	Fresno	Runoff	1999-2022	
5	14S21E-13	Fresno	Runoff	1999-2022	
6	14S21E-16	Fresno	Runoff	1999-2019	
7	14S21E-21	Fresno	Runoff	1999-2022	
8	14S21E-25	Fresno	Runoff	1999-2022	
11	14S22E-01	Fresno	Runoff	1999-2012	Excluded from trend analysis
12	14S22E-03	Fresno	Runoff	1999-2006, 2008-2022	
13	14S22E-12	Fresno	Runoff	1999-2022	
14	14S22E-13	Fresno	Leaching	1999-2022	
15	14S22E-14	Fresno	Runoff	1999-2022	
16	14S22E-14	Fresno	Runoff	1999-2022	
17	14S22E-20	Fresno	Runoff	1999-2005	Excluded from trend analysis
18	14S22E-31	Fresno	Leaching	1999-2015	Excluded from trend analysis
19	14S23E-34	Fresno	Leaching	1999-2022	
20/20B	14S23E-32	Fresno	Leaching	1999-2022	Well No. 20 replaced at residence property by Well No. 20B in 2021
21	14S23E-33	Fresno	Leaching	1999-2022	
22	14S23E-34	Fresno	Leaching	1999-2022	
23/23B	14S23E-35	Fresno	Runoff	1999-2003, 2005-2022	Well No. 23 replaced at residence property by Well No. 23B in 2021
24	15S21E-03	Fresno	Leaching	1999-2001, 2003-2022	
25	15S21E-05	Fresno	Leaching	1999-2022	
26	15S21E-09	Fresno	Leaching	1999-2022	
27	15S21E-14	Fresno	Leaching	1999-2013	Excluded from trend analysis
28	15S21E-34	Fresno	Leaching	1999-2004, 2007-2022	
29	15S22E-03	Fresno	Leaching	1999-2021	
30/30A	15S22E-05	Fresno	Leaching	1999-2022	Well No. 30 replaced at residence property by Well No. 30A in 2015
31	15S22E-06	Fresno	Leaching	1999-2000, 2003	Excluded from trend analysis
32	15S22E-09	Fresno	Leaching	1999-2022	
34	15S22E-15	Fresno	Leaching	1999-2014	Excluded from trend analysis
35	15S22E-16	Fresno	Leaching	1999-2022	
36	15S22E-20	Fresno	Leaching	1999-2022	
37	15S22E-21	Fresno	Leaching	1999-2022	
43	15S23E-02	Fresno	Runoff	1999-2022	
44	15S23E-02	Fresno	Runoff	1999-2022	
45	15S23E-12	Fresno	Runoff	1999-2000, 2007-2022	
47	15S24E-14	Fresno	Runoff	1999-2022	
48	15S24E-36	Fresno	Runoff	1999-2018	
49	15S25E-05	Tulare	Runoff	1999-2022	
50	16S21E-05	Fresno	Leaching	1999-2022	
51	16S21E-07	Fresno	Leaching	1999-2022	

Well ID	Well Address	County	GWPA Type	Years Sampled	Notes
52	16S21E-16	Fresno	Leaching	1999-2022	
53/53A	16S21E-33	Fresno	Leaching	1999-2022	Well No. 53 replaced at residence property by Well No. 53A in 2017
54	16S21E-34	Fresno	Leaching	1999-2022	
56	16S22E-11	Fresno	Leaching	1999-2022	
57	16S22E-11	Fresno	Leaching	1999-2022	
58	16S23E-01	Tulare	Leaching/Runoff	1999-2022	
59/59A	16S24E-14	Tulare	Runoff	1999-2021	Well No. 59 replaced at residence property by Well No. 59A in 2015
60	16S25E-06	Tulare	Leaching	1999-2000	Excluded from trend analysis
61	16S25E-21	Tulare	Runoff	1999-2022	
63/63A	17S25E-05	Tulare	Runoff	1999-2022	Well No. 63 replaced at residence property by Well No. 63A in 2015
65	17S26E-26	Tulare	Runoff	1999-2022	
68	18S26E-02	Tulare	Runoff	1999-2022	
69	18S26E-06	Tulare	Runoff	1999-2022	
70	18S26E-23	Tulare	Runoff	1999-2005, 2007-2013	Excluded from trend analysis
71	18S26E-23	Tulare	Runoff	1999-2022	
72	18S27E-21	Tulare	Runoff	1999-2022	
73	18S27E-29	Tulare	Runoff	1999-2022	
74	19S26E-01	Tulare	Runoff	1999-2022	
75/75A	19S26E-14	Tulare	Runoff	1999-2022	Well No. 75 replaced at residence property by Well No. 75A in 2016
76	19S26E-15	Tulare	Runoff	1999-2003	Excluded from trend analysis
79	20S26E-03	Tulare	Runoff	1999-2015	Excluded from trend analysis
80	20S26E-24	Tulare	Runoff	1999-2022	
83	20S27E-19	Tulare	Runoff	1999	Excluded from trend analysis
84	20S27E-20	Tulare	Runoff	1999-2022	
85	20S27E-31	Tulare	Runoff	1999-2013	Excluded from trend analysis
86	20S27E-32	Tulare	Runoff	1999-2022	
87	20S27E-32	Tulare	Runoff	1999-2001, 2003	Excluded from trend analysis
88	21S27E-08	Tulare	Runoff	1999-2007	Excluded from trend analysis
89	13S22E-33	Fresno	Leaching	1999-2022	
90	15S22E-05	Fresno	Leaching	1999-2022	
92	14S23E-33	Fresno	Leaching	1999-2022	
94	15S24E-10	Fresno	Runoff	1999-2022	
95	14S22E-33	Fresno	Leaching	1999-2022	

Table 8. Method detection limit (MDL) and laboratory reporting limit (RL) of pesticides on the [Groundwater Protection List (3CCR Section 6800[a])] and their degradates analyzed by the Triazine Screen (EMON-SM-62.9) in samples collected from 1999 to 2022 in the Well Network.

Chemical	MDL from 1999-2004 (ppb)	MDL from 2005-2019 (ppb)	MDL from 2020-2022 (ppb)	RL from 1999-2020 (ppb)	RL from 2021-2022 (ppb)
Atrazine	0.05	0.013	0.00316	0.05	0.02
DEA	0.05	0.011	0.00226	0.05	0.02
Simazine	0.05	0.0135	0.00286	0.05	0.02
ACET	0.05	0.013	0.0058	0.05	0.03
DACT	0.05	0.0063	0.00235	0.05	0.03
Bromacil	0.05	0.02	0.00241	0.05	0.02
Diuron	0.05	0.043	0.00241	0.05	0.02
Norflurazon	0.05	0.0063	0.00252	0.05	0.02
DSMN	0.05	0.015	0.00181	0.05	0.01

Table 9. Example of trend direction determination using results of Akritas-Theil-Sen nonparametric regression method for measured concentrations in Well No. 4 of five regulated pesticides (atrazine, simazine, bromacil, diuron, norflurazon) and four degradates (DEA, ACET, DACT, DSMN).

Chemical	p-value	Kendall’s tau	Kendall’s tau Correlation Strength	Trend Direction
Atrazine	<<0.05	-0.50	Strong	Downward
DEA	<<0.05	-0.44	Moderate	Downward
Simazine	<<0.05	-0.72	Strong	Downward
ACET	<<0.05	-0.57	Strong	Downward
DACT	0.17	-0.19	Weak	Sideways
Bromacil	0.50	-0.09	Weak	Sideways
Diuron	<<0.05	-0.59	Strong	Downward
Norflurazon	<<0.05	0.76	Strong	Upward
DSMN	<<0.05	0.68	Strong	Upward

Table10a. Summary of well counts of estimated trend directions for measured concentrations of six regulated pesticides in Well Network wells in Fresno and Tulare counties.

Trend Direction	Number of Wells					
	Atrazine	**Simazine**	**Prometon**	**Bromacil**	**Diuron**	**Norflurazon**
Below 0.05 ppb	60	44	61	47	61	52
Downward	0	13	0	5	0	0
Sideways	1	4	0	8	0	8
Upward	0	0	0	1	0	1
Total Wells	61	61	61	61	61	61

Table 10b. Summary of well counts of estimated trend directions for measured concentrations of four major degradates of the regulated pesticides in Well Network wells in Fresno and Tulare counties.

Trend Direction	Number of Wells			
	DEA (degradate of atrazine)	**ACET** (degradate of simazine)	**DACT** (degradate of simazine)	**DSMN** (degradate of norflurazon)
Below 0.05 ppb	59	27	23	39
Downward	0	22	16	5
Sideways	2	12	20	13
Upward	0	0	2	4
Total Wells	61	61	61	61

Table 11a. Total atrazine use (pounds) by site in Fresno County from 1990 to 2021 (DPR, 2024).

Site	**Atrazine Use (pounds)**	**Application Area (acres)**
CORN, HUMAN CONSUMPTION	887	696
SORGHUM/MILO GENERAL	136	139
GRAPES	45	36
ORANGE (ALL OR UNSPEC)	32	18
RESEARCH COMMODITY	4	5
N-OUTDR CONTAINER/FLD GRWN PLANTS	1	1

Table 11b. Total atrazine use (pounds) by site in Tulare County from 1990 to 2021 (DPR, 2024).

Site	Atrazine Use (pounds)	Application Area (acres)
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	22	25
CHRISTMAS TREE PLANTATIONS	16	7
N-OUTDR CONTAINER/FLD GRWN PLANTS	13	13
OLIVE (ALL OR UNSPEC)	10	9
N-OUTDR GRWN CUT FLWRS OR GREENS	4	3

Table 12a. Total simazine use (pounds) by site in Fresno County from 1990 to 2021 (DPR, 2024).

Site	Simazine Use (pounds)	Application Area (acres)
GRAPES	1,614,012	1,718,788
ORANGE (ALL OR UNSPEC)	658,771	338,517
GRAPES, WINE	360,459	365,256
ALMOND	80,371	106,776
PEACH	74,080	92,707
NECTARINE	53,585	83,519
LEMON	20,555	9,113
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	19,547	19,022
OLIVE (ALL OR UNSPEC)	18,046	8,296
APPLE	8,014	11,439
PEAR	7,702	8,235
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	4,272	1,241
BLUEBERRY	3,890	2,085
AQUATIC AREAS, WATER AREAS (ALL OR UNSPEC)	3,840	110
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	3,547	3,351
CITRUS FRUITS (ALL OR UNSPEC)	3,164	1,469
GRAPEFRUIT	1,881	1,123
ASPARAGUS (SPEARS, FERNS, ETC.)	1,608	631
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	1,124	621
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	566	433
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	371	258
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	362	493
CHERRY	322	332
TANGELO	311	145
N-OUTDR CONTAINER/FLD GRWN PLANTS	274	383
BOYSENBERRY (BOYSENS)	256	266
PISTACHIO (PISTACHE NUT)	231	403

Site	Simazine Use (pounds)	Application Area (acres)
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	219	421
APRICOT	188	486
BLACKBERRY	137	118
RIGHTS OF WAY	101	100
LANDSCAPE MAINTENANCE	78	21
N-GRNHS GRWN PLANTS IN CONTAINERS	53	1
PRUNE	45	46
RESEARCH COMMODITY	19	12
RANGELAND (ALL OR UNSPEC)	18	40
ANIMAL HUSBANDRY PREMISES	16	131
PASTURES (ALL OR UNSPEC)	14	11
PECAN	14	20
AVOCADO (ALL OR UNSPEC)	13	8
N-OUTDR GRWN CUT FLWRS OR GREENS	12	27
N-GRNHS GRWN CUT FLWRS OR GREENS	10	5
INDUSTRIAL SITES (LUMBER YARDS, TANK FARMS, ETC.)	9	1
LOGANBERRY (LOGANS)	8	10
ORCHARDS (FRUIT/NUT ETC)	6	7
ORNAMENTAL TURF (ALL OR UNSPEC)	5	2
PERSIMMON	3	10
SUBTROPICAL AND TROPICAL FRUIT (ALL OR UNSPEC)	2	1
BUILDINGS AND STRUCTURES (NON-AG OUTDOOR)	1	3
KIWI FRUIT FUZZY	1	1

Table 12b. Total simazine use (pounds) by site in Tulare County from 1990 to 2021 (DPR, 2024).

Site	Simazine Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	2,431,406	1,076,014
OLIVE (ALL OR UNSPEC)	297,853	156,468
GRAPES	253,016	267,881
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	216,446	150,488
PEACH	106,300	95,521
GRAPES, WINE	101,494	86,370
LEMON	101,259	43,294
NECTARINE	67,116	104,306
ALMOND	25,195	34,292
GRAPEFRUIT	17,207	7,891
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	7,610	3,292

Site	Simazine Use (pounds)	Application Area (acres)
AVOCADO (ALL OR UNSPEC)	5,617	1,926
BLUEBERRY	4,661	2,774
APPLE	3,724	4,005
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	3,635	3,902
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	3,334	1,158
CITRUS FRUITS (ALL OR UNSPEC)	2,799	1,341
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	1,962	717
PEAR	1,600	1,108
TANGELO	1,047	460
CHERRY	645	696
PECAN	401	584
N-OUTDR GRWN CUT FLWRS OR GREENS	380	264
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	363	1,475
PRUNE	257	150
WHEAT, GENERAL	198	1,179
POMELO (SHADDOCK) (CITRUS GRANDIS)	186	91
CORN (FORAGE - FODDER)	152	622
APRICOT	116	204
N-OUTDR CONTAINER/FLD GRWN PLANTS	79	96
PASTURES (ALL OR UNSPEC)	70	46
COTTON, GENERAL	69	80
KIWI FRUIT FUZZY	68	75
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	60	34
CHRISTMAS TREE PLANTATIONS	37	15
ORNAMENTAL TURF (ALL OR UNSPEC)	30	15
POMEGRANATE (MISCELLANEOUS FRUIT)	29	9
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	23	23
AQUATIC AREAS, WATER AREAS (ALL OR UNSPEC)	18	7
OATS, GENERAL	16	5
RIGHTS OF WAY	14	9
RESEARCH COMMODITY	13	5
PISTACHIO (PISTACHE NUT)	11	17
FILBERT OR HAZELNUT	9	4
QUINCE	9	10
RANGELAND (ALL OR UNSPEC)	9	10
NUT CROPS, NUT TREES (ALL OR UNSPEC)	8	12
FARM OR AG STRUCTURES AND EQUIP. (ALL OR UNSPEC)	7	10
SUBTROPICAL AND TROPICAL FRUIT (ALL OR UNSPEC)	6	8
PERSIMMON	5	6

Table 13a. Total bromacil use (pounds) by site in Fresno County from 1990 to 2021 (DPR, 2024).

Site	Bromacil Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	106,590	88,146
LEMON	8,710	6,891
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	7,776	8,125
TANGELO	3,965	2,923
CITRUS FRUITS (ALL OR UNSPEC)	2,367	1,828
GRAPEFRUIT	567	568
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	335	101
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	142	115
REGULATORY PEST CONTROL	127	40
COTTON, GENERAL	51	150
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	20	130
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	12	10
RIGHTS OF WAY	5	1
GRAPES, WINE	4	4
N-GRNHS GRWN PLANTS IN CONTAINERS	4	4
AQUATIC AREAS, WATER AREAS (ALL OR UNSPEC)	3	5
CHINESE RADISH/DAIKON (LOBOK, JAPANESE RADISH)	2	7
GRAPES	2	65

Table 13b. Total bromacil use (pounds) by site in Tulare County from 1990 to 2021 (DPR, 2024).

Site	Bromacil Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	327,289	265,592
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	16,696	13,399
LEMON	11,728	9,046
TANGELO	6,326	4,808
CITRUS FRUITS (ALL OR UNSPEC)	1,949	730
GRAPEFRUIT	906	759
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	439	184
POMELO (SHADDOCK) (CITRUS GRANDIS)	374	354
N-OUTDR CONTAINER/FLD GRWN PLANTS	313	110
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	118	118
BUILDINGS AND STRUCTURES (NON-AG OUTDOOR)	90	45
CORN (FORAGE - FODDER)	1	63

Table 14a. Total diuron use (pounds) by site in Fresno County from 1990 to 2021 (DPR, 2024).

Site	Diuron Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	1,082,552	351,721
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	481,319	360,045
GRAPES	209,158	353,761
COTTON, GENERAL	133,156	3,861,527
GRAPES, WINE	44,471	73,874
ASPARAGUS (SPEARS, FERNS, ETC.)	29,287	14,337
LEMON	24,456	15,193
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	20,276	14,934
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	13,387	13,846
OLIVE (ALL OR UNSPEC)	10,868	6,904
CITRUS FRUITS (ALL OR UNSPEC)	6,377	3,699
TANGELO	6,078	4,158
COMMERCIAL, INSTITUTIONAL OR INDUSTRIAL AREAS	4,491	1,353
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	4,362	1,983
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	2,206	1,252
GRAPEFRUIT	2,204	1,639
PEACH	1,083	1,226
APPLE	1,024	1,019
N-OUTDR CONTAINER/FLD GRWN PLANTS	616	1,206
IRRIGATION SYSTEMS (DITCHES, CANAL BANKS, ETC.)	500	60
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	310	674
WHEAT, GENERAL	285	388
PECAN	268	180
RIGHTS OF WAY	175	118
ALMOND	150	118
ANIMAL HUSBANDRY PREMISES	140	30
PEAR	126	119
OATS, GENERAL	100	72
REGULATORY PEST CONTROL	65	40
NECTARINE	30	97
RANGELAND (ALL OR UNSPEC)	23	11
ORNAMENTAL TURF (ALL OR UNSPEC)	17	18
SORGHUM/MILO GENERAL	16	16
TOMATO	15	597
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	14	35
INDUSTRIAL SITES (LUMBER YARDS, TANK FARMS, ETC.)	13	4
TOMATOES, FOR PROCESSING/CANNING	12	655
LANDSCAPE MAINTENANCE	10	3

Site	Diuron Use (pounds)	Application Area (acres)
PASTURES (ALL OR UNSPEC)	10	5
BOYSENBERRY (BOYSENS)	6	7
APRICOT	5	12
N-GRNHS GRWN PLANTS IN CONTAINERS	4	4
PERSIMMON	4	7
AQUATIC AREAS, WATER AREAS (ALL OR UNSPEC)	3	5
CORN (FORAGE - FODDER)	3	87
CORN, HUMAN CONSUMPTION	3	62
CHINESE RADISH/DAIKON (LOBOK, JAPANESE RADISH)	2	7
ONION (DRY, SPANISH, WHITE, YELLOW, RED, ETC.)	2	45

Table 14b. Total diuron use (pounds) by site in Tulare County from 1990 to 2021 (DPR, 2024).

Site	Diuron Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	2,233,334	1,264,371
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	473,844	341,053
OLIVE (ALL OR UNSPEC)	213,213	147,212
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	177,706	141,916
LEMON	90,379	48,701
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	86,504	45,247
GRAPES	73,623	106,572
COTTON, GENERAL	73,284	1,136,020
GRAPES, WINE	57,675	47,057
TANGELO	19,156	10,879
GRAPEFRUIT	12,638	7,197
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	7,383	2,124
CITRUS FRUITS (ALL OR UNSPEC)	6,543	3,332
PECAN	2,565	2,277
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	2,239	1,143
POMELO (SHADDOCK) (CITRUS GRANDIS)	2,127	1,360
CORN (FORAGE - FODDER)	2,091	2,309
APPLE	1,107	963
N-OUTDR CONTAINER/FLD GRWN PLANTS	992	358
PEAR	701	505
WHEAT, GENERAL	623	1,709
PEACH	234	393
SOIL APPLICATION, PREPLANT-OUTDOOR (SEEDBEDS,ETC.)	123	84
BEANS, DRIED-TYPE	115	204

Site	Diuron Use (pounds)	Application Area (acres)
BUILDINGS AND STRUCTURES (NON-AG OUTDOOR)	103	47
RIGHTS OF WAY	95	19
CORN, FIELD, DENT (GRAIN CROP)	93	59
PASTURES (ALL OR UNSPEC)	82	60
ALMOND	77	25
IRRIGATION SYSTEMS (DITCHES, CANAL BANKS, ETC.)	41	19
POMEGRANATE (MISCELLANEOUS FRUIT)	19	12
NECTARINE	18	16
PISTACHIO (PISTACHE NUT)	15	15
OATS, GENERAL	13	5
RANGELAND (ALL OR UNSPEC)	8	10
AIRPORTS AND LANDING FIELDS (RUNWAYS, ETC.)	4	15
AQUATIC AREAS, WATER AREAS (ALL OR UNSPEC)	4	2
BEANS (ALL OR UNSPEC)	2	69
RESEARCH COMMODITY	1	14

Table 15a. Total norflurazon use (pounds) by site in Fresno County from 1990 to 2021 (DPR, 2024).

Site	Norflurazon Use (pounds)	Application Area (acres)
GRAPES	224,004	310,732
ALMOND	72,857	68,096
GRAPES, WINE	61,795	88,562
ORANGE (ALL OR UNSPEC)	52,888	37,456
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	42,815	45,249
NECTARINE	39,399	41,916
PEACH	27,596	28,985
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	11,160	7,796
PRUNE	9,749	7,343
APPLE	7,469	6,134
ASPARAGUS (SPEARS, FERNS, ETC.)	5,556	2,481
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	4,968	3,580
APRICOT	3,288	3,243
BLUEBERRY	3,070	1,728
LEMON	1,953	898
CITRUS FRUITS (ALL OR UNSPEC)	1,346	791
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	695	871
PEAR	685	451

Site	Norflurazon Use (pounds)	Application Area (acres)
CHERRY	492	519
GRAPEFRUIT	446	262
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	323	114
TANGELO	157	108
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	52	87
BLACKBERRY	36	39
PECAN	29	35
PISTACHIO (PISTACHE NUT)	20	13
N-OUTDR CONTAINER/FLD GRWN PLANTS	9	23
N-GRNHS GRWN PLANTS IN CONTAINERS	1	2

Table 15b. Total norflurazon use (pounds) by site in Tulare County from 1990 to 2021 (DPR, 2024).

Site	Norflurazon Use (pounds)	Application Area (acres)
ORANGE (ALL OR UNSPEC)	167,050	88,348
ALFALFA (FORAGE - FODDER) (ALFALFA HAY)	138,566	95,144
PLUM (INCLUDES WILD PLUMS FOR HUMAN CONSUMPTION)	56,531	46,886
WALNUT (ENGLISH WALNUT, PERSIAN WALNUT)	24,644	18,274
GRAPES	23,678	24,269
TANGERINE (MANDARIN, SATSUMA, MURCOTT, ETC.)	23,447	11,342
PRUNE	22,599	20,717
NECTARINE	21,316	21,656
ALMOND	17,988	14,629
PEACH	14,911	16,556
GRAPES, WINE	11,234	9,327
GRAPEFRUIT	5,621	2,697
CITRUS FRUITS (ALL OR UNSPEC)	5,190	2,133
LEMON	5,032	2,305
BLUEBERRY	4,846	2,889
N-OUTDR CONTAINER/FLD GRWN PLANTS	2,204	882
CHERRY	2,100	2,082
APPLE	2,086	2,416
PECAN	1,805	1,596
TANGELO	1,419	680
APRICOT	1,201	1,589
UNCULTIVATED AGRICULTURAL AREAS (ALL OR UNSPEC)	837	397
PEAR	583	453

Site	Norflurazon Use (pounds)	Application Area (acres)
UNCULTIVATED NON-AG AREAS (ALL OR UNSPEC)	580	829
AVOCADO (ALL OR UNSPEC)	287	122
POMELO (SHADDOCK) (CITRUS GRANDIS)	200	63
COTTON, GENERAL	120	76
OLIVE (ALL OR UNSPEC)	94	53
CORN (FORAGE - FODDER)	69	70
N-OUTDR GRWN TRNSPLNT/PRPGTV MTRL	36	21
PASTURES (ALL OR UNSPEC)	33	10
N-OUTDR GRWN CUT FLWRS OR GREENS	26	13
PERSIMMON	12	5
BUILDINGS AND STRUCTURES (NON-AG OUTDOOR)	4	5
RESEARCH COMMODITY	4	2
POMEGRANATE (MISCELLANEOUS FRUIT)	1	1

Figure 1. Locations and study identification numbers of 75 domestic wells in the original Well Network in Pest Management Zones (PMZs) in Fresno and Tulare counties along the eastern side of the San Joaquin Valley.

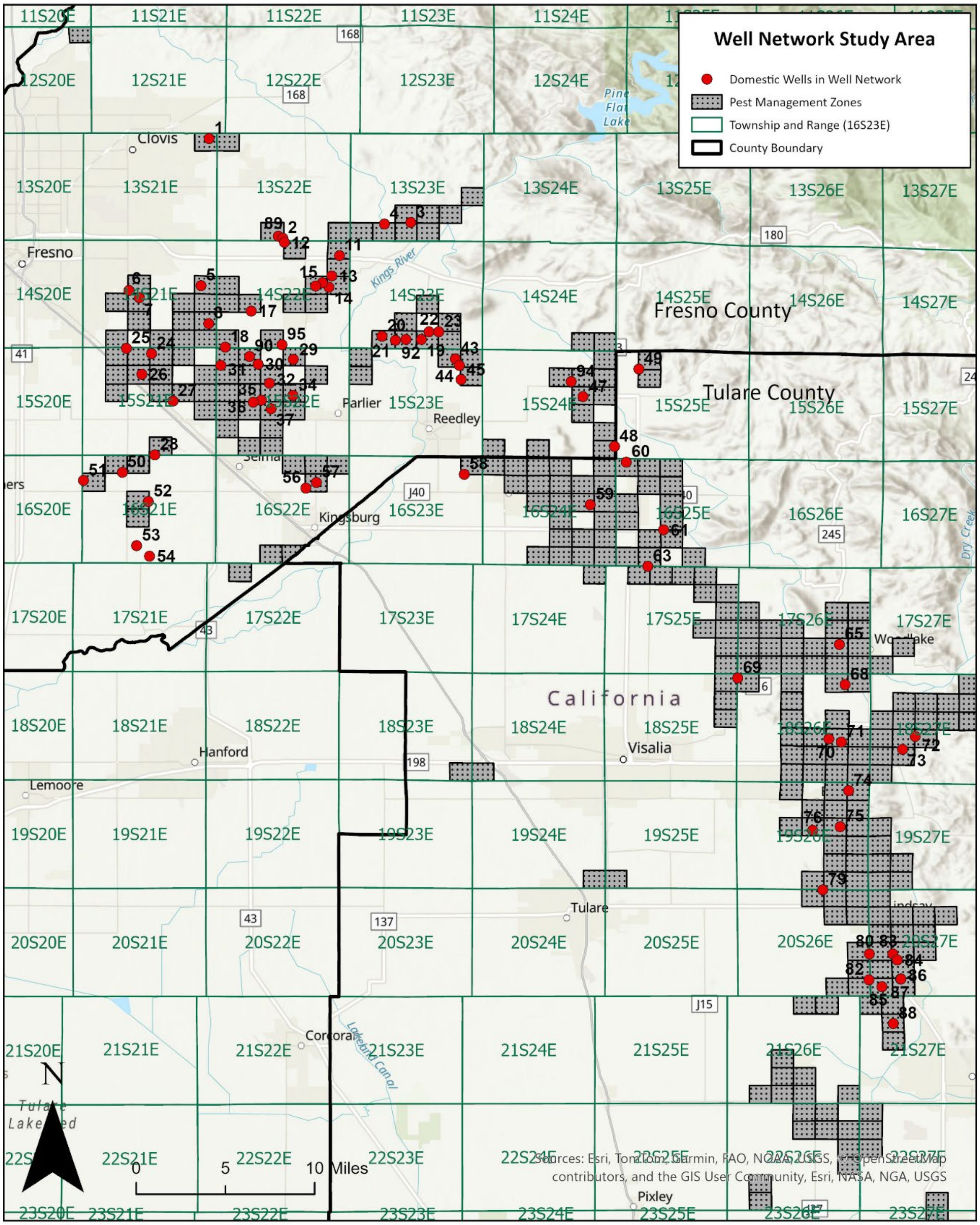


Figure 2. Locations of Groundwater Protection Areas (GWPAs) enacted into regulation in 2004 to replace PMZs.

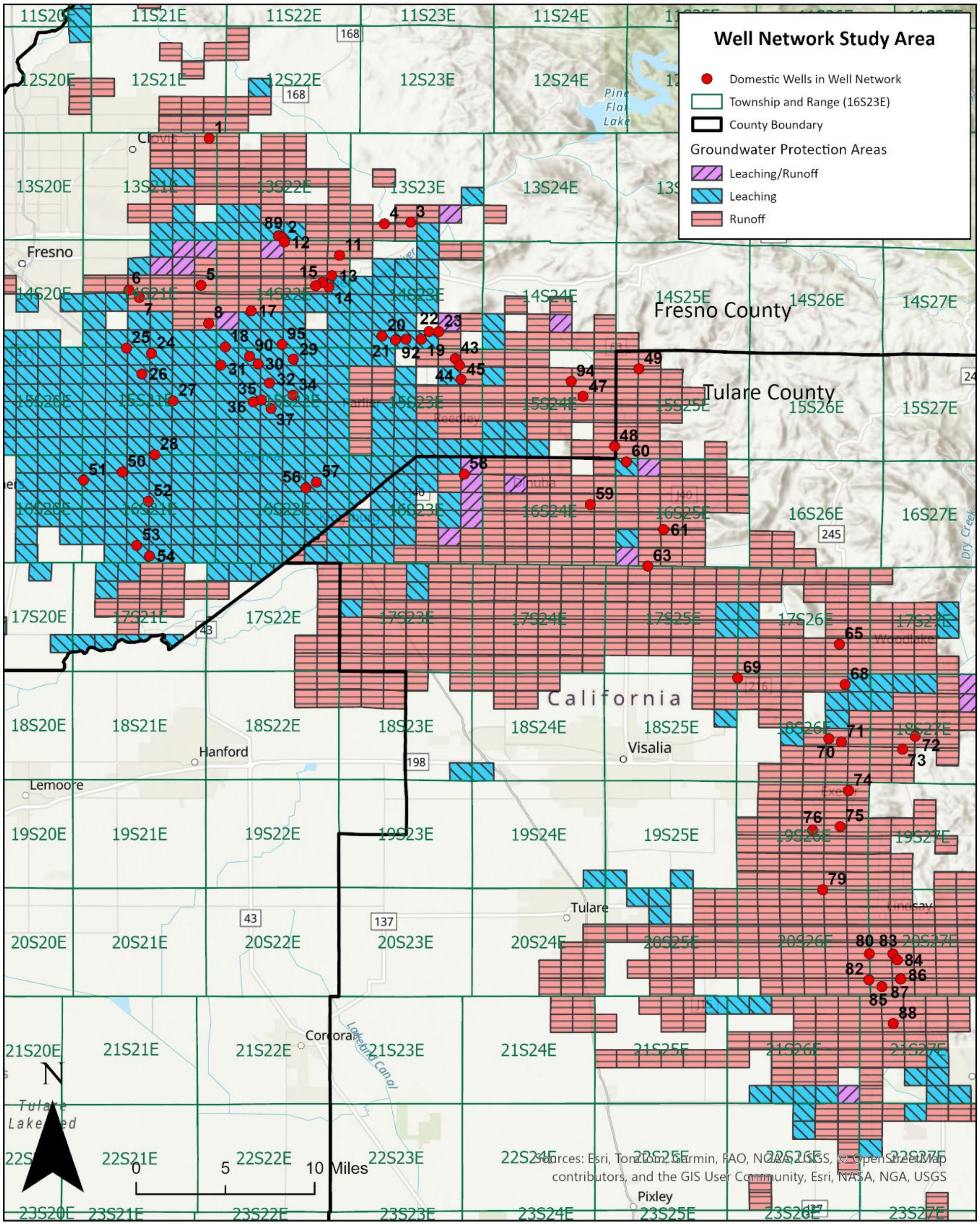


Figure 3. Major land use in the Well Network study area.

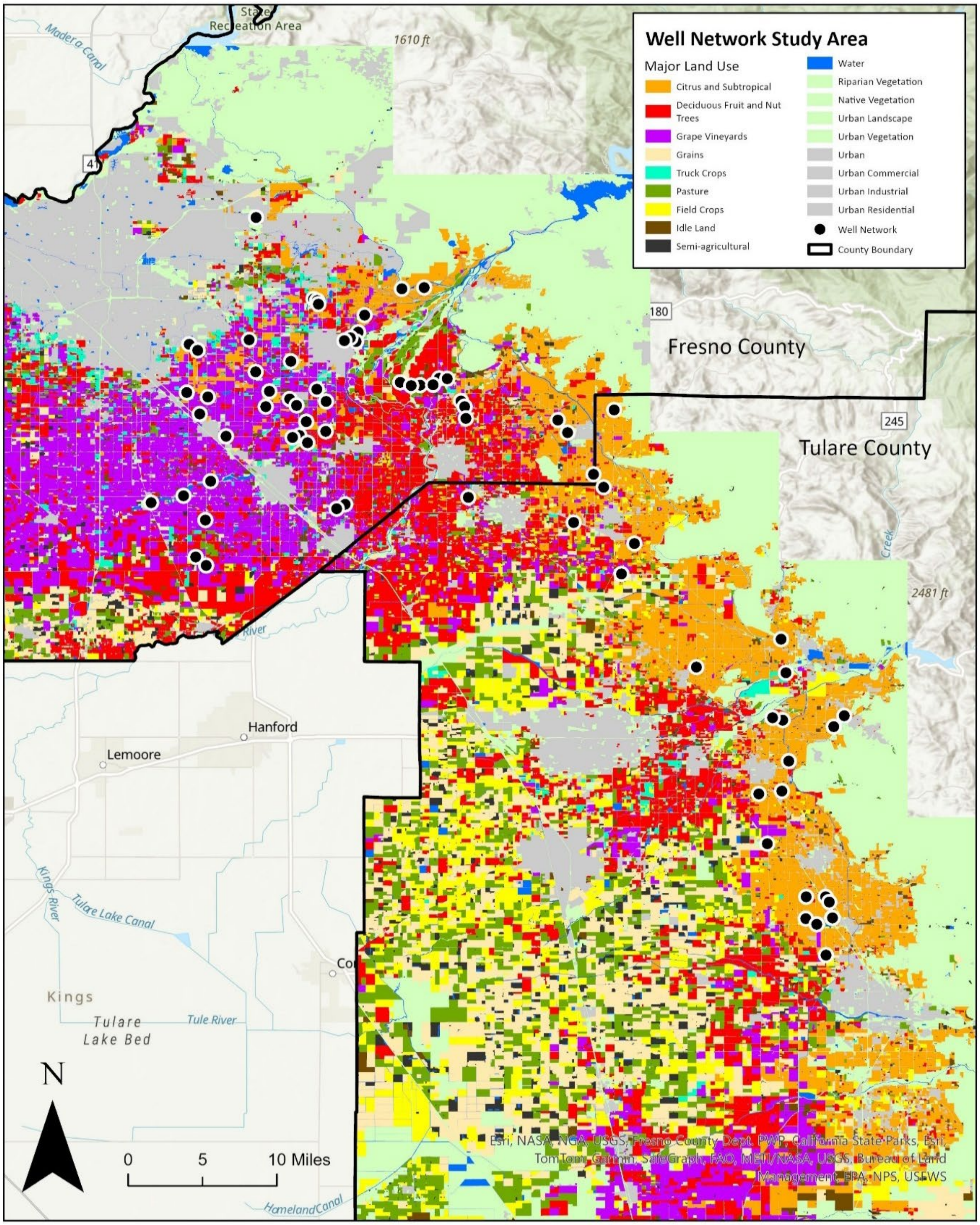


Figure 3 displays the major land use categories in the Well Network study area. The Well Network study area is not enclosed by a well-defined boundary but generally comprises the agricultural regions of eastern Fresno County (east of Fresno) and eastern Tulare County located within the San Joaquin Valley. The most dominant agricultural crops in the region of the study area within eastern Fresno County are grape vineyards, deciduous fruit and nut trees, and citrus and subtropical trees. The most dominant agricultural crops in the region of the study area within eastern Tulare County are citrus and subtropical trees, deciduous fruit and nut trees, and, to a lesser extent, grape vineyards and field crops (corn, beans). The network of domestic wells in the study area is also located in and around several small cities and rural communities. The most notable cities located near monitoring wells within eastern Fresno County are Fowler, Selma, Kingsburg, Sanger, Del Rey, Parlier, Reedley, Orange Cove, and the southeasternmost edge of Fresno. The most notable cities located near monitoring wells within eastern Tulare County are Dinuba, Orosi, Cutler, Ivanhoe, Exeter, Lindsay, Porterville, and Strathmore.

Figure 4. Measured concentrations of five regulated pesticides (atrazine, simazine, bromacil, diuron, norflurazon) and four degradates (DEA, ACET, DACT, DSMN) in Well No. 4 from 1999 to 2022 and estimated concentration trendlines.

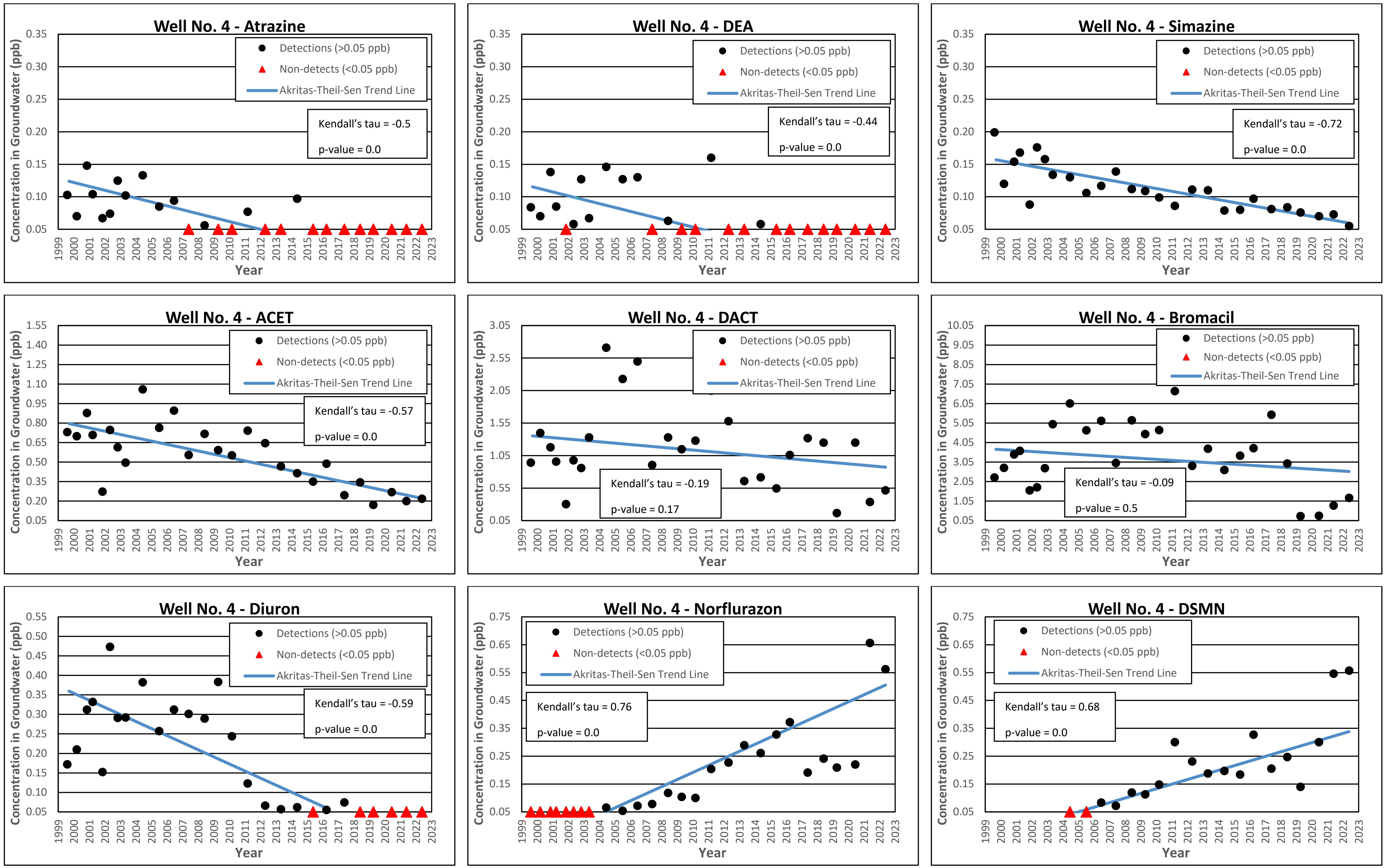


Figure 5. Locations of atrazine-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

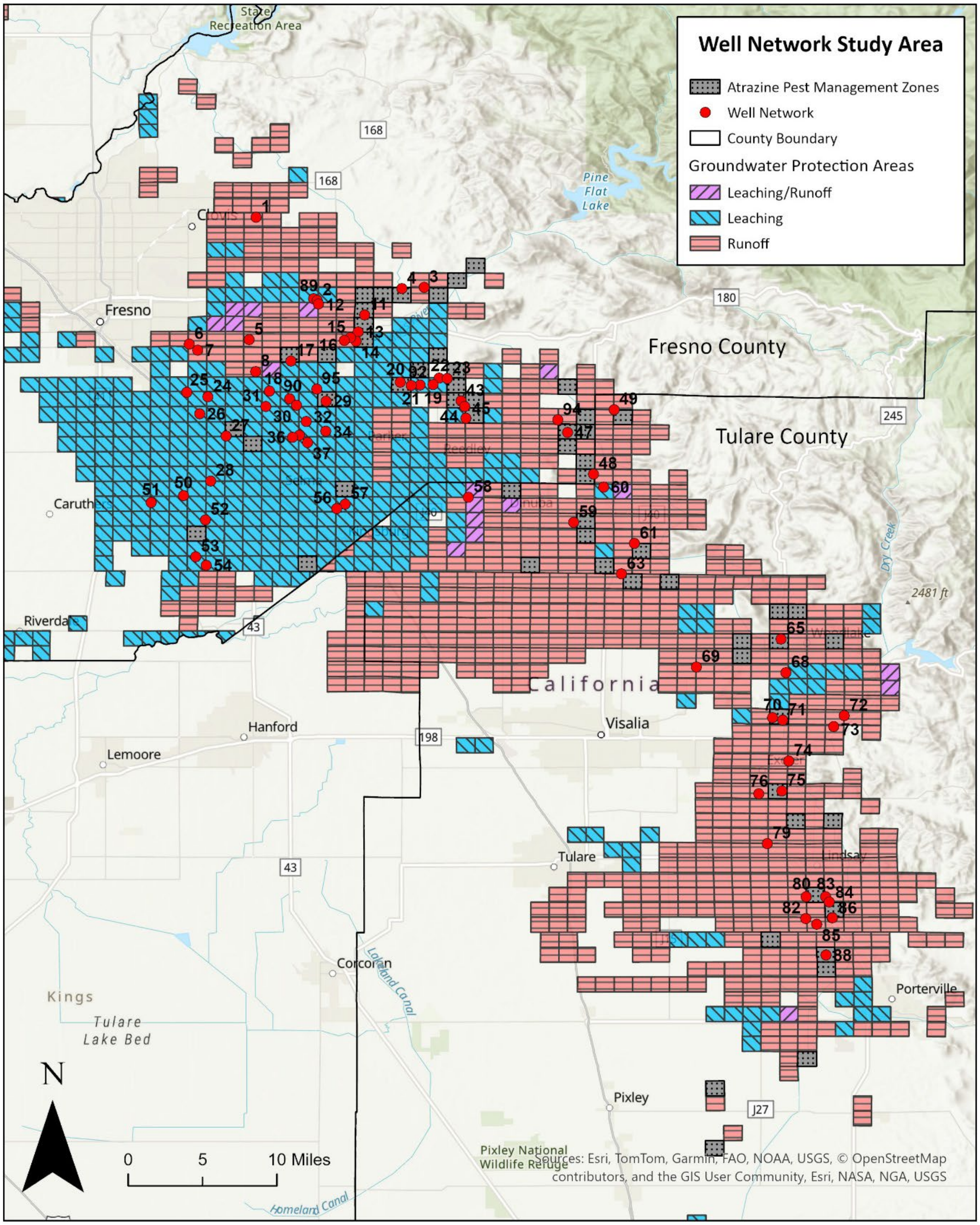


Figure 6a. Annual atrazine use (pounds) in Fresno County from 1990 to 2021.

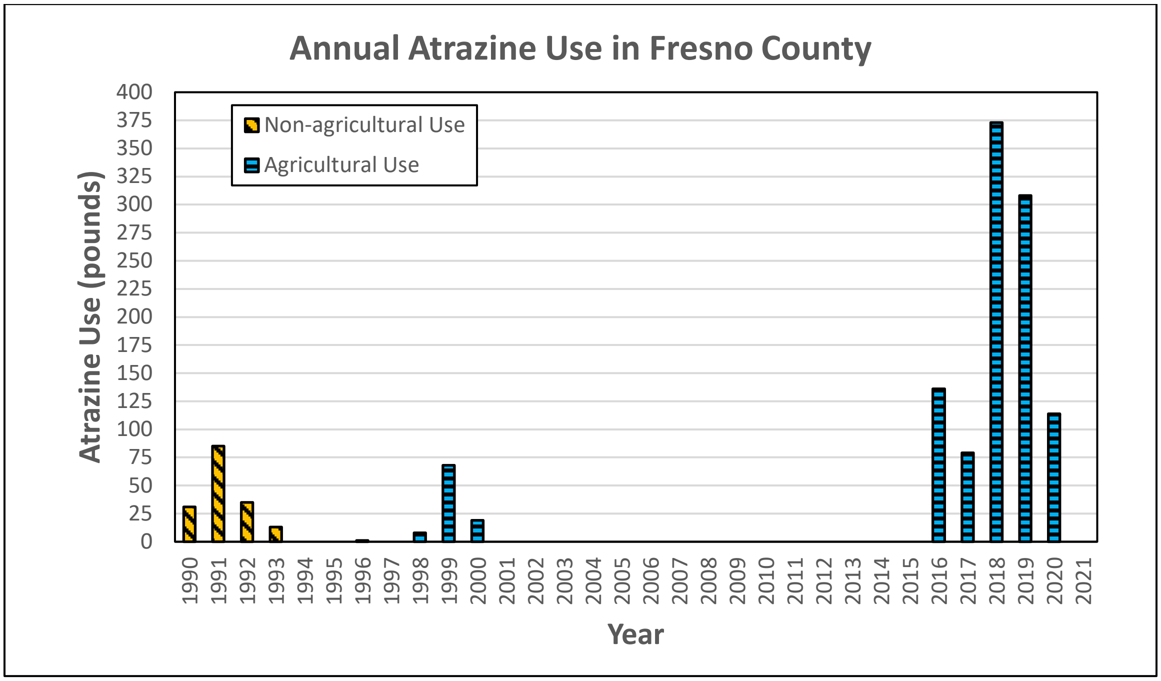


Figure 6b. Annual atrazine use (pounds) in Tulare County from 1990 to 2021.

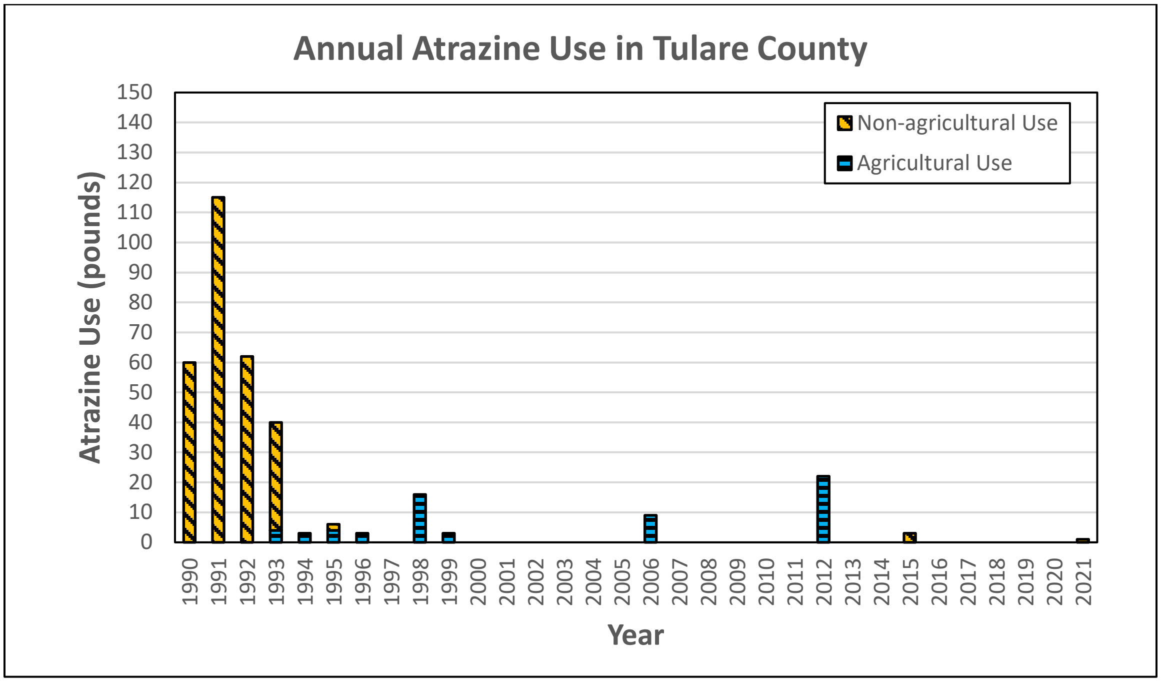


Figure 7. Trend directions of atrazine concentrations in the Well Network and total atrazine use (pounds per section) from 1990 to 2021.

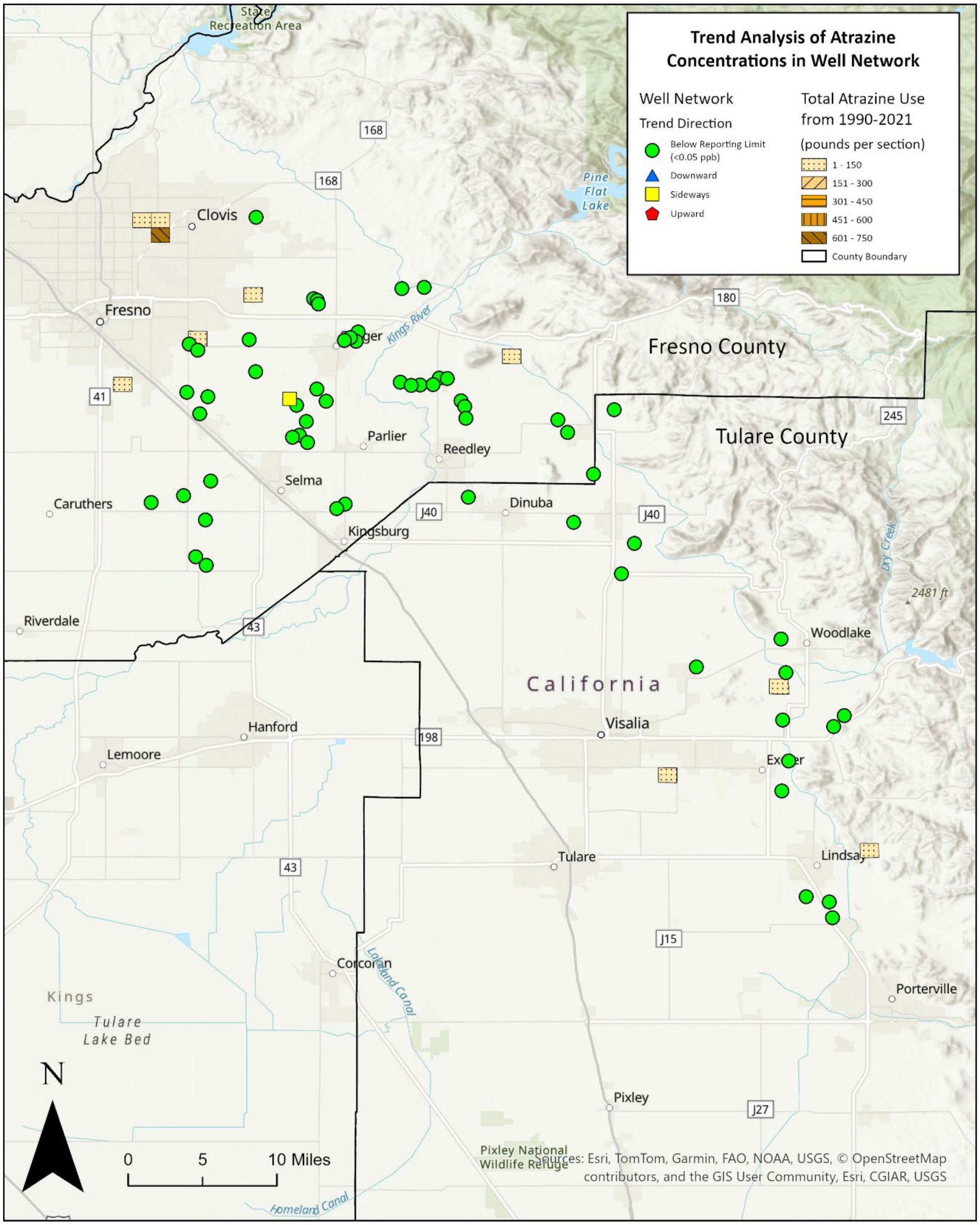


Figure 8. Trend directions of atrazine concentrations in the Well Network relative to GWPAs.

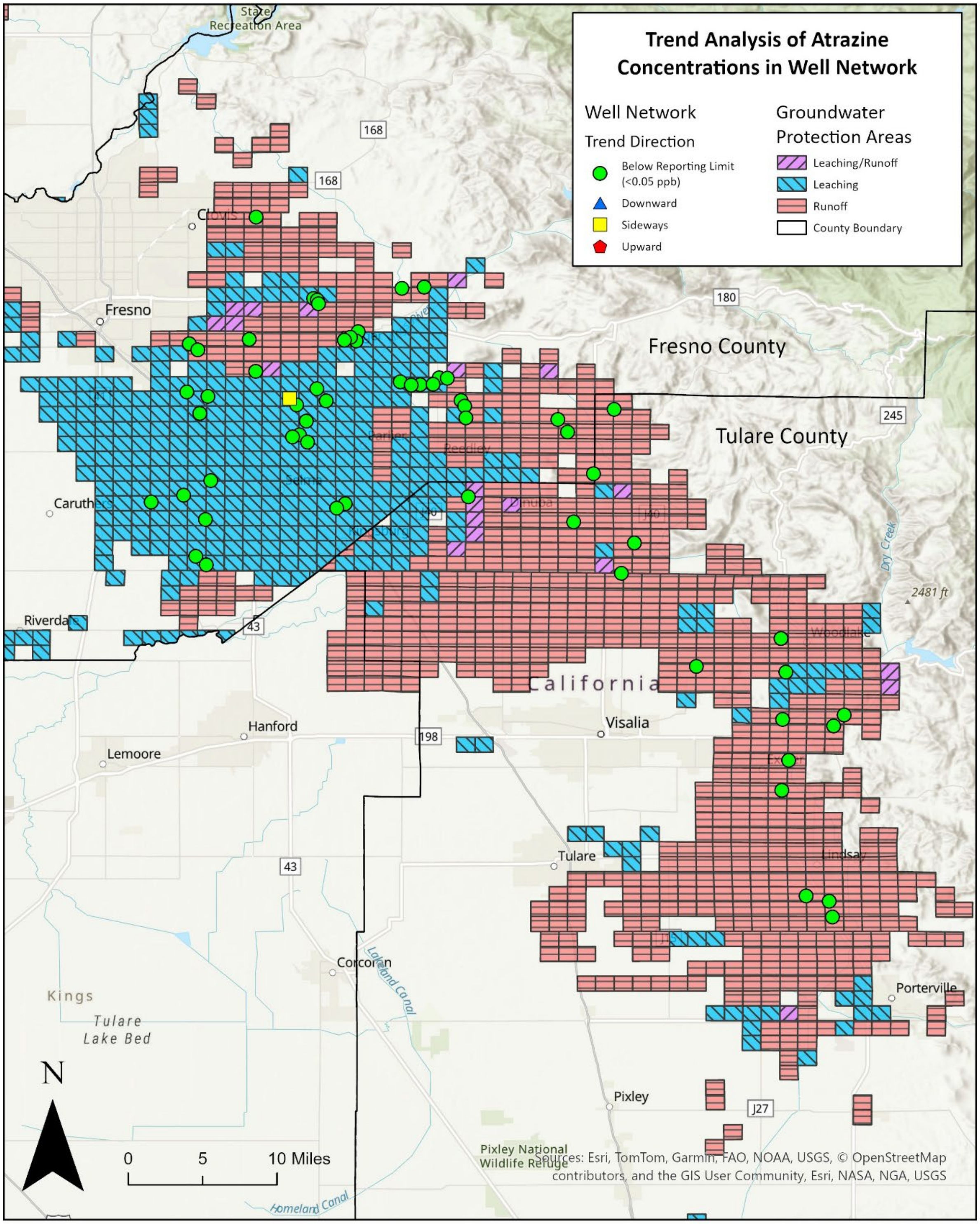


Figure 9. Measured atrazine concentrations in Well Nos. 4, 59/59A, and 90 from 1999 to 2022 and estimated concentration trendlines.

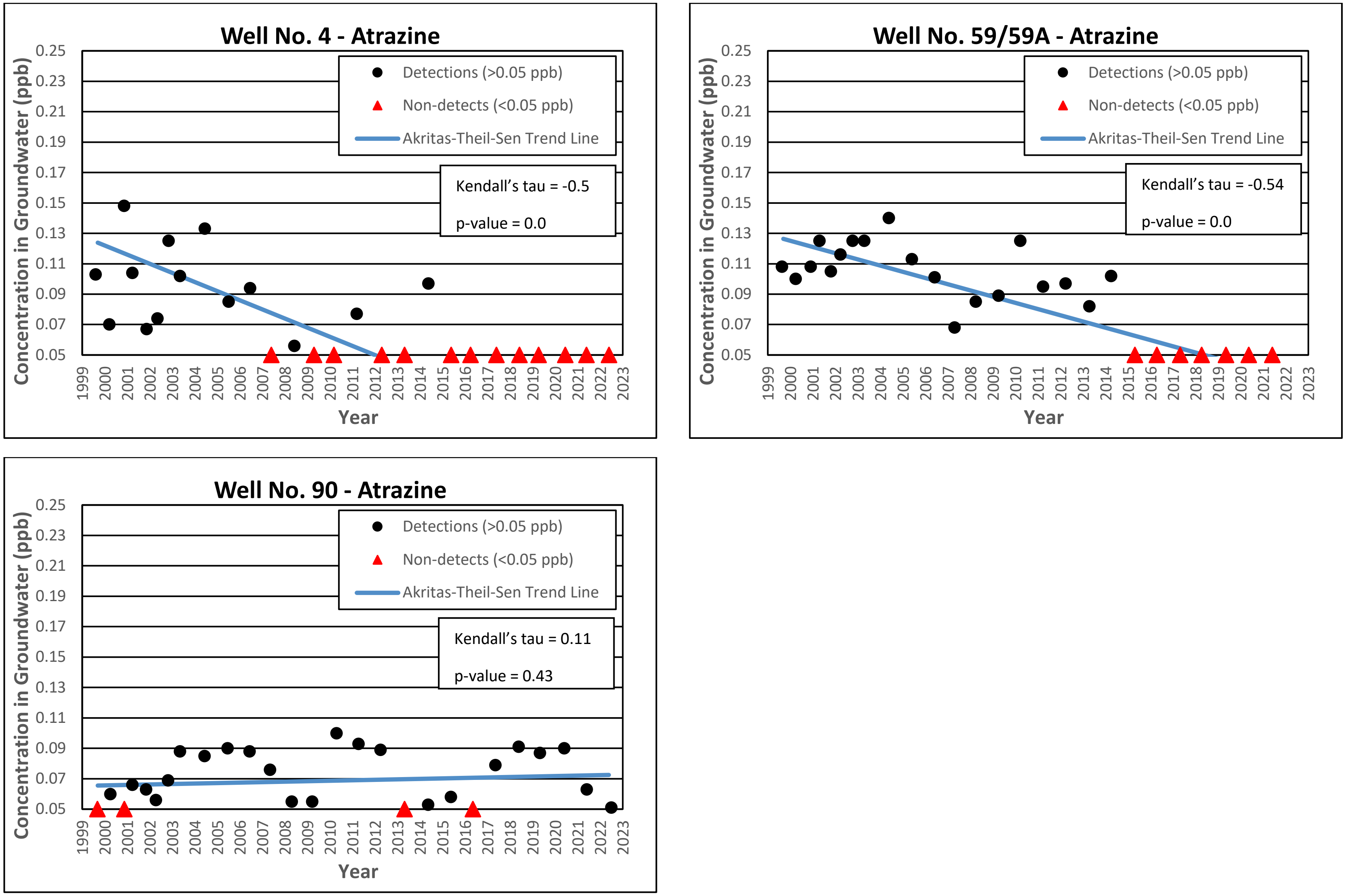


Figure 10. Trend directions of DEA concentrations in the Well Network relative to GWPAs.

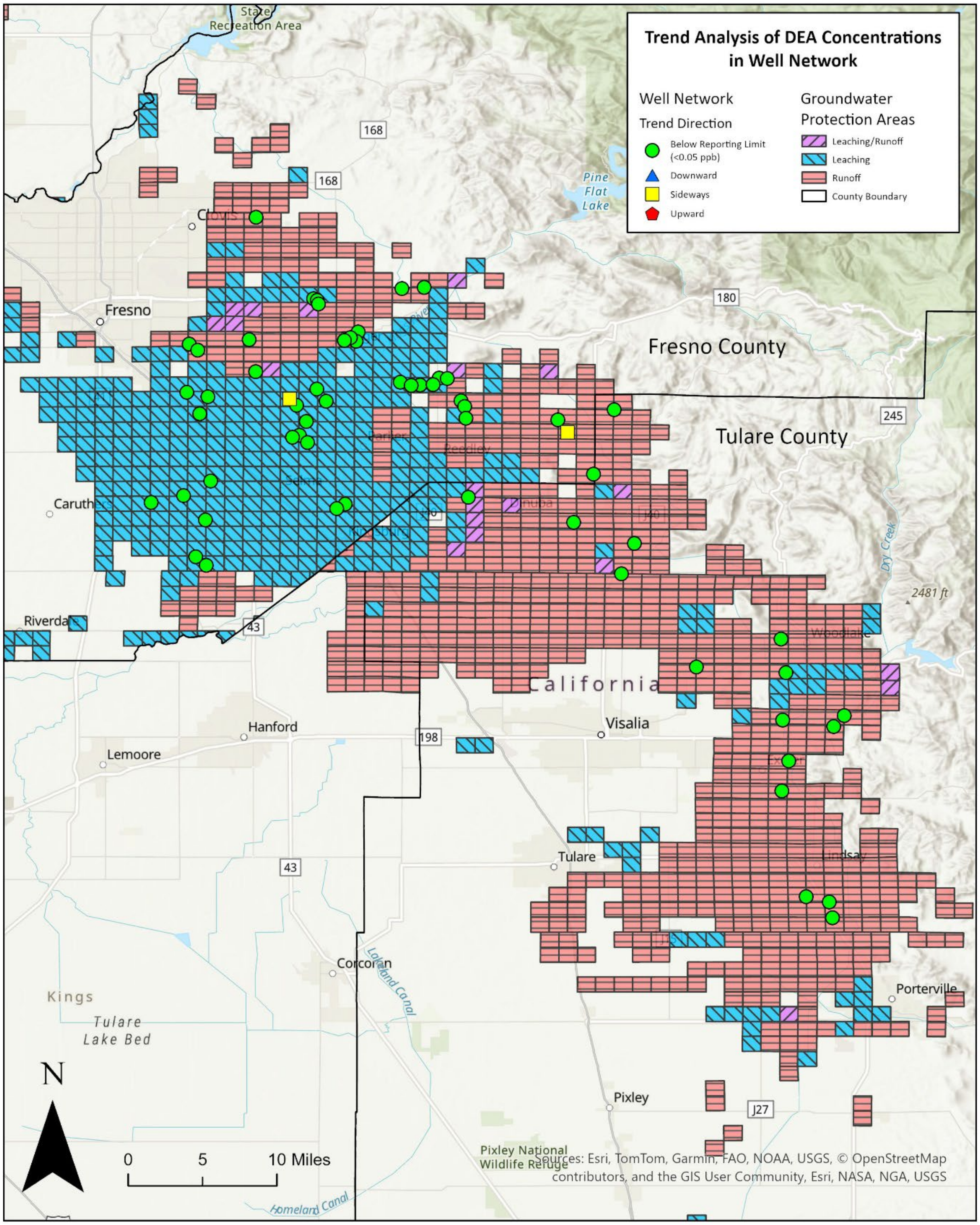


Figure 11. Measured DEA concentrations in Well Nos. 4, 47, 59/59A, and 90 from 1999 to 2022 and estimated concentration trendlines.

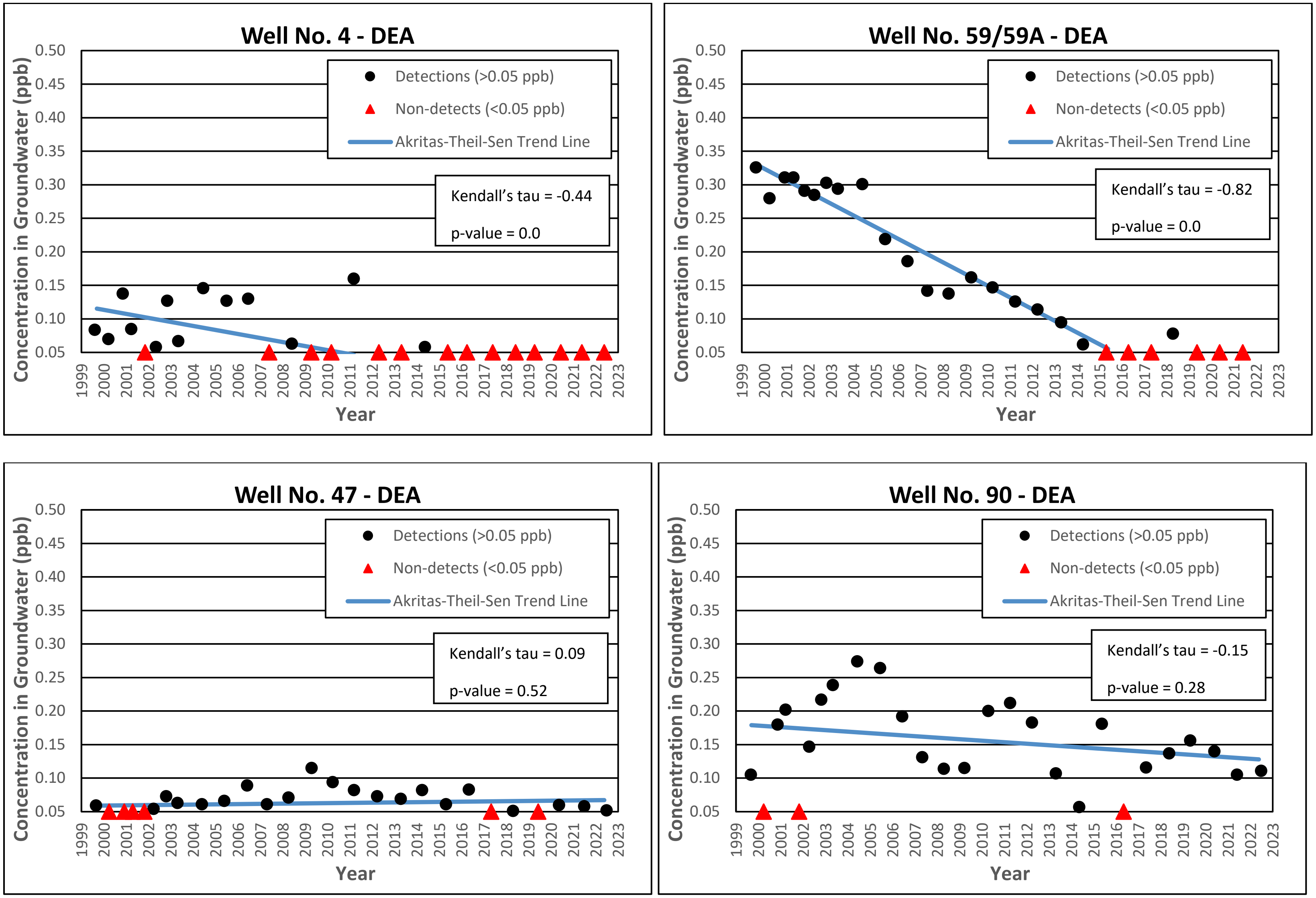


Figure 12. Locations of simazine-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

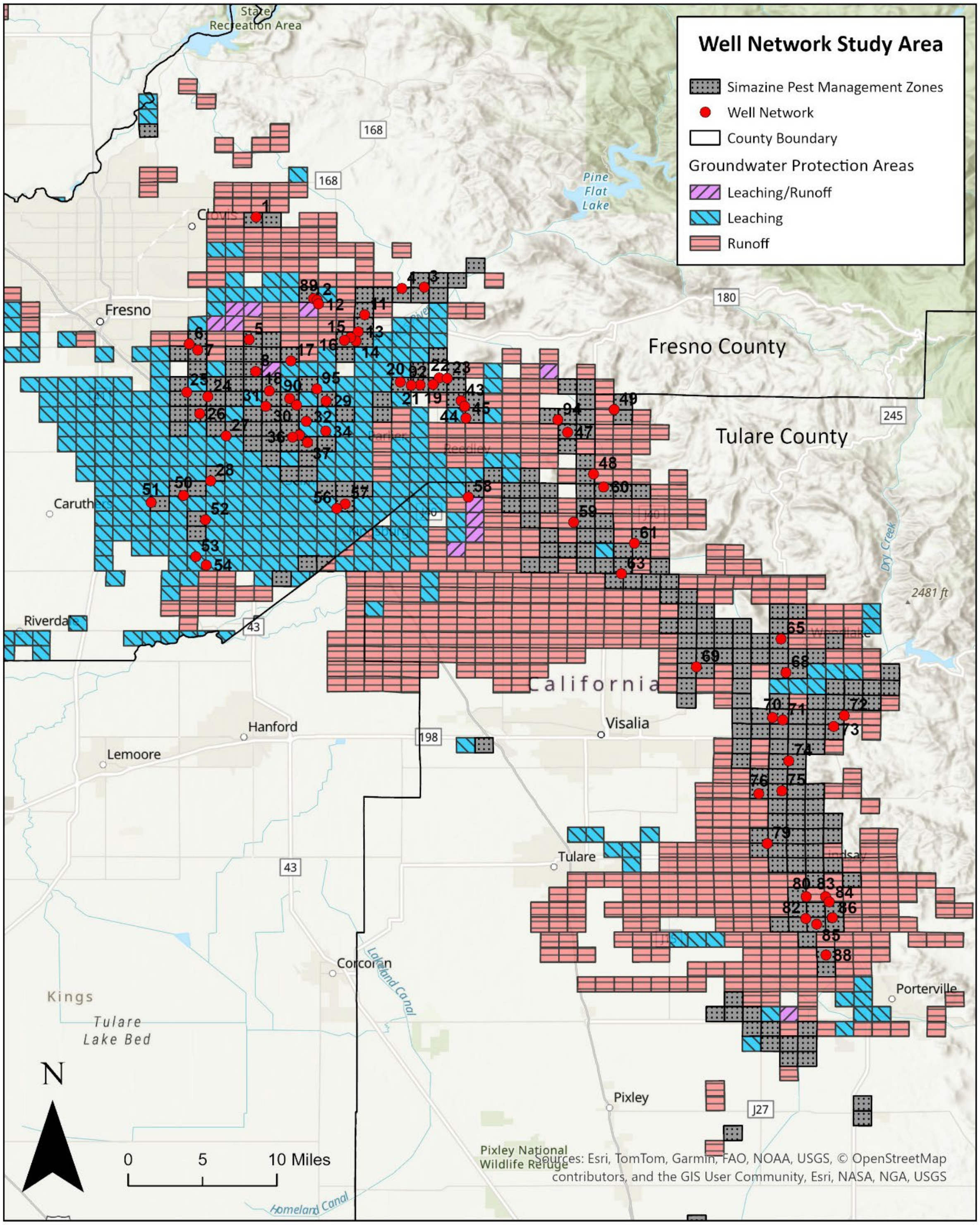


Figure 13a. Annual simazine use (pounds) in Fresno County from 1990 to 2021.

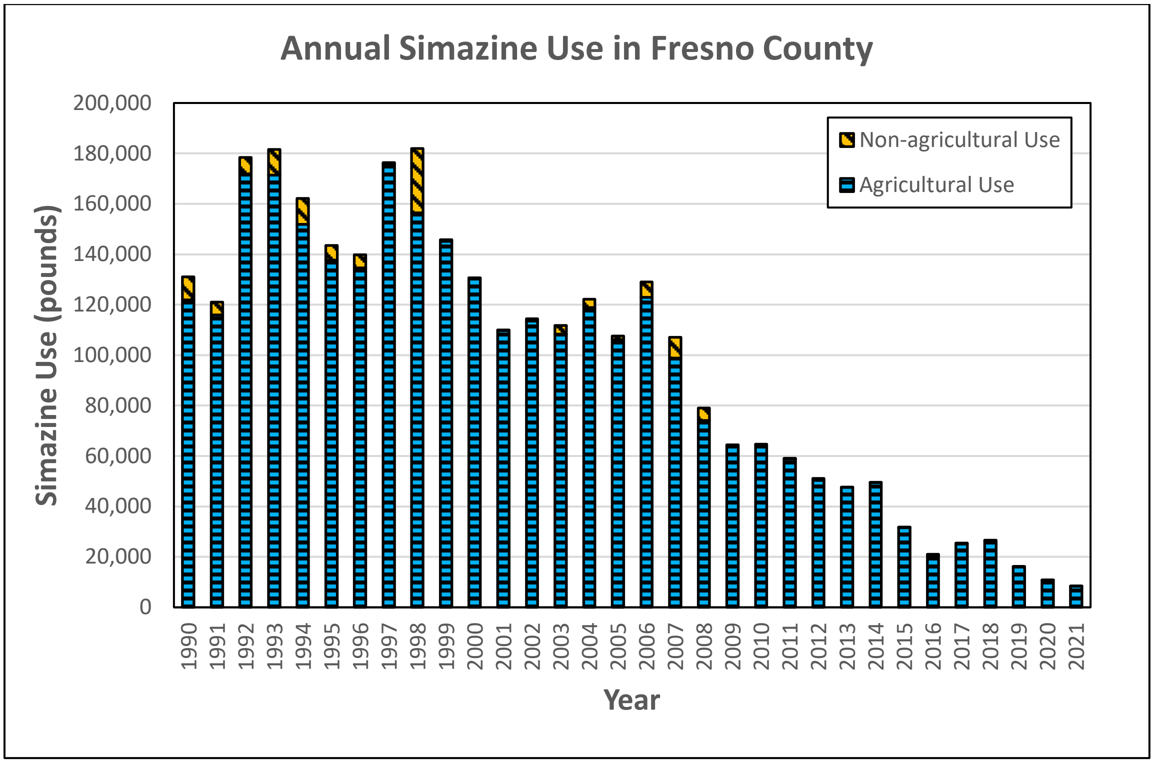


Figure 13b. Annual simazine use (pounds) in Tulare County from 1990 to 2021.

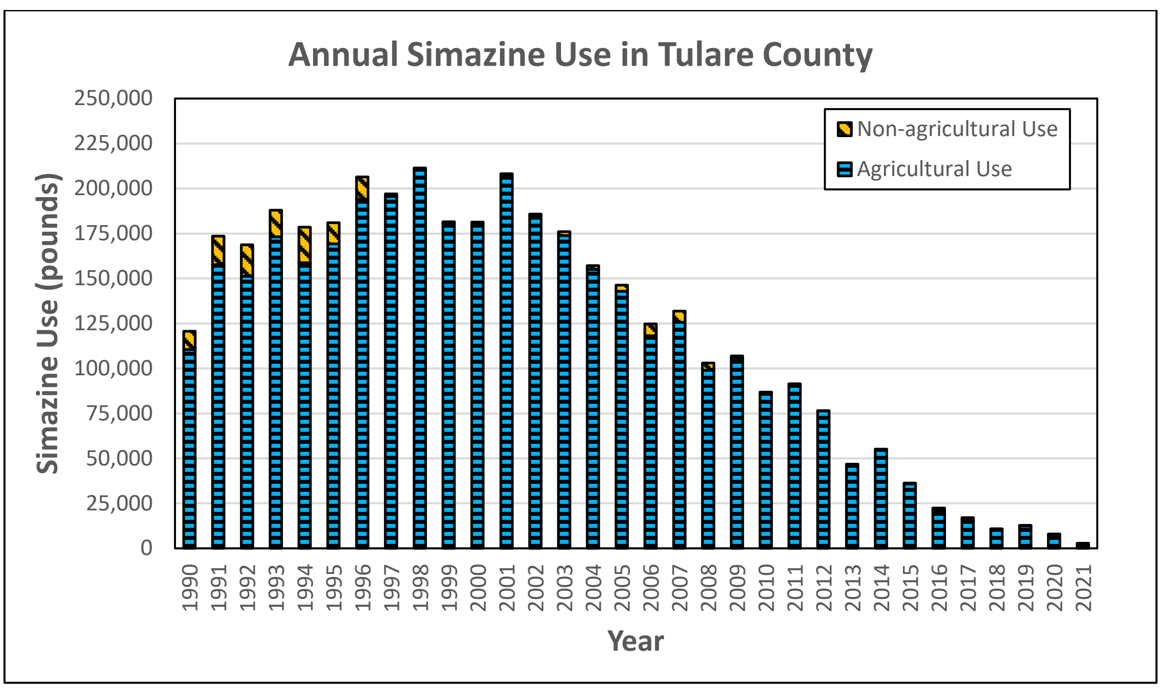


Figure 14. Trend directions of simazine concentrations in the Well Network and total simazine use (pounds per section) from 1990 to 2021.

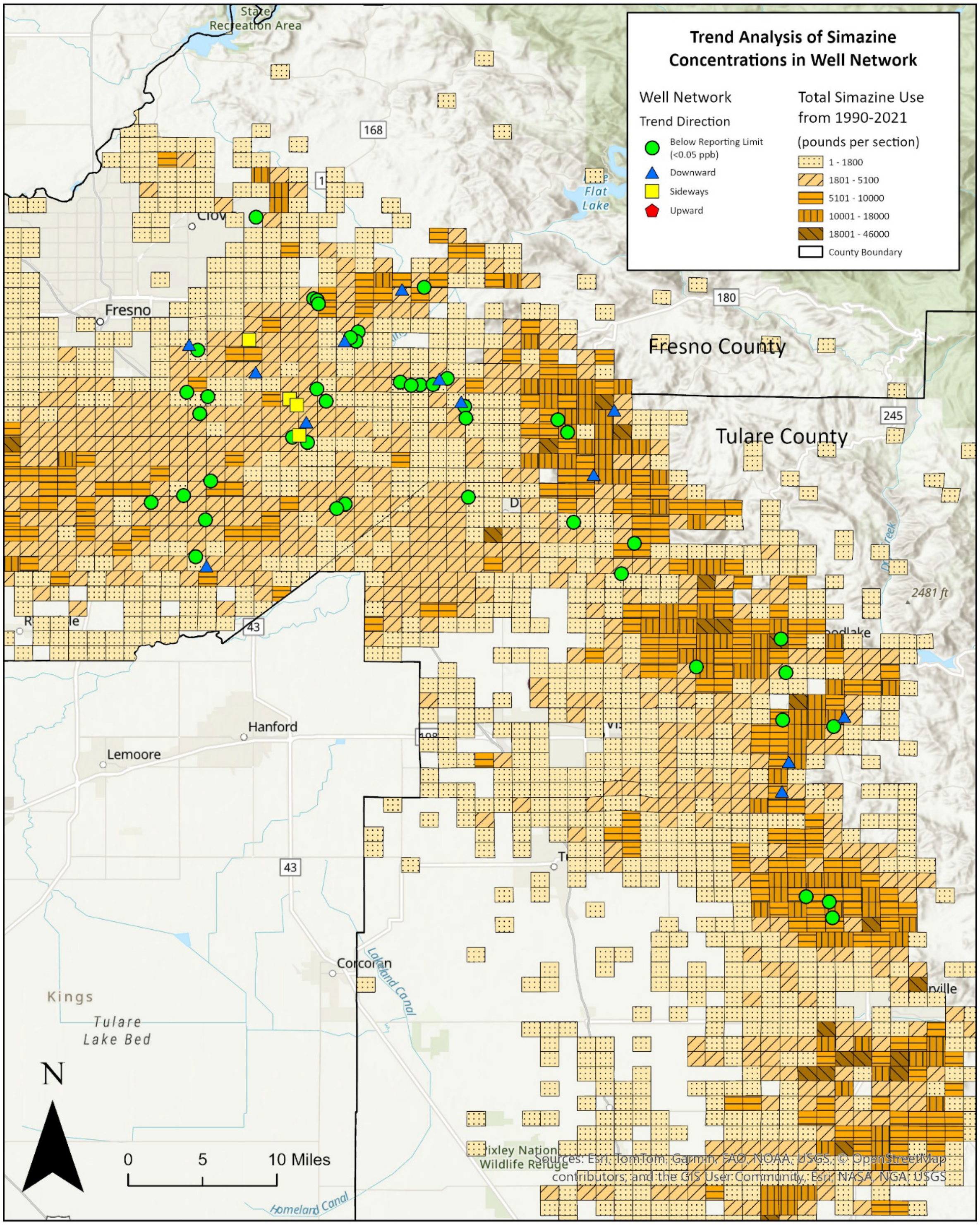


Figure 15. Trend directions of simazine concentrations in the Well Network relative to GWPA locations.

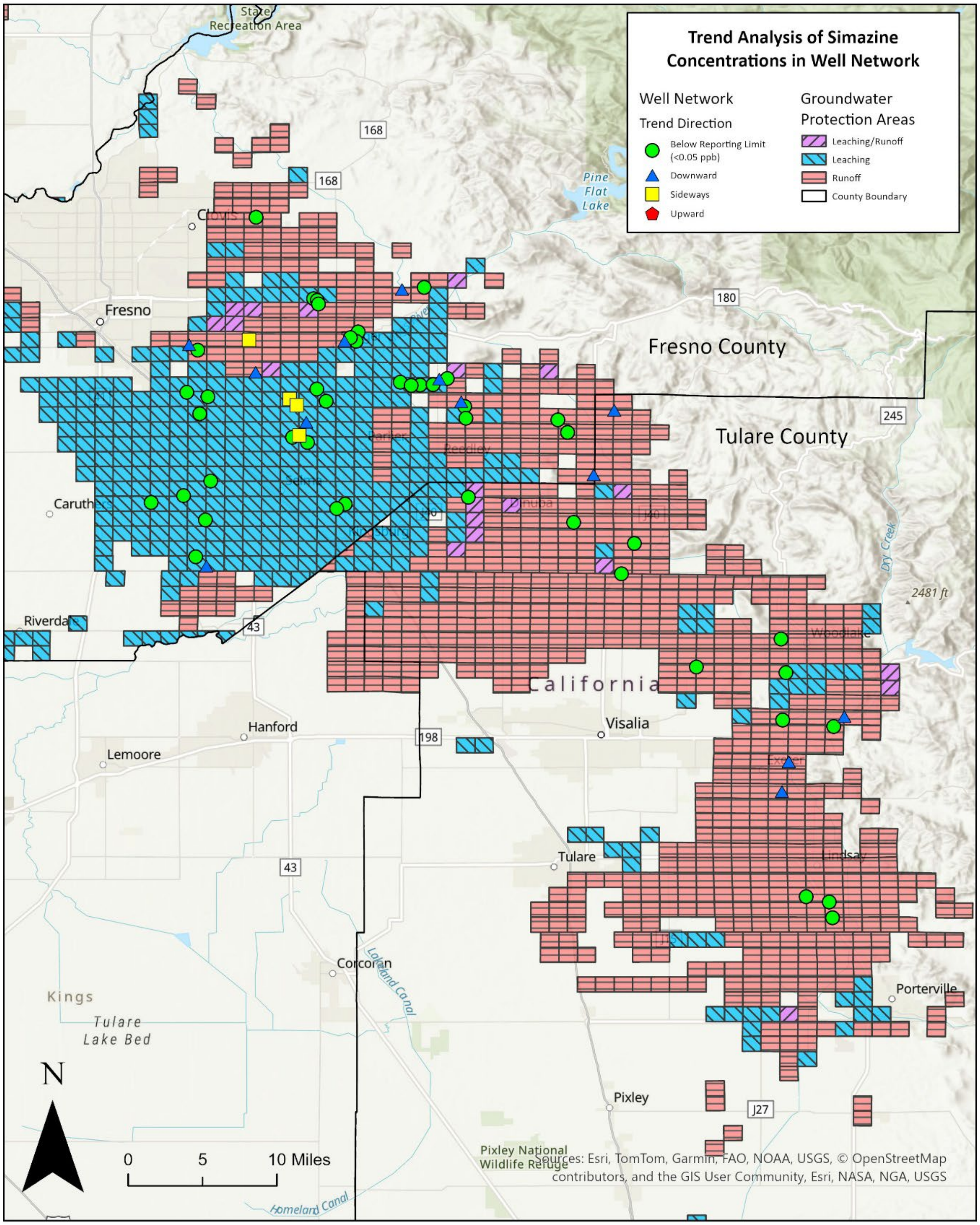


Figure 16. Trend directions of ACET concentrations in the Well Network relative to GWPAs.

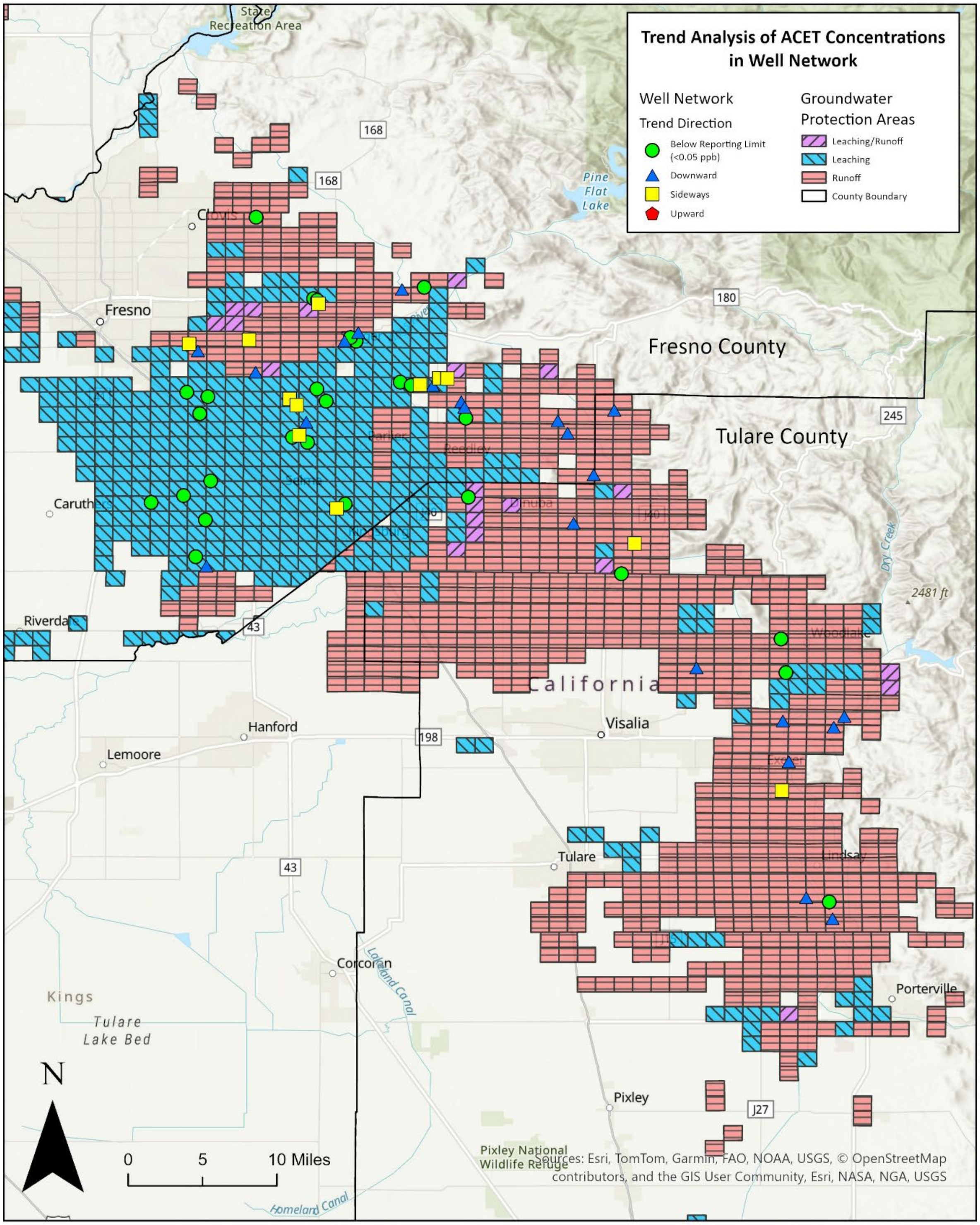


Figure 17. Trend directions of DACT concentrations in the Well Network relative to GWPAs.

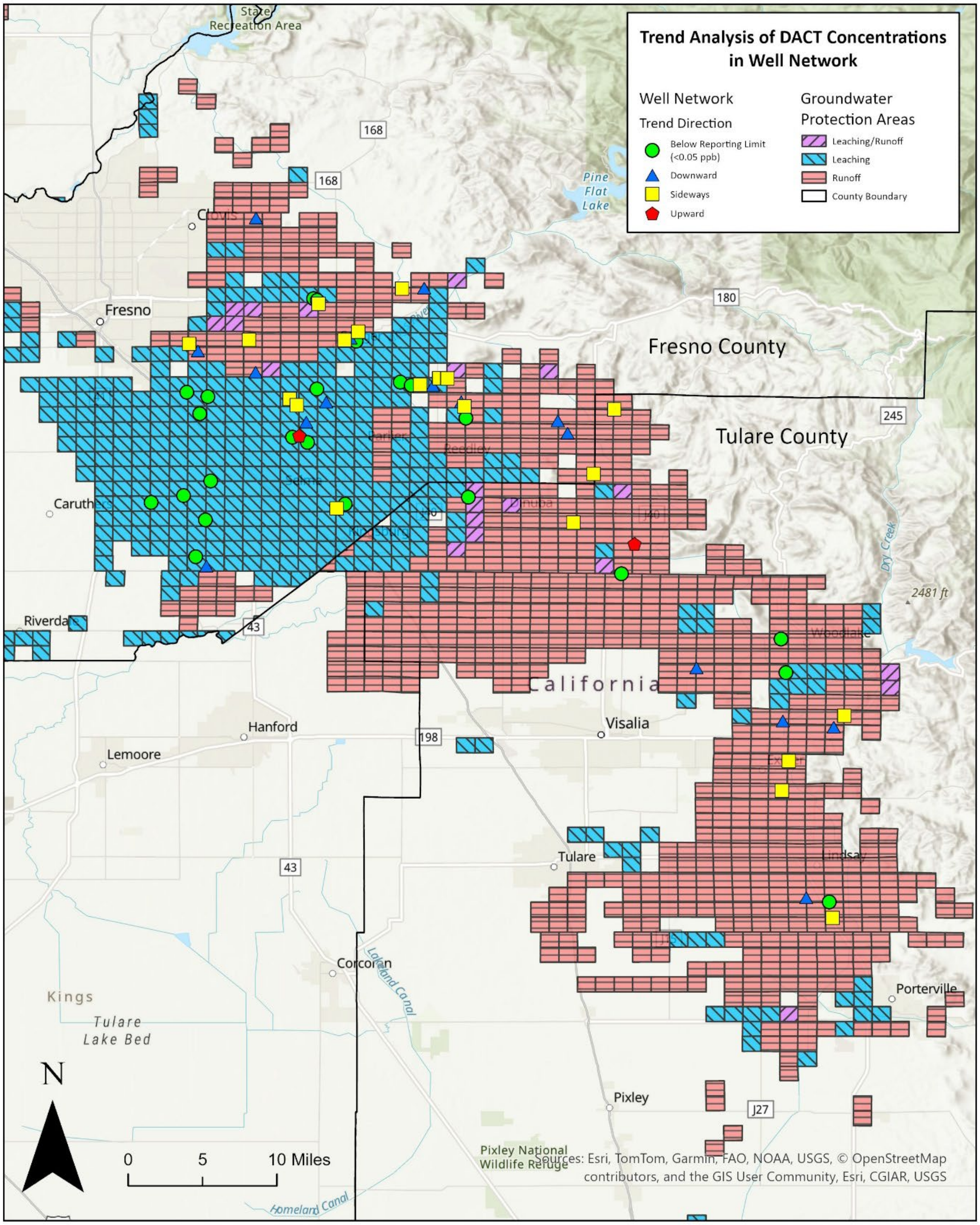


Figure 18. Measured simazine, ACET, and DACT concentrations in Well Nos. 22, 35, and 61 from 1999 to 2022 and estimated concentration trendlines.

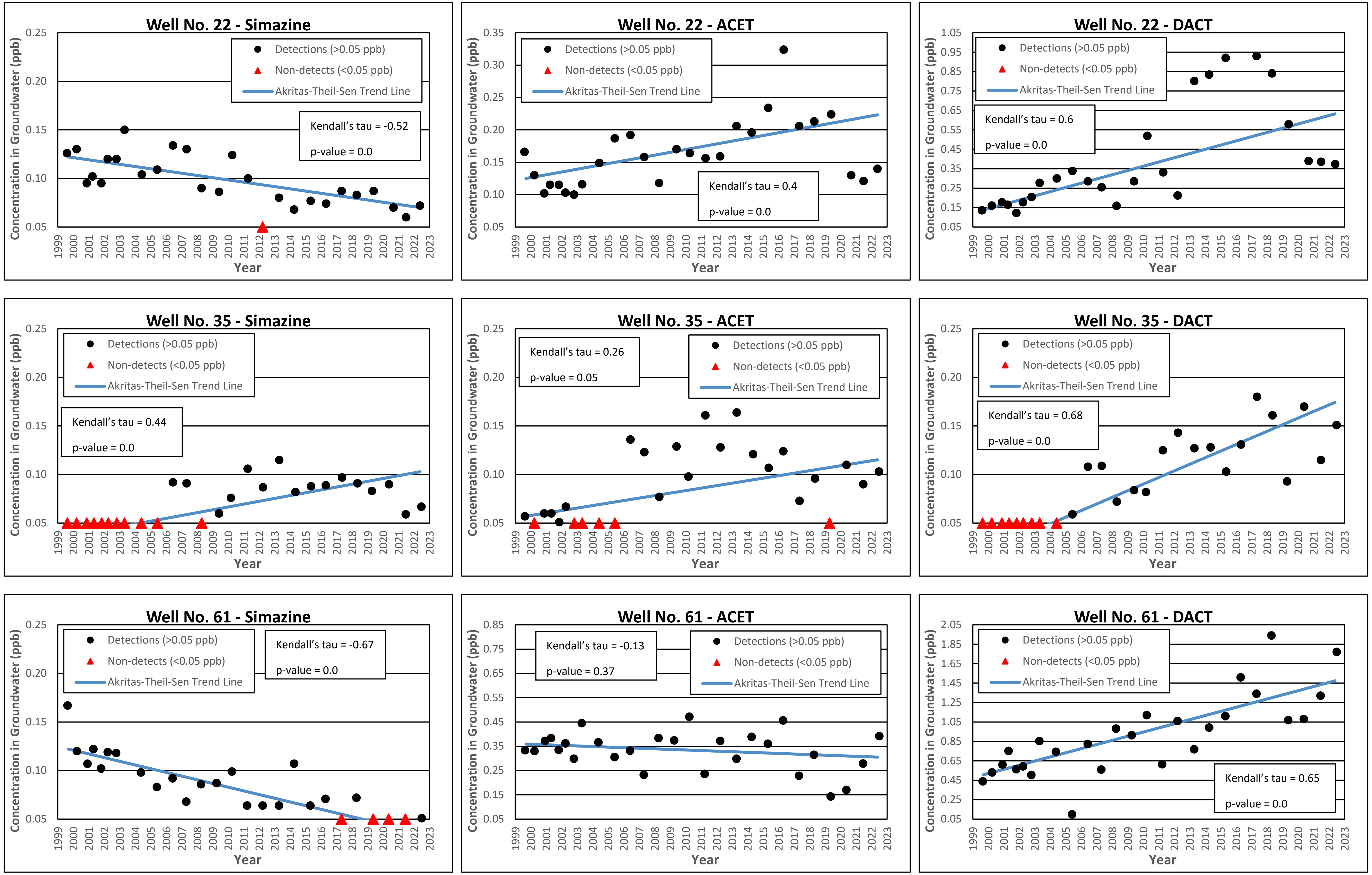


Figure 19. Locations of prometon-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

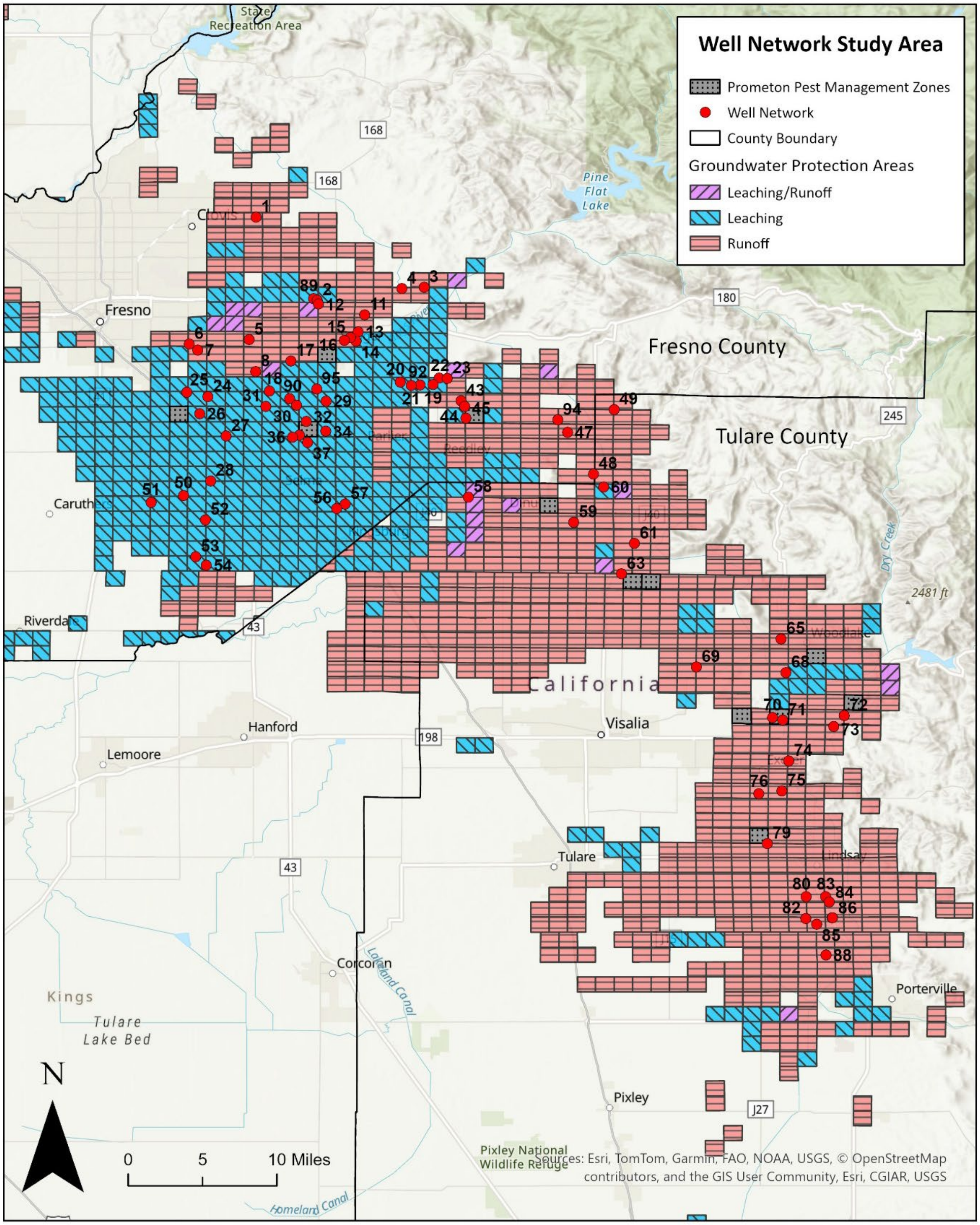


Figure 20. Trend directions of prometon concentrations in the Well Network relative to GWPAs.

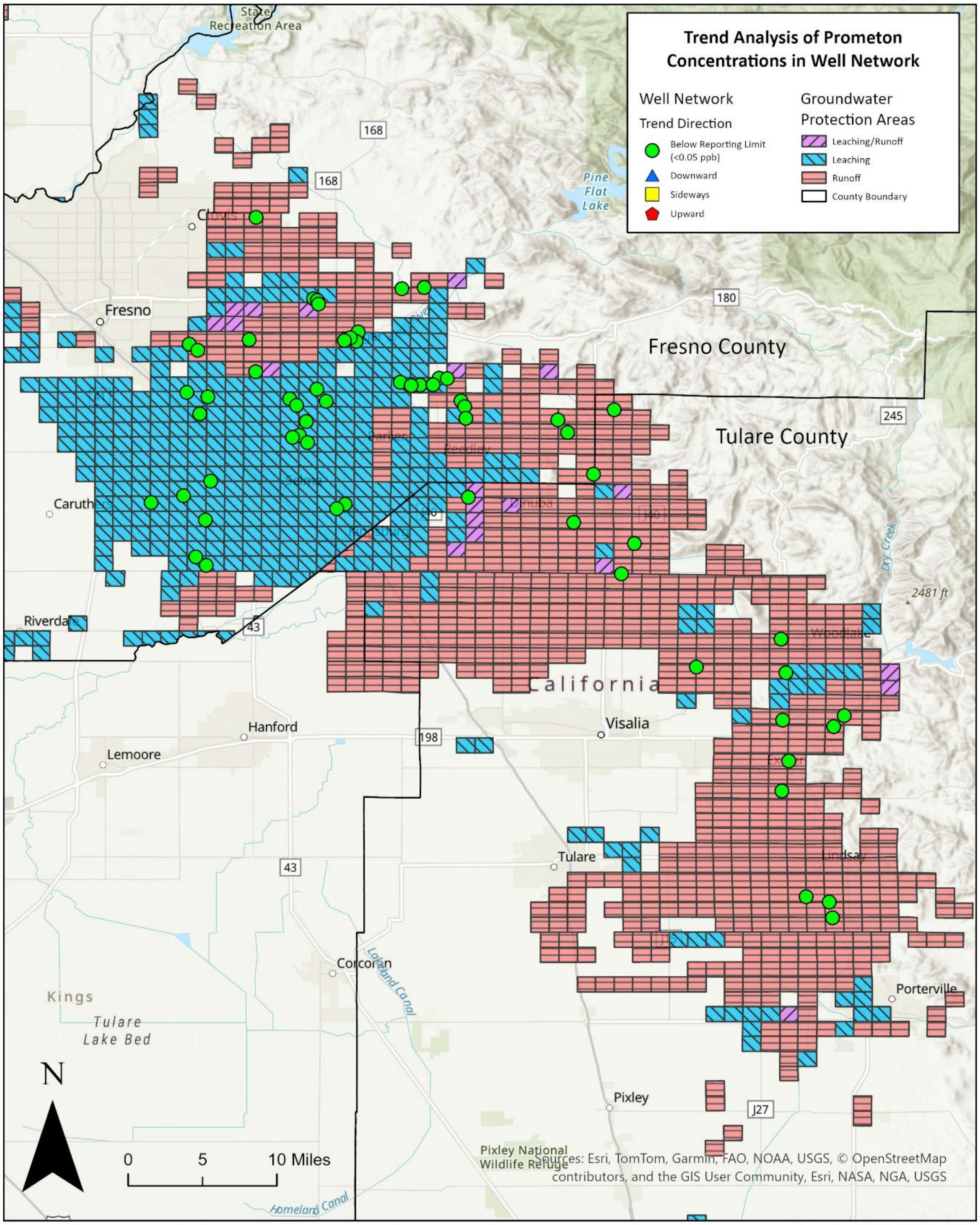
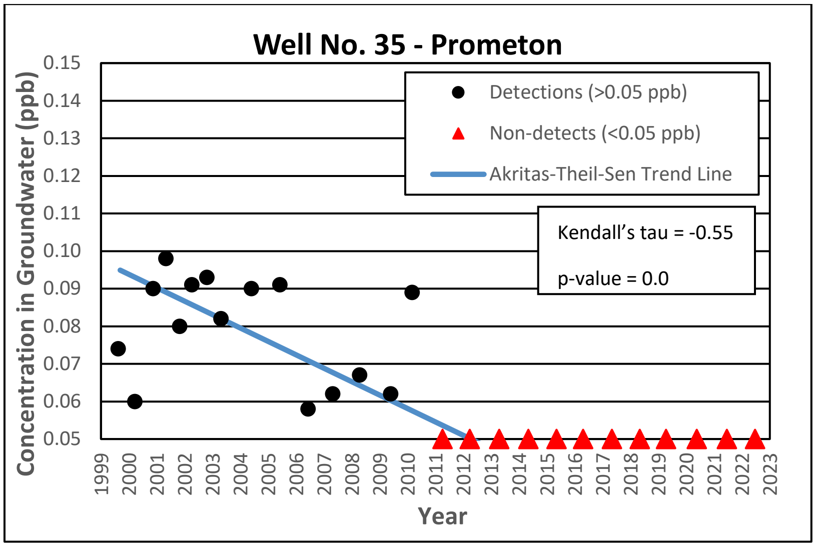


Figure 21. Measured prometon concentrations in Well Nos. 35 and 54 from 1999 to 2022 and estimated concentration trendlines.



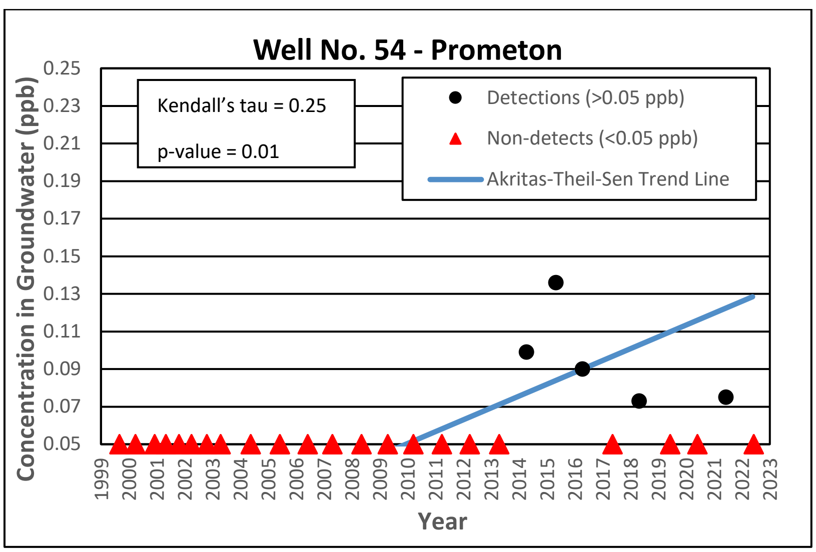


Figure 22. Locations of bromacil-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

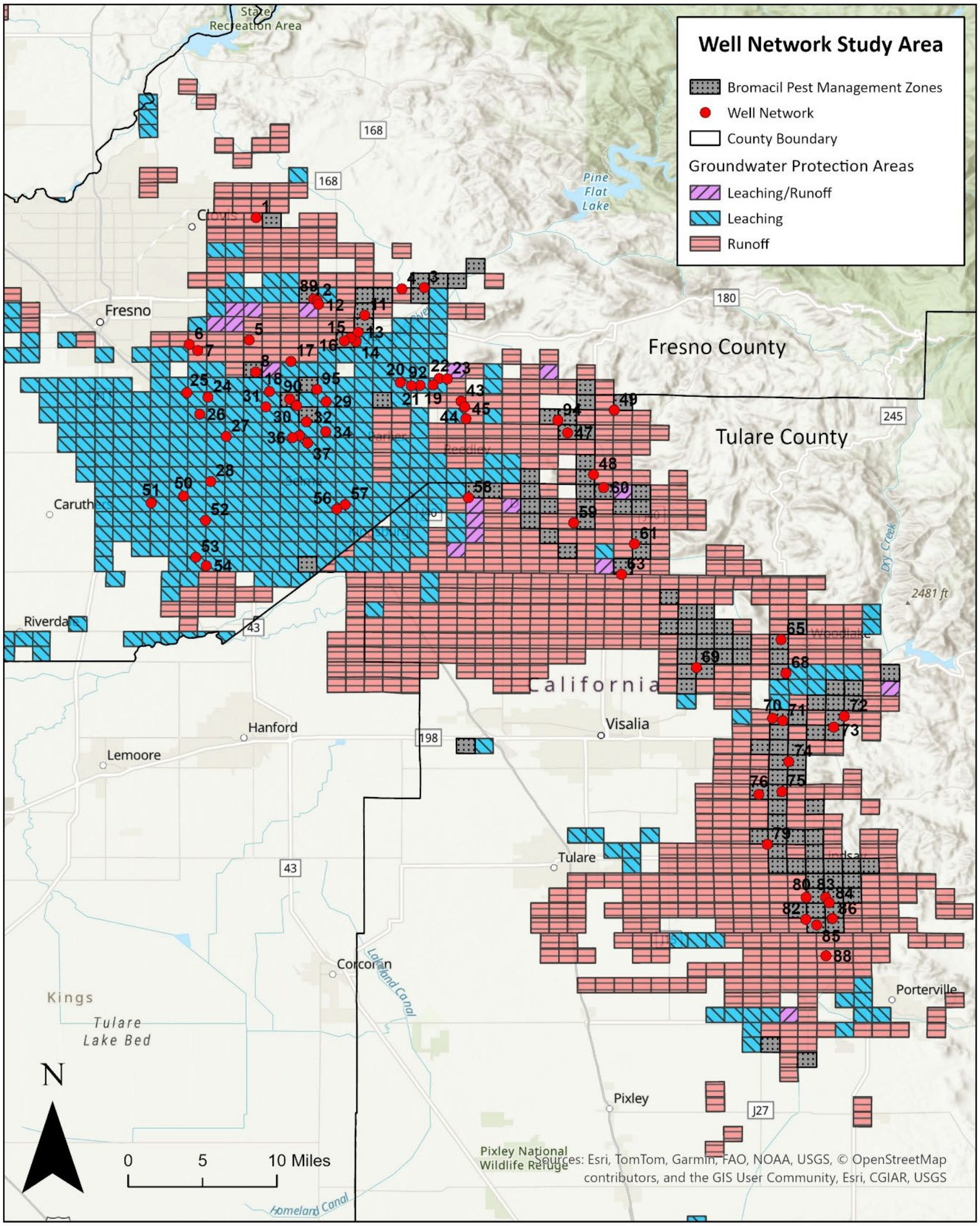


Figure 23a. Annual bromacil use (pounds) in Fresno County from 1990 to 2021.

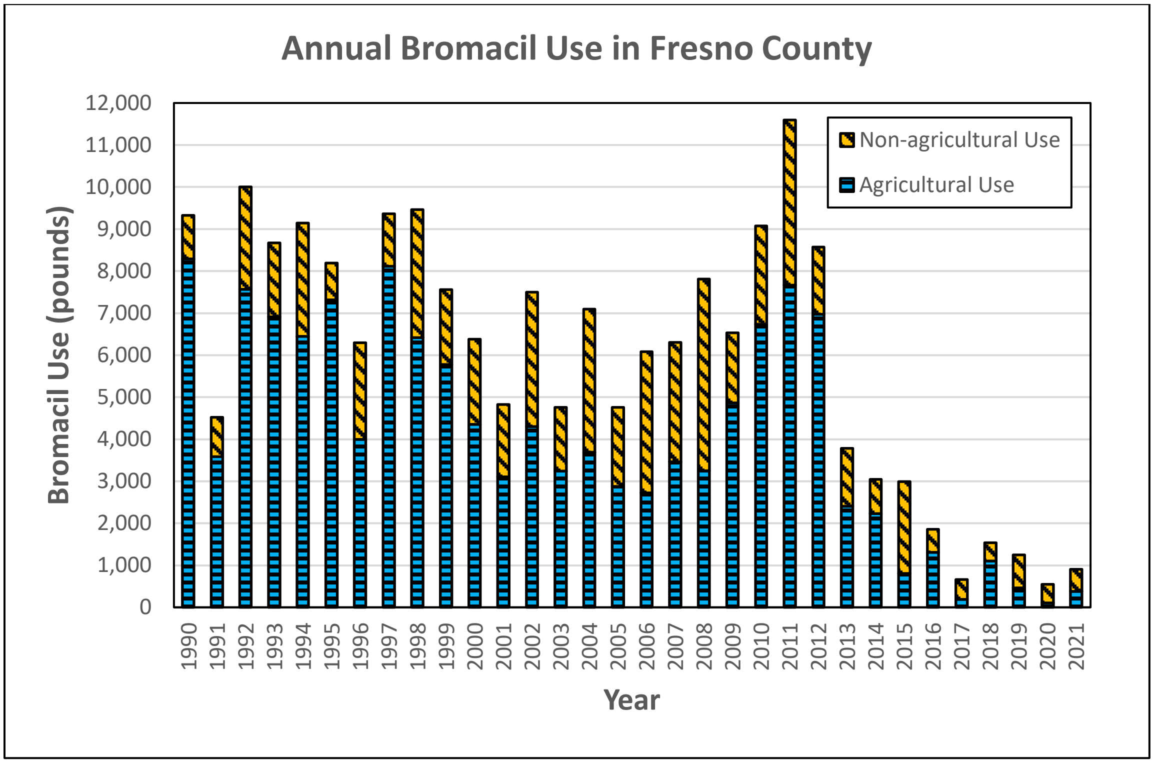


Figure 23b. Annual bromacil use (pounds) in Tulare County from 1990 to 2021.

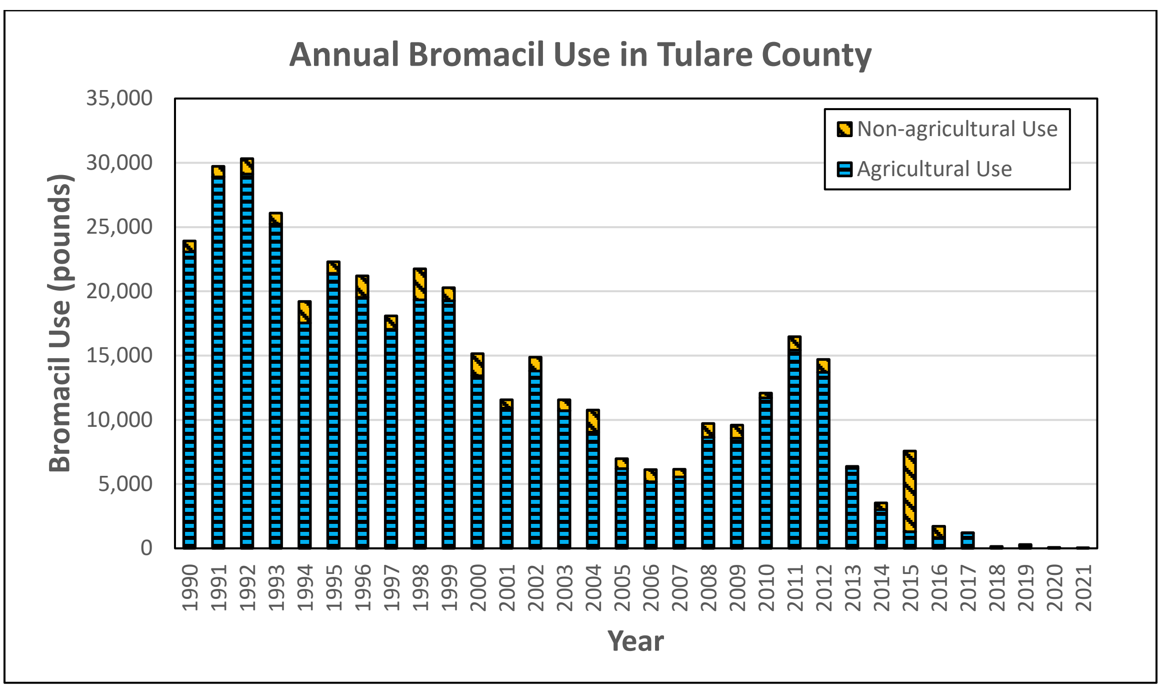


Figure 24. Trend directions of bromacil concentrations in the Well Network and total bromacil use (pounds per section) from 1990 to 2021.

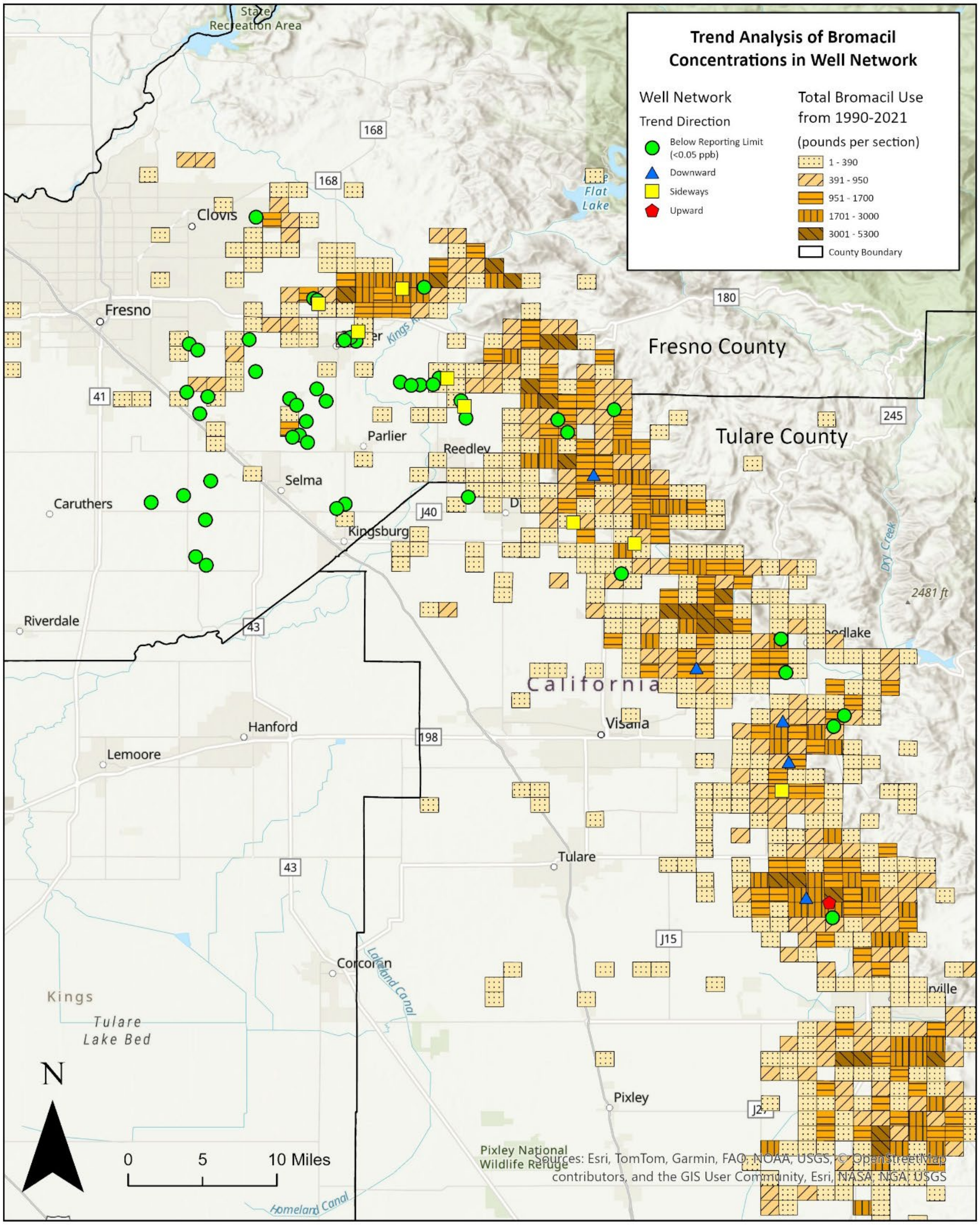


Figure 25. Trend directions of bromacil concentrations in the Well Network relative to GWPAs.

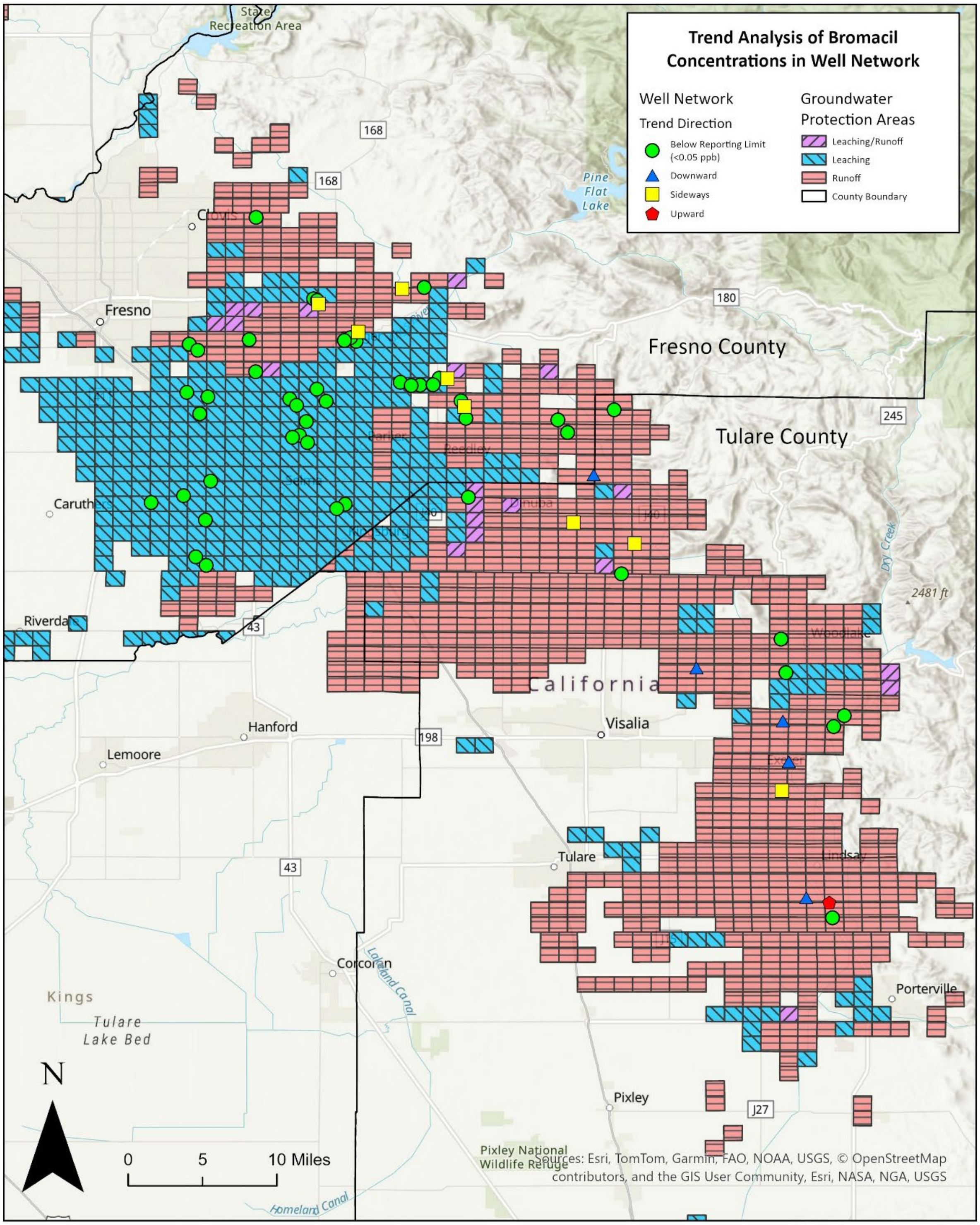


Figure 26. Measured bromacil concentrations in Well Nos. 12, 61, 75/75A, and 84 from 1999 to 2022 and estimated concentration trendlines.

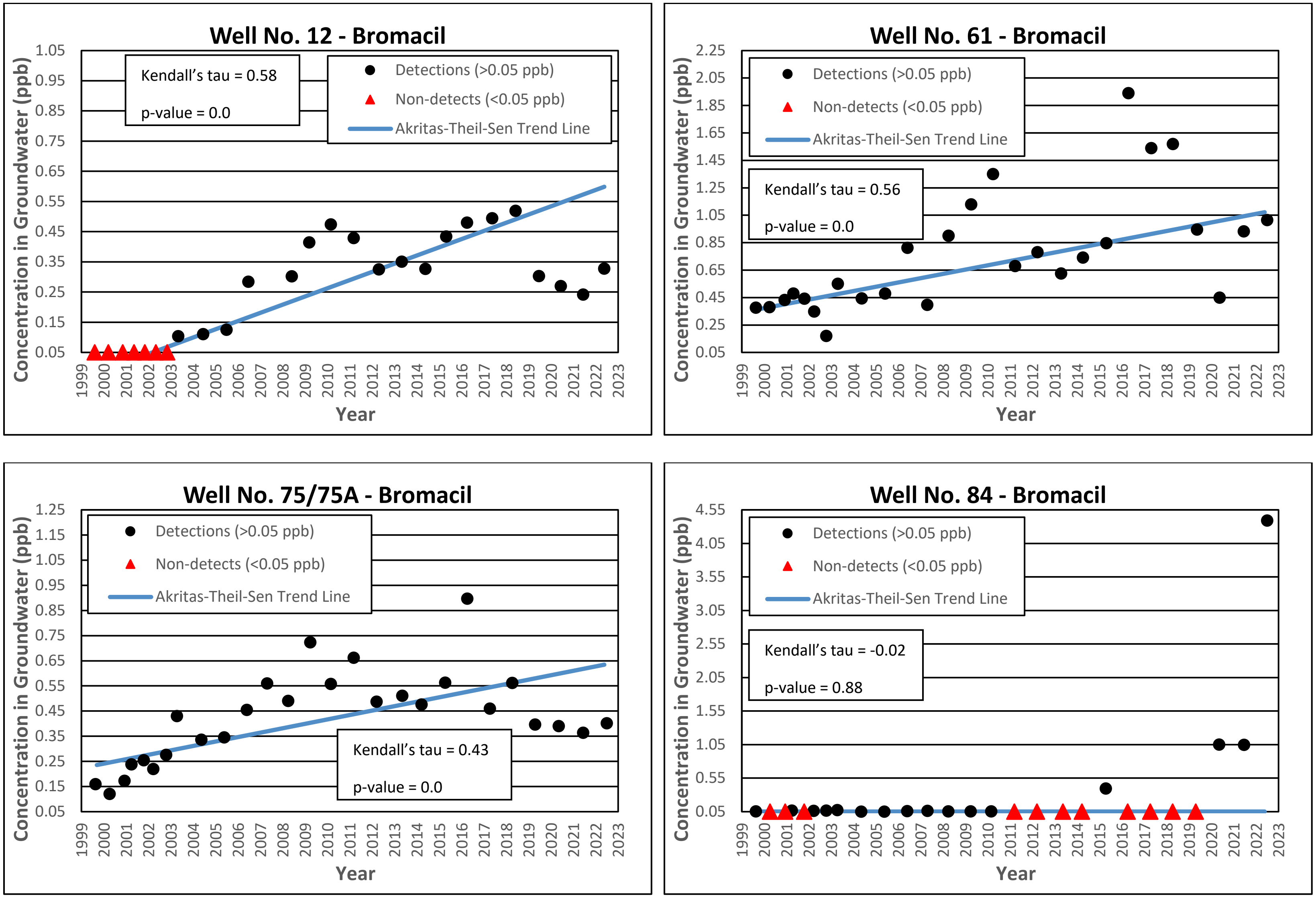


Figure 27. Measured concentrations of five regulated pesticides (atrazine, simazine, bromacil, diuron, norflurazon) and four degradates (DEA, ACET, DACT, DSMN) in Well No. 59/59A from 1999 to 2022 and estimated concentration trendlines.

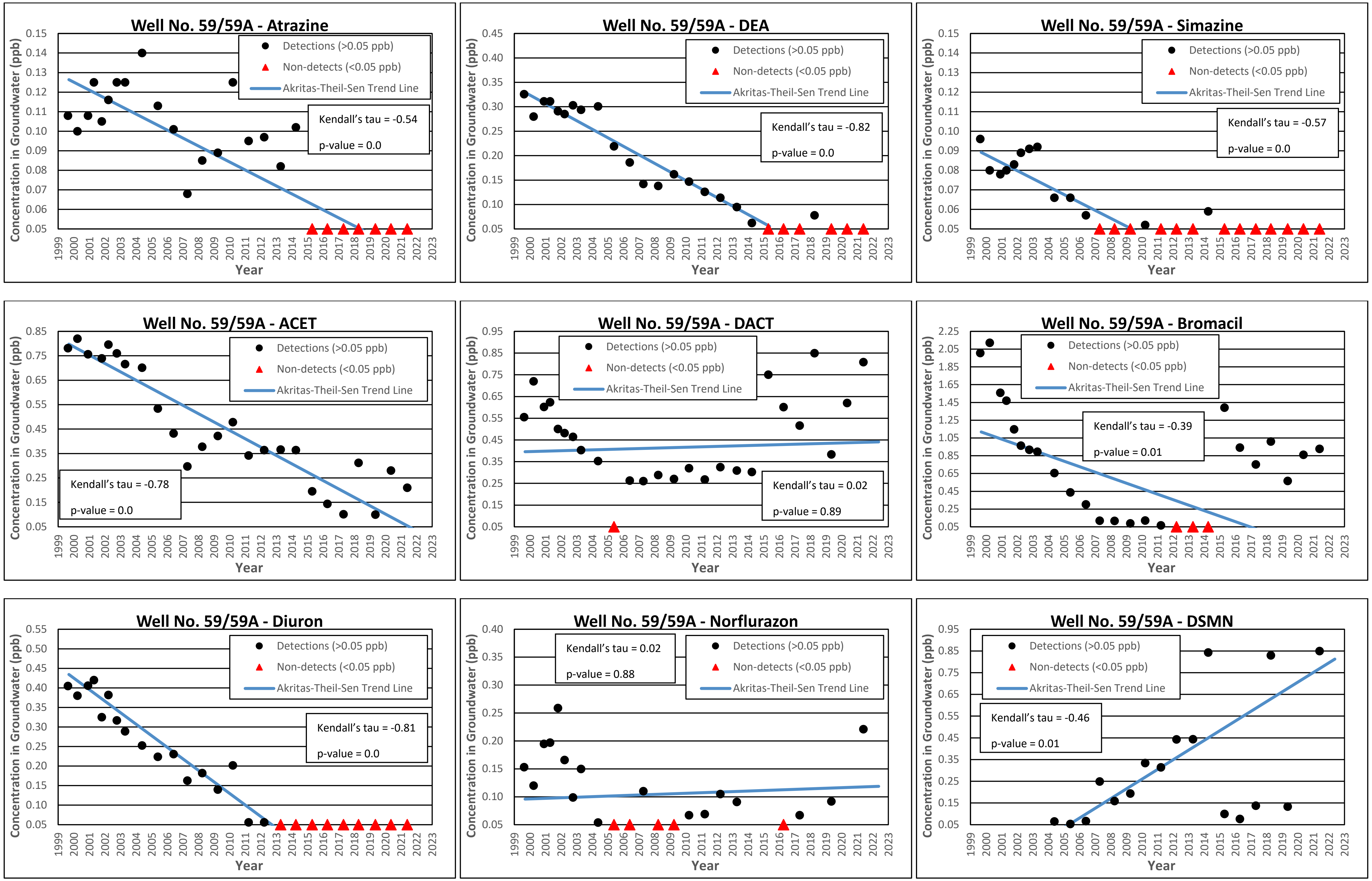


Figure 28. Locations of diuron-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

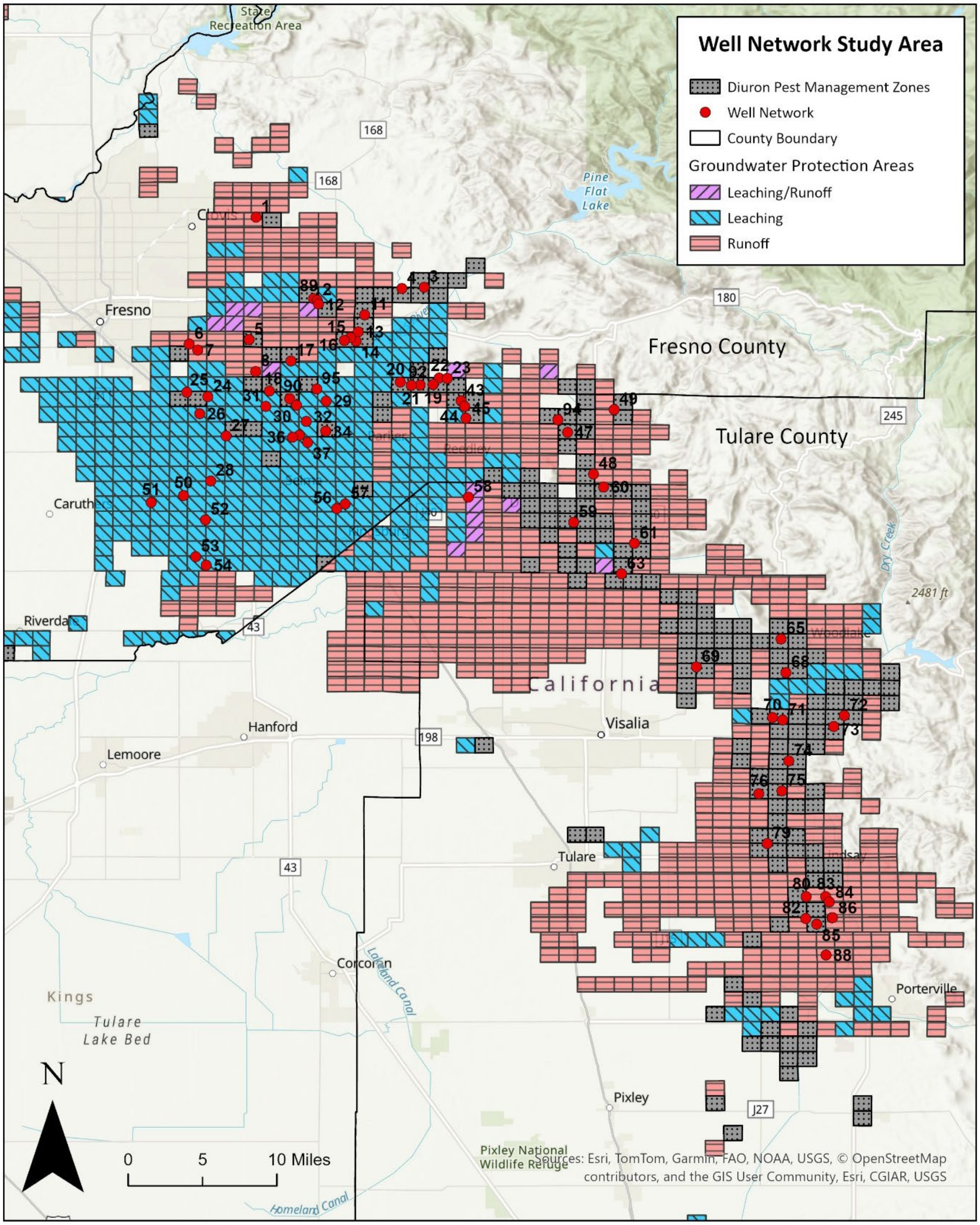


Figure 29a. Annual diuron use (pounds) in Fresno County from 1990 to 2021.

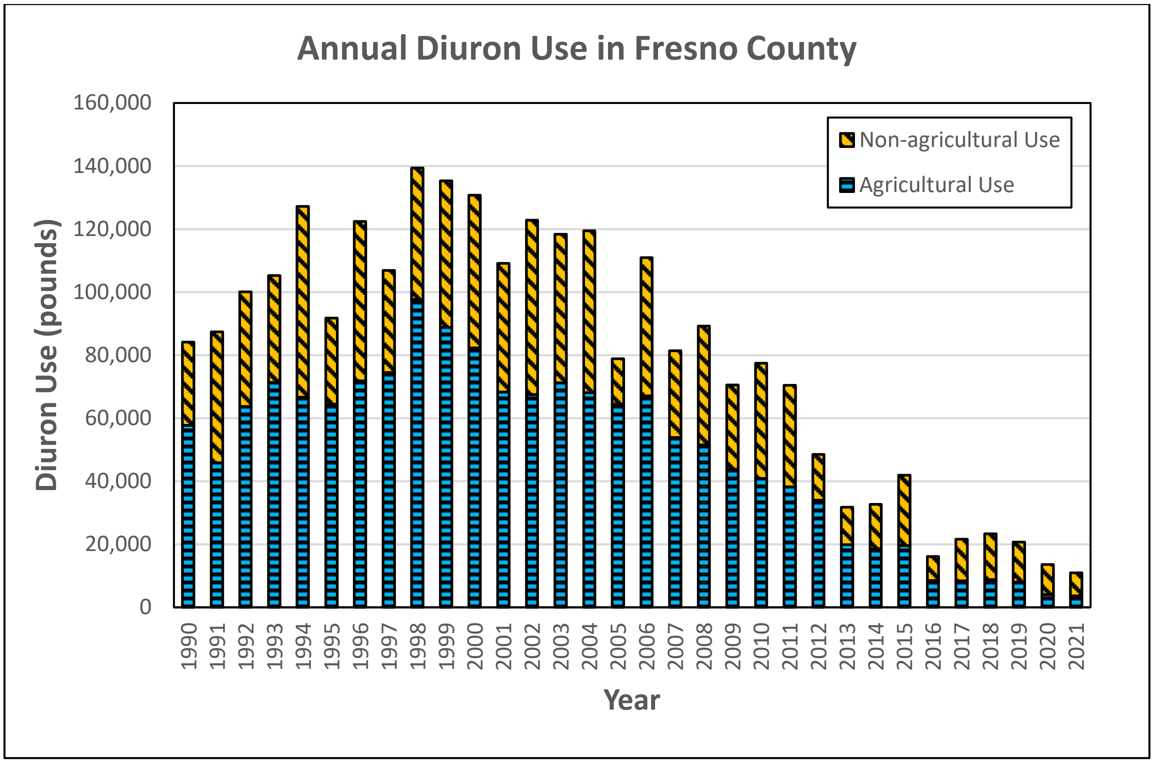


Figure 29b. Annual diuron use (pounds) in Tulare County from 1990 to 2021.

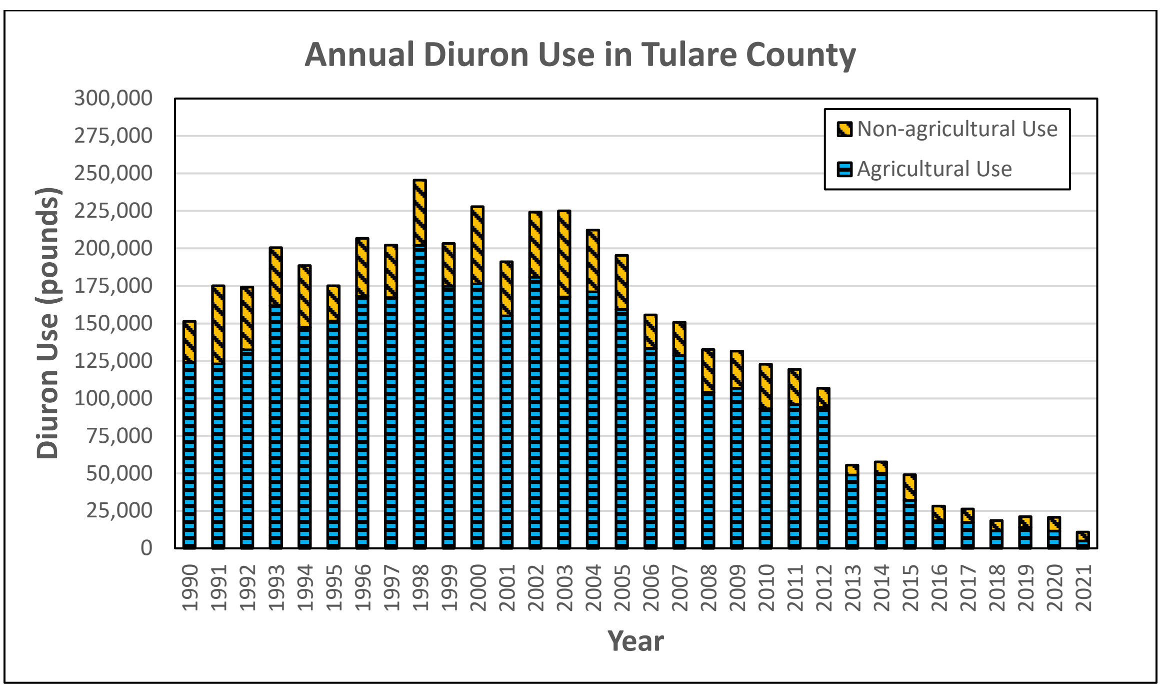


Figure 30. Trend directions of diuron concentrations in the Well Network and total diuron use (pounds per section) from 1990 to 2021.

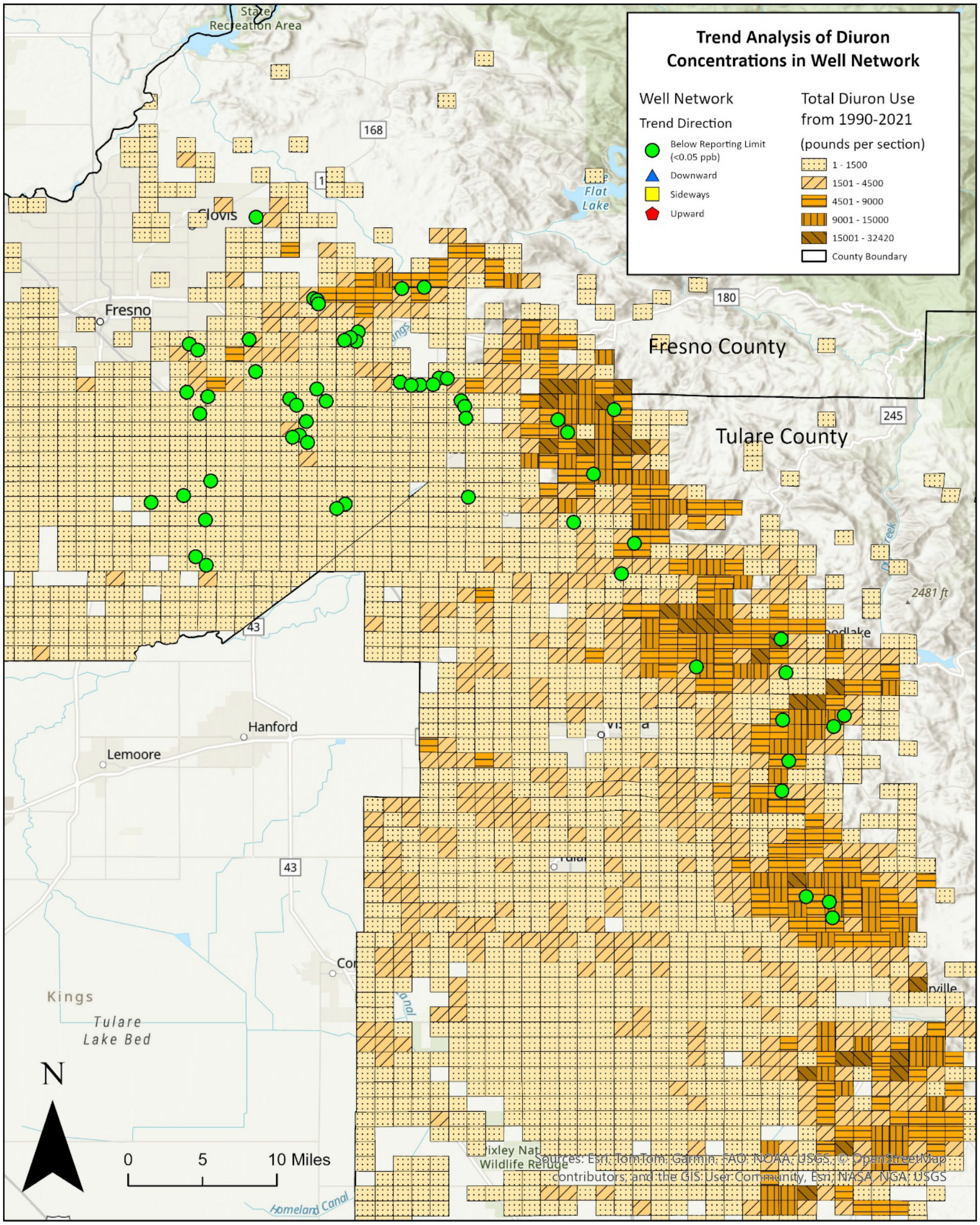


Figure 31. Trend directions of diuron concentrations in the Well Network relative to GWPAs.

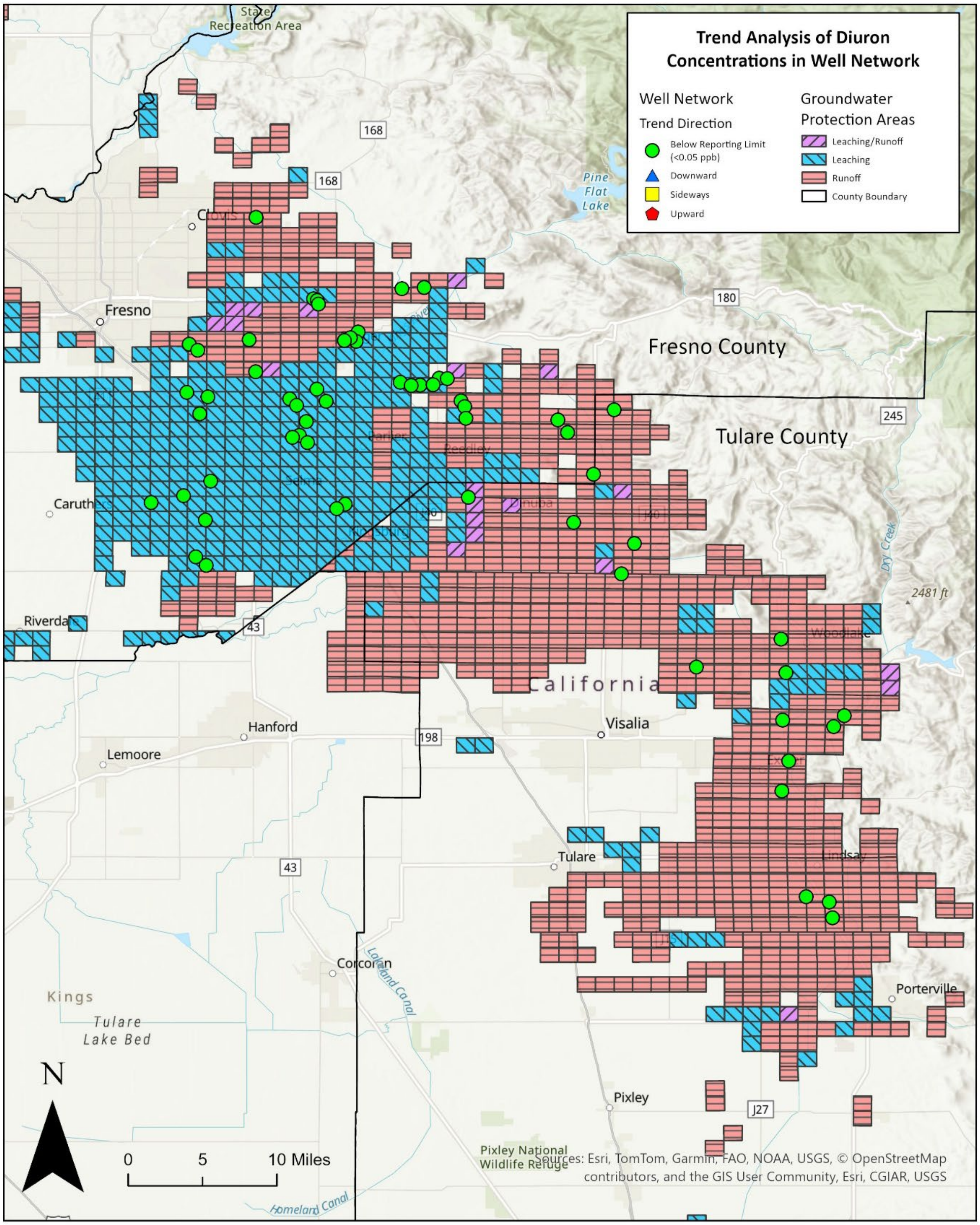


Figure 32. Locations of norflurazon-specific PMZs in regulation by 2001 and the GWPAs that replaced them in regulation in 2004 in the Well Network study area.

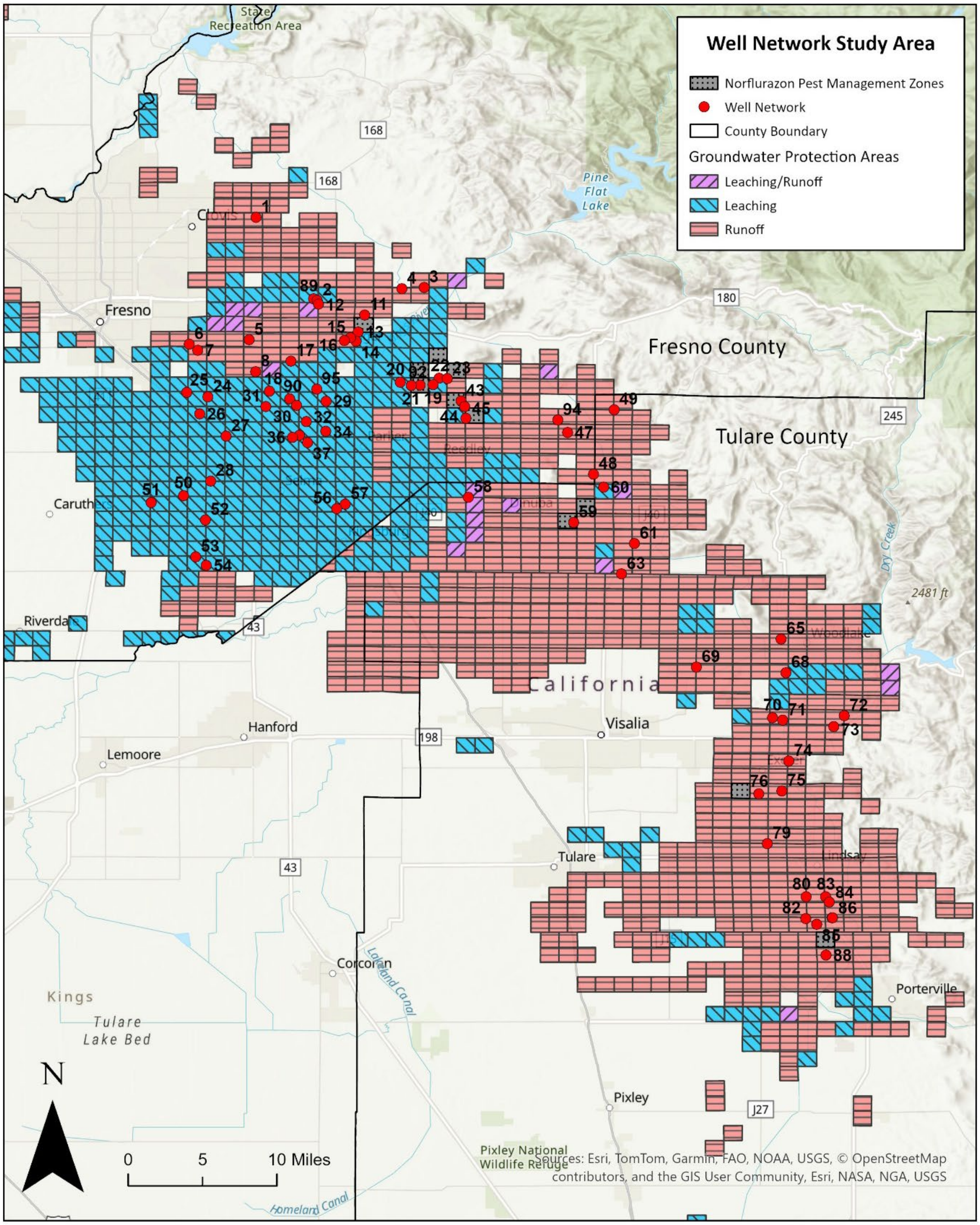


Figure 33a. Annual norflurazon use (pounds) in Fresno County from 1990 to 2021.

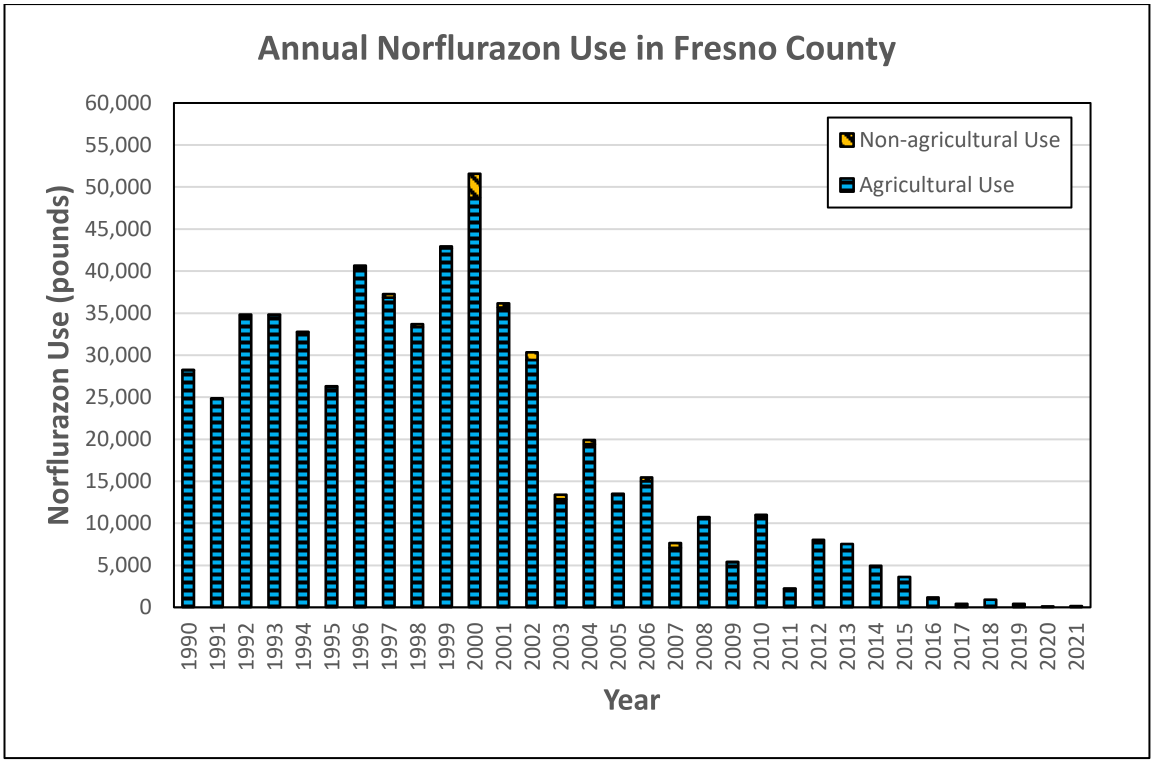


Figure 33b. Annual norflurazon use (pounds) in Tulare County from 1990 to 2021.

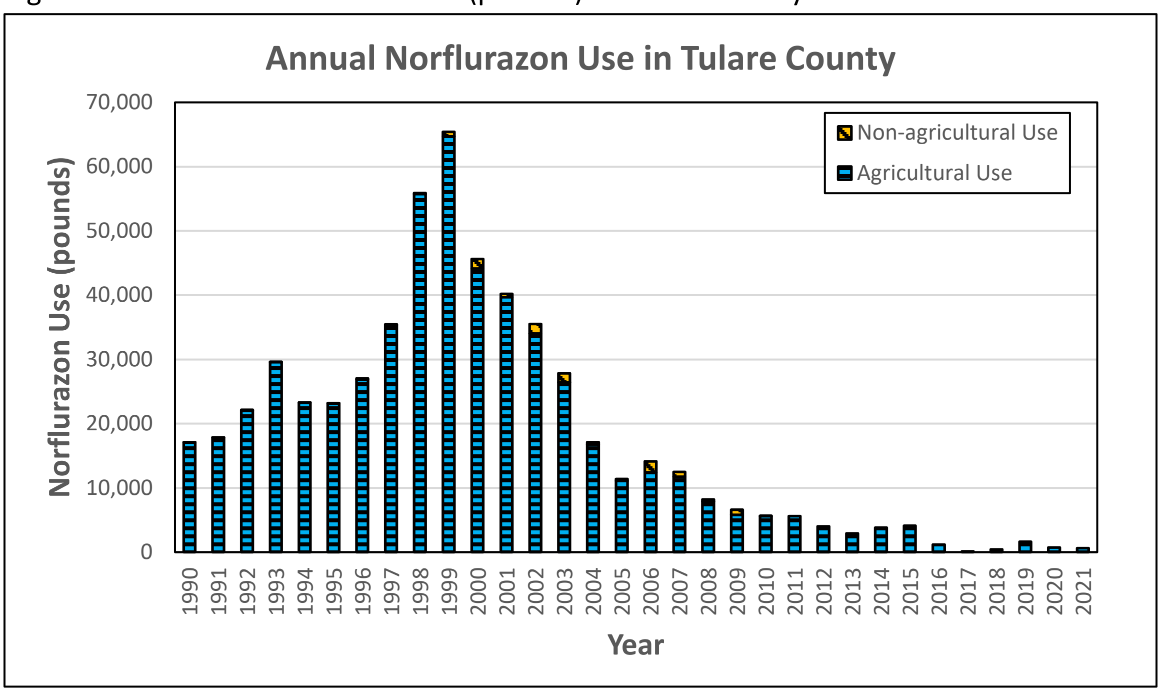


Figure 34. Trend directions of norflurazon concentrations in the Well Network and total norflurazon use (pounds per section) from 1990 to 2021.

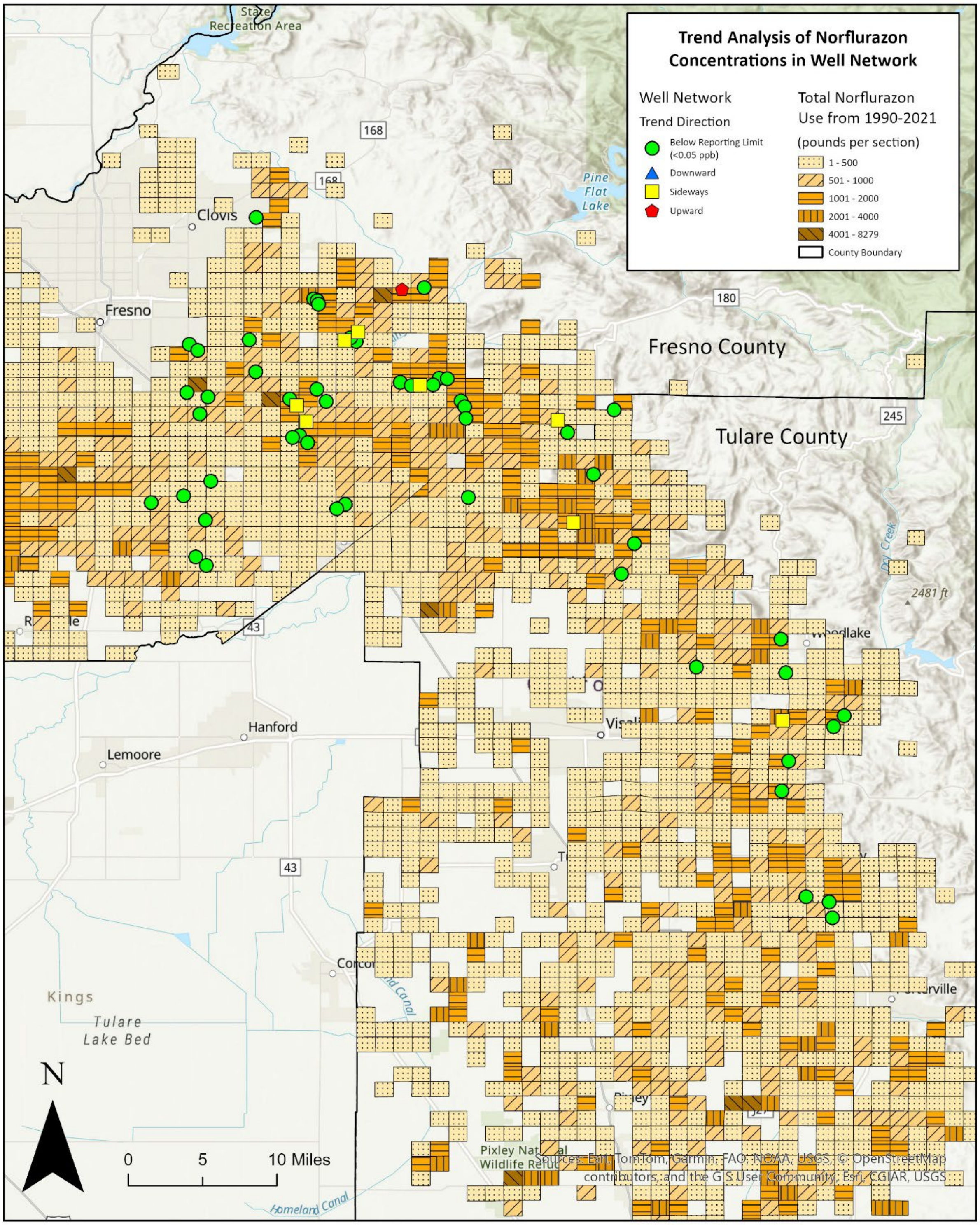


Figure 35. Trend directions of norflurazon concentrations in the Well Network relative to GWPAs.

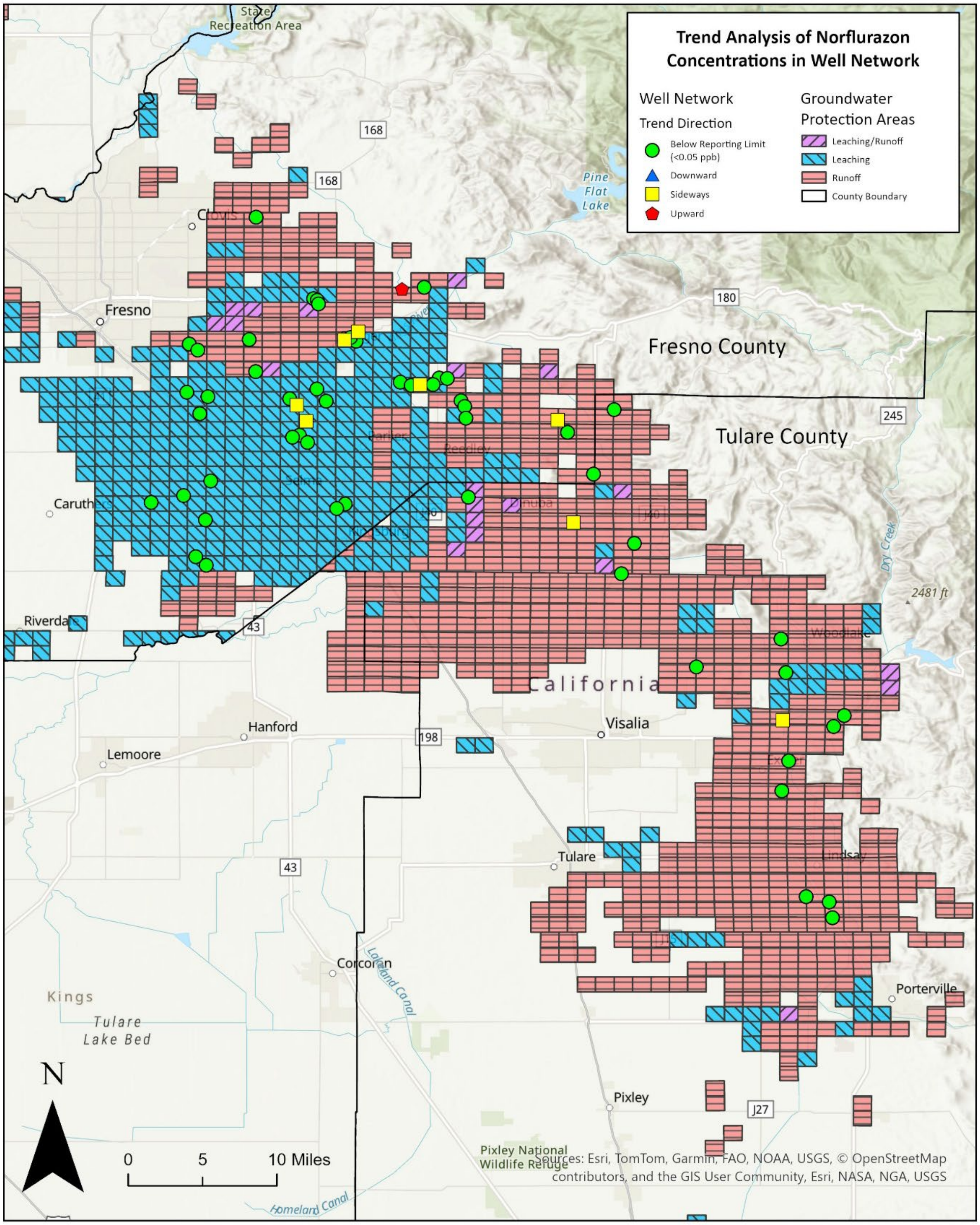


Figure 36. Measured norflurazon and DSMN concentrations in Well Nos. 71 and 94 from 1999 to 2022 and estimated concentration trendlines.

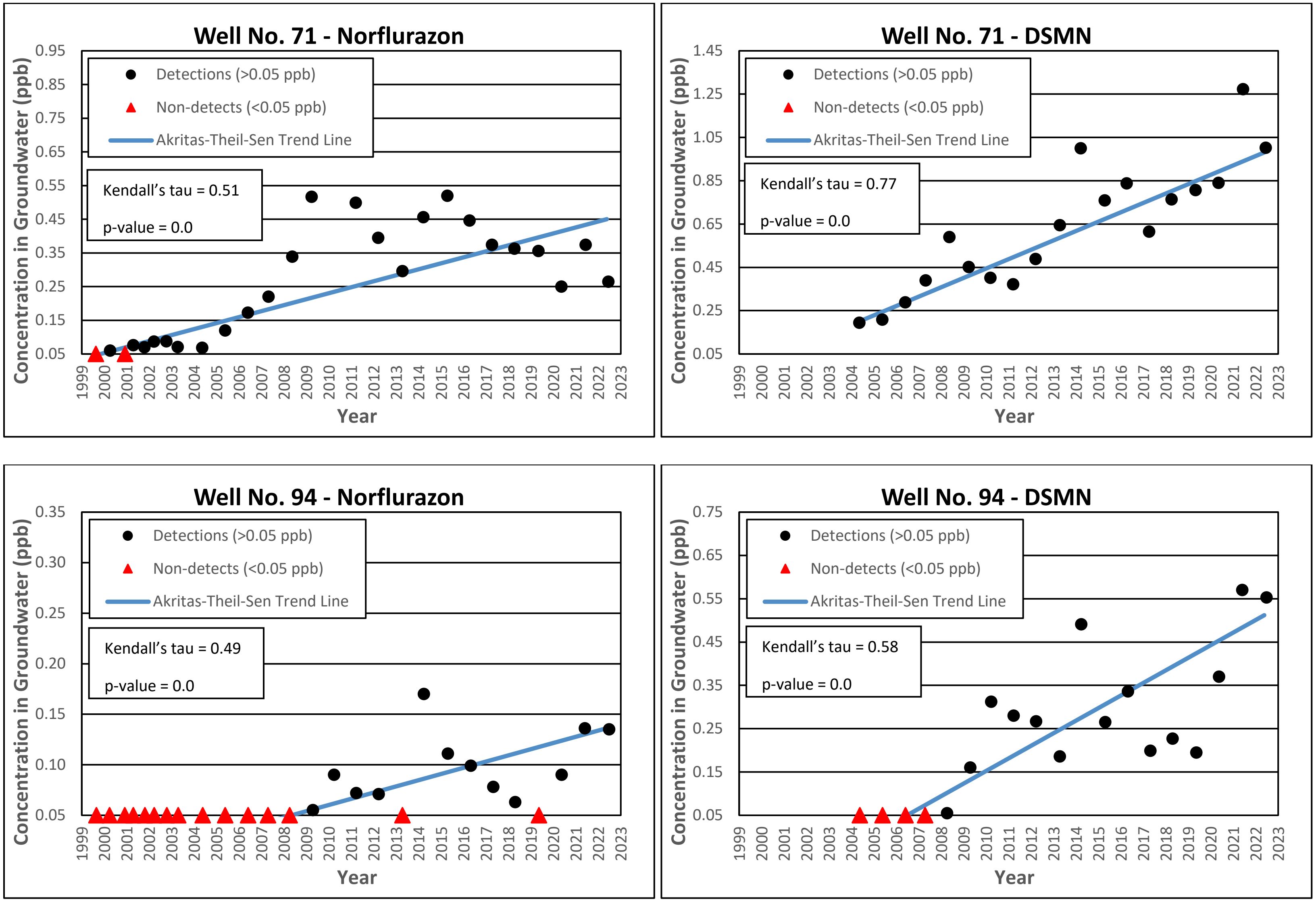
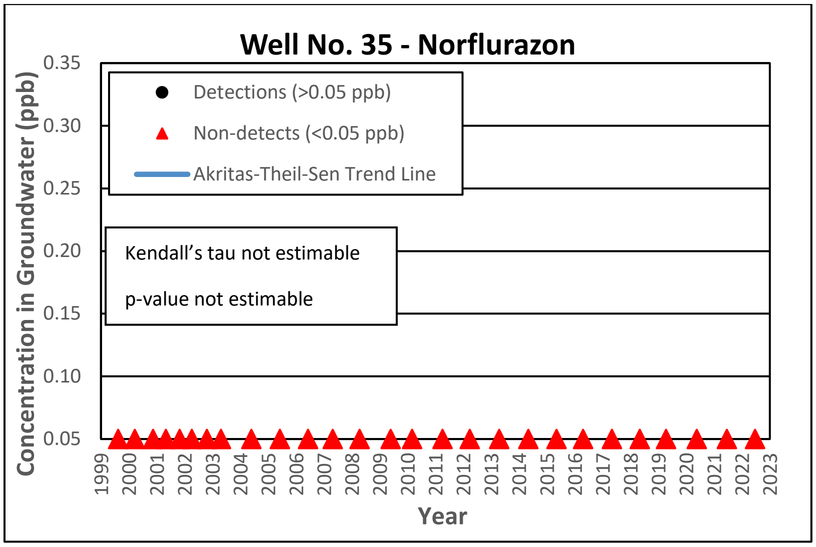


Figure 37. Measured norflurazon and DSMN concentrations in Well No. 35 from 1999 to 2022 and estimated concentration trendlines.



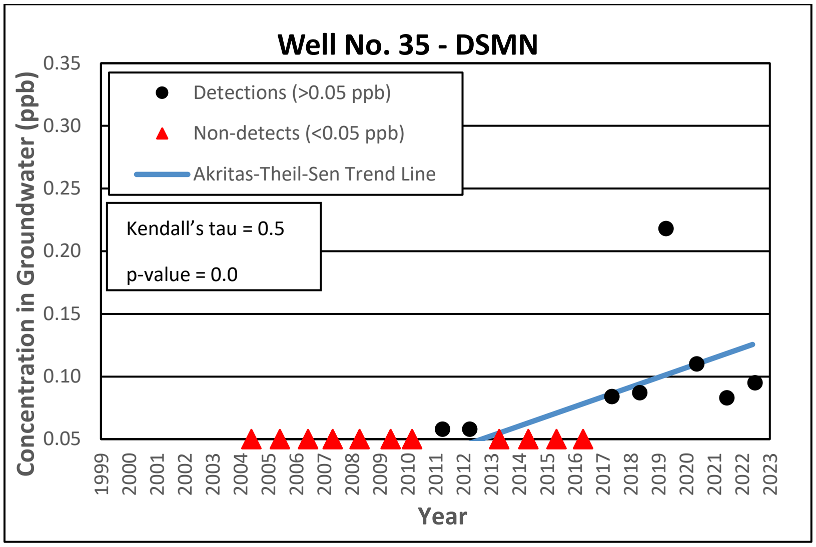


Figure 38. Trend directions of DSMN concentrations in the Well Network relative to GWPAs.