Appendix 2-D

Groundwater Quality and Land Subsidence (October 2021)

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Appendix 2-D: Groundwater Quality and Land Subsidence

Groundwater Quality

Review of Previous Studies

The investigation of the Folsom-East Sacramento area (DWR, 1964) is one of the earliest documents available that has assessed groundwater quality within the South American Subbasin (SASb). Following this report, DWR evaluated groundwater resources in Sacramento County in 1974 (Bulletin No. 118). More recent studies include an investigation of the groundwater quality in the southern Sacramento Valley conducted by the U.S. Geological Survey (USGS) in 2008, which was revised in 2018, and an assessment of the Sacramento-Amador Subwatershed performed by CH2M in 2016. Additionally, SCGA has produced three basin management reports with illustrations for the geographic occurrence of various water quality constituents, including total dissolved solids (TDS), iron, manganese, nitrate, and arsenic.

According to the 1964 and 1974 DWR studies, recharge water enters the groundwater system on the east side of the Subbasin. This carbon dioxide-rich water (derived from the atmosphere and the root zone) develops a mixed cation-bicarbonate composition as it dissolves calcium, magnesium, and sodium from the sediments. As groundwater migrates downgradient and deeper into the aquifer system, the concentrations of these constituents increase. Very deep in the aquifer, the water is unusable and is dominated by a sodium-chloride composition from the original marine deposits.

The Alternative Plan submitted in 2016 evaluated temporal variations in concentrations of TDS, nitrate, iron, manganese, arsenic, and chloride at various locations. The water quality data for this evaluation were obtained from the Geotracker Ground-Water Ambient Monitoring and Assessment program (GAMA) website and subdivided by sampling date into six 3-year intervals. Beginning with 1998, two data periods are presented in **Table 2-D-1**; this table provides a summary of this evaluation. The database included numerous non-detects (ND) for nitrate, iron, manganese, and arsenic which were excluded from the evaluation.

Table 2-D-1: Groundwater Quality Median Concentrations at Specific Wells

Period	TDS (mg/L)	Chloride (mg/L)	Nitrate as N (mg/L)[1]	Iron (µg/L)	Manganese (µg/L)	Arsenic (µg/L)
1998-2000 Median	170	8	2.5	170	11	6.8
2013-2015 Median	210	12	3.2	270	14	9.8
Non-Detects			18-25%	41-79%	20-57%	10-36%

[1] Nitrate as NO_3 converted to Nitrate as N

The slightly increasing trends in the concentration of some of these naturally occurring constituents increased as the groundwater system became more dynamic during the last century of production, and due to wells drilled deeper to increase production capacity. While iron and manganese are known to be present in the deeper groundwater, some traces of arsenic have been occurring in shallow groundwater wells. Prior to the lowering of the public drinking water standard (primary MCL) from 50 ppb to 10 ppb, the occurrence of arsenic was not a significant regulatory issue. After the water standard was lowered, older public supply wells in Sacramento County Water Agency's (SCWA) Laguna service area were replaced with deeper wells designed for centralized treatment of iron and manganese. Additionally, private domestic well owners have been notified and encouraged through outreach to have their water tested once a year for nitrates and arsenic.

The GAMA has addressed conditions throughout much of California via a spatially-unbiased selection protocol for wells and a comprehensive suite of laboratory analyses. During a March to June 2005 study, 16 wells were sampled within the boundaries of the Subbasin and results were compared with selected Federal and State drinking-water standards (USGS, 2008). A summary of the USGS 2018 study, which updated the 2008 study results, is provided below:

- Thirteen out of the 16 wells within the SASb had one or more detections of a volatile organic compound; however, none of these concentrations were greater than an MCL or other threshold values. Their analysis of Tentatively Identified Organic Compounds (TIOCs) found cyclopentane in one well and sulfur dioxide in another well within the SASb area.
- Of the total of 129 pesticide compounds that USGS analyzed, eight were detected at least once within the SASb area, with the most frequently detected pesticide compounds being 2-chloro-4-isopropylamino-6-amino-s-triazine (deethylatrazine, a degradation of atrazine) and atrazine (general application herbicide). All of the detections were below regulatory threshold values for the corresponding pesticide.
- Among nutrients, orthophosphate and nitrate were detected at five and four wells within the SASb, respectively; nitrite was not detected in any well. Nitrate concentrations (as N) were all lower than the California Department of Health Services (CADHS) primary MCL of 10 mg/L.
- While there are no applicable health-based thresholds for the major ions, chloride and sulfate have secondary MCLs (SMCLs) set for aesthetic qualities. Concentrations of these naturally-occurring constituents were lower than the SMCL in all five wells where these constituents were detected within the Subbasin.
- USGS also analyzed 26 trace elements, including 18 trace elements with an MCL or other health-based thresholds in its study area. Three trace elements were detected at concentrations greater than the threshold: arsenic, barium, and boron. However, none of these detections were at wells within the SASb. While two naturally-occurring trace elements, iron and manganese, were detected at concentrations greater than an SMCL in the study unit, only manganese resulted in an exceedance of the SMCL (in one well) within the SASb.
- In the isotopes, radioactivity, and noble gases categories, USGS analyzed Tritium, deuterium, and oxygen-18, helium-3 to helium-4 ratio, helium-4, argon, neon, krypton, and xenon in the SASb area.

Assessment of Current and Historical Conditions

This section presents SASb groundwater quality information, including a discussion of numeric thresholds set by federal and state agencies, the processing of available water quality data, and results of water quality data analysis performed for the GSP.

This assessment focuses on the following water quality parameters that have been identified to be of interest in the Central Valley, generally, and in the SASb, specifically:

- Nitrate
- Total Dissolved Solids (TDS)
- Arsenic
- Hexavalent chromium
- PFAS compounds
- Chloride
- Iron
- Manganese

Additional wells and constituents that are not included in the Main Report's assessment are included in this Technical Appendix.

Regulatory Background

The overarching federal law regulating water quality in surface waters and wetlands is the Clean Water Act (CWA), passed in 1972. When the CWA was written, Congress explicitly left the regulation of discharges to groundwater to the states and to the United States Environmental Protection Agency (USEPA) under other statutory authorities. One of these federal statutory authorities is the federal Safe Drinking Water Act (SDWA), which applies to both surface and groundwater and provides protection to drinking water supplies. Under the SDWA, federal standards were established through USEPA in the form of primary maximum contaminant levels (1° MCLs or primary MCLs) to protect human health. Secondary maximum contaminant levels (2° MCLs or SMCLs) also were established at the federal level to address aesthetics of drinking water sources (i.e., taste, odor, or appearance) and are not federally enforceable. The State of California has its own SDWA that includes 1° MCLs and 2° MCLs which are, in some cases, more strict than those set at the federal level for select constituents. The California 1° and 2° MCLs are codified in Title 22 of the California Code of Regulations (CCR). Water quality standards to protect drinking water as established under the federal and state SDWAs are enforced through the State Water Resource Control Board's (SWRCB or State Water Board) Division of Drinking Water (DDW).

The California Porter-Cologne Water Quality Act, contained in California Water Code Division 7, applies to both groundwater and surface waters, designating responsibility for water quality and safe drinking water protection to the SWRCB and the nine Regional Water Quality Control Boards (RWQCB) in California. The Act requires RWQCBs to develop water quality control plans for the region over which it presides. These water quality control plans (Basin Plans) must include a list of the specific waterbodies and broad categories of waters (e.g., bays, estuaries, ocean waters, wetlands, and groundwaters) the RWQCB is charged with protecting, the beneficial uses designated for those waterbodies, and the water quality objectives used to protect those beneficial uses. These water quality objectives, defined for specific hydrologic regions and waterbodies, protect the quality of surface waters, groundwaters, and their designated beneficial uses.

In the SASb, the Sacramento-San Joaquin Water Quality Control Plan (Basin Plan) issued by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) contains water quality objectives based on primary and secondary MCLs. Where available, these MCLs are used in the assessment of groundwater quality conditions in the SASb.

Groundwater Quality Data Processing

Groundwater quality data were downloaded from the Groundwater Ambient Monitoring and Assessment Program (GAMA) Groundwater Information System Data Download[1]. Data was downloaded for Sacramento County on May 22, 2020, and includes groundwater quality data from the following sources:

- Department of Pesticide Regulation (DPR)
- Department of Water Resources (DWR)
- Lawrence Livermore National Laboratory
- State and Regional Water Board Regulatory Programs (Electronic Deliverable Format (EDF) and Irrigated Agricultural Land Waiver (AGLAND))
- State Water Board, GAMA Program water quality data (GAMA, USGS)
- State Water Board, Division of Drinking Water public supply well water quality (DDW)
- U.S. Geological Survey (USGS)

Additional water quality data in the SASb were obtained directly from GEI Consultants Inc., which developed the Subbasin's 2016 Alternative Plan. All data were then compiled into a database for analysis. Data for nitrate, TDS, chloride, arsenic, iron, and manganese are from both the GAMA and GEI Consultants Inc., databases, while data for hexavalent chromium, and the larger family of per- and polyfluoroalkyl substances (PFAS) are solely from the GAMA database. Constituents were included in this analysis because they were cited in previous studies of the SASb, or they were discussed during public meetings as being of concern to stakeholders in the SASb. Analysis of chloride, iron, and manganese is included in this Technical Appendix and not the Main Report because these constituents are naturally occurring and will not likely be monitored or managed under the GSP.

Groundwater quality samples collected from less than 300 feet bgs were determined to be from the shallow zone, while samples collected from greater than 300 feet were determined to be from the deep zone. With the exception of PFAS, only measurements from wells located entirely in either the shallow zone or the deep zone are included in this analysis. Wells of all depths are analyzed for PFAS as monitoring data is sparse and less temporally extensive than the other constituents. The analysis presented in the Main Report omits State and Regional Water Board Regulatory Program (EDF) data that is included in the GAMA database because this monitoring data represents site specific conditions and is not indicative of regional groundwater conditions. Assessment of this data is included in this Technical Appendix for inclusiveness, and to present a more complete picture of all available data in the Subbasin.

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[1] http://geotracker.waterboards.ca.gov/gama/datadownload

All data, except the TDS dataset, include non-detect (ND) values, as well as estimated values (where the value was detected at a concentration below the reporting limit, but above the method detection limit). Estimated values are included in the box and whisker plots at their reporting limit, and the ND values are not included. Omission of the ND values increases the median, average, and overall statistics, and therefore results in an overestimation of these values.

Groundwater Quality Trends According to Available Historical Data

The following subsections present the temporal and spatial analysis of nitrate, TDS, arsenic, hexavalent chromium, PFAS, chloride, iron, and manganese. Variations of these constituents over time were plotted as “box and whisker” plots, where the box represents the concentration range for the middle 50 percent of the data (first quartile to third quartile, or interquartile range), the mean is represented as an ‘x’, and the median is shown as the line in the center of the box. The top whisker extends to the highest concentration that is less than or equal to the sum of the third quartile and 1.5 times the interquartile range; and the bottom whisker extends to the lowest concentration that is greater than or equal to the difference of the first quartile and 1.5 times the interquartile range. Regulatory limits are displayed as a dashed red line, and the concentration scale is displayed on the left side of each plot.

Figures of spatial groundwater quality data plot the location of wells where groundwater quality samples were collected, and indicate the maximum sampled concentration at each well for the entirety of the dataset. This representation was used in an initial screening to see where threshold values were exceeded, but should not be interpreted as a depiction of problem areas with regular concentrations above thresholds. With the exception of PFAS, individual maps are provided for samples collected from the shallow zone and the deep zone. Due to the scarcity of PFAS data, wells of all depths are included in one map.

Groundwater in the SASb is generally of good quality and meets local needs for municipal, domestic, and agricultural uses. Exceedances of constituent thresholds may be caused by localized conditions and may not be reflective of regional groundwater quality. In the analysis described below, groundwater data that includes monitoring well data from the GAMA data has been assessed. Also, an analysis that omits monitoring well data is presented. This distinction is important, because monitoring well data tends to be focused intensively at specific sites (e.g. remediation areas), and can bias statistical analysis of regional conditions.

Nitrate

Nitrate is an ion with the chemical formula NO_3. Salts containing this ion are called nitrates (e.g. ammonium nitrate, sodium nitrate, potassium nitrate, calcium nitrate, magnesium nitrate). Some forms of nitrates are naturally occurring. Nitrates are commonly found in groundwater as a result of the application of nitrate-containing fertilizers. Other nitrate sources include feedlot discharges, treated and untreated sewage, and emissions from food processing or industrial processes. At elevated levels, nitrates can affect human health. A primary MCL of 10 mg/L (milligrams per liter, or parts per million) exists for nitrate as nitrogen, applicable to drinking water supplies, to provide human health protection.

Nitrate data in wells in the SASb were extensive and spanned from 1951 to present. **Figure 2-D-1** illustrates variation in nitrate with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the primary MCL is displayed as a dashed red line (10 mg/L for Nitrate as N). As shown, nitrate concentrations in both the shallow and deep zone were relatively consistent throughout the period of record. Concentrations in the shallow zone increased slightly between the period 1991-95 and 1996-00; however, this increase was minor and not representative of an increasing trend. Nitrate concentrations in the deep zone have remained relatively stable throughout the period of record. It is noted that the elevated average and statistical distribution shown for the deep zone during the period 1986-90 is the result of one high estimated value (10 mg/L).

Nitrate data is plotted spatially for the shallow zone in **Figure 2-D-9** and the deep zone in **Figure 2-D-11**. **Figure 2-D-10** plots nitrate data for the shallow zone with data from monitoring wells included. The maps divide the wells into three categories: wells where all samples were below 50 percent of the MCL (indicated as a green point), wells where at least one sample was above 50 percent of the MCL (indicated as a yellow point), and wells where at least one sample was above the MCL (indicated as a red point). It is noted that not all wells analyzed are drinking water supply wells; also, a single exceedance of the MCL as indicated on the figures is not a violation of the limits as the SWRCB has set nitrate MCL compliance to be determined by a running annual average.

Figure 2-D-9 shows that the majority of shallow wells sampled for nitrate do not result in a concentration greater than 50 percent of the MCL. Analysis of wells where the maximum sampled concentration was greater than 50 percent of the MCL, or greater than the MCL, indicated that these wells are located in areas where municipal community water systems deliver domestic water supply, and that domestic well density is low. **Figure 2-D-11** shows that one deep well resulted in a concentration greater than the MCL, while no deep wells resulted in a concentration between 5 and 10 mg/L. **Figure 2-D-10** shows that when shallow monitoring wells are included in the analysis, more exceedances of the nitrate MCL occur. Also included in this figure is an inset map that focuses on the region of the Sacramento Regional Wastewater Treatment Plant (Regional San). This inset map and associated shallow water quality data (all shallow monitoring wells) highlight the fact that monitoring well data tends to be focused intensively at specific sites.

Total Dissolved Solids (TDS)

The salinity of freshwater is commonly measured either directly as the total concentration of all dissolved solids (organic and inorganic; TDS), or indirectly, as a water's ability to pass electrical flow (electrical conductivity, or EC). Conductance measured at – or normalized to – 25º Celsius is called specific conductance. Salts are both naturally occurring and man-made, and are persistent in nature. TDS levels in groundwater are often associated with agricultural irrigation, in combination with natural sources, where applied water is used by plants and water is lost in the process of evapotranspiration. Salts in the applied water remain in the root zone until they are leached out into the groundwater basin. Other sources of salts to groundwater may include municipal and industrial discharges.

TDS data in SASb wells were extensive and spanned from 1955 to present. TDS concentrations below the Recommended SMCL of 500 mg/L are desirable for a higher degree of consumer acceptance, while concentrations below the Upper SMCL of 1,000 mg/L are also deemed to be acceptable. **Figure 2-D-2** illustrates variation in TDS with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the

Recommended SMCL and Upper SMCL are displayed as dashed red lines. As illustrated, TDS concentrations measured in the deep zone were consistently below the SMCL value of 500 mg/L and remained relatively stable throughout the period of record. Concentrations in the shallow zone remained relatively stable from 1986 to 2005 and exhibit higher concentrations during the years 2006 to 2020; however, these elevated concentrations are still deemed acceptable.

TDS data is plotted spatially for the shallow zone in **Figure 2-D-12** and the deep zone in **Figure 2-D-14**. The maps divide the wells into four categories: wells where all samples were below 250 mg/L (indicated as a green point), wells where at least one sample was greater than 250 mg/L (indicated as a yellow point), wells where at least one sample was greater than 500 mg/L (indicated as an orange point), and wells where at least one sample was greater than 1,000 mg/L (indicated as a red point). **Figure 2-D-12** appears to show an increasing trend in shallow TDS values from the west of the subbasin to the east; however, the majority of shallow wells produced a maximum TDS concentration below the Recommended SMCL of 500 mg/L. **Figure 2-D-14** shows that no deep wells sampled for TDS resulted in a concentration greater than the Upper SMCL value of 1000 mg/L. **Figure 2-D-13** shows that when shallow monitoring wells are included in the analysis, higher concentrations of TDS are recorded. Also included in this figure is an inset map that focuses on monitoring near the Regional San wastewater treatment plant site. This inset map and associated shallow water quality data (all shallow monitoring wells) highlight the fact that monitoring well data tends to be focused intensively at specific sites.

Arsenic

Arsenic is a chemical element, naturally occurring in the earth's crust. It occurs naturally in many minerals and is naturally occurring in some groundwaters. Historically, it has been used in the production of semiconductors, pesticides and wood preservatives, and can be released during mining operations, smelting, and coal combustion. It is highly toxic in its inorganic form; a primary MCL for arsenic in drinking water is 10 μg/l (micrograms per liter, or parts per billion).

Arsenic data in SASb wells were extensive and spanned from 1982 to present. **Figure 2-D-3** illustrates variation in arsenic with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the MCL of 10 μg/L is displayed as a dashed red line. As shown, arsenic concentrations in the shallow zone have fluctuated over the period of analysis, with concentrations exhibiting slight increases during the 2006-10 and 2016-20 periods. Concentrations of arsenic in the deep zone appear elevated during the periods 1986-90 and 1991-95, and then decline below the MCL for the duration of analysis.

Arsenic data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-15** and the deep zone in **Figure 2-D-16**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the MCL of 10 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the MCL (indicated as a yellow point), and wells where at least one sample was above the MCL (indicated as a red point).

Figure 2-D-15 shows that exceedances of arsenic occur in the shallow zone of the aquifer, with 25 of the 131 sampled wells experiencing one or more exceedances. Evaluation of wells where the maximum arsenic sampled concentration was greater than 50 percent of the MCL, or greater than the MCL, indicates that municipal community water systems deliver domestic water

supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. **Figure 2-D-16** shows that high arsenic values are less prevalent in the deep zone, with no wells exceeding the MCL.

It is noted that arsenic is a naturally occurring element in soils and rocks and has also been used in wood preservatives, animal feed, and pesticides. It can also be released into groundwater from mining. Because it is known to occur naturally in the aquifer sediments, some trace is expected to occur in shallow wells. Whether the arsenic is released from a geologic source into groundwater depends on the chemical form of the arsenic, the geochemical conditions in the aquifer, and the biogeochemical processes that occur. It is noted that recent groundwater pumping, observed through land subsidence, may result in increased arsenic aquifer concentrations (Smith et al., 2018). It is unclear if this is the cause of elevated arsenic in the Basin; regardless, increased land subsidence is not predicted, and therefore is not expected to result in increased arsenic concentrations in the shallow zone.

Hexavalent Chromium

Hexavalent chromium is one of the valence states of the element chromium. It is used in many industrial applications, including electroplating, welding and chromate painting. Hexavalent chromium is found in some groundwaters. A human health-based primary MCL of 50 µg/L exists in California; a proposed MCL of 10 µg/L is being considered by the State Water Board.

Hexavalent chromium data span from 2001 to present. **Figure 2-D-4** illustrates variation in hexavalent chromium with time for three intervals; the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells. The current MCL of 50 µg/L is displayed as a dashed red line, as well as the proposed MCL of 10 µg/L. As shown, hexavalent chromium concentrations in the subbasin are consistently below 10 µg/L in the deep zone for the duration of analyses. Concentrations in the shallow zone are consistently below the MCL of 50 µg/L, but are slightly elevated over the proposed MCL of 10 µg/L in some locations. As shown in the bottom plot concentrations in the shallow zone increase when data from monitoring wells is included in the analysis.

Hexavalent chromium data is plotted spatially for the shallow zone in **Figure 2-D-17**, and the deep zone in **Figure 2-D-18**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the proposed MCL of 10 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the proposed MCL (indicated as a yellow point), and wells where at least one sample was above the proposed MCL (indicated as a red point). As shown, wells in the shallow zone produced a result above the proposed MCL of 10 µg/L, and no wells in the deep zone exhibited concentrations above 5 µg/L.

Polyfluoroalkyl substances (PFAS)

Per- and polyfluoroalkyl (PFAS) are a group of man-made chemicals, which numbers close to 5000, that have been manufactured since the 1940's. They are used in a variety of products, are commonly found in food, household products, in water supplies and in aquatic organisms, and characteristically are very persistent in the environment and in the human body. Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which are no longer in production in the U.S., were the most extensively produced and have been the most extensively studied of the PFAS substances. At elevated levels, there is evidence of adverse human health effects associated with PFOA, PFOS and other PFAS substances. The State Water Board has established notification levels and response levels for PFOA (5.1 and 10 parts per trillion or ng/L) and PFOS (6.5 and 40 parts per trillion), respectively. The California Office of Environmental Health Hazard Assessment (OEHHA) is working to develop Public Health Goals (PHG) for PFOA and PFOS, a step in the development of MCLs by the State Water Board. OEHHA has recently released proposed PHGs of 0.007 ng/l for PFOA and 1 ng/l for PFOS, which will be considered in a public process prior to adoption.

Monitoring of PFAS has begun more recently, with data available beginning in 2017. **Figure 2-D-5** presents box and whisker plots for nine PFAS substances, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells. No MCL currently exists for PFAS substances, and the notification level for PFOA and PFAS is displayed as a dashed line. As shown, the notification levels of 5.1 and 6.5 ng/L have been regularly exceeded at wells for PFOA and PFOS, respectively. Additionally, it is noted that when data from monitoring wells are included in the plots, more substances are detected.

PFOA and PFAS data are plotted spatially in **Figure 2-D-19**, and indicate that 31 of 55 samples have PFOS concentrations greater than 6.5 ng/L, and 22 of 43 samples have PFOA concentrations greater than 5.1 ng/L. Data used to generate the maps includes EDF data, as the data was sparse.

Chloride

Chloride is an ion of the element chlorine. It is commonly associated with sodium as the salt sodium chloride. A SMCL of 250 mg/L exists for chloride to address taste issues in drinking water, while concentrations below the Upper limit of 500 mg/L are also deemed to be acceptable. Chloride data in the SASb were extensive and spanned from 1952 to present. **Figure 2-D-6** illustrates variation in chloride with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As illustrated, chloride concentrations in the shallow and deep zone were consistently below the SMCL value of 250 mg/L. It is noted that the elevated average and statistical distribution shown for the deep a zone quifer during the period 1986-90 is the result of one high estimated value (250 mg/L).

Chloride data is plotted spatially for the shallow zone in **Figure 2-D-20** and the deep zone in **Figure 2-D-21**. The maps divide the wells into four categories: wells where all samples were below 50 percent of the Recommended MCL of 250 mg/L (indicated as a green point), wells where at least one sample was greater than 50 percent of the Recommended MCL (indicated as a yellow point), wells where at least one sample was greater than the Recommended MCL (indicated as an orange point), and wells where at least one sample was greater than the Upper limit of 500 mg/L (indicated as a red point). As shown, wells in the shallow zone are more likely to exceed the SMCL or Upper Limit in the western portion of the SASb; however, the vast majority of shallow wells have not resulted in a concentration above 125 mg/L. **Figure 2-D-21** shows that no wells in the deep zone exceeded the SMCL.

Iron

Iron is a chemical element, a metal, which is the most common element on Earth, by mass. Iron occurs naturally as a mineral in sediments and rocks and is commonly found in groundwater in its dissolved form. A SMCL of 300 µg/L exists for iron to address aesthetics (discoloration). Iron data in the SASb were extensive and spanned from 1958 to present. **Figure 2-D-6** illustrates variation in iron with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As shown, when monitoring wells are omitted the average concentrations are consistently below the SMCL in both the shallow and deep zone. When monitoring wells are included in the analysis, concentrations increase for wells in the shallow zone during the period 2001 to present.

Iron data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-22** and the deep zone in **Figure 2-D-23**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the SMCL of 300 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the SMCL (indicated as a yellow point), and wells where at least one sample was above the SMCL (indicated as a red point). **Figure 2-D-22** shows that exceedances of iron occur in the shallow zone of the aquifer. Evaluation of wells where the maximum iron sampled concentration was greater than 50 percent of the SMCL, or greater than the SMCL, indicates that municipal community water systems deliver domestic water supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. Data from the deep zone is more sparse than the shallow zone, and **Figure 2-D-23** shows that maximum sampled concentrations greater than the SMCL occur throughout the region of the deep zone sampled.

Manganese

Manganese is a chemical element often found in minerals associated with iron. Manganese is a metal which occurs naturally and is typically found in its dissolved form in groundwater. A SMCL of 50 µg/L exists for manganese to address aesthetics in drinking water supplies associated with discoloration. Manganese data in the SASb were extensive and spanned from 1958 to present. **Figure 2-D-8** illustrates variation in manganese with time for seven intervals, the top plot omits data from monitoring wells, and the bottom plot includes data from monitoring wells; the SMCL is displayed as a dashed red line. As shown in the top and bottom plot, average concentrations in the shallow and deep zone are often elevated above the SMCL. When monitoring wells are included in the analysis, the average and statistical distribution of wells in the shallow zone increase greatly from the period 2001 to present.

Manganese data for the period 2005 – 2020 is plotted spatially for the shallow zone in **Figure 2-D-24** and the deep zone in **Figure 2-D-25**. The maps divide the wells into three categories: wells where all samples were below 50 percent of the SMCL of 50 µg/L (indicated as a green point), wells where at least one sample was above 50 percent of the SMCL (indicated as a yellow point), and wells where at least one sample was above the SMCL (indicated as a red point). **Figure 2-D-24** shows that exceedances of manganese occur in the shallow zone of the aquifer. Evaluation of wells where the maximum manganese sampled concentration was greater than 50 percent of the SMCL, or greater than the SMCL, indicates that municipal community water systems deliver domestic water supply to these areas, and that domestic well density is low. Within water system boundaries, monitoring and treatment should be available to protect beneficial users of groundwater. The boundary of municipal community water systems is shown in the figure. Data from the deep zone is more sparse than the shallow zone, and **Figure 2-D-23** shows that maximum sampled concentrations greater than the SMCL occur throughout the region of the deep zone sampled.

Sustainable Management Criteria

As noted in Section 3, Sustainable Management Criteria (SMC) were developed for two of the constituents of concern in the Subbasin: nitrate and specific conductance. Although the evaluation of water quality in the Subbasin also identified elevated concentrations of arsenic, iron, and manganese, these constituents were not assigned SMCs because their presence is impacted significantly by natural processes and local geologic conditions that are not controllable by the GSAs through groundwater management processes. The GSP will monitor these constituents to track any potential mobilization of elevated concentration or exceedances of the MCLs or SMCLs. Monitoring for these constituents will be carried out as part of the GSP monitoring network that is discussed in **Section 3.5.2**, as well as the Volunteer Monitoring Program that is described in **Section 4.7.1**. The period of historical monitoring data for arsenic, iron, and manganese is presented for the upper aquifer zone in **Table 2-D-2**, and the lower aquifer zone in **Table 2-D-3**. New constituents of concern may be added with changing conditions and as new information becomes available.

Figure 2-D-1: Historical Range of Nitrate Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

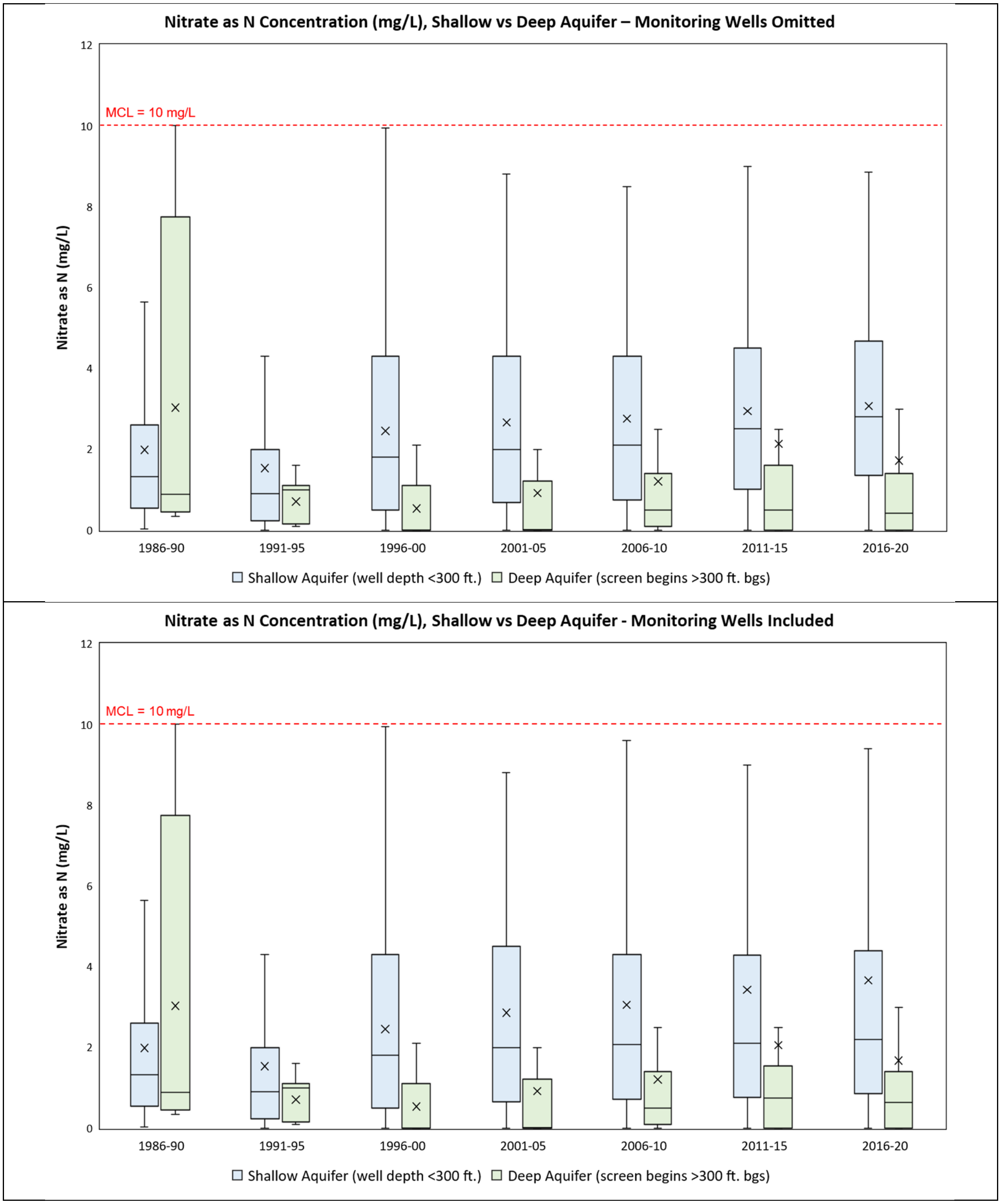


Figure 2-D-2: Historical Range of TDS Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

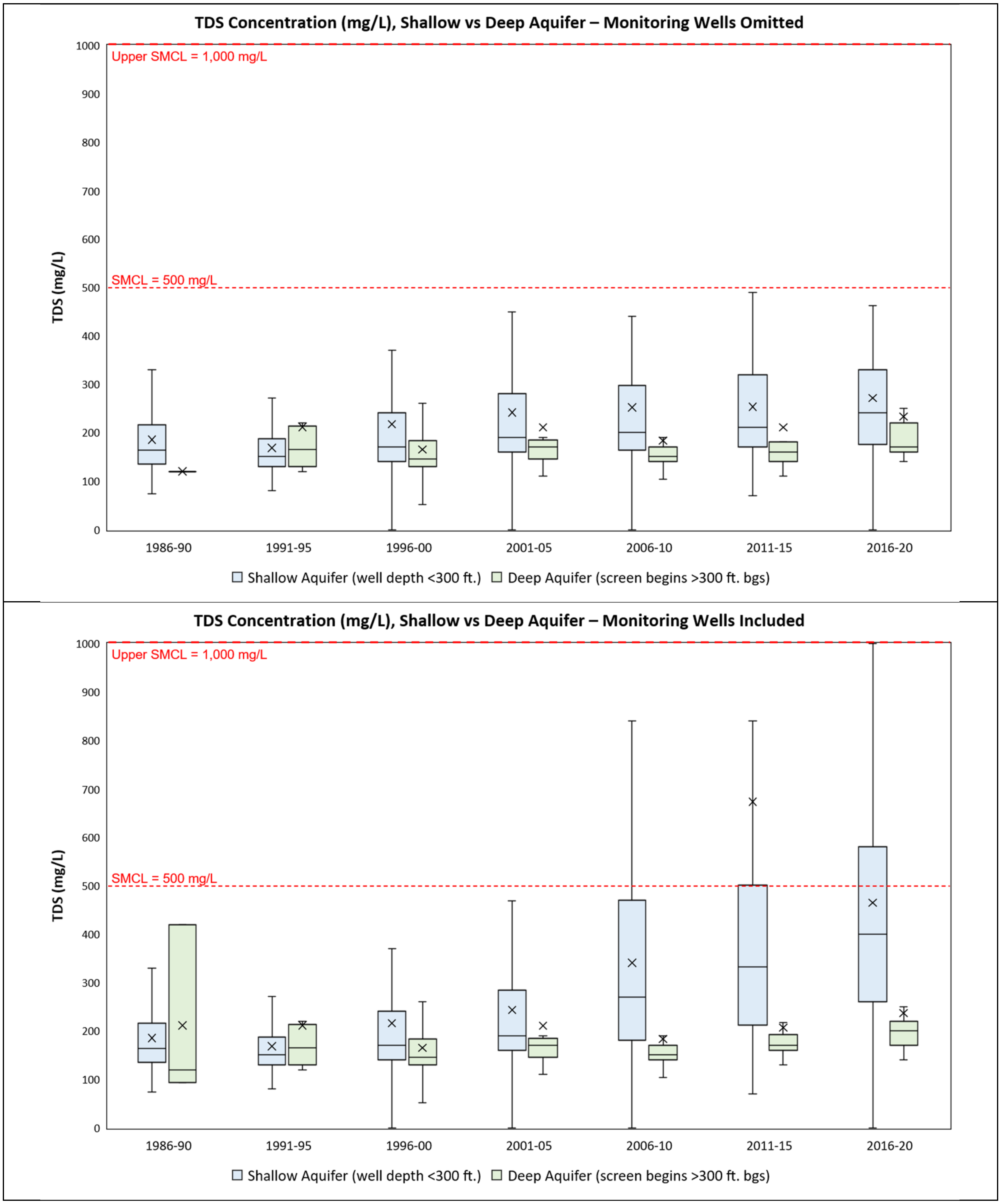


Figure 2-D-3: Historical Range of Arsenic Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

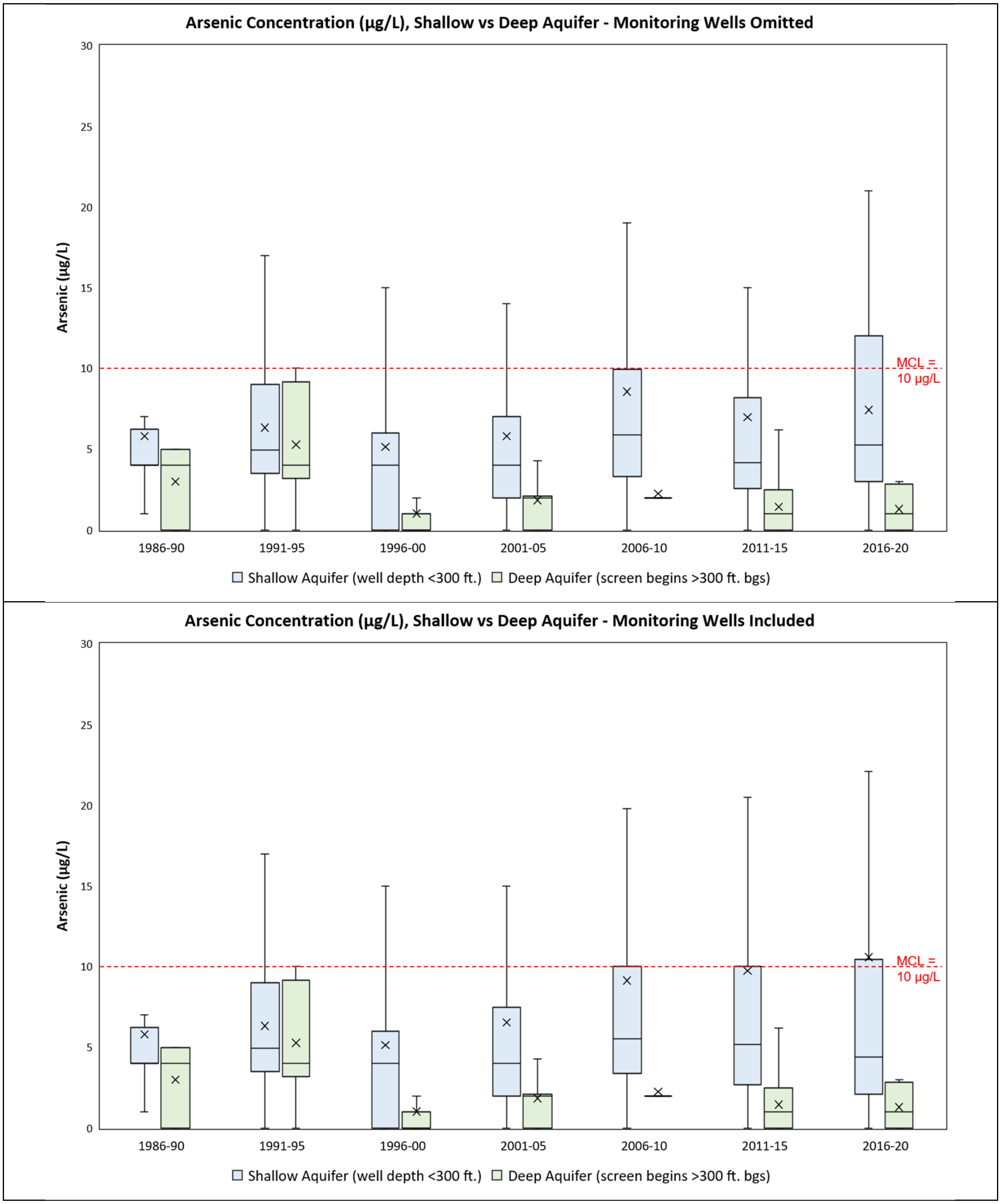
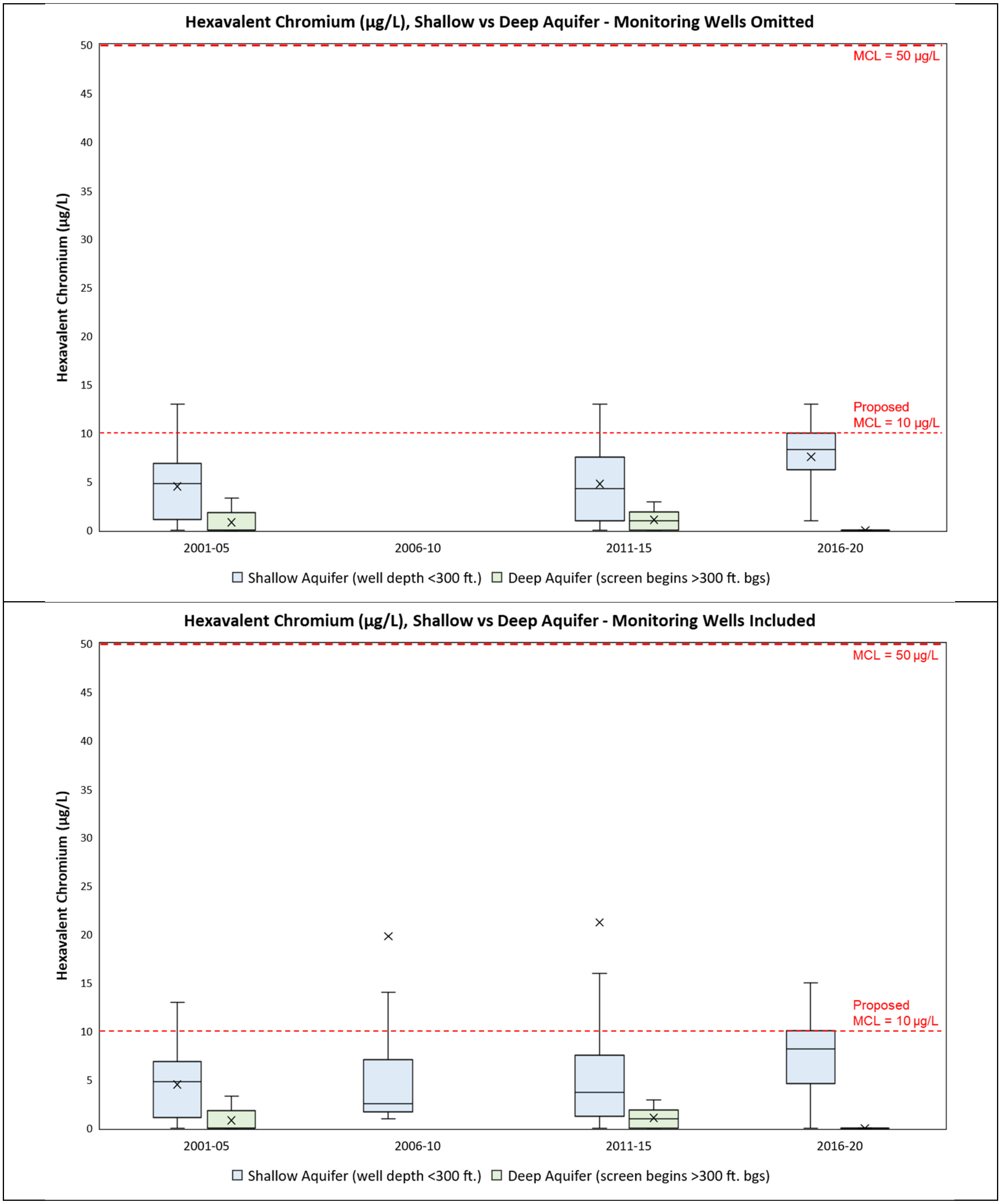


Figure 2-D-4: Historical Range of Hexavalent Chromium Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)



Hexavalent Chromium (µg/L), Shallow vs Deep Aquifer - Monitoring Wells Omitted

Hexavalent Chromium (µg/L), Shallow vs Deep Aquifer - Monitoring Wells Included

Figure 2-D-5: Range of PFAS Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

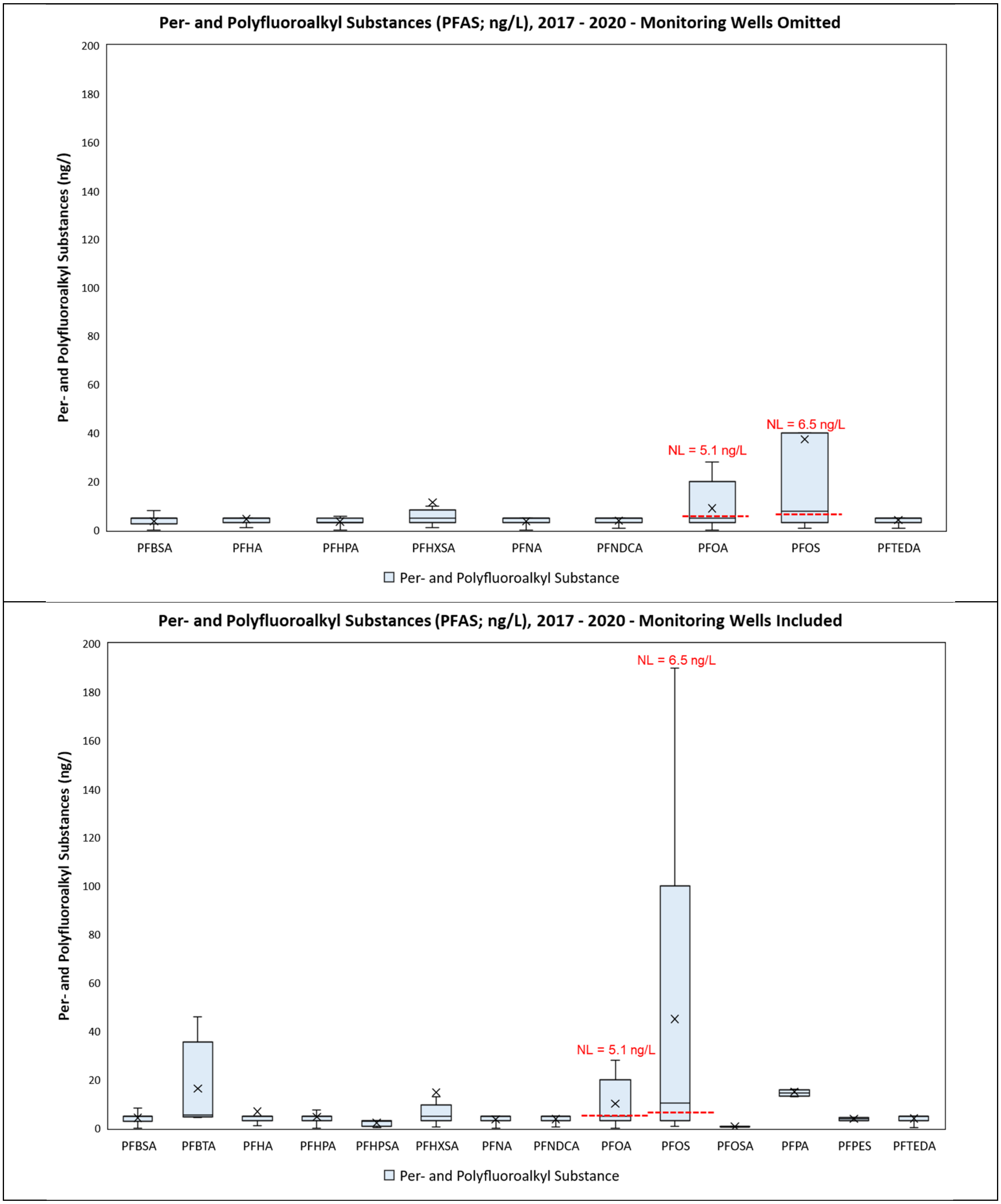


Figure 2-D-6: Historical Range of Chloride Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

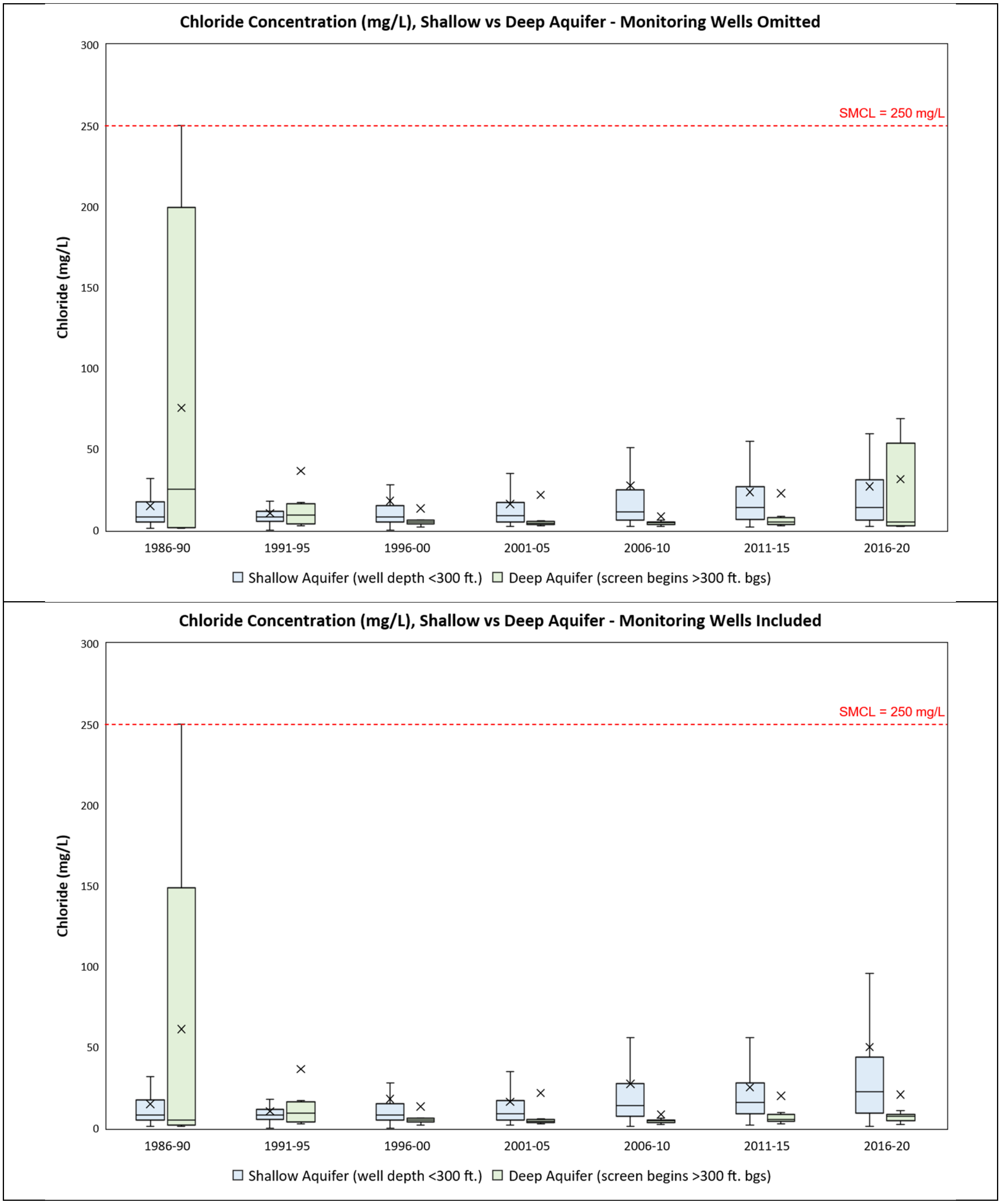


Figure 2-D-7: Range of Iron Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

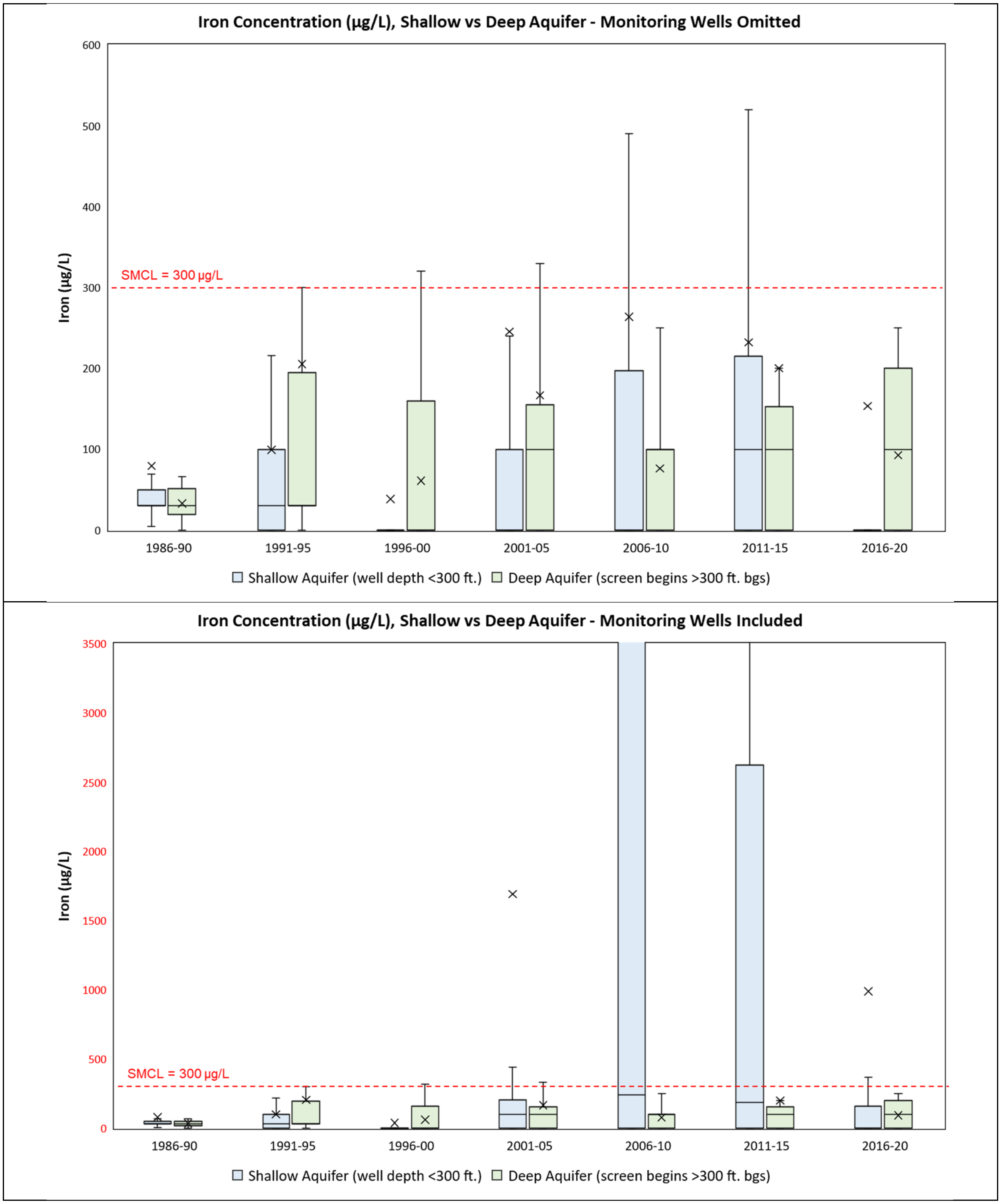


Figure 2-D-8: Range of Manganese Concentrations, without Monitoring Wells (top), with Monitoring Wells (bottom)

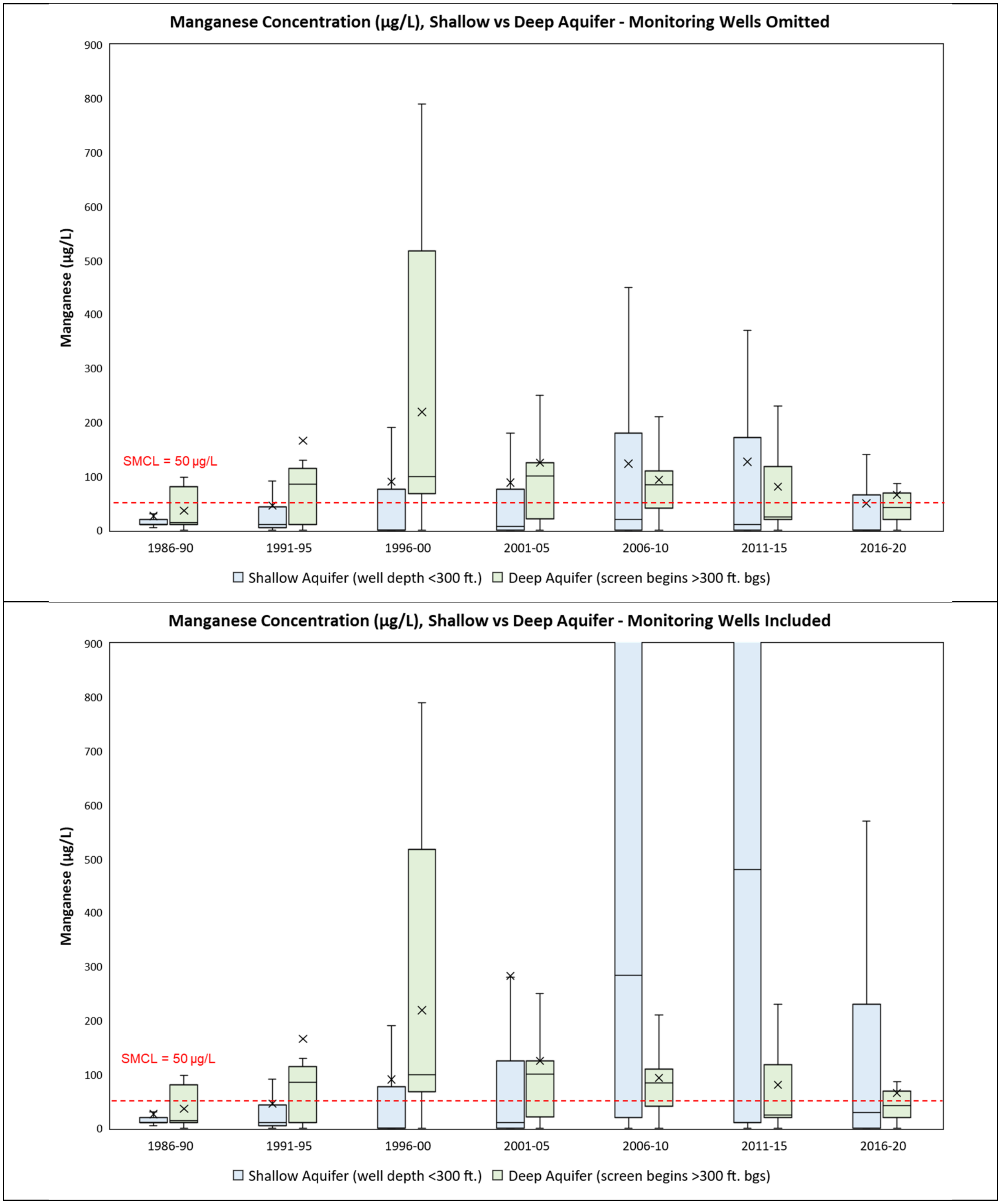


Figure 2-D-9: Nitrate Concentrations in the Shallow Zone, Monitoring Wells Omitted

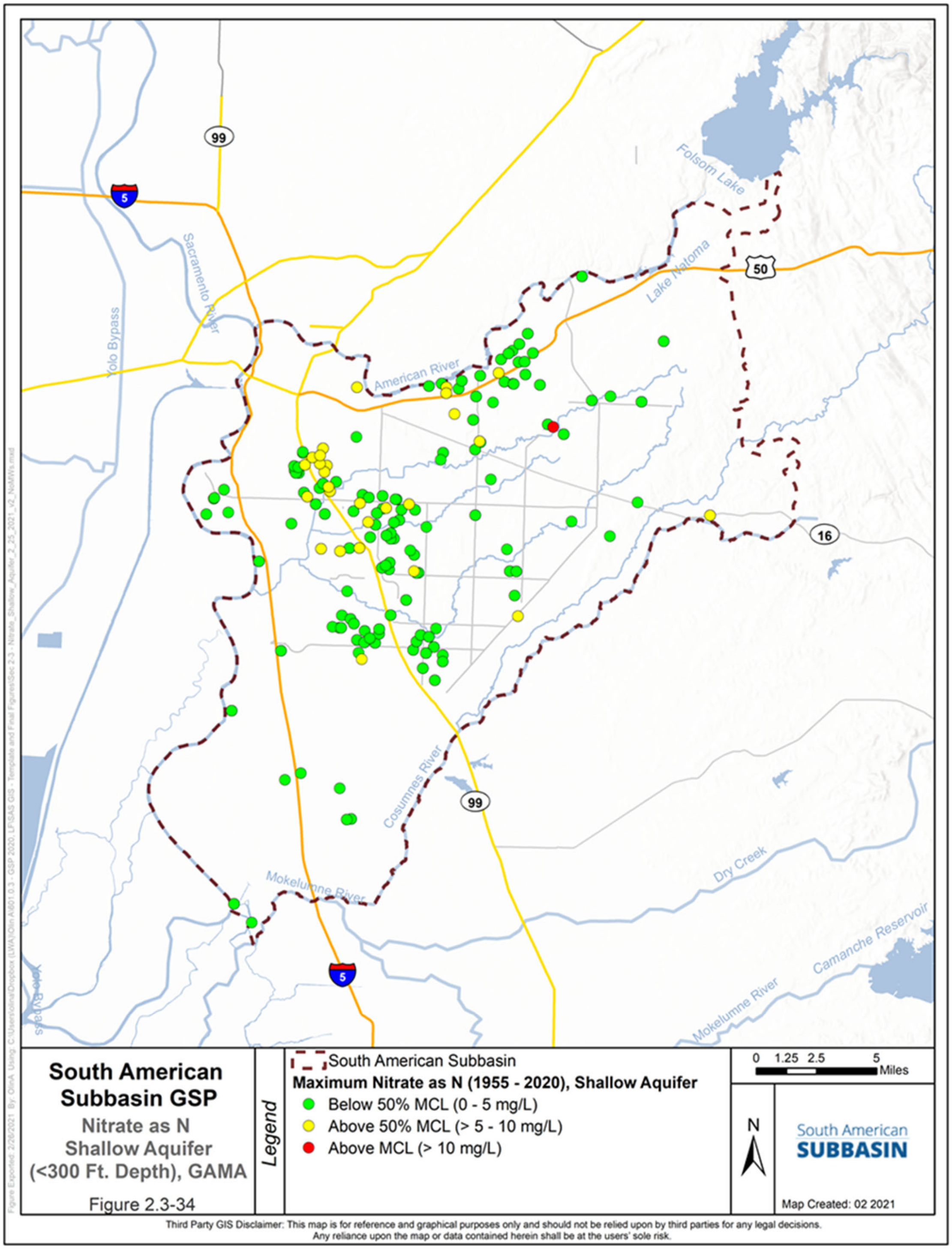


Figure 2-D-10: Nitrate Concentrations in the Shallow Zone, Monitoring Wells Included

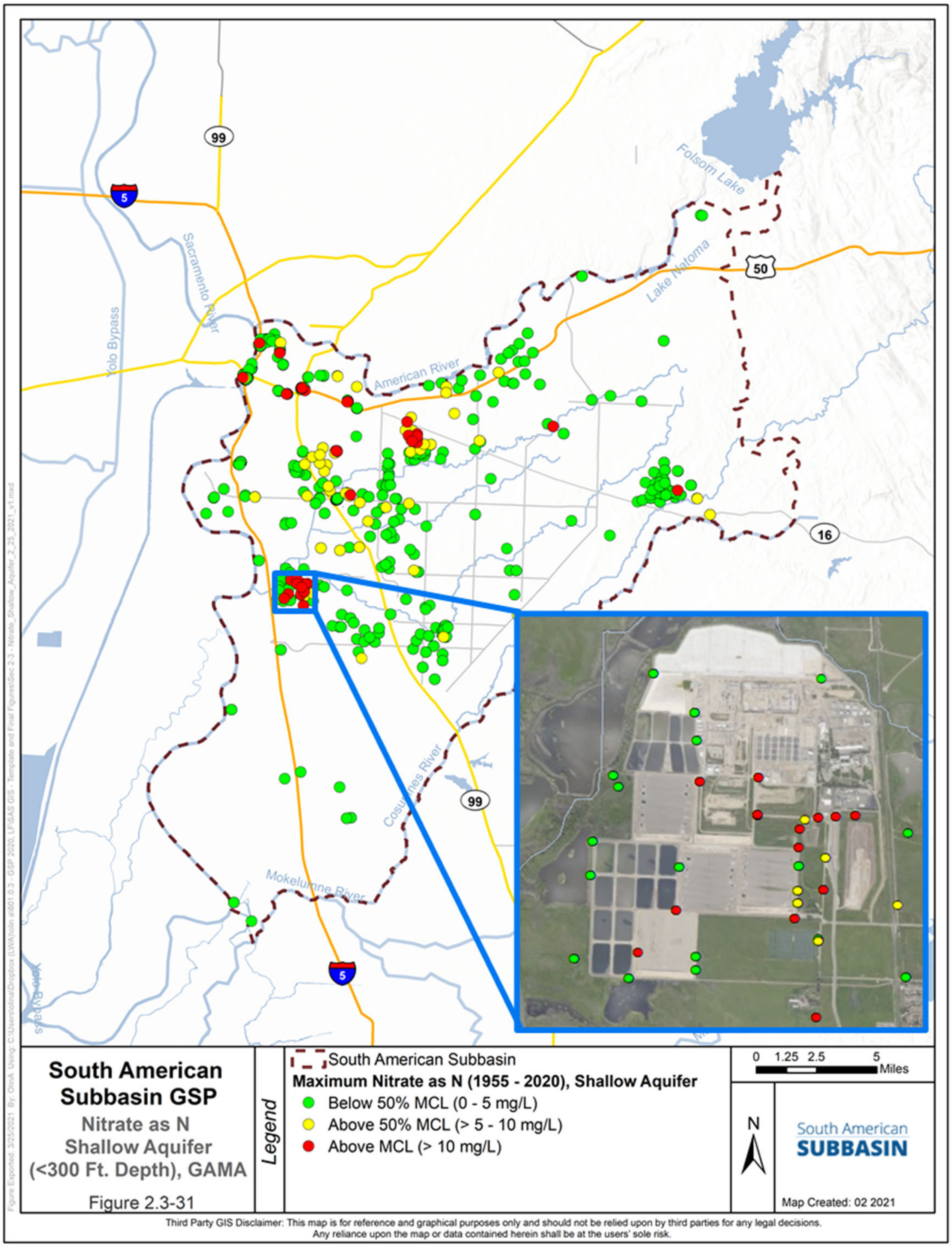


Figure 2-D-11: Nitrate Concentrations in the Deep Zone, Monitoring Wells Omitted

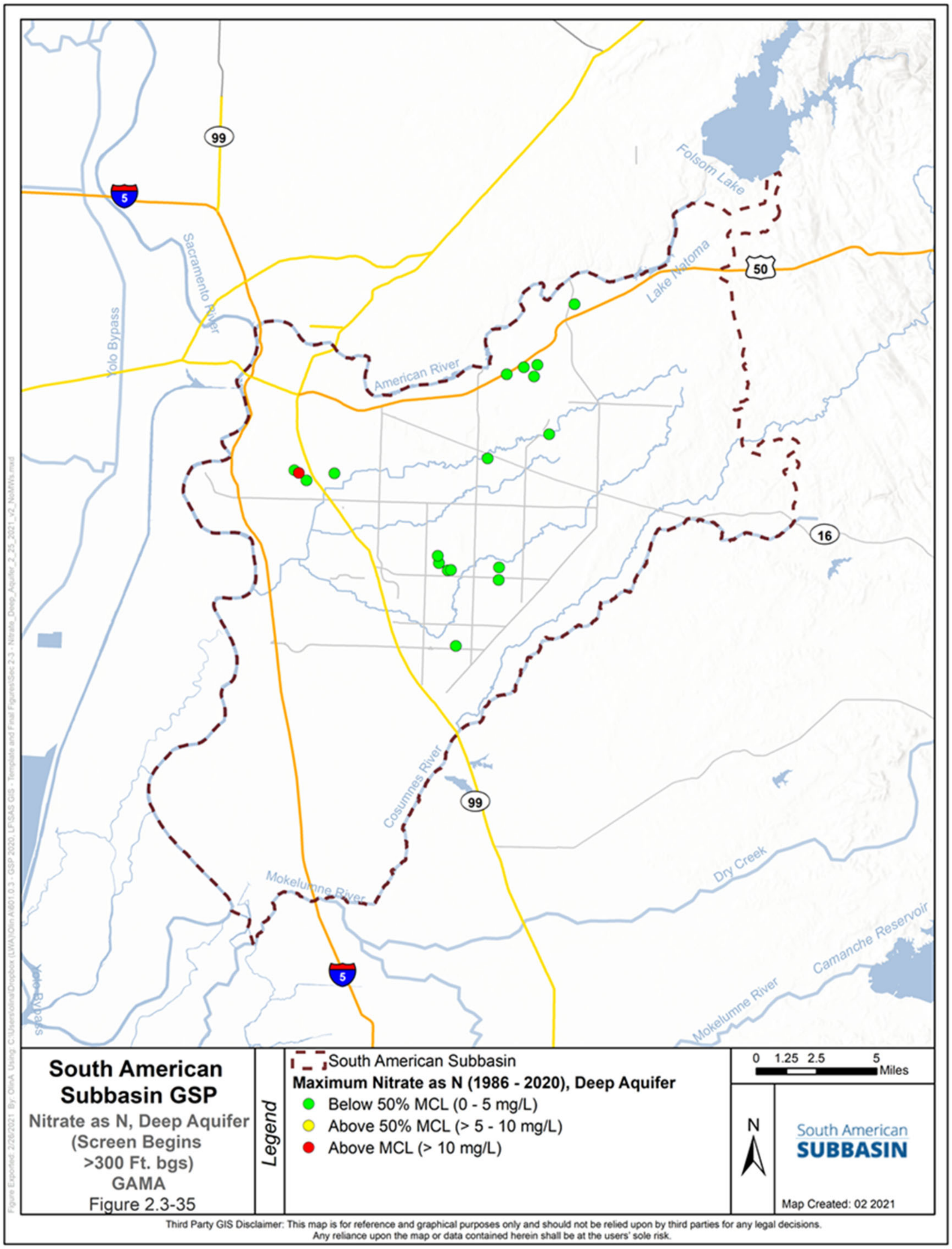
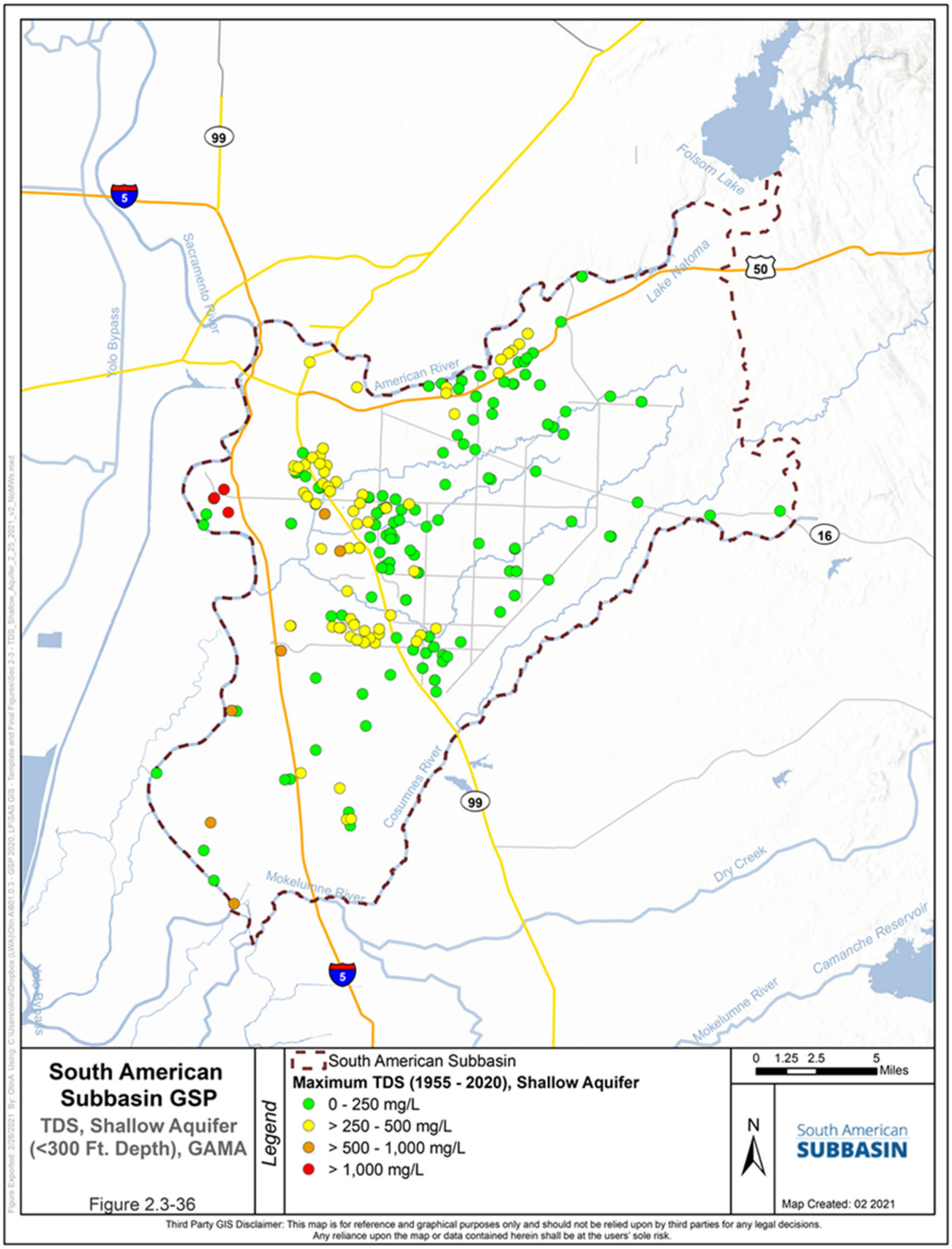


Figure 2-D-12: TDS Concentrations in the Shallow Zone, Monitoring Wells Omitted



South American Subbasin GSP

TDS, Shallow Aquifer (<300 Ft. Depth), GAMA

Figure 2.3-36

Figure 2-D-13: TDS Concentrations in the Shallow Zone, Monitoring Wells Included

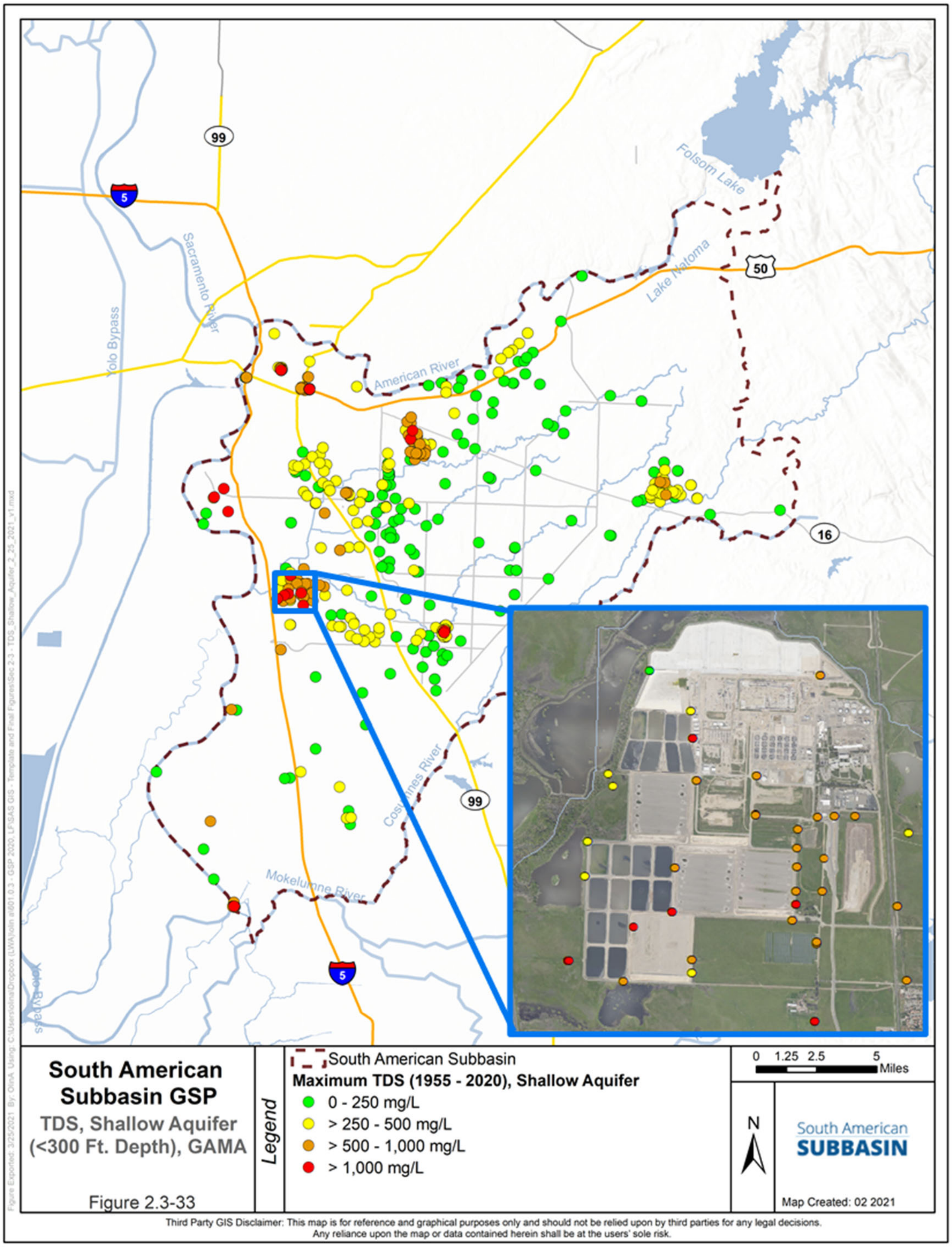
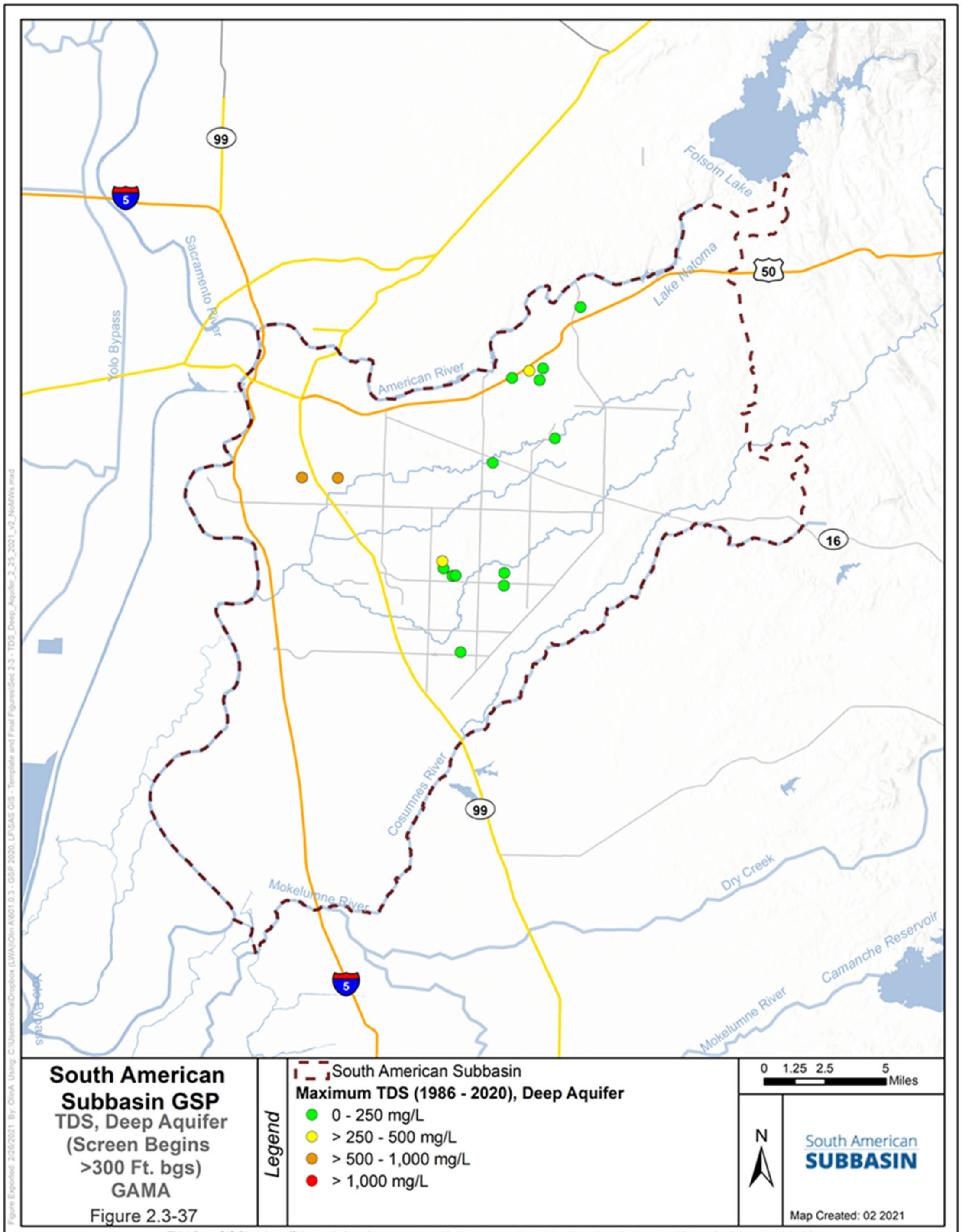


Figure 2-D-14: TDS Concentrations in the Deep Zone, Monitoring Wells Omitted



South American Subbasin GSP
TDS, Deep Aquifer (Screen Begins >300 Ft. bgs) GAMA
Figure 2.3-37

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Figure 2-D-15: Arsenic Concentrations in the Shallow Zone, Monitoring Wells Omitted

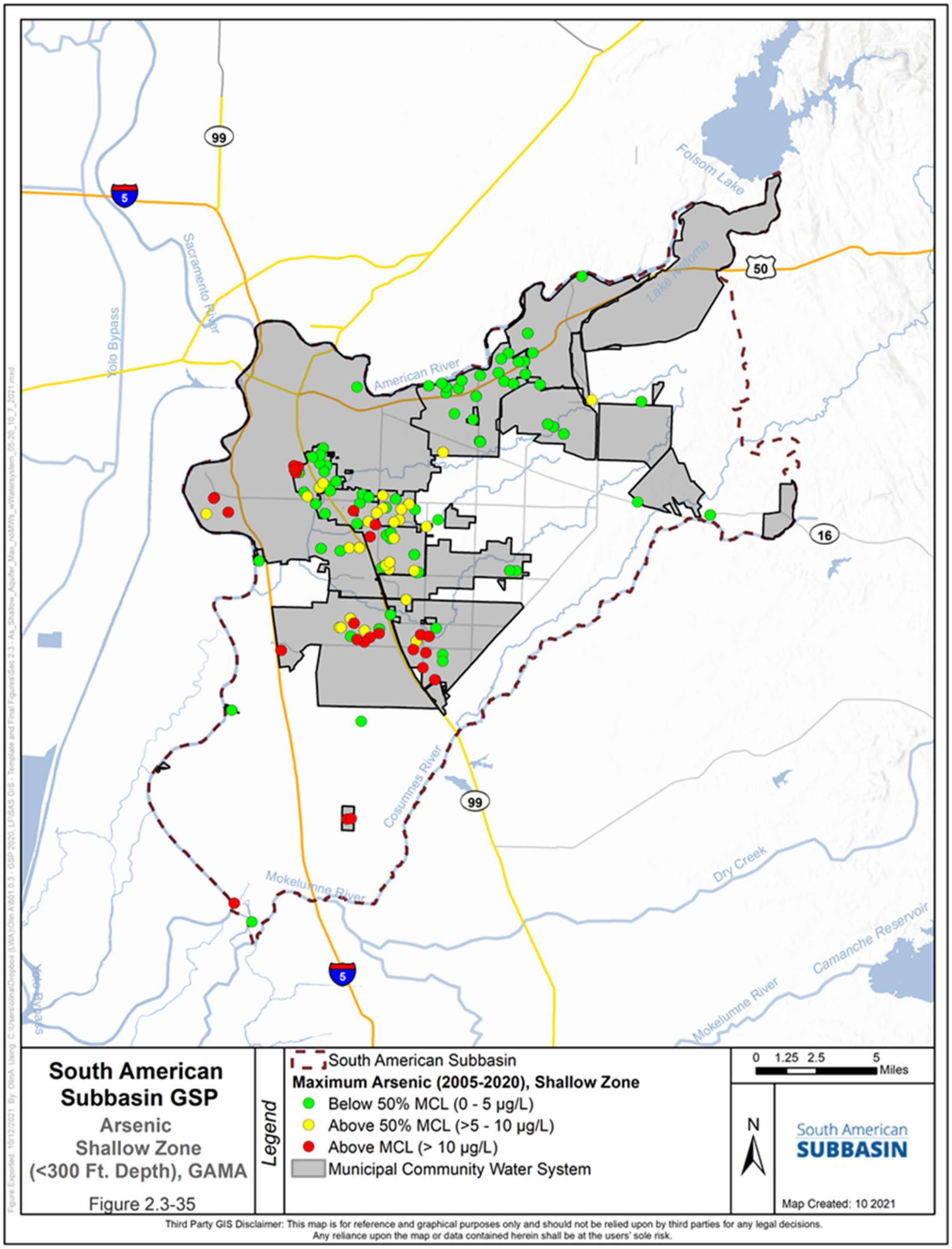

Figure 2-D-16: Arsenic Concentrations in the Deep Zone, Monitoring Wells Omitted

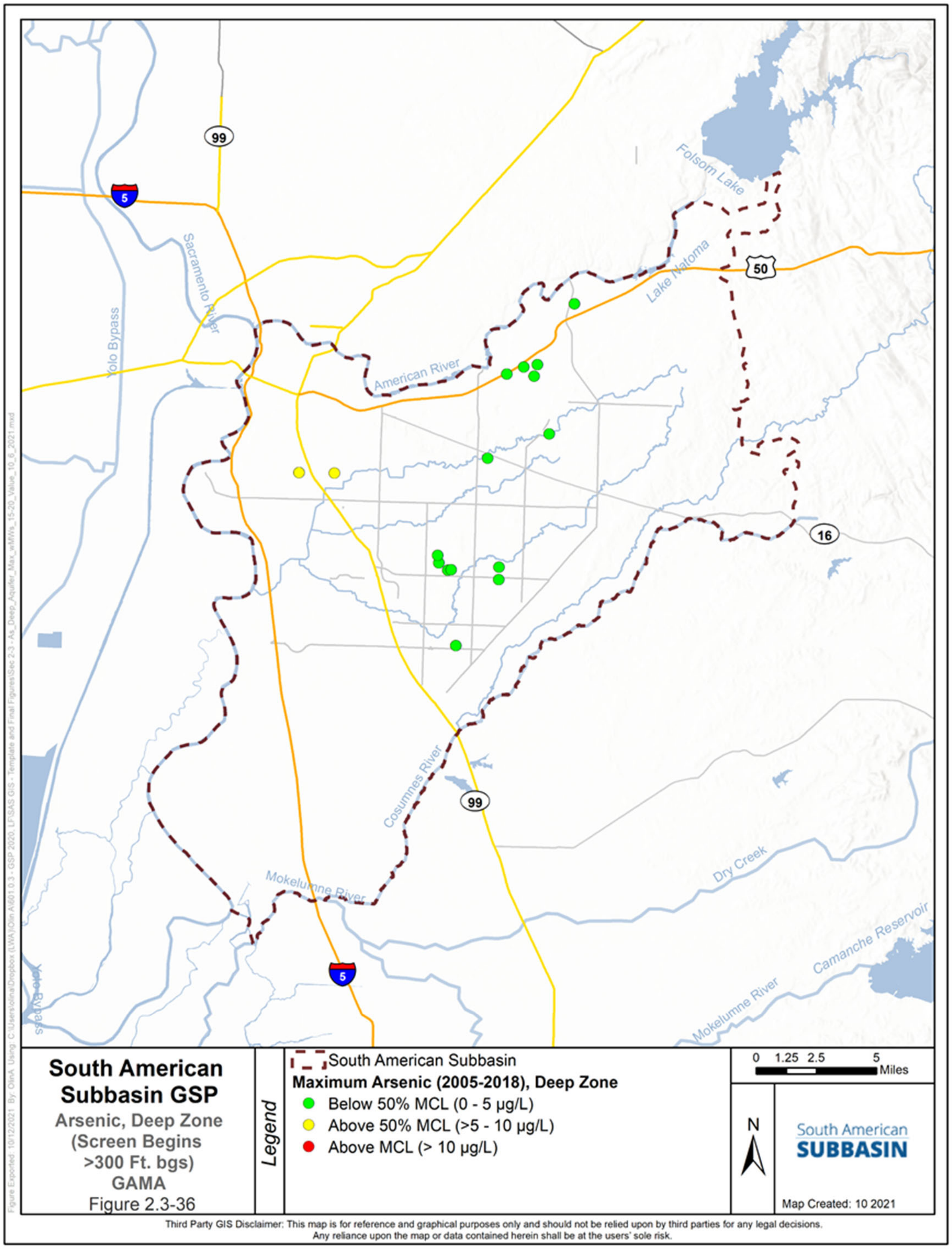

Figure 2-D-17: Hexavalent Chromium Concentrations in the Shallow Zone, Monitoring Wells Omitted

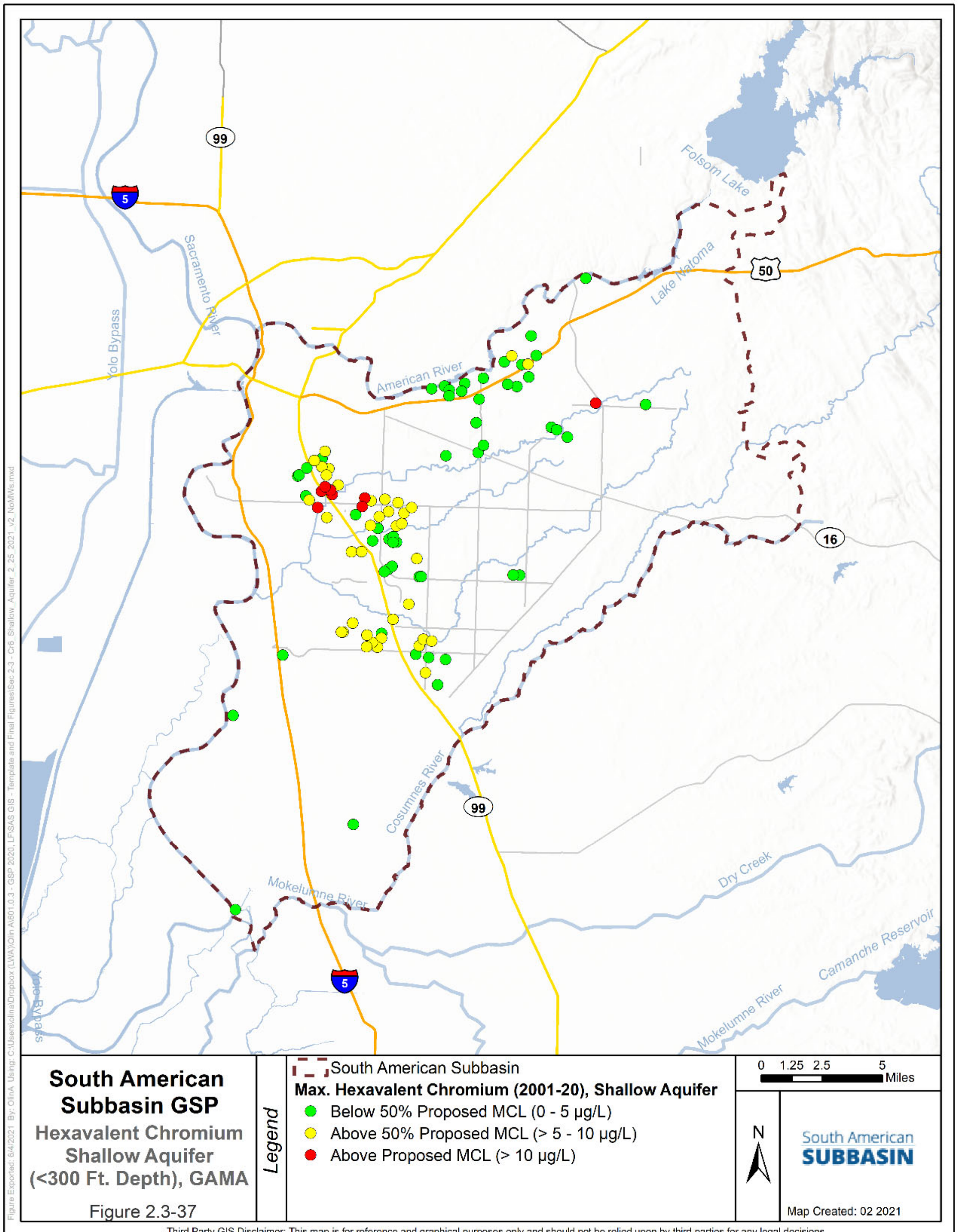

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Figure 2-D-18: Hexavalent Chromium Concentrations in the Deep Zone, Monitoring Wells Omitted

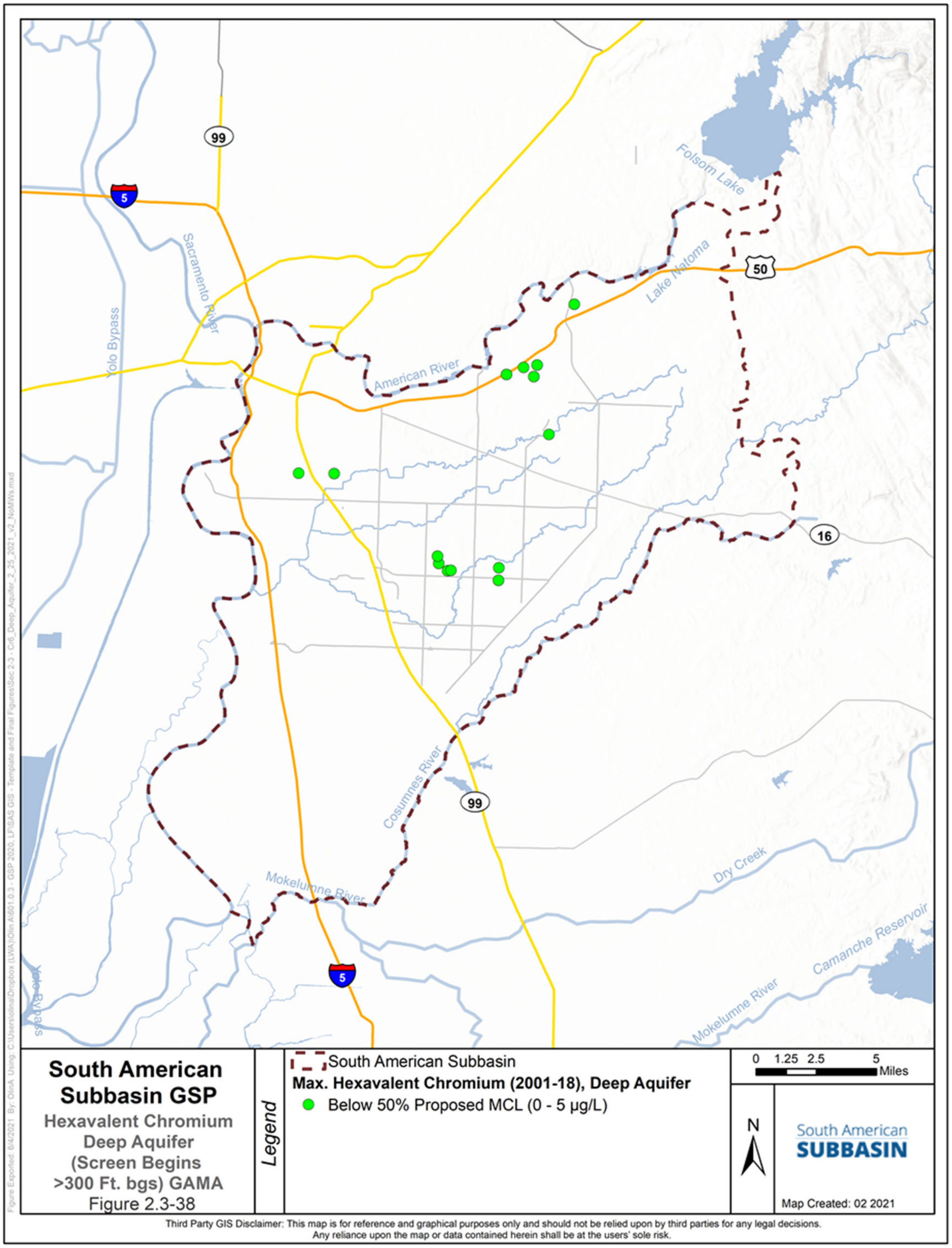

Figure 2-D-19: PFAS Concentrations in Groundwater, Monitoring Wells Included

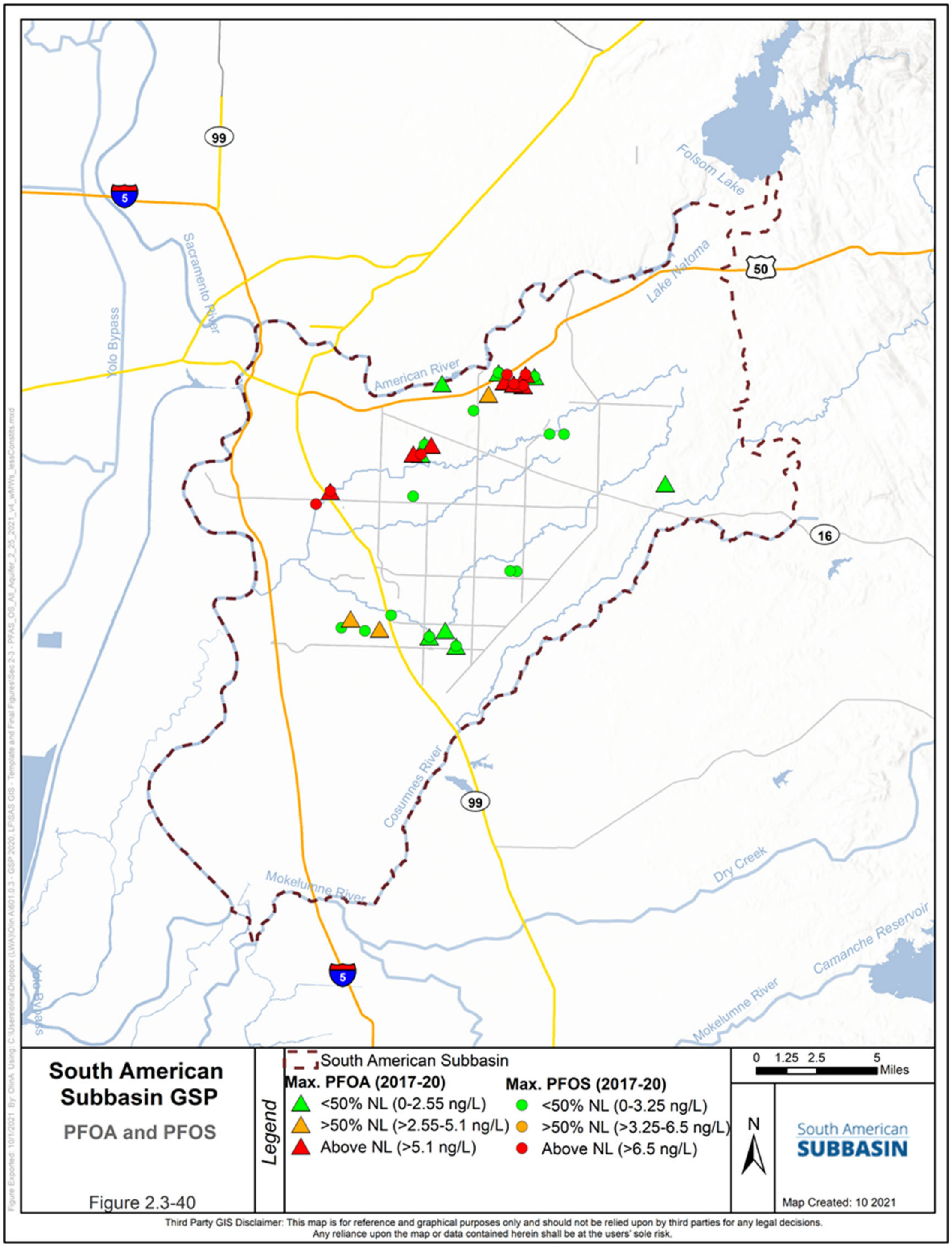

Figure 2-D-20: Chloride Concentrations in the Shallow Zone, Monitoring Wells Omitted

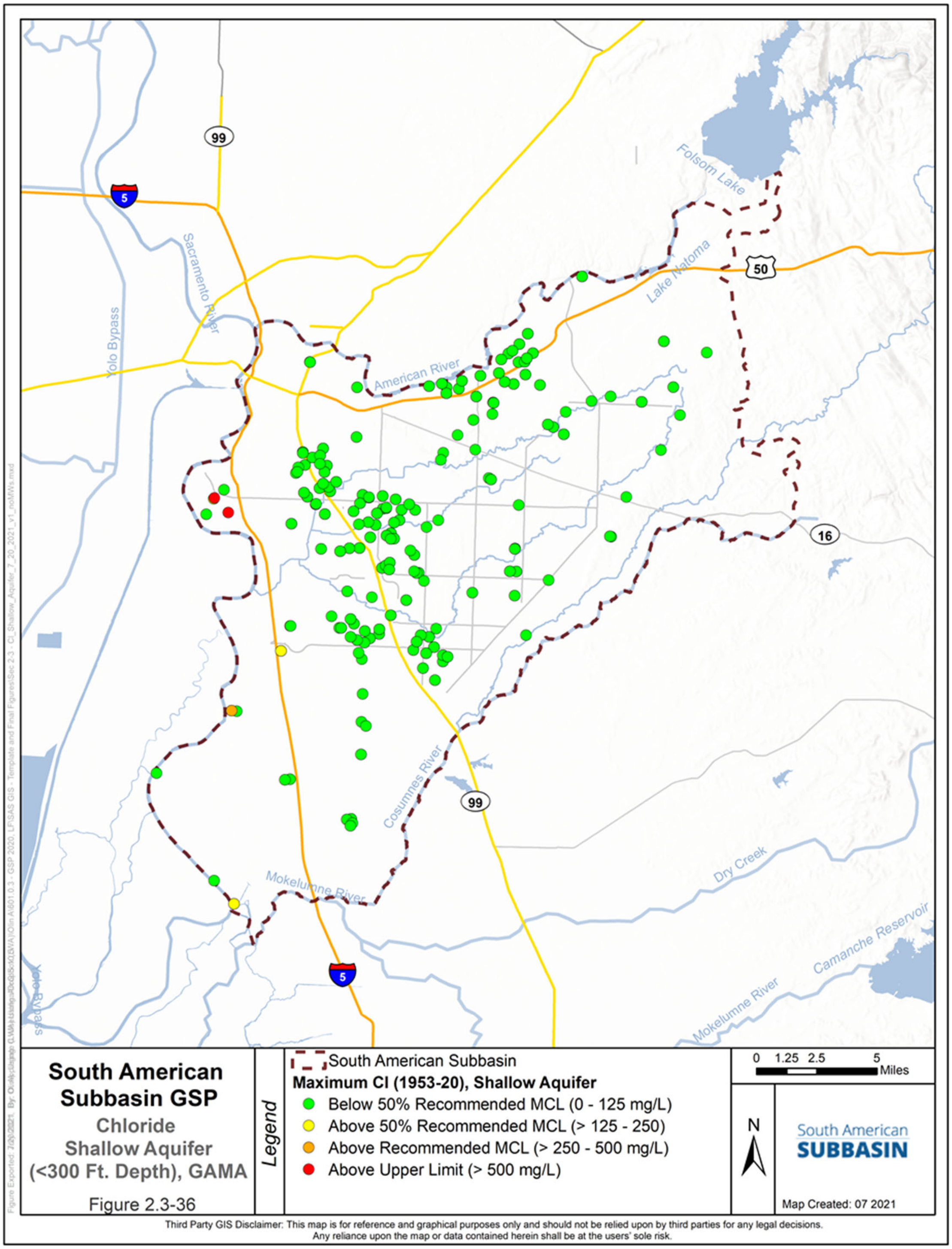

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Figure 2-D-21: Chloride Concentrations in the Deep Zone, Monitoring Wells Omitted

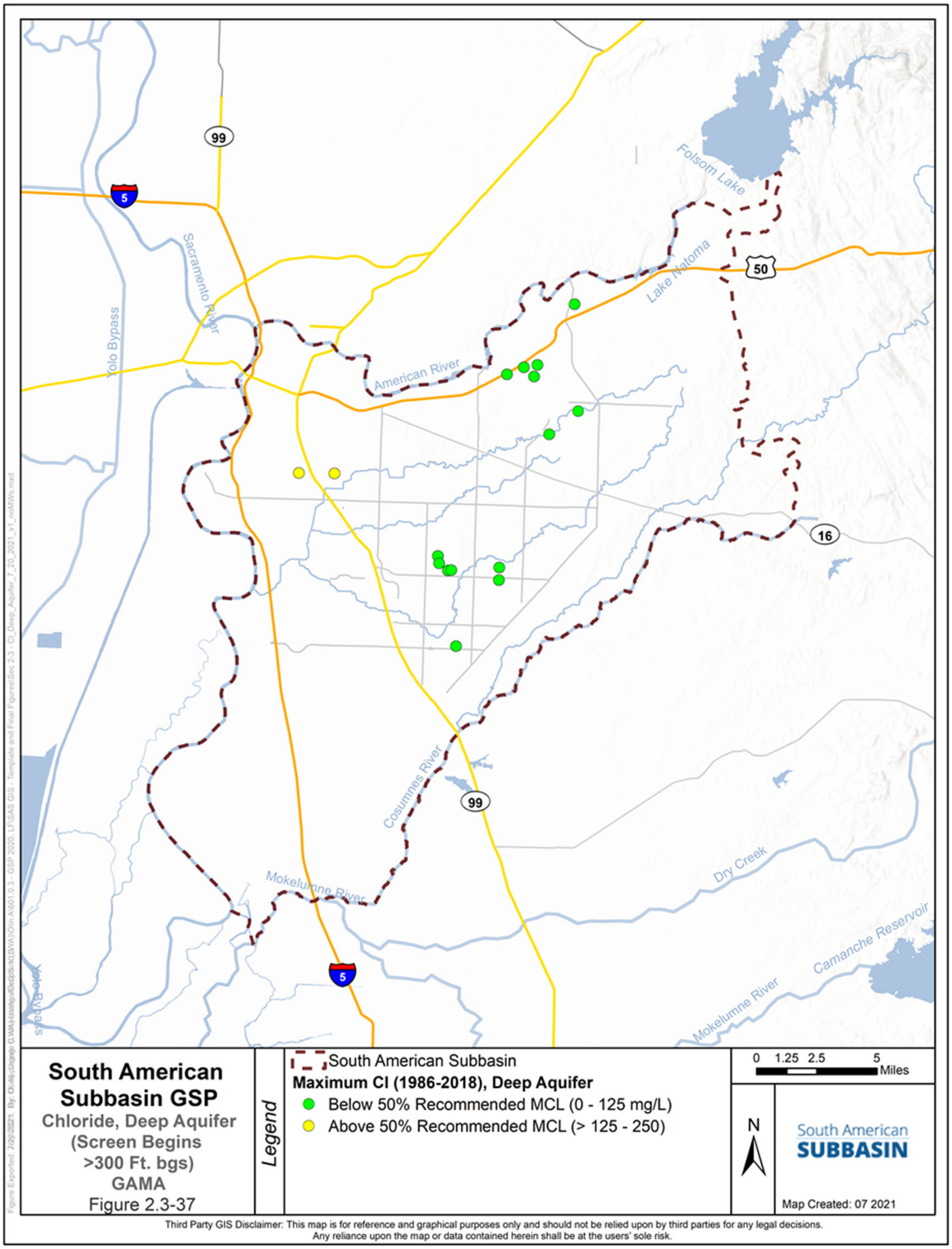

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Figure 2-D-22: Iron Concentrations in the Shallow Zone, Monitoring Wells Omitted

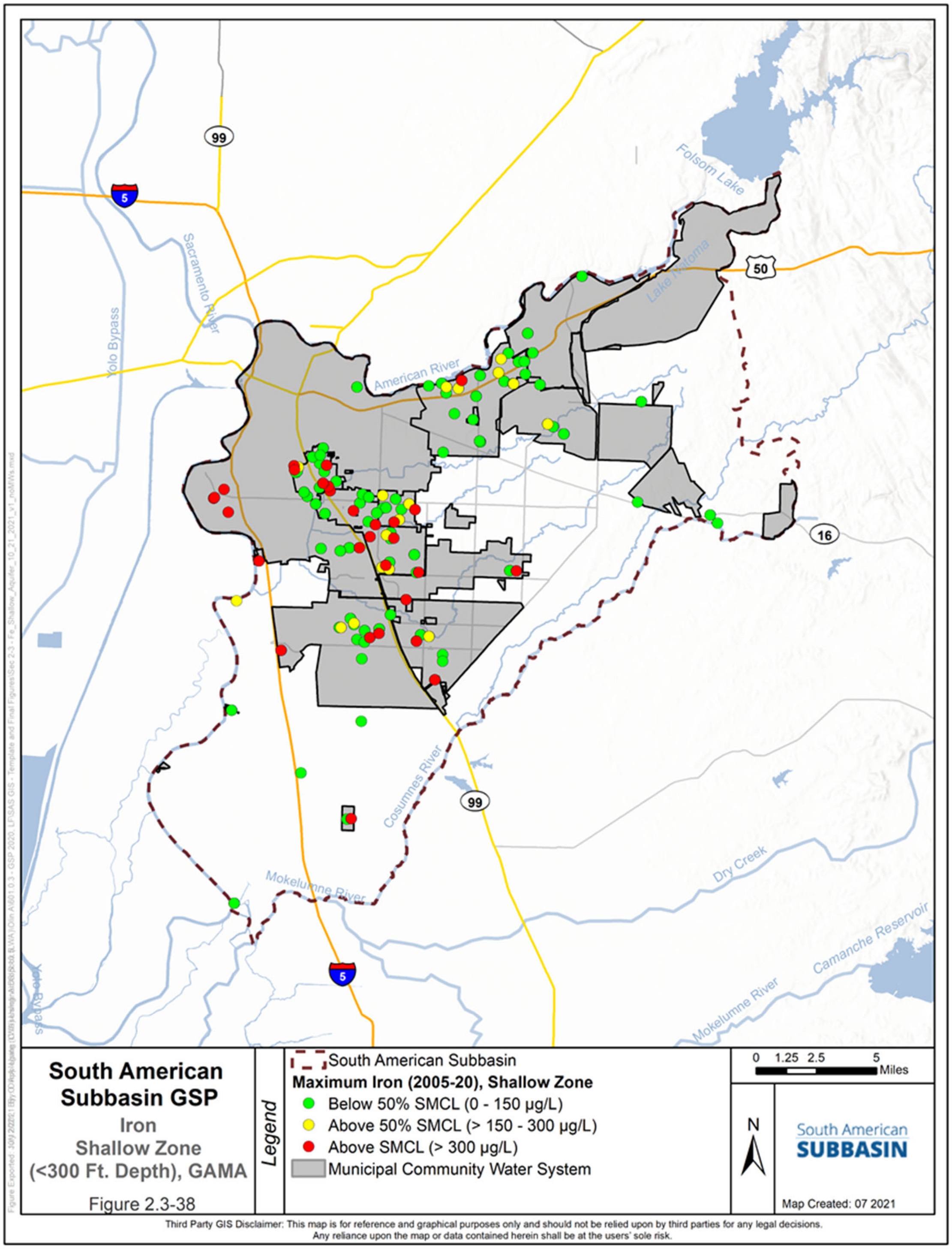


Figure 2-D-23: Iron Concentrations in the Deep Zone, Monitoring Wells Omitted

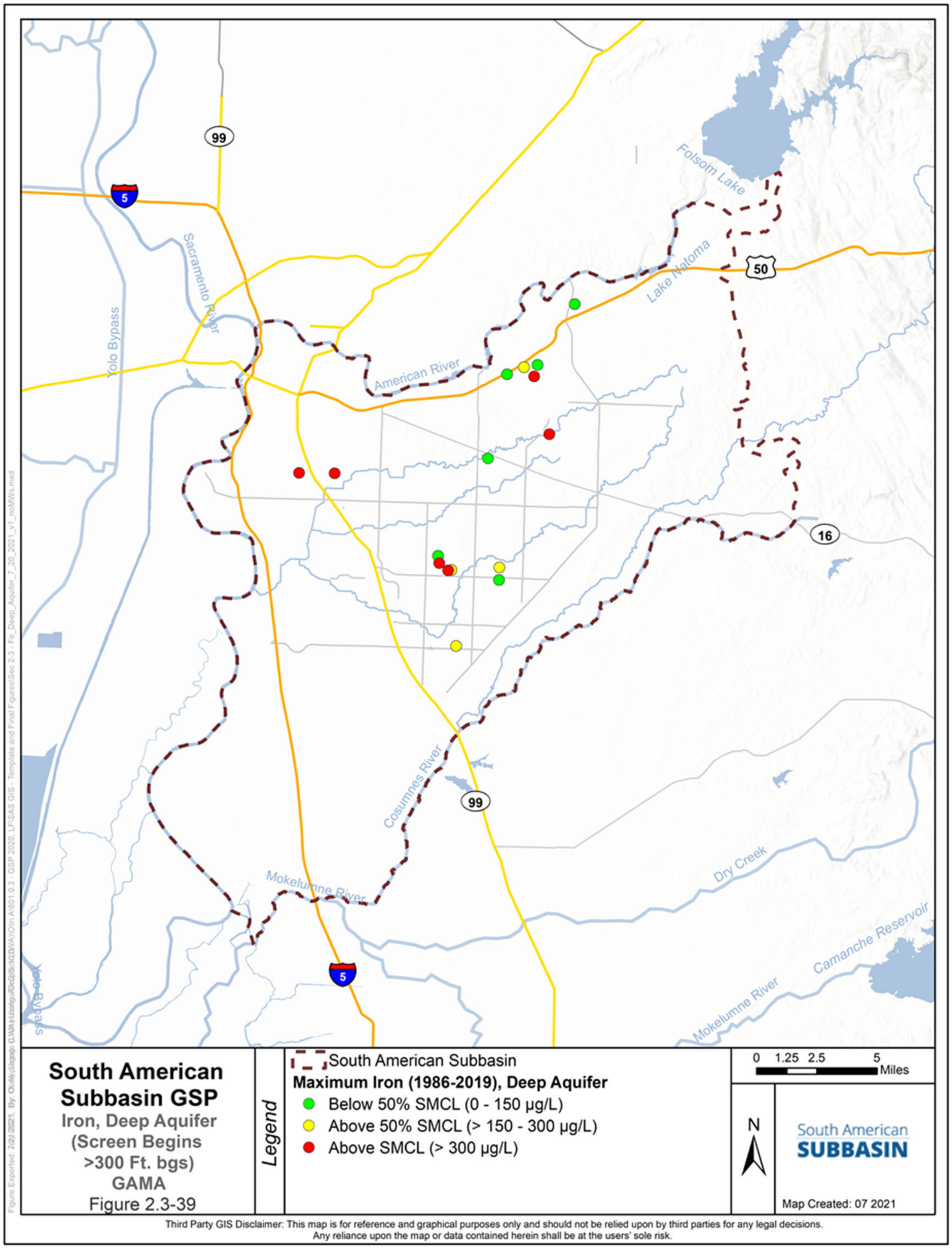


Figure 2-D-24: Manganese Concentrations in the Shallow Zone, Monitoring Wells Omitted

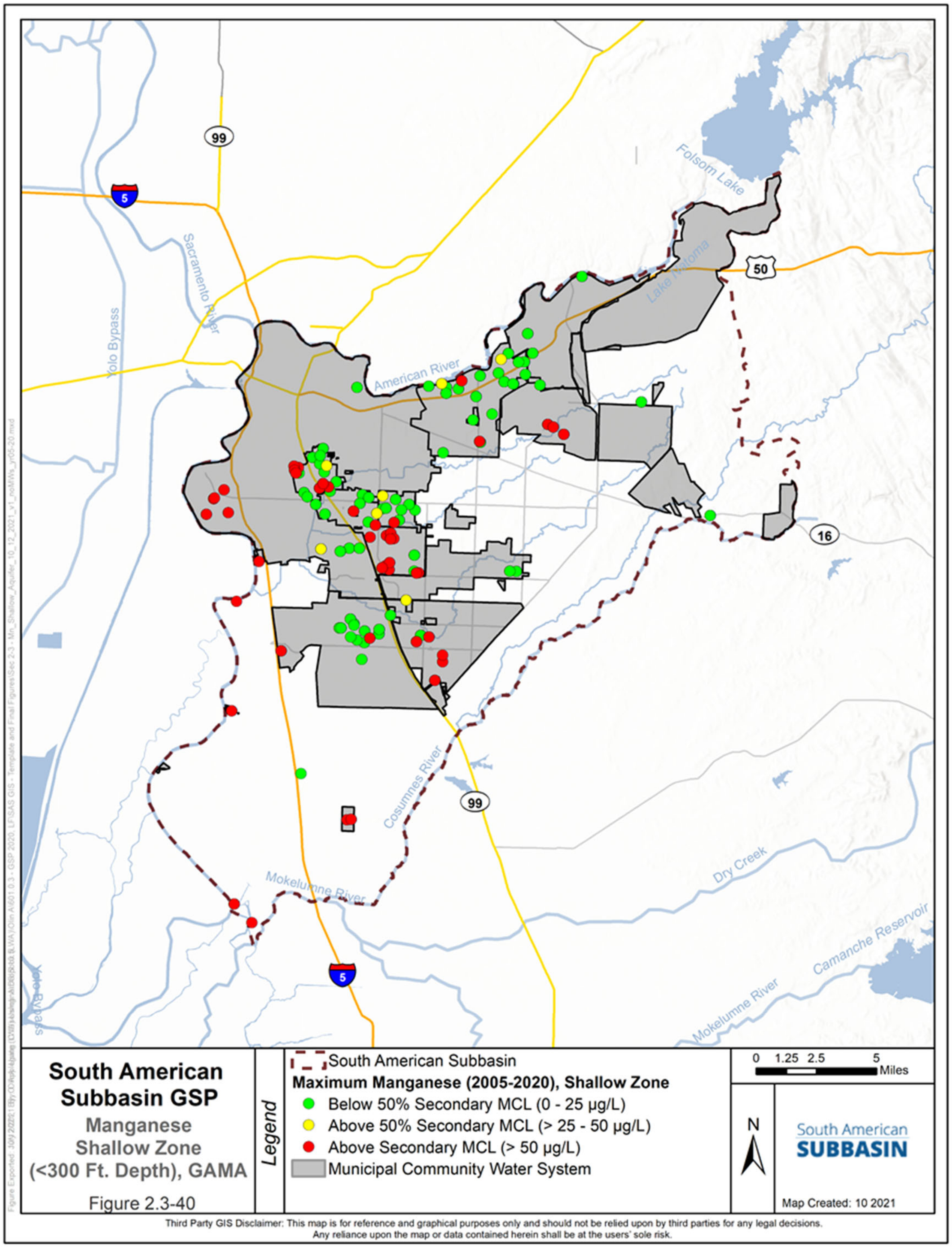


Figure 2-D-25: Manganese Concentrations in the Deep Zone, Monitoring Wells Omitted

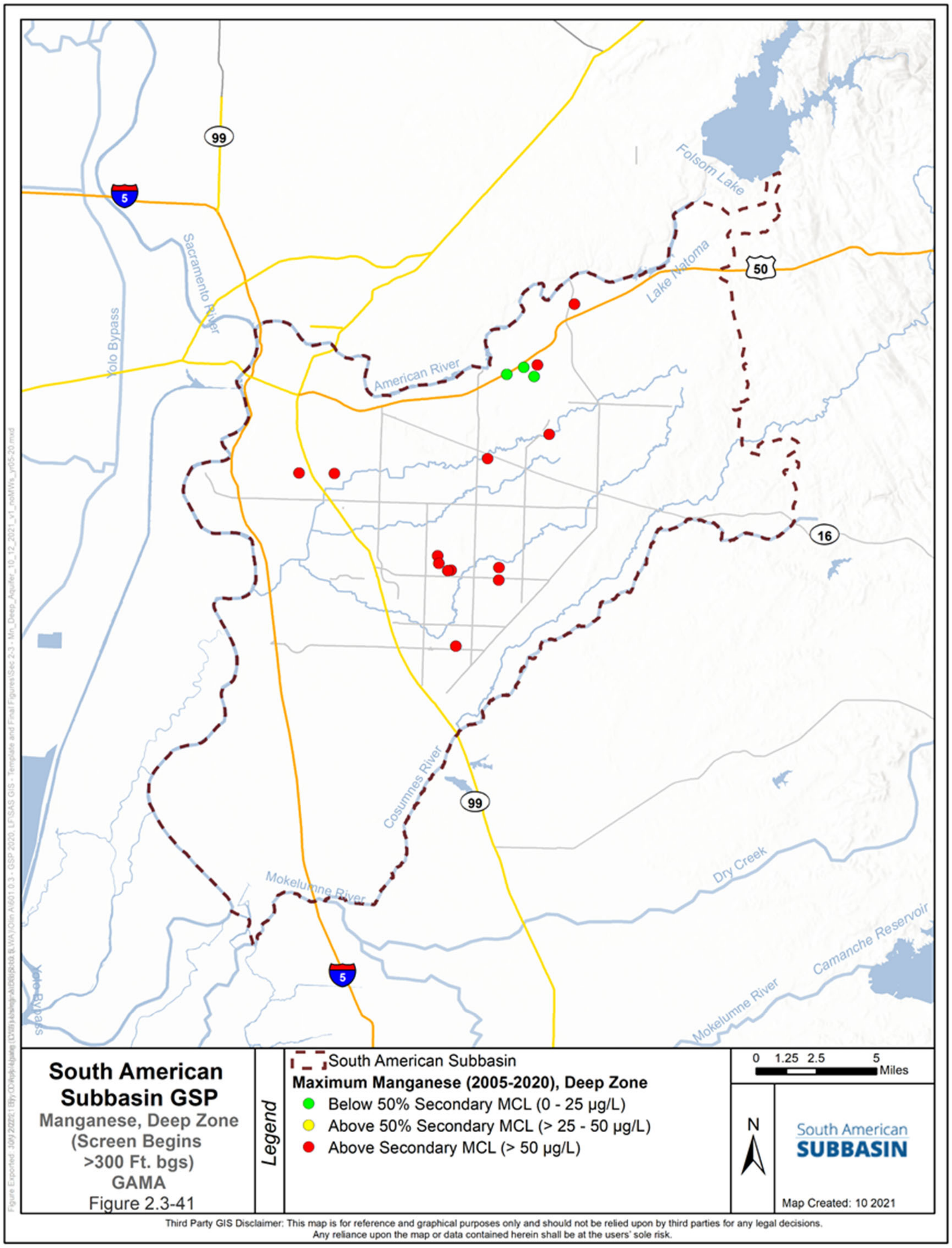


Table 2-D-2: Period of Record, Groundwater Quality Monitoring Wells in the Upper Aquifer Zone

Well ID	Arsenic Measurements			Iron Measurements			Manganese Measurements		
	From	To	# of records	From	To	# of records	From	To	# of records
3410020-009	11/16/88	5/9/17	13	11/16/88	2/4/20	13	11/16/88	2/4/20	13
3410029-002	2/21/91	2/6/17	11	7/27/89	2/13/20	15	7/27/89	2/13/20	16
3410029-016	7/1/88	2/10/20	10	7/1/88	2/10/20	13	7/1/88	2/18/14	12
3410029-029	10/25/01	2/18/14	7	10/25/01	2/18/14	6	10/25/01	2/13/20	7
3410033-006	7/13/90	12/12/13	8	5/8/87	6/13/19	12	5/8/87	6/13/19	12
L10005519750-MW-G(S)	N/A	N/A	0	10/23/17	10/23/17	1	5/20/15	5/20/15	1
L10008601447-MW-13	N/A	N/A	0	6/4/15	2/22/18	5	2/26/15	10/17/18	8
3400101-001	2/19/08	11/20/14	2	2/24/05	2/6/17	4	8/15/05	2/19/08	2
3410029-024	8/26/02	5/1/17	71	8/26/02	5/1/17	73	8/26/02	7/29/14	72
3410029-025	3/21/01	12/3/19	172	3/21/01	9/22/14	158	3/21/01	9/22/14	164
3901216-001	5/21/02	7/25/17	5	5/22/02	2/4/20	6	5/22/02	2/4/20	2

Table 2-D-3: Period of Record, Groundwater Quality Monitoring Wells in the Lower Aquifer Zone

Well ID	Arsenic Measurements			Iron Measurements			Manganese Measurements		
	From	To	# of records	From	To	# of records	From	To	# of records
3400375-001	5/5/05	6/8/12	2	5/5/05	6/8/12	2	5/5/05	6/8/12	2
3410015-020	5/27/86	1/14/14	11	5/27/86	2/28/17	14	5/27/86	2/28/17	14
3410015-022	5/19/93	5/25/17	8	5/19/93	1/14/14	10	5/19/93	10/8/19	83
3410023-015	2/15/91	1/8/15	6	7/18/89	1/8/15	23	7/18/89	1/8/15	23
3410029-015	7/1/88	5/23/18	10	7/1/88	5/23/18	16	7/1/88	5/13/15	19
3410029-026	10/25/01	5/11/17	9	10/25/01	2/18/14	10	10/25/01	5/11/17	16
3410029-027	11/19/03	8/18/11	5	11/19/03	2/5/19	8	11/19/03	2/5/19	11
3410704-001	4/30/92	5/20/14	6	4/30/92	5/11/17	8	4/30/92	5/20/14	11
L10007396297-MW-40B	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0
S7-SAC-SA10	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0

Land Subsidence

Land subsidence is the lowering of the ground surface elevation. This is often caused by pumping below thick clay layers. Land subsidence can be elastic or inelastic. Inelastic subsidence is generally irreversible. Elastic subsidence is small, reversible lowering and rising of the ground surface and can be cyclical with seasonal changes year to year. Land subsidence is not known to be historically or currently significant in South American Groundwater Subbasin.

Previous Land Subsidence Studies and Current Data Sources

Previous efforts to quantify land subsidence in the South American Subbasin have yielded results showing small-to-zero amounts of subsidence having occurred. Such efforts have mainly been through leveling profiles studied between 1947 and 1966, the 2006 GMP, a 2008 DWR and the US Bureau of Reclamation subsidence project throughout the Sacramento Valley using GPS technology (Frame Surveying & Mapping, 2008), and DWR's Sacramento Valley 2017 GPS Survey program (specific results are summarized in SCGA [2018]), all of which demonstrated that subsidence has been very minimal, not significant or unreasonable, across the Subbasin during the time period 2008-2017.

DWR published Interferometric Synthetic Aperture Radar (InSAR) satellite data on their SGMA Data Viewer web map in 2019 (with an additional update in 2020), providing an estimate of land subsidence covering the time period from June 2015 to September 2019 (see **Figure 2-D-1**). These data are processed by TRE Altamira and are made available by DWR as downloadable raster and point datasets for monthly time steps, updated annually.

The only current CGPS (Continuous GPS) data available within the Subbasin are from the UNAVCO CGPS station (# P274). The CGPS station data are available for the period from October 2005 to present (). The data from this station are used in estimating current land subsidence conditions in the area surrounding the CGPS station. The CGPS data are also planned for use by the GSA in estimating future land subsidence conditions in the Subbasin.

The DWR/TRE Altamira InSAR data are the only currently available subsidence-related dataset covering the whole Subbasin and provide high-resolution estimates of total vertical displacement, complementary to the CGPS station data. The CGPS and InSAR data are described in further detail below.

CGPS Data Analysis

The vertical displacement data available from the UNAVCO CGPS network station #P274 start in October 2005 and continue to the present. The record of this subsidence data product from October 2005 to December 2020 are shown in **Figure 2-D-2**Figure 2-D-2. The data suggest minimal land subsidence has occurred since measurement began in October 2005, equating to about -0.14 ft in total, or roughly -0.01 ft/year. The InSAR record of subsidence for the same area the CGPS station lies within compares similarly for the equivalent period of June 2015 to September 2019 (both recording about -0.03 ft of subsidence). This demonstrates the accuracy of InSAR to be approximate to the CGPS stations for purposes of tracking land subsidence according to SGMA needs.

InSAR Data Analysis

Using the TRE Altamira InSAR Dataset provided by DWR, it is observed that the majority of the vertical displacement values in South American Subbasin are very low to essentially zero, with minimal outliers and within the range of 0.0 to -0.14 ft (see **Figure 2-D-1**). These values are about the same to about one order of magnitude smaller than the combined data and raster conversion error. While there are areas of slight subsidence near and to the southwest of Elk Grove, these are noted by previous studies as being due to a persistent cone of depression from groundwater extraction due to pumping near Elk Grove (2006 GMP) and Delta area sediment-oxidation subsidence (DWR, 1995), respectively. The Subbasin overall reflects subsidence signals that are very low or are essentially noise in the data. Any actual signals at this level could be due to a number of possible activities, including land use change and/or agricultural or urban operational activities at the field scale, as well as sediment-oxidation induced subsidence. For perspective, during this same period (2015-2019), sections of the San Joaquin Valley in California's Central Valley experienced -3.5 ft of total vertical subsidence.

InSAR Data Quality

DWR has stated that the total vertical displacement measurement error for InSAR data are as follows:

1. The error between InSAR data and continuous GPS data is 0.052 ft (16 mm) with a 95% confidence level.
2. The measurement accuracy when converting from the raw InSAR data to the maps provided by DWR is 0.048 ft (15 mm) with 95% confidence level.

By simply adding the errors 1 and 2, the combined error is 0.1 ft (~30.5 mm) (B. Brezing, personal communication, February 27, 2020). While this is not a robust statistical analysis, it does provide an estimate of the potential error in the InSAR maps provided by DWR. A land surface change of less than 0.1 ft is therefore within the noise of the data and may not be indicative of subsidence in the basin. Additionally, the InSAR data provided by DWR reflects both elastic and inelastic subsidence. While it is difficult to compensate for elastic subsidence, visual inspection of monthly changes in ground elevations suggest that elastic subsidence is largely seasonal.

Figure 2-D-1: South American Subbasin InSAR Subsidence, June 2015 – September 2019

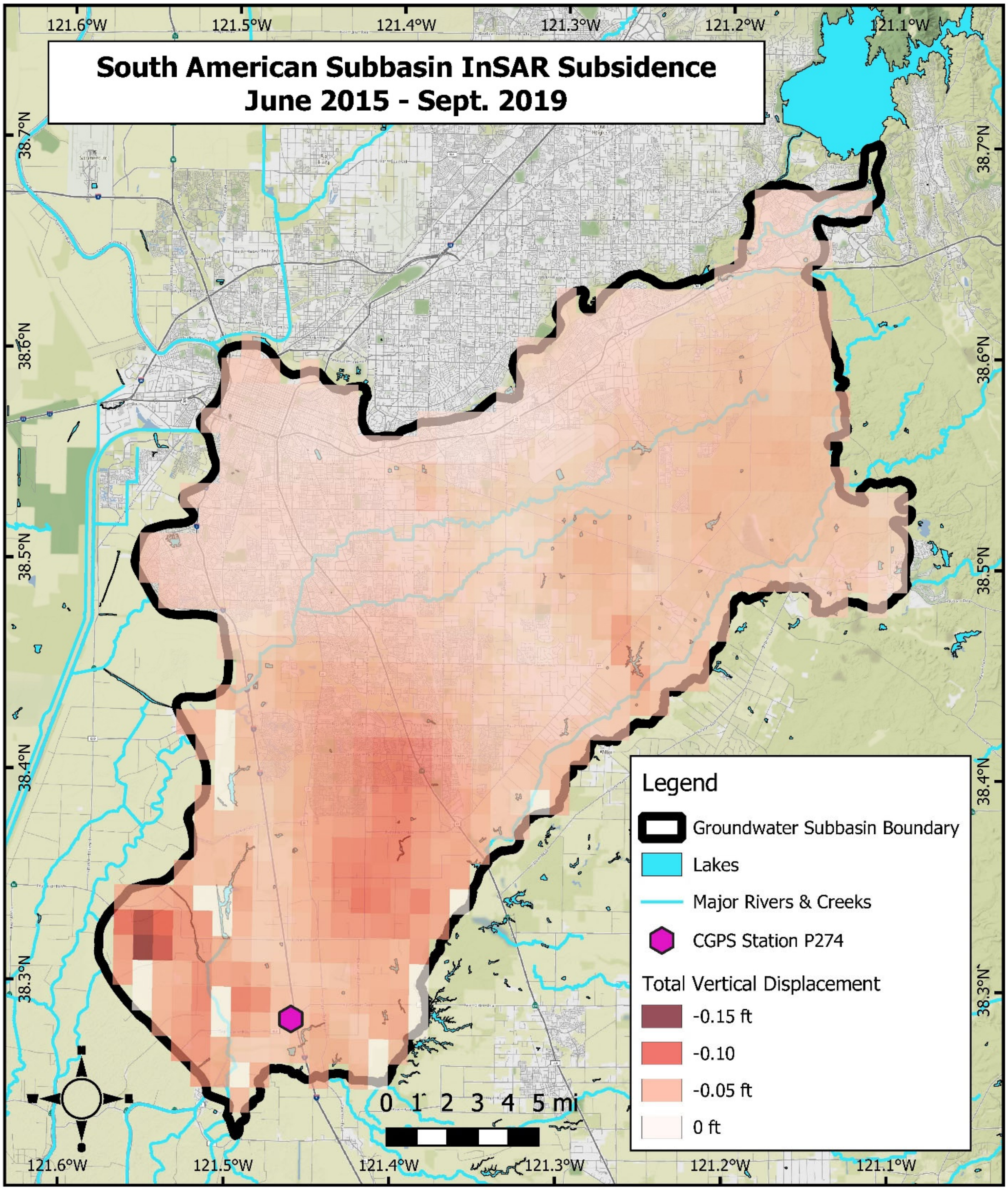
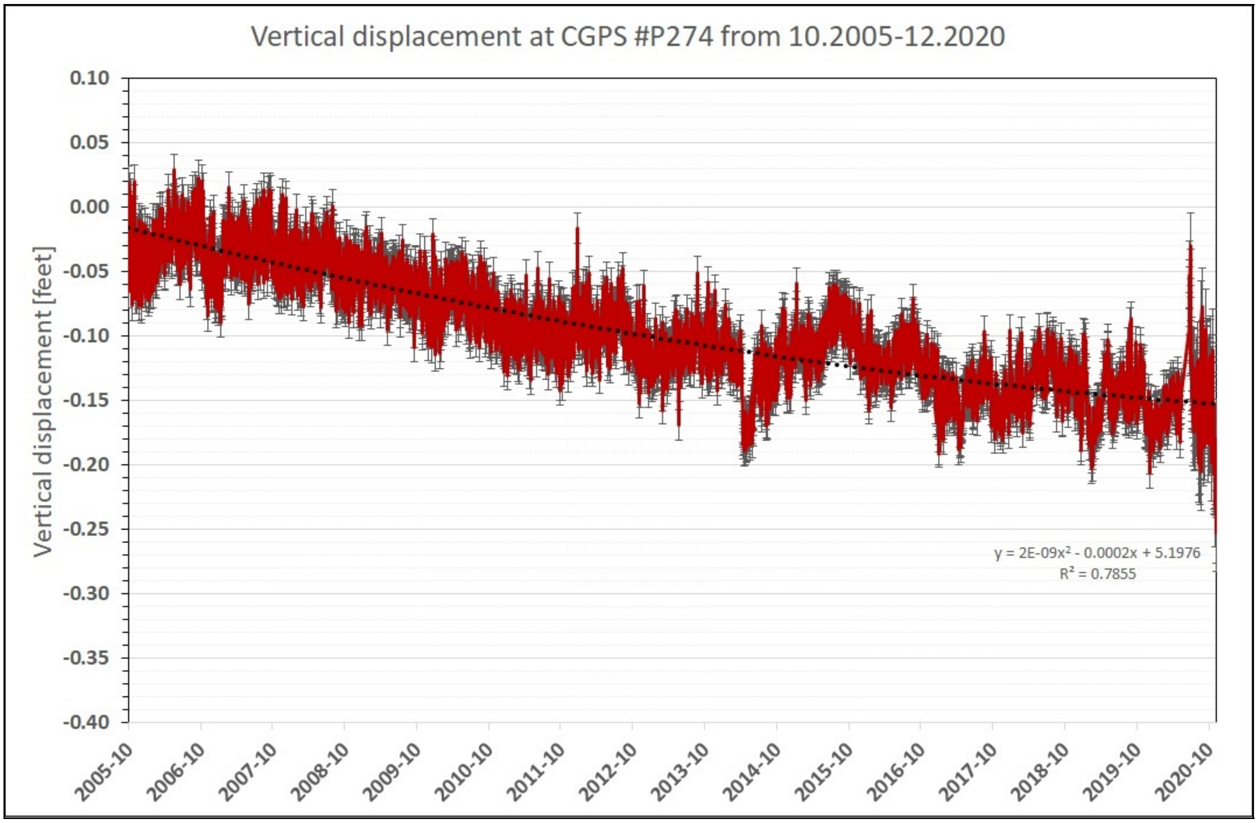


Figure 2-D-2: South American Subbasin CGPS Station (UNAVCO #P274) Subsidence, October 2005 – December 2020. Note: Trend line added solely for the purpose of added assistance with the interpretation of subsidence time series data. Trend line equation included for reference.



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