



**TM1 - DATA REVIEW, MODELING
AND MONITORING PLAN**

**EVALUATION OF THE INFLUENCE
OF WASTEWATER RECLAMATION
PLANT 10 (WRP 10) ON
GROUNDWATER TDS AND NITRATE
CONCENTRATIONS**

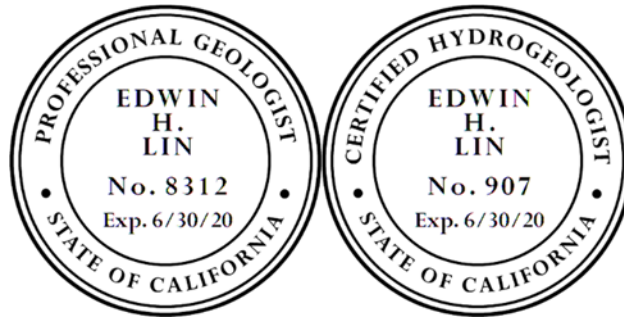
**Prepared in Compliance with Regional
Water Quality Control Board Order
R7-2018-0001 Waste Discharge
Requirements for
Coachella Valley Water District
Wastewater Reclamation Plant 10**

April 2019



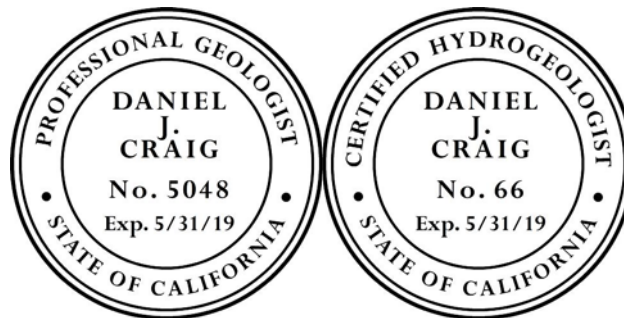
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EXECUTIVE SUMMARY

The Coachella Valley Water District (CVWD) has operated Wastewater Reclamation Plant 10 (WRP 10) in the City of Palm Desert since 1971. On March 8, 2018, the Regional Water Quality Control Board - Colorado River Basin Region (RWQCB) adopted WDRs Board Order R7-2018-0001 (Order) for WRP 10. Special Provision F.1 of the Order requires CVWD to prepare and submit a workplan (culminating in the preparation of a technical report) that describes the methods to be used to evaluate the vertical and lateral extent of groundwater containing greater than 10 milligrams per liter (mg/L) nitrogen and evaluate overall TDS impacts in the vicinity of WRP 10.

On August 28, 2018, CVWD submitted a workplan (Workplan) to the RWQCB. The Workplan addresses the objectives and requirements described in Special Provision F.1 through the completion of five tasks completed under three phases of work. The initial phase of work (Phase 1) consists of the following three tasks:

- Task 1. Compile and review hydrogeologic data and construct and calibrate a local groundwater flow model
- Task 2. Perform groundwater flow and solute transport modeling
- Task 3. Establish a groundwater level and water quality monitoring network and develop a sampling and analysis plan

This Technical Memorandum No. 1 (TM1) documents the results and key findings from Tasks 1 through 3.

Local Hydrogeologic Conditions

WRP 10 is situated in the mid-valley area of the Indio (Whitewater River) Subbasin of the greater Coachella Valley Groundwater Basin. To focus data collection, evaluation, and modeling efforts for this study, a 30-square mile (mi²) Study Area centered around the WRP 10 facility was selected. Historically, the Study Area has supported a variety of land uses. Historical and current land uses have contributed to elevated groundwater nitrate concentrations across parts of the Study Area. Nitrogen sources include naturally-occurring nitrates in desert vadose zone soils and nitrogen-rich organic matter associated with native (pre-development) mesquite forests. Anthropogenic sources of nitrogen include nitrogen-based fertilizers and wastewater sources (historical septic tank discharge, WRP 10 effluent discharge, and other wastewater discharges upgradient of WRP 10 that enter the Study Area with subsurface flow). Irrigation return flows also contain elevated TDS concentrations due to the evapotranspiration of applied water and leaching of minerals and previously applied soil amendments and fertilizers.

Local hydrogeologic conditions in the vicinity of WRP 10 (Task 1), including information on the local hydrostratigraphy, groundwater production, groundwater levels and flow, groundwater quality, and groundwater recharge sources are described in Section 2 of this TM. Alluvial

aquifers in the vicinity of WRP 10 are comprised of interbedded coarse-grained and finer-grained fan, stream wash, and lacustrine deposits extending to depths exceeding 1,500 feet near the center of the valley. Shallow and deeper aquifers are separated locally by fine-grained (silt and clay) deposits.

Groundwater production within the study area occurs primarily via municipal pumping, with additional private pumping for mostly irrigation use. Groundwater production has declined steadily since 2000, reflecting implementation of water conservation measures and increased use of recycled water and imported water. The average annual production has declined from 89,870 AFY (from 2000 to 2002) to 56,267 AFY (from 2015 to 2017).

Groundwater generally flows across the Study Area in a northwest-to-southeast direction. Groundwater pumping has resulted in groundwater level declines of about 1 to 3 feet per year from 1985 to 2015, corresponding to declines of about 50 feet in the northwest to 100 feet in the southeast. Water levels have been increasing over the past few years in response to reduced local pumping due to water conservation measures and increased use of recycled water and imported water, as well as groundwater replenishment activities at the Whitewater River Groundwater Replenishment Facility (WWR-GRF).

Recharge sources in the Study Area include infiltration of WRP 10 secondary effluent discharge, local groundwater replenishment with imported Colorado River Water (CRW) at the Palm Desert Groundwater Replenishment Facility (PD-GRF) beginning in 2019, outdoor irrigation return flows, and subsurface inflows.

- Secondary effluent discharge rates increased from 1975 through the early 2000s, peaking at 7,721 AF in WY 2002-03, and have gradually declined to 2,404 acre-feet AF in WY 2017-18. The average annual secondary effluent discharge rate over the 43-year historical period was 4,709 AFY. With projected increases in local demand for recycled water and improvements to optimize treated effluent storage capacity and delivery of recycled water at WRP 10, secondary effluent discharge at the WRP 10 site is expected to no longer be needed by WY 2026-27.
- In 2018, CVWD completed planning and environmental studies along with engineering and construction of a portion of the PD-GRF. The PD-GRF will provide an estimated 23,000 acre-feet per year (AFY) of direct groundwater replenishment using imported CRW in the Palm Desert area. The PD-GRF will be constructed and implemented in two phases. Phase I of the project involved re-purposing nine existing ponds adjacent to and north of WRP 10 to function as CRW recharge basins and is expected to provide up to 8,000 AFY of CRW recharge capacity. Delivery and recharge of CRW in the Phase I recharge basins began in February 2019. Phase II of the PD-GRF involves construction of recharge basins in the Whitewater River Stormwater Channel (WWR-SC) south/southeast of WRP 10 and is expected to provide up to 15,000 AFY of CRW recharge capacity. Phase II recharge operations are expected to be completed by 2021.

- Outdoor irrigation return flow in the Study Area was estimated at 20,600 AFY based on an evaluation of groundwater pumping, WRP 10 effluent, recycled water deliveries, and imported CRW rates from 2011 to 2015.
- Subsurface inflows to the Study Area occur primarily through the northwest boundary. South of Highway 111, storm runoff in the San Jacinto Mountains enters the Basin as subsurface inflow, resulting in groundwater to flow locally in a northeasterly direction upgradient of WRP 10. Subsurface inflows are estimated using the groundwater flow model.

Groundwater Flow Model Construction, Calibration, and Simulations

A four-layer, transient MODFLOW groundwater flow model was constructed and applied to address the technical issues in Special Provision F.1. The groundwater flow model was constructed based on available information on aquifer hydraulic properties, groundwater levels, groundwater production, and groundwater recharge sources. The model was calibrated to observed groundwater elevations from 1985 to 2018 and used to predict future groundwater level and flow responses and lateral and vertical flow paths of secondary effluent.

The local model simulates a historical period beginning in January 1975 using annual stress periods and extends through 2042. Model input parameters included the following:

- Aquifer layer geometry and thickness
- Aquifer horizontal and vertical hydraulic conductivity and storage coefficients
- Boundary conditions (subsurface inflows and outflows)
- Groundwater production
- Areal recharge
 - WRP 10 effluent discharge
 - PD-GRF CRW recharge
 - Outdoor irrigation return flow

Simulated forward flowpaths were developed to show the direction and flowrate of secondary effluent from the WRP 10 discharge area beginning in 1985, 1995, 2005, and 2015. Flowpaths reveal the expected radial flowpath away from the effluent pond area, with subsequent flow to the east-southeast for each period. Travel time from WRP 10 to the southeastern model boundary is approximately 50 years, corresponding to an average groundwater velocity of 1.3 feet per day (ft/day). Simulated flowpaths spread out over an area approximately 2 miles at its maximum width. Velocities for flowpaths beginning in 2015 are slightly higher than during previous years, due to the steeper hydraulic gradient across the Study Area.

Flowpath analysis was also used to depict the vertical migration of secondary effluent from shallower to deeper aquifer zones for the same historical release periods. The analysis shows that effluent primarily travels within Model Layers 1, 2, and the upper portions of Layer 3. Only a small fraction of effluent travels into the upper portions of Model Layer 4, and most of

these deeper flowpaths occur several miles downgradient of the WRP 10 facility, after several decades of travel time in the aquifer.

A future scenario was simulated that included phased reductions in effluent discharge coinciding with implementation of Phase I and II PD-GRF recharge operations in 2019 and 2021, respectively. Simulated groundwater elevations and forward flowpaths with time and depth were developed from the effluent recharge area beginning in 2020 and 2025. Flowpaths indicate that the secondary effluent migrates in a southerly and easterly direction, due to the mounding associated with the PD-GRF Phase I recharge to the north of the effluent discharge area. However, when Phase II PD-GRF recharge operations commence in 2021, flowpaths from the WRP 10 effluent area are “squeezed” by CRW recharge from the north and south. Accordingly, migration of secondary effluent is predicted to occur to the east (downgradient) and west (upgradient) of WRP 10.

Groundwater Monitoring Plan

The evaluation of local groundwater level and water quality conditions (Task 1) combined with groundwater flow modeling results (Task 2) provided a technical basis for establishing a groundwater monitoring network and sampling and analysis plan (Task 3) to address the technical issues in Special Provision F.1. Considerations pertinent to the selection of individual monitoring wells include the need for the following:

1. A mix of shallow and deep monitoring wells both within and outside of the model-predicted historical and future effluent flowpaths to confirm the vertical and lateral extent of elevated nitrogen and TDS concentrations and identify the potential impact of secondary effluent discharge to existing water supply wells downgradient of WRP 10
2. Additional shallow monitoring wells located further northwest, west, and southwest of the WRP 10 facility are warranted to characterize upgradient “background” TDS and nitrate concentrations.
3. Additional shallow monitoring wells to monitor the local aquifer hydraulic response to secondary effluent discharge and PD-GRF Phase I and II CRW recharge operations.

A monitoring network including a total of 32 wells completed in the shallow and deep aquifer zones were selected. Relative to WRP 10 facility, monitoring wells are located upgradient (northwest, west, and southwest), cross-gradient (north and south), and downgradient (east and southeast), providing a good distribution for characterizing the lateral and vertical extent of elevated TDS and nitrate and the influence of WRP 10 secondary effluent discharges on groundwater quality. The monitoring network includes the following wells:

- Thirteen (13) shallow monitoring wells. This includes the six existing WRP 10 monitoring wells and seven new shallow monitoring wells (scheduled for full completion by December 2019). Collectively, the thirteen shallow monitoring wells will be used to monitor the hydraulic head associated with infiltration of wastewater, characterize upgradient “background” groundwater quality, and verify the vertical

and lateral extent of nitrate and TDS concentrations associated with historical WRP 10 secondary infiltration volumes, infiltration head, and groundwater flow velocities in the shallow aquifer system.

- Nineteen (19) production wells screened. This includes five active and eight inactive CVWD wells and six private production wells. Several wells are located upgradient (northwest, west, and southwest) of the model-predicted historical and future WRP 10 effluent flowpaths and will be valuable in characterizing background water quality in the deeper aquifer. Other production wells are situated firmly within the lateral extent of the effluent flowpaths or along the margins or slightly outside the lateral extent of the effluent flowpaths. These wells will help to characterize the impact of secondary effluent to drinking water supply wells.

Water level monitoring and groundwater quality sampling of all 32 wells in the monitoring network will be performed to identify the extent of elevated groundwater TDS and nitrate concentrations and identify their potential sources. The groundwater level and water quality monitoring program is scheduled to commence in January 2020 (when all proposed shallow monitoring wells are constructed) and will be conducted for a one-year period ending December 2020.

For all wells, groundwater levels will be measured, and samples will be collected and analyzed for TDS, nitrate, and major ions on a quarterly basis (1st Quarter, 2nd Quarter, 3rd Quarter, and 4th Quarter 2020).

All wells with sufficient nitrate concentration (greater than 3 mg/L as nitrate) will also be sampled and analyzed for oxygen and nitrogen stable isotopes in nitrate to differentiate between the various nitrate sources in local groundwater. Because the isotopic signature of nitrate in a specific well is not expected to vary significantly over time, sampling and analysis of oxygen and nitrogen stable isotopes in nitrate will be conducted semi-annually (2nd Quarter and 4th Quarter 2020). Additionally, WRP 10 secondary effluent will also be analyzed for TDS, major ions, and nitrate on a quarterly basis in 2020 and for stable isotopes in nitrate semi-annually to provide a basis for comparison with collected groundwater quality samples.

Phase 2 and 3 Workplan Implementation Schedule

The Workplan schedule assumes a 60-day RWQCB review period for TM1 (ending June 30, 2019). Upon receipt of RWQCB comments on TM1, the groundwater monitoring plan will be implemented under Phase 2 (Task 4), which consists of installing the seven proposed new monitoring wells (through December 2019) and implementing the one-year sampling and analysis plan (through December 2020).

A technical memorandum (TM2) documenting the monitoring installation work and sampling results will be developed and submitted to the RWQCB by March 31, 2021 for review and comment. The Workplan schedule assumes a 60-day RWQCB review period for TM2 (ending May 31, 2021).

Upon receipt of RWQCB comments on TM2, a final technical report will be prepared and submitted to the RWQCB by August 31, 2021 under Phase 3 (Task 5). The final technical report will integrate the groundwater modeling results and analysis of existing historical water quality and new sampling results. Solute transport modeling proposed in the Workplan using a normalized concentration approach will be performed following Phase 2 groundwater quality sampling and analysis. Results of the groundwater sampling program will provide a dataset with which solute transport modeling results can be compared to verify the lateral and vertical extent and relative contribution of secondary effluent discharge in areas with elevated groundwater TDS and nitrate concentrations.

1. INTRODUCTION

The Coachella Valley Water District (CVWD) has operated Wastewater Reclamation Plant 10 (WRP 10) in the City of Palm Desert since 1971. Since its construction, WRP 10 has been regulated by the Regional Water Quality Control Board - Colorado River Basin Region (RWQCB) initially by Board Order 72-7 and subsequent Board Orders.

On June 28, 2000, Waste Discharge Requirements (WDRs) Board Order R7-00-008 was adopted, regulating discharges from WRP 10. On April 11, 2014, CVWD submitted a Report of Waste Discharge (ROWD) to the RWQCB to update the WDRs for WRP 10. On October 16, 2017, CVWD submitted an updated ROWD to incorporate design modifications removing the nine northern-most evaporation/percolation ponds from WRP 10.

On March 8, 2018, the RWQCB adopted WDRs Board Order R7-2018-0001 (Order) for WRP 10 to incorporate the design modifications and implement the most current laws and regulations applicable to the discharge from WRP 10. Special Provision F.1 of the Order requires CVWD to prepare and submit a workplan (culminating in the preparation of a technical report) that describes the methods to be used to evaluate the vertical and lateral extent of groundwater containing greater than 10 milligrams per liter (mg/L) nitrogen and evaluate overall TDS impacts in the vicinity of WRP 10.

The technical report is required to address the following issues:

- a. The adequacy of the monitoring network with regard to upgradient “background” water quality.
- b. The adequacy of the existing monitoring network to monitor the hydraulic head associated with infiltration of wastewater.
- c. The anticipated vertical and lateral extent of elevated nitrogen and TDS concentrations based on historical infiltration volumes, infiltration head, and groundwater flow velocities, and the method to be used to test the accuracy of this prediction.
- d. The potential threat to the existing water supply wells posed by groundwater containing elevated nitrogen and/or TDS concentrations, based on both the location and well-screen intervals of threatened wells.
- e. Proposed methods to evaluate the Discharger’s nitrogen and TDS contribution to groundwater in the vicinity of WRP 10.
- f. A schedule for implementation of the workplan.

The workplan is required to include details regarding sampling locations and methods, the chemical testing program, and the methods that will be used to evaluate the data obtained.

On August 28, 2018, CVWD submitted a workplan (Workplan) to the RWQCB (CVWD and Todd, 2018). The Workplan addresses the objectives and requirements described in Special

Provision F.1 through the completion of five tasks completed under three phases of work, culminating in the preparation of a technical report.

The initial phase of work (Phase 1) consists of the following three tasks:

- Task 1. Compile and review hydrogeologic data and construct and calibrate a local groundwater flow model
- Task 2. Perform groundwater flow and solute transport modeling
- Task 3. Establish a groundwater level and water quality monitoring network and develop a sampling and analysis plan

This Technical Memorandum No. 1 (TM1) documents the results and key findings from Tasks 1 through 3. The TM is organized to document the results and key findings from each Phase 1 task as follows:

- TM Section 2 – Local hydrogeologic conditions in the vicinity of WRP 10 (Task 1)
- TM Section 3 – Groundwater flow model construction and calibration approach, and data sources, model inputs, and results of model simulations (Task 1 and 2)
- TM Section 4 – Groundwater monitoring plan detailing the locations, methods, and frequencies of water level monitoring and water quality sampling to address the technical issues identified in Special Provision F.1 (Task 3)
- TM Section 5 – Workplan schedule for completion of Phase 2 and Phase 3 work

It is noted that solute transport modeling using a normalized concentration approach proposed in the Workplan (Task 2) will be performed following groundwater quality sampling and analysis (as part of Phase 3 – Task 5), results of which will be incorporated into the final technical report. The reason for this change is that results of the groundwater monitoring and sampling program will provide a dataset with which groundwater flow and solute transport modeling results can be compared to verify the lateral and vertical extent and relative contribution of secondary effluent discharge in areas with elevated groundwater TDS and nitrate concentrations.

2. LOCAL HYDROGEOLOGIC CONDITIONS

This section describes the hydrogeologic conditions in the vicinity of WRP 10 (Task 1), including information on the local hydrostratigraphy, groundwater production, groundwater levels and flow, groundwater quality, and groundwater recharge sources.

2.1. WRP 10 FACILITY AND MONITORING WELLS

WRP 10 is located at 43000 Cook Street in Palm Desert, CA (**Figure 1**). It is situated in the mid-valley area of the Indio (Whitewater River) Subbasin (DWR Subbasin 7-021.01) of the greater Coachella Valley Groundwater Basin (DWR Basin No. 7-021) (DWR, 2003) (see map inset).

As of 2018, the WRP 10 facility consists of an activated sludge treatment plant (providing secondary treatment of wastewater), a tertiary wastewater treatment plant, recycled water delivery facilities, six holding ponds, nine secondary effluent percolation ponds, and a lined back feed reservoir currently used to store Colorado River Water (CRW) prior to delivery to CVWD irrigation customers. The design capacity for secondary treatment is 18 million gallons per day (MGD). Design capacity for tertiary treatment used for recycled water is 15 MGD. CVWD is updating its Non-Potable Water Master Plan and plans to increase recycled water deliveries and optimize onsite storage, which would eliminate the need for onsite discharge of secondary effluent.

There are six groundwater monitoring wells associated with WRP 10 (WRP 10 MW1 to MW6). The WRP 10 monitoring wells allow for the assessment of groundwater level and water quality conditions in the approximately upper 100 feet of saturated aquifer. The existing WRP 10 monitoring wells were located to allow for characterization of upgradient (background) and downgradient (effluent-impacted) shallow groundwater quality, as well as monitoring of shallow groundwater levels. WRP 10 MW1, MW2, and MW3 were installed in 1995 and were sampled quarterly for groundwater quality through the second quarter of 2012; the wells continue to be measured for groundwater levels on a quarterly basis. WRP 10 MW4, MW5, and MW6 were installed in 2012 and have been sampled for water quality and measured for water levels on a quarterly basis since their construction.

2.2. WRP 10 STUDY AREA

To focus data collection, evaluation, and modeling efforts for this evaluation, an approximately 30-square mile (mi²) Study Area centered around the WRP 10 facility was selected (**Figure 2**). The Study Area extends from WRP 10 approximately 2 miles northwest (upgradient) and 4 miles southeast (downgradient). The approximate central axis of the Indio (Whitewater River) Subbasin forms the northeastern Study Area boundary, while shallow and outcropping bedrock forms the southern Study Area boundary. The Study Area is oriented in the general direction of groundwater flow (northwest-to-southeast) and includes numerous (active and inactive) CVWD production wells, private production wells, as well as the six existing WRP 10 monitoring wells.

2.3. HISTORICAL AND CURRENT LAND USES

Historically, the Study Area has supported a variety of land uses, including irrigated agriculture and low-density residential land uses through the mid-1900s. More recently, land uses have included medium to high-density residential, commercial office/retail, and industrial land uses, as well as golf courses, public parks, and schools.

Historical and current land uses have contributed to elevated groundwater nitrate concentrations across portions of the Study Area. Nitrogen sources include naturally-occurring nitrates in desert vadose zone soils and nitrogen-rich organic matter associated with native (pre-development) mesquite forests. Previous investigators (Huberty, et. al., 1948) observed very high nitrate concentrations in production wells in the Palm Desert-Indian Wells area as early as the 1940s and concluded that the area was once covered by extensive nitrogen-fixing mesquite forests. Under natural conditions, there was insufficient moisture for the leaf and twig litter to decompose. However, when these lands were levelled and irrigated for agriculture, the organic matter readily decomposed, and nitrogen was converted to nitrate and leached into the groundwater system.

Anthropogenic sources of nitrogen include nitrogen-based fertilizers applied historically on agricultural lands and more recently on landscaping/turf areas. Wastewater nitrogen sources include historical septic tank discharge, WRP 10 secondary effluent discharge, and other wastewater discharges upgradient of WRP 10 that enter the Study Area with subsurface flow.

Irrigation return flows associated with agriculture, golf courses, residential/commercial and land uses also contain elevated TDS concentrations due to the evapotranspiration of applied water and leaching of naturally-occurring minerals and applied soil amendments and fertilizers accumulated in the root zone and deeper vadose zone.

2.4. HYDROSTRATIGRAPHY AND AQUIFER PROPERTIES

Alluvial aquifers in the vicinity of WRP 10 are comprised of interbedded coarse-grained and finer-grained fan, stream wash, and lacustrine deposits. Based on available well driller's logs, the thickness of alluvial deposits in the vicinity of WRP 10 exceeds 1,500 feet near the center of the valley and consists of predominantly coarse-grained gravels and sands, constituting the aquifer system that is the main source of water supply in the region. Shallow and deeper aquifers are separated locally by fine-grained (silt and clay) deposits.

Aquifer hydraulic properties in the vicinity of WRP 10 have been characterized on the basis of pumping tests and a basin-wide aquifer textural study. In 2000, Fogg et. al. conducted a kriging analysis of aquifer textures and associated hydraulic properties and prepared a regional MODFLOW model of the Indio (Whitewater River) Subbasin. The model includes four model layers representing the shallow and deep aquifers. For this evaluation, the regional model layers were modified slightly to develop the local WRP 10 groundwater model. The local WRP 10 model retained four model layers but used different layer top and bottom elevations in Model Layers 1 and 2 in order to provide a fully-saturated simulation of the

shallow aquifer system. This change also necessitated re-assignment of hydraulic conductivity values in Model Layers 2 and 3 to accommodate the representation of clay deposits in Layer 2 of the local model (instead of Layer 3 in the regional model). Additional discussion of the local model layers is provided in Sections 3.1 and 3.2.

In the WRP 10 study area, horizontal hydraulic conductivities range from approximately 5 feet per day (ft/day) for low-permeability clay deposits to a maximum horizontal hydraulic conductivity of 224 ft/day for the most permeable sand/gravel deposits. Additional discussion of the aquifer characteristics and hydraulic properties is included in Section 3.3.3.

2.5. GROUNDWATER PRODUCTION

Groundwater production within the study area occurs primarily via municipal pumping, with additional private pumping for primarily irrigation use. Municipal production wells in the area are generally screened in the lower portions of the aquifer with screen intervals ranging from 500 to 1,200 feet-bgs. Screen intervals of private irrigation wells are generally shallower, ranging from 200 to 1,200 feet-bgs.

Since 2000, groundwater has been pumped from a total of 143 wells in the Study Area. This includes 60 CVWD wells (35 currently active and 25 currently inactive) and 83 private irrigation wells. **Figure 3** shows the total annual pumping volumes in the Study Area from 2000 through 2017 (well locations are shown on Figure 2). As shown on the figure, groundwater production has declined steadily since 2000, reflecting implementation of water conservation measures and increased use of recycled water and imported water in the Study Area. From 2000 to 2002, the average annual production was 89,870 AFY. Over the recent three-year period from 2015 to 2017 average annual production was only 56,267 AFY.

2.6. GROUNDWATER LEVELS

Groundwater level data are available for approximately 120 wells in the Study Area. **Figure 4** shows groundwater elevation contour maps for four time periods covering a 30-year period (1985, 1995, 2005, and 2015) which includes the majority of the operational period of WRP 10. Using GIS Spatial Analyst, contours were used to create interpolated groundwater elevation surfaces and calculate groundwater level changes over time. **Figure 5** shows groundwater level change maps for the three successive 10-year periods (1985 to 1995, 1995 to 2005, and 2005 to 2015). **Figure 6** shows the 2018 water level hydrographs for selected wells across the Study Area. Water level data for two or more adjacent wells were combined in some hydrographs to illustrate long-term water level trends and identify vertical hydraulic gradients in areas where shallow and deep monitoring data are available. Groundwater level and flow conditions are summarized below.

The groundwater elevation maps show that groundwater generally flows across the Study Area in a northwest-to-southeast direction. South of Highway 111, storm runoff in the San Jacinto Mountains enters the Basin as subsurface inflow, resulting in localized groundwater to flow in a northeasterly direction upgradient of WRP 10. Water level mounding from

discharge of secondary effluent at WRP 10 is indicated by local contours deflecting to the east (e.g., at the 10-foot contour in 1995, -20-foot contour in 2005, and -30-foot contour in 2015 on Figure 4).

Groundwater pumping has resulted in groundwater level declines of about 1 to 3 feet per year from 1985 to 2015. In 1985, groundwater levels ranged from 50 feet msl in the northwest to -20 feet msl in the southeast, representing a 70-foot gradient across the Study Area. In 2015, groundwater levels ranged from 0 feet msl in the northwest to -120 feet msl in the southeast. These water levels represent water level declines of 50 feet in the northwest to 100 feet in the southeast over the past 30 years. As shown on Figures 5 and 6, declines were most pronounced from 1995 to 2005, particularly in the southeastern portion of the Study Area. The rate of water level decline between 2005 and 2015 was smaller, responding to about 1 foot per year on average (10 feet over the 10-year period).

Between 2015 and 2018 water levels have been increasing in response to reduced local pumping due to water conservation measures and increased use of recycled water and imported water, as well as groundwater replenishment activities at the Whitewater River Groundwater Replenishment Facility (WWR-GRF), upgradient of the Study Area. This is reflected in the hydrographs for several wells shown on Figure 6.

2.7. GROUNDWATER RECHARGE SOURCES

Recharge in the area includes infiltration of WRP 10 secondary effluent discharge, local groundwater replenishment with imported Colorado River Water (CRW) at the Palm Desert Groundwater Replenishment Facility (PD-GRF) beginning in 2019, outdoor irrigation return flows, and subsurface inflows.

2.7.1. WRP 10 Secondary Effluent Discharges

Secondary-treated effluent is disposed of through percolation ponds at the WRP 10 facility. **Figure 7** shows the annual WRP 10 effluent discharges from WY 1975-76 to WY 2017-18. As shown on the figure, secondary effluent discharge rates increased from 1975 through the early 2000s, peaking at 7,721 AF in WY 2002-03. Secondary effluent discharge volumes have gradually declined since the early 2000s as a result of increased tertiary treatment capacity and delivery of recycled water to satisfy local non-potable water demands. In WY 2017-18, 2,404 acre-feet (AF) of secondary treated effluent was discharged to onsite percolation ponds. The average annual secondary effluent discharge rate over the 43-year historical period was 4,709 AFY.

Estimates of future secondary effluent discharges were developed based on CVWD projections of new recycled water connections and planned improvements to optimize storage and delivery of recycled water at the WRP 10 site. CVWD plans to add several additional non-potable water service connections in the near future, which will increase the local demand for recycled water and reduce secondary treated effluent discharges at WRP 10. Improvements to optimize treated effluent storage capacity and delivery of recycled water at WRP 10 are also planned that will allow for improved balancing of supply and

demand timing. Based on current projections, secondary effluent discharge at the WRP 10 site is expected to no longer be needed by WY 2026-27, as shown on Figure 7.

2.7.2. PD-GRF CRW Recharge

In 2018, CVWD completed planning and environmental studies along with engineering and construction of a portion of the PD-GRF. The primary objectives of the PD-GRF are to (1) provide an estimated 23,000 acre-feet per year (AFY) of direct groundwater replenishment using imported CRW in the Palm Desert area, (2) enable CVWD to maximize use of its annual allocation of CRW, (3) meet the goals of the Coachella Valley Water Management Plan to assure adequate quantities of safe, high-quality water at the lowest cost to CVWD water users, and (4) improve local groundwater supply and quality conditions.

The PD-GRF will be constructed and implemented in two phases (see **Figure 8** for recharge locations).

- Phase I of the project involved re-purposing nine existing ponds adjacent to and north of WRP 10 to function as CRW recharge basins. Phase I recharge basins are expected to provide up to 8,000 AFY of CRW recharge capacity. Delivery and recharge of CRW in the Phase I recharge basins began in February 2019.
- Phase II of the PD-GRF involves construction of recharge basins using native sediments to build silt berms in the Whitewater River Stormwater Channel (WWR-SC) south/southeast of WRP 10 between Cook Street and Fred Waring Drive. The WWR-SC recharge basins are expected to provide up to 15,000 AFY of CRW recharge capacity. While construction of the Phase II WWR-SC recharge basins has yet to commence, Phase II recharge operations are expected to be completed by 2021.

2.7.3. Outdoor Irrigation Return Flow

Outdoor irrigation return flow is the volume of the irrigation water applied to golf course turf/lakes, municipal parks, and commercial/residential landscaping that infiltrates past the root zone and returns to groundwater. **Figure 9** shows the landscaped and turf areas in the Study Area that require nearly year-round irrigation.

To estimate the annual volume of applied irrigation water and irrigation return flow in the Study Area, groundwater pumping, WRP 10 effluent, recycled water deliveries, and imported CRW rates from 2011 to 2015 were evaluated.

- Total Study Area water use from 2011 to 2015 was estimated at 76,974 AFY, equivalent to the sum of groundwater production (68,482 AFY) and annual recycled water (6,874 AFY) and imported water (1,618 AFY) delivered to local irrigation customers.
- Non-consumptive use (including indoor and outdoor return flows) has recently been estimated at 34 percent of total water use (CVWD, 2016). Based on that estimate, the average non-consumptive use in the Study Area from 2011 to 2015 was 26,171 AFY ($=76,974 \text{ AFY} \times 0.34$).

- A portion of the Study Area non-consumptive use is represented by indoor water use. The portion of non-consumptive use represented by indoor use can be estimated from total effluent flow at WRP 10. The average annual effluent produced at WRP 10 from 2011 to 2015 was 11,072 AFY. However, it is estimated that approximately 50 percent of the effluent from WRP 10 (5,536 AFY) is produced within the Study Area, while the other 50 percent of effluent from WRP 10 represents (indoor) water use outside of the Study Area.
- By subtracting the Study Area indoor effluent return flow at WRP 10 (5,536 AFY) from the estimated (indoor and outdoor) non-consumptive use (26,171 AFY), the Study Area outdoor irrigation return flow is estimated at 20,635 AFY. This volumetric rate is applicable to the irrigated landscaped/turf areas in the Study Area.

2.7.4. Subsurface Inflows

In addition to areal recharge sources, subsurface inflows represent a significant source of inflow to the WRP 10 Study Area. Groundwater level contour maps (Figure 4) reveal that the primary source of subsurface inflows into the Study Area is from the northwest, where groundwater is recharged by natural runoff along the northern flanks of the San Jacinto Mountains and replenishment operations at CVWD's WWR-GRF northwest of Palm Springs. South of Highway 111, storm runoff in the San Jacinto Mountains enters the Basin as subsurface inflow, resulting in groundwater to flow locally in a northeasterly direction upgradient of WRP 10. The rate of subsurface inflow is governed by the cross-sectional area of groundwater flow, aquifer hydraulic properties, and the hydraulic gradient. Given the hydraulic gradient varies over time, subsurface inflows are estimated by the groundwater flow model.

2.8. GROUNDWATER QUALITY

Groundwater quality varies laterally and vertically across the Study Area. Groundwater quality data for the WRP 10 monitoring wells and available deeper CVWD and private production wells were used to characterize groundwater quality conditions across the Study Area for TDS and nitrate.

Figure 10 shows the locations of wells with available well construction (screen interval) information and water quality data for the period of 2005 to 2018 (data for WRP 10 MWs extend back to 1995). As noted on the figure, wells are labeled according to their abbreviated California State Well Number (e.g., 8N2 = 5N/6E-8N2) and, if available, also by their CVWD Well ID (e.g., 5623-1). To facilitate groundwater quality characterization, six water quality zones within the Study Area were delineated (Zones A through F) corresponding to six vertical cross sections (A-A' through F-F').

Figures 11 through 16 show well concentrations for TDS and nitrate grouped by water quality zone. From left to right, each cross section is oriented from southwest to northeast. The well screens on each cross section are color-coded according to the most recent concentration as reported between 2005 and 2018. Also shown on each of the cross sections are the elevations

of the four model layers selected for the local groundwater flow model developed for this study (see Section 3.2 for further discussion). The model layers provide a useful reference for describing observed groundwater quality variability with depth.

Plan-view maps for TDS and nitrate are also provided on **Figures 17 and 18**. Additionally, time-concentration plots of TDS and nitrate for production wells grouped by water quality zone (**Figures 19 and 20**) and for the six WRP 10 monitoring wells (**Figure 21 and 22**) are also provided.

Observations of groundwater quality conditions in the Study Area with respect to TDS and nitrate are described below.

2.8.1. TDS

Figure 17 and the upper cross sections on Figure 11 through Figure 16 show TDS concentrations in available wells across the Study Area. Together, the cross sections reveal that TDS concentrations are significantly higher in the shallow aquifer than in deeper aquifers (435 to 683 mg/L in WRP 10 monitoring wells compared to approximately 150 to 300 mg/L in deeper production wells). It is noted that slightly elevated TDS concentrations of 459 mg/L in 5S/6E-14B2 and 490 mg/L in 5S/6E-12M2 (northeastern end of D-D', north of and cross-gradient to WRP 10) are associated with shallow screens in both wells (Model Layer 1 through upper portion of Model Layer 3). The elevated TDS concentration of 1,400 mg/L in well 5S/6E-27C3 (southwestern end of D-D', south of and cross-gradient to WRP 10) is associated with relatively shallow well screen (upper Model Layer 3). Additionally, this well is located towards the southern portion of the Study Area along the basin margins, where groundwater velocities are slower and more mineralized groundwater quality is expected.

TDS concentrations in the upper portions of the deep aquifer (in Model layer 3) gradually increase from northwest to southeast (downgradient) and towards the southern margins of the Basin. In contrast, TDS concentrations in the lower portions of the deep aquifer (in Model Layer 4) decrease slightly from northwest to southeast (downgradient). Given that the average TDS concentrations of secondary effluent approximately 460 mg/L (based on 2012 to 2017 data), concentrations exceeding 500 to 600 mg/L in shallow monitoring and production wells indicates that elevated TDS concentrations in shallow local groundwater are influenced by sources other than WRP 10 effluent (e.g., irrigation return flows).

There is no fixed consumer acceptance contaminant level established for TDS. Title 22 states that constituent concentrations lower than the Recommended contaminant level of 500 mg/L are desirable for a higher degree of consumer acceptance; constituent concentrations ranging to the Upper contaminant level (1,000 mg/L) are acceptable if it is neither reasonable nor feasible to provide more suitable waters; and constituent concentrations up to the Short-Term contaminant level (1,500 mg/L) are acceptable only for existing community water systems on a temporary basis pending construction of treatment facilities or development of acceptable new water sources.

Time-concentration plots (Figures 19) reveal gradually increasing TDS trends for most wells in all six water quality zones (i.e., both upgradient and downgradient of WRP 10) over the past 10 years. These trends are indicative of the downward migration of higher-TDS groundwater from shallow aquifers to deeper aquifers induced by groundwater pumping.

2.8.2. Nitrate

Figure 18 and the lower cross sections on Figure 11 through Figure 16 show the groundwater nitrate-NO₃ concentrations for available wells in the Study Area. Similar to TDS trends, the figures indicate that the nitrate-NO₃ concentrations in the shallow aquifer is generally higher than in deeper aquifer zones. Nitrate concentrations in the shallower WRP 10 monitoring wells range from 20 to 75 mg/L. In comparison, the average nitrate concentration of WRP 10 secondary effluent from 2011 to 2015 was 62 mg/L. Nitrate concentrations for deeper wells generally increase from northwest to southeast and along the southern margins of the Basins. Concentrations in twelve wells have exceeded the primary drinking water MCL for nitrate-NO₃ of 45 mg/L during the last sampling event at each well.

As stated in Section 2.3, high groundwater nitrate concentrations have been observed in the Palm Desert-Indian Wells area by the 1940s. Elevated nitrate concentrations have been associated with irrigated agriculture in areas that were once covered with extensive mesquite forests. Under natural conditions, moisture was insufficient to decompose leaves and twigs. Consequently, large amounts of nitrogen-containing litter accumulated under the mesquite trees. When the lands were levelled for agriculture and irrigated, the organic matter decomposed, and nitrate was leached by irrigation return flow and migrated to the underlying water table (Huberty, et. al., 1948). This explanation helps to explain the elevated nitrate-NO₃ concentration of 130 mg/L in well 5S/6E-27C3 (southwestern end of D-D', south of and cross-gradient to WRP 10). While recent water quality data are limited in the southern portion of the Study Area (south of Highway 111), nitrate concentrations are known to be very high in this area based on historical monitoring. As shown on Figure 18, additional areas of elevated nitrate in the deeper aquifer occur upgradient of WRP 10 in wells to the west (5S/6E-9P1) and north (5S/6E-11D2).

Time-concentration plots (Figure 20) reveal increasing nitrate concentrations in deeper production wells in the Study Area (both upgradient and downgradient of WRP 10) and show an increasing trend since 2005. These trends are indicative of the downward migration of higher-nitrate groundwater from shallow aquifers to deeper aquifers induced by groundwater pumping. This trend has resulted in the replacement of several existing shallower-screened production wells with deeper wells.

2.8.3. Preliminary Nitrate Stable Isotopic Sampling and Analysis

As described in the Workplan, the sampling and analysis of nitrate-nitrogen ($\delta^{15}\text{N}$) and nitrate-oxygen ($\delta^{18}\text{O}$) stable isotopes and $\delta^{15}\text{N}/\delta^{18}\text{O}$ ratios in secondary effluent and groundwater is proposed as a method to evaluate the nitrate and TDS contribution to groundwater in the vicinity of WRP 10. The purpose of analyzing for oxygen and nitrogen stable isotopes in nitrate is to (1) verify the accuracy of model-predicted flowpaths of secondary effluent and (2)

differentiate between groundwater with elevated nitrate concentrations that are impacted by WRP 10 effluent discharges versus groundwater that is impacted by other nitrate sources.

Analysis of oxygen and nitrogen stable isotopes in nitrate is a useful technique in identifying the sources of nitrate and other nitrogen compounds in groundwater. Nitrogen has a wide range of oxidation numbers in its compounds ranging from -3 (in the ammonium ion) to +5 (in nitrate) and has two stable isotopes: nitrogen-14 (^{14}N) and ^{15}N , with ^{14}N forming 99.63 percent and ^{15}N forming 0.37 percent. The wide range in oxidation state and the isotopic masses allows for distinctive isotopic signatures. $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, $\delta^{15}\text{N}/\delta^{18}\text{O}$ isotopic ratios in particular can provide fingerprints of possible nitrogen sources. The ratio of $^{15}\text{N}/^{14}\text{N}$ compared with the standard mean ocean chloride (SMOC), is given the delta (δ) notation, as in $\delta^{15}\text{N}$. The abundance of ^{15}N in the atmosphere is relatively constant because of the inert character of atmospheric nitrogen; this value is fixed at 0.36765 percent, which essentially results in a $\delta^{15}\text{N}$ of 0. Nitrogen isotopes also fractionate by biochemical processes including:

- Nitrification, in which ammonium (NH_4^+) oxidizes to form nitrite (NO_2^-) and nitrate (NO_3^-)
- Denitrification, which is the reduction of nitrate to molecular nitrogen, and
- Nitrogen fixation, where dissolved nitrogen is converted to nitro-organic compounds.

The above processes occur by bacterial action in which the lighter nitrogen isotope (^{14}N) more easily reacts, resulting in more positive $\delta^{15}\text{N}$ values. Oxygen isotopes in nitrate are more difficult to determine; however, by obtaining $\delta^{18}\text{O}$ nitrate, greater definition of the boundary conditions is possible.

In 2018, CVWD conducted a preliminary round of sampling and analysis of oxygen and nitrogen isotopes in nitrate for three WRP 10 monitoring wells (MW-4, MW-5, and MW-6) and five production wells in the vicinity of WRP 10 (one active CVWD well and four private wells). Sampling and analysis of WRP 10 secondary effluent was also performed for comparison. Samples were analyzed by Isotech Laboratories (Champaign, IL). **Figure 23** shows the stable isotope results on a two-axis chart developed by Kendall (1998). As shown on the figure, natural desert sources, nitrogen-based fertilizers, wastewater, and animal wastes have unique $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ signatures. The figure reveals the isotopic signatures are distinctive for secondary effluent, shallow monitoring wells, and deeper production wells. For example, the signature of WRP 10 MW-4 indicates a source of “nitrate in fertilizer”, while the five production wells (triangle symbols) are located in the “Soil N” source category. The secondary effluent and WRP 10 MW-5 data plot in the “manure and wastewater” source category.

The preliminary sampling and analysis results indicate that nitrate isotopic analysis is a promising method for delineating the variable sources of nitrate in groundwater in the vicinity of WRP 10 and identifying the horizontal and vertical extent of groundwater impact from WRP 10 secondary effluent. Additional nitrate isotopic sampling and analysis is needed to better understand the variability in nitrate isotopes upgradient and downgradient of WRP 10 in shallow and deeper aquifers across the Study Area.

3. GROUNDWATER FLOW MODEL CONSTRUCTION, CALIBRATION, AND SIMULATIONS

As identified in Tasks 1 and 2 of the Workplan, a three-dimensional transient MODFLOW groundwater flow model was constructed and applied to address the technical issues identified in Special Provision F.1. Specifically, the objectives of groundwater flow modeling were as follows:

1. Predict the lateral and vertical extent of historical and future WRP 10 secondary effluent discharges in groundwater
2. Assess the potential threat to existing water supply wells posed by groundwater containing elevated nitrogen and/or TDS concentrations (due to presence of secondary effluent), and
3. Assess the adequacy of the existing monitoring well network to monitor upgradient “background” groundwater quality and the hydraulic head associated with the infiltration of secondary effluent (under current and future hydraulic conditions).

Model results provided a technical basis for developing the proposed WRP 10 groundwater monitoring program (Task 3), described in Section 4.

The groundwater flow model was constructed based on available information on aquifer hydraulic properties, groundwater levels, groundwater production, and groundwater recharge sources (described in Section 2). The model was calibrated to historical and recent groundwater levels and used to predict future groundwater level and flow responses and lateral and vertical flow paths of secondary effluent. Discussion of the model construction approach and methods, simulation inputs, and model results are presented below.

3.1. REGIONAL GROUNDWATER FLOW MODEL REVIEW

An existing regional MODFLOW model of the entire Coachella Valley (Fogg, et al., 2000) was reviewed to aid in development of the local WRP 10 model. The regional model simulates flow throughout the Coachella Valley, from the San Geronio Pass area to the Salton Sea. The historical simulation period is 1936 and 2018, using annual stress periods. The model includes four model layers representing the shallow and deep aquifers, and a regional aquitard within Model Layer 3. Variable model layer thickness and heterogeneous hydraulic conductivities are simulated. Variable annual production well pumping rates along with non-uniform natural and return flow recharge is simulated, along with groundwater replenishment at the WWR-GRF and Thomas E. Levy Groundwater Replenishment Facility (TEL-GRF).

TODD reviewed the regional model documentation and input parameters, obtained the MODFLOW input files, imported the regional model to the Groundwater Modeling System™ (GMS), ran the historical simulation, and evaluated the results. Based on comparison of measured groundwater elevations and flow patterns over time and simulation results the regional model adequately represents the groundwater flow system in the Palm Desert area.

Selected input parameters from the regional model were used to develop the local WRP 10 model. The distribution of horizontal hydraulic conductivity and aquifer storage coefficients in the regional model were extracted and used as input to the local WRP 10 model. The regional model layering was slightly modified for the local model. The local model retained four model layers but used different layer top and bottom elevations in Model Layers 1 and 2 in order to provide a fully-saturated simulation of the upper portions of the aquifer. This change also necessitated re-assignment of hydraulic conductivity values in Model Layers 2 and 3 to accommodate the representation of clay deposits in Layer 2 in the local model instead of Layer 3 in the regional model.

To account for more recent and future groundwater conditions, new model inputs for groundwater production, return flow recharge rates, and model boundary conditions were developed for the local WRP 10 model.

3.2. LOCAL WRP 10 MODEL CONSTRUCTION APPROACH

The model was constructed using the United States Geologic Survey (USGS) MODFLOW code, along with the particle-tracking flowpath model MODPATH. Model construction and calibration was performed using GMS (version 10.3), which pre-processes and post-processes the MODFLOW and MODPATH files.

The local groundwater model area coincides with the WRP 10 Study Area shown on Figure 2. Accordingly, the active model area encompasses 30-mi² and extends from near Gerald Ford Drive and Highway 10 on the north and east to near Route 111 and Jefferson Street on the southeast, and from the groundwater basin boundaries along outcropping bedrock south and west of the WRP 10 site. Model boundaries are located approximately 2.5 miles northwest, 2.5 miles east, 4 miles southeast, and 4 miles southwest of the WRP 10 facility.

The local model simulates a historical period beginning in January 1975 using annual stress periods and extends through 2042. Model input parameters included the following:

- Aquifer Layer Geometry and Thickness
- Aquifer Horizontal and Vertical Hydraulic Conductivity and Storage Coefficients
- Boundary Conditions (Subsurface Inflows and Outflows)
- Groundwater Production
- Areal Recharge
 - WRP 10 Effluent Discharge
 - PD-GRF CRW Recharge
 - Outdoor Irrigation Return Flow

As described in Section 3.1, local model layer geometry/thickness and aquifer hydraulic properties were assigned based on characteristics of CVWD Basin-wide Coachella Valley MODFLOW model and modified to more reliably simulate local groundwater flow in the shallow and deep aquifers.

Subsurface flows into the model area occurs primarily through the northwestern (upgradient) model boundary, while subsurface outflows out of the model area occurs primarily through the southeastern model boundary. Respective rates are governed by the cross-sectional area of flow, aquifer hydraulic properties, and hydraulic gradient along these boundaries. Accordingly, time-varying specified (general) heads defined along each of the model boundaries in each model layer were assigned based on evaluation of observed groundwater elevations from 1975 to 2018. These general-head boundaries, combined with aquifer hydraulic properties and model-predicted hydraulic gradients along the margins of the model, govern the rate of subsurface flows into and out of the model area.

A steady-state groundwater production rate and distribution was estimated and applied in model simulations. The average production rate for producing wells over the three-year period from 2000 to 2002 was selected to simulate a relatively fast hydraulic condition with respect effluent and groundwater travel times and increased capture of secondary effluent discharge in downgradient production wells. Percentages of the average annual pumping rate from 2000 and 2002 were allocated to respective model layers based on the total screen length within each model layer.

With respect to areal recharge, time-varying (transient) WRP 10 effluent discharges, phased simulation of PD-GRF recharge operations, and steady-state outdoor irrigation return flows were simulated.

3.3. MODEL INPUTS

3.3.1. Model Domain Grid and Layering

The model area covers approximately 20 square miles, roughly centered on the WRP 10 site. The model grid comprises 326 rows by 245 columns with a variable cell size of 25 feet in the WRP 10 area to 250 feet at the model boundaries. Model grid columns were oriented north to south.

Four model layers were used to simulate the shallow and deep aquifers. **Figure 24** shows the elevations of the bottoms of the Model Layers 1 through 4. Model Layer 1 is unconfined with the sloping base of the layer defined as approximately 50 feet below the 2015 water table (between 250 and 320 feet-bgs). Model Layer 2 is the model layer with variable thickness at it includes the low-permeability regional clay deposits, which was simulated in the regional MODFLOW model. Model Layer 2 ranges from 10 feet in the southern portion of the Study Area up to 160 feet thick in the eastern portion of the Study Area. Model Layer 2 is approximately 100 feet thick beneath the project site. Model Layers 3 and 4 are parallel with the Model Layer 2 bottom elevation surface, and were defined as 300 and 400 feet thick, respectively. While permeable alluvial sediments exist beneath Model Layer 4, a 400-foot thickness for Model Layer 4 was selected to effectively simulate flow conditions in the deepest portion of the aquifers tapped by production wells.

3.3.2. Model Simulation Period

The model simulates historical groundwater flow conditions beginning in 1975 using annual stress periods. While historical groundwater level data are limited prior to 1985, distinct water level trends were observed from 1985 to 2018 (as discussed in Section 2.5). The model accounts for the historical declining groundwater levels and changes in hydraulic gradients using time-varying boundary conditions and rates of WRP 10 secondary effluent discharge, as well as phased implementation of PD-GRF operations. A future simulation period extending to 2042 was selected to allow for prediction of effluent discharge flowpaths approximately 20 years into the future.

3.3.3. Aquifer Hydraulic Properties

Aquifer hydraulic properties include horizontal hydraulic conductivity (K_H), vertical hydraulic conductivity (K_V), and storage coefficients (effective porosity, specific yield [S_y], and confined storage coefficient [S]), are based on the respective values assigned in the regional flow model. Adjustments to K_H values were made to represent clay layers in local Model Layer 2, as compared with its simulation in Model Layer 3 of the regional model. Final K_H values assigned to each model layer are shown on **Figure 25**. As shown on the figure, final K_H values for Model Layers 1, 3, and 4 are identical and range from 30 feet per day (feet/day) in the northeastern margins of the Study Area up to 225 feet/day in the western portion of the Study Area. In Model Layer 2, low K_H values (blue colors on the upper right map on Figure 22) in the central portion of the Study Area exist and correspond to the low permeability regional clay aquitard. K_H values in these areas of Model Layer 2 are $1/10^{\text{th}}$ of the K_H values assigned to Model Layers 1, 3, and 4.

In contrast to K_H values, K_V values were modified during calibration. Initial simulations used a horizontal to vertical hydraulic conductivity (K_H/K_V) ratio of 10:1 for each model layer. However, the apparent hydraulic isolation of the lower aquifer zone from the overlying aquifers (based on water quality distributions) warranted larger K_H/K_V ratios. The final calibrated model used a K_H/K_V ratio of 100:1, similar to the regional flow model.

Transient flow simulations utilized the aquifer storage properties (specific yield and specific storage). A specific yield value of 0.2 was assigned to Model Layer 1, and specific storage values of 0.001 to 0.00005 were assigned to Model Layers 2 through 4.

3.3.4. Boundary Conditions (Subsurface Inflows and Outflows)

Because the local model comprises a much smaller area than the regional MODFLOW model, different model boundary conditions were required. Time-varying specified (general) heads were defined along each of the model boundaries in each layer. The assigned general head values are based on 1985 to 2018 groundwater elevation measurements across the local model area (Figure 4), changing over time in accordance with observed historical groundwater elevation trends. Time-series heads were assigned to “nodes” along each boundary arc, with head values changing (decreasing) between 1985 and 2015 in accordance with observed groundwater level declines. Heads between 1975 and 1985 and between 2015 and 2042 were held constant at each boundary. For example, along the northwestern

boundary, the specified head was decreased from approximately 40 feet msl in 1985 to 0 feet msl during 2015. Along the southeastern boundary, simulated boundary heads range from approximately 0 feet msl along the northwestern boundary in 1975 to -120 feet msl in 2015. Future boundary heads are held constant using the 2015 values. The same boundary condition elevation values were used for each model layer.

3.3.5. Production Well Pumping

As described in Section 2.4, groundwater has been pumped from a total of 143 wells in the Study Area since 1975. This includes 60 CVWD wells (35 currently active and 25 currently inactive) and 83 private irrigation wells. Well locations and annual production totals since 2000 are shown on Figures 2 and 3, respectively. As shown on Figure 3, groundwater production has declined steadily over the past 18 years as a result of increased conservation and increase use of recycled water (and to a lesser degree, imported water). From 2000 to 2002, average annual production in the Study Area was 89,870 AFY. In contrast, from 2015 to 2017, average annual production was 56,267 AFY.

For the historical model simulations, average annual production over the three-year period between 2000 and 2002 were simulated. This period represents the highest overall pumping rates in the Study Area. The average annual pumping rates from 2000 to 2002 were assigned to each of the 103 wells that were pumped from 2000 to 2002 in the local model. This approach is considered conservative with respect to simulating higher groundwater flow velocities and increased capture of secondary effluent discharge in downgradient production wells.

As shown on water quality cross sections (Figures 11 through 16), production wells are completed (screened) at various depths within the deeper aquifer zones, with most wells completed across Model Layers 3 and 4. For these wells, percentages of the average annual pumping rate from 2000 and 2002 were allocated to respective model layers based on the total screen length within each model layer. For example, for a well completed with 300 feet of screen in Model Layer 3 and 200 feet of screen in Model Layer 4, 60 percent of the pumping was allocated to Layer 3, and 40 percent was allocated to Model Layer 4. Wells were simulated using the MODFLOW Well Package.

3.3.6. WRP 10 Secondary Effluent Discharges

Historical and projected future WRP 10 secondary effluent discharge rates shown on Figure 7 were applied over the historical and current WRP 10 percolation pond areas in the WRP 10 groundwater flow model. As shown on Figure 7, annual secondary treated effluent discharge rates at WRP 10 generally increased from the 1970s to early 2000s and have gradually decreased since that time. CVWD has developed plans to expand deliveries of non-potable water, including recycled water, to golf courses in the mid-valley area, which will reduce the need for secondary effluent discharge at WRP 10 in the future. For the simulated future period (beginning in WY 2018-19), effluent discharges were reduced to the rates shown on Figure 7 and applied over the current secondary effluent pond area at WRP 10.

3.3.7. PD-GRF CRW Recharge

Recharge of imported CRW at the PD-GRF is scheduled to be implemented in two phases. Phase I involves recharge of up to approximately 8,000 AFY of CRW in recharge basins north of the WRP 10 facility, and Phase 2 will recharge an additional 15,000 AFY in recharge basins located in the WWR-WC south of WRP 10. Phase I recharge began in February 2019. Phase II recharge facilities are scheduled to be completed by 2021.

Model simulation of future conditions include constant recharge of the proposed Phase I and II replenishment, with 8,000 AFY of Phase I replenishment beginning in 2019 and an additional 15,000 AFY of Phase II replenishment beginning in 2021.

3.3.8. Outdoor Irrigation Return Flow

While it is recognized that irrigation return flows vary due to changes in land use and irrigation practices, the influence of irrigation return flow changes on the subsurface transport of WRP 10 secondary effluent discharges is considered to be relatively minor compared to other key factors, including the rate of WRP 10 secondary effluent discharge and local horizontal and vertical hydraulic gradients. Accordingly, a constant distribution and volume of irrigation return flow was considered a reasonable simplifying assumption for the model.

Average estimated annual outdoor irrigation return flows of 20,600 AFY described in Section 2.6.1 were apportioned across mapped irrigated areas within the Study Area. To facilitate import of irrigation return flow recharge into the model, recharge was aggregated into 38 return flow polygons (as shown on Figure 9). The zones were mapped to the model grid and simulated using the MODFLOW Recharge Package.

3.4. MODEL RESULTS

3.4.1. Historical Calibration Results

The local model was calibrated to observed groundwater elevations from 1985 to 2018. During model calibration, boundary condition head values were adjusted until simulated groundwater elevations matched observed patterns and trends. Model layer elevations, hydraulic conductivities, recharge rates, and production well pumping rates were not adjusted.

Simulated groundwater elevations in Model Layer 1 during 1985, 1995, 2005, and 2015 are shown on **Figure 26**, and can be compared with measured groundwater elevations during these same periods (Figure 4). As shown on the figures, the observed and simulated hydraulic gradients during each period are northwest-to-southeast across the Study Area. During 1985, observed and simulated groundwater elevations both range from approximately 50 feet msl at the northwest (upgradient) model boundary to approximately -20 feet msl at the southeastern model boundary. A water table mound of around 15 to 20 feet is simulated beneath the WRP 10 effluent discharge pond area (see closed 40 ft msl elevation contour). Overall, the simulated groundwater levels reasonably match the observed 1985 groundwater levels.

Simulated groundwater levels are also depicted on Figure 26 for 1995, 2005, and 2015 conditions and reflect observed regional water level declines over these time periods. Between 1985 and 2015, simulated groundwater elevations declined by approximately 60 feet at the northwest (upgradient) model boundary (from approximately 50 feet msl to approximately -10 feet msl), and by about 90 feet at the southeastern model boundary (from about -20 to -110 feet msl). These simulated declines match the observed groundwater elevations trends during this period. The greatest amount of water table mounding was simulated during 2005 with about 40 feet of recharge mounding, which corresponds to a period of high effluent discharge (Figure 7). The simulated mound height generally matches the observed mound height in 2005.

3.4.2. Historical Effluent Discharge Flowpaths

Forward flowpaths from the WRP 10 site were simulated using MODPATH. MODPATH uses the three-dimensional flow solution from MODFLOW and tracks particles (flowpaths) from the effluent ponds to downgradient areas. Flow velocities and travel times are also calculated. It is noted that estimated flow velocities and travel times from the effluent ponds to the production wells are dependent on aquifer hydraulic properties including hydraulic conductivity and effective porosity. For this analysis, an effective porosity of 20 percent was assumed for all model layers.

Figure 26 shows the simulated forward flowpaths in map view with time from the WRP 10 discharge area beginning in 1985, 1995, 2005, and 2015. The upper left map on Figure 26 shows the simulated forward flowpaths beginning in 1985. The 1985 flowpaths reveal the expected radial flowpath away from the effluent pond area, with subsequent flow to the east-southeast. For the highest velocity flowpaths, the travel time from WRP 10 to the southeastern model boundary (a distance of approximately 4.5 miles) is approximately 50 years, corresponding to an average groundwater velocity of 1.3 ft/day. Higher velocities are present near the effluent disposal mound, corresponding to the steeper hydraulic gradients within the recharge mound. Simulated flowpaths spreads out over an area approximately 2 miles at its maximum width. A few monitoring and production wells west of WRP 10, such as WRP 10 MW4, are predicted to be partially within the simulated flowpath. Simulated flowpaths beginning in 1995, 2005, and 2015 show similar flow directions and velocities. Velocities for flowpaths beginning in 2015 are slightly higher than during previous years, due to the steeper hydraulic gradient across the Study Area.

The illustrated flowpath lines are 2-dimensional projections of the simulated 3-dimensional curvilinear paths calculated within the four-layer model. **Figure 27** shows the same forward flowpaths from the WRP 10 discharge area beginning in 1985, 1995, 2005, and 2015 color-coded to show their elevation. The flowpaths depict the vertical migration of secondary effluent from shallower to deeper aquifer zones over time. Because well screen intervals for most production wells are completed in Model Layers 3 and 4, downward vertical migration of secondary effluent indicates potential water quality impact to water supply wells within the effluent flowpath. The figure shows that effluent primarily travels within Model Layers 1, 2, and the upper portions of Layer 3 (below approximately -300 feet msl). Only a small fraction of effluent travels into the upper portions of Model Layer 4 (below approximately -600

feet msl), and most of these deeper flowpaths occur several miles downgradient of the WRP 10 facility, after several decades of travel time in the aquifer.

3.4.3. Future Effluent Discharge Flowpaths

In addition to the historical calibration simulation, a future scenario was simulated that included phased reductions in effluent discharge coinciding with implementation of Phase I and II PD-GRF recharge operations.

Future WRP 10 improvements are scheduled that will increase recycled water deliveries to irrigation customers. As a consequence, secondary effluent discharges will gradually decline and are anticipated to be eliminated by the end of WY 2026-27 (see Figure 7). PD-GRF recharge will be conducted at rates of approximately 8,000 AFY in Phase I recharge basins (commenced in February 2019) and 15,000 AFY in the Phase II WWR-SC recharge basins (by 2021) for a total replenishment rate of 23,000 AFY. For the future scenario simulation, boundary hydraulic head conditions were set at 2015 levels and held constant. Irrigation return flow and production well pumping rates were also held at constant historical values.

Figure 28 shows the simulated groundwater elevations and forward flowpaths with time and depth from the reduced effluent recharge area beginning in 2020 and 2025. In 2020, after one year of Phase I recharge, the maximum water table mounding simulated beneath the PD-GRF Phase I recharge area is approximately 100 feet. Flowpaths indicate that the secondary effluent migrates in a southerly and easterly direction, due to the mounding associated with the PD-GRF Phase I recharge to the north of the effluent discharge area. Effluent velocities are generally higher relative to historical rates due to the steeper local hydraulic gradients. Effluent velocities decline with increasing distance from the WRP 10 facility.

As shown on Figure 28, beginning in 2025, effluent flowpaths and elevations are affected by the hydraulic mounding associated with the PD-GRF Phase I and II recharge operations. Large recharge mounds occur under both recharge areas, and flowpaths from the WRP 10 effluent area are “squeezed” by CRW recharge from the north and south. Accordingly, migration of secondary effluent is predicted to occur to the east (downgradient) and west (upgradient) of WRP 10.

4. GROUNDWATER MONITORING PLAN

The purpose of the groundwater monitoring plan is to track the historical and future aquifer hydraulic response to WRP 10 secondary effluent discharge, identify the vertical and lateral and extent of elevated TDS and nitrate concentrations in the vicinity of WRP 10, and assess the potential sources of those constituents (including, but not limited to, WRP 10 effluent discharge) and their potential threat to existing water supply wells.

As stated in the Workplan (Task 3), a proposed monitoring well network consisting of shallow monitoring wells and deep CVWD municipal and private production wells will be used to monitor groundwater levels and water quality in the shallow and deeper aquifer systems. In addition to the monitoring well network, a sampling and analysis plan is presented describing the field parameter and laboratory analyte list and sampling schedule.

4.1. TECHNICAL BASIS FOR ESTABLISHMENT OF MONITORING WELL NETWORK

The evaluation of local groundwater level and water quality conditions (Task 1) combined with groundwater flow modeling results (Task 2) provided a technical basis for establishing a groundwater monitoring network to address the technical issues in Special Provision F.1. Considerations pertinent to the selection of individual monitoring wells are presented below:

1. A mix of shallow and deep monitoring locations (wells) is needed to confirm the vertical extent of elevated nitrogen and TDS concentrations and identify the potential impact of secondary effluent discharge to existing water supply wells downgradient of WRP 10.
2. The inclusion of monitoring locations (wells) both within and outside of the model-predicted historical and future effluent flowpaths is critical for verifying the lateral extent of secondary effluent discharges and its influence on TDS and nitrate concentrations.
3. In addition to WRP 10 MW4, additional shallow monitoring wells located further northwest, west, and southwest of the WRP 10 facility are warranted to characterize upgradient “background” TDS and nitrate concentrations.
4. Existing WRP 10 MW1, MW2, and MW3 can be used effectively to monitor the hydraulic mound associated with secondary effluent discharge; however, additional shallow monitoring wells are warranted to monitor the local aquifer hydraulic response to PD-GRF Phase I and II CRW recharge operations.

4.2. MONITORING WELLS

The proposed monitoring network includes a total of 32 wells completed in the shallow and deep aquifer zones.

Figure 29 shows the locations of the wells to be included in the WRP 10 monitoring program in relation to simulated historical and future WRP 10 secondary effluent flowpaths (pink

lines). Relative to WRP 10 facility, monitoring wells are located upgradient (northwest, west, and southwest), cross-gradient (north and south), and downgradient (east and southeast), providing a good distribution for characterizing the lateral and vertical extent of elevated TDS and nitrate and the influence of WRP 10 secondary effluent discharges on groundwater quality.

Table 1 lists the well names, type/status, screen interval depths of the 32 wells in the monitoring network.

4.2.1. Shallow Monitoring Wells

As listed in Table 1, thirteen shallow monitoring wells are proposed for inclusion in the WRP 10 monitoring program. This includes the six existing WRP 10 monitoring wells and seven new shallow monitoring wells. Collectively, the thirteen shallow monitoring wells will be used to monitor the hydraulic head associated with infiltration of wastewater, characterize upgradient “background” groundwater quality, and verify the vertical and lateral extent of nitrate and TDS concentrations associated with historical WRP 10 secondary infiltration volumes, infiltration head, and groundwater flow velocities in the shallow aquifer system.

Existing WRP 10 Monitoring Wells (MW-1 through MW-6): WRP 10 MW-1 and MW-4 are located southwest and west of the effluent discharge area, respectively, while WRP 10 MW-2, MW-3, MW-5, and MW-6 are located east (downgradient) of WRP 10.

All of the existing WRP 10 monitoring wells have been monitored historically for groundwater quality. WRP 10 MW-4 through MW-6 are actively monitored, while MW-1 through MW-3 were last sampled in 2012 and will require some rehabilitation to allow for collection of representative water quality samples. In October 2018, MW-4, MW-5, and MW-6 were sampled and analyzed for oxygen and nitrogen isotopes in nitrate. The previous sampling results will be included with the new monitoring results to assess WRP 10 effluent influence on local groundwater quality.

Proposed New Shallow Monitoring Wells: Seven new shallow monitoring wells are proposed for inclusion in the WRP 10 monitoring network. Four wells (PD MW-1 through MW-4; orange circles) are scheduled to be installed by July 2019. Three wells (WRP 10 MW-7 through MW-9; red circles) are scheduled to be installed by December 2019. The three wells will have similar screen depth intervals ranging from approximately 260 to 340 feet-bgs. WRP 10 MW7, PD-MW2, and PD-MW-3 represent reliable upgradient shallow monitoring wells allowing for characterization of “background” TDS and nitrate concentrations and sources.

4.2.2. Deep (CVWD and Private) Production Wells

Nineteen production wells are proposed for inclusion in the WRP 10 monitoring program to characterize water quality in the deeper aquifers surrounding the WRP 10 facility.

Of the nineteen wells, thirteen are CVWD production wells. These include five active wells (light blue circles) and eight inactive CVWD wells (grey circles). Six private production wells are also proposed for inclusion in the WRP 10 monitoring program (green circles). All private

wells have been historically monitored for water quality (at a generally lower frequency than CVWD production wells). As highlighted in Table 1, one CVWD well (5671-1) and four private wells were sampled and analyzed for oxygen and nitrogen isotopes in nitrate in 2018.

As shown on Figure 29, several of the production wells in the groundwater monitoring network are located reliably upgradient (northwest, west, and southwest) of the model-predicted historical and future WRP 10 effluent flowpaths, including CVWD 5682-1, 5637-1, 5671-1, and 5674-1. These wells will be valuable in characterizing background water quality in the deeper aquifer. Other production wells are situated firmly within the lateral extent of the effluent flowpaths (e.g., CVWD 5620-2 and 5603-2 and private wells 10I1, 15H1, and 24D1). Finally, some production wells are located along the margins or slightly outside the lateral extent of the effluent flowpaths (e.g., CVWD 5636-1, 5626-1, 5665-1, 5666-1, and 5710-1 and private wells 22B1 and 22C2).

4.3. SAMPLING AND ANALYSIS PLAN

Water level monitoring and groundwater quality sampling of all 32 wells in the monitoring network will be performed to identify the extent of elevated groundwater TDS and nitrate concentrations and identify their potential sources. The right portion of Table 1 shows the proposed sampling and analysis plan, including the field measurements and laboratory analyses proposed along with sampling frequency for each well in the monitoring network. As stated in the Workplan and shown in Table 1, the groundwater level and water quality monitoring program is scheduled to commence in January 2020 (when all proposed shallow monitoring wells are constructed) and will be conducted for a one-year period ending December 2020.

Groundwater levels fluctuate seasonally in response to variations in natural recharge, effluent discharges, groundwater replenishment, and groundwater pumping. Accordingly, groundwater levels for all wells in Table 1 will be measured on a quarterly basis ((1st Quarter, 2nd Quarter, 3rd Quarter, and 4th Quarter 2020).

In compliance with the Work Plan, all wells in Table 1 will be sampled and analyzed for TDS, nitrate, and major ions (including calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) on a quarterly basis (1st Quarter, 2nd Quarter, 3rd Quarter, and 4th Quarter 2020).

All wells in Table 1 will also be sampled and analyzed for oxygen and nitrogen stable isotopes in nitrate to differentiate between the various nitrate sources in local groundwater. Because the isotopic signature of nitrate is not expected to vary significantly over time, sampling and analysis of stable isotopes in nitrate will be conducted semi-annually, or twice in 2020 (2nd Quarter and 4th Quarter 2020). It is noted that a minimum concentration of 3 mg/L of nitrate as NO₃ is required to analyze for stable isotopes in nitrate. Accordingly, wells determined to have nitrate as NO₃ concentrations below 3 mg/L in the 1st Quarter 2020 sample will not be sampled for stable isotopes in nitrate. The four production wells that may fall into this category are highlighted in pink in Table 1. CVWD already collects groundwater level

measurements and water quality samples at some of the well in Table 1 for other programs. Monitoring will be coordinated between the programs to avoid duplication.

As shown on the top row of Table 1, WRP 10 secondary effluent will also be analyzed for TDS, major ions, and nitrate on a quarterly basis in 2020 and for stable oxygen and nitrogen isotopes in nitrate semi-annually to provide a basis for comparison with collected groundwater quality samples.

The groundwater samples for TDS and nitrate will be analyzed by a certified California Department of Public Health Environmental Laboratory Accreditation Program (ELAP) laboratory. The nitrate stable isotope samples will be analyzed by Isotech Laboratories.

Sampling activities will be performed by CVWD staff, who have already developed specific protocols for groundwater level and water quality monitoring. CVWD's protocols include procedures for:

- Pre-field preparations
- Operations, maintenance, and calibration procedures for field instruments
- Water level monitoring
- Well purging and sampling (minimum purge volumes, field parameter stabilization guidelines prior to sample collection)
- Sample handling and preservation
- Equipment decontamination
- Laboratory analytical program
- QA/QC (blanks and sample duplicates)
- Record keeping and documentation (surface casing inspection form, purging and sampling form, and chain of custody form)

5. PHASE 2 AND PHASE 3 WORKPLAN IMPLEMENTATION SCHEDULE

5.1. PHASE 2 (TASK 4) GROUNDWATER MONITORING PLAN

The Workplan schedule assumes a 60-day RWQCB review period for TM1 (ending June 30, 2019). Upon receipt of RWQCB comments on TM1, the groundwater monitoring plan will be implemented under Phase 2 (Task 4), which consists of installing the seven proposed new monitoring wells (through December 2019) and implementing the one-year sampling and analysis plan (through December 2020).

All groundwater level and water quality data collected from the groundwater monitoring program will be incorporated in spreadsheet and Geographic Information System (GIS) databases. These data management systems will allow for efficient data tabulation, mapping, and charting, and facilitate evaluation of flow and water quality trends in space and time. A certified hydrogeologist will evaluate the groundwater monitoring data. Water level hydrographs and maps of groundwater elevations and water quality over time will be prepared. Water quality distributions and trends will be identified and correlated to TDS and nitrate sources.

As stated in the Workplan, a technical memorandum (TM2) documenting the monitoring installation work and sampling results will be developed and submitted to the RWQCB by March 31, 2021 for review and comment. Technical issues addressed under Phase 2 include:

- The method used to test the accuracy of model-based predictions with regard to the anticipated vertical and lateral extent of elevated nitrogen and TDS concentrations.
- Proposed methods to evaluate the WRP 10 nitrogen and TDS contribution to groundwater in the vicinity of the facility.

5.2. PHASE 3 (TASK 5) FINAL TECHNICAL REPORT

The Workplan schedule assumes a 60-day RWQCB review period for TM2 (ending May 31, 2021). Upon receipt of RWQCB comments on TM2, a final technical report will be prepared and submitted to the RWQCB by August 31, 2021 under Phase 3 (Task 5). The final technical report will integrate the groundwater modeling results and analysis of existing historical water quality and new sampling results. As stated previously, solute transport modeling proposed in the Workplan using a normalized concentration approach will be performed following Phase 2 groundwater quality sampling and analysis (as part of Phase 3 – Task 5). Results of the groundwater sampling program will provide a dataset with which solute transport modeling results can be compared to verify the lateral and vertical extent and relative contribution of secondary effluent discharge in areas with elevated groundwater TDS and nitrate concentrations.

6. REFERENCES

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Table 1. Groundwater Monitoring Locations and Sampling and Analysis Plan

#	State Well Number	CVWD ID	Current Status	Well Screen Interval (ft-bgs)	Most recent Nitrate-NO ₃ mg/L	Monitoring Type	Field Measurements		Laboratory Analyses	
							Groundwater (GW) Levels	pH, Specific Conductance, and Temperature	Major Ions, TDS, and Nitrate ^a	Stable Isotopes in Nitrate
Other										
1	WRP 10 Secondary Effluent					WQ		Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
Shallow Monitoring Wells										
1	05S06E15M01S	WRP 10 MW-1	Existing MW (requires rehabilitation)	145-295	4 - 27 (2012)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
2	05S06E15F01S	WRP 10 MW-2	Existing MW (requires rehabilitation)	160-290	24 - 33 (2012)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
3	05S06E15P01S	WRP 10 MW-3	Existing MW (requires rehabilitation)	130-290	0 - 8 (2012)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
4	05S06E16A03S	WRP 10 MW-4	Existing MW	190-270	4- 18 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
5	05S06E14G03S	WRP 10 MW-5	Existing MW	240-320	26 - 133 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
6	05S06E14P03S	WRP 10 MW-6	Existing MW	190-270	71 - 80 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
7		WRP 10 MW-7	Proposed MW (to be completed by Dec. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
8		WRP 10 MW-8	Proposed MW (to be completed by Dec. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
9		WRP 10 MW-9	Proposed MW (to be completed by Dec. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
10		PD-GRF MW-1	Proposed MW (to be completed by Jul. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
11		PD-GRF MW-2	Proposed MW (to be completed by Jul. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
12		PD-GRF MW-3	Proposed MW (to be completed by Jul. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
13		PD-GRF MW-4	Proposed MW (to be completed by Jul. 2019)	~260-340		GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
CVWD Production Wells										
1	05S06E14P02S	5603-2	Active	720-795; 815-975	11 - 12 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
2	05S06E16A04S	5620-2	Active	1040-1070; 1100-1360	1.8 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
3	05S06E16L01S	5668-1	Active	400-900	21 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
4	05S06E09M02S	5671-1	Active	550-640; 710-750; 840-990	8.1 - 8.9 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
5	05S06E09A01S	5682-1	Active	850-1300	10 - 12 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
6	05S06E13D01S	5602-1	Inactive (GW Level/WQ sampling; Casing Only)	518-566; 614-878	1.5 (1987)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
7	05S06E12N01S	5626-1	Inactive (GW Level/WQ sampling; Casing Only)	454-990	2.3 (2001)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
8	05S06E24G01S	5636-1	Inactive (GW Level/WQ sampling; Casing Only)	480-930	36 (2006)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
9	05S06E09F01S	5637-1	Inactive (GW Level sampling; Casing Only; Lid Welded)	450-490; 530-670; 770-830	116 (1999)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
10	05S06E14B02S	5665-1	Inactive (GW Level/WQ sampling; Casing Only)	400-460; 480-600	67 (2006)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
11	05S06E13G02S	5666-1	Inactive (CASGEM sampling; Casing Only)	450-510; 550-670; 770-830; 890-940	60 (2006)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
12	05S06E20A02S	5674-1	Inactive (GW Level/WQ sampling; Casing Only)	750-1050	76 (2002)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
13	05S07E19D02S	5710-1	Inactive (GW Level/WQ sampling; Casing Only)	440-600; 620-660; 700-730; 750-800	39 (1995)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
Private Production Wells										
1	05S06E10L01S		Active (The Lakes CC)	500-1020	170 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
2	05S06E15H01S		Active (Toscana CC)	430-950	32 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
3	05S06E22B01S		Active (Desert Horizons CC)	350-502	110 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
4	05S06E22C02S		Active (Desert Horizons CC)	300-490	80 (2001)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
5	05S06E24D01S		Active (Indian Wells Golf Resort)	450-700	3.7 (1999)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)
6	05S06E27C03S		Active (Vintage Club)	160-360	130 (2018)	GW Levels and WQ	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Quarterly (Q1 to Q4, 2020)	Semi-Annual (Q2 and Q4 2020)

Notes:

Green highlighted cells indicate wells that were sampled in 2018 for oxygen and nitrogen stable isotopes in nitrate

Pink highlighted cells indicate wells with relatively low most recent nitrate concentration and may not be suitable for analysis of oxygen and nitrogen stable isotopes in nitrate

a - Major ions include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride

mg/L = milligrams per liter

ft-bgs = feet below ground surface

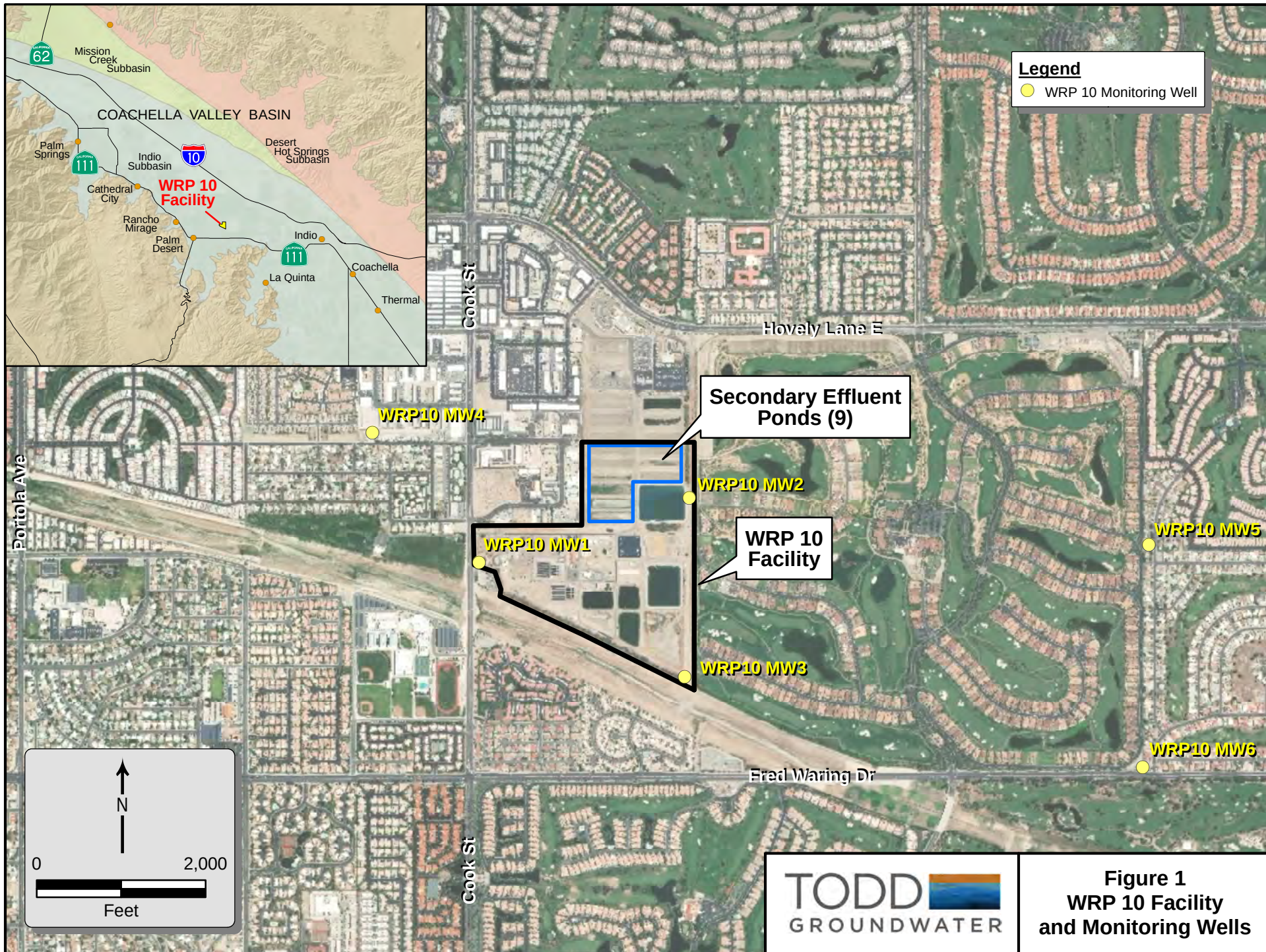
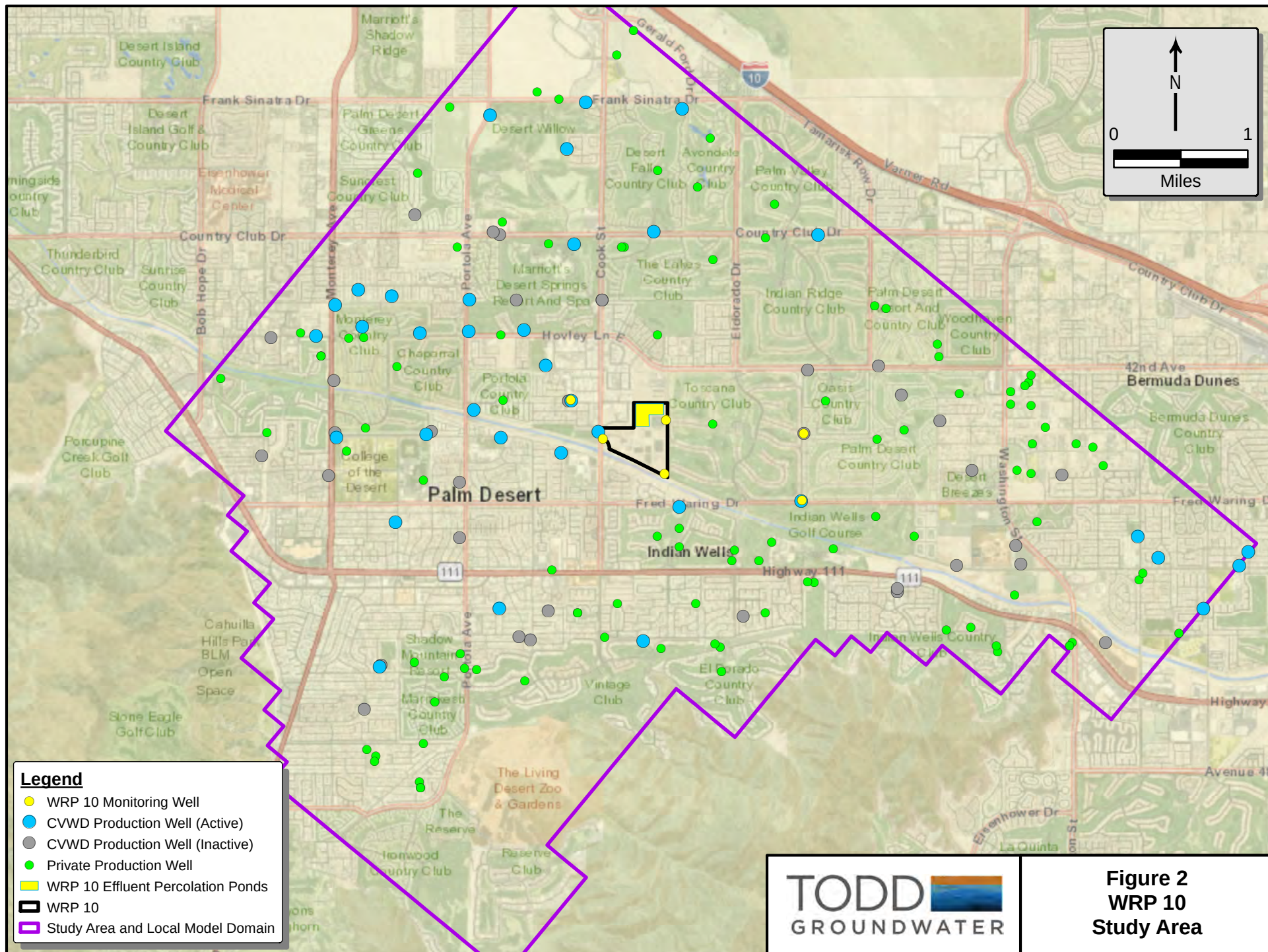
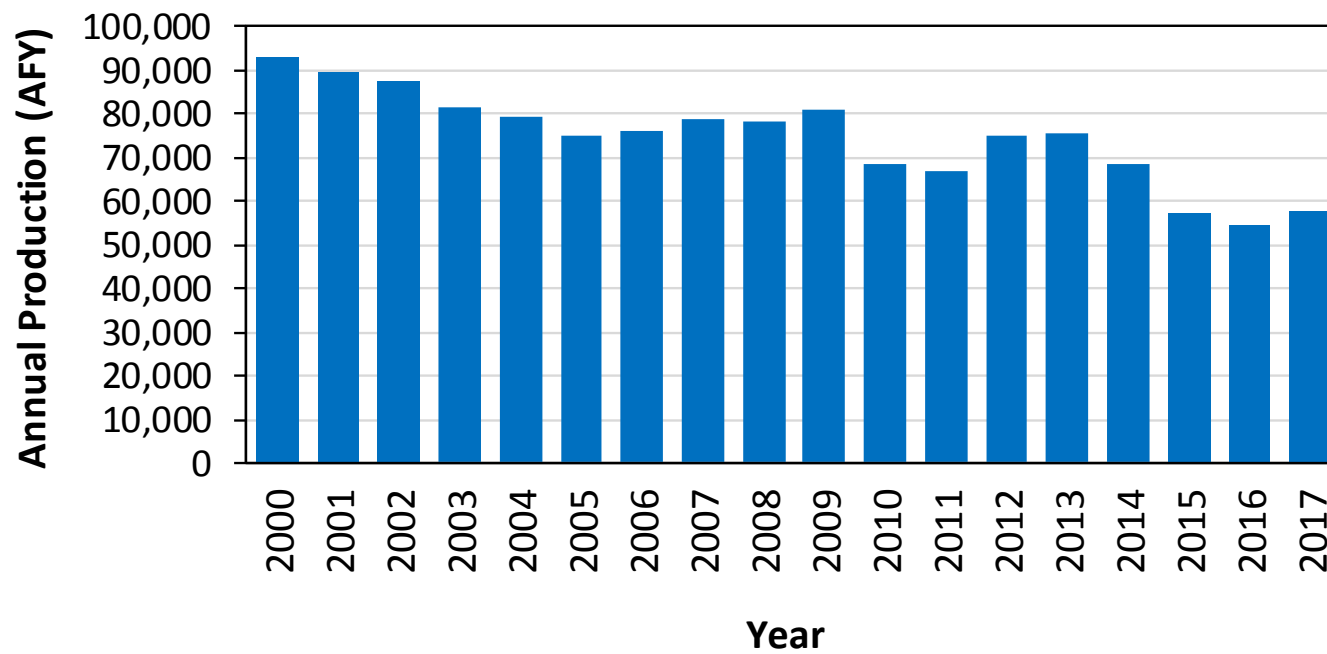
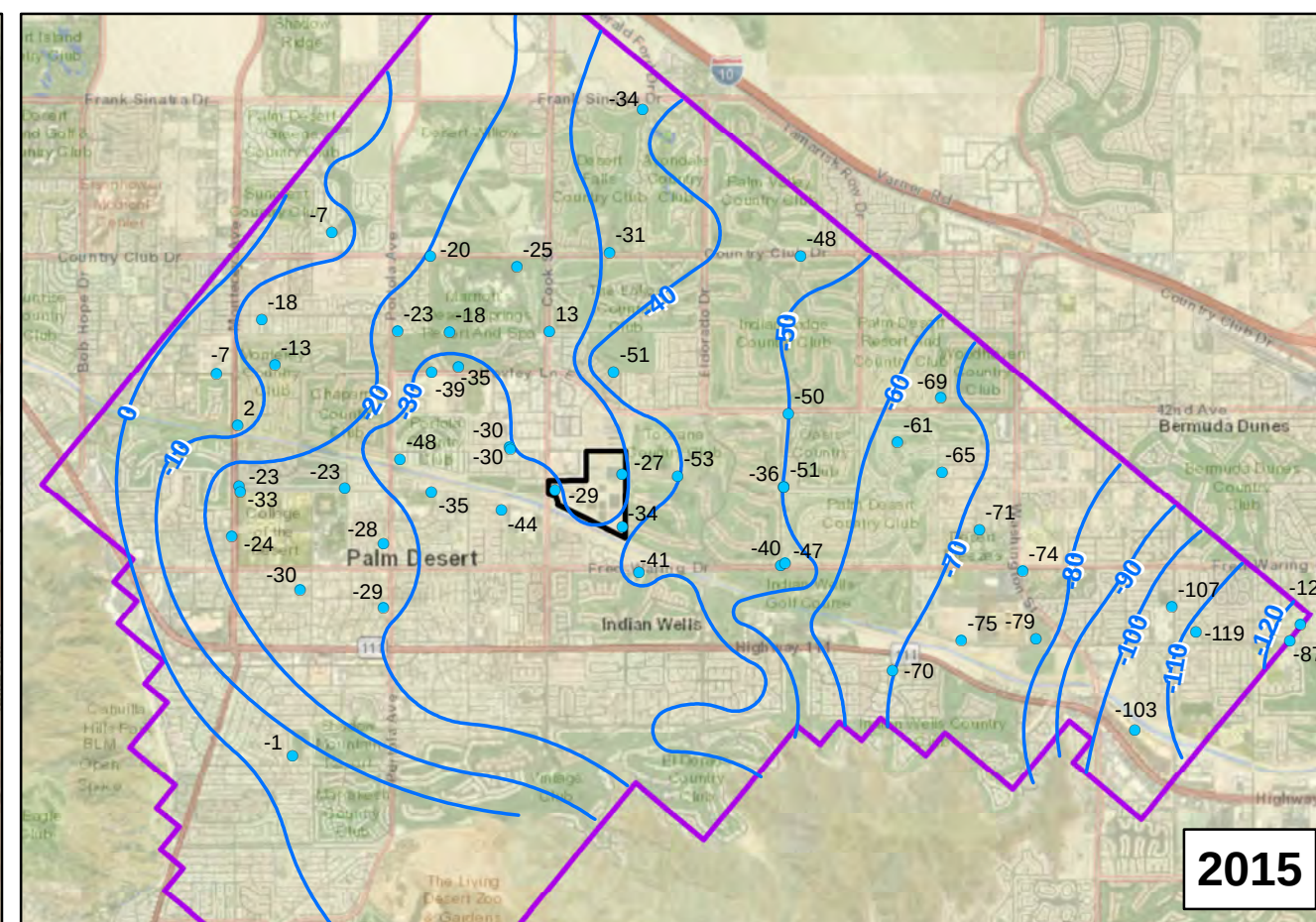
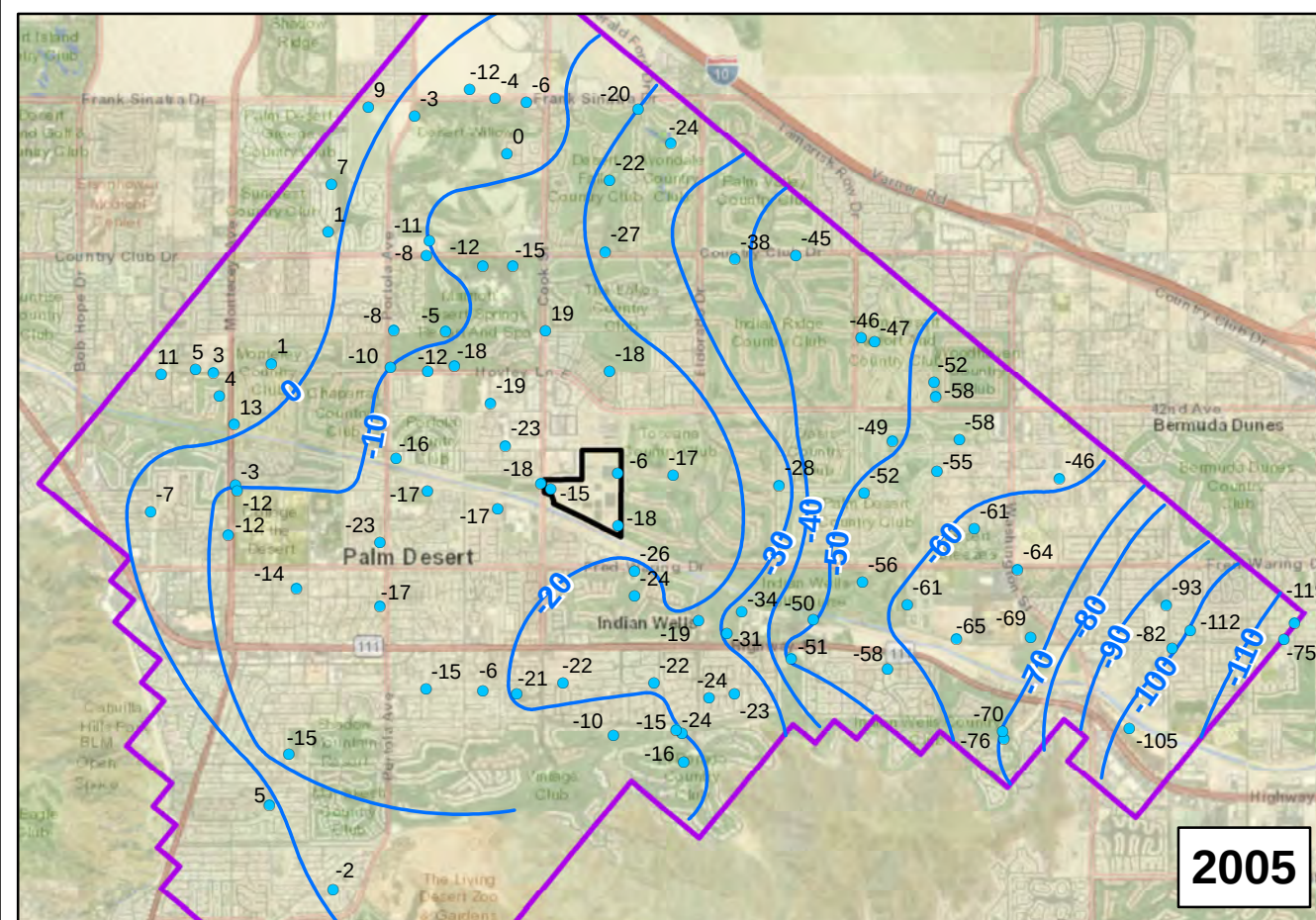
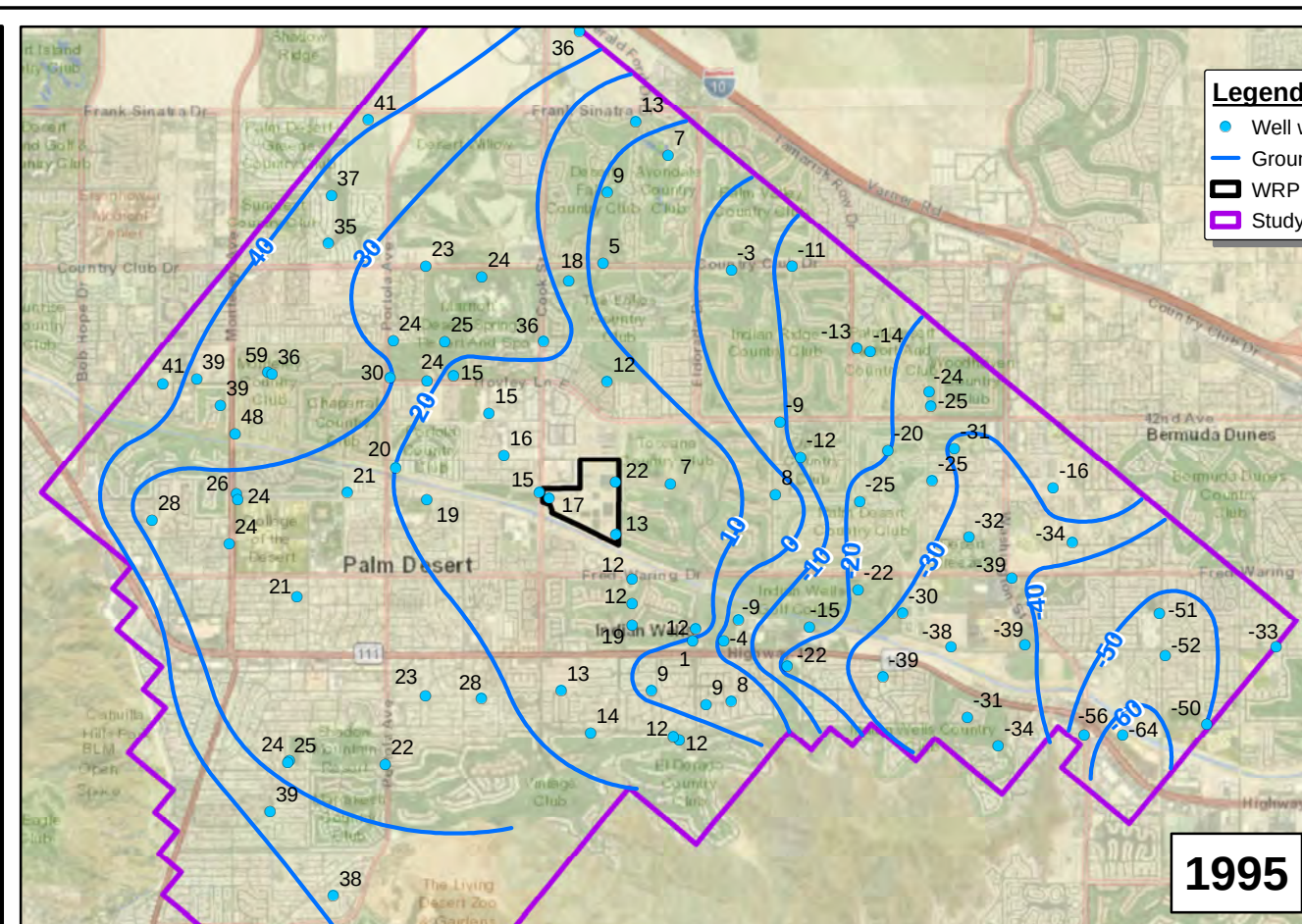
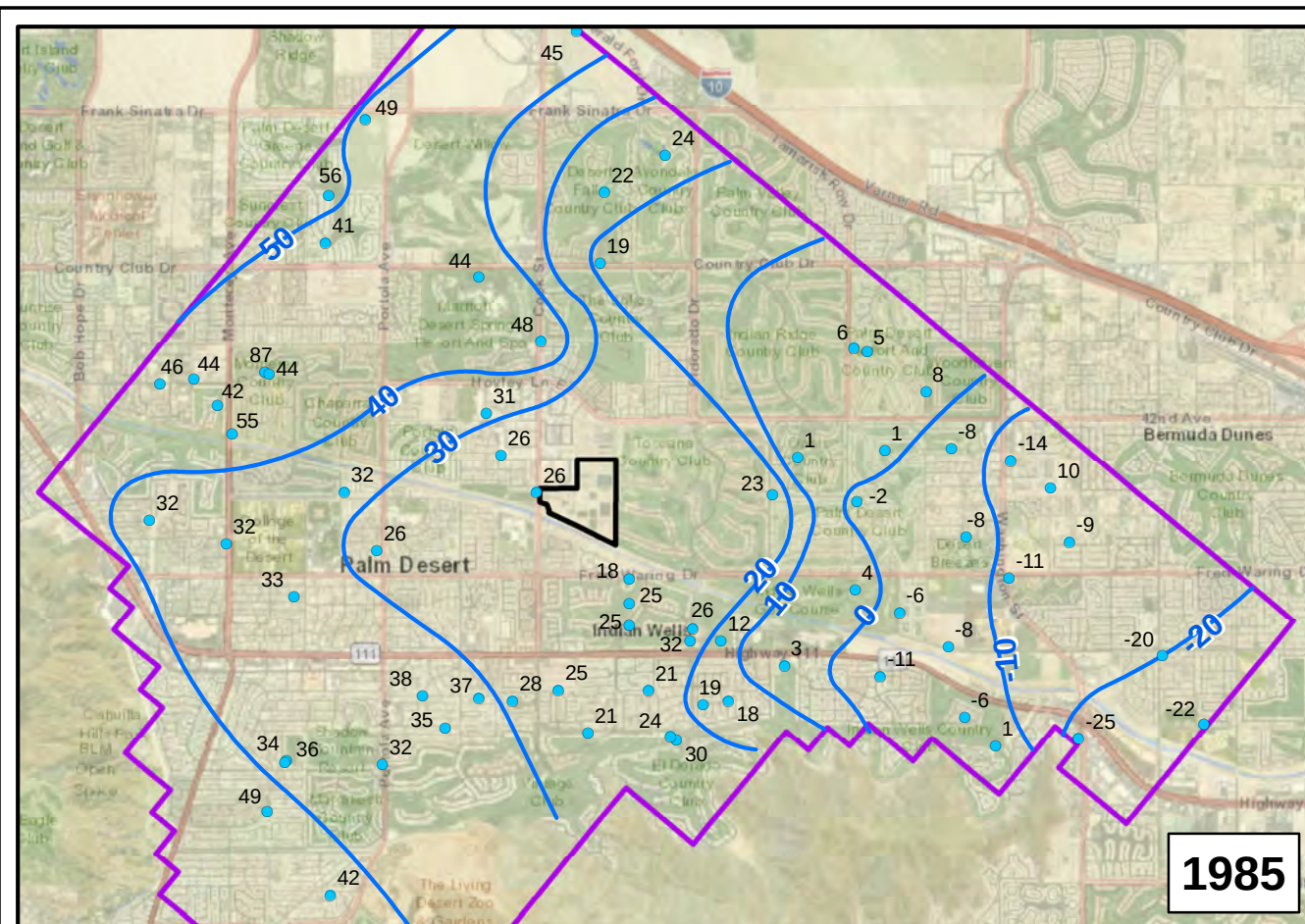


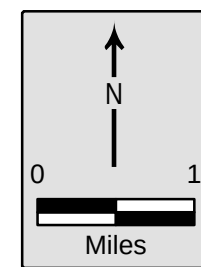
Figure 1
WRP 10 Facility
and Monitoring Wells





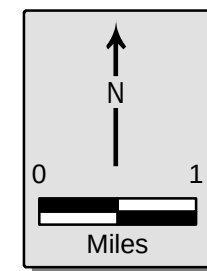
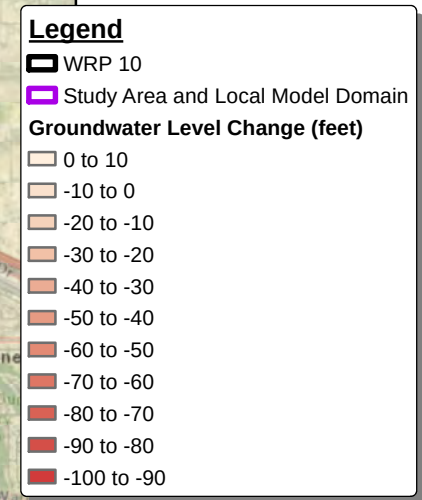
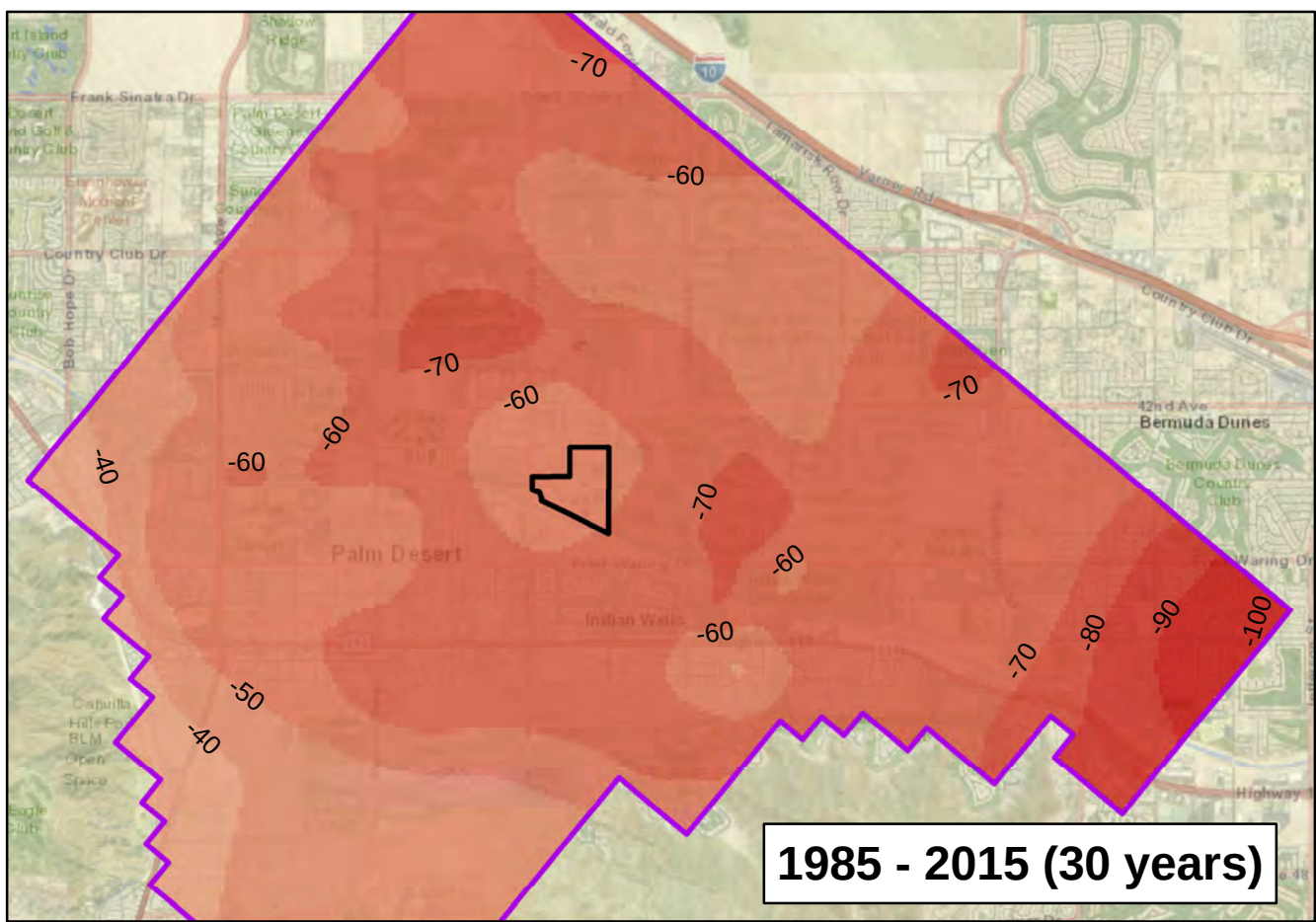
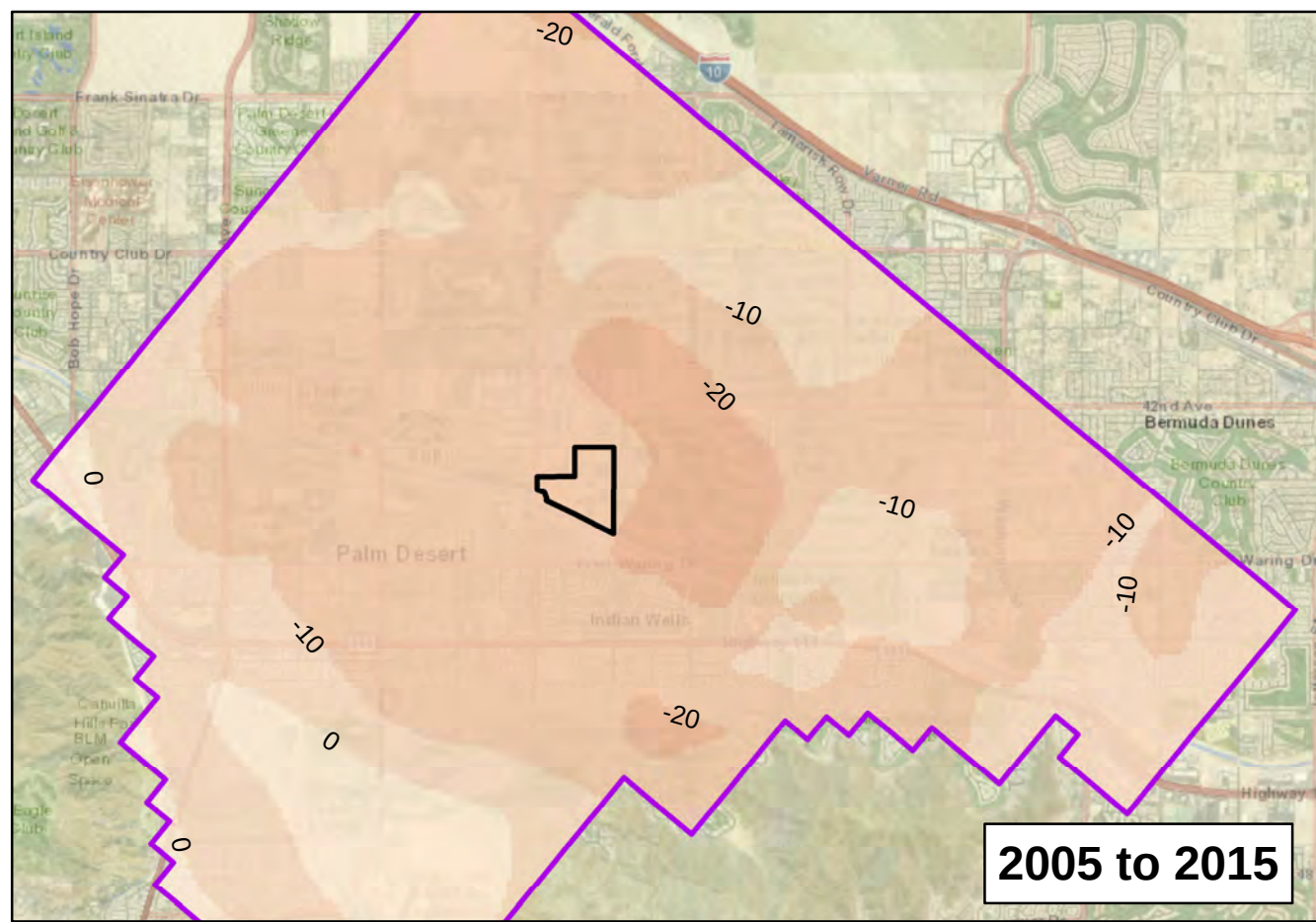
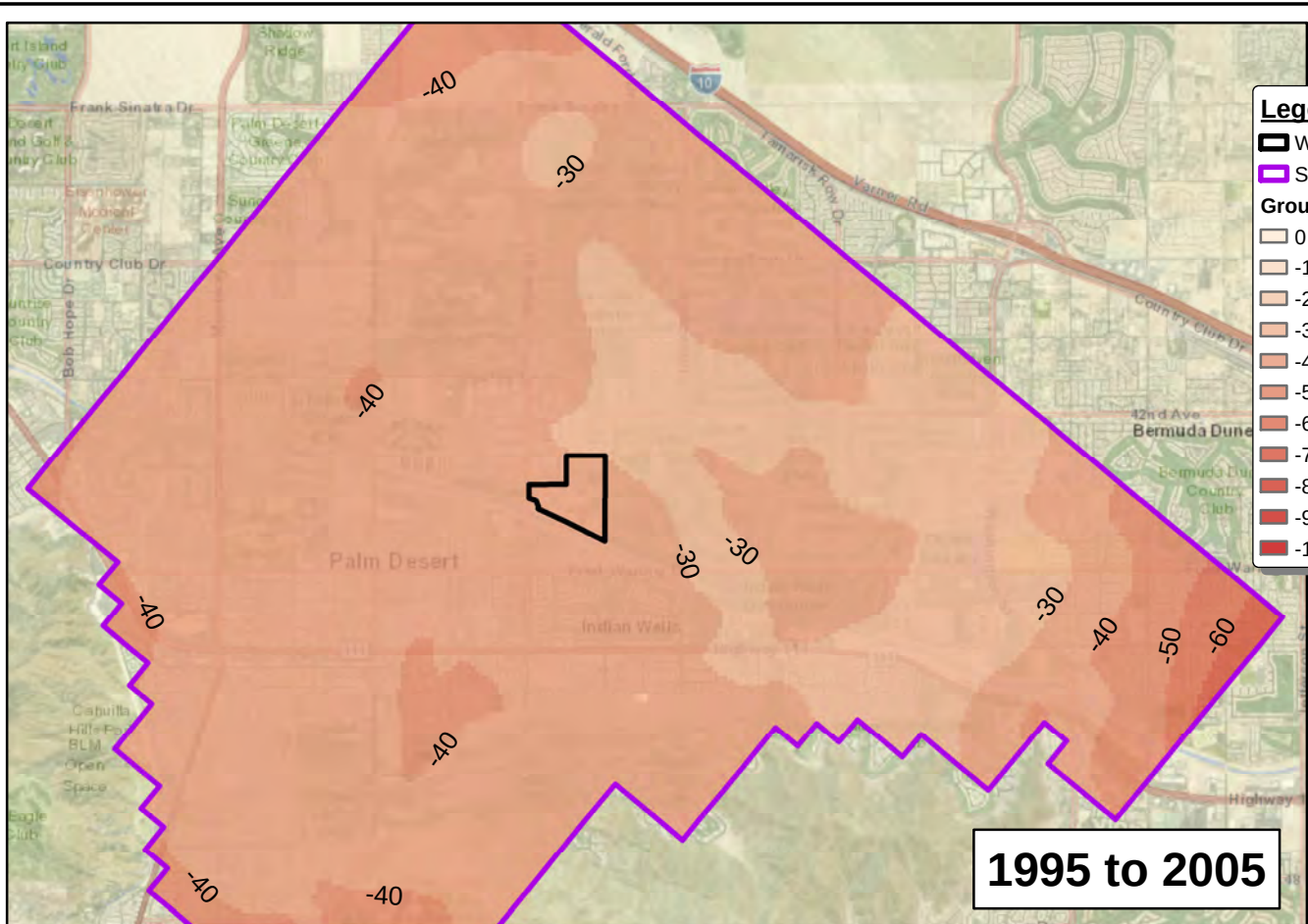
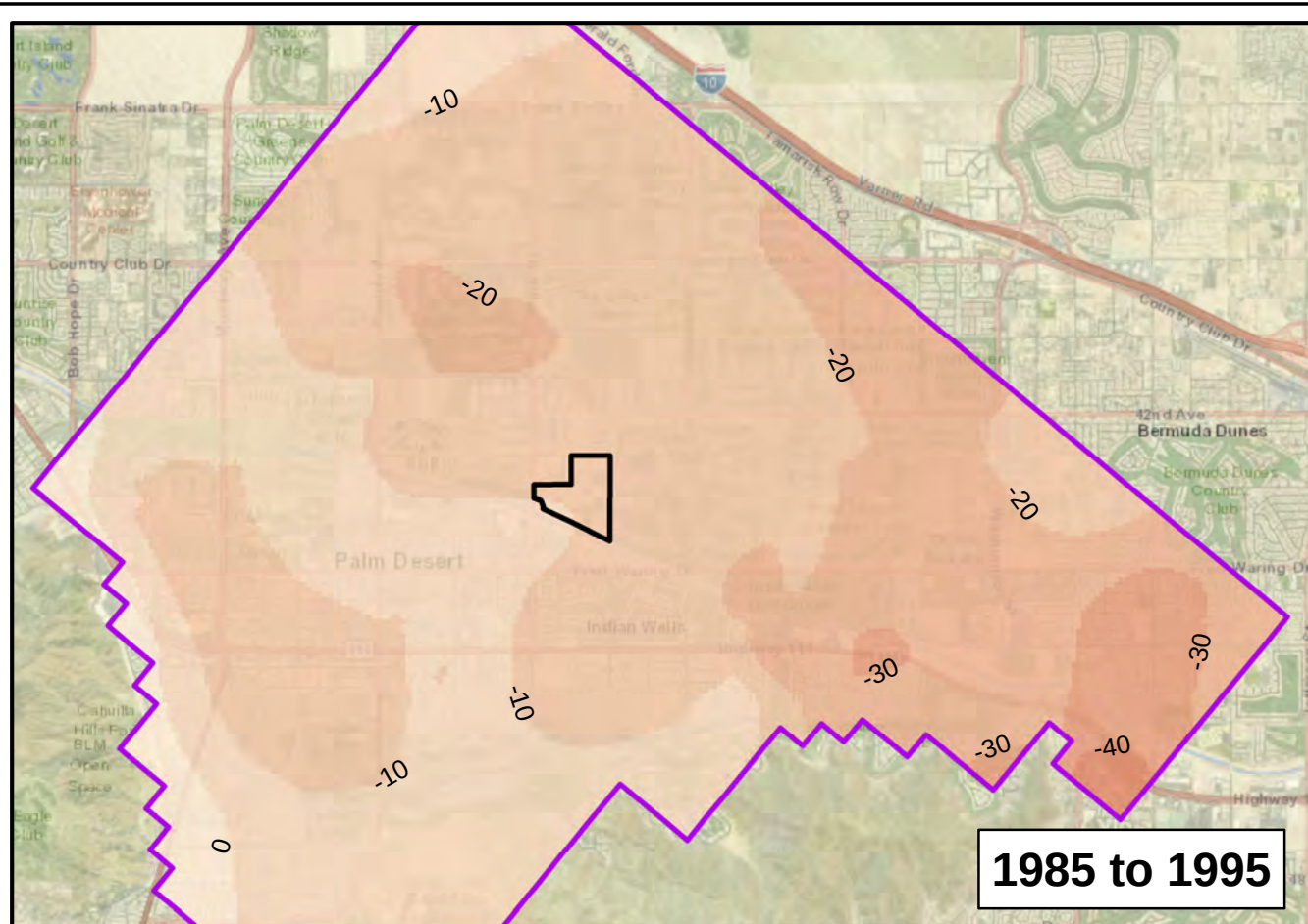


- Legend**
- Well with groundwater level in feet msl
 - Groundwater Level Contour (feet msl)
 - WRP 10
 - Study Area and Local Model Domain



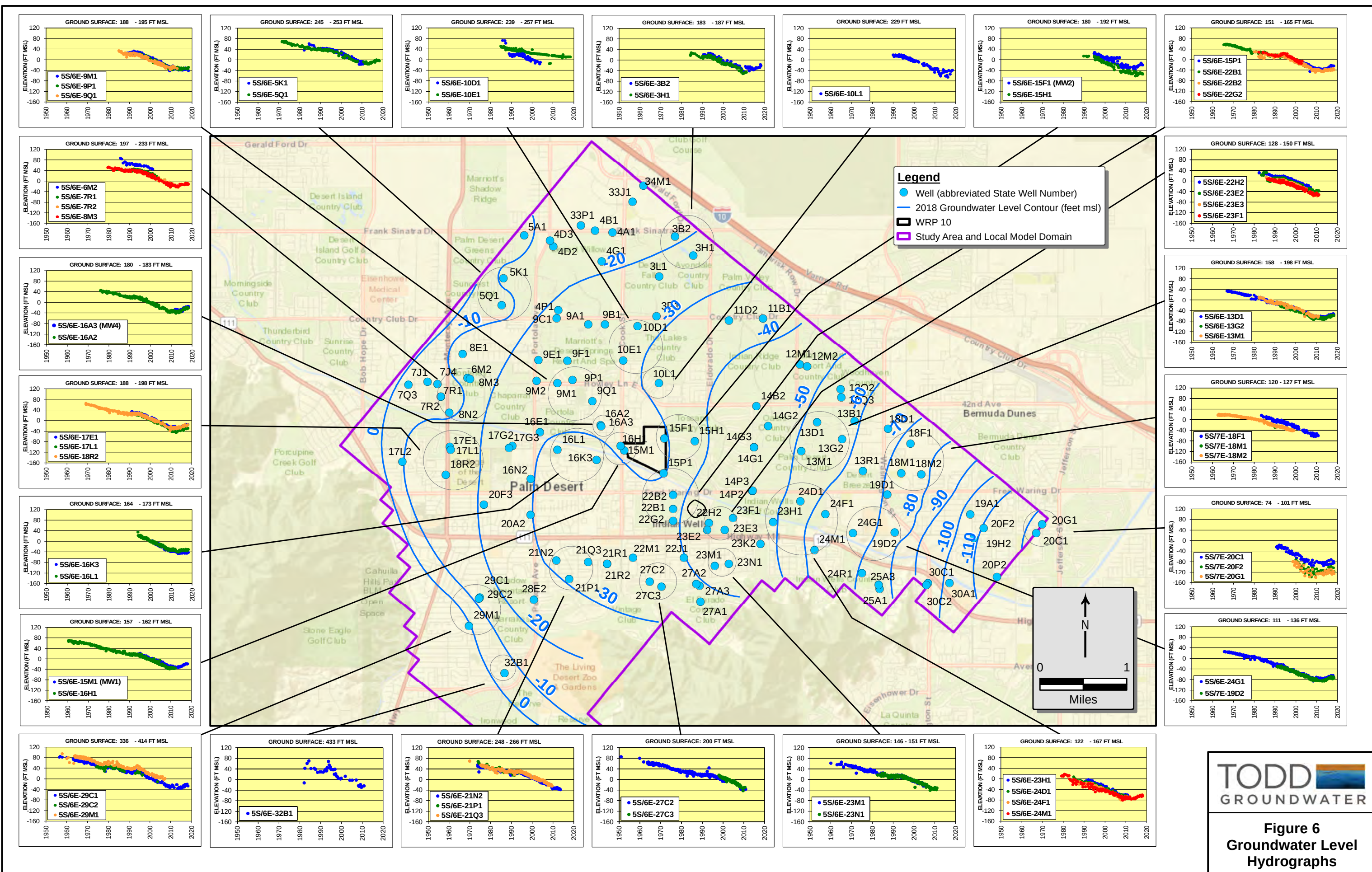
TODD
GROUNDWATER

Figure 4
Groundwater Levels
1985, 1995, 2005, 2015



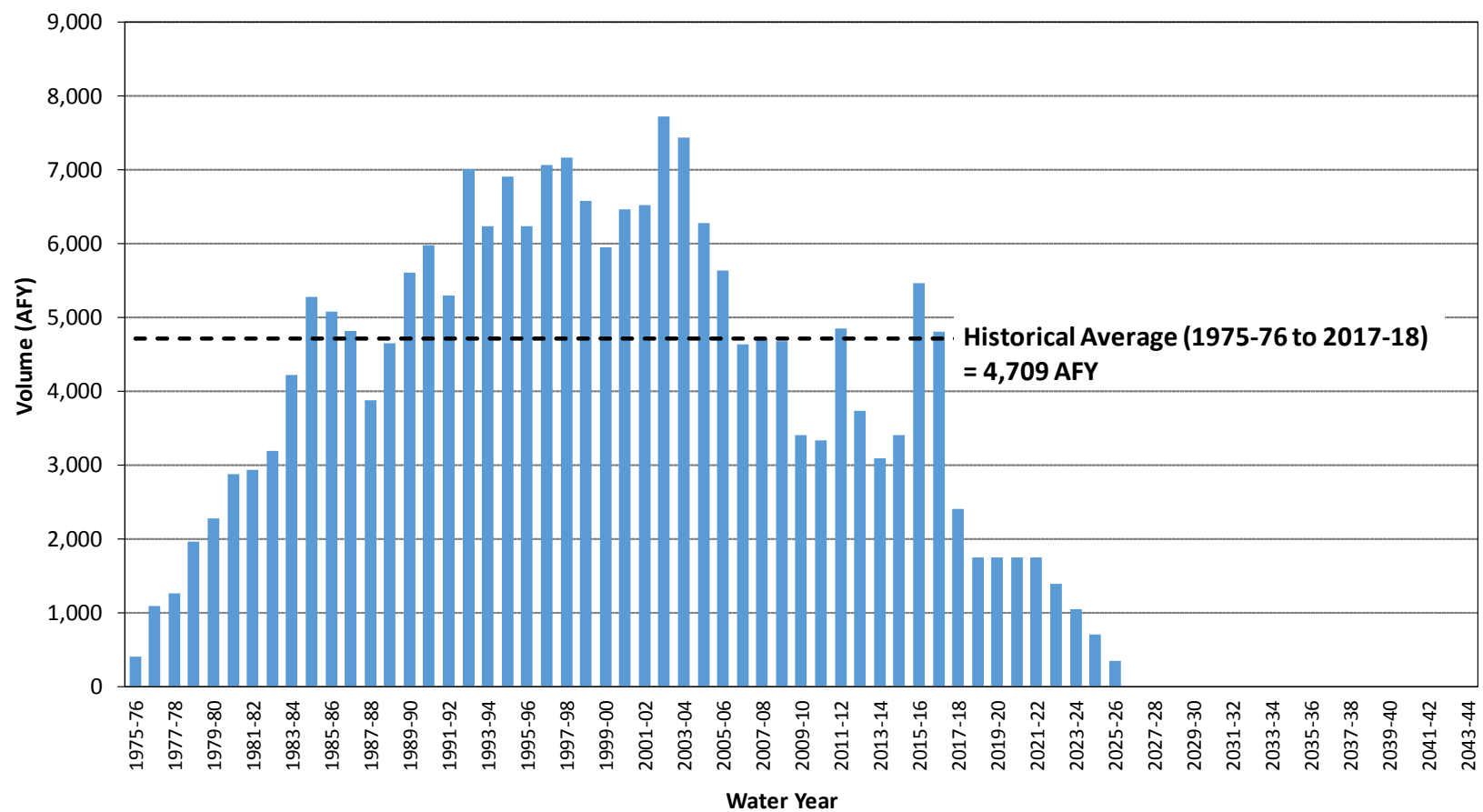
TODD
GROUNDWATER

Figure 5
Groundwater Level
Change Maps



TODD
GROUNDWATER

Figure 6
Groundwater Level
Hydrographs



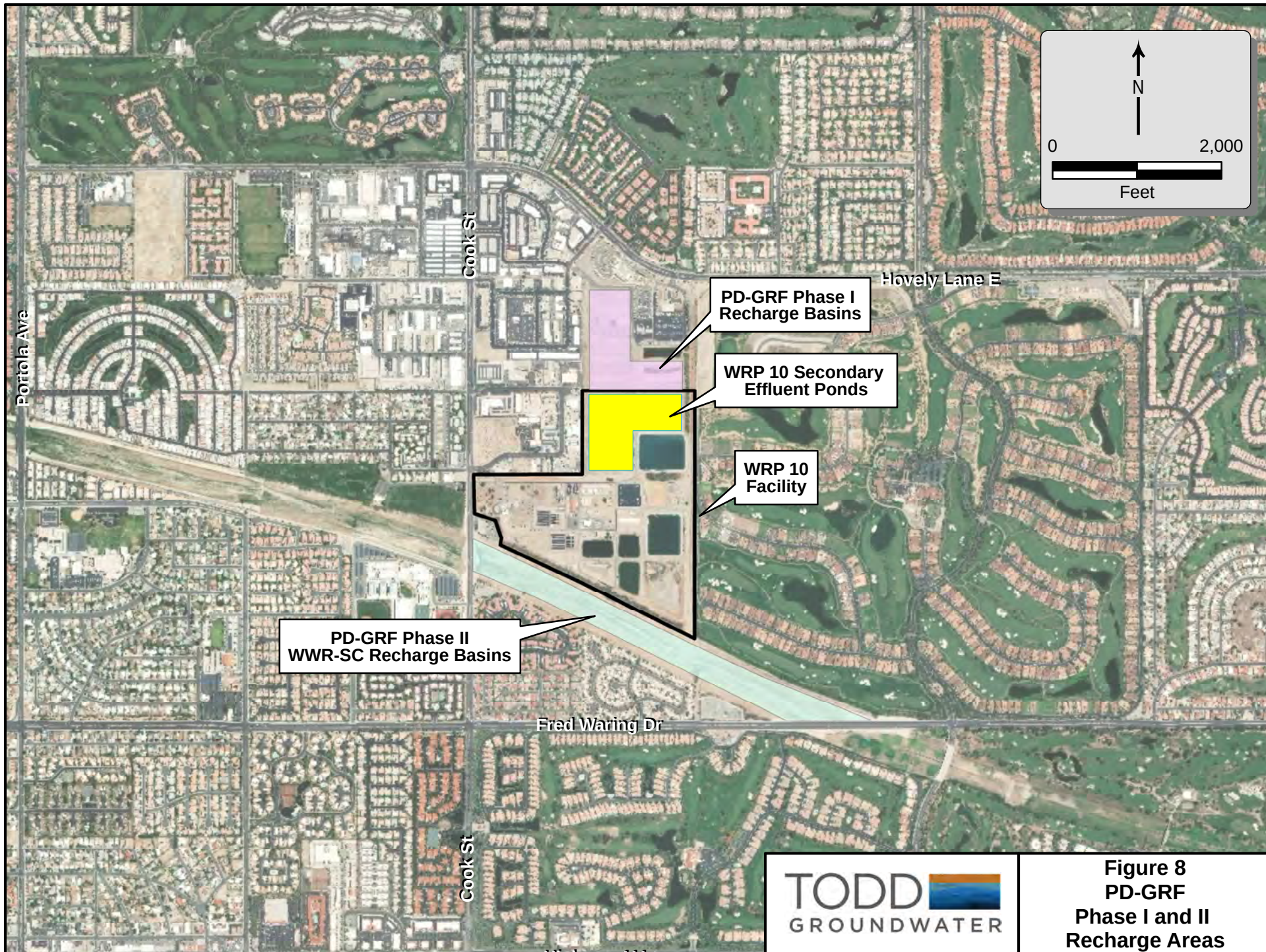
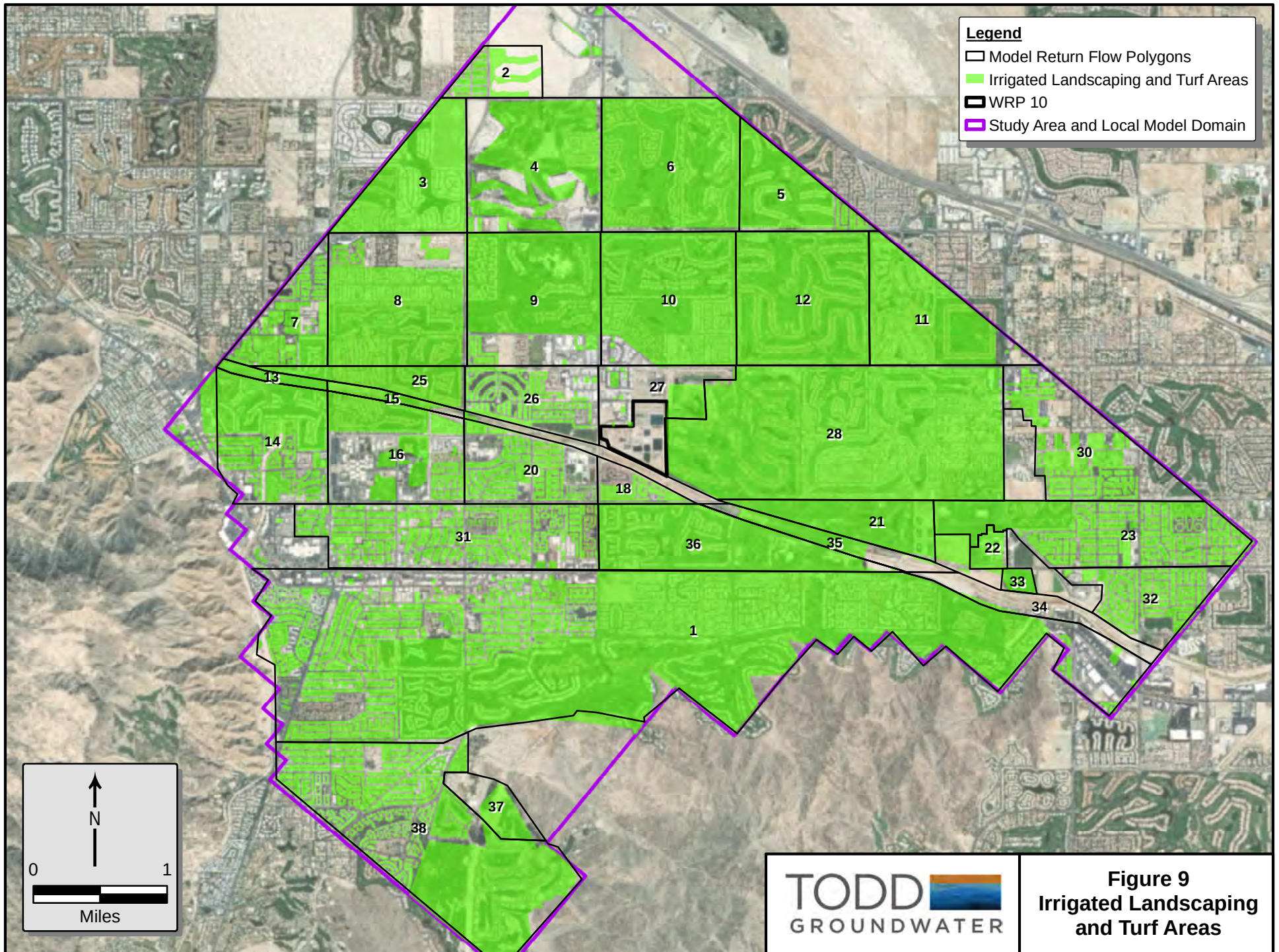
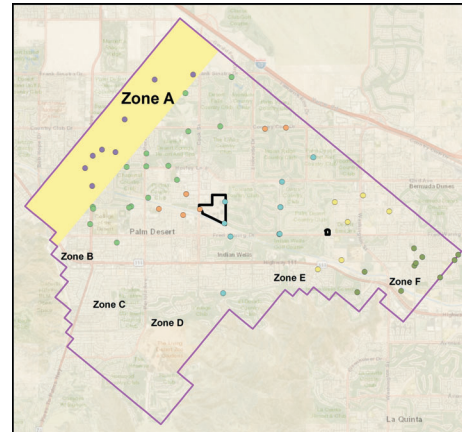
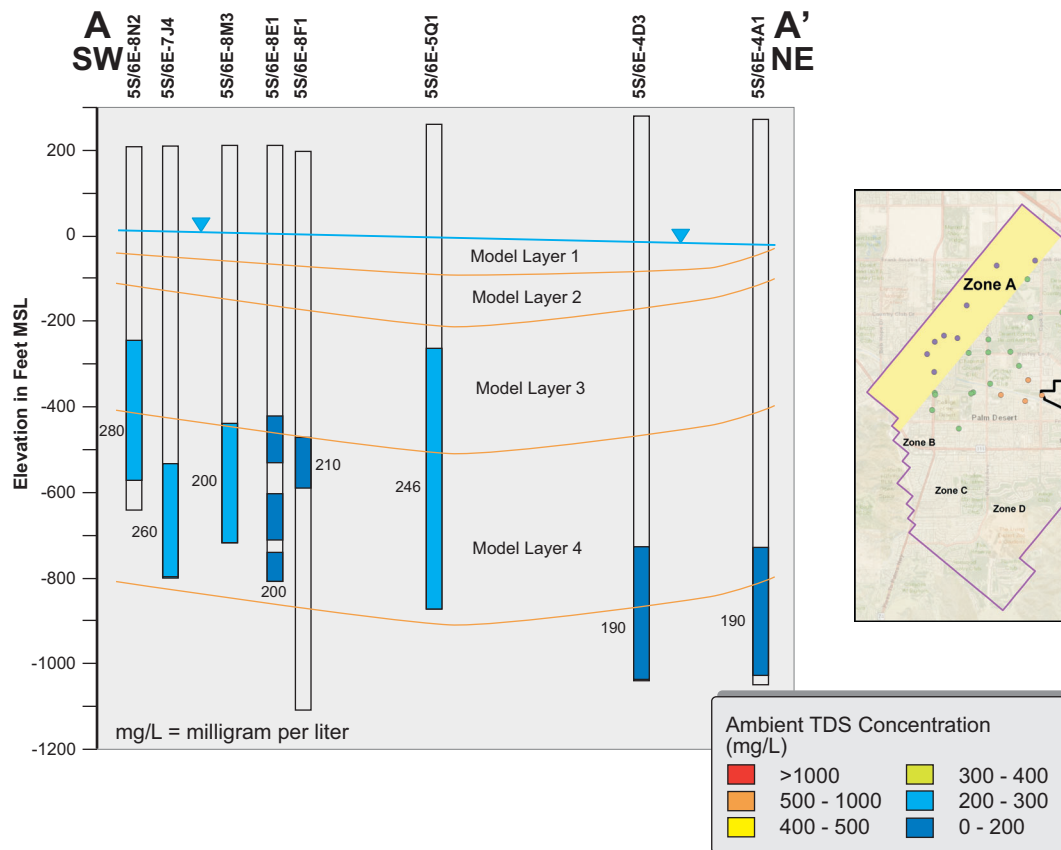


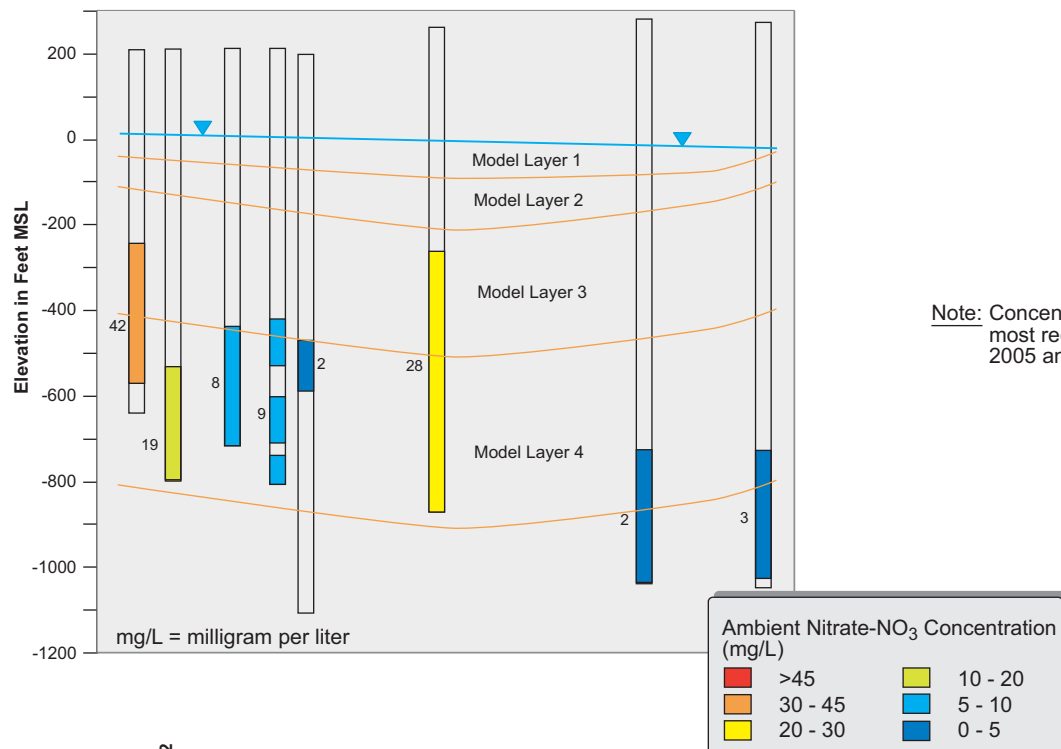
Figure 8
PD-GRF
Phase I and II
Recharge Areas



TDS



Nitrate-NO₃



Note: Concentrations represent most recent sample between 2005 and 2018.

Well name (State Well Number)

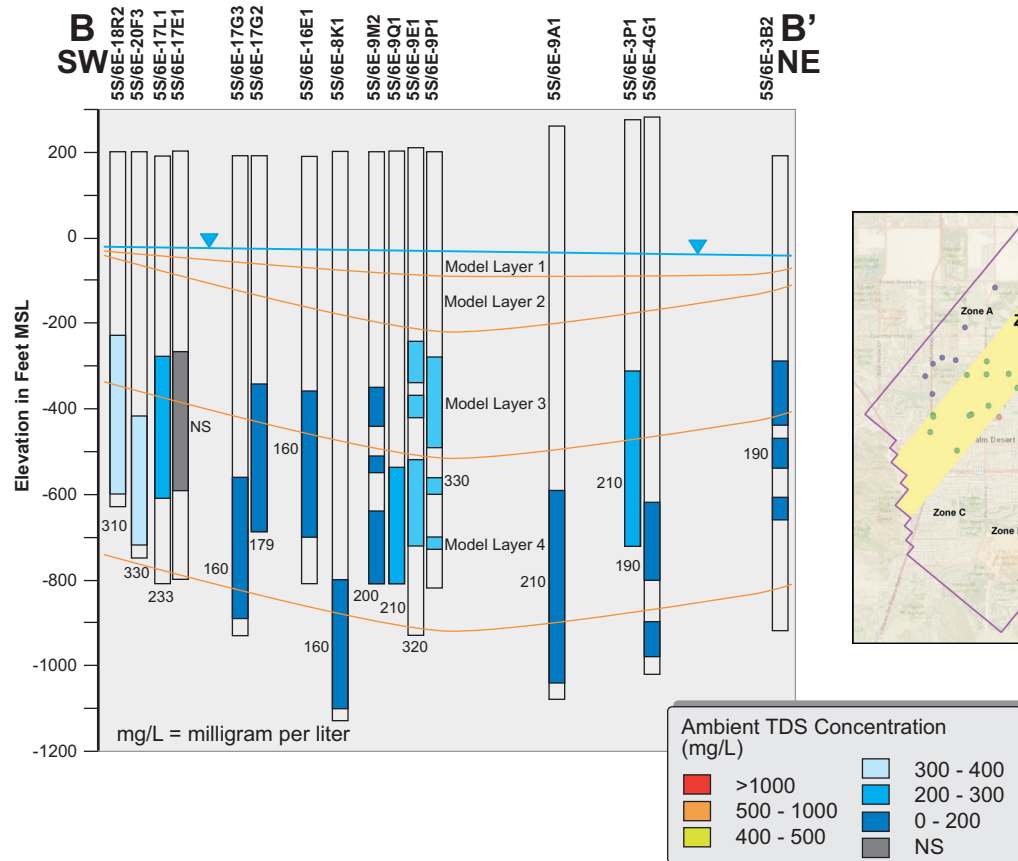
Well screen { }
Blank casing { }
Well screen { }

Detection value
NS = not sampled

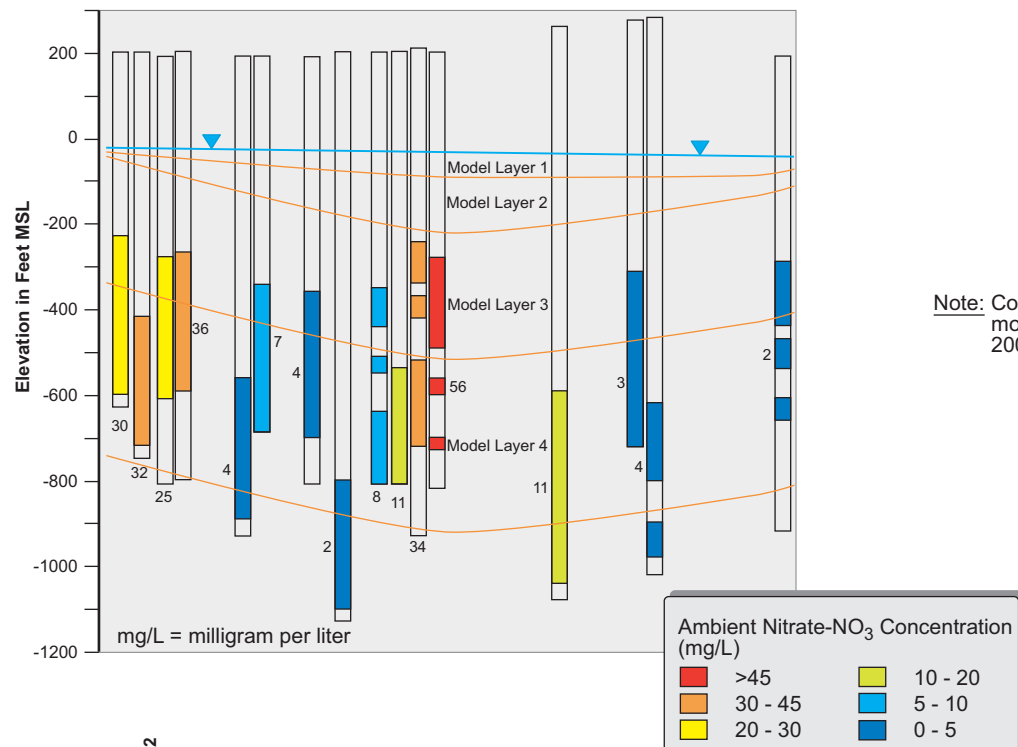
TODD
GROUNDWATER

Figure 11
Cross Section A - A'

TDS



Nitrate-NO₃



Note: Concentrations represent most recent sample between 2005 and 2018.

Well name (State Well Number)

Well screen { } Detection value

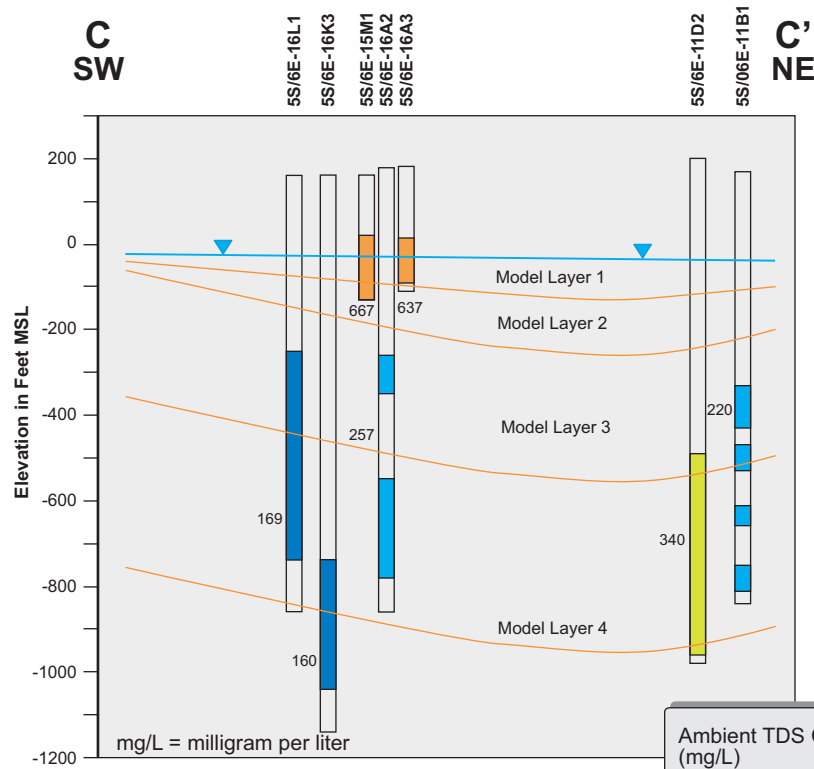
Blank casing { } 640

Well screen { } NS = not sampled

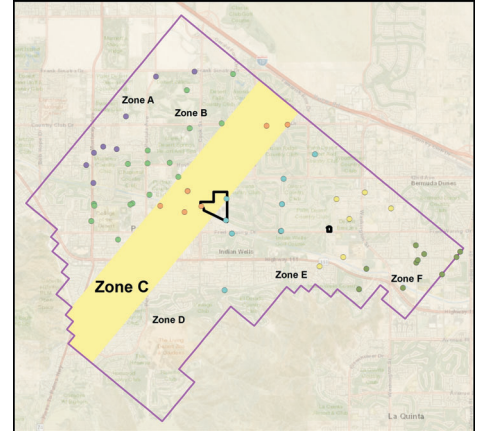
TODD 
GROUNDWATER

Figure 12
Cross Section B - B'

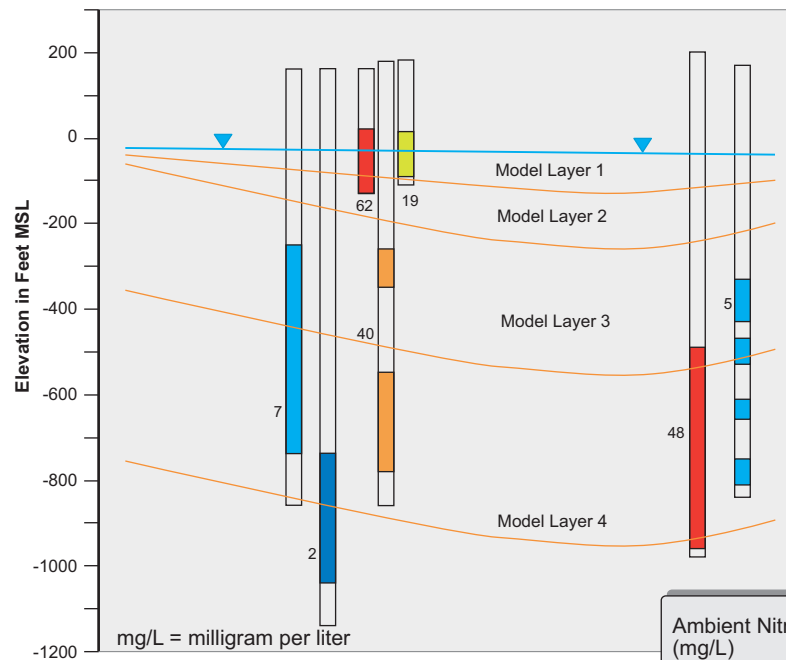
TDS



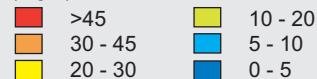
Ambient TDS Concentration (mg/L)



Nitrate-NO₃



Ambient Nitrate-NO₃ Concentration (mg/L)

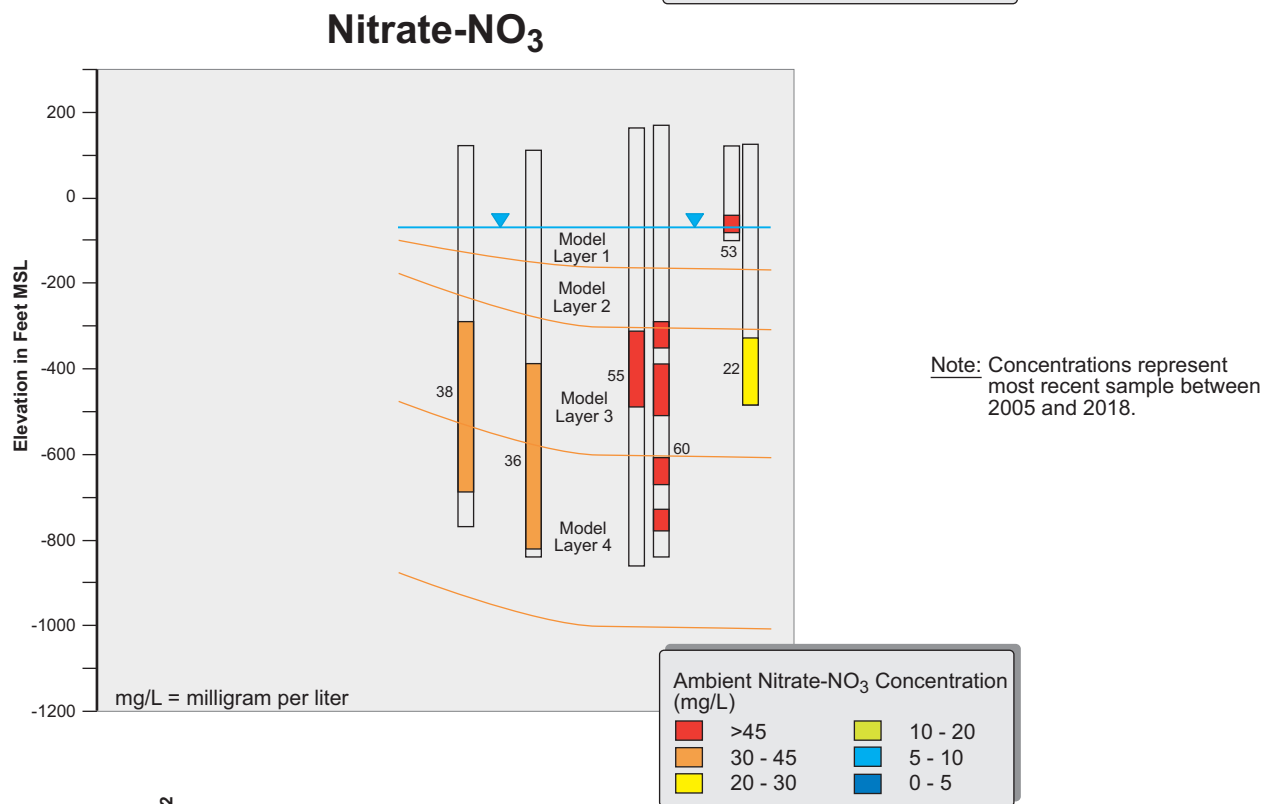
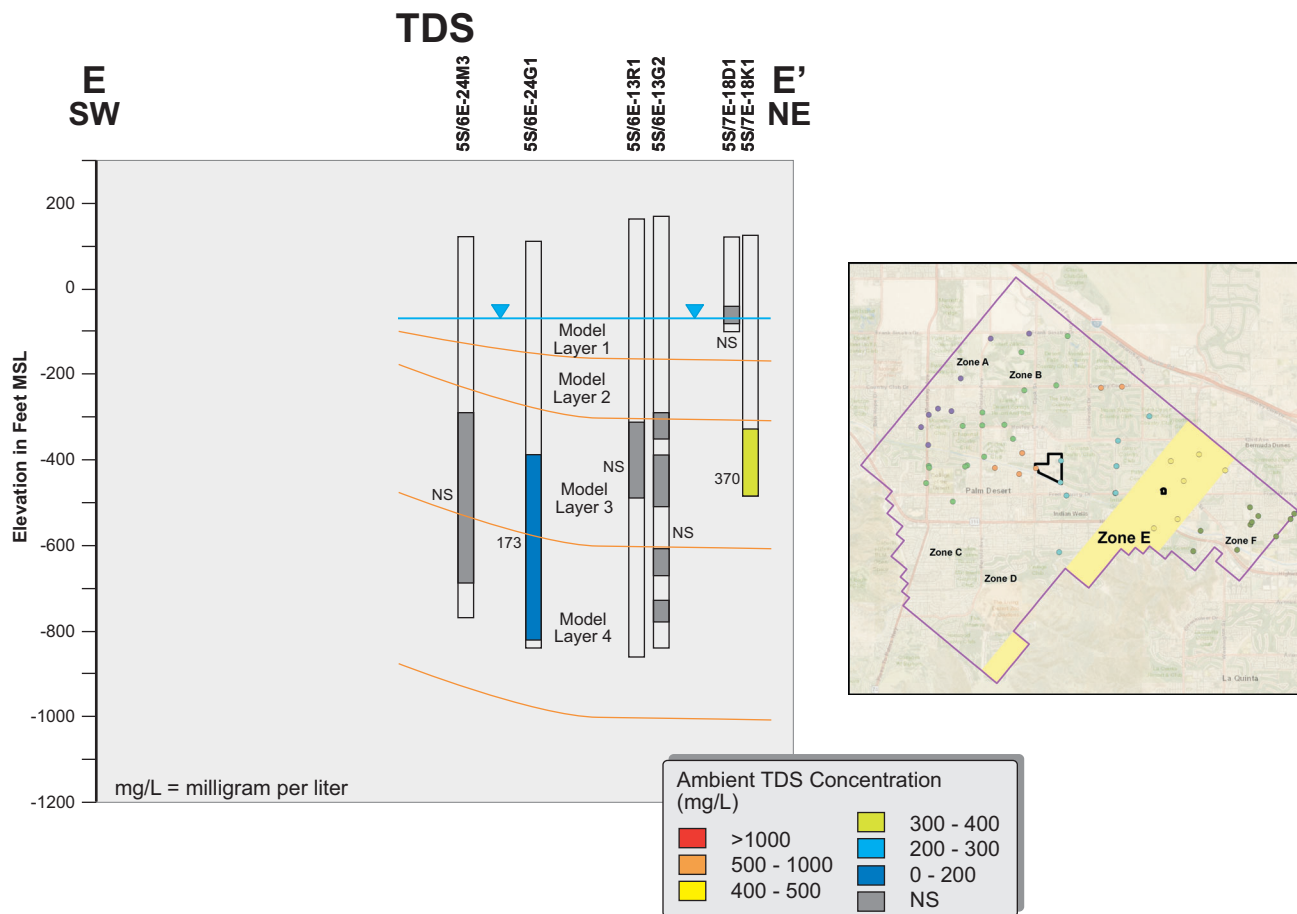


Note: Concentrations represent most recent sample between 2005 and 2018.

Well name (State Well Number)
Well screen { }
Blank casing { }
Well screen { }
Detection value
NS = not sampled

TODD
GROUNDWATER

Figure 13
Cross Section C - C'



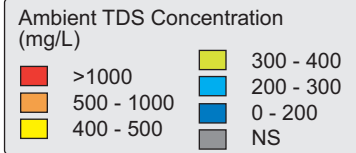
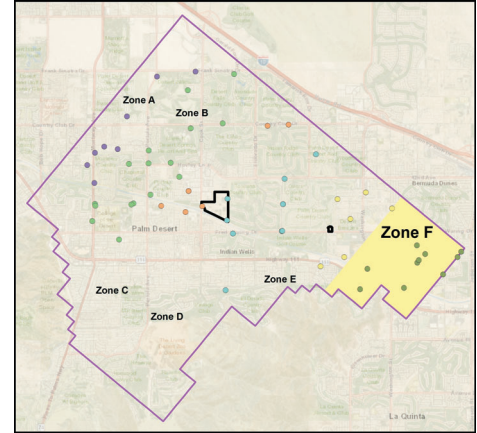
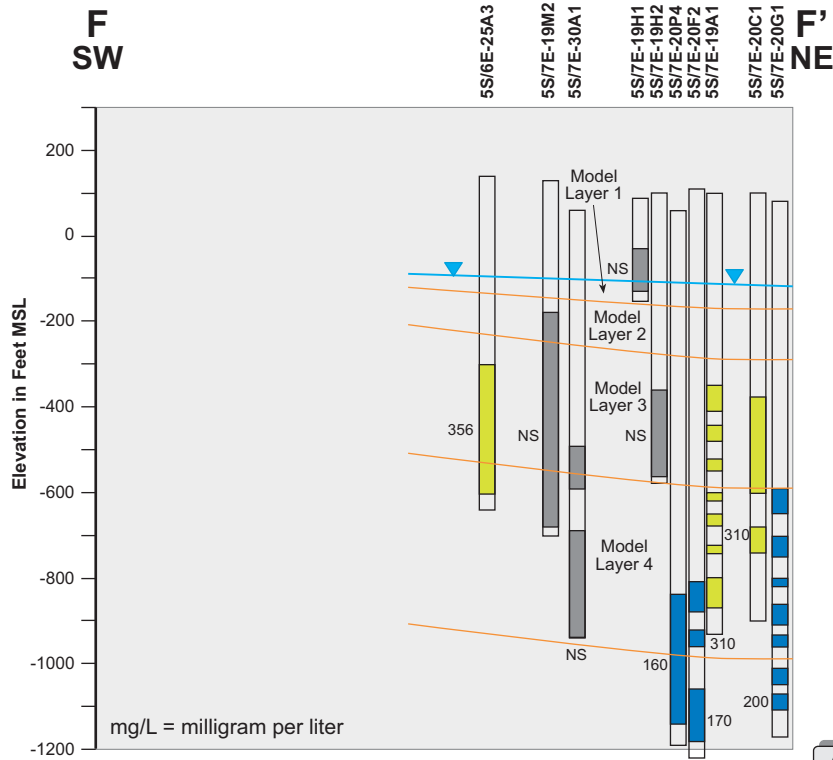
5S/6E-24M3 — Well name
(State Well Number)

Well screen { } Detection value
Blank casing { } 640
Well screen { } NS = not sampled

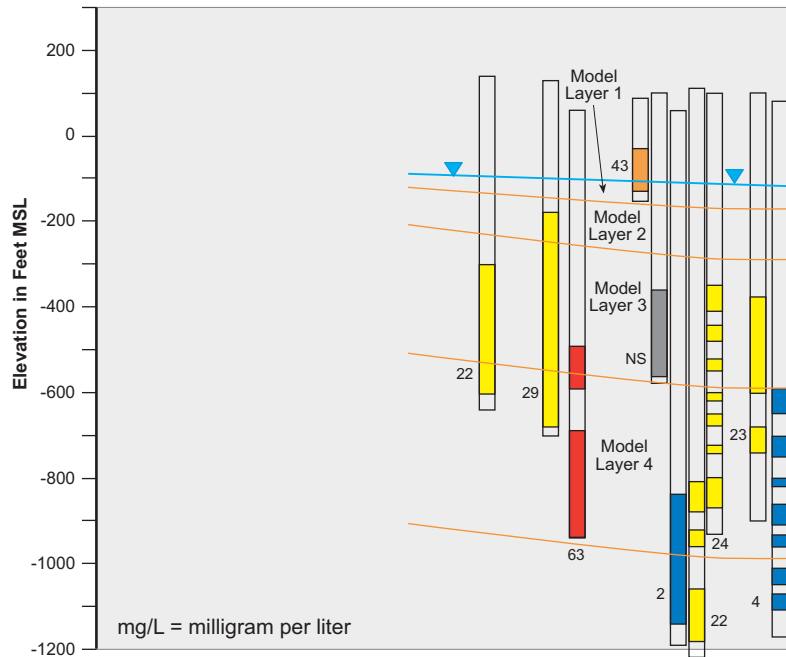
TODD
GROUNDWATER

Figure 15
Cross Section E - E'

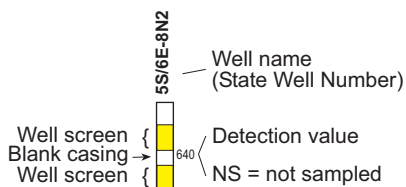
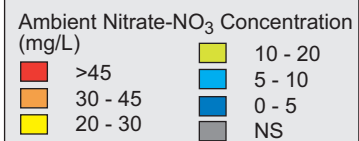
TDS



Nitrate-NO₃

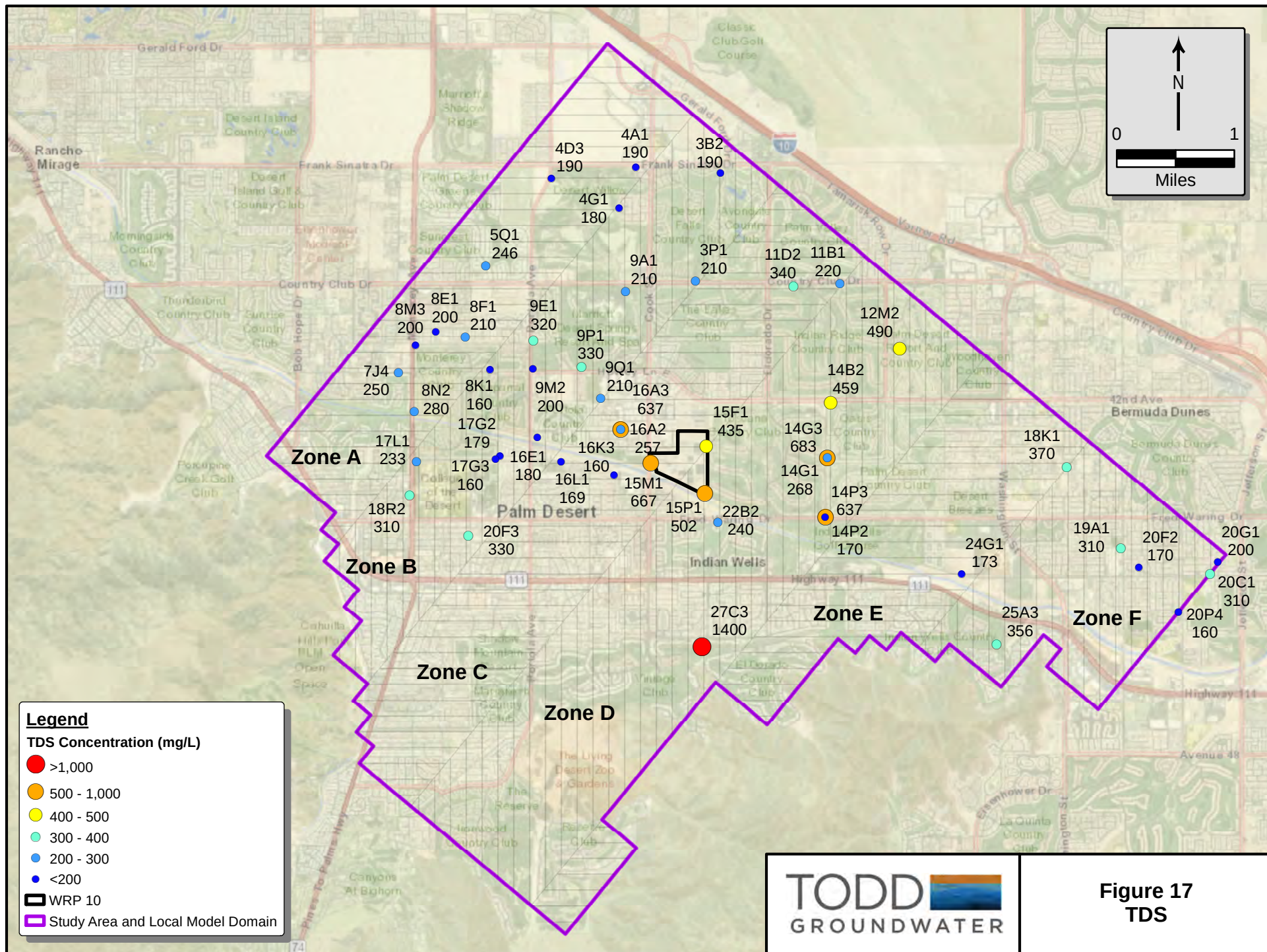


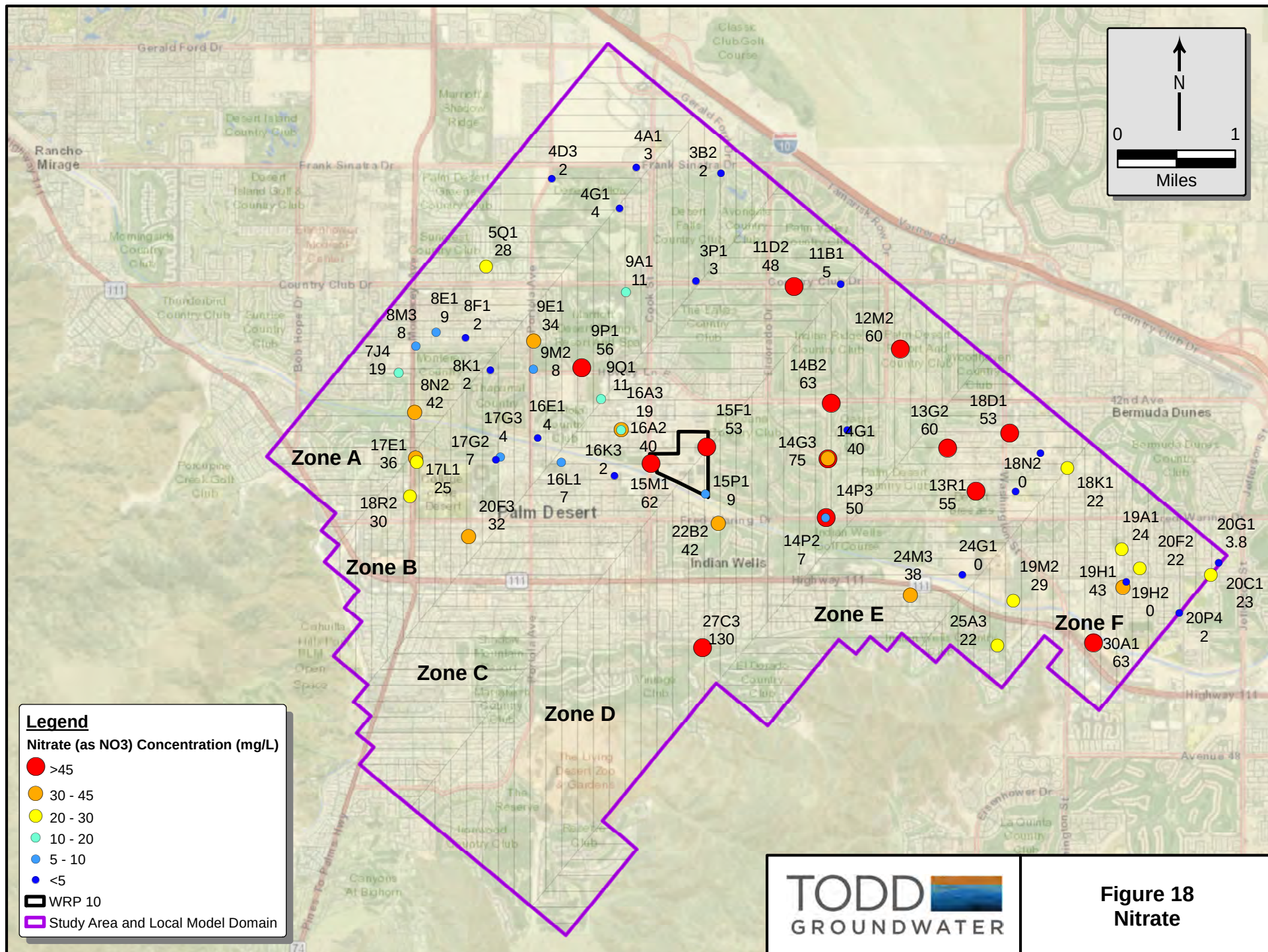
Note: Concentrations represent most recent sample between 2005 and 2018.

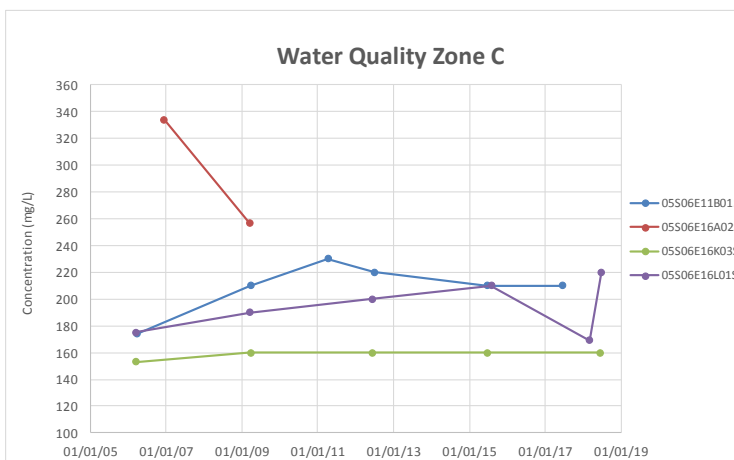
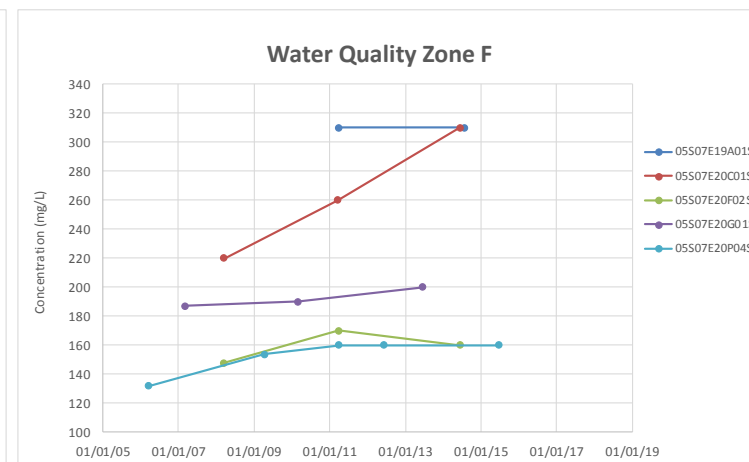
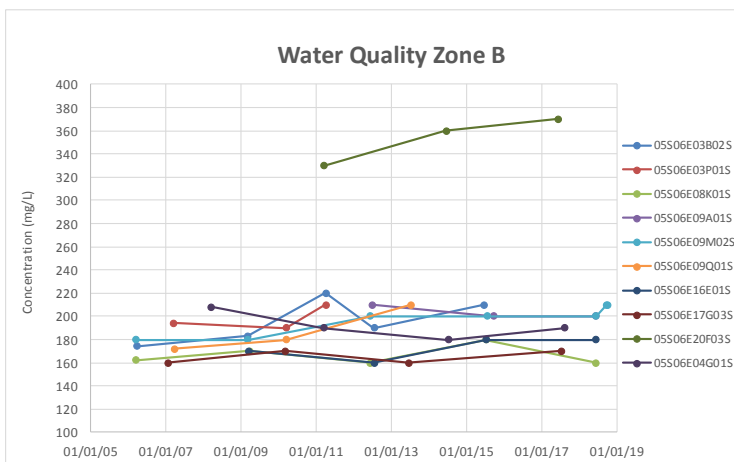
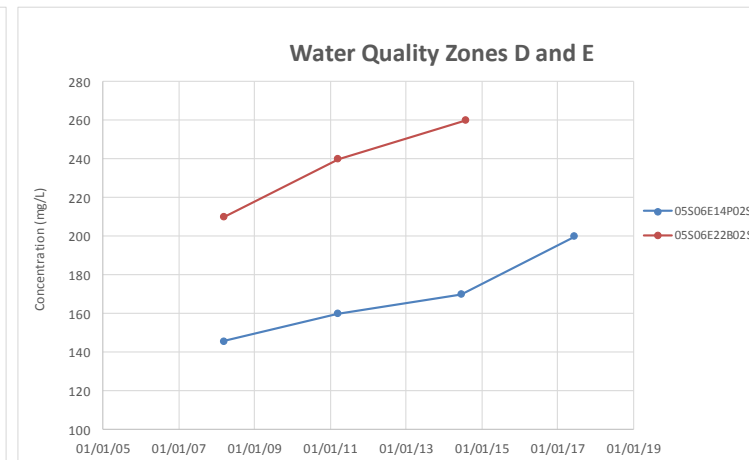
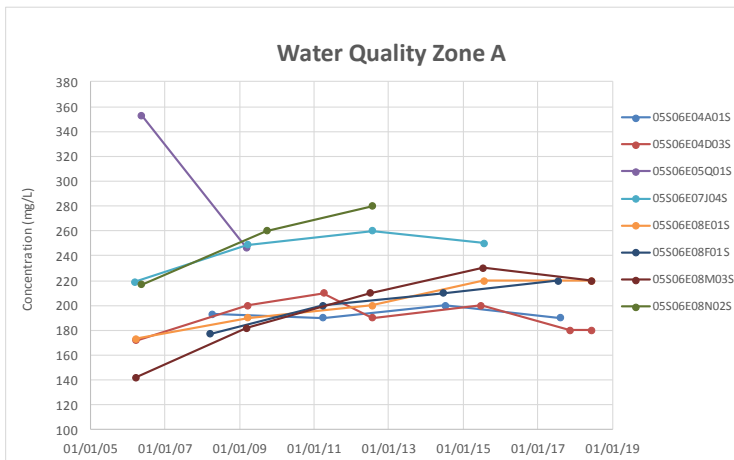


TODD
GROUNDWATER

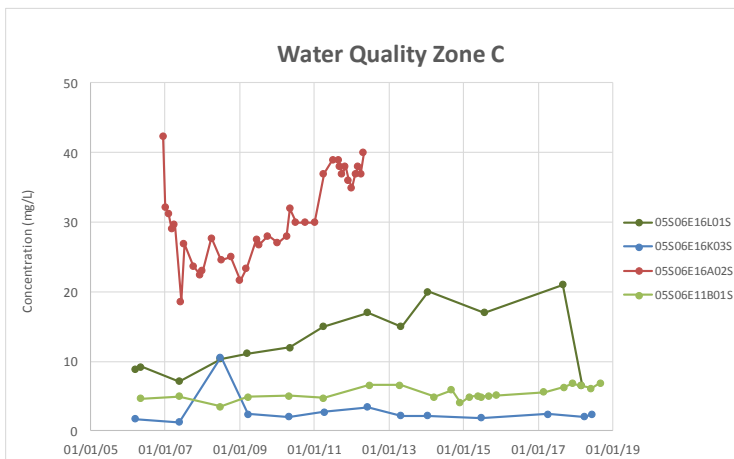
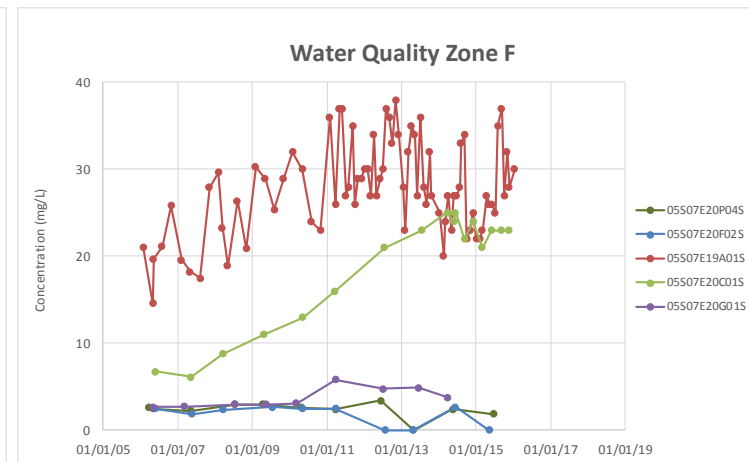
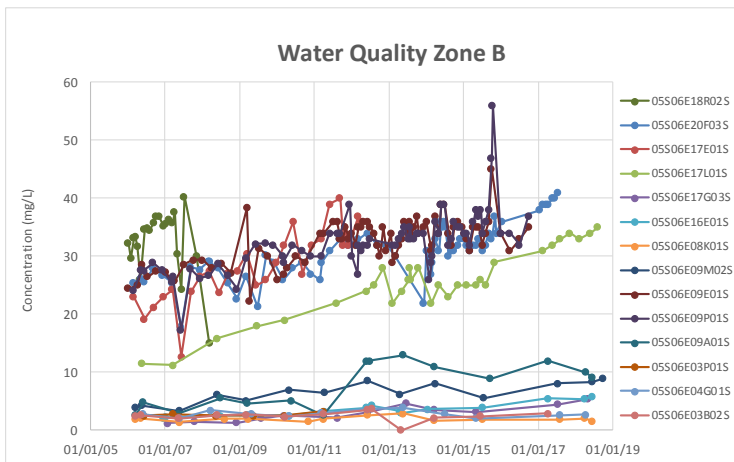
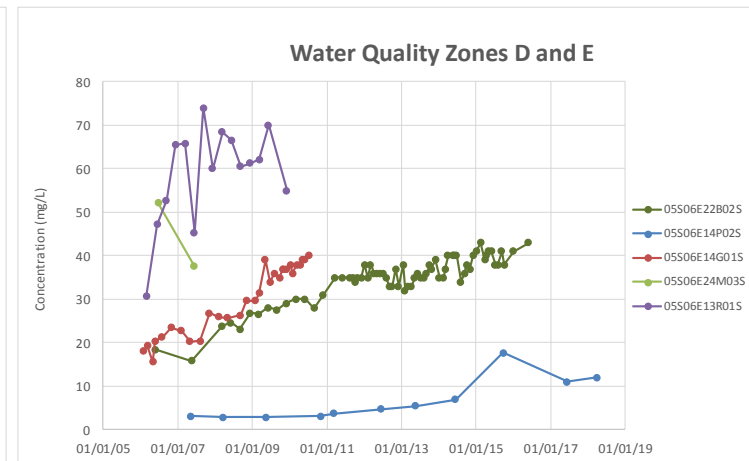
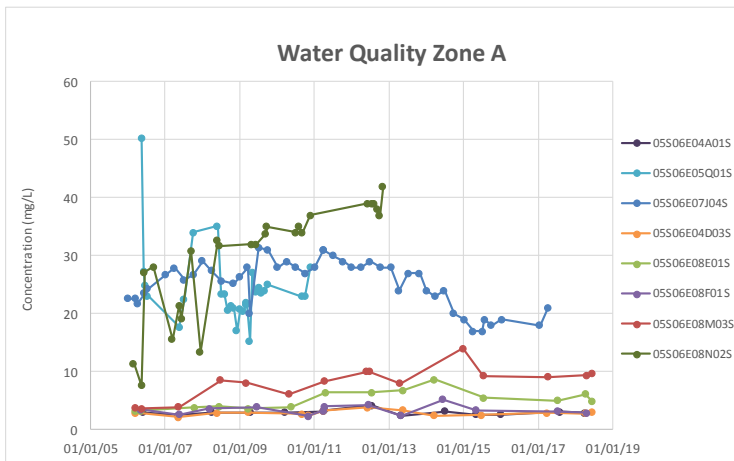
Figure 16
Cross Section F - F'







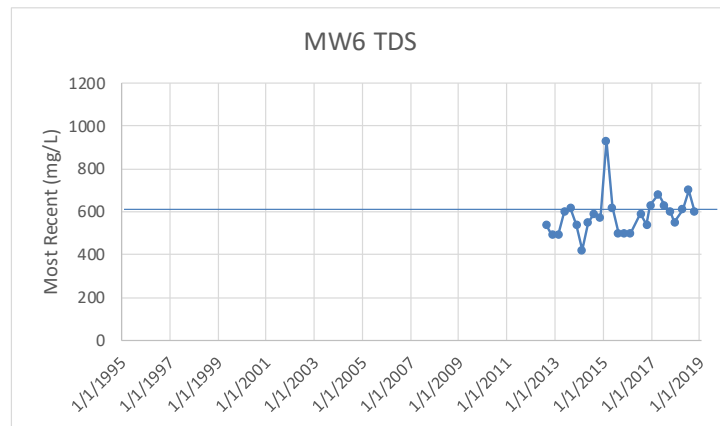
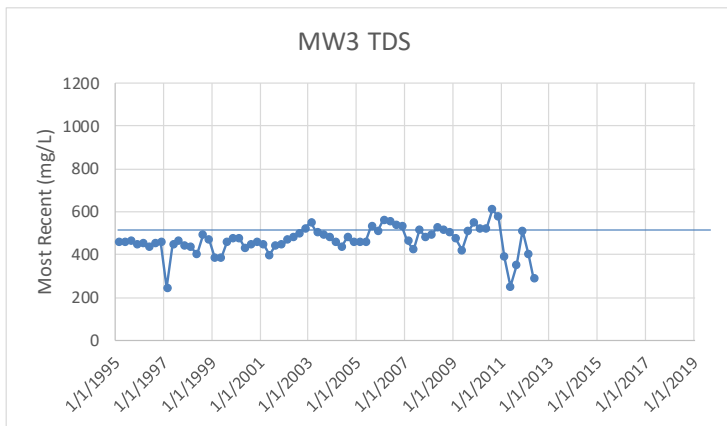
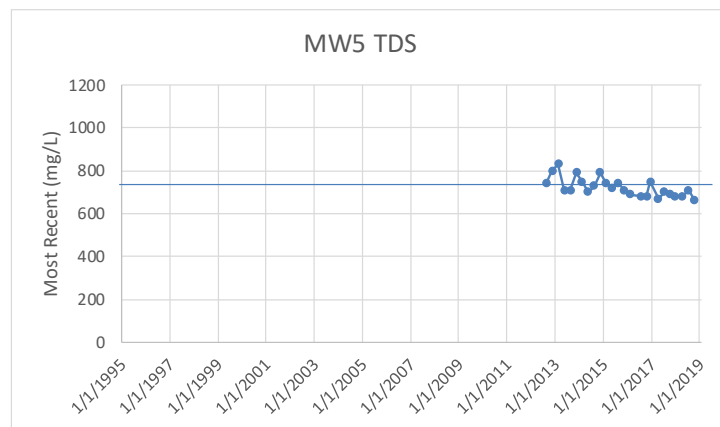
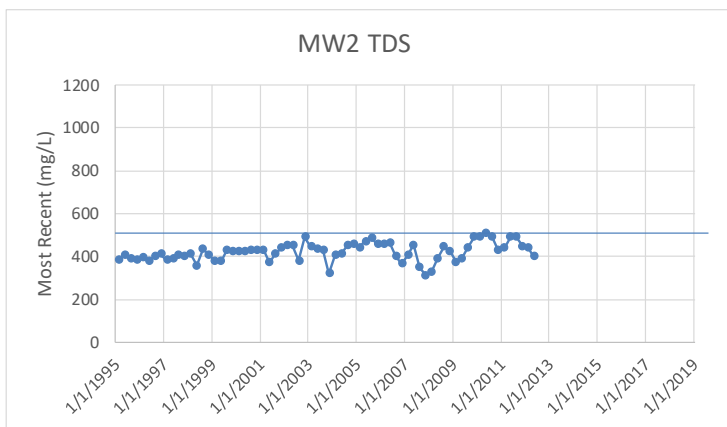
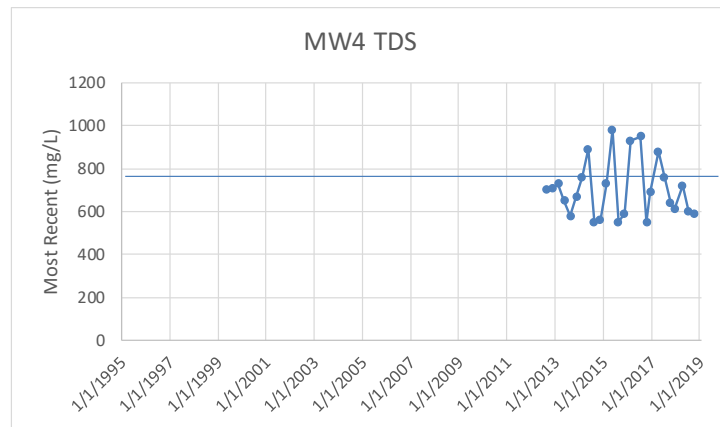
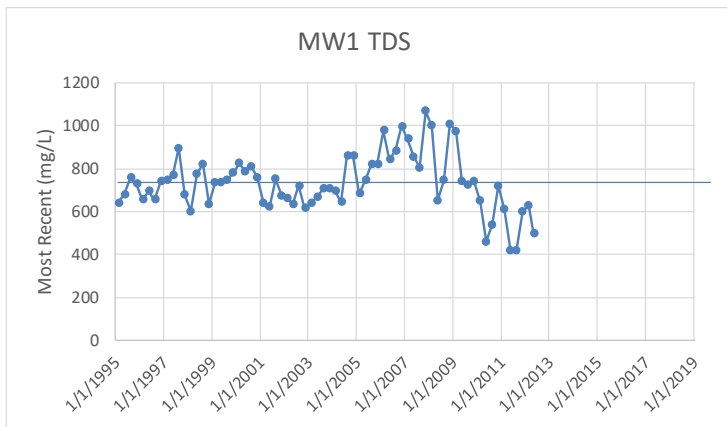
Note: charts do not include WRP 10 monitoring wells



Note: charts do not include WRP 10 monitoring wells



Figure 20
Time-Concentration
Plots - Nitrate



blue line = representative
concentration shown on
cross sections C-C and D-D

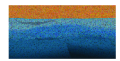
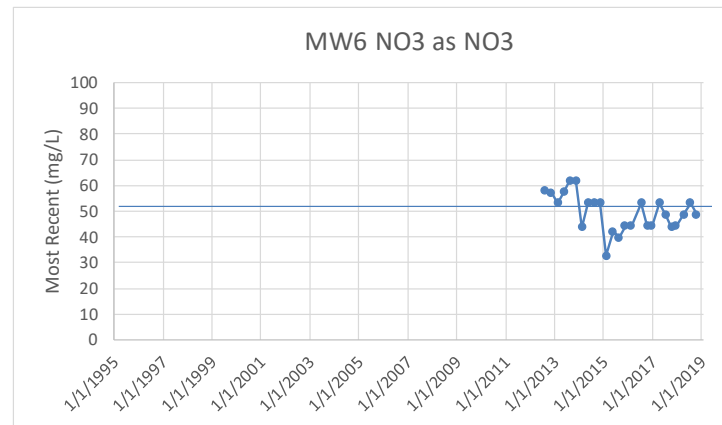
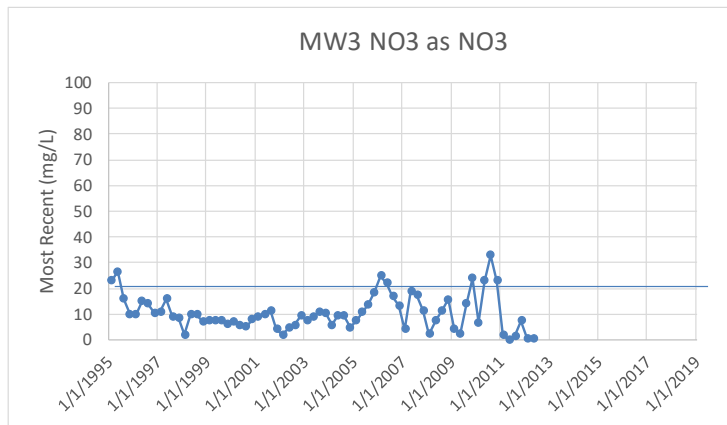
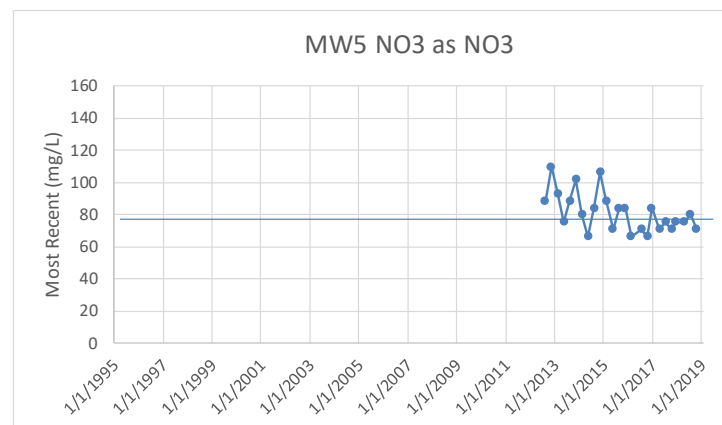
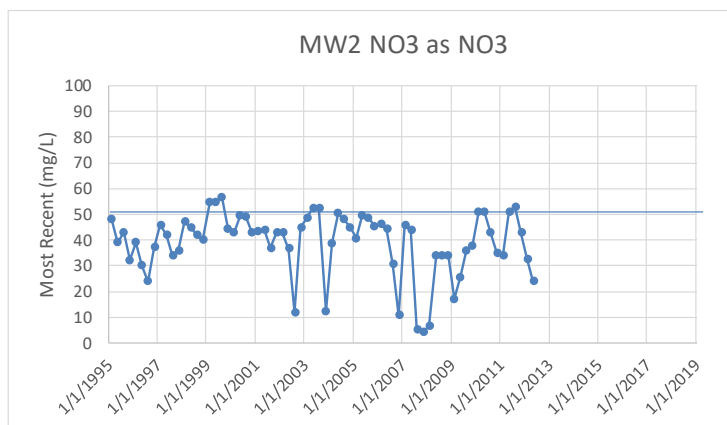
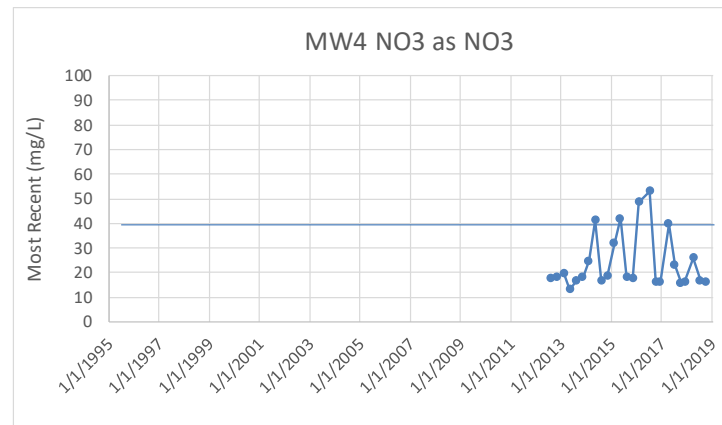
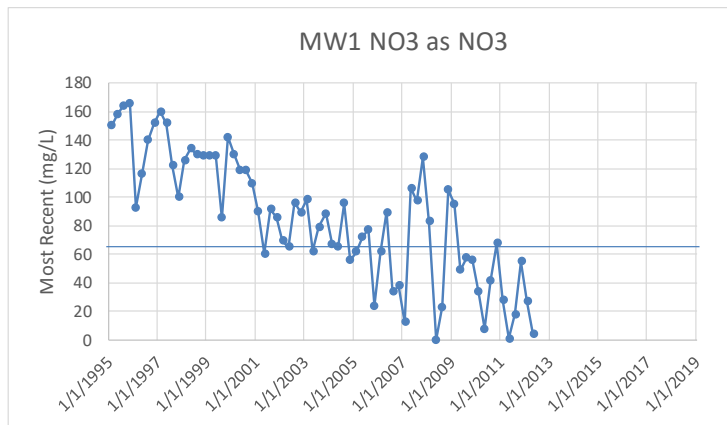
TODD 
GROUNDWATER

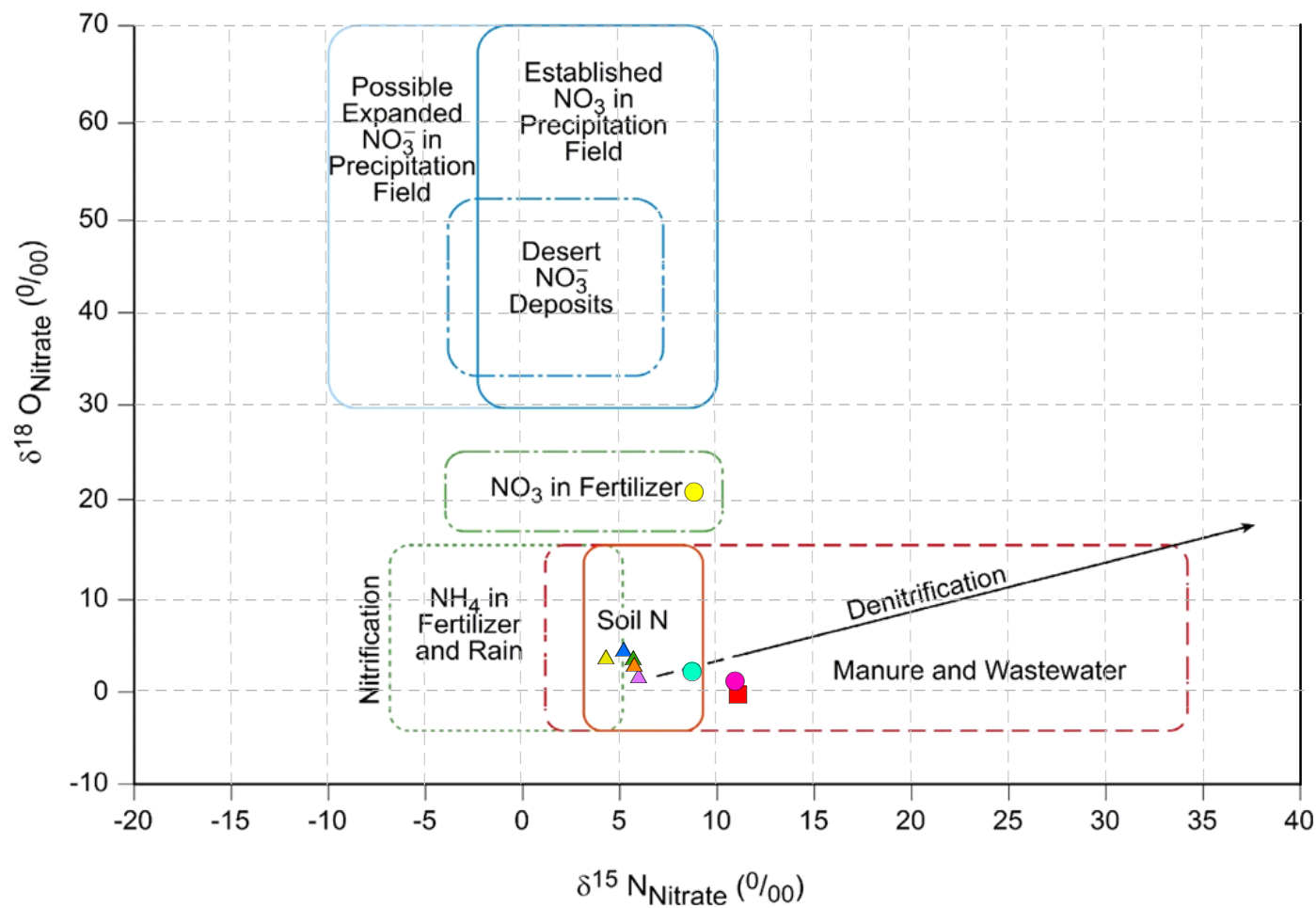
Figure 21
Time-Concentration
Plots - WRP 10 MWs
TDS



blue line = representative
concentration shown on
cross sections C-C and D-D

TODD
GROUNDWATER

Figure 22
Time-Concentration
Plots - WRP 10 MWs
Nitrate



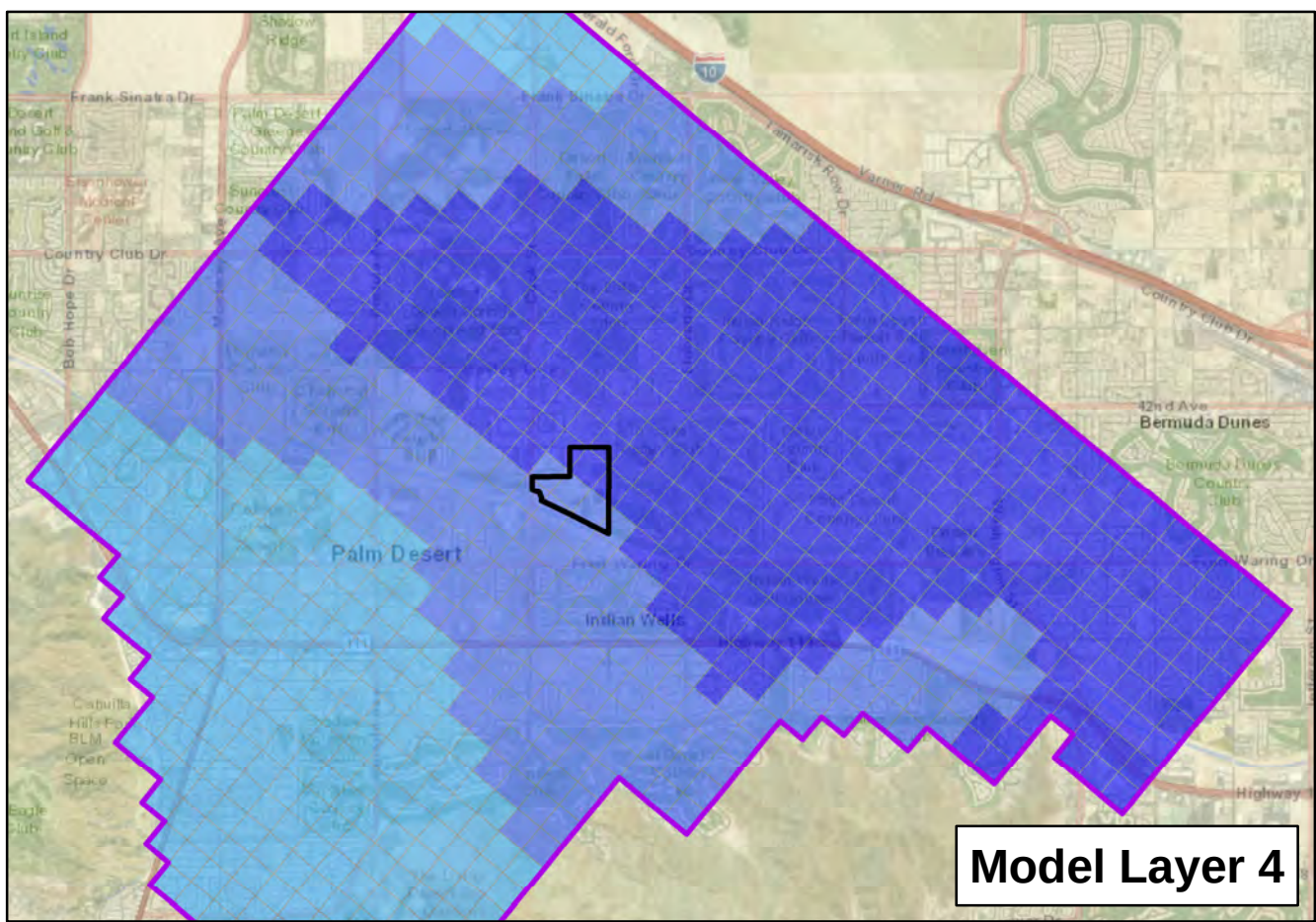
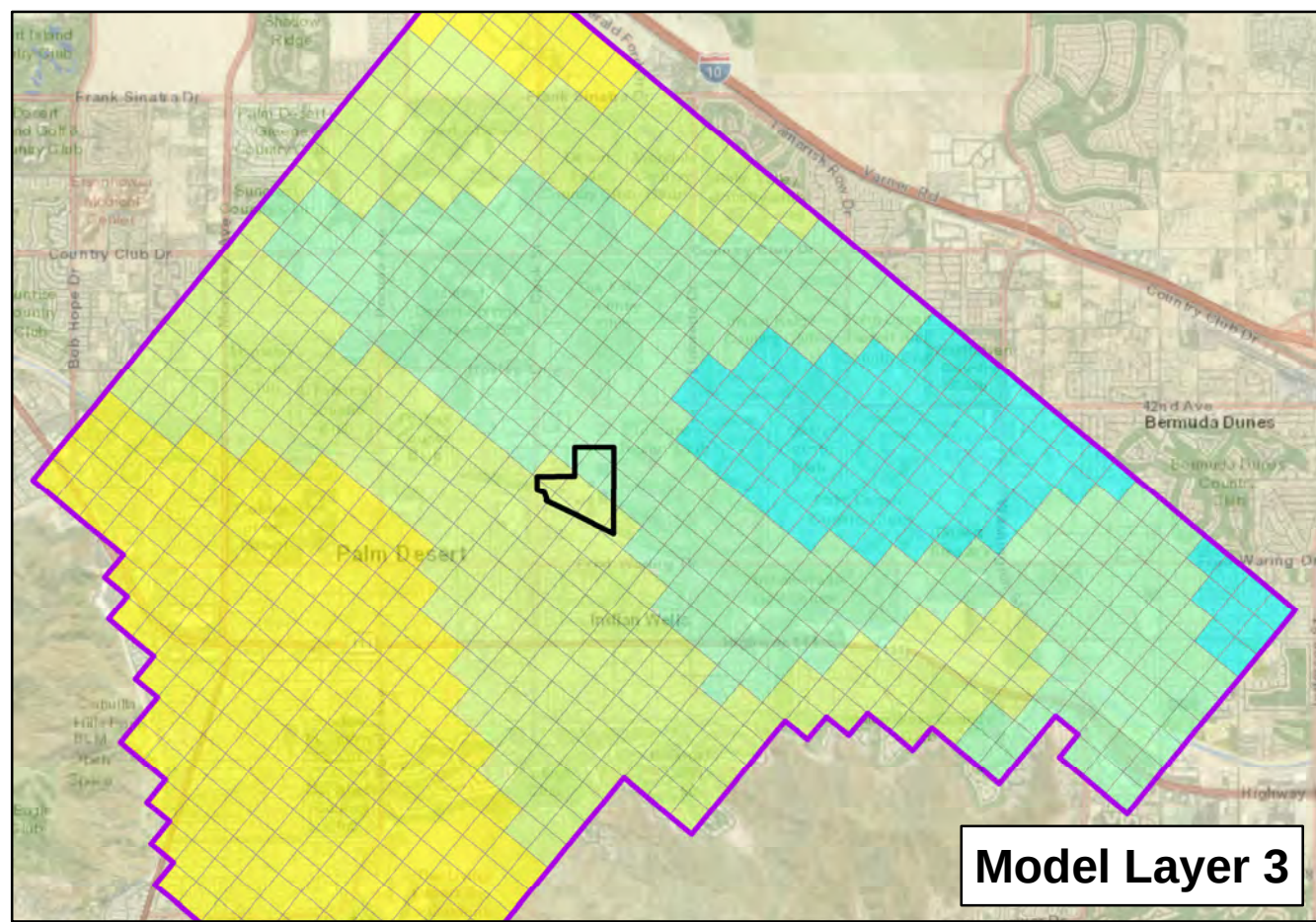
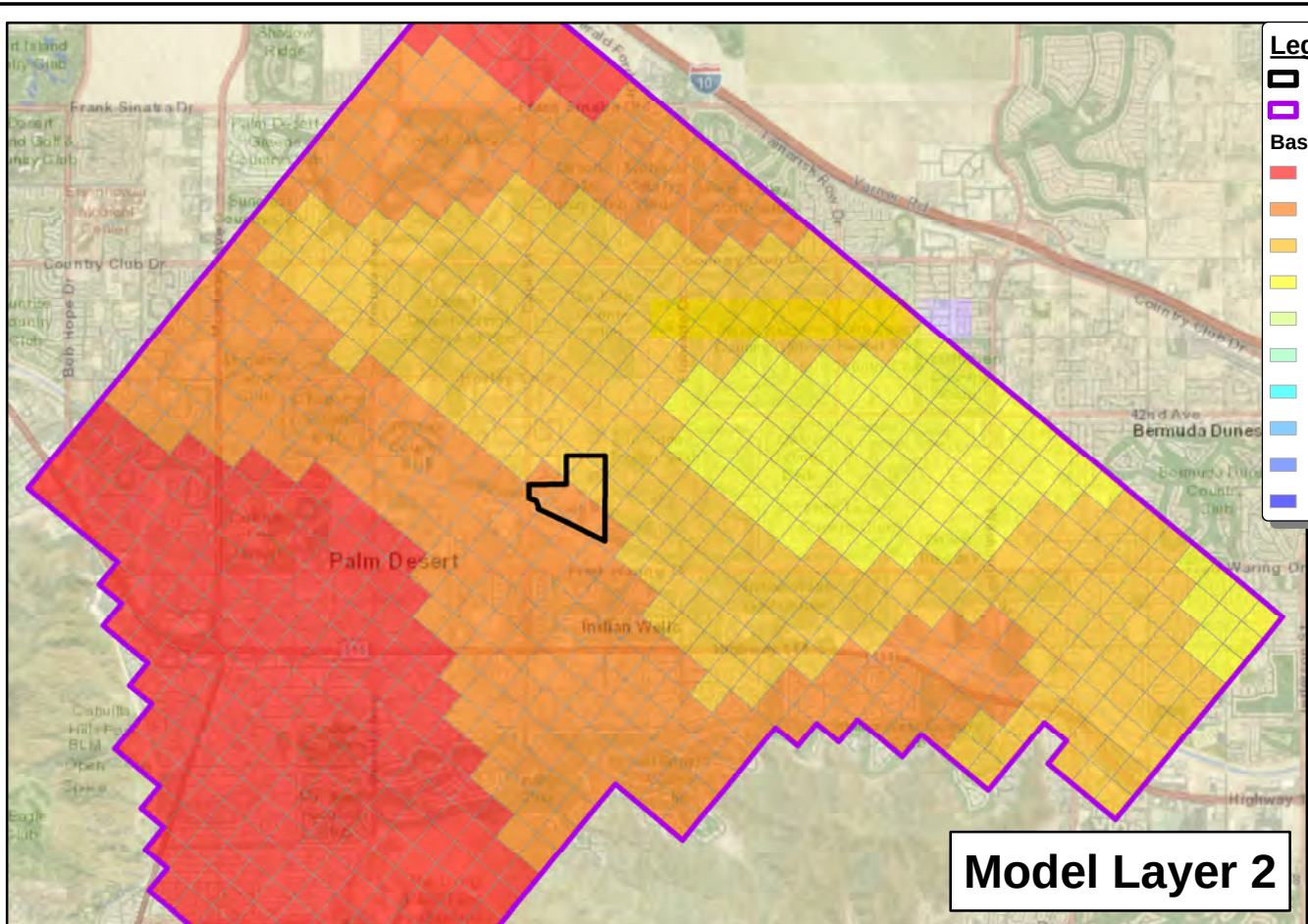
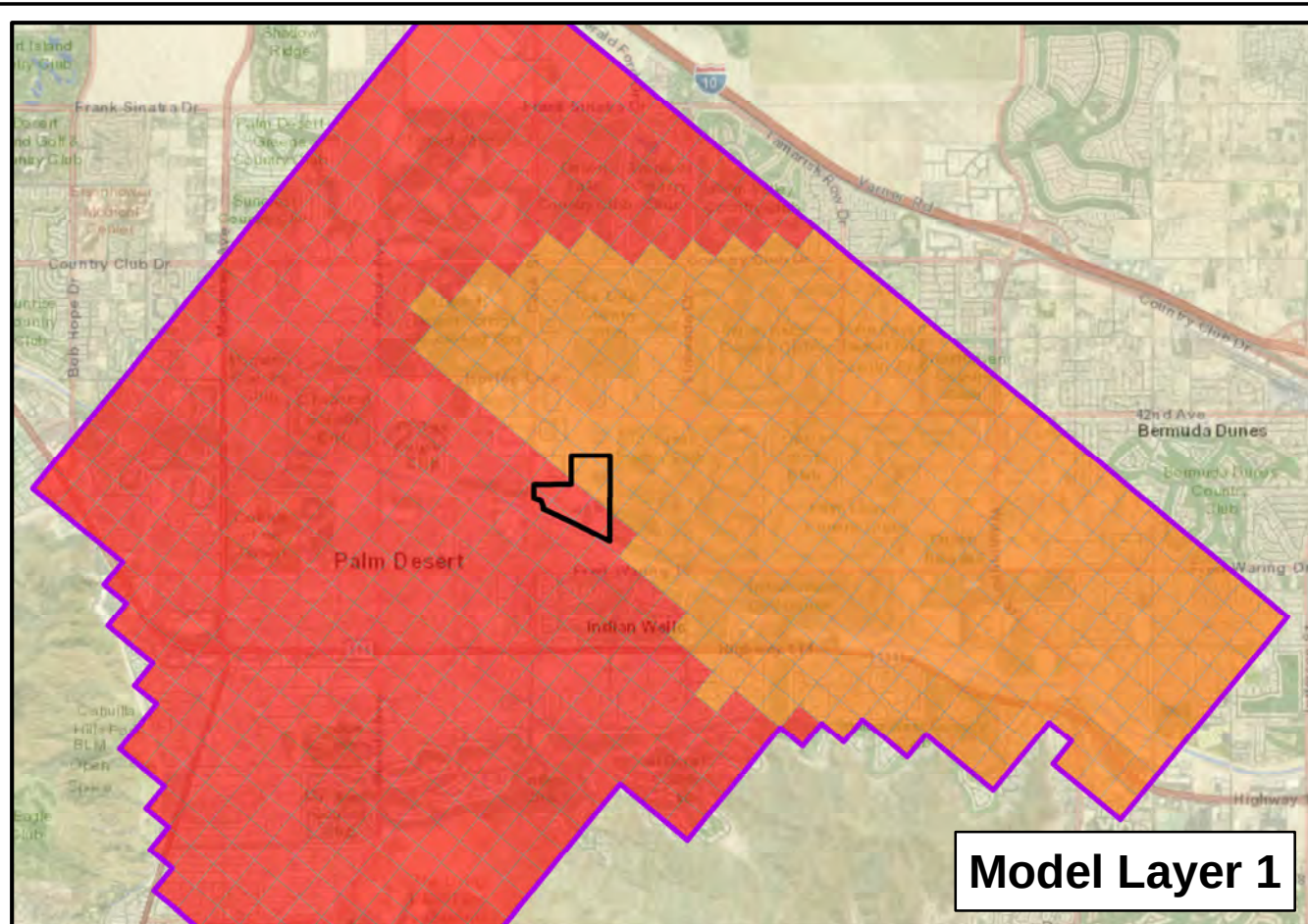
Monitoring Point	State Well Number	$\delta^{15}\text{N}$ of Nitrate (‰)	$\delta^{18}\text{O}$ of Nitrate (‰)
WRP 10 Effluent		11.3	-0.7
WRP 10 MW 4 (at well site 5620-2, active)	05S06E16A03S	8.1	21.3
WRP 10 MW 5 (at well site 5627-1, active)	05S06E14G03S	11.6	1.6
WRP 10 MW 6 (at well site 5603-2, active)	05S06E14P03S	8.8	2.2
Domestic Supply Well No. 5671-1	05S06E09M02S	4.2	4.1
The Lakes Country Club	05S06E10L01S	5.2	4.9
Sunrise Desert Partners (Currently: Toscana CC)	05S06E15H01S	5.7	4.0
Adelle Warner (Desert Horizons CC)	05S06E22B01S	6.1	1.6
Vintage Country Club	05S06E27C03S	5.8	3.4

Effluent and wells sampled In October 2018

Kendall, C. (1998) Tracing nitrogen sources and cycling in catchments. In: Isotope Tracers in Catchment Hydrology (Eds C. Kendall & J.J. McDonnell), pp. 519–576. Elsevier, Amsterdam.

TODD
GROUNDWATER

Figure 23
O-18 / N-15 in Nitrate
Stable Isotope Results

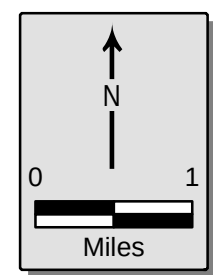


Legend

- WRP 10
- Study Area and Local Model Domain

Base of Model Layer (feet msl)

- 100 - 0
- 200 - -100
- 300 to -200
- 400 to -300
- 500 to -400
- 600 to -500
- 700 to -600
- 800 to -700
- 900 to -800
- 1020 to -900



TODD
GROUNDWATER

Figure 24
Elevations of Base
of Model Layers

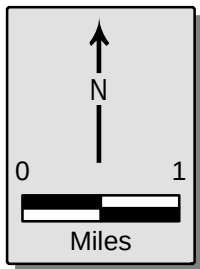
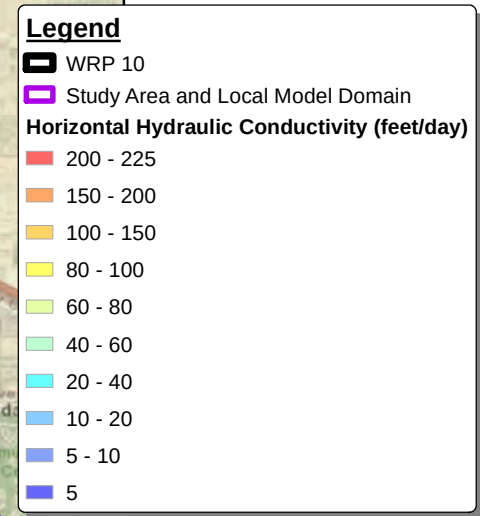
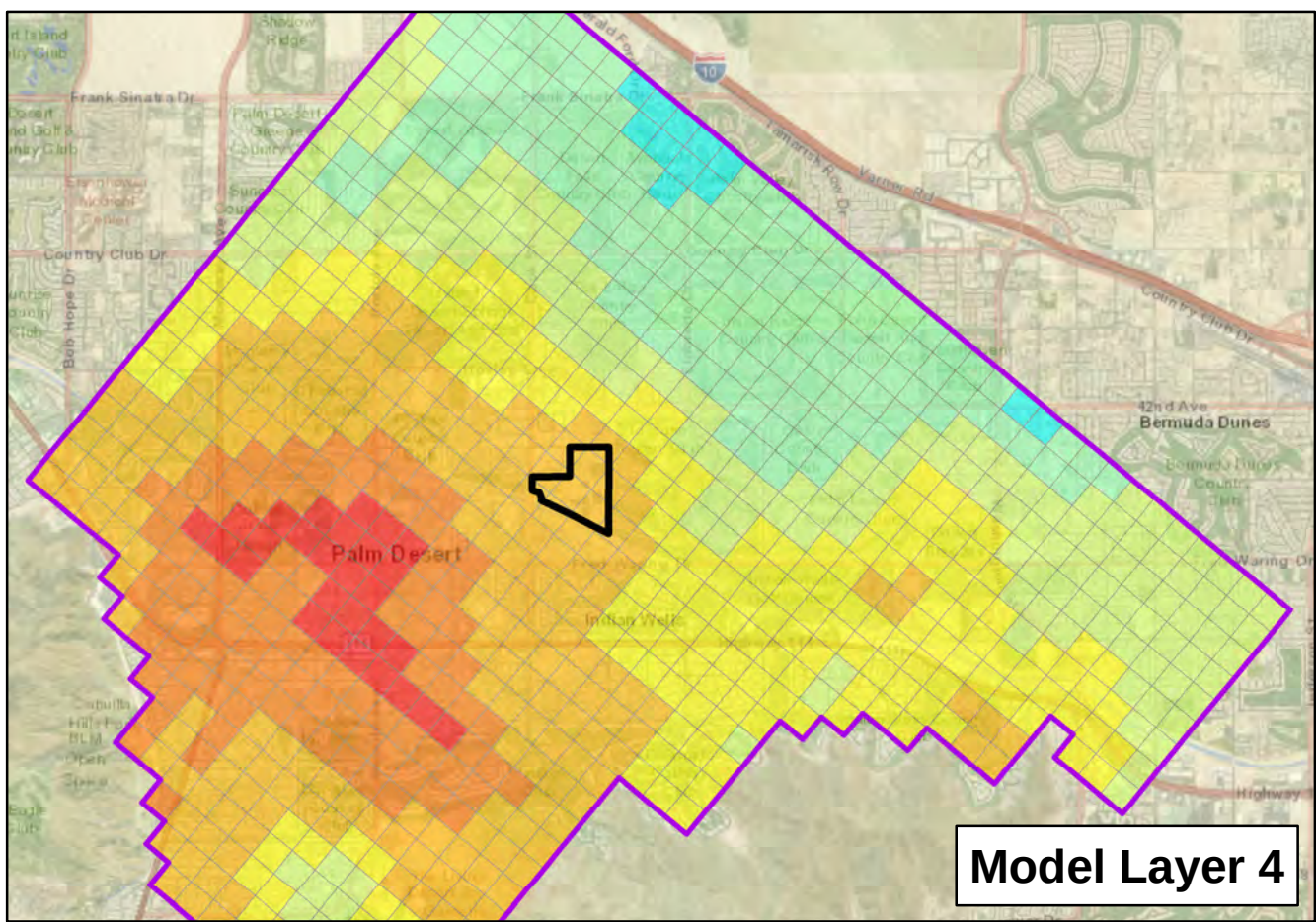
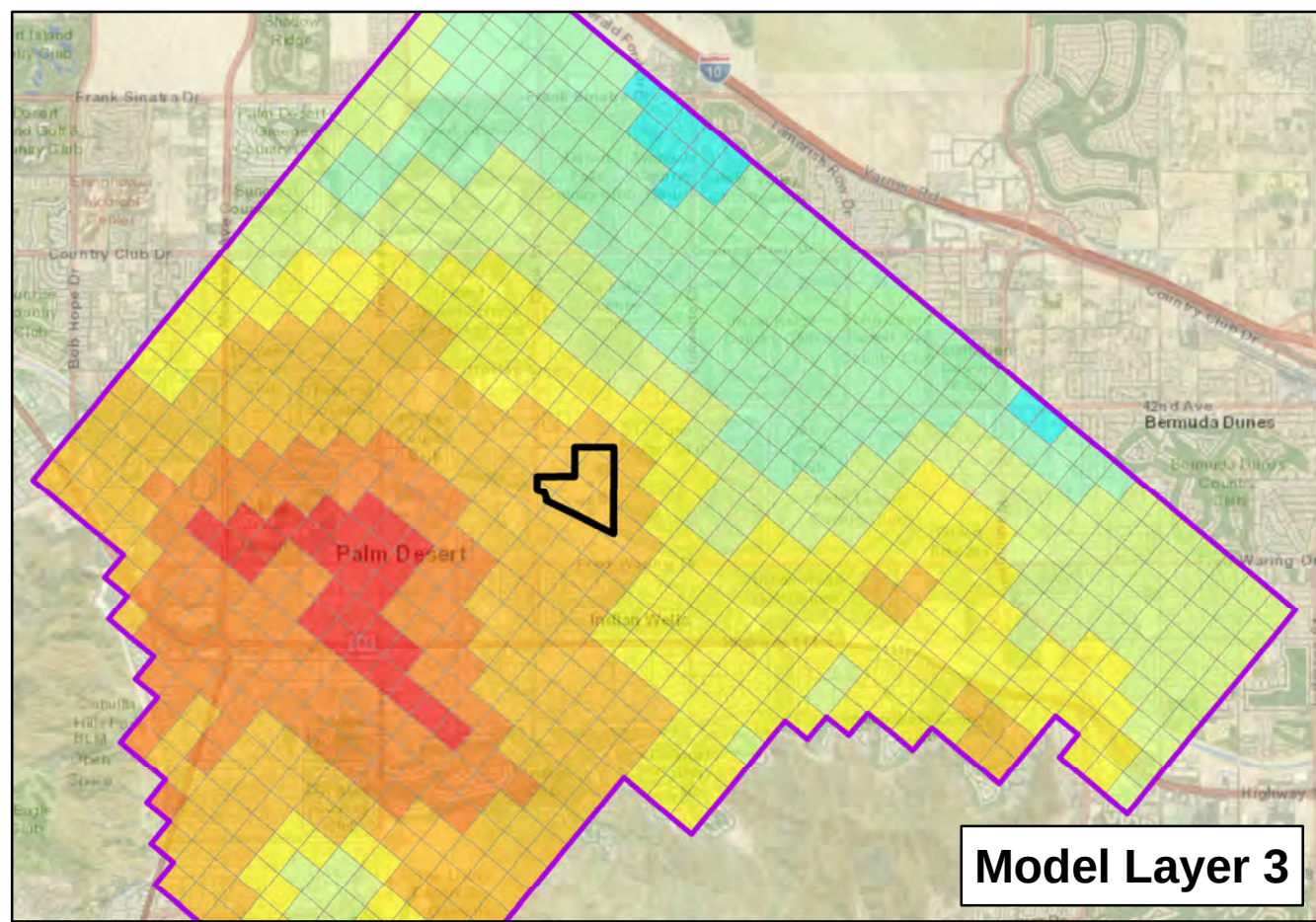
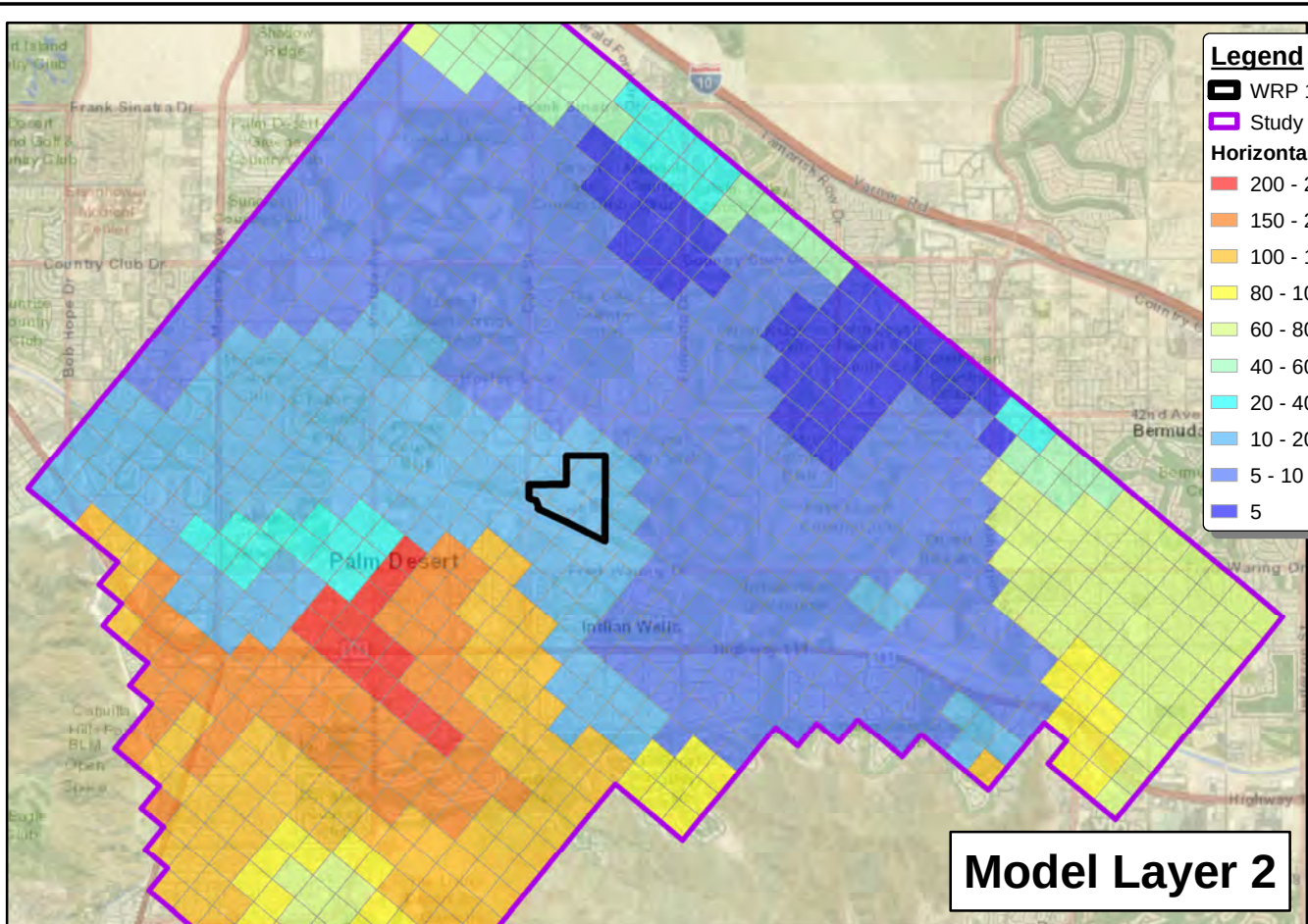
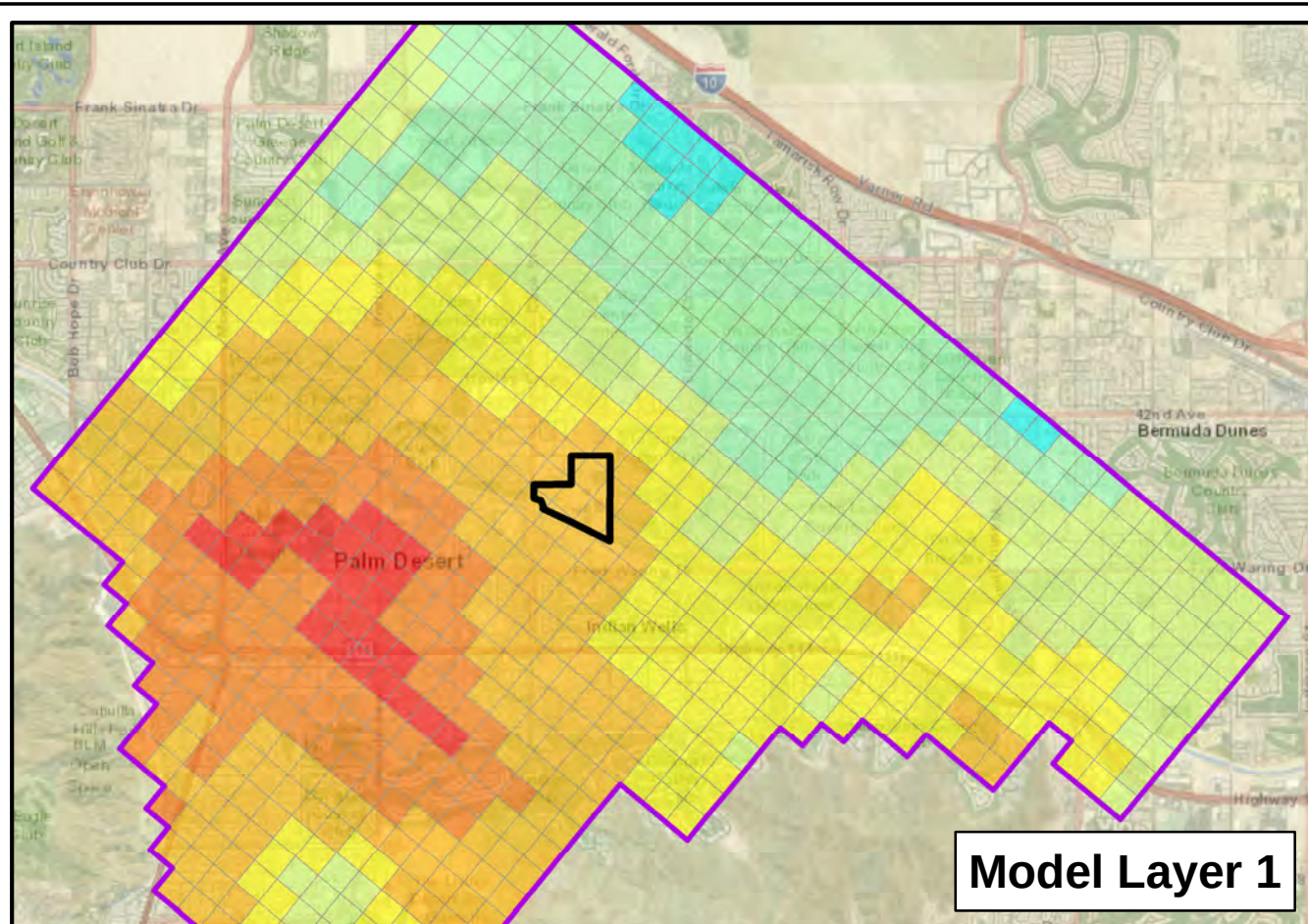
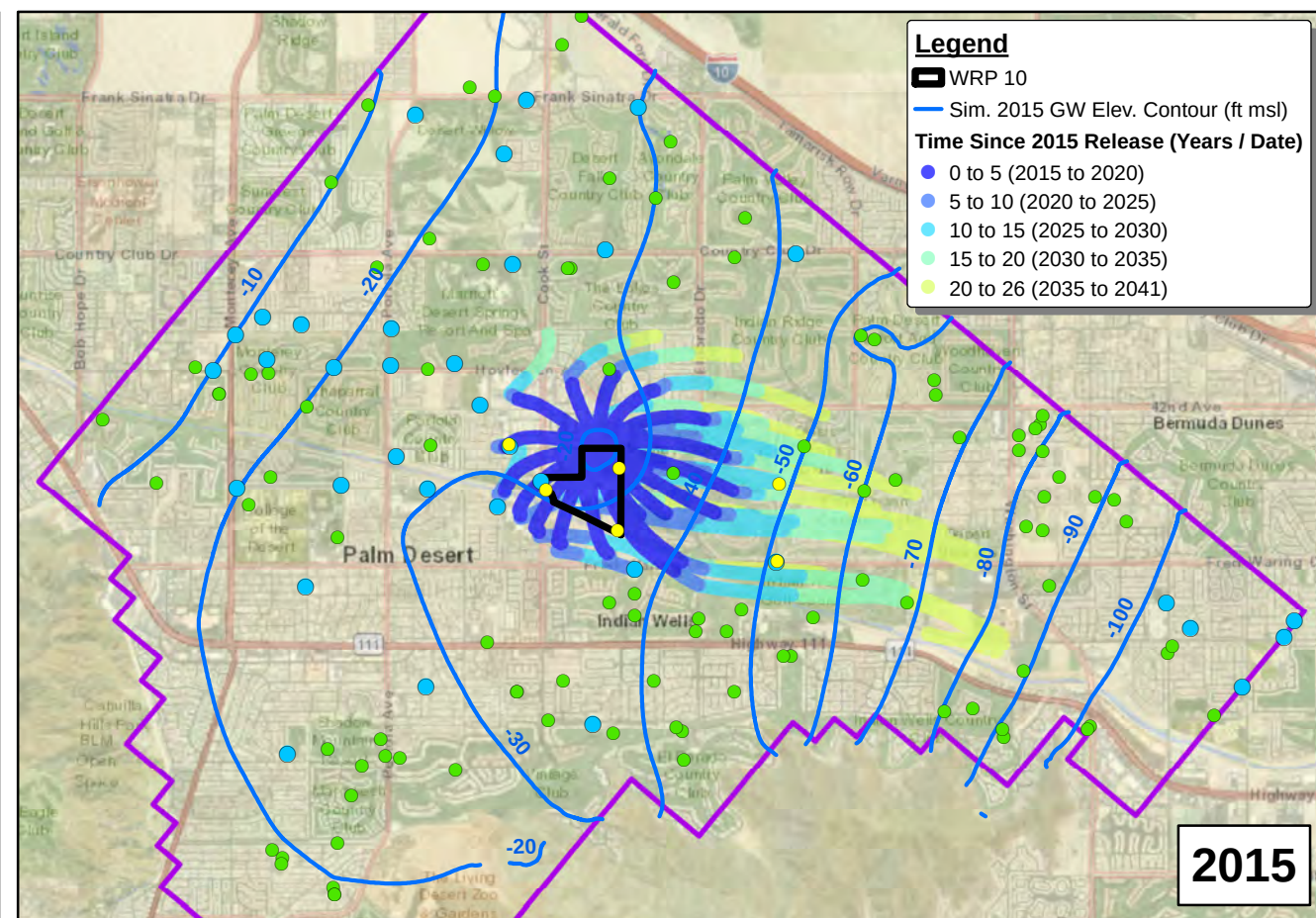
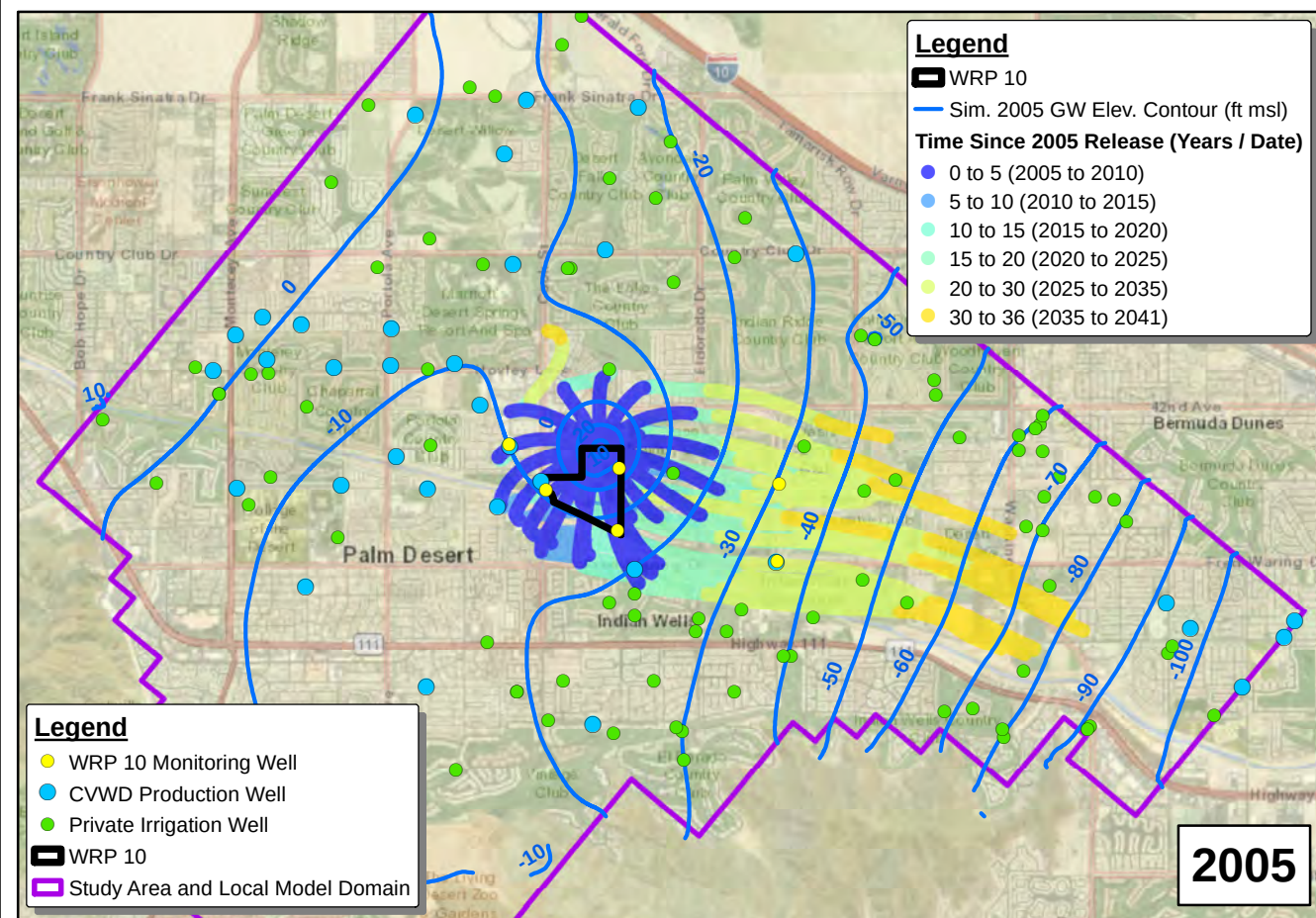
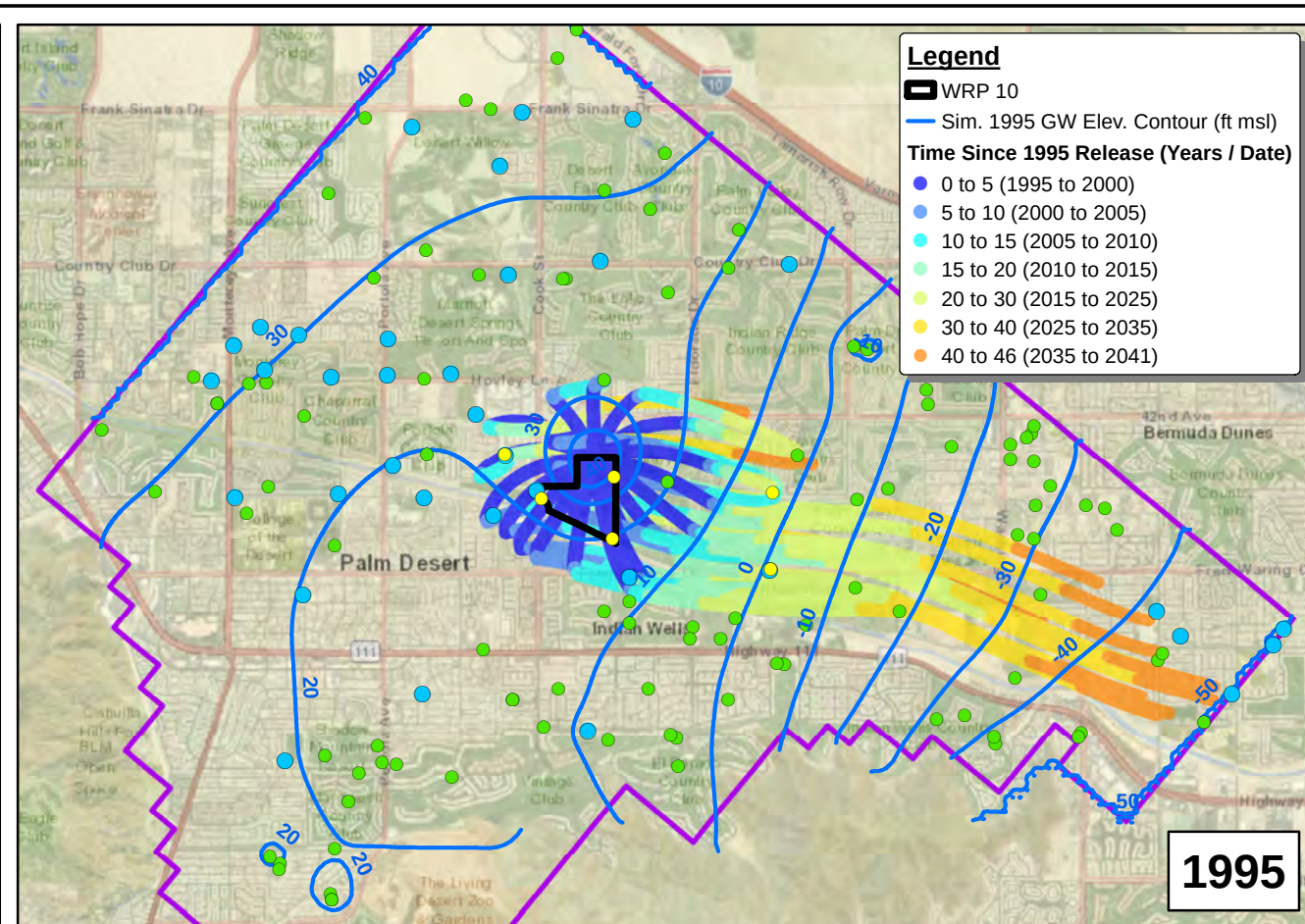
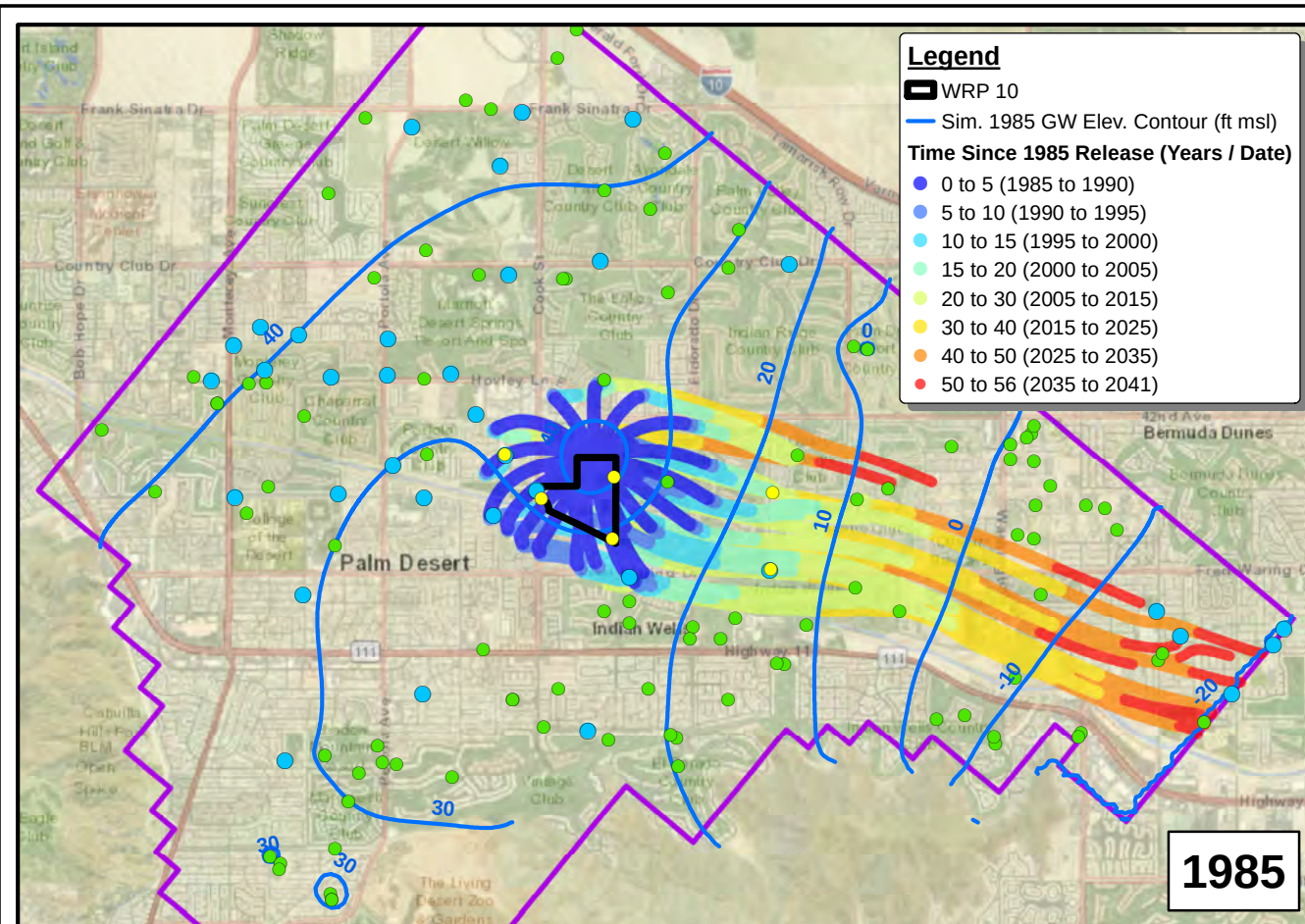
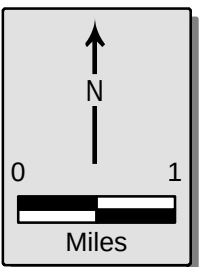


Figure 25
Hydraulic Conductivity
Distributions



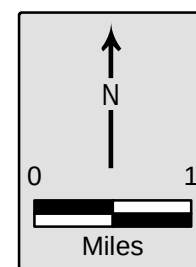
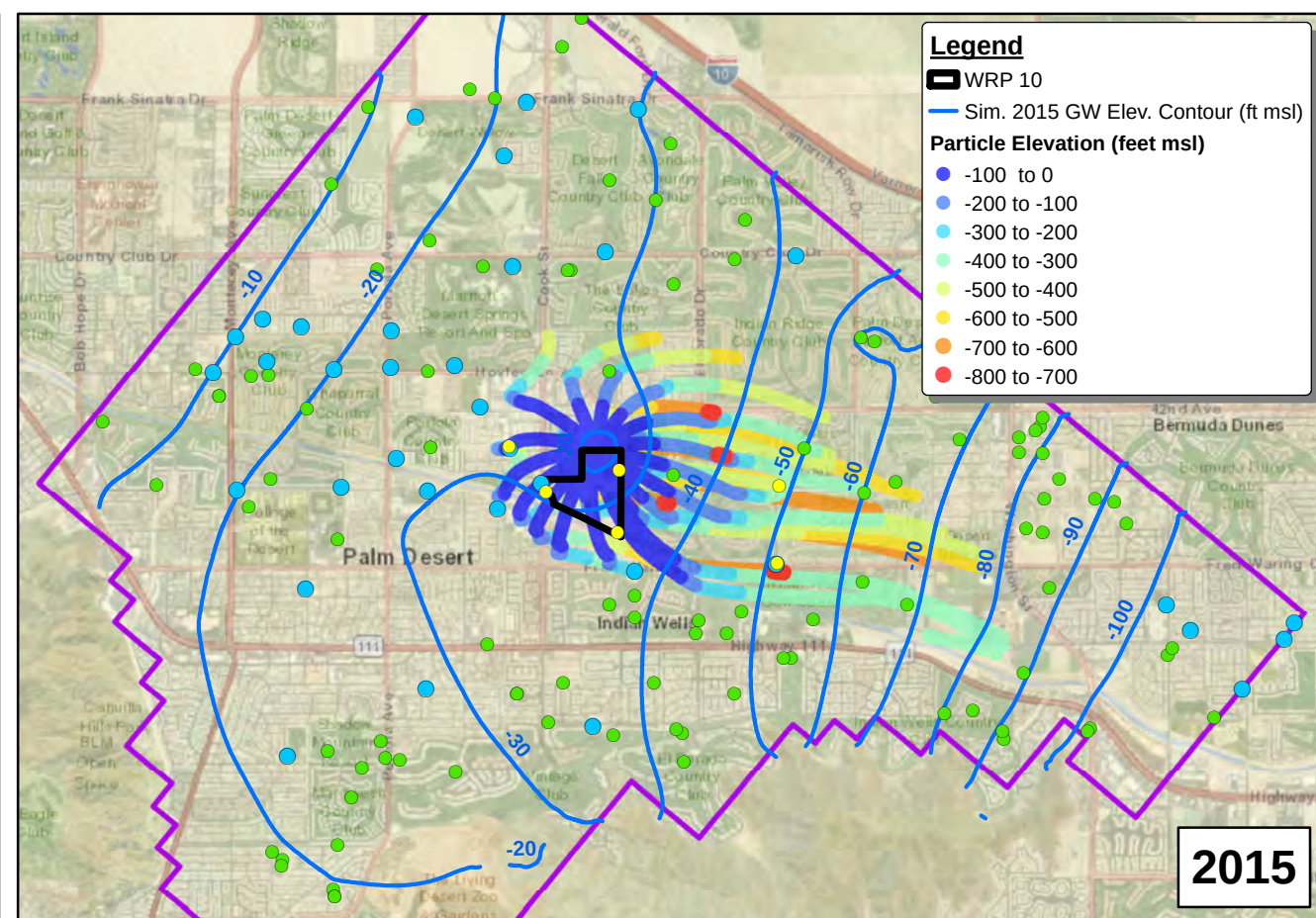
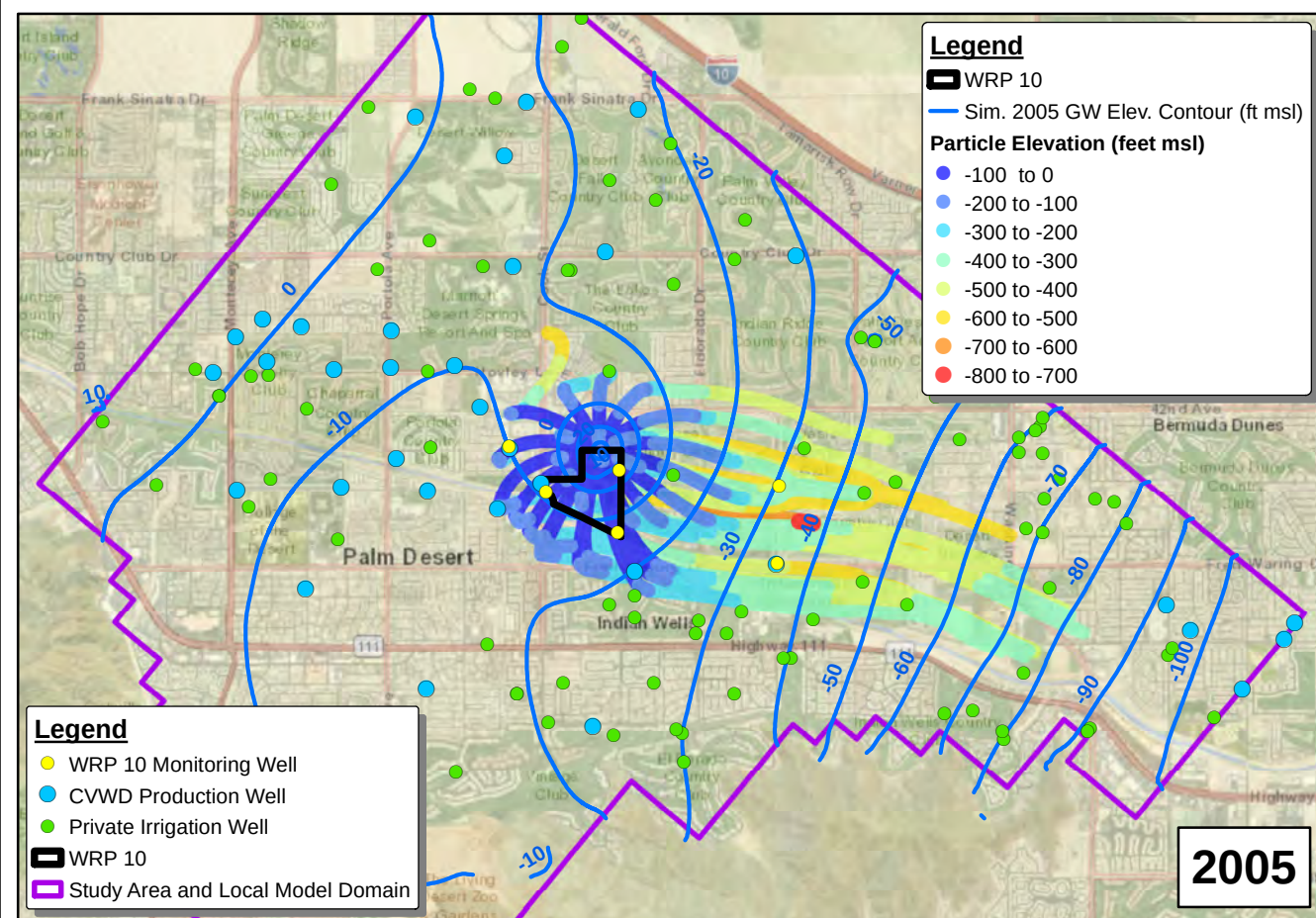
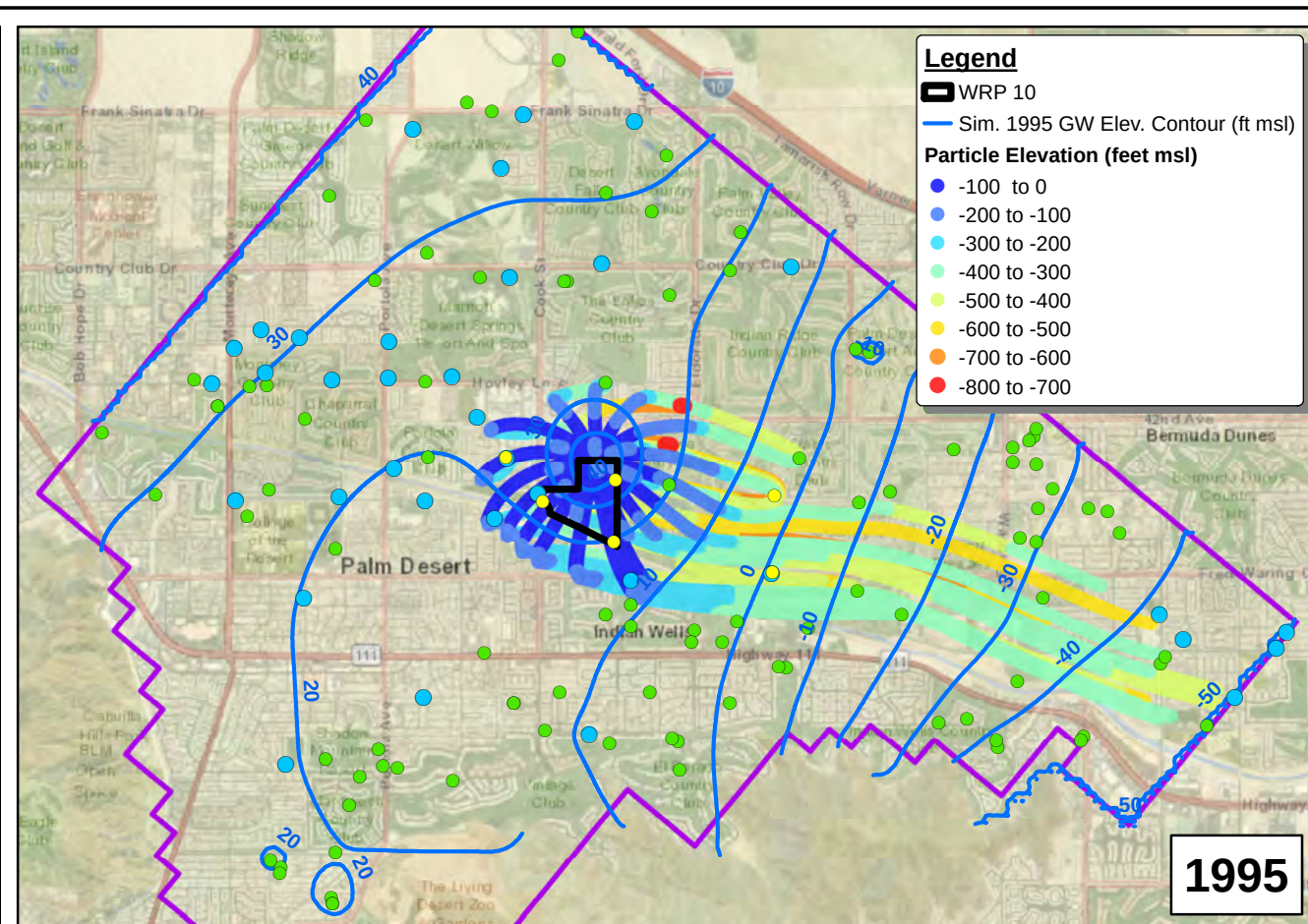
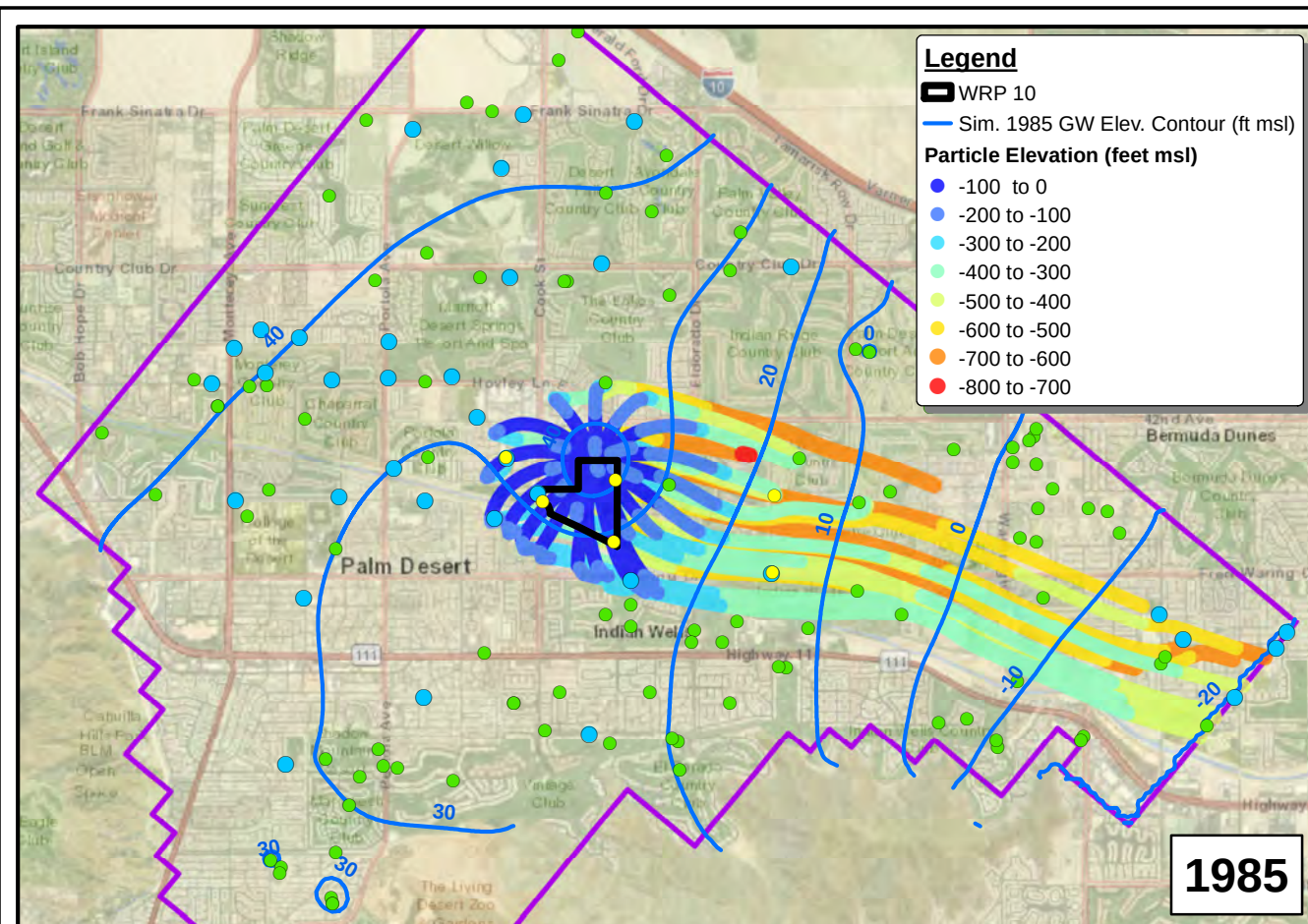
TIME



TODD
GROUNDWATER

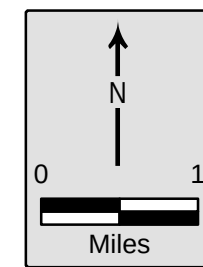
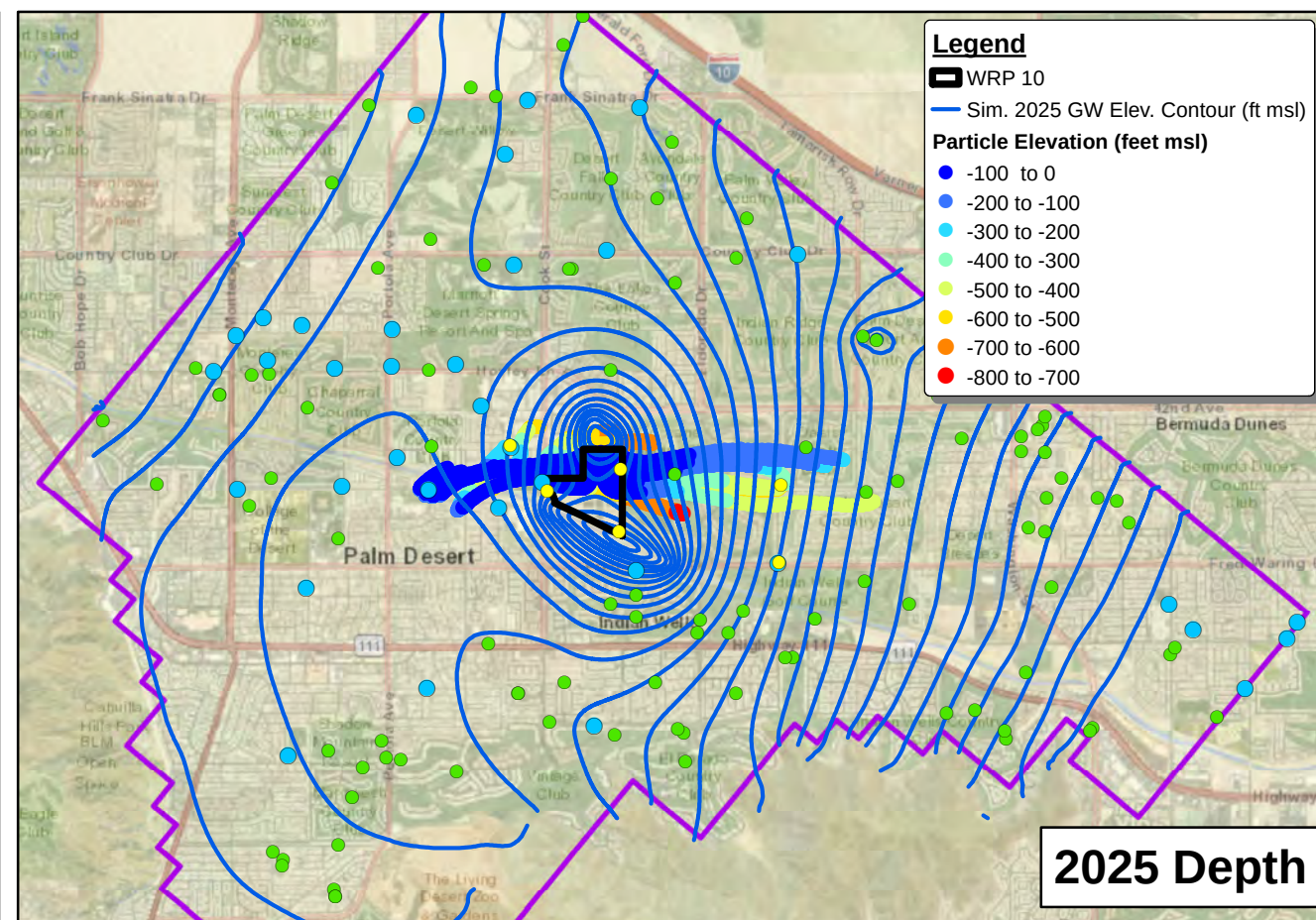
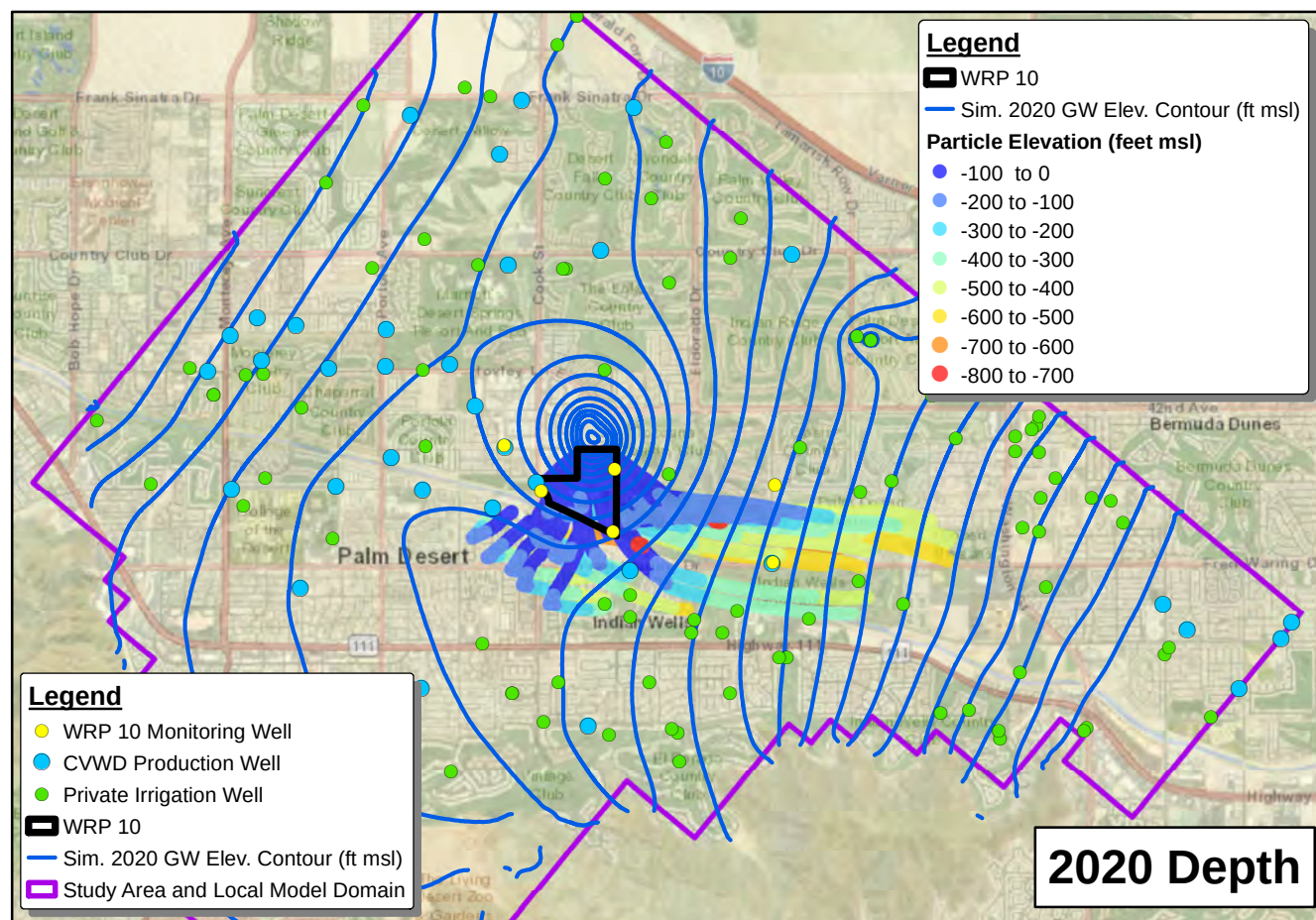
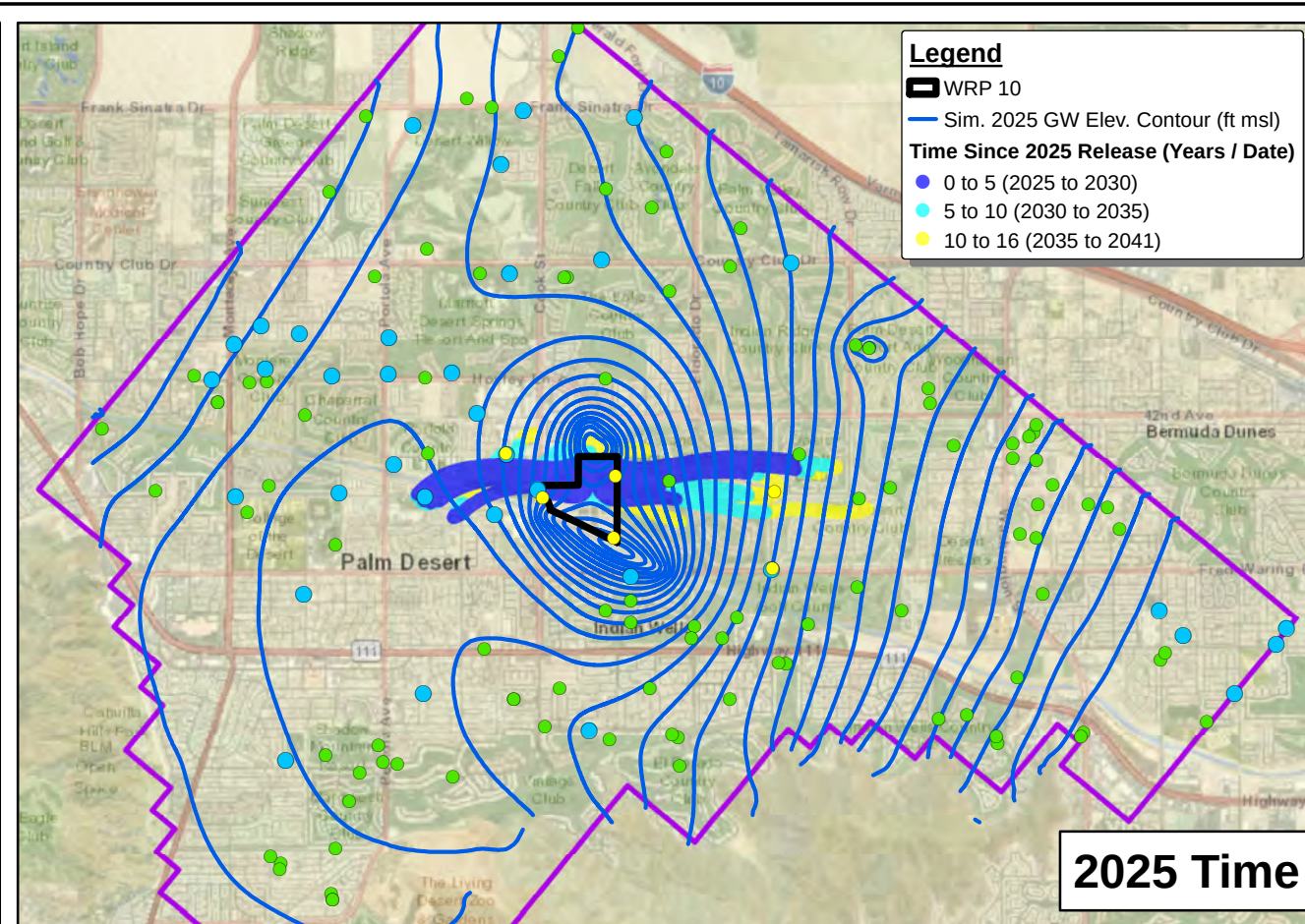
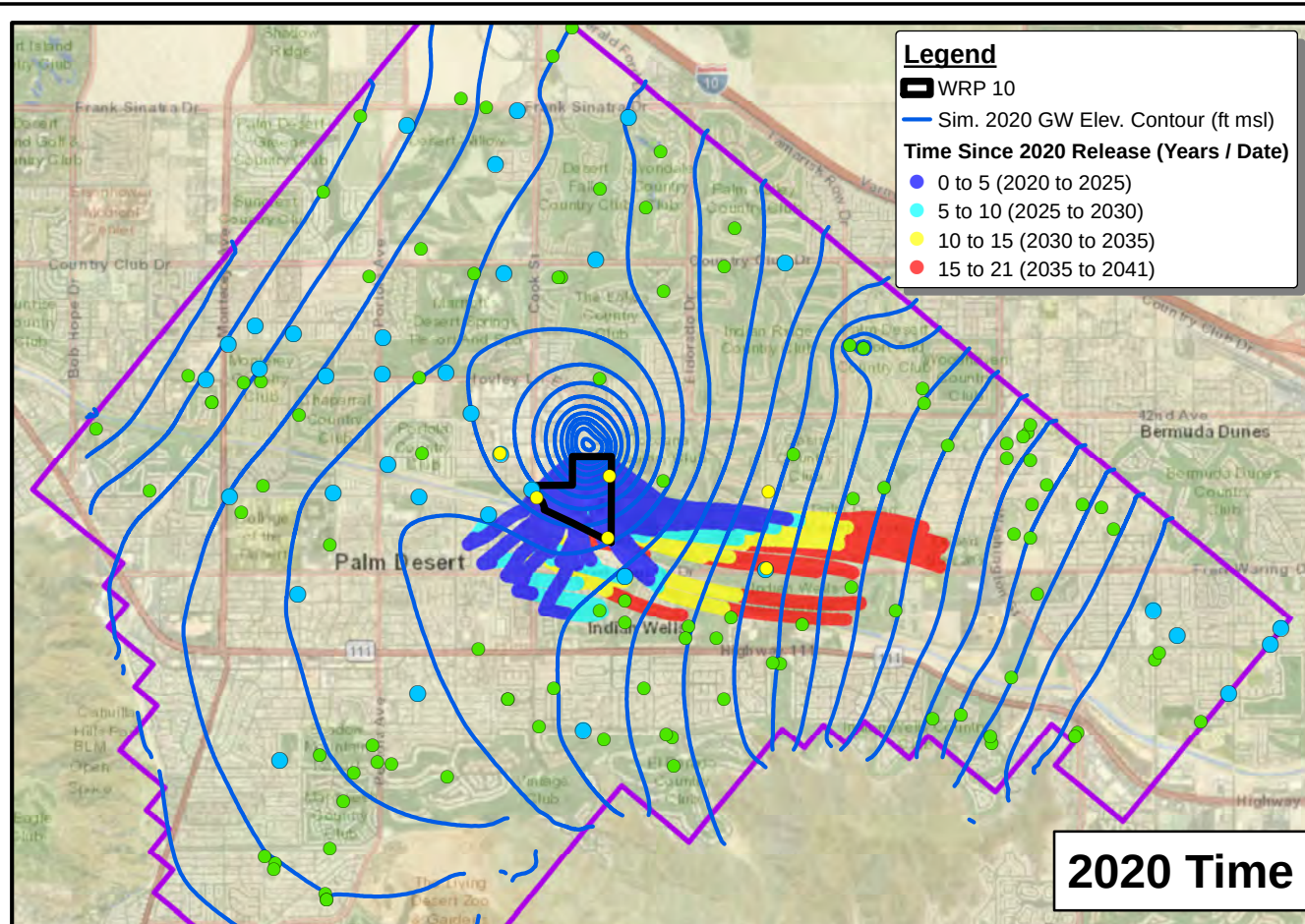
Figure 26
Simulated
Groundwater Elevations
and Flowpaths with Time
1985, 1995, 2005, 2015

DEPTH (ELEVATION)



TODD
GROUNDWATER

Figure 27
Simulated
Groundwater Elevations
and Flowpaths with Depth
1985, 1995, 2005, 2015



TODD
GROUNDWATER

Figure 28
Simulated
Groundwater Elevations
and Flowpaths with Time
and Depth 2020 and 2025

