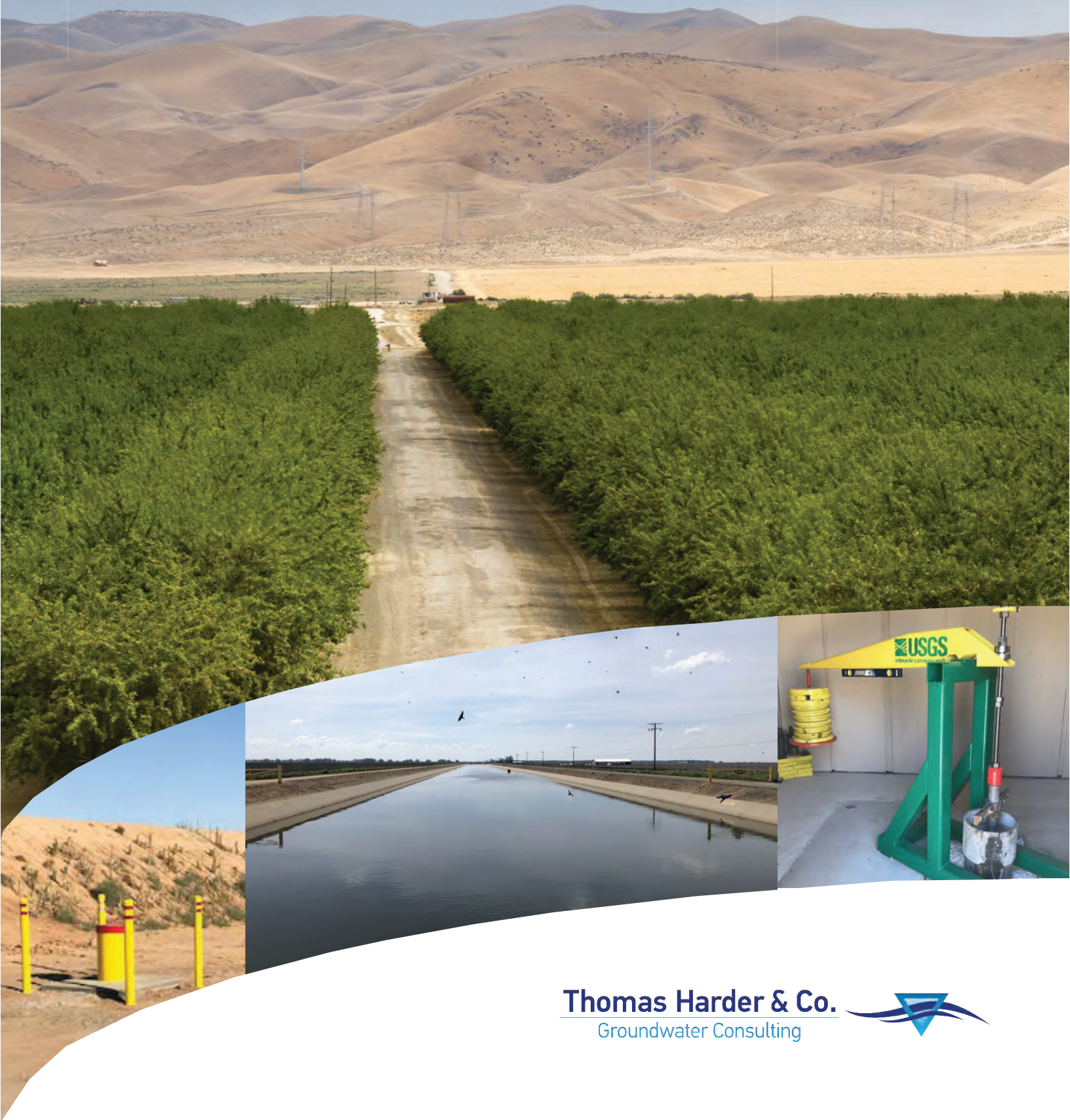


APPENDIX G

ETGSA Land Subsidence Monitoring Program

Eastern Tule Groundwater Sustainability Agency Land Subsidence Monitoring Plan

September 2021



Thomas Harder & Co.
Groundwater Consulting

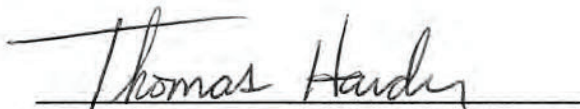


Eastern Tule Groundwater Sustainability Agency Land Subsidence Monitoring Plan

September 2021

Prepared for
Eastern Tule Groundwater Sustainability Agency

Prepared by


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Principal Hydrogeologist

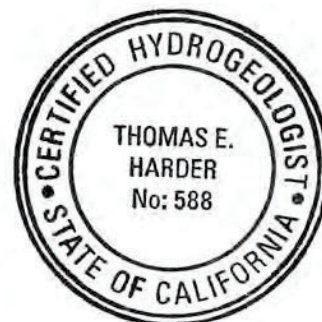


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1.0 Background

The Eastern Tule Groundwater Sustainability Agency (ETGSA) is a Groundwater Sustainability Agency (GSA) formed in response to the Sustainable Groundwater Management Act of 2014 (SGMA). The ETGSA is one of seven GSAs within the Tule Subbasin in the southern San Joaquin Valley of California (see Figure 1). The area of the ETGSA covers approximately one-third of the eastern part of the Tule Subbasin.

The sustainable management of the groundwater resources within the Tule Subbasin, including the ETGSA, is being achieved in the context of multiple sustainability indicators including:

- Chronic lowering of groundwater levels indicating a depletion of supply if continued over the planning and implementation horizon;
- Reduction of groundwater storage;
- Seawater intrusion;
- Degraded water quality, including the migration of contaminant plumes that impair water supplies;
- Land subsidence that substantially interferes with surface land uses; and
- Depletions of interconnected surface water that have adverse impacts on beneficial uses.

Four of these seven sustainability indicators have been identified as having the potential to cause significant and unreasonable effects in the Tule Subbasin. They are:

- Chronic lowering of groundwater levels indicating a depletion of supply if continued over the planning and implementation horizon;
- Reduction of groundwater storage;
- Degraded water quality, including the migration of contaminant plumes that impair water supplies; and
- Land subsidence that substantially interferes with surface land uses.

The Tule Subbasin GSAs have each developed Groundwater Sustainability Plans (GSPs) that identify key monitoring features (Representative Monitoring Sites; RMS), minimum thresholds, interim milestones, and measurable objectives to monitor each of the four relevant sustainability indicators. The GSPs are coordinated through a common set of Sustainable Management Criteria, as defined in the Tule Subbasin Coordination Agreement. The minimum set of monitoring features, including RMS, to address each of the sustainability indicators, including land subsidence, are identified in the Tule Subbasin Monitoring Plan, which is Attachment 1 to the Tule Subbasin Coordination Agreement.

This Land Subsidence Management Plan (LSMP) has been developed to specifically address land subsidence within the ETGSA and is separate from, and in addition to, the land subsidence monitoring specified in the Tule Subbasin Monitoring Plan. Given the documented impacts of



land subsidence on the Friant-Kern Canal, this LSMP takes into consideration the Settlement Agreement between the Friant Water Authority (FWA), Arvin-Edison Water Storage District (AEWSD), and ETGSA, which releases certain claims against the ETGSA provided the GSA is in compliance with its GSP.¹ The ETGSA GSP identifies three feet of additional subsidence as the minimum threshold. The Pixley Irrigation District GSA has also entered into a Settlement Agreement with the FWA to coordinate with the ETGSA in the development and implementation of this LSMP.

1.1 Documented Land Subsidence in the Tule Subbasin

Land surface subsidence resulting from groundwater withdrawal has been well documented in numerous places throughout the Central Valley of California, including the Tule Subbasin (Ireland et al., 1984; Faunt, 2009; Luhdorff and Scalmanini, 2014). Land subsidence in the Tule Subbasin was documented as early as the late 1930s (Lofgren and Klausing, 1969). Prior to 1970, as much as 12 ft of land surface subsidence was documented for the area immediately south of Pixley (Ireland et al., 1984). As groundwater levels rose in the area throughout the 1970s and early 1980s, land subsidence was largely arrested. Spirit level monitoring for land subsidence that had previously been conducted along the portion of the Friant-Kern Canal that is within the ETGSA was discontinued in the 1980s.

Land survey elevation data from the Porterville Global Positioning System (GPS) station indicates land subsidence in the Tule Subbasin has been reactivated, since at least 2007 (see Figures 2 and 3). Interferometric Synthetic Aperture Radar (InSAR) data from satellites indicates that the maximum rates of land subsidence since 2007 have occurred in the northwest portion of the subbasin. However, as much as 9 feet of land subsidence has occurred beneath the Friant-Kern Canal (FKC) in the ETGSA (see Figure 4). Land subsidence in the Tule Subbasin is attributed to lowering of groundwater levels from groundwater pumping in areas where the subsurface sediments include thick sequences of fine-grained material (silt and clay) (Lofgren and Klausing, 1969).

1.2 Documented Land Subsidence in the ETGSA

Evidence of land subsidence in the ETGSA has been observed from benchmark surveys along the FKC, a GPS established near Porterville in 2007, and InSAR data. Survey benchmarks were established along the FKC in 1959 and were periodically surveyed by the Friant Water Authority (FWA) between 1959 and 2019, with a survey hiatus from the early-1980s to 2017. Cumulative land subsidence along the canal between 1959 and 2017, based on benchmark surveys, has ranged

¹ Settlement Agreement Regarding Transitional Overdraft Pumping and Anticipated Subsidence Damages/Repairs to the Friant Kern Canal. Dated January 12, 2021.



from approximately 1.7 ft at the FKC/Tule River crossing to approximately 9 feet in the vicinity of Deer Creek (see Figure 4). Approximately 2.7 ft of land subsidence was documented at the Porterville GPS station between 2007 and 2020 (see Figure 3). Between January 2020 and October 2020, the greatest amount of land subsidence has occurred in an area approximately four to five miles north and south of Deer Creek and between Highway 65 and the western ETGSA boundary (see Figure 5).

1.3 Mechanisms of Land Subsidence

Land surface subsidence from groundwater withdrawal occurs in areas where the subsurface aquifer system includes relatively thick aquitards and the groundwater level is lowered from groundwater pumping. Aquitards are low permeability layers with relatively high silt and clay content. As the aquitards are compressible, the release of pore pressure caused by the lowering of groundwater levels results in compression of the low permeability layers. Within a limited range of groundwater level fluctuation, the compressed aquitards can accept water back into their structure when groundwater levels rise resulting in elastic rebound. However, if groundwater levels are maintained at these lower levels for long enough periods of time as a result of groundwater pumping, the compression of aquitards becomes permanent. This permanent compression of subsurface layers results in land surface subsidence.

1.4 Hydrogeological Conditions in the ETGSA that Cause Land Subsidence

Large areas of the ETGSA are susceptible to land surface subsidence due to a combination of thick fine-grained layers in the subsurface and locally declining groundwater levels. The subsurface sediments in the vicinity of the FKC consist of interbedded layers of silt, clay and sand. The percentage of clay layers (which are compressible) relative to sand layers (which are not compressible) that makes up the cross-sectional subsurface area varies from place to place. As shown on Figure 6, the area of the FKC where historical land subsidence has been greatest is also an area where the percentage of subsurface fine-grained sediments (which includes clay) is relatively high (dark brown areas). As such, these areas of substantial thickness of subsurface clay are conducive to subsidence. In addition, groundwater levels in wells located along the canal have dropped as much as 60 feet between 2007 and 2018 (see Figure 7). The subsurface conditions that result in land subsidence are not unique to the ETGSA and significant land subsidence has been observed in the Tule Subbasin to the west and throughout much of the Central Valley. It is possible that some of the groundwater level decline causing land subsidence at the FKC is from pumping outside the ETGSA (see Section 1.6 of this LSMP). The combination of thick sequences of subsurface clay and dropping groundwater levels in the vicinity of the FKC has resulted in land subsidence along the canal.

The relationship between groundwater levels and aquifer system compaction that results in land subsidence is further illustrated by extensometer data from the United States Geological Survey



(USGS) station 22S/27E-30D02 located on the FKC approximately one mile north of Deer Creek, where the greatest amount of land subsidence along the canal has occurred. This extensometer consists of a 2-inch diameter steel pipe anchored at the bottom of a 12-inch diameter well with a total depth of 1,180 feet. The well is perforated from 1,083 to 1,180 feet below ground surface (ft bgs) to allow for the measurement of groundwater levels, which are indicative of the Lower Aquifer. The top of the 2-inch diameter extensometer pipe is connected to instrumentation at the land surface that measures changes in land surface elevation relative to the elevation of the top of the pipe, which does not move. The changes in land surface elevation are equated to aquifer system compaction.

Figure 8 shows cumulative aquifer compaction at the USGS extensometer between June 2018 and May 2021 as a function of groundwater level. The hydrograph (blue line) shows seasonal variations in groundwater levels between a low of approximately 25 feet above mean sea level (ft amsl) and a high of approximately 125 ft amsl (approximately 100 feet). The aquifer compaction record (orange line) is cumulative, indicating approximately 0.2 feet of aquifer compaction has occurred at this location over the period of record. As groundwater levels drop, aquifer compaction occurs as pore pressure in the aquitards is reduced and the effective stress of overburden increases. When groundwater levels rise, the aquitards can take some water back into their structure resulting in rebound (October 2018 to March 2019). When the compaction no longer fully recovers to zero, despite groundwater levels rising, the compaction is considered permanent or non-recoverable.

Preliminary review of the groundwater level data from the USGS extensometer 22S/27E-30D02 suggests that the Lower Aquifer system at this location is confined and there is a groundwater level in this aquifer that is protective of further aquifer compaction and land subsidence. The 100-ft seasonal swings in groundwater levels are typical of a confined aquifer system. Further, the magnitude of the groundwater level change will likely result in a significant increase in effective stress of the aquifer system resulting in compaction. This compaction is seen in the extensometer data when groundwater levels drop. In addition, compaction reduces to near zero when the groundwater level rises above approximately 125 ft amsl. This suggests that maintaining groundwater levels in the deep aquifer above 125 ft amsl are protective of further compaction and land subsidence.

1.5 Impacts of Land Subsidence on Surface Water Delivery Capacity in the Friant-Kern Canal

Differential land subsidence rates along the portion of the Friant-Kern Canal that extends through the ETGSA has had a significant impact on the ability of the FWA to deliver surface water downstream of the impacted areas. Where the FKC crosses the northern and southern ETGSA boundaries, land subsidence rates have been relatively low and cumulative land subsidence in those areas have been on the order of 1 to 2 feet between 1959 and 2019. Land subsidence between the Tule River and White River, however, have resulted in up to approximately 9 feet of cumulative



land subsidence at the FKC. This differential land subsidence has resulted in a low spot along the canal in the vicinity of Deer Creek that restricts flow in the canal. The original design flow capacity of the FKC was approximately 4,000 cubic feet per second (cfs). As of 2019, the flow capacity at the canal at Deer Creek had been reduced to approximately 1,900 cfs (United States Bureau of Reclamation, 2019). The FWA is currently pursuing repairs to the FKC to restore the original flow capacity. The long-term effectiveness of the repairs at maintaining flow capacity in the canal relies on limiting additional land subsidence during the SGMA transition period from 2020 to 2040 within the design of the repairs and arresting land subsidence altogether after 2040.

1.6 Previous Analyses of Land Subsidence Along the Friant-Kern Canal

Preliminary analyses of the relationship between groundwater pumping distance from the FKC on land subsidence at the canal was conducted in the Spring of 2019 and published by Thomas Harder & Co. (TH&Co) in a draft report to the Tule Subbasin Technical Advisory Group (TH&Co, 2019). The analysis also examined the potential relationship between groundwater pumping depth and land subsidence. The analysis showed that land subsidence along the canal is sensitive to both the location of groundwater pumping with respect to the canal and the depth from which the pumping is occurring. On a subbasin-wide scale, groundwater pumping closer to the canal had a greater impact on land subsidence than groundwater pumping further away. The analysis also showed that the depth from which groundwater was being extracted also contributed to land subsidence at the canal. While the TH&Co (2019) report was never finalized, key aspects of the analysis, as they relate to the ETGSA LSMP are summarized in this section.

1.6.1 Analyses Methodology

Preliminary analysis of land subsidence near the portion of the Friant-Kern Canal that is within the Tule Subbasin was conducted using a calibrated numerical groundwater flow model (Tule Subbasin GFM) developed for the Tule Subbasin Technical Advisory Committee in support of their compliance with the Sustainable Groundwater Management Act (SGMA). The model domain (i.e. active model area) is focused on the Tule Subbasin but extends approximately 4 to 6 miles outside the subbasin on each side (see Figure 8).

1.6.1.1 Model Code

The Tule Subbasin GFM was developed using MODFLOW. MODFLOW is a block centered, finite difference groundwater flow modeling code developed by the USGS for simulating groundwater flow (MacDonald and Harbaugh, 1989). MODFLOW is one of the most widely used and critically accepted model codes available (Anderson and Woessner, 2002). The version of MODFLOW utilized for this work is the USGS One Water Hydrologic Flow Model (OWHFM) (Hanson et al., 2014), which integrates both surface water and groundwater processes. The model includes a subsidence and aquifer system compaction package (Hoffman et al., 2003), which was utilized for the analysis of subsidence in this study.



1.6.1.2 Model Domain and Boundary Conditions

The Tule Subbasin GFM domain is as shown on Figure 9. This domain encompasses the Tule Subbasin alluvial groundwater system covering an area of approximately 1,500 square miles (i.e., approximately 1 million acres). The model is subdivided into uniform 1,000-foot by 1,000-foot cells. Vertically, the model is subdivided into five hydrostratigraphic layers, which represent groupings of geologic sediments with generally similar properties. The vertical layers are described as follows (from shallow to deep):

- Layer 1 is the upper unconfined aquifer and ranges in thickness from approximately 100 feet in the northeast part of the subbasin to approximately 400 feet in the northwestern part of the subbasin;
- Layer 2 is an underlying comparatively low permeability unit separating the upper and lower aquifers and generally coincides with the Corcoran Clay west of Highway 99. This layer ranges in thickness from approximately 300 feet in the western part of the subbasin to zero in the eastern part of the subbasin;
- Layer 3 is the lower alluvial aquifer, which is semi-confined in the east and confined below the Corcoran Clay in the west. This layer ranges in thickness from approximately 200 feet on the east side of the subbasin to greater than 1,600 feet on the west side;
- Layer 4 is a low permeability layer separating the lower alluvial aquifer from the underlying Santa Margarita Formation aquifer. This layer ranges in thickness from approximately 200 feet on the east side of the subbasin to more than 800 feet in the central part of the subbasin; and
- Layer 5 is the Santa Margarita Formation aquifer, which is located at depth only on the eastern side of the subbasin. This layer ranges in thickness from approximately 200 feet on the east side of the subbasin to more than 600 feet in the central part of the subbasin.

Groundwater flow into and out of the model area is controlled by boundary conditions. On the north, south and west boundaries of the Tule Subbasin GFM, historical groundwater flow is conditioned to measured groundwater levels (i.e. hydrographs) from wells located along the boundaries. On the east side of the model, groundwater flow from the bedrock of the Sierra Nevada Mountains is difficult to simulate due to the fractured nature of the granitic rock and lack of data. This issue has been addressed by assigning the area of the Sierra Nevada Mountains as "no flow" or inactive and assigning recharge from the mountains as a boundary condition along the bedrock/alluvium interface. The granitic bedrock also forms the base of the model (assumed to be impermeable) in the subsurface beneath model Layer 5. This boundary is not vertical but slopes towards the west consistent with our understanding of how the Sierra Nevada basement extends beneath the subbasin.



1.6.1.3 Model Transient Setup and Calibration

The version of the Tule Subbasin GFM (hereinafter referred to as Tule Subbasin GFM v.2019) used for the preliminary analysis was calibrated from 1986 through 2017 with monthly stress periods. Thus, historical groundwater pumping and recharge data is input into the model monthly. The model calibration was achieved for the 1986 to 2017 time period by adjusting aquifer parameters until the best possible match between measured and model-generated groundwater levels was obtained. The model calibration process included both manual and automated methods. Based on the comparison of model-generated and measured groundwater levels, it is our opinion that the historical model is adequately calibrated to measured data for the preliminary analysis of land subsidence (see Figure 10).

In addition to calibrating groundwater levels, TH&Co also calibrated model-generated land subsidence to measured land subsidence in the Tule Subbasin. Measured historical changes in land surface elevation were obtained from Global Positioning System (GPS) stations in the subbasin and satellite data (Interferometric Synthetic Aperture Radar or InSAR). GPS measures land surface elevation at any given time based on position relative to multiple satellites. TH&Co received GPS data from the Friant Water Authority (FWA) for multiple stations with records from 2005 to 2018. Historical cumulative subsidence at the GPS stations is shown on Figure 2. InSAR enables estimates of changes in land surface elevation over time based on radar images from multiple satellite passes over the same area. Changes in land surface elevation based on InSAR data were obtained from the Jet Propulsion Laboratory (JPL) for the following time periods:

- InSAR Dataset 1: 2007 - 2011
- InSAR Dataset 2: 2014 – 2015
- InSAR Dataset 3: 2015 – 2017

Results of the land subsidence calibration for selected locations near the FKC is shown on Figure 11. Based on comparison of model generated and measured rates of land surface subsidence in the Tule Subbasin, the calibration of land elevation changes over time was considered acceptable for analyzing future projections of land subsidence under varying pumping conditions in the subbasin.

1.6.2 Analysis Approach

TH&Co developed a stepwise approach to 1) assess the sensitivity of land subsidence to the distance of pumping laterally from the Friant-Kern Canal, and 2) assess the sensitivity of land subsidence to the depth of wells in the vicinity of the Friant-Kern Canal. The general process included the following:

- Refining the agricultural water budget zones within the eastern portion of the model domain (see Figure 12).



- Modifying the historical calibrated model to remove pumping in selected agricultural zones at progressively increasing distances from the Friant-Kern Canal to assess the sensitivity of pumping distance from the canal on land subsidence at the canal.
- Analyzing the sensitivity of land subsidence to pumping distance from the Friant-Kern Canal assuming a future scenario whereby the Tule Subbasin transitions to sustainable pumping within 10 years, starting in 2020.
- Modifying the historical calibrated model to remove pumping at progressively decreasing depths in the vicinity of the FKC to assess the sensitivity of well depth on land subsidence.

1.6.2.1 Sensitivity of Well Production Location Relative to the Friant-Kern Canal Using the Historical Groundwater Flow Model

As an initial step in evaluating the sensitivity of pumping distance from the Friant-Kern Canal on land subsidence at the canal, TH&Co analyzed twelve water budget zone alternatives for the historical period of the model (1986 to 2017). In this analysis, groundwater pumping in selected zones at increasingly greater distances from the canal was turned off for the historical period to assess what the land subsidence at the canal would have been if that production had not occurred. The twelve water budget zone combinations analyzed in this step are shown on Figures 13a and 13b.

1.6.2.2 Water Budget Zone Combinations Analyzed for the Model Projection Under a 10-Yr Tule Subbasin Transitional Pumping Scenario

As of the May 2019 analysis, the transitional pumping schedules for each of the GSAs within the Tule Subbasin had not been determined. In addition, the projects and management actions that would be incorporated into the version of the model later used in support of the Tule Subbasin GSPs had not been fully defined. As such, three pumping transition scenarios (5-yr ramp down, 10-yr ramp down, and 20-yr ramp down) were developed from which to evaluate potential impacts on land subsidence beneath the FKC. Land subsidence predicted by the 10-yr transitional pumping scenario most closely matched the land subsidence predicted by the later version of the model used to support the GSPs (Tule Subbasin GFM v.2020a). As such, only results of the 10-yr transitional pumping scenario are presented herein. The 10-yr transitional pumping scenario assumed that 2019 groundwater pumping rates in the regional Tule Subbasin would be reduced to sustainable levels (as determined from the sustainable yield of the subbasin) in ten years, starting in 2020. Each simulation was run 50 years into the future, to 2070. The scenario also incorporated the following assumptions:

- Surface water hydrology in the Tule River, Deer Creek, and White River are based on an average of the historical flow from 1986 to 2017 and adjusted for climate change based on California Department of Water Resources (DWR) climate change scenarios



- Water deliveries from the Friant-Kern Canal were based on projections published in FWA (2018).
- The sustainability target for consumptive use of crops was 0.37 acre-ft/acre.

It is noted that it was necessary to lower the sustainability target in a later version of the Tule Subbasin GFM (Tule Subbasin GSM v.2020a) in order to obtain a balance of recharge and discharge in the Tule Subbasin (TH&Co, 2020). In addition, the scenario did not incorporate planned projects and management actions, including the final transitional pumping schedules of the Tule Subbasin GSAs. As such, the analysis results are conceptual. However, they are useful for identifying areas where management actions are most effective for mitigating land subsidence along the FKC.

Multiple water budget zone alternatives were identified for analysis under the 10-yr transitional pumping scenario. Each alternative included a different combination of water budget zones whereby the pumping in the selected zones was turned off in 2020 and left off for the duration of the model simulation. In some zones where surface water deliveries were available, agricultural consumptive use continued even though groundwater pumping was curtailed on the assumption that the crop demand could be fulfilled through increased deliveries. The objective of the analysis was to identify the smallest total managed area most effective at limiting future land subsidence. The most effective water budget zone alternatives at mitigating land subsidence beneath the portion of the FKC in the ETGSA are shown on Figure 14.

1.6.2.3 Sensitivity Analysis of Well Depth and Land Subsidence Near the Friant-Kern Canal

To assess the sensitivity of well depth on land subsidence at the FKC, TH&Co analyzed multiple scenarios for the historical model whereby the wells in the refined water budget area shown on Figure 12 were shortened at progressively shallower depths. The groundwater pumping rate was kept the same but the contribution of water to the wells was from progressively shallower portions of the aquifer system. The purpose of the exercise was to assess what the land subsidence along the Friant-Kern would have been in history if well depths were shallower. The following nine scenarios were analyzed:

1. Maximum well depth limited to 1,200 ft bgs
2. Maximum well depth limited to 1,100 ft bgs
3. Maximum well depth limited to 1,000 ft bgs
4. Maximum well depth limited to 900 ft bgs
5. Maximum well depth limited to 800 ft bgs
6. Maximum well depth limited to 700 ft bgs
7. Maximum well depth limited to 600 ft bgs
8. Maximum well depth limited to 500 ft bgs
9. Maximum well depth limited to 400 ft bgs



1.6.3 Analysis Results

Analysis of the historical simulation whereby groundwater pumping is eliminated from progressively larger areas around the FKC (Figures 13a and 13b) shows that the larger the area of eliminated pumping, the greater the reduction in land subsidence at the canal (see Figure 15). It also showed that preferentially reducing pumping east of the FKC had a greater reduction in land subsidence than preferentially reducing pumping west of the FKC (compare scenarios H10 and H11). Finally, the analysis was not successful at eliminating land subsidence at the FKC, suggesting that groundwater pumping and groundwater level declines outside the study area were also contributing to land subsidence at the FKC.

Analysis of potential future land subsidence at the FKC under a 10-yr transitional pumping scenario showed that as much as three feet of additional land subsidence was projected between Deer Creek and White River (see Figure 16). Of the water budget area scenarios evaluated, the ones that focused on a combination of pumping elimination and continuance of irrigation from surface water deliveries (see NP1-F7 on Figures 14 and 16) were the most effective at preventing further land subsidence along the FKC south of Deer Creek. Scenarios such as H11 that extended no pumping zones north to the Tule River were effective at preventing land subsidence north of Deer Creek.

The analysis of restricting pumping depth on land subsidence at the FKC showed that, at least with the model as conceptualized and calibrated, restricting pumping depth helped reduce land subsidence at the FKC (see Figure 17). The greatest impact on land subsidence mitigation was achieved by limiting groundwater pumping to the upper 600 feet below land surface. However, limits on pumping depth will need to be further evaluated using extensometer data, as discussed in Section 1.4.

1.7 Potential Future Land Subsidence per the ETGSA Groundwater Sustainability Plan

Model analyses of potential future land subsidence using Tule Subbasin GSM v.2020a, which incorporates planned transitional pumping schedules by the ETGSA and other Tule Subbasin GSAs, has shown that continued groundwater pumping over and above the Sustainable Yield during the transition period allowed under SGMA (2020 to 2040) is projected to result in further groundwater level declines and land subsidence along the FKC during that period. The model analysis is documented in TH&Co (2020) and the simulation incorporates the following assumptions:

- Municipal pumping by the City of Porterville was increased in accordance with their 2015 Urban Water Master Plan (UWMP).
- Baseline stream flow hydrology for the Tule River, Deer Creek and White River for the future projection model was based on the 20-yr average of historical stream flows measured



or estimated between water years 1990/91 and 2009/10. This base period approximates the 115-year average surface water flow within the Tule River between 1903/04 and 2016/17 (TRA 2018 Annual Report, Appendix).

- The baseline streamflow on the major streams used in the future projection for the model were adjusted to account for projections of future climate change, as described in TH&Co (2020).
- Projected surface water deliveries from the Friant-Kern Canal were based on climate adjusted historical average deliveries from 1990/91 to 2009/10 provided by the Friant Water Authority (FWA, 2018), as described in TH&Co (2020).

From 1986 to 2017, estimated average annual groundwater pumping in the ETGSA was approximately 206,600 acre-ft/yr. The Sustainable Yield of the ETGSA has been estimated to be approximately 22,500 acre-ft/yr. In order to reduce groundwater pumping to sustainable levels by 2040, the ETGSA has developed the following transitional pumping schedule:

Eastern Tule GSA

2020-2025	90% of over-pumping
2025-2030	80% of over-pumping
2030-2035	30% of over-pumping
2035-2040	Sustainable
2040+	Sustainable

The effect of reducing groundwater pumping to sustainable levels will stabilize groundwater levels and help reduce land subsidence rates around the FKC. The model analysis of future land subsidence incorporates the ETGSA transitional pumping schedule as well as the transitional pumping schedules for all other GSAs in the Tule Subbasin.

The model projection assumes that the following projects will be implemented within the ETGSA:

Lead Entity	Project Name	Description	Time Frame	Annual Volume	Water Source
City of Porterville	Population Increase	Increase GW Production	2.5%/yr 2020-2040	9,500 af/yr by 2040	Groundwater
City of Porterville	Recycling Increase	Increase RW Applied to Ag	2.5%/yr 2020-2040	1,900 af/yr by 2040	Recycled Water



City of Porterville	Recycling Increase	Increase RW Recharge	2.5%/yr 2020-2040	1,600 af/yr by 2040	Recycled Water
City of Porterville	Tule River Recharge	Recharge Project	Starting 2019/20	900 af/yr	Tule River
City of Porterville	FKC Recharge	Recharge Project	Starting 2020/21	1,100 af/yr	FKC via Porterville ID
Porterville ID	SA 1 & 2	Expand distribution system	Starting 2018/19	3,200 af/yr	Tule River and FKC
Porterville ID	FKC/Tule River Banking Project	Develop water bank	Starting 2020/21	3,300 af/yr of leave-behind	FKC and others
Porterville ID	Recharge Policy	On-Farm recharge	Starting 2019/20	3,000 af/yr	Tule River and FKC
Saucelito ID	FKC/Deer Creek Banking Project	Develop water bank	Starting 2020/21	1,100 af/yr of leave-behind	FKC and others
Saucelito ID	Recharge Policy	On-Farm recharge	Starting 2019/20	2,000 af/yr	FKC
Kern-Tulare WD	In-District Pricing	Pricing change	Starting 2020/21	2,600 af/yr	N/A
Kern-Tulare WD	Reservoir Storage	Surface water storage	Starting 2029/30	500 af/yr	FKC and others
Kern-Tulare WD	CRC Pipeline	Deliver produced water	Starting 2024/25	680 af/yr	CRC Produced water
Terra Bella ID	Deer Creek Recharge	Divert and recharge DC	Starting 2017/18	800 af/yr	Deer Creek



PWC, VWD, & CMDC	SREP	Success Dam Enlargement	Starting 2024/25	400 af/yr	Tule River
Hope WD	In-District Recharge	Recharge Project	Starting 2022/23	5,000 af/yr every 3 years	FKC and others / unknown
Ducor ID	In-District Recharge	Pipeline and Recharge Project	Starting 2023/24	4,000 af/yr	FKC and others / unknown

These projects would add an additional 38,000 acre-ft of groundwater recharge to the ETGSA and all were included in the Tule Subbasin GFM v.2020a model simulation that projected potential future land subsidence, as published in the GSP for ETGSA.

The model analysis of future land subsidence conducted for the ETGSA GSP predicted as much as four feet of additional land subsidence beneath the FKC between 2020 and 2040 (see Figures 18 and 19). The greatest land subsidence was predicted to occur between Deer Creek and White River. Between 2040 and 2050, the rate of land subsidence is predicted to decrease as groundwater levels stabilize throughout the ETGSA. Less than 0.5 feet (average of 0.05 ft/yr) of land subsidence is predicted in the vicinity of the FKC after 2040.

While the Tule Subbasin GFM is good at predicting relative changes in land surface elevation given predicted groundwater pumping stresses, there remains uncertainty as to the magnitude and spatial distribution of land subsidence that would result from the ETGSA's planned transitional pumping schedule. Figure 19 shows the statistical ranges of potential land subsidence at various locations along the FKC based on multiple groundwater flow model realizations of the area. These predictions will be refined over time through the collection of additional data.

Critical elements of uncertainty include (but are not necessarily limited to):

- The groundwater elevation near the FKC at which inelastic compaction of the aquifer system is triggered (i.e. the groundwater elevation at which land subsidence will not occur).
- Depth-specific groundwater levels in the Monitored Area
- The depth of groundwater pumping that causes the greatest stress to the aquifer system and the most aquifer compaction.
- The relationship and timing of groundwater level changes with aquifer system compaction (the delay or lag between groundwater level changes and aquifer compaction or rebound).



- Aquifer system parameters of transmissivity and storativity including elastic and inelastic storage properties specific to the FKC area.
- Future precipitation conditions.

For this LSMP, potential uncertainty will need to be considered when selecting management actions to minimize future land subsidence.



2.0 Land Subsidence Management Goal

The goal of the Eastern Tule Land Subsidence Management Plan (LSMP) is to implement groundwater management measures necessary to minimize future non-recoverable land subsidence along the FKC in the SGMA transition period from 2020 – 2040 and to arrest nonrecoverable land subsidence along the FKC after 2040.

The LSMP includes the following elements to meet the goal:

- A land subsidence enhanced monitoring area that includes additional monitoring features and monitoring frequency relative to the Tule Subbasin-wide Monitoring Plan (the “Monitored Area”).
- An enhanced land subsidence monitoring network within the Monitored Area to collect the data necessary to address data gaps and uncertainty and inform basin managers regarding the status of land subsidence within the ETGSA with focus along the FKC.
- A land subsidence data collection program for the Monitored Area that ensures that data are collected in sufficient quantities, areal distribution, frequency and accuracy to provide meaningful results for evaluating progress with respect to meeting the land subsidence goal for the ETGSA.
- A central, secure monitoring database available to the ETGSA for their use in monitoring land subsidence and progress toward arresting land subsidence along the FKC.
- A land subsidence managed area (the “Managed Area”) where groundwater management actions may be different than those specified in the GSP to address the most active land subsidence along the FKC.
- Management Zones within the Managed Area where land subsidence management actions would be implemented.

The LSMP is both flexible and iterative, allowing for the addition or subtraction of monitoring features, as necessary, and to accommodate changes in monitoring frequency and alternative methodologies, as appropriate. The LSMP is also adaptive, to enable changes in management actions to address undesirable results.



3.0 Area Encompassed by the Land Subsidence Management Plan

To meet the land subsidence management goals identified in Section 2.0 of this LSMP, it will be necessary to implement a combination of monitoring and management actions in the vicinity of the canal. The recommended enhanced Monitored Area presented herein is the area, based on existing information and data, where land subsidence in the ETGSA has occurred in the past and where future groundwater level management is considered critical to avoiding land subsidence in the future. Throughout much of the recommended Monitored Area, the only management action specific to limiting land subsidence at the FKC will be an increase in the number of monitoring features (e.g. GPS Benchmarks) and frequency of monitoring those features. A portion of the Monitored Area will be set aside as a Managed Area where more urgent management actions may be needed to meet the land subsidence management goals.

It is noted that previous studies have shown that reductions in pumping to the west and outside the ETGSA boundary help mitigate land subsidence along the FKC. In accordance with Pixley Irrigation District GSA's commitment to coordinate and cooperate with the ETGSA as it relates to land subsidence mitigation along the FKC and implementation of the LSMP, as stated in the FWA Settlement Agreement, the southeastern portion of the Pixley Irrigation District GSA is included in this LSMP (see Figure 20). Coordination with other adjacent GSAs may be necessary to achieving the goals of the LSMP.

3.1 Monitored Area

The area addressed by the LSMP is defined by the Monitored Area shown on Figure 20. This area includes additional land subsidence monitoring features that are not included in the Tule Subbasin Monitoring Plan. The monitored area covers most of the ETGSA. The basis for the eastern and northern boundaries of the monitored area is the limit of land subsidence detected by the 2015 – 2018 InSAR map (see Figure 20). This area of land subsidence is considered recently active and prone to continued subsidence in the future. These boundaries are approximately two to three miles east of the communities of Ducor and Terra Bella and approximately one mile north of the Tule River at the FKC. The western and southern boundaries of the Monitored Area are the western and southern boundaries of the ETGSA.

3.2 Managed Area

A land subsidence Managed Area has been identified based on InSAR satellite data and groundwater flow model analysis of land subsidence presented in Section 1.6 of this LSMP (see Figure 21). The Managed Area extends two miles on either side of the Friant-Kern Canal from the Tule River to the southern boundary of the ETGSA. Preliminary analysis using a groundwater flow model showed that an elimination of groundwater pumping in this area had the greatest impact on groundwater levels in the immediate vicinity of the canal and were most effective at mitigating future land subsidence along the FKC (see Figures 14 and 16). Management actions



within this area will be separate from, and may be different than, planned management actions published in the ETGSA GSP for the greater ETGSA.

3.3 Management Zones

The Managed Area has been subdivided into 96 Management Zones where management actions specific to that area will be implemented (see Figure 21). There are eight, ¼-mile east-west zones on each side of the FKC (20 total). There are six north-south zones (A through F). Thus, there are 96 total Management Zones within the Managed Area. Crop types in the Managed Area, as of 2018, are shown on Figure 22.



4.0 Land Subsidence Monitoring Network

The land subsidence monitoring network specified herein includes, and builds upon, the land subsidence monitoring network described in the Tule Subbasin Monitoring Plan.² There are multiple tools available to monitor land subsidence, including:

- Benchmarks
- InSAR satellite surveys
- Extensometer Data

In addition, given that the potential for land subsidence is a function of groundwater levels, monitoring wells are also a critical tool for predicting and preventing land subsidence. In consideration of this, monitoring wells specific to this LSMP have been incorporated in addition to the minimum groundwater level monitoring network described in the Tule Subbasin Monitoring Plan.

4.1 Land Subsidence Monitoring Features

Monitoring of changes in land surface elevation related to groundwater withdrawal will be conducted through global positioning surveys, data collected from extensometers, and satellite data.

4.1.1 Global Positioning Surveys

Existing GPS Benchmarks in the Tule Subbasin Monitoring Plan

The FWA measures land surface elevation at 32 stations along the Friant-Kern Canal, including 16 within the ETGSA Monitored Area, using a Global Positioning System (GPS) (see Figure 23). Data from these surveys are entered into the Tule Subbasin Data Management System (DMS) on an annual basis and will be available for download and analysis.

Nineteen GPS survey stations have been established in the ETGSA Monitored Area as part of the Tule Subbasin Monitoring Plan (see Figure 23). Each survey station consists of a benchmark labeled with the station identification.

The Porterville GPS Station (Station P056) is operated by UNAVCO and has been collecting daily land surface elevation data since November 2005.

² Tule Subbasin Coordination Agreement, 2020. Attachment 1: Tule Subbasin Monitoring Plan. Prepared for the Tule Subbasin Technical Advisory Committee. Dated January 2020.



Proposed Additional GPS Benchmarks for the Eastern Tule GSA Land Subsidence Monitoring and Management Plan

Additional GPS benchmarks are proposed for both the Monitored Area and Managed Area of the ETGSA LSMP. Recommended benchmarks will be located at approximately 1-mile spacing throughout the Managed Area (see Figure 23). Where possible, benchmarks consisting of a brass disc will be affixed to an existing concrete structure. If no concrete structure is available, the benchmark will be constructed within a 3-foot deep hole encased with 6-inch diameter PVC casing. Two 4-foot long sections of 0.625-inch diameter copper-plated steel rod or rebar will be advanced into the soil within the encased borehole and cemented into place. The benchmark will be completed at the surface with a 3.25-inch diameter brass tablet cemented to the top of the rods with industrial-grade epoxy. Each benchmark will be stamped with the bench-mark identifier.

4.1.2 Extensometers

Existing Extensometer

The USGS collects data on aquifer system compaction, which causes land subsidence, from one existing extensometer located adjacent to the FKC approximately one mile north of Deer Creek (22S/27E-30D2; see Figure 30). The USGS extensometer consists of a 2-inch diameter steel pipe anchored within a 12-inch diameter well at a depth of 1,180 ft bgs. The extensometer measures the mechanical response of the aquifer system to changes in piezometric pressure (changes in groundwater levels). The well is perforated from 1,083 to 1,180 to allow for groundwater level measurements, which are measured once a day using a pressure transducer. The data are accessed via the USGS website and entered annually into the Tule Subbasin DMS.

4.1.3 Satellite Data (InSAR)

Changes in land surface elevation over time can be observed on a regional scale using satellite data. The data is generated using interferometric synthetic aperture radar (InSAR). Monthly InSAR datasets will be published on a quarterly basis by the DWR. Additional information on the DWR's InSAR subsidence data is available at <https://data.cnra.ca.gov/dataset/tre-altamira-insar-subsidence>.

4.2 Land Subsidence Monitoring Procedure

4.2.1 Global Positioning Surveys

The GPS network will be established and monitored in accordance with National Geodetic Survey (NGS) Guidelines for Establishing GPS-Derived Ellipsoid Heights (National Oceanographic and Atmospheric Administration and Guidelines for Establishing GPS-Derived Orthometric Heights. All GPS-derived elevations will be constrained to an established NGS benchmark located on Lake



Success Dam (KT 200). All land surface elevation readings will be to an accuracy of 0.1 feet relative to NAVD88.

Land surface from the Porterville GPS Station will be downloaded from the UNACO website <https://www.unavco.org/instrumentation/networks/status/nota/overview/P056> for analysis once a month.

4.2.2 Extensometers

The USGS extensometer (Site 355933119062001) is equipped with a continuous monitoring device to record aquifer system compaction. Aquifer system compaction data will be downloaded from the USGS website <https://maps.waterdata.usgs.gov/mapper/index.html> for analysis once a month.

4.2.3 Satellite Data (InSAR)

InSAR data will be downloaded from <https://gis.water.ca.gov/arcgisimg/rest/services/SAR> to develop maps showing regional land surface changes.

4.3 Frequency of Measurement

4.3.1 Global Positioning Surveys

GPS surveys of the stations within the LSMP managed area shown on Figure 23 will be conducted on a quarterly basis. GPS surveys of stations located outside the managed area but within the LSMP monitored area will be conducted annually. If monthly extensometer data indicate relatively rapid changes in land subsidence, more frequent surveys may be required. Otherwise, the GPS survey frequency requirements will be reevaluated on an annual basis.

4.3.2 Extensometers

Aquifer system compaction is measured on a continuous basis at the USGS extensometer. Aquifer system compaction data will be downloaded from the USGS website for analysis monthly.

4.3.3 Satellite Data (InSAR)

InSAR data will be downloaded from the DWR website and analyzed on a quarterly basis as it is published.

4.4 Groundwater Level Monitoring

ETGSA, monitoring wells have been identified to enable the collection of data from both the Upper Aquifer and Lower Aquifer. The depths of each of these units follow the hydrogeological



conceptual model of the Tule Subbasin outlined in the hydrogeological conceptual model and incorporated into the Tule Subbasin Groundwater Flow Model (TH&Co, 2020). The Upper Aquifer is generally unconfined to semi-confined. The bottom of the Upper Aquifer varies in depth in the Monitored Area from approximately 400 ft bgs in the western portion to less than 100 ft bgs in the northeastern. The Lower Aquifer occurs below the Upper Aquifer with total depths up to 1,300 ft bgs.

Monitoring wells are identified with perforations exclusively in the Upper Aquifer or Lower Aquifer. Individual wells perforated across multiple aquifer layers will not be allowed for new wells constructed as part of this LSMP. Over time, wells in the monitoring network that are perforated across multiple aquifers will be replaced with nested or cluster wells with perforations specific to the Upper or Lower aquifers.

4.4.1 Monitoring Features

4.4.1.1 Upper Aquifer Monitoring Wells

Upper aquifer monitoring wells are shown on Figure 24. A total of 42 monitoring wells have been identified for measuring groundwater levels within the Upper Aquifer within the Monitored Area. Of the 42 wells, seven are existing wells. The remaining 35 wells are proposed to be constructed. Within the LSMP Managed Area, Upper Aquifer well spacing is generally 1.5 to 2 miles and spread evenly across the area. The same spacing was applied to the Monitored Area west of the Managed Area. Upper Aquifer well spacing east of the Managed Area was more spread out, particularly in the southern part where the Upper Aquifer is not saturated.

The depths and perforation intervals of the new Upper Aquifer monitoring wells will vary depending on location within the LSMP Monitored Area. In general, Upper Aquifer monitoring wells will be perforated from approximately 10 ft below the then current static groundwater level to the bottom of the Upper Aquifer, as defined by the Tule Subbasin model. In general, new Upper Aquifer wells constructed on the west side of the Monitored Area will be the deepest and new Upper Aquifer wells constructed in the northeast Monitored Area will be shallowest. It is noted that the depths presented herein are for planning purposes. The final well construction details will be refined in the field during drilling once site-specific data have been obtained and reviewed. As such, the final well depths and perforation intervals may be adjusted for site specific conditions.

A conceptual well design drawing for new Upper Aquifer monitoring wells is shown on Figure 25. In general, new monitoring wells will be constructed of 5-inch diameter Schedule 80 PVC blank and slotted casing. A filter pack for the new wells will be placed in the annular borehole space opposite the perforations from the total borehole depth to at least 10 feet above the top of perforations. The upper portion of the annular space shall be backfilled with a seal consisting of bentonite or other approved sealing material. The surface completion for each new monitoring well will include a steel above-ground riser equipped with a protective locking cap for keeping the



wellhead secure. The above-ground riser will be surrounded by cement-filled steel bollards for further protection.

A dedicated reference point will be established and marked on the top of each monitoring well casing. All groundwater level measurements shall be obtained relative to the reference point. The elevation of the reference point shall be surveyed to an accuracy of 0.1 foot relative to mean sea level (NAVD88) by a California licensed land surveyor. The location of each well will be surveyed to an accuracy of 1 foot.

4.4.1.2 Lower Aquifer Monitoring Wells

Lower Aquifer monitoring wells are shown on Figure 26. A total of 47 wells have been identified for monitoring groundwater levels in the Lower Aquifer within the Monitored Area. Of the 47 wells, 22 are existing wells. The remaining 25 wells are proposed to be constructed. Within the LSMP Managed Area, Lower Aquifer well spacing is generally the same as for the Upper Aquifer monitoring wells. More Lower Aquifer wells are included in the southeast part of the Monitored Area where the Lower Aquifer is present and saturated.

Potential existing Lower Aquifer wells for which access is denied or, upon investigation, do not otherwise meet the minimum criteria specified in Section 3.2.1.1 of the Coordination Agreement, will be removed and replaced with an alternate existing well with documented total depth and perforation interval located in the same area. If no other wells exist in the area, a new Lower Aquifer well will be constructed in the area.

The depths and perforation intervals of the new Lower Aquifer monitoring wells will vary depending on location within the Monitored Area. In general, Lower Aquifer monitoring wells will be perforated at depths where the aquifer is assumed to be confined, as defined by the Tule Subbasin conceptual model. New Lower Aquifer monitoring wells will be constructed with total depths ranging from 400 to 1,000 ft bgs. It is noted that the depths presented herein are for planning purposes. The final well construction details will be refined in the field during drilling once site-specific data have been obtained and reviewed. As such, the final well depths and perforation intervals may be adjusted for site specific conditions.

A conceptual well design drawing for new Lower Aquifer monitoring wells is shown on Figure 27. In general, new monitoring wells shall be constructed of 5-inch diameter PVC blank and slotted casing. A dedicated reference point shall be established and marked on the top of each monitoring well casing. All groundwater level measurements shall be obtained relative to the reference point. The elevation of the reference point shall be surveyed to an accuracy of 0.1 foot relative to mean sea level (NAVD88) by a California licensed land surveyor. The location of each well will be surveyed to an accuracy of 1 foot.



4.4.2 Monitoring Procedure

Groundwater level measurements shall be collected from each well using either a steel tape, a calibrated well sounder, or a pressure transducer. Where possible, groundwater level measurements shall be collected with a steel tape or an electrical groundwater level sounder calibrated to the nearest 0.01 ft. For pre-existing wells with limited access, a calibrated steel tape and chalk may be used. All equipment must be in good working condition. No damaged or refurbished electrical sounding tape shall be used. All new monitoring wells shall be equipped with calibrated pressure transducers.

Groundwater level measurements must be representative of static (i.e. non-pumping) groundwater level conditions. To ensure measurement of static groundwater levels in active pumping wells, the field technician collecting the data must verify that the pump has been off for at least 24 hours prior to collecting the data.

4.4.2.1 Manual Groundwater Level Measurements

The following monitoring procedure shall be used to obtain manual groundwater level measurements in the field:

- Upon arrival at each site, the field technician shall note the well name, time of day, and date on the standard groundwater level data form (see Appendix A).
- All monitoring equipment shall be cleaned prior to lowering it into the well(s) using the following decontamination procedure:
 - Wash equipment with an Alconox solution which is followed by a deionized water rinse.
 - Triple rinse equipment with deionized water.
 - Place equipment on clean surface such as teflon or polyethylene sheet to air dry.
- To measure the depth to groundwater with a steel tape or an electrical sounder or meter, slowly lower the steel tape or water level electrical tape into the designated sounding port for production wells and into the main well for monitoring wells. Steel tapes and electrical tapes are lowered to the water surface, as determined by the audio signal, meter, or technician. Depths to groundwater are measured relative to the dedicated reference point at the top of the casing or sounding tube. Depth to groundwater shall be immediately recorded on the standard groundwater level data form (see Appendix A). Depths to groundwater shall be compared to previous measurements in the field and re-measured if significantly different.
- For wells with limited access (such as agricultural wells or domestic wells equipped with a pump), a steel tape and chalk may be used. For this method, chalk is applied to a 1- to 3-foot section of the steel tape prior to lowering in the well. The steel tape is lowered to a depth at least 1-ft below the static groundwater level and a whole number on the calibrated tape is matched to the reference point at the surface. Both the foot mark held at the



reference point and the groundwater level observed on the chalk shall be recorded on the standard field forms (see Appendix B). The difference between the two is the depth to groundwater.

- When finished sounding the groundwater level, all downhole equipment shall be removed, and where existing, the well cap shall be replaced, and the riser locked.
- Prior to leaving the monitoring well site, the field representative shall note any physical changes in the concrete well pad and riser pipe, such as erosion, cracks or damage. All changes shall be recorded on the standard field forms provided in Appendices A and B.

4.4.2.2 Automatic Groundwater Level Measurements Using Transducers

Transducers shall be installed in all new monitoring wells and existing monitoring wells. Transducers shall be installed below the groundwater level with enough submergence to accommodate anticipated groundwater level fluctuations.

4.4.3 Frequency of Measurement

Groundwater level measurements will be collected from existing monitoring wells within the Monitored Area on a quarterly basis. Groundwater level measurements from all new monitoring wells will be collected using pressure transducers permanently installed in the wells and set to collect one measurement per day. Pressure transducers will be downloaded on a quarterly basis. During each download session, the field technician will also obtain a manual groundwater level measurement to verify transducer readings and ensure that the instruments are working properly.



5.0 Assessment and Improvement of Monitoring Network

The LSMP is both flexible and iterative, allowing for the addition or subtraction of monitoring features, as necessary, and to accommodate changes in monitoring frequency and alternative methodologies, as appropriate.

5.1 Land Surface Monitoring Data Gaps

The land surface elevation benchmark stations identified in the Tule Subbasin Monitoring Plan do not provide the spatial resolution necessary to provide detailed confirmation of areal land subsidence indicated by InSAR satellite data in the enhanced Monitored Area and particularly in the Managed Area of this LSMP. To address this data gap, a total of 85 additional benchmark stations have been identified within the Monitored Area, which would be added to the 13 benchmarks that have been established for the Tule Subbasin Monitoring Plan (see Figure 23). Of the 85 new benchmarks, 57 would be located within the Managed Area at a spacing of approximately 1 mile between benchmarks to provide detailed resolution of land surface elevation changes along the FKC. It is recommended to obtain GPS surveys of these benchmarks on a quarterly basis.

In addition to the existing USGS extensometer, two additional extensometers are planned for the Tule River/Friant-Kern Canal Water Bank and Deer Creek/Friant-Kern Canal Water Bank projects. Assuming that these monitoring features are constructed and that the USGS extensometer can be preserved, they will provide suitable sites for monitoring aquifer system compaction and determining protective groundwater elevations.

5.2 Groundwater Monitoring Data Gaps

Despite the number of existing monitoring wells that have been identified within the Tule Subbasin, there remain data gaps that, if addressed, would improve the ability to monitor groundwater level changes and flow patterns specific to the Upper and Lower aquifers. The current data gaps relate primarily to spatial coverage of monitoring features necessary to prepare detailed groundwater level contour maps and hydrographs specific to the Upper and Lower aquifers in the enhanced Monitored Area. Thirty-five (35) additional Upper Aquifer monitoring wells are recommended for the Monitored Area in addition to the seven existing Upper Aquifer monitoring wells to address the data gaps. In addition, 25 new Lower Aquifer monitoring wells are recommended for this area to supplement the 22 existing Lower Aquifer monitoring wells. Selected new monitoring wells will be designated as RMS wells for monitoring compliance with groundwater level sustainable management criteria near the FKC.

In addition to groundwater level data gaps, there is a lack of aquifer parameter data, as obtained from controlled pumping tests of wells. The groundwater flow model has been developed based predominantly on short-term pumping tests, which enable the development of estimates of aquifer



transmissivity. However, these tests are not as representative as long-term pumping tests (24-hr tests or longer). Further, pumping tests where groundwater level interference is measured in nearby monitoring wells have not been conducted. These tests enable the estimation of aquifer storage properties. During the construction of new monitoring features, it is anticipated that long-term pumping tests will be conducted to obtain aquifer parameter data specific to both the Upper and Lower aquifers. Further, pumping tests will be planned, where feasible, on existing high capacity groundwater production wells.



6.0 Land Subsidence Monitoring and Management Committee

A Land Subsidence Monitoring and Management Committee (LSMC) will be formed as part of the LSMP to periodically review data and technical reports collected as part of the plan. The LSMC will consist of technical experts assigned by the stakeholders as defined in Section 6.1 below. The LSMC would review data and technical analyses collected by ETGSA or their technical representatives and provide technical comments and recommendations to the ETGSA. The LSMC will be a standing committee and will be subject to opening meeting requirements of the Ralph M. Brown Act.

6.1 Representation

The LSMC shall consist of seven representative technical experts from the following agencies:

- ETGSA (two representatives with alternates),
- FWA (one representative with alternate),
- Tule Subbasin Technical Advisory Committee (one representative with alternate),
- Pixley Irrigation District (one representative with alternate), and
- Eastern Tule White Area Growers, Inc. (two representatives with alternates).

Additionally, the ETGSA may consult with other public agencies deemed to have relevant expertise or interest such as the California State Department of Water Resources, County of Tulare, USGS, or others. The ETGSA may also invite guests to participate in meetings of the LSMC to present, explain, or clarify the data and analyses collected in accordance with the LSMP.

6.2 Responsibilities

The ETGSA will convene timely meeting(s) of the LSMC to review monitoring data and reports and evaluate changes to the LSMP. The LSMC will meet at the request of the ETGSA, no less than in July and December of each year to:

- Review and analyze monitoring data and updated model results.
- Evaluate land surface elevation trends related to interim milestones, minimum thresholds and measurable objectives.
- Review proposed refinements to the LSMP.
- Provide recommendations to the ETGSA.

6.3 Recommendations to the ETGSA

Recommendations from the LSMC to the ETGSA may include (but are not limited to):

- Changes to the number or location of monitoring wells.



- Changes to the number or location of extensometers.
- Changes in monitoring frequency.
- Changes in monitoring technology.
- Changes in management actions.
- Refinement of models.
- Other modifications to the LSMP.
- Changes to the LSMC meeting schedule.



7.0 Reporting

At the end of each water year (ending September 30), ETGSA's technical consultant will analyze the data generated per the LSMP during the prior water year. The results and interpretations generated from the analysis will be documented in an annual report to be submitted to the ETGSA in January following the water year. Key sections of the annual report will include:

Section 1 – Introduction. This section provides background information on the history of land subsidence in the ETGSA, the formation of the LSMC and its responsibilities, and the LSMP.

Section 2 – Ground-Level Monitoring Program. This section describes the monitoring and testing activities performed by ETGSA per the LSMP during the previous calendar year.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring and testing data collected and analyzed during the previous calendar year. It also includes an evaluation of the effectiveness of the LSMP at maintaining land subsidence rates in accordance with the goals of the LSMP.

Section 4 – Conclusions and Recommendations. This section summarizes the main conclusions derived from the monitoring program through the previous calendar year and recommends updates to the LSMP, if any, as warranted by the data.

Section 5 – References. This section lists the publications cited in the report.

A draft version of the annual report will be submitted to the LSMC for review and comment prior to the December LSMC meeting. Upon consideration of all comments, the final report will be submitted to the ETGSA in January for review and consideration.



8.0 References

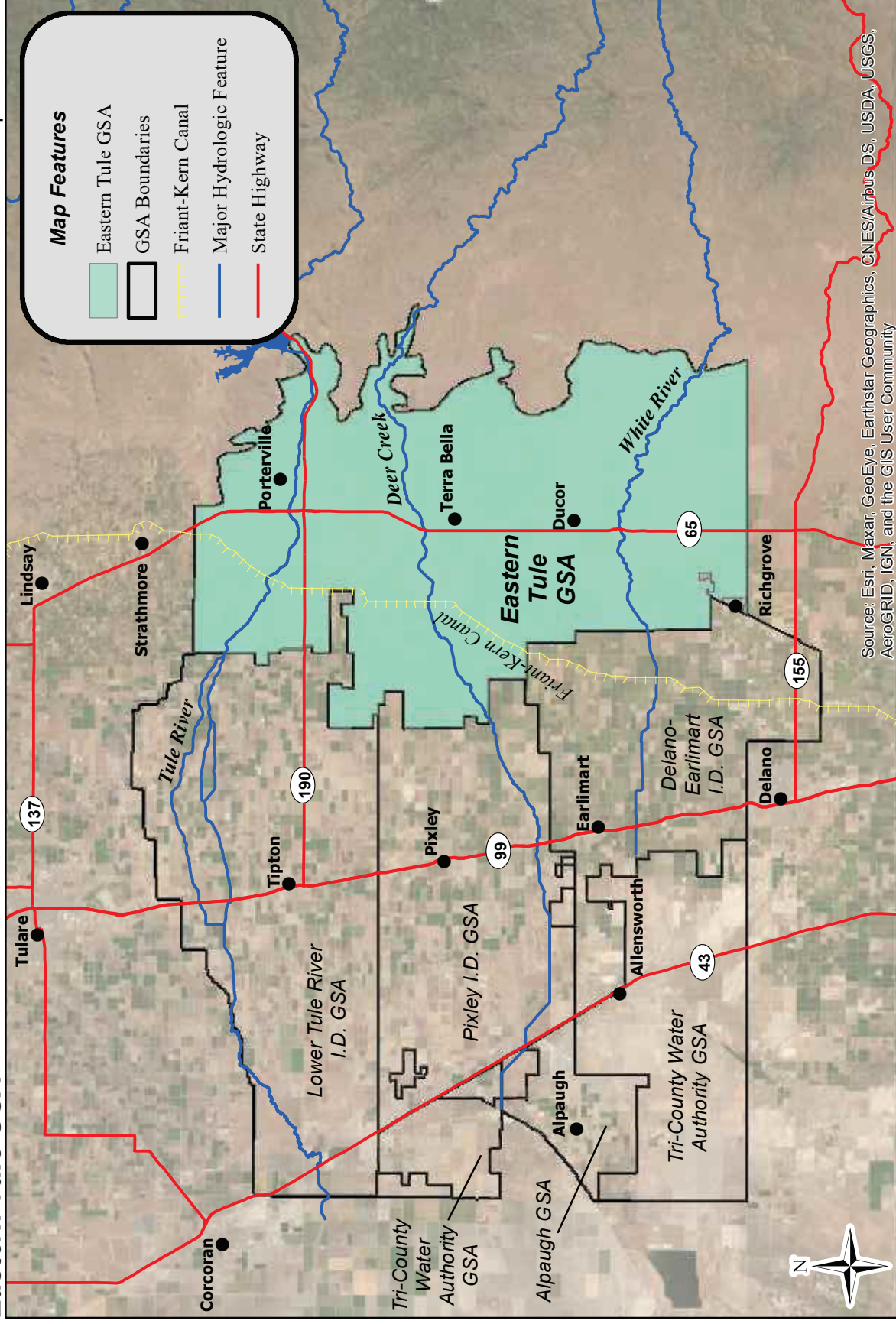
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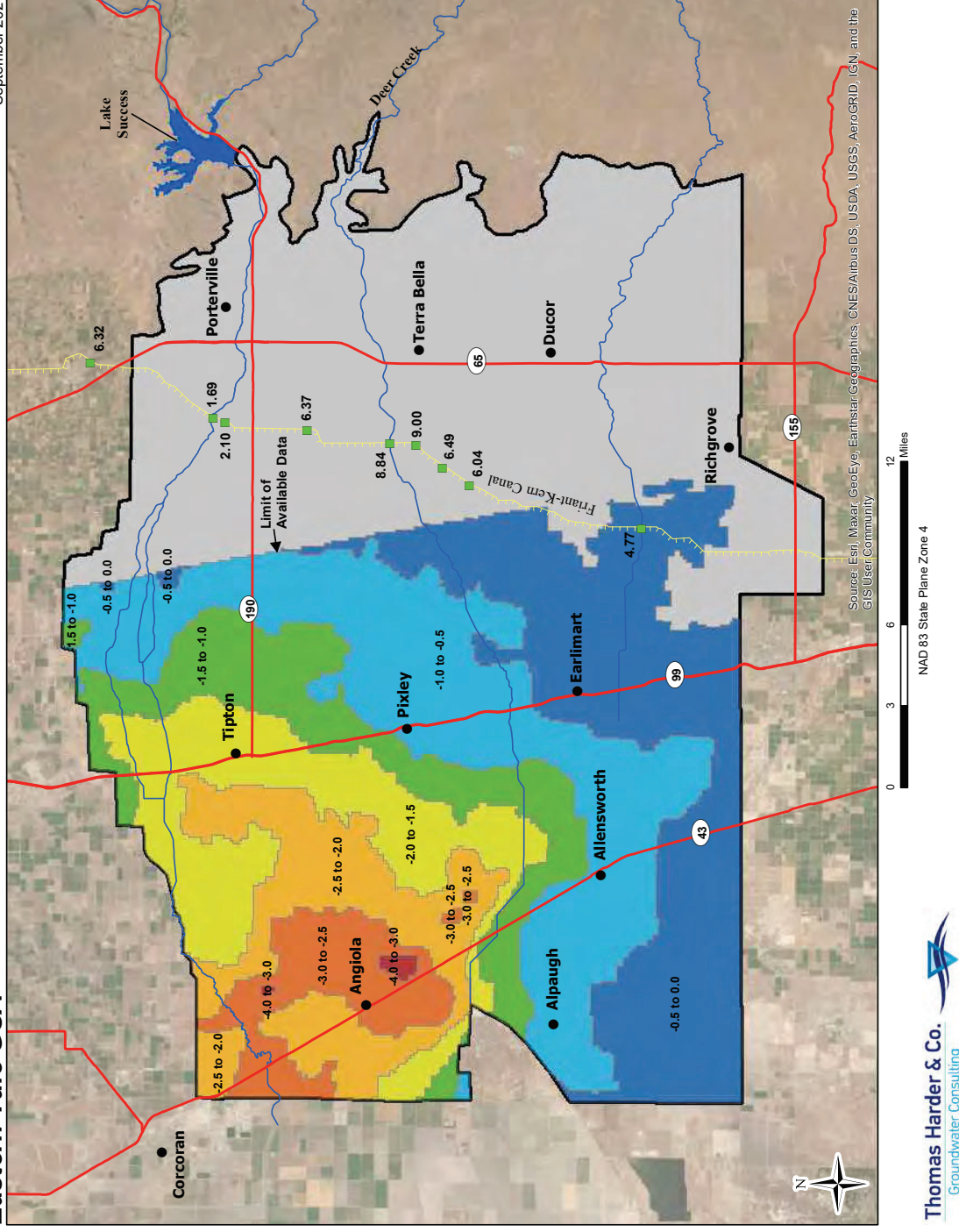


Figures



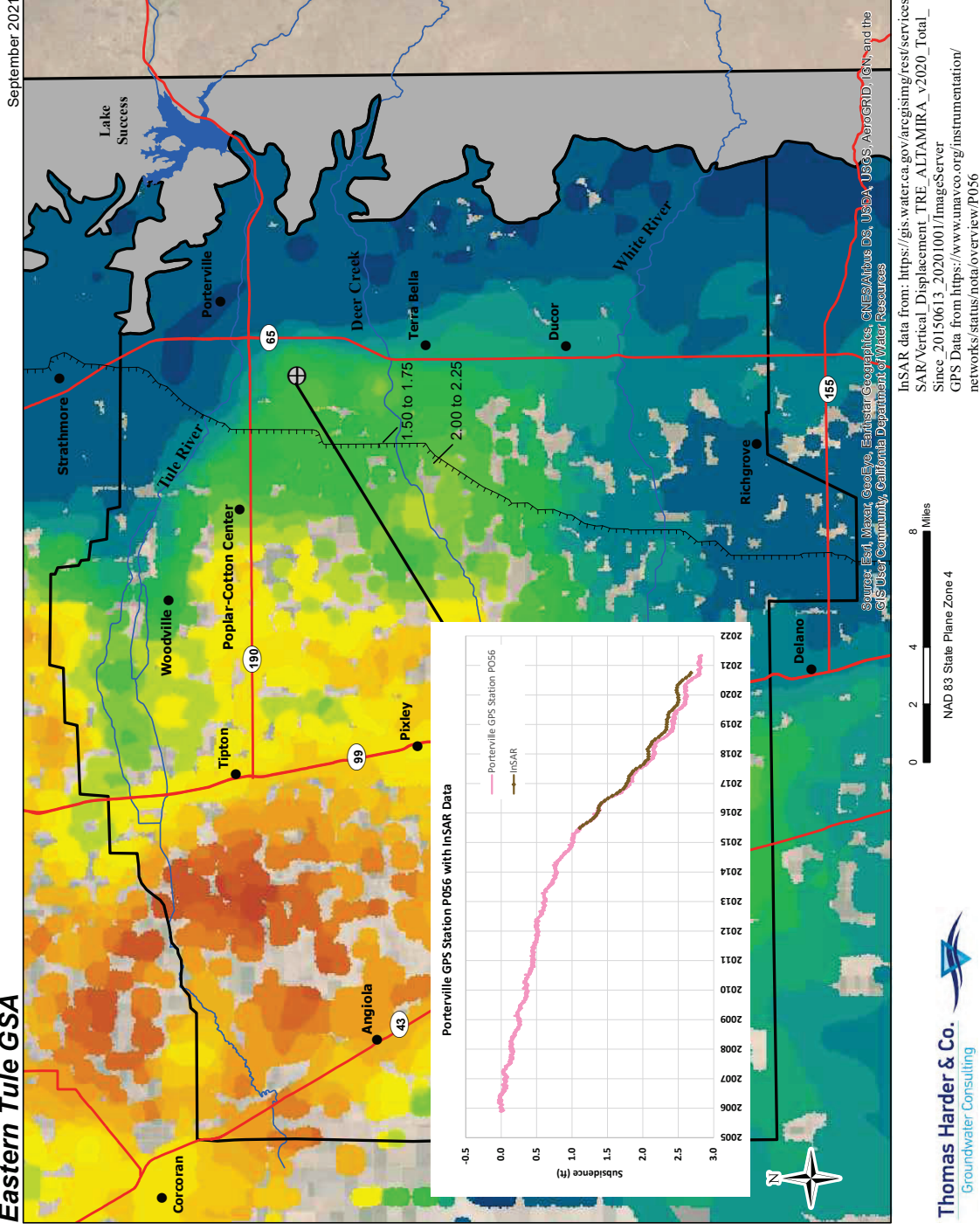
Eastern Tule GSA





2007 to 2011 Land Subsidence

Figure 2

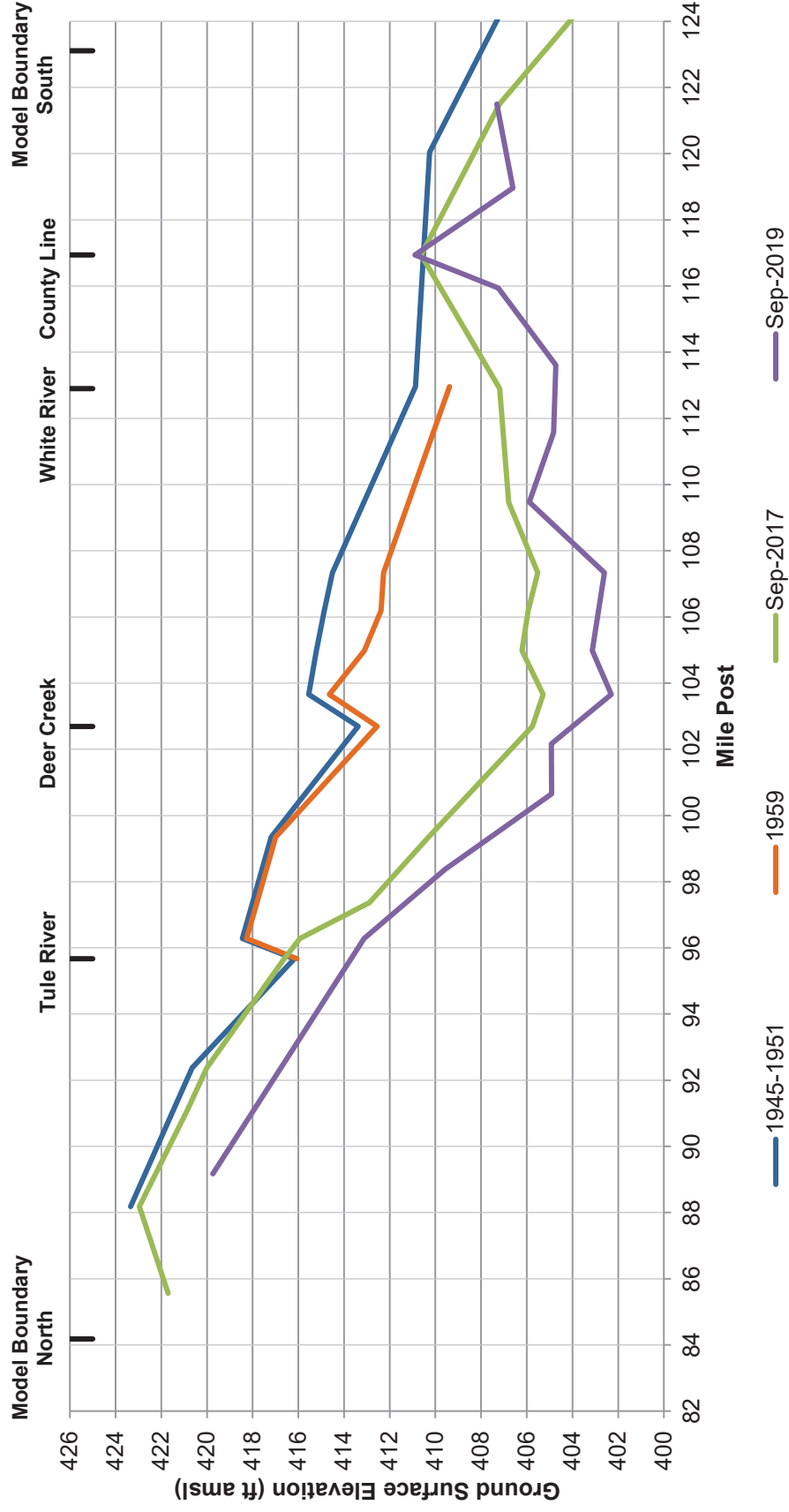


2015 to 2020 Land Subsidence

Figure 3

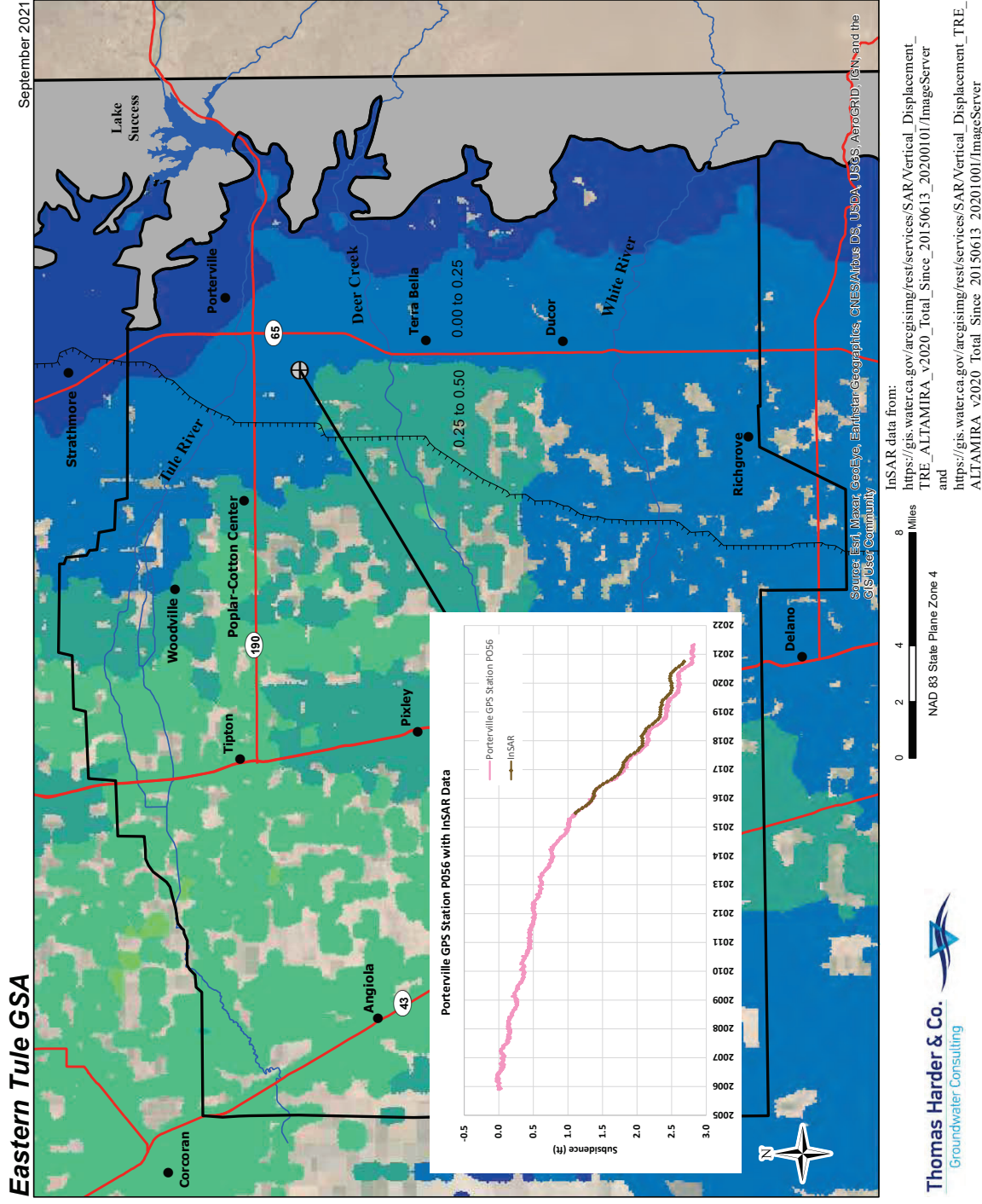
Figure 4

Profile of Historical Land Surface Elevation Change Along the Friant-Kern Canal



Note: Historical elevations from Stantec. 2019 GPS data not shown.

Eastern Tule GSA



Land Subsidence Monitoring Plan

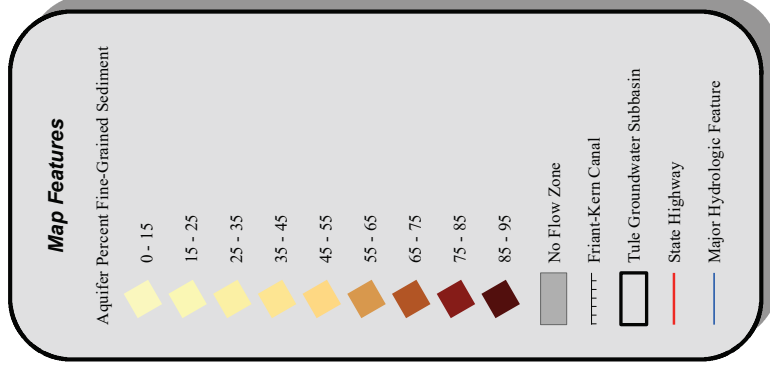
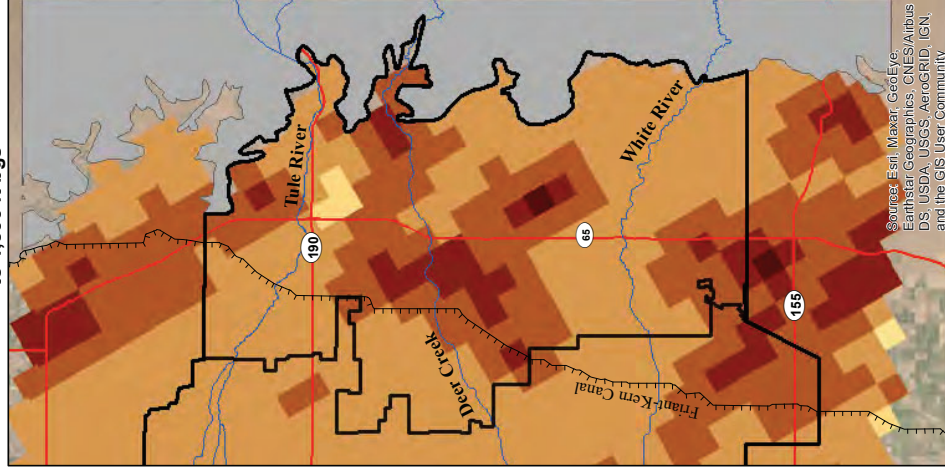
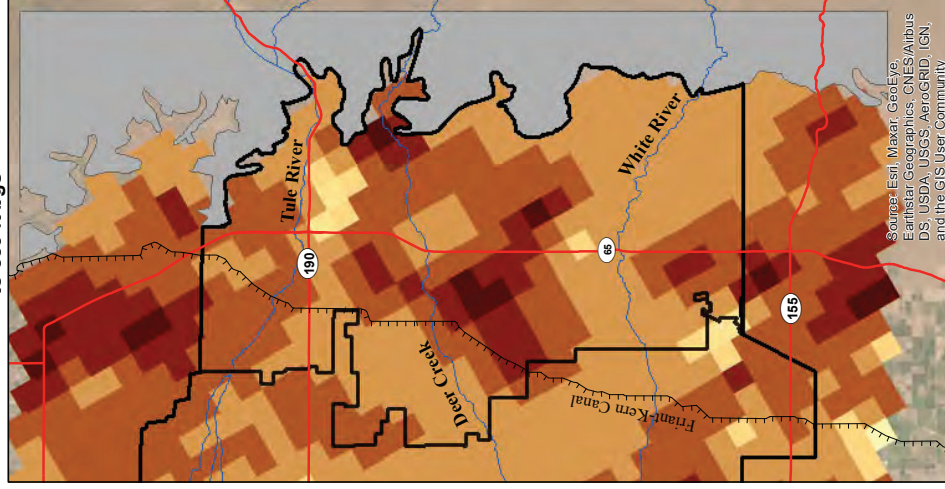
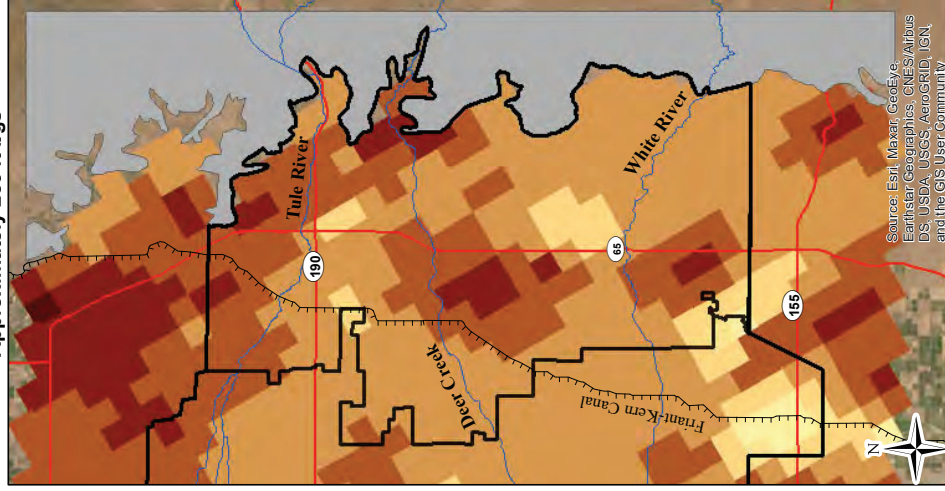
**Land Subsidence in the
Tule Subbasin
January 2020 - October 2020**
Figure 5

Land Subsidence Monitoring Plan

Eastern Tule GSA

Land Surface to
Approximately 250 ft bgs

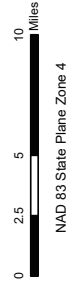
September 2021
Approximately 350 ft bgs
to 1,300 ft bgs



Note: Data modified from USGS
Professional Paper 1766

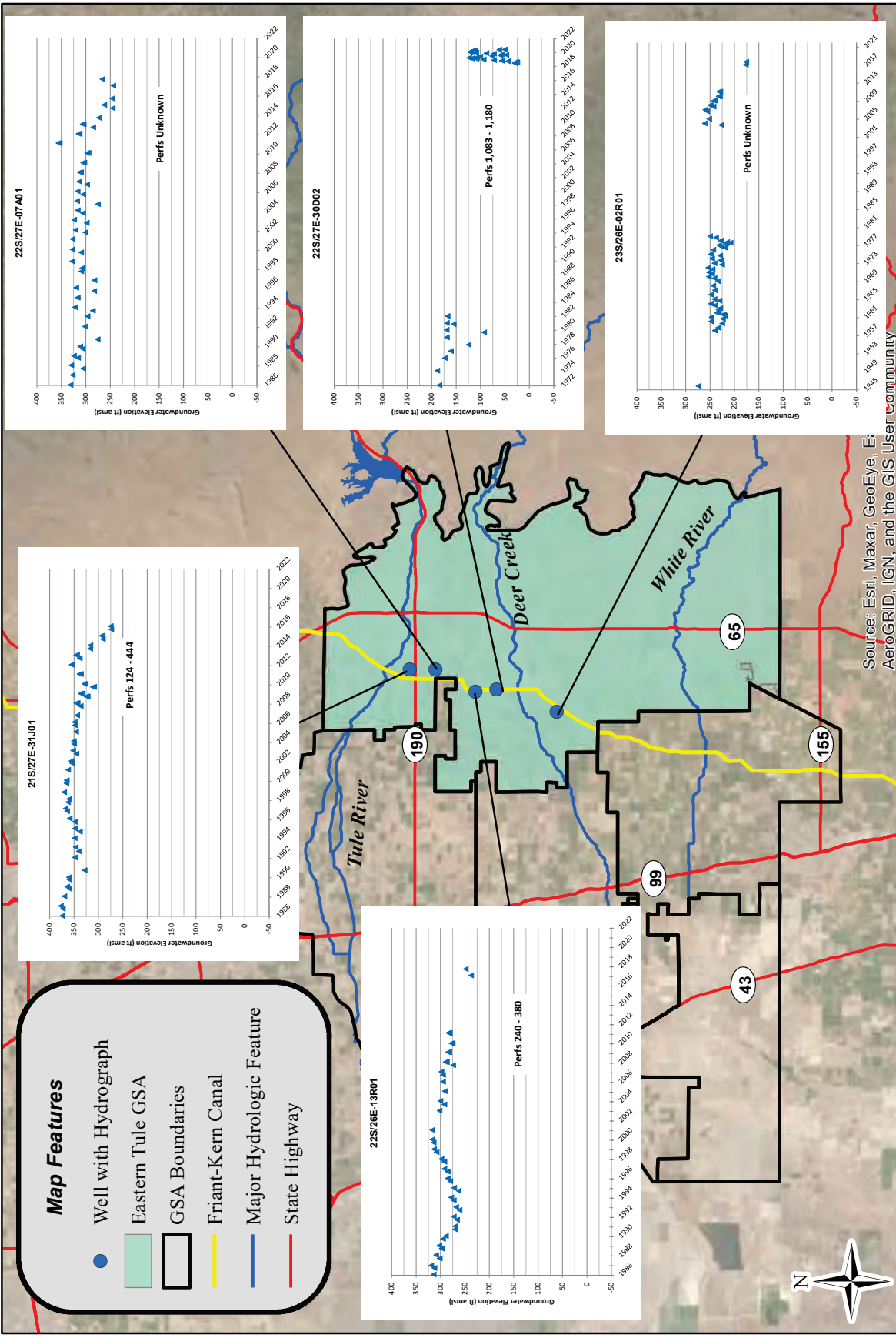
Percent Fine-Grained Sediments with Depth

Figure 6



Eastern Tule GSA

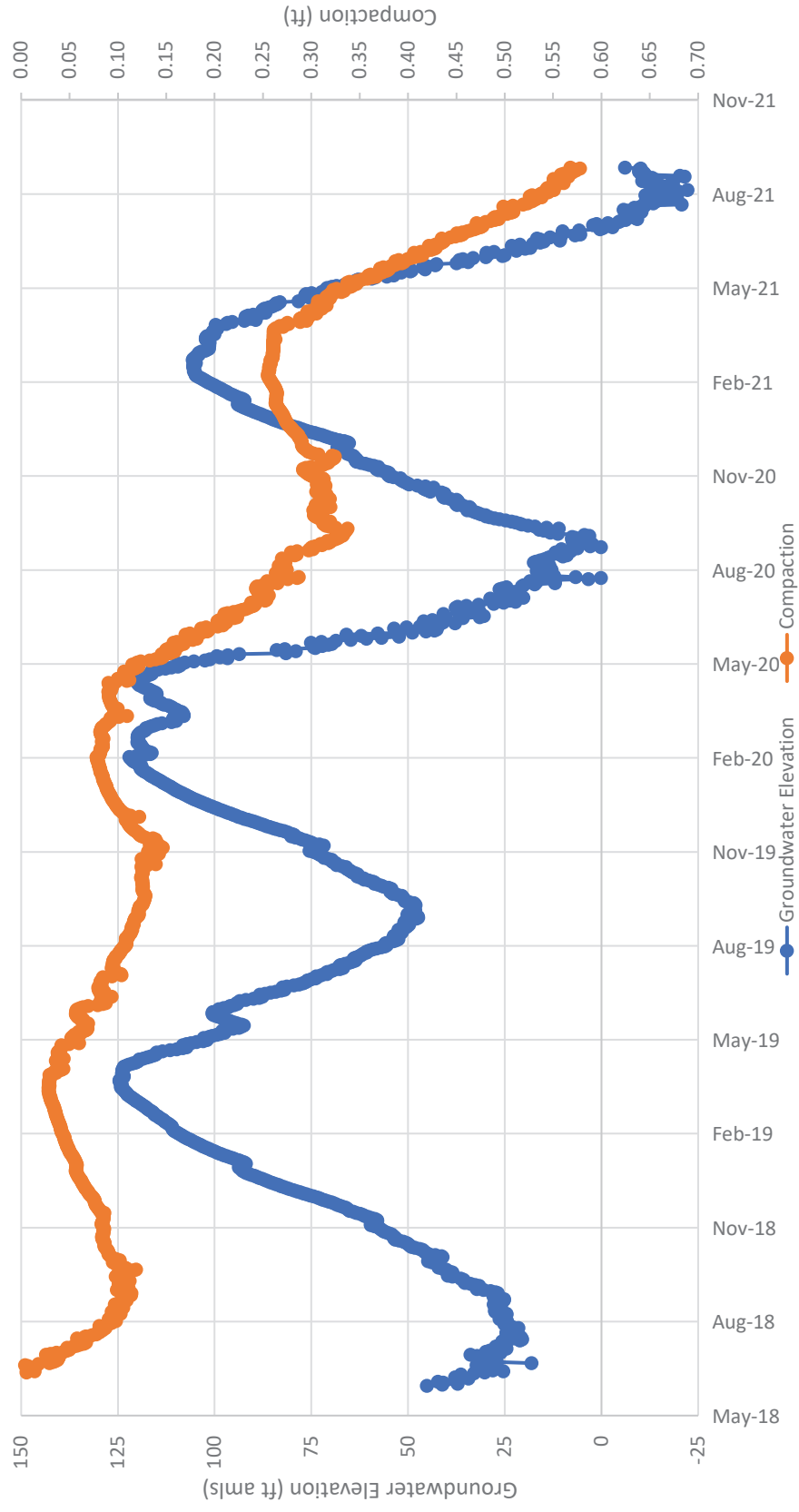
Land Subsidence Monitoring Plan September 2021



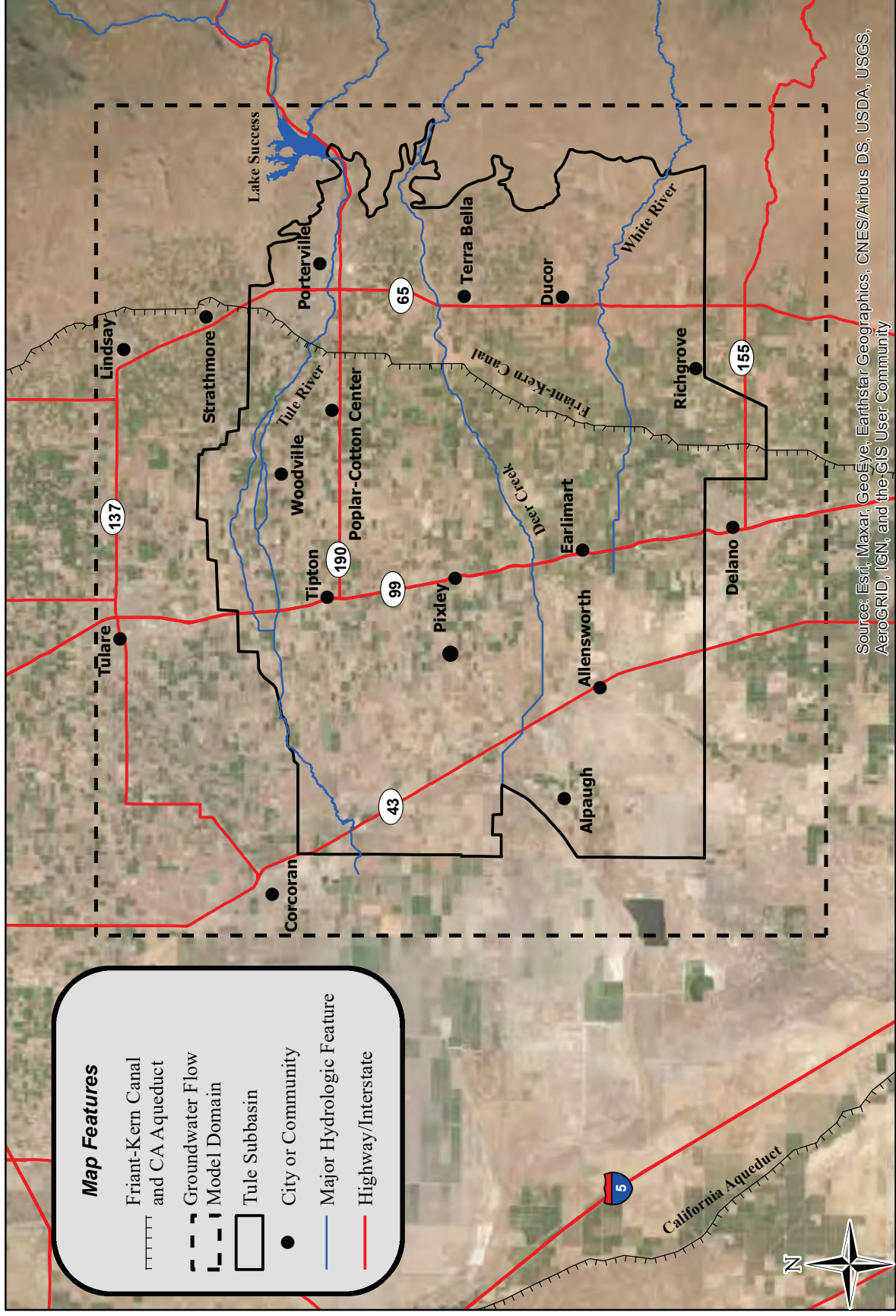
Groundwater Levels in Selected Wells Along the Friant-Kern Canal
Figure 7

Figure 8

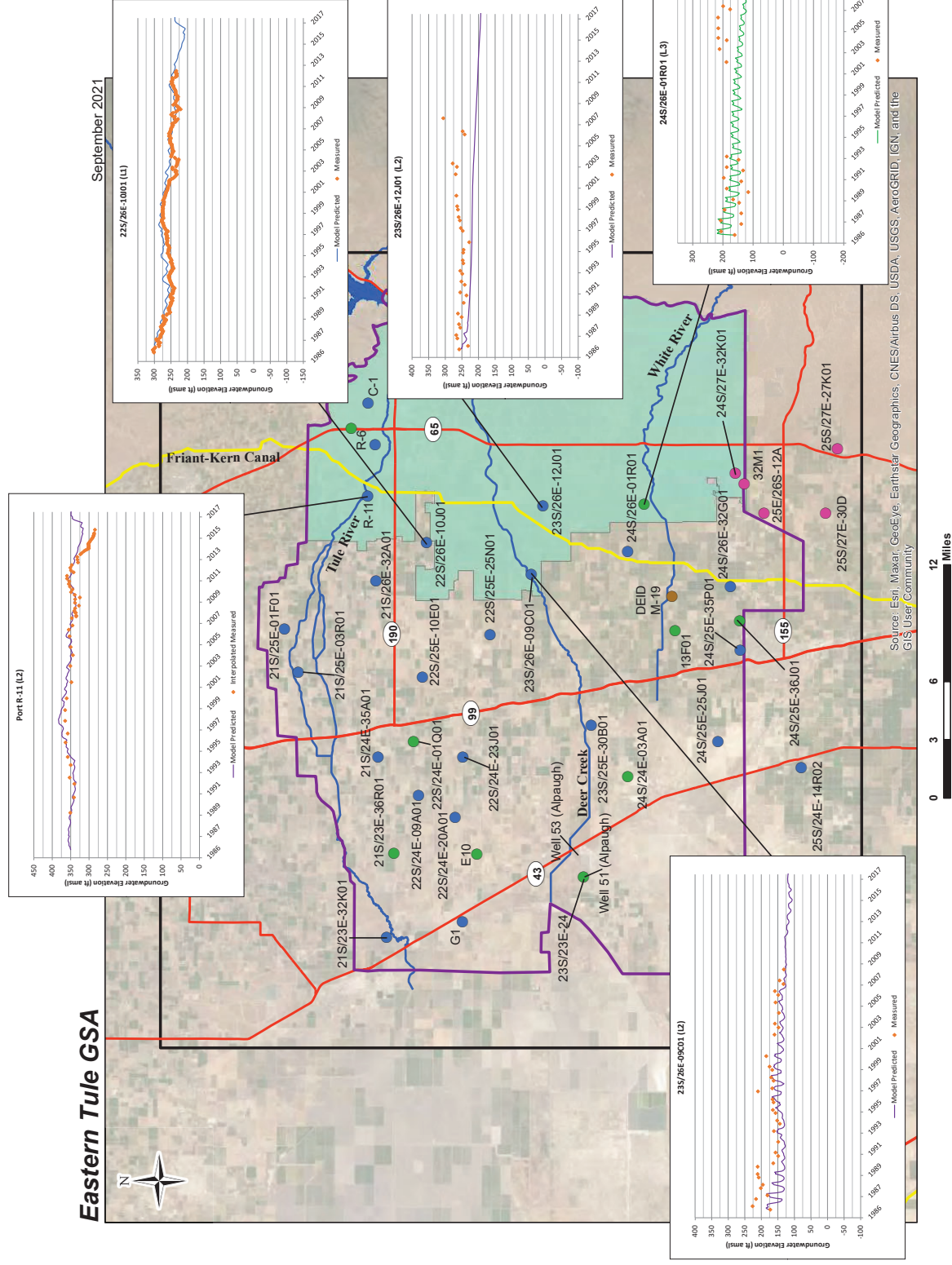
Aquifer System Compaction and Groundwater Level Change at USGS Extensometer
at Friant-Kern Canal near Deer Creek (22S/27E-30D02)



Data from USGS Site 3559331 19062001, <https://maps.waterdata.usgs.gov/mapper/index.html>
Extensometer depth 1,180 ft bgs and screened interval 1,083-1,180 ft bgs.



Land Subsidence Monitoring Plan



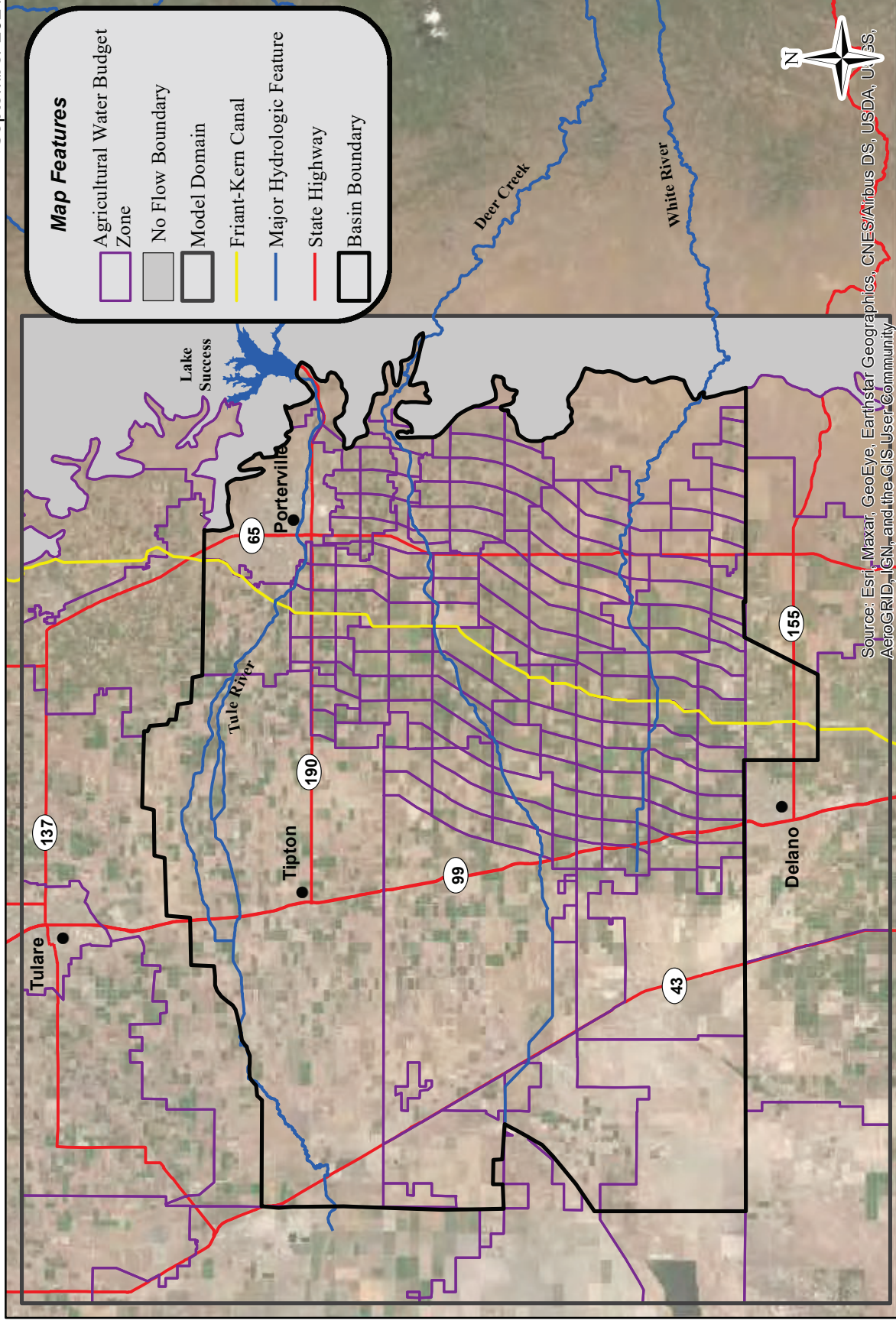
**Selected Model Calibration
Hydrographs - ETGSA**
Figure 10

Eastern Tule GSA



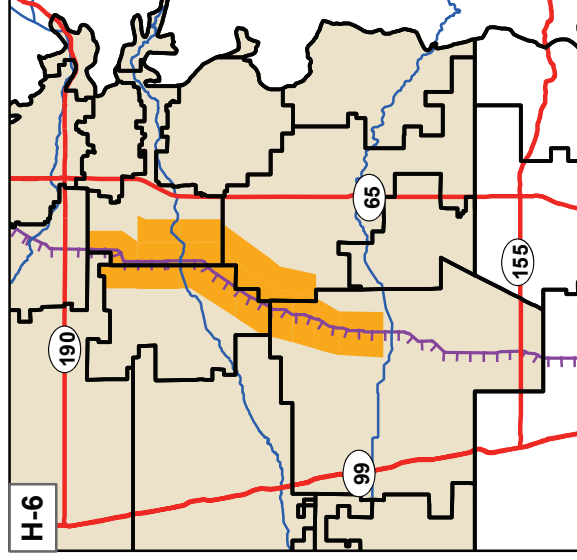
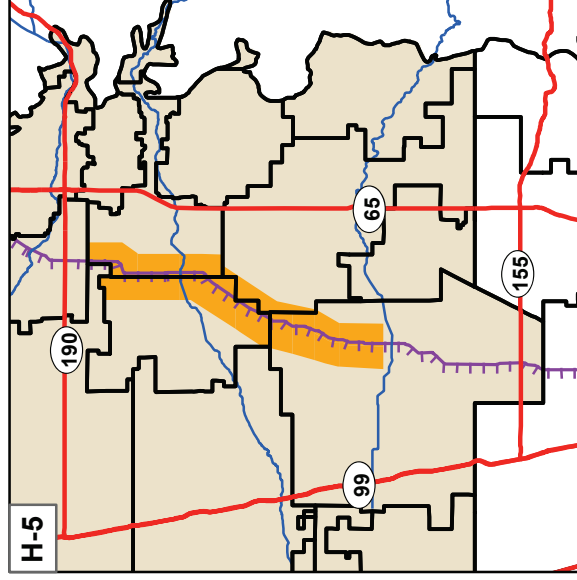
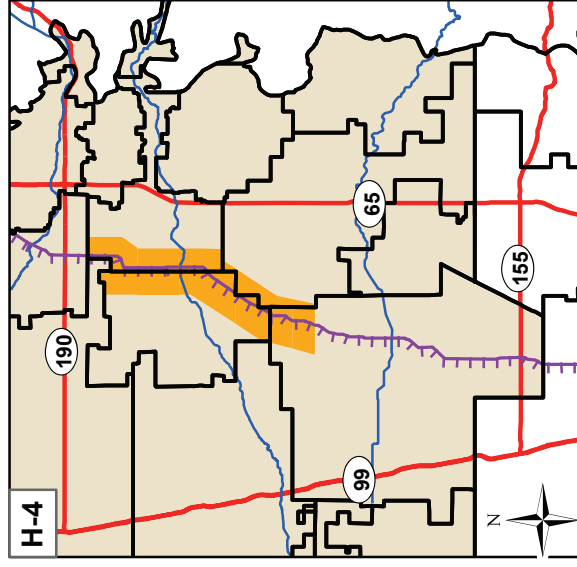
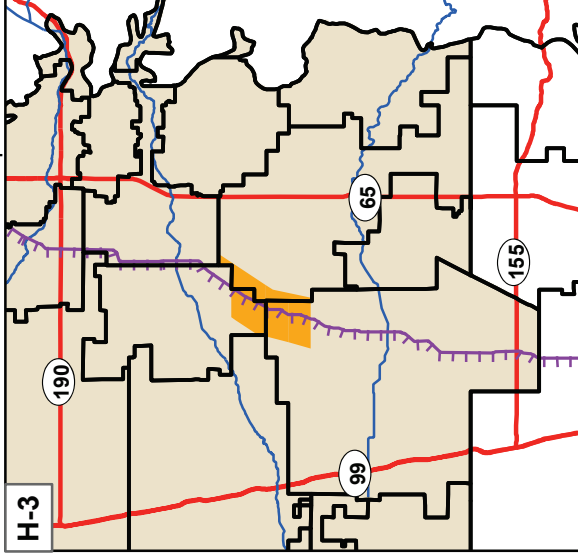
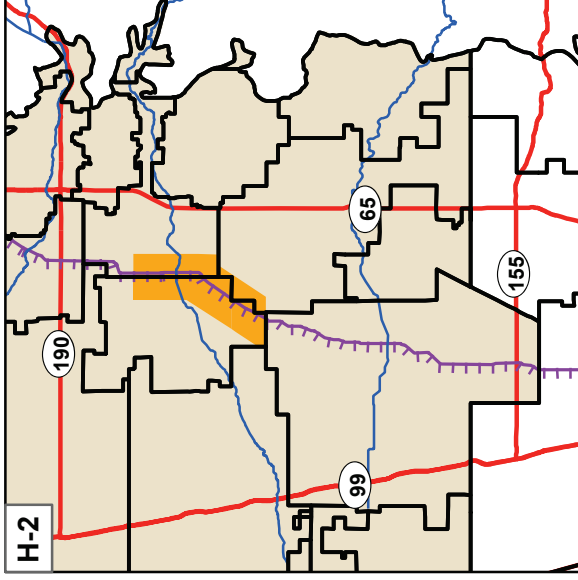
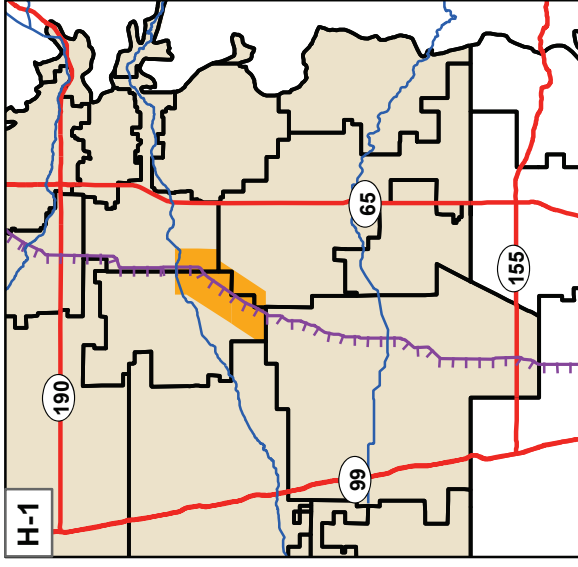
● Subsidence Target
 Eastern Tule GSA
 Friant-Kern Canal
 Major Hydrologic
 State Highway
 Tule Subbasin
 Model Domain

**Selected Land Subsidence
Calibration Plots - ETGSA**
Figure 11



Eastern Tule GSA

Land Subsidence Monitoring Plan
September 2021



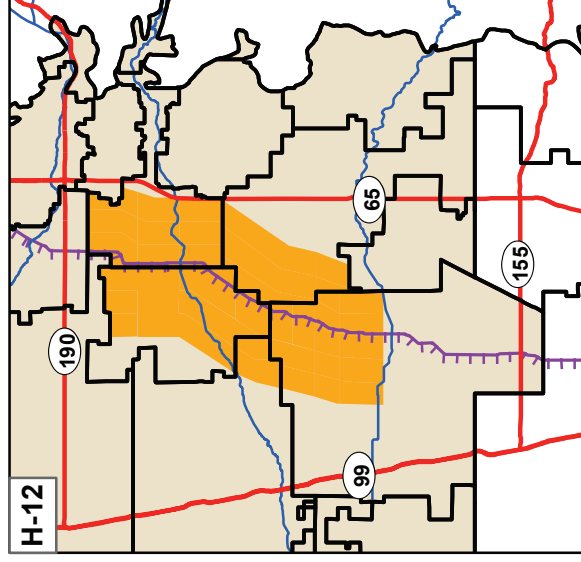
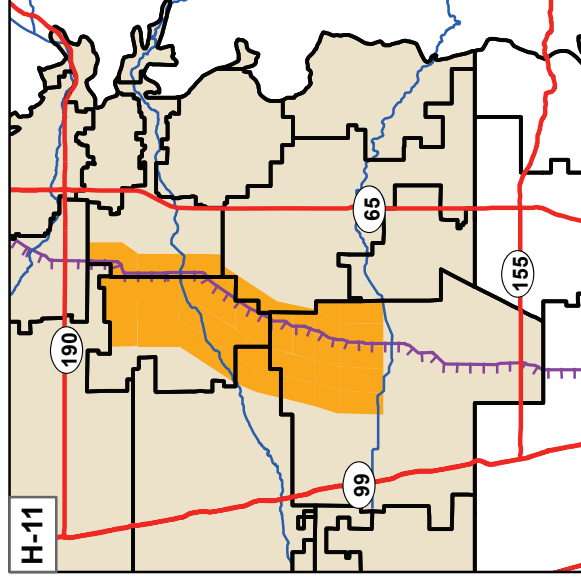
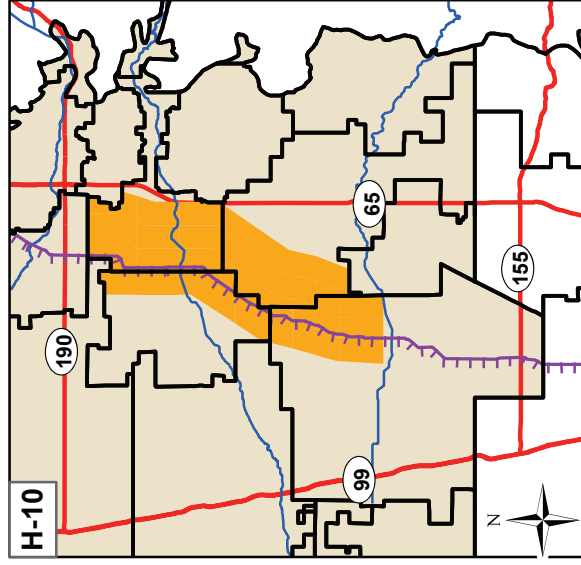
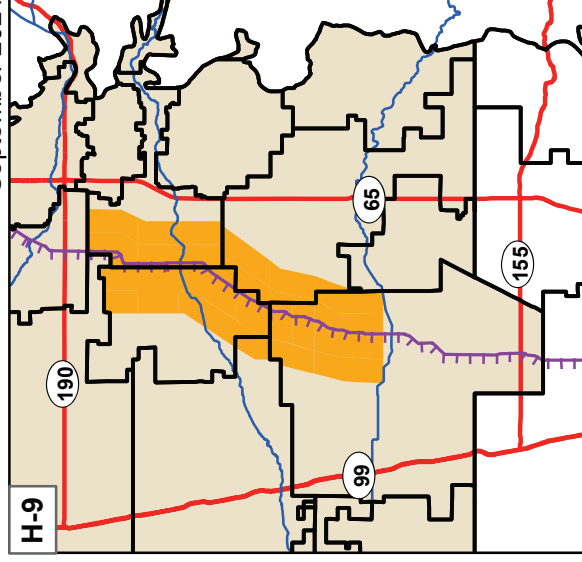
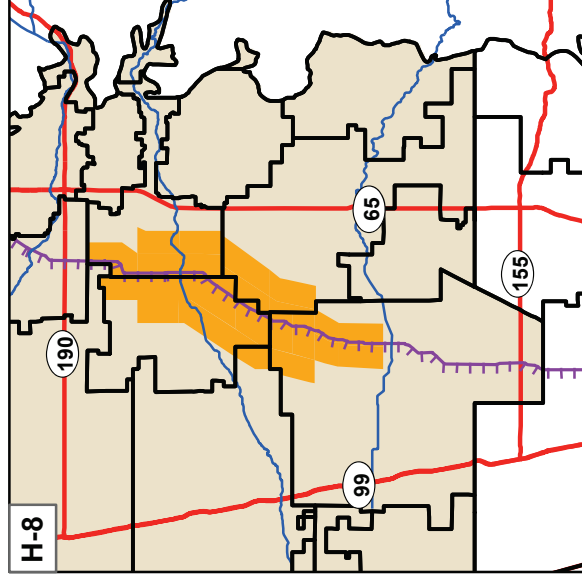
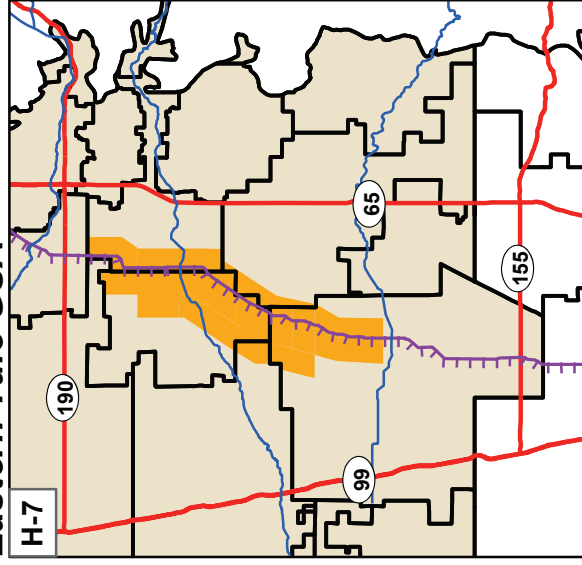
Thomas Harder & Co.
Groundwater Consulting



**Water Budget Zone Combinations
Analyzed with the Model: Historical**
Figure 13A

Eastern Tule GSA

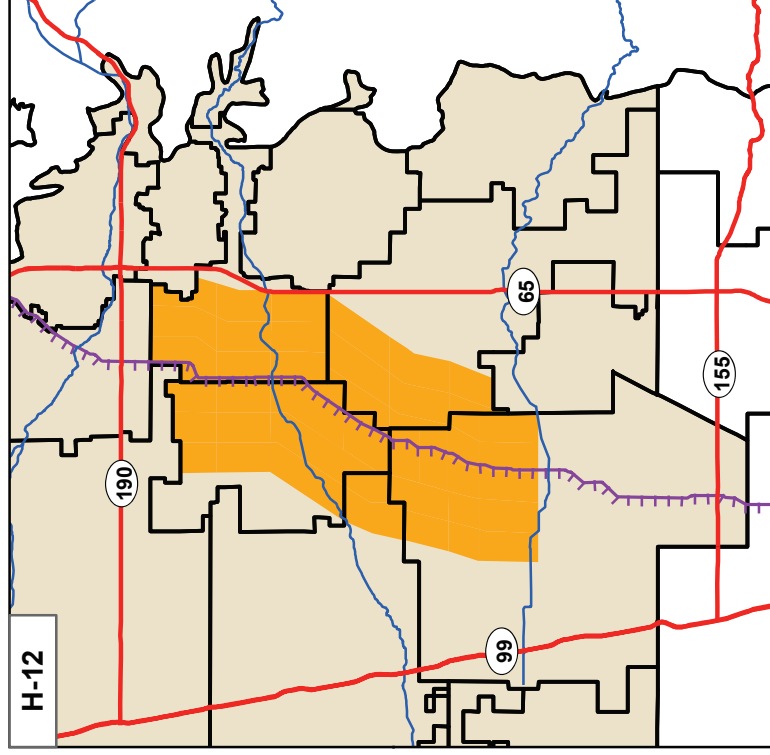
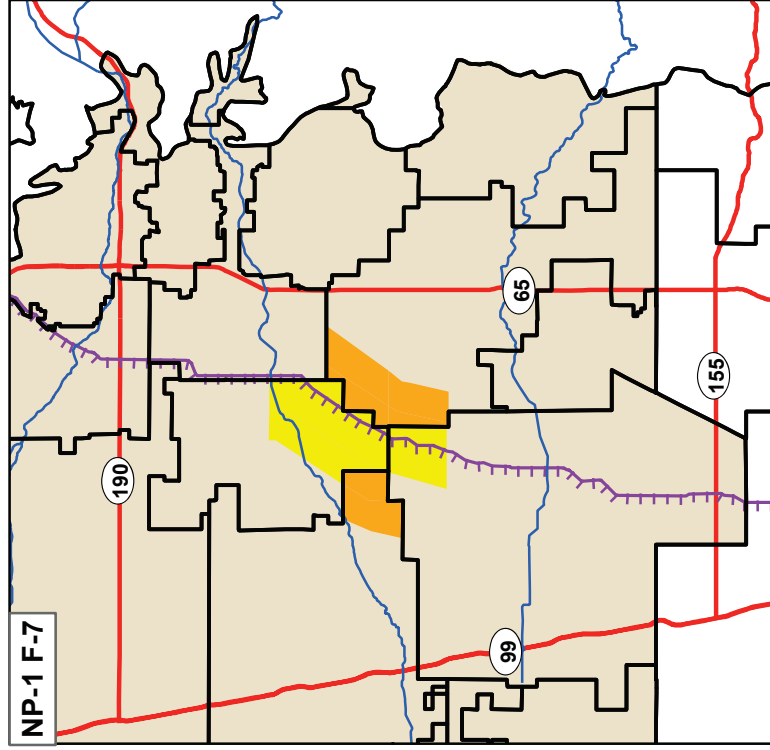
Land Subsidence Monitoring Plan
September 2021



Thomas Harder & Co.
Groundwater Consulting

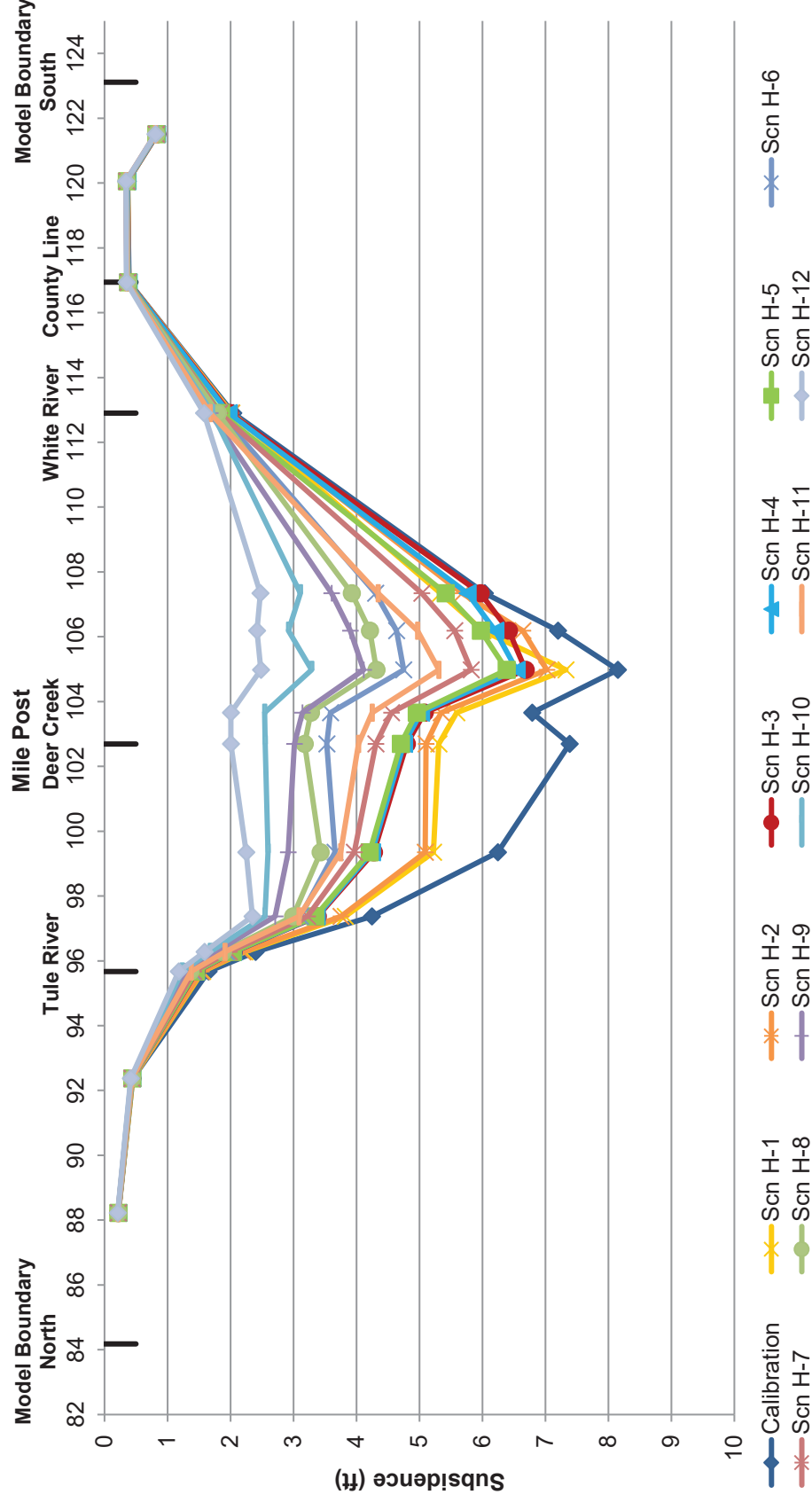


**Water Budget Zone Combinations
Analyzed with the Model: Historical**
Figure 13B



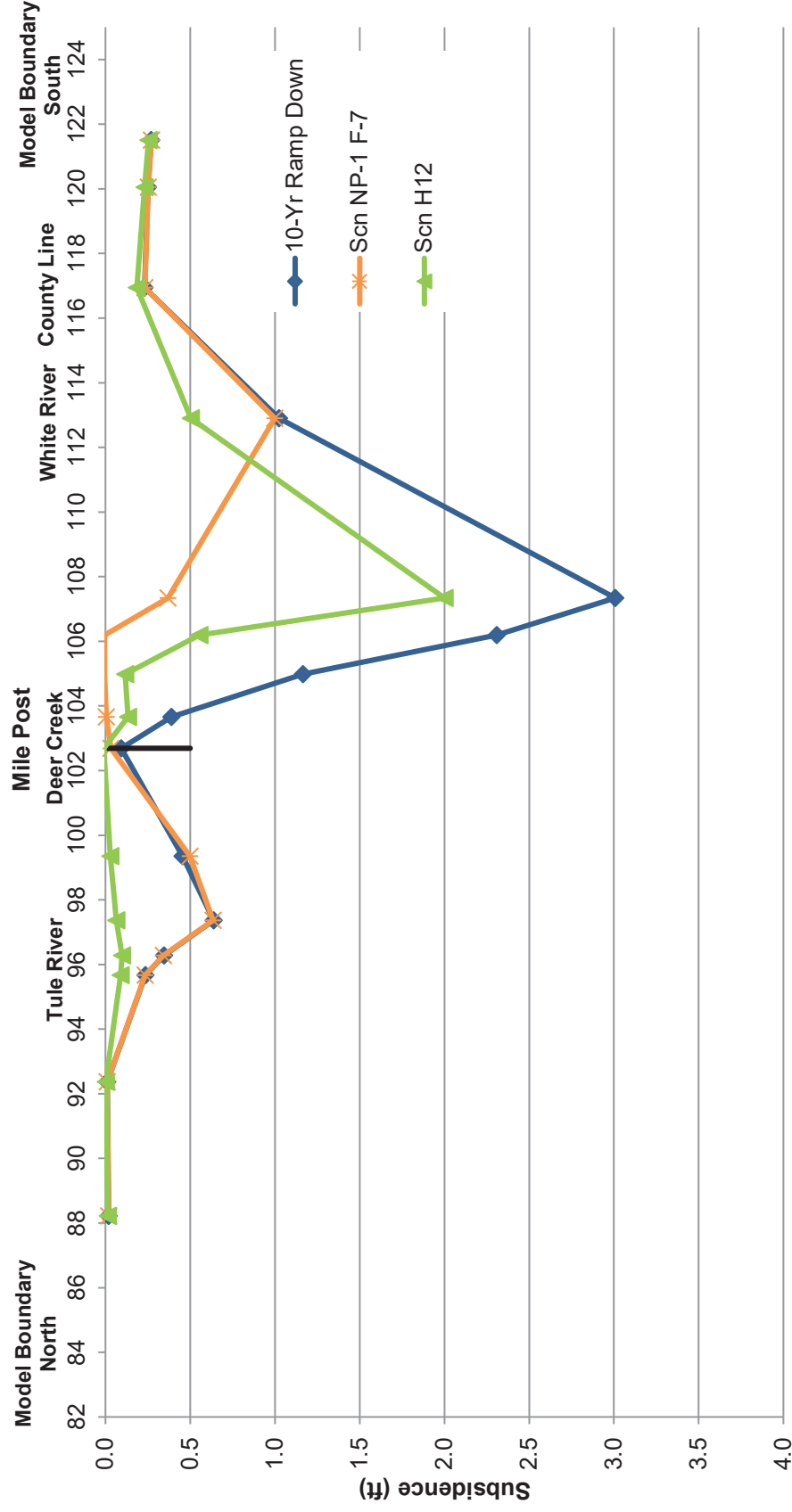
**Water Budget Zone Combinations
Most Effective at Mitigating Land
Subsidence Along Friant-Kern Canal**
Figure 14

Model-Simulated Land Subsidence Along Friant-Kern Canal
for Historical (1986-2017) Water Budget Zone Combinations



*The data shown are for October 1986 through September 2017. See Figure 12a and 12b for Water Budget Zones.

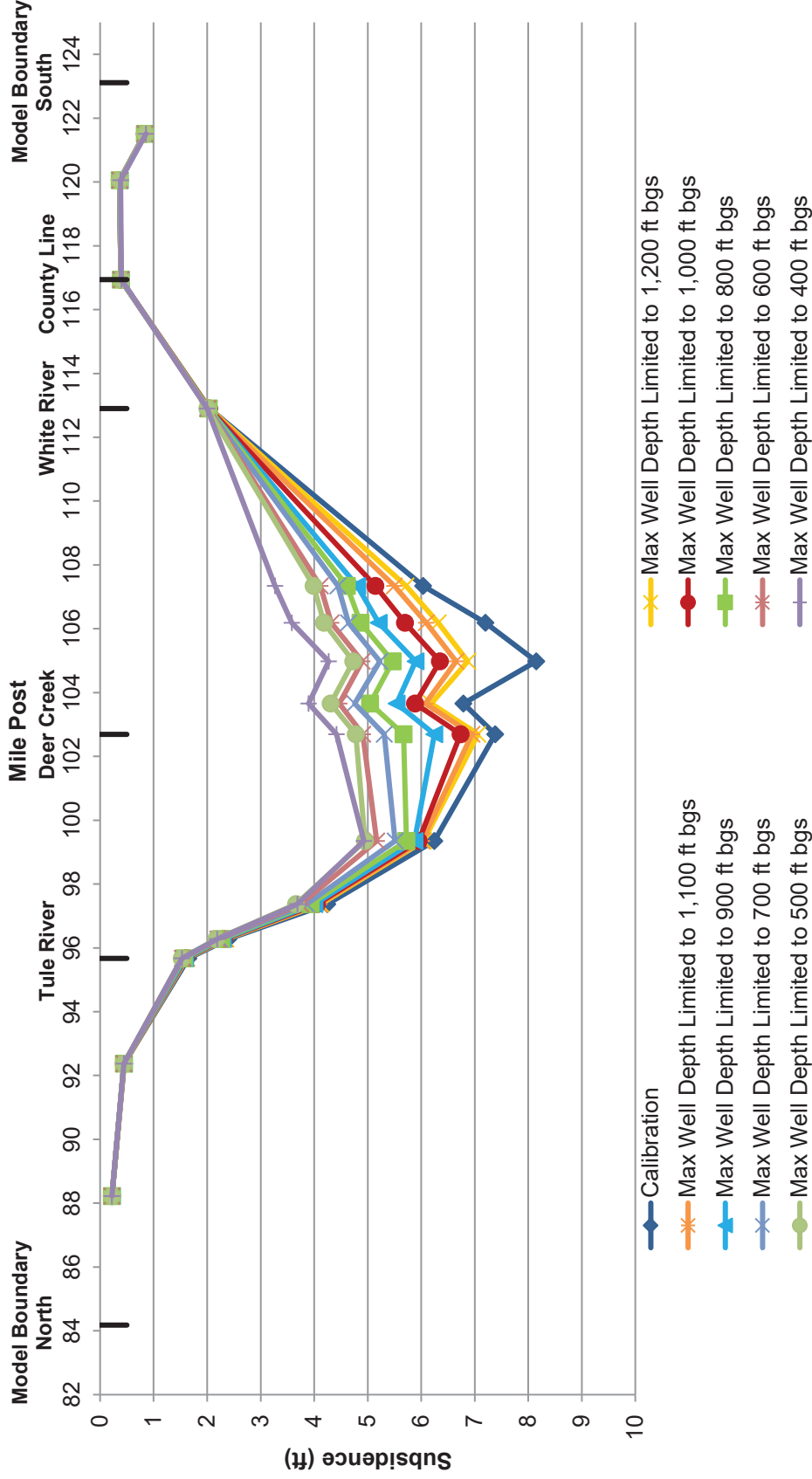
Model Simulations of Potential Future Land Subsidence Along the
Friant-Kern Canal for the Most Effective Water Budget Zone Combination



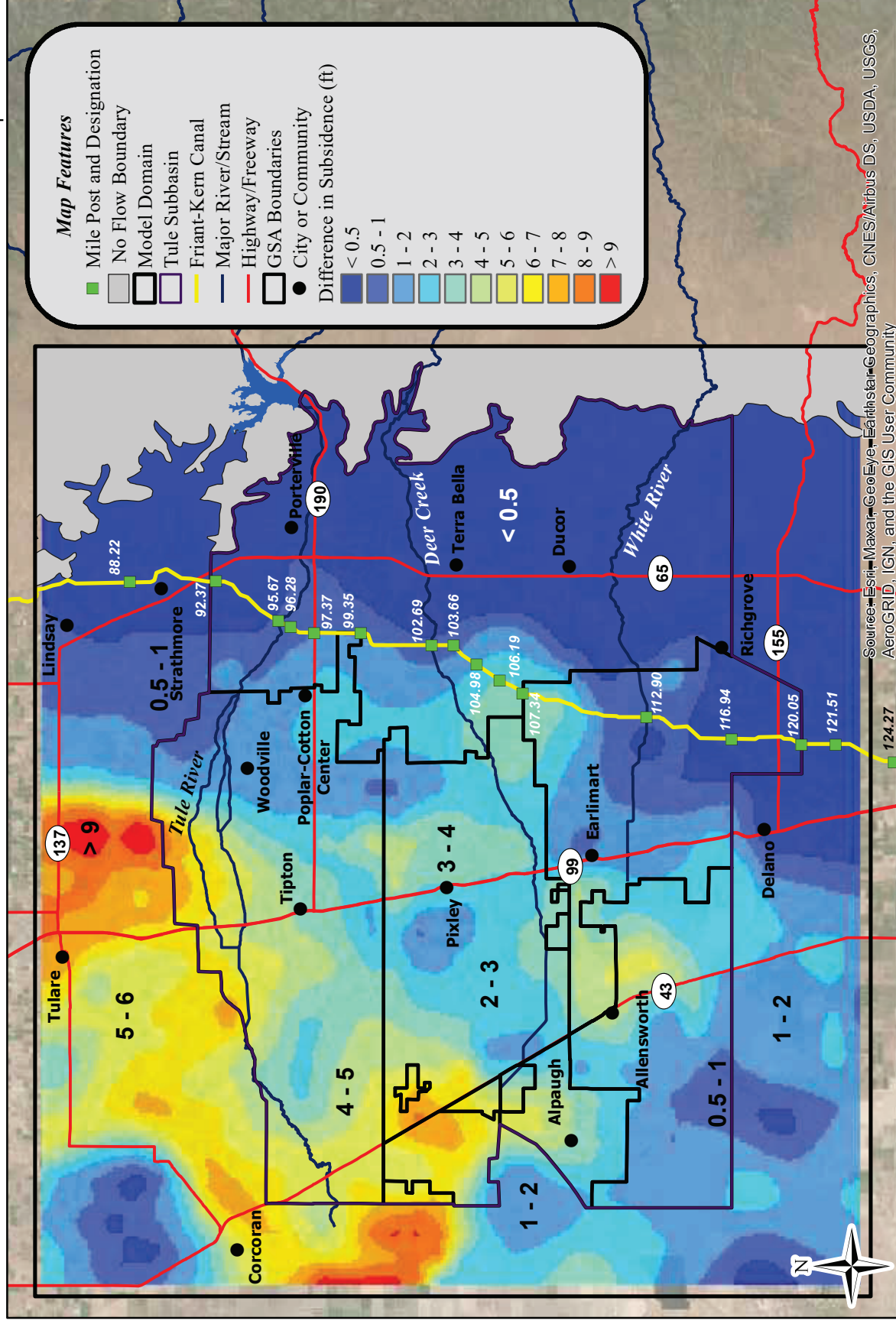
*The data shown are for October 2019 through September 2040. 10-Yr Ramp Down 0.37 CU; DEID Capped at 2017 CU.



Model-Simulations of Land Subsidence at Friant-Kern Canal with Progressively Shallower Pumping Depths



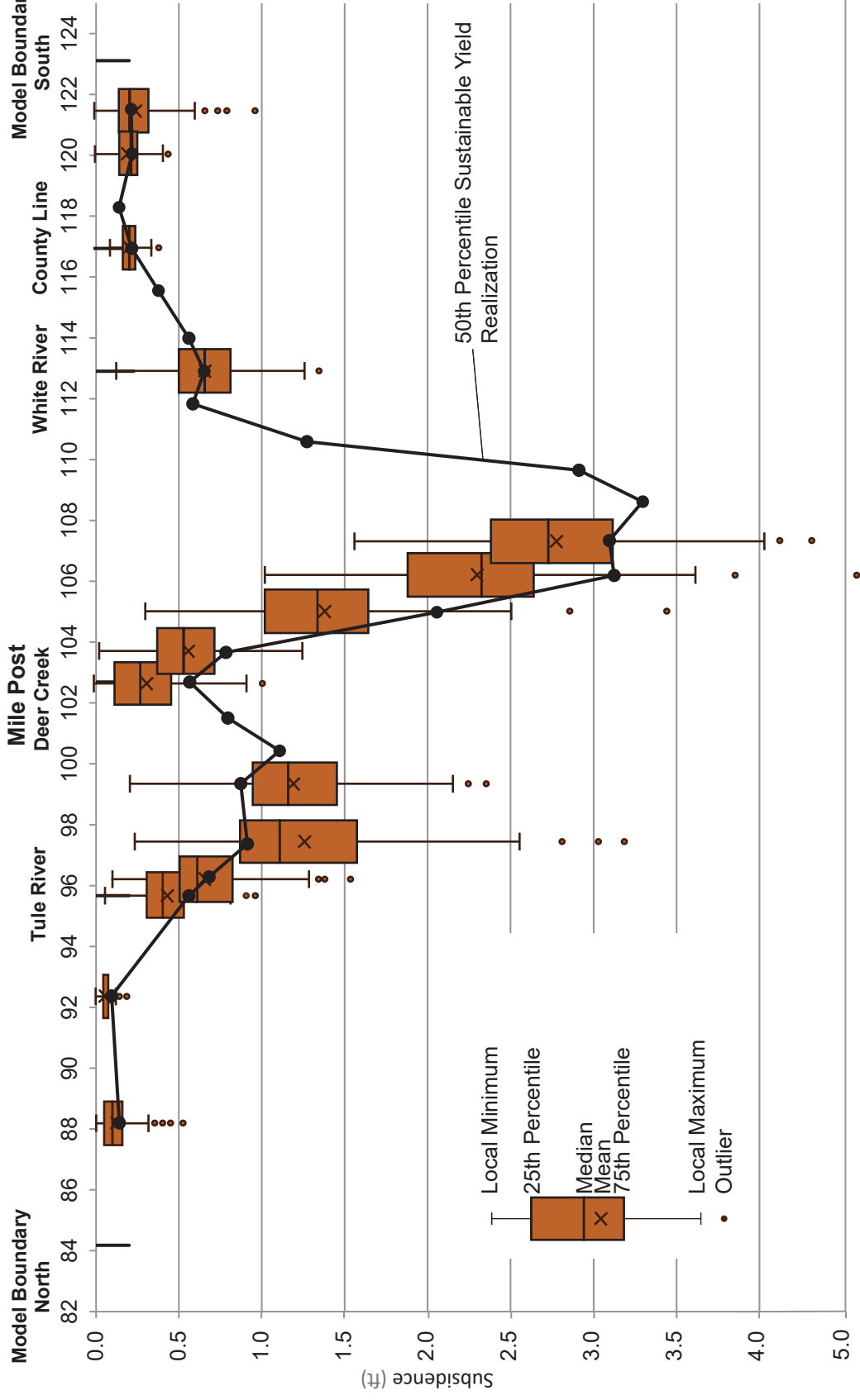
*October 1986 through September 2017

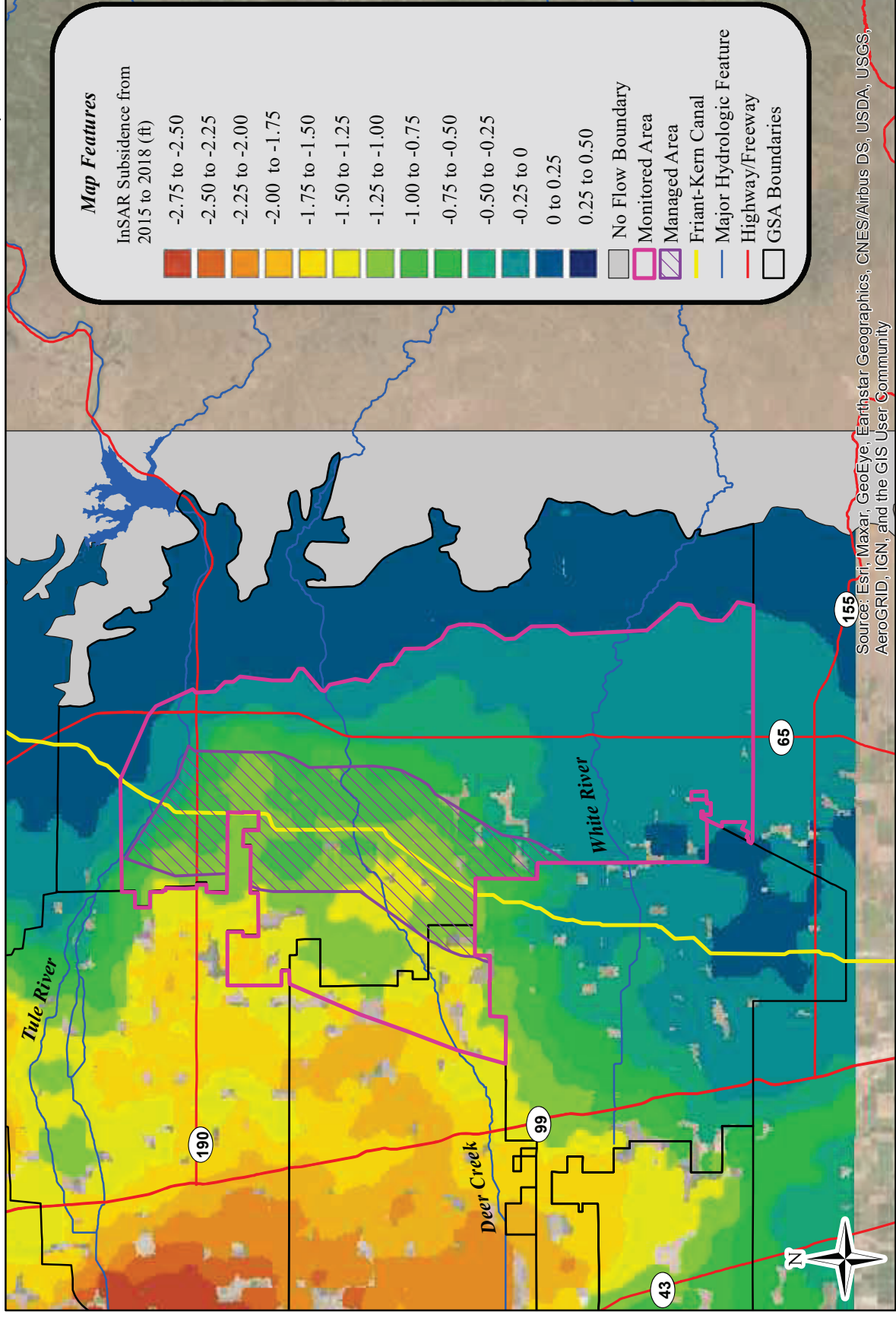


**Cumulative Land Subsidence in the
Tule Subbasin from 2020 to 2040**
Figure 18

Figure 19

Model-Predicted Cumulative Land Subsidence Along Friant-Kern Canal From 2020 through 2040

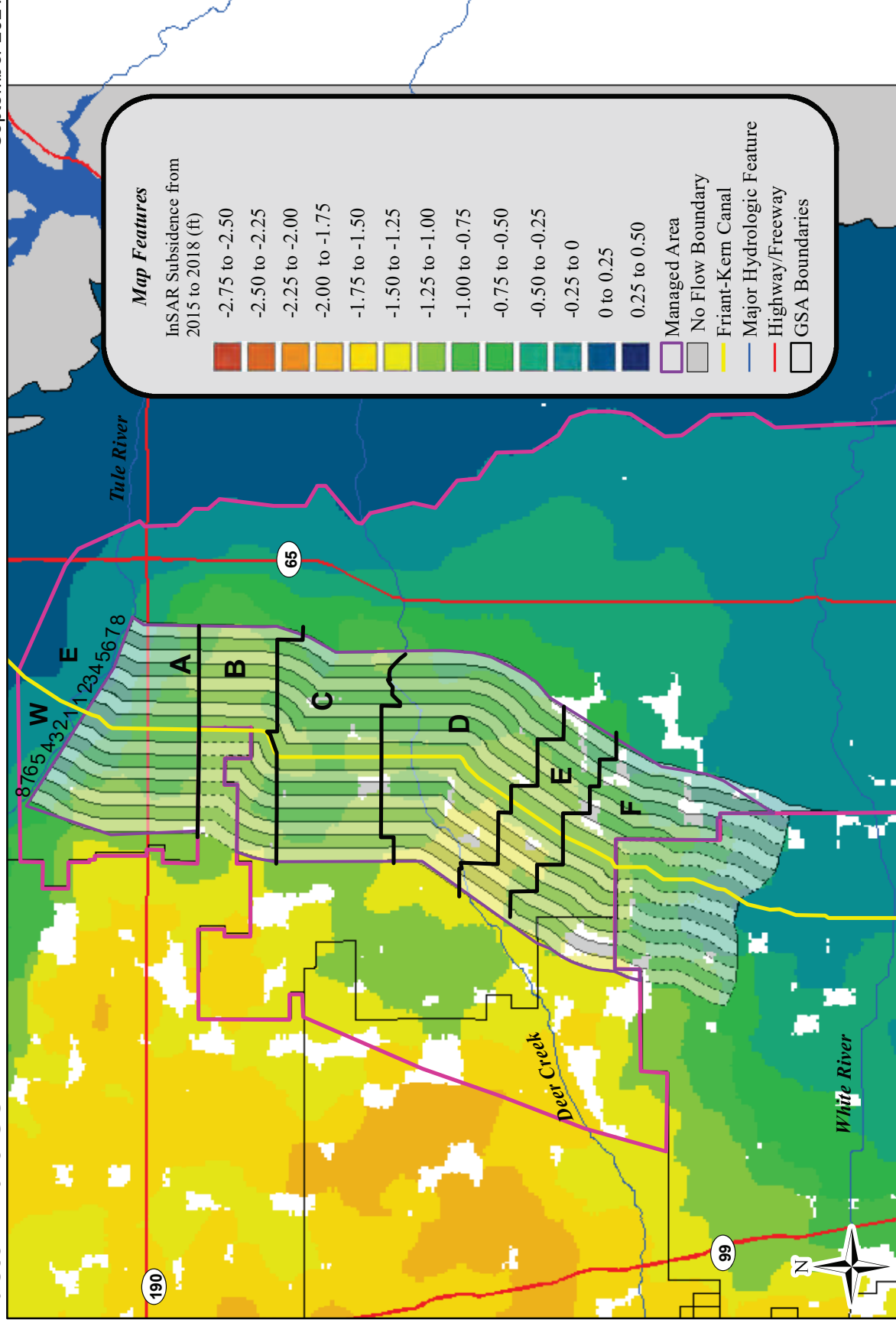




Land Subsidence Monitoring Plan

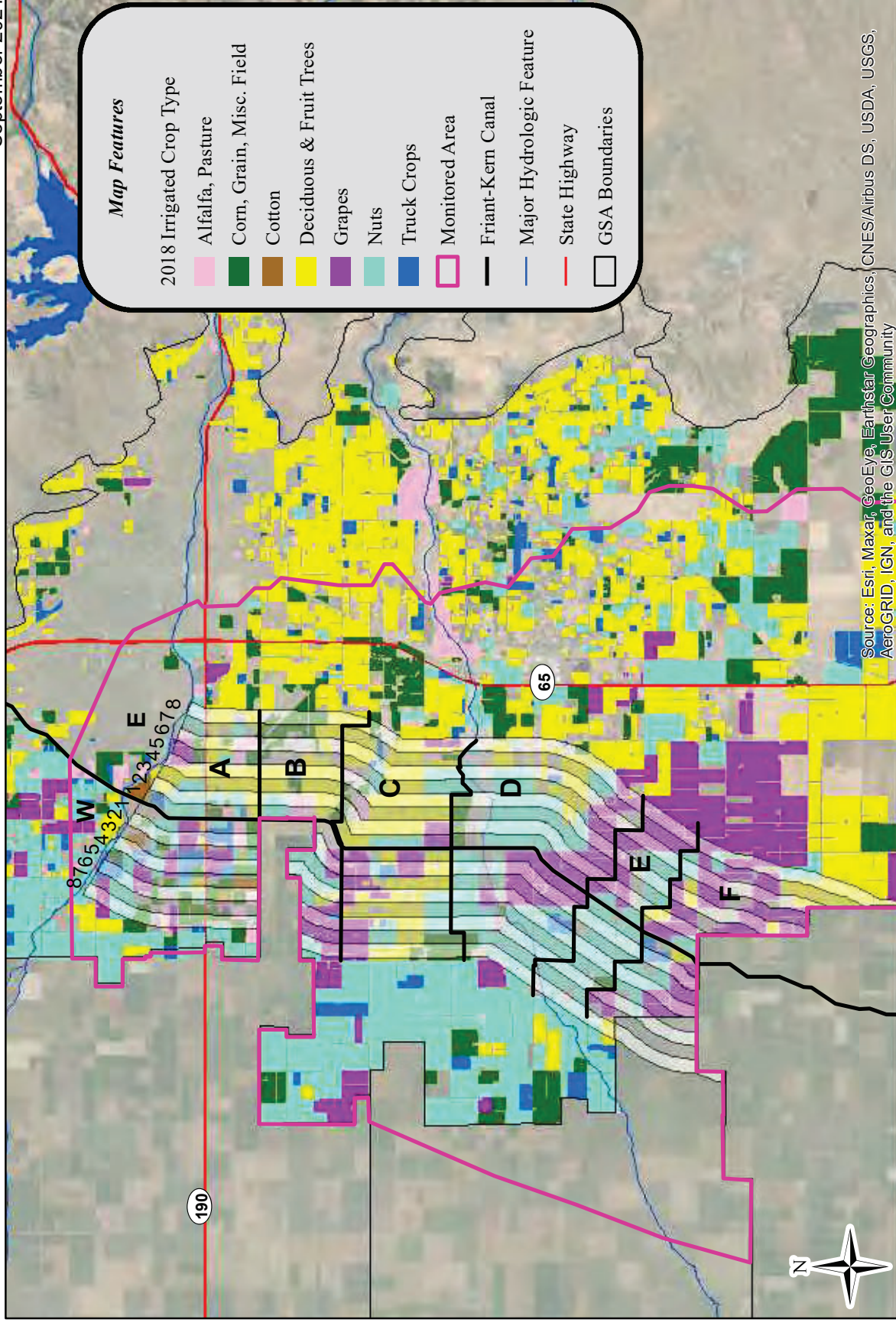
Eastern Tule GSA

September 2021



Land Subsidence Managed Area with Management Subzones

Figure 21

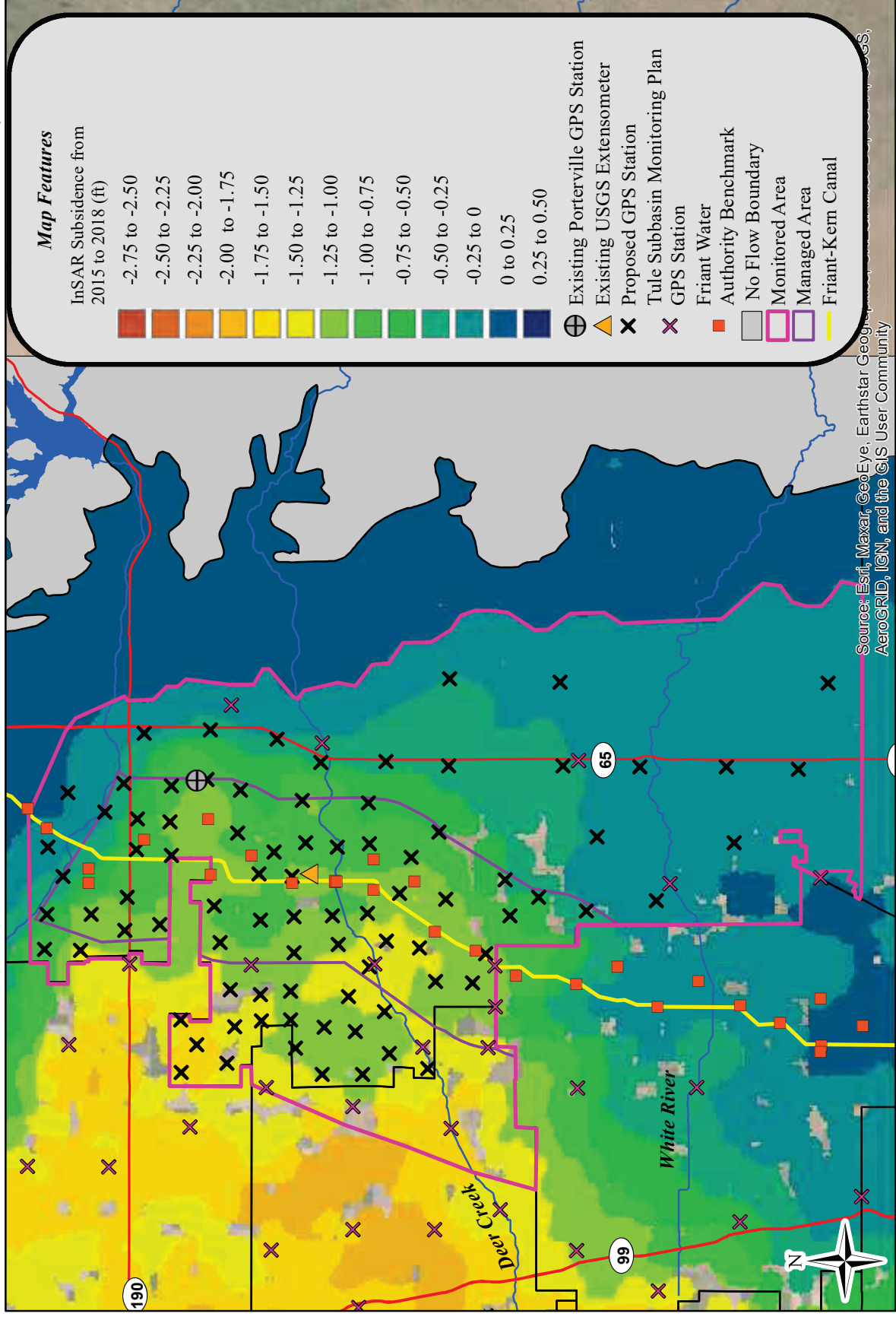


**Irrigated Crops in the
Eastern Tule GSA in 2018**
Figure 22

Land Subsidence Monitoring Plan

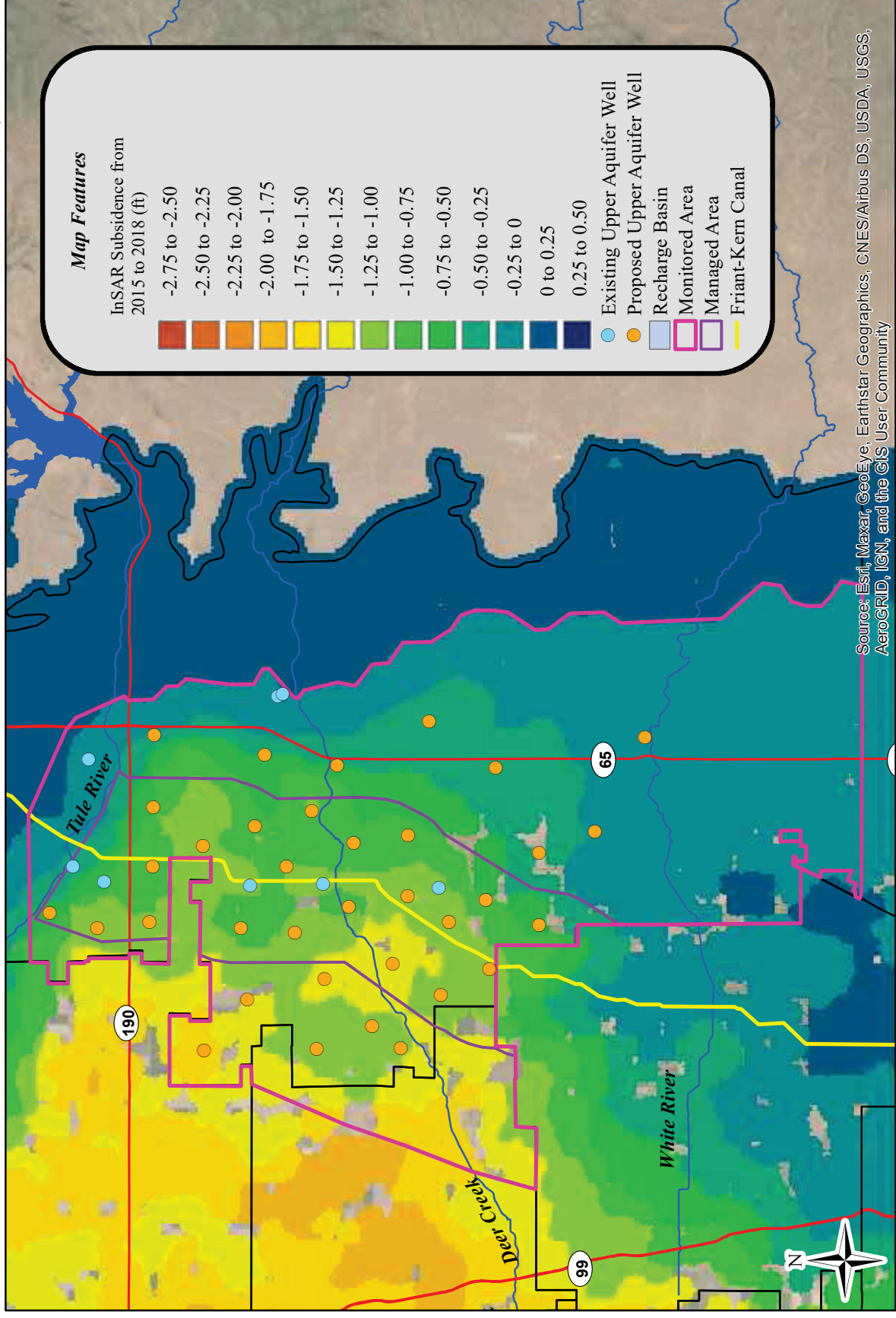
September 2021

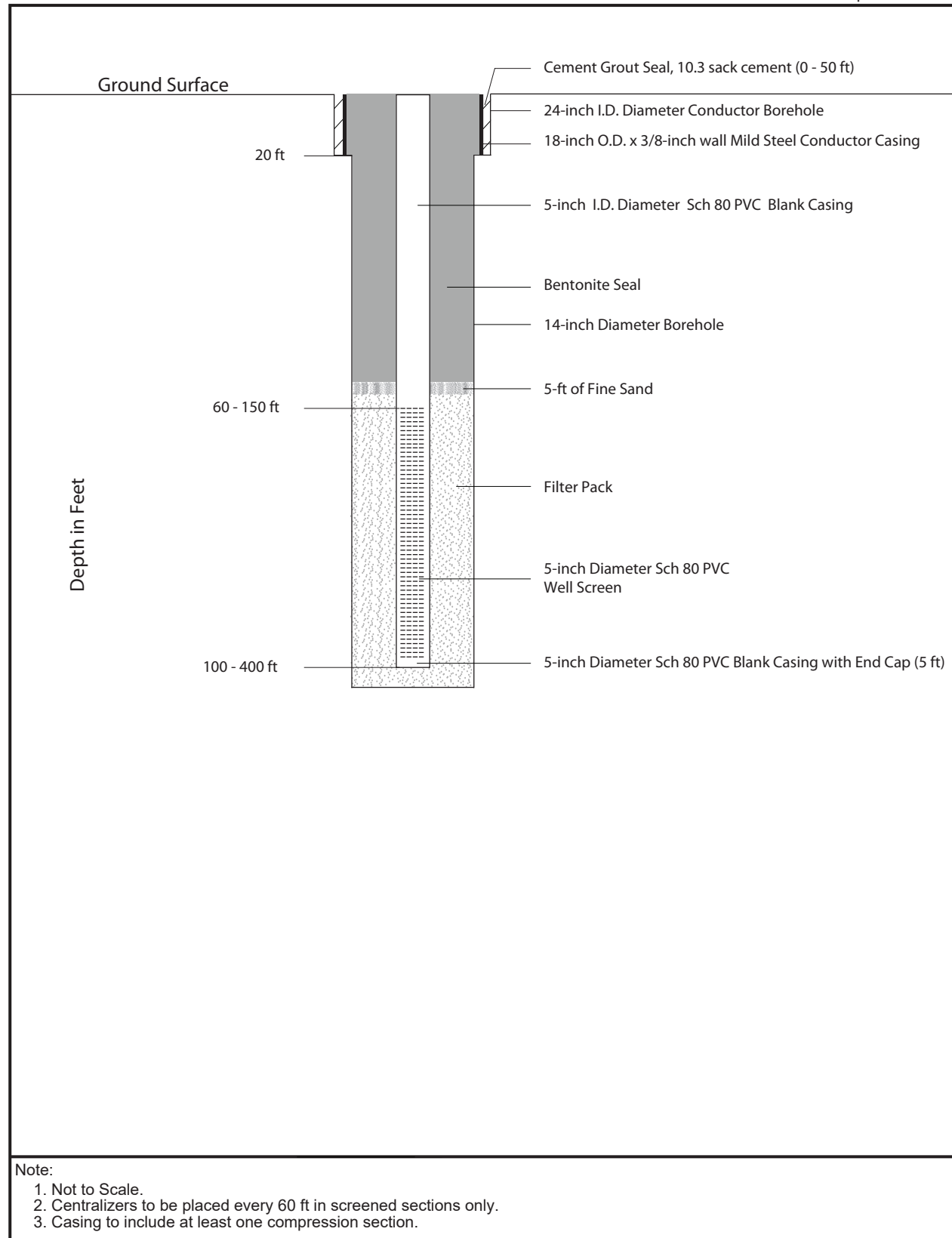
Eastern Tule GSA

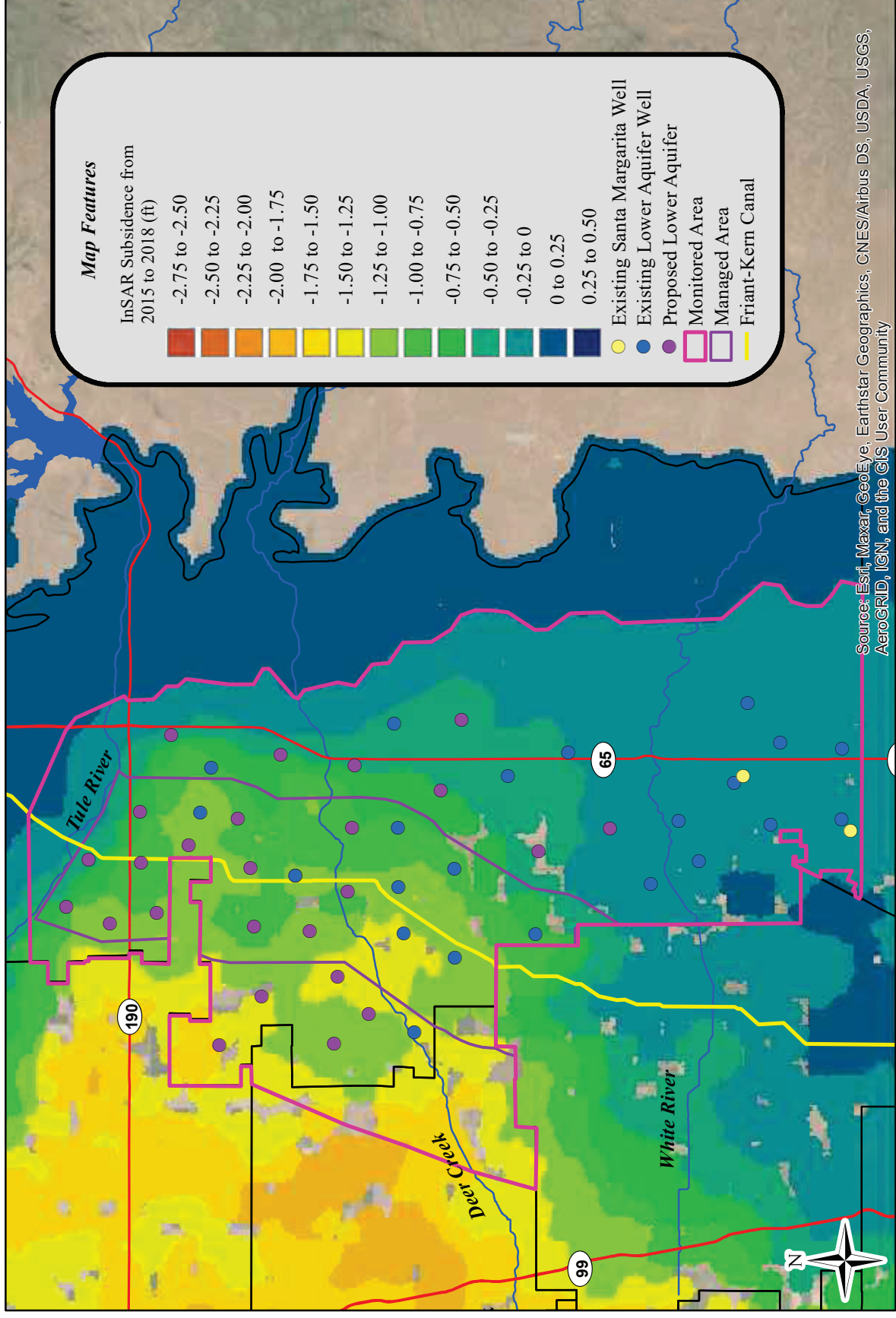


ETGSA Enhanced Land Elevation Subsidence Monitoring Network

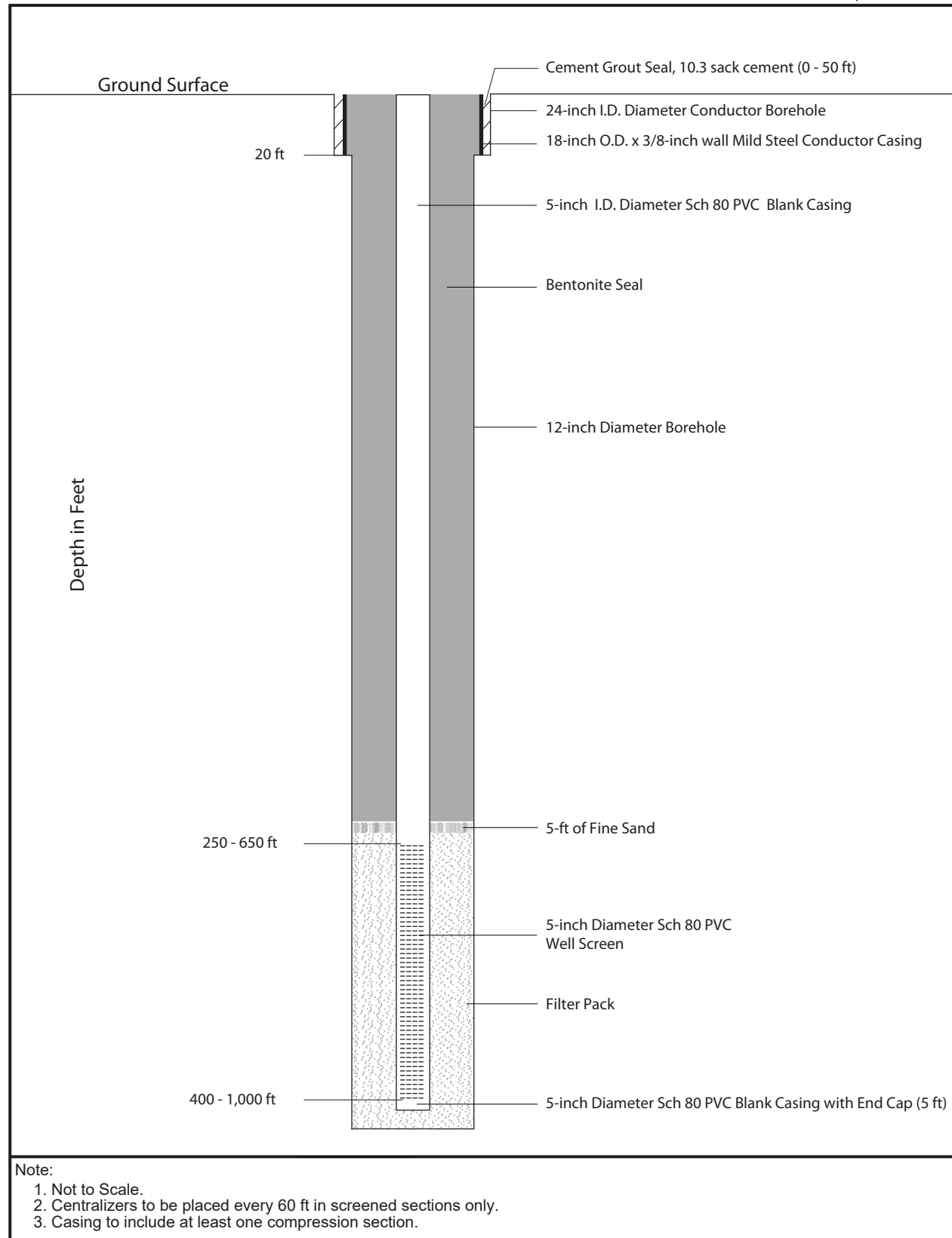
Figure 23







**Groundwater Monitoring Network
Lower Aquifer Wells**



Tables



**Annual and Cumulative Land Subsidence
ETGSA Land Subsidence Managed Area**

Management Zone ¹		2020 Annual Land Subsidence ² (ft)	Cumulative Land Subsidence ² (ft)	Management Action
North-South	East-West			
A	1 E	0.16	0.16	TBD ³
A	2 E	0.16	0.16	TBD
A	3 E	0.14	0.14	TBD
A	4 E	0.16	0.16	TBD
A	5 E	0.13	0.13	TBD
A	6 E	0.11	0.11	TBD
A	7 E	0.14	0.14	TBD
A	8 E	0.11	0.11	TBD
A	1 W	0.17	0.17	TBD
A	2 W	0.18	0.18	TBD
A	3 W	0.17	0.17	TBD
A	4 W	0.18	0.18	TBD
A	5 W	0.19	0.19	TBD
A	6 W	0.19	0.19	TBD
A	7 W	0.19	0.19	TBD
A	8 W	0.21	0.21	TBD
B	1 E	0.24	0.24	TBD
B	2 E	0.21	0.21	TBD
B	3 E	0.21	0.21	TBD
B	4 E	0.23	0.23	TBD
B	5 E	0.21	0.21	TBD
B	6 E	0.24	0.24	TBD
B	7 E	0.23	0.23	TBD
B	8 E	0.19	0.19	TBD
B	1 W	0.24	0.24	TBD
B	2 W	0.23	0.23	TBD
B	3 W	0.21	0.21	TBD
B	4 W	0.21	0.21	TBD
B	5 W	0.21	0.21	TBD
B	6 W	0.21	0.21	TBD
B	7 W	0.23	0.23	TBD
B	8 W	0.27	0.27	TBD
C	1 E	0.27	0.27	TBD
C	2 E	0.26	0.26	TBD
C	3 E	0.29	0.29	TBD
C	4 E	0.27	0.27	TBD

**Annual and Cumulative Land Subsidence
ETGSA Land Subsidence Managed Area**

Management Zone ¹		2020 Annual Land Subsidence ² (ft)	Cumulative Land Subsidence ² (ft)	Management Action
North-South	East-West			
C	5 E	0.35	0.35	TBD
C	6 E	0.27	0.27	TBD
C	7 E	0.33	0.33	TBD
C	8 E	0.37	0.37	TBD
C	1 W	0.27	0.27	TBD
C	2 W	0.26	0.26	TBD
C	3 W	0.24	0.24	TBD
C	4 W	0.26	0.26	TBD
C	5 W	0.25	0.25	TBD
C	6 W	0.29	0.29	TBD
C	7 W	0.30	0.30	TBD
C	8 W	0.31	0.31	TBD
D	1 E	0.38	0.38	TBD
D	2 E	0.35	0.35	TBD
D	3 E	0.34	0.34	TBD
D	4 E	0.34	0.34	TBD
D	5 E	0.33	0.33	TBD
D	6 E	0.33	0.33	TBD
D	7 E	0.33	0.33	TBD
D	8 E	0.31	0.31	TBD
D	1 W	0.40	0.40	TBD
D	2 W	0.35	0.35	TBD
D	3 W	0.33	0.33	TBD
D	4 W	0.38	0.38	TBD
D	5 W	0.39	0.39	TBD
D	6 W	0.38	0.38	TBD
D	7 W	0.42	0.42	TBD
D	8 W	0.46	0.46	TBD
E	1 E	0.38	0.38	TBD
E	2 E	0.39	0.39	TBD
E	3 E	0.35	0.35	TBD
E	4 E	0.35	0.35	TBD
E	5 E	0.34	0.34	TBD
E	6 E	0.30	0.30	TBD
E	7 E	0.33	0.33	TBD
E	8 E	0.30	0.30	TBD

**Annual and Cumulative Land Subsidence
ETGSA Land Subsidence Managed Area**

Management Zone ¹		2020 Annual Land Subsidence ² (ft)	Cumulative Land Subsidence ² (ft)	Management Action
North-South	East-West			
E	1 W	0.41	0.41	TBD
E	2 W	0.38	0.38	TBD
E	3 W	0.41	0.41	TBD
E	4 W	0.42	0.42	TBD
E	5 W	0.40	0.40	TBD
E	6 W	0.43	0.43	TBD
E	7 W	0.47	0.47	TBD
E	8 W	0.45	0.45	TBD
F	1 E	0.31	0.31	TBD
F	2 E	0.33	0.33	TBD
F	3 E	0.27	0.27	TBD
F	4 E	0.27	0.27	TBD
F	5 E	0.28	0.28	TBD
F	6 E	N/A ³	N/A ³	N/A ⁴
F	7 E	0.24	0.24	TBD
F	8 E	0.24	0.24	TBD
F	1 W	0.32	0.32	TBD
F	2 W	0.32	0.32	TBD
F	3 W	0.35	0.35	TBD
F	4 W	0.33	0.33	TBD
F	5 W	0.35	0.35	TBD
F	6 W	0.37	0.37	TBD
F	7 W	0.39	0.39	TBD
F	8 W	0.35	0.35	TBD

Notes:

- ¹ See Figure 21 for Management Zone Locations.
² Land subsidence values based on InSAR data from January 2020 to October 2020.
Values represent average subsidence within each Management Zone.
³ To be determined.

Appendices



Appendix A

Groundwater Level Field Measurement Form



Well Name/ Number:	Checked By:
Project:	Field Personnel:

[illegible]

Appendix B

Chalk/Tape Groundwater Level Measurement



[illegible]