Appendix A-6

Tule Subbasin Coordination Agreement
Attachment 6: Draft Technical Memorandum Re: Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Draft Technical Memorandum

To:	Tule Subbasin Technical Advisory Committee
From:	Thomas Harder, P.G., C.HG. Thomas Harder & Co.
Date:	22-Jul-24
Re:	Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

1 Introduction

This technical memorandum (TM) summarizes an updated coordinated approach and criteria used by the Tule Subbasin Groundwater Sustainability Agencies (GSAs) to determine sustainable management criteria (SMC) for land subsidence and lower aquifer groundwater levels in the Tule Subbasin in Tulare County, California (see Figure 1). Both the approach and criteria were modified significantly from that presented in the previous Tule Subbasin Coordination Agreement[1] to address comments to the groundwater sustainability plans (GSPs) from the California Department of Water Resources (CDWR).

1.1 Background

In their initial review of the Tule Subbasin GSPs,[2] the CDWR made the following general comments as they relate to land subsidence:

1. *For areas defined as adjacent to the Canal in the Eastern Tule GSP, Delano-Earlimart Irrigation District GSP, and Lower Tule River Irrigation District GSP areas, the GSAs should identify, through analysis, the total amount of subsidence that can be tolerated by the Canal during implementation of the GSPs to maintain the ability to reasonably operate to meet contracted water supply deliveries. Eastern Tule GSA, Delano-Earlimart Irrigation District GSA, and Lower Tule River Irrigation District GSA should explain how*

[1] Tule Subbasin Coordination Agreement, dated July 13, 2022.
[2] CDWR, 2022. Incomplete Determination of the 2020 Groundwater Sustainability Plans Submitted for the San Joaquin Valley – Tule Subbasin. Letter dated January 28, 2022.

implementation of the projects and management actions is consistent both with achieving the long-term avoidance or minimization of subsidence and with not exceeding the tolerable amount of cumulative subsidence adjacent to the Canal.

   a. *GSPs adjacent to the Canal should provide an updated description of the Land Subsidence Management and Monitoring Plan and the associated subsidence management in the vicinity of the Canal. The GSPs should include details of any projects, management actions, or mitigation programs associated with the management of land subsidence in the Subbasin.*

2. *For areas not adjacent to the Canal, the GSAs should identify facilities and/or structures, land uses and property interests that may be susceptible to impacts from land subsidence and should quantify the amount of land subsidence that would result in undesirable results. The GSAs should describe the rationale and any analysis performed to inform the quantification of undesirable results in these areas.*
3. *Tule Subbasin GSAs should define the criteria for when undesirable results occur in the Subbasin based on the results of analyses completed in response to Corrective Actions 1 and 2, the rationale behind the approach, and why it is consistent with avoiding the significant and unreasonable effects identified by the GSAs.*
4. *The GSAs should revise their minimum thresholds and measurable objectives for land subsidence to be consistent with the intent of SGMA that subsidence be avoided or minimized once sustainability is achieved. In doing that, the GSAs should identify a cumulative amount of tolerable subsidence that, if exceeded, would substantially interfere with groundwater and land surface beneficial uses and users in the Subbasin. The GSPs should explain how the extent of any future subsidence permitted by the GSPs would not substantially interfere with surface land uses. The GSAs should explain how implementation of the projects and management actions is consistent both with achieving the long-term avoidance or minimization of subsidence and with not exceeding the tolerable amount of cumulative subsidence.*

In July 2022, the Tule Subbasin GSAs submitted a revised Coordination Agreement and revised GSPs to address the CDWR comments. The revised Coordination Agreement included an updated definition of Undesirable Results and an analysis of potentially impacted infrastructure, at the minimum thresholds proposed at that time.

In their determination letter,[3] the CDWR identified the following deficiencies regarding the revised Coordination Agreement and GSPs:

[3] CDWR, 2023. Inadequate Determination of the Revised 2020 Groundwater Sustainability Plans Submitted for the San Joaquin Valley – Tule Subbasin. Letter dated March 2, 2023.

Corrective Action 1:

"Based on the quantification of the undesirable result and additional description related to the monitoring, management, and mitigation plans, Department staff conclude the GSAs have sufficiently responded to part 1 and 1a of the corrective action. However, Department staff note that current InSAR data shows subsidence surrounding the Friant Kern Canal has already reached 1.5 feet and is concerned the management of the Subbasin may not be on track to reach sustainability by 2040."

CDWR Inadequate Determination Letter, Section 4.2.2.1; Pg. 16 2nd Paragraph

Corrective Action 2:

"The 2022 Coordination agreement states "the quantitative definition of undesirable results for land subsidence is ongoing land subsidence below the minimum threshold at any given representative monitoring site that cannot be attributable to recoverable land subsidence;" this is not based on the avoidance of significant and unreasonable effects, but rather the results of the forecasted subsidence by the groundwater flow model for the 2020 to 2040 transition period."

"*…the Plan does not quantify the amount of land subsidence that would result in undesirable results for areas not adjacent to the Canal as indicated in corrective action 2*."

CDWR Inadequate Determination Letter, Section 4.2.2.1; Pg. 17 1st Paragraph

Corrective Action 3:

"*…the GSAs still have not defined what constitutes significant in this context and Department staff again conclude the lack of clearly defined undesirable results to mean that it would be impossible to understand and monitor whether the GSPs are managing the Subbasin in a manner that would achieve the sustainability goal and avoid impacts to land uses and property interests for those areas not adjacent to the Friant-Kern Canal."*

CDWR Inadequate Determination Letter, Section 4.2.2.1 Pg. 17 2nd Paragraph

Corrective Action 4:

"…the GSA's approach has not changed in the manner in which thresholds are established. The 2022 Coordination Agreement and the Subbasin's GSPs (except Tri-County GSP) continue to establish the minimum thresholds and measurable objectives for land subsidence based on the output of the groundwater flow model during the implementation period (2020-2040), which considers transitional pumping during that period. By continuing to take this approach, the GSAs have not identified a cumulative amount of tolerable subsidence that, if

exceeded, would substantially interfere with groundwater and land surface beneficial uses and users in the Subbasin."

"SGMA and the GSP Regulations does not differentiate residual subsidence; therefore, GSAs should assess total subsidence impacts caused by groundwater pumping. The GSP does not identify the studies and additional data are needed to determine the subsidence expected past 2040. Regardless, SGMA requires GSAs to avoid or minimize subsidence and the GSAs have not demonstrated the Plan's intent do accomplish this. It is not clear whether the Plan will experience undesirable results beyond 2040."

CDWR Inadequate Determination Letter, Section 4.2.2.2 Pg. 19 2nd Paragraph

In their Tule Subbasin Probational Hearing Draft Staff Report[4] the State Water Resources Control Board (SWRCB) agreed with the CDWR findings and identified additional deficiencies necessary to address. The Draft Staff Report also identified potential actions to address the deficiencies. The deficiencies and potential actions are summarized below:

Deficiency LS-1 – The GSPs claim without justification that their goals would prevent significant and unreasonable impacts.

Potential Action LS-1 – Revise goals so that they demonstrably prevent significant and unreasonable impacts.

Deficiency LS-2 – The GSPs plan to measure progress against modeled projections rather than goals that achieve sustainability while avoiding harm caused by declining groundwater levels.

Potential Action LS-2 – Revise how progress toward sustainability is measured.

Deficiency LS-3 – The GSPs allow more subsidence along the Friant-Kern Canal than the maximum subsidence allowed in an agreement between GSAs and the Friant Water Authority.

Potential Action LS-3 – Limit subsidence to, at most, the limits in other agreements.

Deficiency LS-4 – GSPs lack crucial detail about how they plan to meet their goals and subsidence since 2020 indicates that GSAs are not on track to meet their goals.

Potential Action LS-4 – Develop and implement plans to limit pumping near critical infrastructure. Do not allow new wells near critical infrastructure. Develop plans to repair damage caused by subsidence.

[4] SWRCB, 2024. Tule Subbasin Probationary Hearing Draft Staff Report. March 2024.

Deficiency LS-5 – GSPs allow subsidence to continue beyond 2040.

Potential Action LS-5 – Do not allow subsidence beyond 2040.

These SWRCB deficiencies are addressed herein.

1.2 Purpose and Scope

The purpose of this TM is to address the deficiencies the CDWR identified in Corrective Actions 2 through 4 and the SWRCB identified through deficiencies LS-1 through LS-5. This was accomplished through:

1. A revised approach for addressing significant and unreasonable land subsidence conditions.
2. A more detailed definition of significant and unreasonable conditions correlated with different types of land uses and infrastructure vulnerable to impacts from land subsidence.
3. A revised quantification of Undesirable Results for land subsidence in the Tule Subbasin.
4. A revised methodology for setting minimum thresholds (MTs) and revised MT values to avoid significant and unreasonable land subsidence conditions.
5. Incorporation of a new land subsidence measurable objective (MO) and interim milestones based on land subsidence rates the subbasin needs to avoid to achieve land subsidence goals.
6. A correlation of Lower Aquifer groundwater level MTs that are consistent with minimizing land subsidence and achieving the land subsidence goals.

1.3 Sustainability Goal

The Sustainability Goal of the Tule Subbasin is defined as the absence of undesirable results, accomplished by 2040 and achieved through a collaborative, Subbasin-wide program of sustainable groundwater management by the various Tule Subbasin GSAs.

In furtherance of this goal, the Tule Subbasin GSAs are committed to minimizing and avoiding land subsidence across the Tule Subbasin, in accordance with the SMC defined herein and the requirements of the Sustainable Groundwater Management Act (SGMA).

2 Approach

The approach to revise land subsidence SMCs involved a coordinated effort between technical consultants, agricultural stakeholders, and non-governmental organizations (NGOs). The process was iterative and included feedback from California State Water Resources Control Board (SWRCB) staff. Key aspects of the process are summarized in Figure 2 and described below.



Figure 2. Approach for Determining Sustainable Management Criteria for Land Subsidence and Lower Aquifer Groundwater Levels in the Tule Subbasin.

3 Land Uses Vulnerable to Land Subsidence in the Tule Subbasin

There are multiple types of land uses that can be impacted by subsidence. In the Tule Subbasin, these land uses/infrastructure are summarized in Table 1 and include:

- Canals
- Water Delivery Pipelines
- Flood Control
- Wells
- Other Infrastructure (e.g. roads, buildings, other types of pipelines, etc.)

Given the regional importance of the Friant-Kern Canal (FKC), the historical impacts that have occurred on this canal, and its unique significance criteria, it is shown separately in Table 1 and addressed separately in this TM.

3.1 Friant-Kern Canal

The Friant-Kern Canal is a regional water delivery canal that extends from Millerton Reservoir northeast of Fresno to the Kern River in Bakersfield (see Figure 3). The canal was completed by the United States Bureau of Reclamation (USBR) in 1951 with an original design capacity of 5,300 cubic feet per second (cfs). The canal delivers water for 26 contractors along its length.

Differential land subsidence rates along the portion of the Friant-Kern Canal that extends through the ETGSA has impacted 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 (see Figure 4). 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. As of 2019, the flow capacity of the canal at Deer Creek had been reduced to approximately 1,900 cfs (United States Bureau of Reclamation, 2019).

The FWA is currently repairing 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 in the future within the design of the repairs. Recognizing the regional importance and value of the FKC, the ETGSA developed a Land Subsidence Monitoring Plan[5] and Management Plan[6] for the areas on either side of the canal. These plans are separate from, and in addition to, the monitoring plan established for the Tule Subbasin. The goal of the Land Subsidence Monitoring and Management Plans 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 stop nonrecoverable land subsidence along the FKC after 2040. The area encompassed by the plan is shown on Figure 5, along with Management Zones that have been identified where management actions may be implemented.

The ETGSA Land Subsidence Monitoring Plan includes:

- An enhanced benchmark and groundwater level monitoring network,
- Establishment of a Land Subsidence Monitoring and Management Committee, and
- Annual Reporting

The Land Subsidence Management Plan establishes management action criteria for implementing enhanced management actions should land subsidence in any given Management Area reach certain thresholds. Four land subsidence thresholds, or "Tiers" have been established:

- Tier 1 – 0 to 1.49 ft of land subsidence
- Tier 2 – 1.5 to 1.99 ft of land subsidence
- Tier 3 – 2.0 to 2.49 ft of land subsidence
- Tier 4 – 2.5 to 2.99 ft of land subsidence.

[5] TH&Co, 2021. Eastern Tule Groundwater Sustainability Agency Land Subsidence Monitoring Plan. Dated September 2021.
[6] ETGSA, 2022. Eastern Tule Groundwater Sustainability Agency Land Subsidence Management Plan. Dated February 2022.

Progressively aggressive management actions have been identified for each tier. Land subsidence in any given Management Area that exceeds the criteria, as measured semi-annually using InSAR data, triggers the management actions in the next higher tier.

3.2 Local Canals

There are more than 290 miles of unlined local canals that deliver water for agricultural irrigation throughout the Tule Subbasin (see Figure 6). All of these canals are owned and operated by the irrigation districts, water districts and private growers in the GSAs including the following:

- Lower Tule River Irrigation District
- Pixley Irrigation District
- Porterville Irrigation District
- Various Tule River Association members (e.g. Porter Slough, Campbell-Moreland Ditch, etc.)
- Angiola Water District
- Alpaugh Irrigation District

Flow in the canals is gravity driven utilizing the land surface slope to maintain hydraulic head and velocity (and therefore flow capacity). Land subsidence resulting in changes in the slope of the land surface, particularly differential land subsidence in some areas relative to others, could reduce the flow capacity of the canals.

3.3 Water Delivery Pipelines

Some irrigation districts and cities in the Tule Subbasin convey water through gravity pipelines (see Figure 6). These irrigation districts and cities include:

- Porterville Irrigation District
- Saucelito Irrigation District
- Delano-Earlimart Irrigation District
- Terra Bella Irrigation District
- Kern-Tulare Irrigation District
- Tea Pot Dome Irrigation District
- City of Porterville

At a local level, differential subsidence around pipelines can result in ruptures or other damage. At a regional level, changes in land slope and pipeline grade cause increases in pipeline flow pressure that can exceed the original as-built design pressure class of the pipe, causing impacts to delivery capacity.

3.4 Flood Control

Areas of the Tule Subbasin in the vicinity of major river/stream drainages and the ancestral Tulare Lakebed have historically been subject to periodic flooding during above-normal precipitation events/seasons. Prior to SGMA, the Federal Emergency Management Agency (FEMA) published maps showing areas susceptible to flooding (see Figure 7). These areas are primarily located around the Tule River, Deer Creek, the White River, and the ancestral Tulare Lakebed. Multiple types of infrastructure and land uses near these features were prone to flooding prior to SGMA, including:

- State Highways (e.g. Highway 99 and Highway 43)
- Local Roads
- Railroads
- Stream Channels
- Tulare Lakebed

In addition to existing infrastructure/land use types vulnerable to flooding, the tracks for the planned California High Speed Rail (HSR) cross the western part of the Tule Subbasin over the ancestral Tulare Lakebed, the Tule River channel, and the Deer Creek channel, all areas historically prone to flooding (see Figure 7).

The same infrastructure and land uses that were vulnerable to historical flooding will be vulnerable to flooding after SGMA implementation. Further, the proposed HSR will also be vulnerable to flooding given its location across the ancestral Tulare Lakebed. AMEC Foster Wheeler (2017) noted that potential flooding of the Tulare Lakebed is the primary concern for subsidence impacts to the California High Speed Rail (CSHR), more so than potential physical impacts to the track structure.[7] TH&Co conducted analyses to assess the relative impact of land subsidence that has occurred since 2015 and could occur before 2040 (per SGMA) on land uses and infrastructure, including existing flood control levees (see Section 6.4 herein).

3.5 Wells

The California Department of Water Resources (CDWR's) Online System of Well Completion Reports (OSWCR)[8] database suggests that there are more than 4,500 wells in the Tule Subbasin (see Figure 8). The types of wells include private domestic, agricultural irrigation, municipal supply, and industrial supply. Domestic wells in the Tule Subbasin are relatively shallow, with an average depth of approximately 280 feet. In contrast, the average municipal well depth is approximately 565 feet and the average agricultural well depth is approximately 710 feet.

[7] AMEC Foster Wheeler, 2017. Ground Subsidence Study Report – Corcoran Subsidence Bowl, San Joaquin Valley, California. Prepared for the High Speed Rail Authority. Dated December 2017.
[8] CDWR, 2023. https://data.ca.gov/dataset/well-completion-reports, v. 3.

Wells are susceptible to damage from land subsidence. As the aquifer system compacts, it causes vertical compression on the well casing, which may result in collapsing, bending, ripping, rupturing, or otherwise breaking. In some cases, land subsidence may result in the need to repair or replace damaged wells and difficulty or inability to remove pumps.

Casing compression is proportional to the thickness of compressing sediment, which varies in the Tule Subbasin spatially and with depth. In the Tule Subbasin, compression of the Lower Aquifer is greater than that of the Shallow Aquifer. Therefore, wells constructed in the Lower Aquifer are more susceptible to damage from land subsidence than wells constructed only in the Upper Aquifer. To date, there has been no evidence of shallower domestic wells being impacted by land subsidence.[9]

3.6 Other Infrastructure

There is various other infrastructure in the Tule Subbasin that are potentially vulnerable to land subsidence but for which there is no documented evidence of historical impact and no basis for developing quantitative criteria. These include:

Roads, Highways and Bridges - Roads and bridges could become unstable and crack due to localized subsidence. The GSAs contacted the Tulare County Resources Management Agency (TCRMA) regarding road impacts from subsidence. The TCRMA stated that they, "…don't recall seeing subsidence as an issue with our roads".[10]

Railroads - Historical subsidence does not appear to have significantly impacted local railroads. Discussions with representatives of the BNSF railroad suggest that no cracks or damage to railroads related to subsidence have been observed.[11] A section of the planned California High-Speed Rail (CHSR) is to be located on the western side of the Tule Subbasin (see Figure 9). AMEC (2017) conducted a detailed evaluation of potential subsidence-related impacts to the CHSR including potential for (1) changes in slopes, vertical curvature, horizontal curvature, and twist; (2) development of fissures or compaction faults; and (3) changes in floodplains and site drainage. Aside from potential flood impacts (addressed in Section 3.4 and 6.4.2 herein), they concluded that "In general, we anticipate that embankments and MSE walls will be able to tolerate the anticipated degree of differential subsidence."[12] AMEC (2017) also recommended structural design considerations to accommodate land

[9] Self Help Enterprises, 2024. Personal communication.
[10] Personal communication with Johnny Wong, TCRMA
[11] Personal communication with Bill Chavez, BNSF
[12] AMEC Foster Wheeler, 2017. Ground Subsidence Study Report – Corcoran Subsidence Bowl, San Joaquin Valley, California. Prepared for the High Speed Rail Authority. Dated December 2017. Section 10.2.1 General Considerations, Pg. 123.

subsidence at extents exceeding those proposed by the Tule Subbasin revised cumulative land subsidence MTs.[13]

Gas/Petroleum pipelines - There is a regional hazardous liquid pipeline along Highway 99 and a number of natural gas pipelines that have been identified by the National Pipeline Mapping System.[14] No local data exist correlating land subsidence with impacts to these petroleum or natural gas lines.

Wastewater pipelines – The following cities have sanitary sewer systems with subsurface pipelines (see Figure 1):

- City of Porterville
- Terra Bella Sewer Maintenance District (SMD)
- Woodville Public Utilities District (PUD)
- Tipton Community Services District (CSD)
- Pixley PUD
- Earlimart PUD
- Richgrove CSD

Historically, there has been no reported impacts to wastewater collection systems in the Tule Subbasin attributed to land subsidence. Further, there has been no evidence or studies documenting differential land subsidence that has impacted wastewater infrastructure in the subbasin.

Buildings – The most concentrated urban development with building infrastructure is in the City of Porterville although buildings are scattered throughout the subbasin. Buildings are vulnerable to land subsidence through differential settlement that can result in cracks in foundations and building walls. Based on correspondence with the City of Porterville, there has been no evidence of land subsidence impacts to buildings in the City.[15]

The locations of these other types of infrastructure in the Tule Subbasin are shown on Figure 9.

[13] Ibid., Section 10.2.2 Design Considerations, Pg. 123
[14] https://www.npms.phmsa.dot.gov/
[15] Personal correspondence with Mr. Michael Knight, City of Porterville.

4 Significant and Unreasonable Land Subsidence Conditions for Infrastructure and Land Uses

The 2022 Tule Subbasin Coordination Agreement addressed undesirable results related to land subsidence as the following: *"Land subsidence that occurs during the transition period from 2020 to 2040 will be considered significant and unreasonable if damage and/or loss of functionality of a structure or a facility occurs to the extent that the structure or facility cannot reasonably operate without either repair or replacement, as determined by the GSA where the structure and facility are located or where beneficial use is impacted due to the damage and/or loss of functionality of the structure or facility."*

At a qualitative level, this definition is still applicable in the Tule Subbasin. Quantitative criteria for defining significant and unreasonable conditions varies depending on the type of land use and infrastructure under consideration. Table 1 summarizes the criteria by which significant and unreasonable conditions are determined for each infrastructure category.

Friant-Kern Canal	An unmitigated reduction in flow capacity as defined by the Middle Reach Capacity Correction Project[16] design flow rates for the Friant-Kern Canal should those flow rates be achieved after construction of the FKC Middle Reach Capacity Correction Project as defined in the Record of Decision cited below.
Local Canals	Loss of delivery capacity or damage to canals that cannot be mitigated by the canal owners. This level of damage is not anticipated at the land subsidence goals for other types of infrastructure in the subbasin and is, therefore, not the limiting factor for setting minimum threshold criteria.
Water Delivery Pipelines	Loss of pipeline delivery capacity or exceedance of pipeline pressure ratings, which cannot be mitigated.

[16] The FKC Middle Reach Capacity Correction Project seeks to address needed repairs to 33 miles of the 152-mile-long FKC from mile post 88.2 to 121.5. As of July 2024, only Phase 1 construction consisting of 10 miles of the FKC from downstream of Avenue 136 bridge and south of Avenue 64 has been completed. As per the Bureau of Reclamation Record of Decision (2020), the Canal Enlargement and Realignment Alternative (CER Alternative) would restore the capacity of the Middle Reach to the original design rates and are broken into four distinct segments separated by check structures:

1) Segment 1 (MP 88.2 to MP 95.7) would have a design flow rate of 4,500 cubic feet per second (cfs)
2) Segment 2 (MP 95.6 to MP 102.6) would have a design flow rate of 4,000 cfs
3) Segment 3 (MP 102.6 to MP 112.9) would have a design flow rate of 4,000 cfs
4) Segment 4 (MP 112.9 to MP 121.5) would have a design flow rate of 3,500 cfs

In and around the Delano-Earlimart Irrigation District (DEID) GSA, any additional land subsidence after 2023 is considered significant and unreasonable (see Section 6.3).

For other areas of the Tule Subbasin, pipeline damage is not anticipated at the land subsidence goals for other types of infrastructure and is, therefore, not the limiting factor for setting minimum threshold criteria.

Flood Control

Loss of land uses or function of a structure or facility from flooding caused by land subsidence occurring after 2015.

Along the Tule River west of Highway 99, slope analysis has shown that limiting the cumulative land subsidence, relative to 2020, to seven (7) feet avoids causing the flattening of the channel slope that can lead to flooding (see Section 6.4.1). Further, the Lower Tule River Irrigation District (LTRID) GSA has determined that levee improvements needed to accommodate land subsidence exceeding seven (7) feet is significant and unreasonable.

In the western part of the Tule Subbasin, analysis of potential flooding impacts on railroads and roads from seven (7) feet of additional land subsidence (relative to 2020) indicates that flooding is not forecast to be worse than what would have occurred prior to 2015 (see Section 6.4.2).

Along Deer Creek west of Highway 99, slope analysis has shown that limiting cumulative land subsidence relative to 2020 to five (5) feet avoids a flattening of the channel slope that could worsen flooding that already occurs in this area (see Section 6.4.3).

Wells

The point at which well damage from land subsidence prevents the use of the well and requires repair or replacement that cannot be mitigated. For deeper wells equipped with compression sections, this criterion is 14 feet (see Section 6.5). For all other wells, damage attributable to land subsidence is addressed through the Tule Subbasin Mitigation Plan.

Other Infrastructure	The point at which damage and/or loss of functionality of a structure or facility occurs to the extent that the structure or facility cannot function or operate without repair or replacement that cannot be mitigated. Damage attributable to land subsidence is addressed through the Tule Subbasin Mitigation Plan.

5 Quantification of Undesirable Results for Land Subsidence

5.1 Criteria for Defining Land Subsidence Undesirable Results

The SGMA defines an undesirable result for land subsidence as "Significant and unreasonable land subsidence that substantially interferes with surface land uses."[17] DWR Best Management Practices for establishing SMC add that "All undesirable results will be based on minimum threshold exceedances. Undesirable results will be defined by minimum threshold exceedances at a single monitoring site, multiple monitoring sites, a portion of a basin, a management area, or an entire basin."[18]

In the Tule Subbasin, the primary criteria and metric to determine if land subsidence undesirable results occur will be the cumulative subsidence at each RMS. Reflecting the GSAs' commitment to minimizing subsidence and avoiding significant and unreasonable impacts to land uses throughout the subbasin, the quantitative definition of undesirable result is:

Ongoing land subsidence after 2020 that exceeds the cumulative subsidence minimum threshold at any given RMS Site that cannot be attributable to elastic conditions or measurement error is an undesirable result.

If the subsidence rate exceeds the interim milestone rate at any location or combination of locations in any given year, the GSA will expedite management actions before subsidence undesirable results occur.

5.2 Potential Causes of Undesirable Results

Land subsidence in the Tule Subbasin is caused by prolonged pumping induced groundwater level declines, particularly during periods of below normal precipitation and limited surface water supplies. The rates and extent of subsidence in some areas of the subbasin are higher than others due to groundwater pumping patterns and unique area-specific hydrogeological conditions.

[17] California Water Code Part 2.74 Sustainable Groundwater Management, Chapter 2 Definitions, Section 10721(w)(5)
[18] CDWR, 2017. Best Management Practices for the Sustainable Management of Groundwater – Sustainable Management Criteria.

Subsidence impacts may occur in the Subbasin even if groundwater levels stabilize, as residual subsidence from past overdraft can continue for many years after groundwater level decline slows or stops.[19]

5.3 Effects on Beneficial Users and Land Uses

Land uses vulnerable to undesirable results from land subsidence include canals, pipelines, flood control, wells, or potentially other infrastructure (see Section 3.0). Historical land subsidence in the eastern part of the subbasin has caused reduced flow capacity in the Friant-Kern Canal (FKC), which has impacted downstream water rights holders.

The Tule Subbasin GSAs have established a Mitigation Program to address subsidence impacts to domestic and small community water system wells (see Attachment 8 to the Coordination Agreement). The Mitigation Program allows for those believed to be impacted by land subsidence to submit a claim. Technical assistance to address claims and mitigation funding for claims shown to be caused by GSA activities will commence in the second quarter of 2025. The GSAs will perform outreach with local utility and infrastructure agencies to raise their awareness of the Mitigation Plan, how to apply, and benefits to them. The GSAs will also set up channels to routinely inquire as to any infrastructure damage from land subsidence which may occur during GSP implementation.

6 Cumulative Land Subsidence Minimum Thresholds

The minimum thresholds for cumulative land subsidence in the Tule Subbasin have been established to avoid significant and unreasonable impacts to land uses across the subbasin (see Figure 10). Quantitative values for significant and unreasonable conditions were established for the FKC, local canals, water delivery pipelines, flood control and wells (see Table 1). In areas with multiple land uses/infrastructure types, the cumulative land subsidence MTs were selected to be protective of the most vulnerable land uses.

The analyses to inform determination of MTs to avoid significant and unreasonable conditions related to local canals and potential changes in flooding was iterative in that multiple MT extents and distributions across the basin were analyzed until a MT distribution was identified that prevented undesirable results and was acceptable to the GSAs and stakeholders. One exception to this approach was along the FKC where the MT has been established in accordance with separate analyses and established agreements as to allowable land subsidence in the Management Area of the canal (see Section 6.1 herein). The other exception to this approach is in DEID, where studies showed that the pipeline system in the GSA could not accommodate any additional land

[19] Lees, M., Knight, R., and Smith, R., 2022. Development and Application of a 1D Compaction Model to Understand 65 Years of Subsidence in the San Joaquin Valley. Water Resources Research, 58, e2021WR031390.

subsidence (see Section 6.3 herein). The MT distribution shown on Figure 10 is the culmination of this iterative process and other analyses.

Land subsidence MTs were also selected to be coordinated with neighboring subbasins. Minimum thresholds along the northern, western and southern Tule Subbasin boundaries are consistent with those being proposed for the Kaweah Subbasin, Tulare Lake Subbasin, and Kern Subbasin, respectively.

It is noted that there is ongoing work among the GSAs to coordinate the land subsidence MTs, particularly along the FKC and around the perimeter of DEID. Through this ongoing coordination, and with the collection of additional data, MTs in these areas may change.

6.1 Friant-Kern Canal

Groundwater flow model analysis forecasts as much as three feet of additional land subsidence at some locations of the FKC during the transition period from 2020 to 2040 (Figure 11).[20] Through coordination with the Friant Water Authority staff and consultants, this value became the basis for engineering design modifications to restore canal flow capacity to its original condition. Land subsidence along the canal exceeding three feet was determined to be an undesirable result because it would be beyond what the engineering design could accommodate to restore the flow capacity to its original condition and what the parties to the FWA/ETGSA/Pixley GSA settlement agreement agreed to mitigate. Thus, the minimum threshold for the ETGSA land subsidence management area is three feet (see Figure 10).

6.2 Local Canals

Changes in land surface slope or localized changes in land surface elevation have the potential to impact the flow capacity of local canals. For the 2022 Tule Subbasin Coordination Agreement, TH&Co had conducted a slope analysis based on the previous subsidence MTs, to assess the potential impact of changing slopes on canals (see Figure 12).[21] While that analysis showed a potential flattening of the land surface slope in the vicinity of the Tule River west of Highway 99 and in portions of the western part of the subbasin north of Deer Creek, it did not indicate a potential impact to flow in local canals.

[20] TH&Co, 2021. Eastern Tule Groundwater Sustainability Agency Land Subsidence Monitoring Plan. Dated September 2021.
[21] TH&Co, 2022. Technical Support for Addressing Department of Water Resources Comments Regarding Land Subsidence in the Tule Subbasin. Technical Memorandum dated July 13, 2022. Tule Subbasin Coordination Agreement Attachment 6.

Analysis of potential impacts to the delivery capacity of local canals was informed through an analysis of potential change in slopes across the Tule Subbasin based on the cumulative subsidence MTs on Figure 10 and updated data. The analysis involved the following steps:

1. TH&Co started with a land surface topography based on 2021 Light Detection and Ranging (LiDAR)[22] satellite data (the latest date for which these datasets are available) from the United States Geological Survey (USGS). LiDAR satellite data provides land surface elevations within an accuracy of 4 inches (10 centimeters).
2. A 2020 land surface topography was derived by subtracting InSAR land subsidence between 2020 and 2021[23] from the LiDAR topography (see Figure 13). This 2020 land surface topography was used as the baseline against which to compare potential changes in land elevation and slope between 2020 and 2040.
3. A comparison topography was developed by subtracting the cumulative land subsidence MT distribution (Figure 10) from the 2020 derived topography (see Figure 14) to assess potential flattened slopes that could present a flooding or canal impact.
4. Using the slope tool in GIS, TH&Co calculated the topographical slopes across the subbasin for both the 2020 topography and 2040 topography.
5. The difference in slopes between the 2020 and 2040 topographies is shown on Figure 15.

Results of the updated analysis using the revised MTs showed that the reducing the allowable land subsidence in the northern part of the subbasin reduced the flattening of the slope along the Tule River and would likely reduce the potential for flooding during high runoff events/years (see Section 6.4.1).

With respect to local canals, the change in slope associated with land subsidence is not predicted to impact the ability to deliver water in east-west trending canals (see Figures 15 and 16). While the slope is predicted to steepen slightly in the central part of the Pixley Irrigation District GSA, this is not expected to change the impact on delivery capacity. Based on communication with Lower Tule River Irrigation District's (LTRID's) and Pixley Irrigation District's general manager, there has been no observed change in delivery capacity in any of the canals in these two districts (which correspond to the LTRID and Pixley GSAs).

Local canals trending north-south have shown impacts to their flow capacity since before 2015. Differential land subsidence along the Taylor Ditch, which trends north-south on the western end

[22] USGS, 2023. 3DEP LidarExplorer. https://apps.nationalmap.gov/lidar-explorer/#/. Accessed November 2023.
[23] CDWR, 2023. TRE ALTIMERA InSAR Subsidence Data. https://data.ca.gov/dataset/tre-altamira-insar-subsidence-data.

of the subbasin (see Figures 15 and 17), required installation of a pump station near the southern end of the canal to boost water downstream. Analysis of Google Earth images indicates that the pump station was installed in approximately 2014. Similarly, a pump station was needed to boost water in the north-south trending Homeland Canal, also located at the western side of the Tule Subbasin (see Figure 18). That pump station was installed between 2015 and 2017.

The Taylor Ditch and Homeland Canal are locally owned and operated. The owners of these canals have indicated that any changes in the lift requirements after 2015 are considered business expenses and are not significant and unreasonable because they can be mitigated by the owners.[24] Any costs necessary to fix these canals or increase boosting capacity would be paid by the owners.

Based on the revised analysis and updated data, it is concluded that limiting additional land subsidence within the revised MTs shown on Figure 10 will avoid significant and unreasonable impacts to local canals.

6.3 Water Delivery Pipelines

The potential for damage to pipelines from land subsidence in the Tule Subbasin varies from area to area. Representatives of cities and irrigation districts with pipelines in the northeastern and eastern parts of the subbasin (Porterville, Porterville Irrigation District, Sausalito Irrigation District, Terra Bella Irrigation District; see Figure 6) have not observed impacts to their pipelines or water delivery capacity from land subsidence.[25] This may be because they are in areas that are less susceptible to damage from subsidence due to lower subsidence rates than other parts of the subbasin. As such, pipeline damage from subsidence in these areas is not a limiting factor for setting MTs.

The Delano-Earlimart Irrigation District (DEID) GSA has indicated that any further land subsidence in their area beyond what has occurred to date (January 2024), will potentially impact their pipeline system.[26] Accordingly, the cumulative subsidence minimum threshold in the DEID GSA is limited to the land subsidence that occurred between 2020 and 2024 (see Figure 10). In acknowledgment that groundwater pumping induced land subsidence outside the perimeter of DEID could contribute to land subsidence inside DEID, the GSAs have identified a preliminary perimeter buffer zone as shown on Figure 10. The purpose of the perimeter buffer zone is to limit land subsidence near DEID to be protective of DEID's pipelines. The perimeter zone is preliminary and approximate at this time as the data and analysis necessary to define the extent and projects and management actions needed to protect DEID's pipelines are not available at this time (this is a data gap). In the meantime, the GSAs are coordinating to implement more frequent

[24] Personal communication, Tri-County Water Authority.
[25] Personal communication with Michael Knight of the City of Porterville, Sean Geivet with PID, SID and TBID.
[26] Dan Howes, 2024. Delano-Earlimart Irrigation District – Pipeline Subsidence Susceptibility Risk. Dated June 23, 2024.

land subsidence monitoring as well implementing a land subsidence management plan to avoid impacts to DEID's pipelines until the analysis can be completed (see Section 8 herein). Any land subsidence impacts to DEID pipelines attributable to groundwater pumping from outside DEID would be mitigated in accordance with the Tule Subbasin Mitigation Plan (see Tule Subbasin Coordination Agreement Attachment 8).

6.4 Flood Control

Localized changes in land elevation due to subsidence have the potential to increase flood risk to infrastructure or other land uses. Areas of the Tule Subbasin in the vicinity of major river/stream drainages (Tule River, Deer Creek and White River) and the ancestral Tulare Lakebed have historically been subject to periodic flooding during above-normal precipitation events/seasons. TH&Co conducted analyses to assess the relative impact of land subsidence that has occurred since 2015 and could occur before 2040 (per SGMA) on land uses and infrastructure, including existing flood control levees.

6.4.1 Potential for Flooding Along the Tule River

Differential land subsidence has been observed along an approximate six mile stretch of the Tule River west of Highway 99 (see Figure 19). This has resulted in a flattening of the slope along this portion of the river, which, if allowed to continue, could present a flood risk to the lands on either side. Some flooding along this portion of the river was observed during the above-normal precipitation and runoff that occurred in 2023.

To address the potential for future flooding and inform sustainable management criteria for land subsidence along this portion of the Tule River, TH&Co performed a review of existing levees along the river west of Highway 99 and an analysis of how much additional levee height would be needed to prevent flooding in the future at various amounts of additional land subsidence. The analysis included the following assumptions:

- The current riverbanks and levee heights are at capacity for runoff events of the magnitude observed in 2023.
- Every foot of further land subsidence along this stretch of the river would require a commensurate foot of levee height to prevent flooding.
- Levees would be required on either side of the river.
- The cost per cubic foot of levee improvement was $0.68, based on communication with LTRID regarding the cost for levee improvements incurred during the 2023 flood season.

The analysis included the following steps:

1. TH&Co divided the Tule River channel west of Highway 99 into segments that were determined based on predicted change in slope from Section 6.2 and whether levees had

already been established. Segments ranged in length from approximately 6,100 to 21,000 feet.

2. At each segment, TH&Co developed comparative costs to raise levees to be protective of flooding with three scenarios (see Table 2):
    a. Scenario 1 – No more allowable land subsidence starting in 2024 (allowance of 2 feet for residual land subsidence)
    b. Scenario 2 – Reduction in cumulative land subsidence allowance, relative to 2020, to half of that allowed in the 2022 GSPs.
    c. Scenario 3 – Allowance of cumulative land subsidence to the MTs originally established in the 2022 GSPs (cumulative subsidence MTs are relative to 2020 conditions).

Results of the analysis showed that estimated costs for levee improvements were approximately:

1. Scenario 1 - $1,400,000
2. Scenario 2 - $5,000,000
3. Scenario 3 - $7,500,000

Based on the analysis, the LTRID GSA determined that improvements costing more than what was estimated for Scenario 2 was significant and unreasonable. The cumulative subsidence minimum threshold for Segment 1, which was the highest of the segments under this scenario, was 7.0 feet. Based on this, the GSAs capped the land subsidence MT in this area at seven feet, relative to 2020 (see Figure 10). As noted in Section 6.2, limiting land subsidence in the area of the Tule River to seven feet or less limits the impact of surface slope flattening and associated flooding west of Highway 99 as was predicted for the previous MTs and thereby reduces flooding risk in this area.

6.4.2 Potential for Flooding in the Western Tule Subbasin

The western part of the Tule Subbasin is located over the ancestral footprint of the Tulare Lake (see Figure 7). As noted earlier, this area has always been subject to periodic flooding. To analyze the relative impact of land subsidence since 2015 on flooding risk to land uses and infrastructure, TH&Co conducted an analysis of potential changes in flooding patterns from accrued subsidence since 2015 and potential future land subsidence to provide a basis for establishing significant and unreasonable conditions and associated cumulative subsidence MTs. The primary infrastructure vulnerable to flooding in the western part of the Tule Subbasin are Highway 43 and the BNSF railroad, which run parallel and relatively close to each other as does the planned HSR (see Figure 9). Key sources of information for comparing historical and projected future flooding elevations with elevations of infrastructure were:

- USGS, 2023. LiDAR topographic data[27]
- CDWR, 2023. InSAR land subsidence data[28]
- BNSF, 2024; current track elevations[29]
- HSR, 2021; design drawings for planned track elevations[30]
- USGS, 2023; LiDAR data on Highway 43 road elevations
- Google Earth Imagery from April 2023

The analysis included the following steps:

- TH&Co started with a land surface topography based on 2021 LiDAR data.
- A 2015 land surface topography was derived by subtracting InSAR land subsidence between 2015 and 2021 from the LiDAR topography. This 2015 land surface topography was used as the baseline against which to compare potential changes in land elevation and flooding patterns from land subsidence since that time.
- Assuming a 100-yr flood volume in Tulare Lake (1,685,000 acre-ft)[31], TH&Co estimated the flooding extent and surface water elevation of Tulare Lake at the derived topography for 2015 (see Figure 20). The extent considered the existing levee southwest of Corcoran and existing levees on the west side of Tulare Lake.
- To estimate the potential topographical conditions in 2040, TH&Co subtracted the cumulative land subsidence MT distribution shown on Figure 10, from the 2020 derived topography described in Section 6.2. This analysis incorporated the proposed cumulative land subsidence MTs from the neighboring Tulare Lake Subbasin (see Figure 21).[32]
- Using the forecasted 2040 topography, TH&Co estimated the flood extent of the same 100-yr flood volume used above (1,685,000 acre-ft). For comparison, the CDWR estimated that the volume of water that entered Tulare Lake during the 2023 above-normal runoff year was approximately 420,000 acre-ft.
- TH&Co also derived the 2015 elevations of the BNSF tracks and Highway 43 surface by adding the InSAR land subsidence that has occurred along these features from 2015 to 2023 to the 2015 topographic surface.

One goal of the analysis was to determine if flooding would have impacted the existing infrastructure in the western Tule Subbasin prior to 2015. To do this, TH&Co compared the hypothetical 100-year flooding extent for 2015 topographic conditions to the derived railroad track

[27] USGS, 2023. 3DEP LidarExplorer. https://apps.nationalmap.gov/lidar-explorer/#/. Accessed November 2023.
[28] CDWR, 2023. TRE ALTIMERA InSAR Subsidence Data. https://data.ca.gov/dataset/tre-altamira-insar-subsidence-data.
[29] BNSF, 2024. Email correspondence with Mr. Bill Chavez of BNSF. April 5, 2024.
[30] HSR, 2021. California High-Speed Train Project, Sierra Subdivision, Segment 3, Package 1, Construction Package 2-3, North Track Guideway, S2 STA 2665+00.00 to S2 STA 3449+00.00. Dated March 17, 2021.
[31] AMEC Foster Wheeler, 2017. Ground Subsidence Study Report Corcoran Subsidence Bowl, San Joaquin County, California. Prepared for High-Speed Rail Authority. Dated December 2017.
[32] Personal Correspondence with Amer Hussain, GeoSyntec, 2024.

and Highway 43 road elevations at that time (see Figure 20). Based on this analysis, both the BNSF railroad tracks and Highway 43 would have been submerged to depths of approximately 3 to 9 feet during a 100-yr flood in Tulare Lake had it occurred in 2015.

Under 2023 flooding conditions, neither the BNSF nor Highway 43 became submerged, although flooding was observed on either side of the infrastructure (see Figure 22). The surface water elevation in Tulare Lake was 179 ft above mean sea level (amsl) in 2023 relative to BNSF track elevations of 185 ft amsl and Highway 43 road elevations of 184 to 182 ft amsl in the flooded area.

Another goal of the analysis was to assess whether further lowering the land surface in accordance with a proposed cumulative land subsidence MT of seven feet relative to 2020 (see Figure 7) would worsen the flooding impact by 2040 relative to what would have historically occurred prior to 2015. As shown on Figure 23, the forecast extent of flooding under a topographic condition whereby the land surface was further lowered in accordance with the cumulative MTs shifts to the west, primarily due to higher land subsidence MTs in the central part of Tulare Lake Subbasin, relative to the Tule Subbasin. The projected surface water elevation in 2040 is 183 ft amsl relative to forecast track elevations of 177 to 181 ft amsl, Highway 43 road elevations of 176 to 181 ft amsl, and HSR elevations of 190 to 198 ft amsl. While the BNSF tracks and Highway 43 are forecast to be flooded during a 100-yr event, the extent of flooding is less than what would have happened in 2015 (approximately 2 to 7 feet at greatest allowable land subsidence versus approximately 3 to 9 feet in 2015). The analysis suggests that the cumulative subsidence MT of seven feet will not increase flooding impacts to the BNSF railroad and Highway 43 and will not impact the planned HSR.

Based on the above analysis, the cumulative land subsidence MT for the western Tule Subbasin has been set at seven feet.

6.4.3 Potential for Changes in Flooding Patterns at the West End of Deer Creek

The western extent of Deer Creek in the Tule Subbasin has historically flooded during above average precipitation years or events (see Figure 7). Slope analysis conducted assuming the land surface was lowered in accordance with the 2022 cumulative subsidence MTs showed a flattening of the land slope north of the creek channel at the western end (see Figure 12). This slope change had the potential to impact the ability of some stakeholder to divert water from the western end of Deer Creek at times when the water was available.

To reduce the potential for changes in flooding patterns and to minimize potential impacts to stakeholders diverting water from Deer Creek, TH&Co reevaluated the potential slope changes at reduced allowable subsidence MTs. As shown on Figure 15, reducing the allowable land subsidence in the downstream area of Deer Creek to the MT values shown on Figure 10 has the effect of minimizing potential slope changes north of the creek which should minimize impacts to stakeholders diverting water. Based on the slope analysis based on the MTs shown on Figure 10,

it is concluded that limiting additional land subsidence within the revised MTs will avoid significant and unreasonable impacts to land uses and infrastructure in this area.

6.5 Wells

As indicated in Section 3.5, deeper wells are more susceptible to damage from land subsidence in the Tule Subbasin. Self Help Enterprises has indicated that they have not had to mitigate any shallow domestic wells in the Tule Subbasin that were damaged from land subsidence (SHE, 2024). While well casing damage from land subsidence is known to occur in deeper wells, details regarding the number of impacted wells and the amount of land subsidence that leads to casing damage/failure are not documented. Further, most new wells constructed in the last approximately 20 years have been designed with compression sections in their casing to accommodate the effects of land subsidence. Communication with Roscoe Moss, the primary well casing supplier in the area, indicates that each compression section can accommodate up to 14 feet of land subsidence. They indicated that some wells for which they've supplied casing in the area are equipped with more than one compression section. Based on this information, casing damage from land subsidence was not considered a limiting factor in identifying cumulative land subsidence MTs. However, any well owner in the Tule Subbasin can submit a claim of impact and those claims will be addressed in accordance with the Tule Subbasin Mitigation Plan.

6.6 Other Infrastructure

Historically, there has been no reported damage to state highways, railroads, gas pipelines, roads, bridges, buildings, or electrical infrastructure in the Tule Subbasin attributed to land subsidence (see Section 3.6).

The Tule Subbasin GSAs have established a Mitigation Program to address subsidence impacts to domestic and small community water system wells (see Attachment 7 to the Coordination Agreement). The Mitigation Program allows for those believed to be impacted by land subsidence to submit a claim. Technical assistance and mitigation funding will commence in the second quarter of 2025. The GSAs will perform outreach with local utility and infrastructure agencies to raise their awareness of the Mitigation Plan, how to apply, and benefits to them. The GSAs will also set up channels to routinely inquire as to any infrastructure damage from land subsidence which may occur during GSP implementation.

7 Land Subsidence Rate Sustainable Management Criteria

Land subsidence rates in the Tule Subbasin will be used to define the subsidence measurable objective and interim milestones. Subsidence rates, as measured at each RMS, will provide the basis for compliance with subbasin subsidence goals.

The measurable objective (MO) for land subsidence in the Tule Subbasin is no inelastic (nonrecoverable) land subsidence after 2040. This is consistent with the GSAs' goal of minimizing and avoiding land subsidence in the Tule Subbasin.

Annual land subsidence rate interim milestones (IM) have been established to enable tracking of progress toward achieving the subsidence goals and to trigger projects and/or management actions if exceeded. Subsidence rate IMs were established at each RMS (see Figure 24). The subsidence rate IM was established for the period from 2024 to 2040 (16 years) and decreases over time. At each RMS, the rate IM for the first six years (2024 to 2030) is the average annual allowable land subsidence between 2024 and 2040 multiplied by 1.5 (see Figure 25). This allows for a higher rate in the first six years after revised GSP implementation to allow for implementation of projects and management actions to achieve the more aggressive cumulative land subsidence goals. The IM for the period between 2030 and 2035 is equal to the average annual subsidence multiplied by 0.75 to reflect the need to reduce subsidence to meet the goals. The MO for the period between 2035 and 2040 is zero inelastic land subsidence. Reducing the subsidence rate to zero prior to 2040 is intended to provide flexibility to account for potential residual subsidence although it is noted that Lower Aquifer groundwater level MTs have been established at elevations above the historical low elevations to enable meeting subsidence goals and minimizing residual land subsidence after 2040 (see Section 8).

Subsidence rate IMs specific to each RMS are provided in Appendix A.

8 Land Subsidence Monitoring Network

Progress towards meeting land subsidence minimum thresholds, measurable objectives, and interim milestones will be tracked via the subsidence monitoring network shown on Figure 26. This monitoring network consists of 95 established benchmarks that will be supplemented with InSAR data monitored at an additional 84 locations. Each of these benchmarks and InSAR data monitoring points constitutes a representative monitoring site for the purpose of monitoring progress with respect to land subsidence goals. Land subsidence rates will be documented on an annual basis.

9 Lower Aquifer Groundwater Level Minimum Thresholds and Measurable Objectives

The occurrence of land subsidence in the Tule Subbasin is directly correlated with pumping induced lowering of groundwater levels in areas where the subsurface aquifer system includes relatively thick silt and clay layers. This relationship is expressed mathematically[33] as:

$$\Delta b = S_k \Delta h$$

where:

Δb = change in thickness of the sediment layer
S_k = the skeletal storage coefficient
Δh = the change in hydraulic head (i.e. groundwater level change)

Under a stable condition, also known as a pre-consolidation condition, the forces maintaining the thickness of the compressible clay layers in the subsurface (the grain-to-grain contact and pore pressure) can counterbalance the weight of the sediments above the layer (the geostatic load). If the groundwater level is lowered below the pre-consolidation head, the pore pressure between the grains in the clay is reduced and the clay compresses under the weight of the sediments above it.

In the Tule Subbasin, the Lower Aquifer is confined beneath low permeability (i.e. silt and clay) layers (see Coordination Agreement Attachment B). The large seasonal fluctuations and long-term decline in Lower Aquifer groundwater levels from pumping in this aquifer is a primary cause of land subsidence. Groundwater pumping from this aquifer creates large seasonal changes in groundwater levels, in many cases more than 100 feet. Land subsidence rates have been observed to increase during the low seasonal pumping levels.

Given the correlation between Lower Aquifer groundwater levels and land subsidence, it is essential to establish Lower Aquifer groundwater level MTs and MOs to enable meeting the land subsidence goals described earlier in this TM. This is the reason that Lower Aquifer groundwater level MTs and MOs are addressed in this land subsidence TM.

Apart from land subsidence, TH&Co conducted an analysis of beneficial uses and users of groundwater potentially impacted by lowered groundwater levels in the Lower Aquifer using the same methodology as described in Attachment 4 to the Tule Subbasin Coordination Agreement.[34] The analysis showed that no wells were predicted to be impacted at the Lower Aquifer MTs and

[33] Hoffman, J., Leake, S.A., Galloway, D., and Wilson, A.M., 2003. MODFLOW-2000 Ground-Water Model - User Guide to the Subsidence and Aquifer-System Compaction (SUB) Package. USGS Open-File Report 03-233.
[34] TH&Co, 2024. Technical Support for Addressing Department of Water Resources Comments Regarding Sustainable Management Criteria for Upper Aquifer Groundwater Levels in the Tule Subbasin.

MOs previously established in the 2022 GSPs. As the revised Lower Aquifer groundwater level MTs and MOs described herein are higher than the previous values, this finding has not changed.

9.1 Methodology

The methodology to establish Lower Aquifer MTs and MOs changed relative to what was conducted for the 2022 Tule Subbasin Coordination Agreement. The previous methodology utilized the groundwater flow model of the Tule Subbasin to forecast the Lower Aquifer groundwater level in 2040 if all projects and management actions proposed by the GSAs were implemented. The 2040 groundwater level became the basis for the MT. This revised analysis does not rely on the groundwater model but is, instead, based on new data collected from InSAR and Lower Aquifer groundwater levels that have, for the most part, been collected since 2021. The methodology included the following steps:

1. TH&Co identified Lower Aquifer RMS wells with a suitable historical groundwater level record with which to correlate with land subsidence rates from InSAR (see Figure 24).
2. Historical groundwater levels were plotted on the same charts with InSAR land subsidence data to enable analysis of land subsidence rates and groundwater level changes over time (see Figure 25 and Appendix B).
3. Lower Aquifer groundwater level MTs were selected to correlate to land subsidence rates that would prevent cumulative land subsidence at that location from reaching the cumulative land subsidence MT.

Lower Aquifer groundwater level MOs were selected as the midpoint between the groundwater level MT and the April 2023 high groundwater level. Given the significant seasonal swings in groundwater levels, the MO level is meant to be an average annual groundwater level that should provide for operational flexibility while maintaining seasonal low levels above the MT.

9.2 Results

A comparison of previous lower aquifer groundwater level MT elevations with the revised values is shown on Figure 27. In all cases, the MT was raised relative to the previous MT. Lower aquifer groundwater level recovery in 2023 resulting from the above-average precipitation and runoff condition during that year slowed land subsidence rates considerably across the subbasin, suggesting that the groundwater level conditions in 2023 are near the pre-consolidation heads (i.e. critical heads) needed to minimize land subsidence. These conditions, which are above the historical low levels, helped inform selection of the MTs. Based on available data, maintaining Lower Aquifer groundwater levels above the selected MTs has the greatest chance of limiting land subsidence within the cumulative subsidence goals and has the greatest chance of minimizing and avoiding residual land subsidence after 2040. As additional groundwater levels and land

subsidence data are collected during the SGMA implementation period, the Lower Aquifer groundwater level MTs and MOs will continuously be evaluated to ensure they are protective of Tule Subbasin land subsidence goals.

10 Undesirable Results for Lower Aquifer Groundwater Levels

The SGMA regulations stipulate that "Undesirable results occur when significant and unreasonable effects for any of the sustainability indicators are caused by groundwater conditions occurring throughout the basin."[35] For the "chronic lowering of groundwater levels" sustainability indicator, an undesirable result has already been defined for the Upper Aquifer (see Coordination Agreement Attachment 4). Given that the only potential significant and unreasonable effects for chronic lowering of Lower Aquifer groundwater levels is inducement of land subsidence at rates that exceed the SMC for subsidence (see Section 9 herein), the definition of undesirable results for Lower Aquifer groundwater levels is correlated with the ability to satisfy the land subsidence undesirable result, which is an exceedance of the cumulative subsidence at any given RMS that is not attributable to elastic conditions or measurement error (see Section 5 herein).

11 Estimated Projects and Management Actions Needed to Achieve Land Subsidence Goals

The management actions needed to achieve the land subsidence and lower aquifer groundwater level goals were informed through analysis using the Tule Subbasin groundwater flow model.[36] The objective of the analysis was to determine the consumptive use and associated groundwater pumping that the Tule Subbasin can sustain while meeting the land subsidence and Lower Aquifer groundwater level goals. The analysis was conducted as a forecast, starting in October 2019 (the last month of the model calibration) and extending through 2070. The primary variable that was adjusted in the model forecast was consumptive use demand and its associated groundwater pumping. Accelerated reductions in consumptive use, relative to the transitional pumping schedules published in the 2022 GSPs, were started in 2024 of the forecast simulation. Through an iterative process, TH&Co progressively reduced consumptive use in the GSAs during the transition period between 2024 and 2040 until there was no subbasin wide net negative change in groundwater storage after 2040 and land subsidence was minimized. The forecasted land subsidence and groundwater levels were analyzed under an average hydrology condition and incorporated climate change factors, as was done for the 2020 forecast analysis.[37]The revised

[35] California Code of Regulations, Title 23 Waters, Division 2 Department of Water Resources, Chapter 1.5 Groundwater Management, Subchapter 2 Groundwater Sustainability Plans, Article 5 Plan Contents, Subarticle 3 Sustainable Management Criteria, Section 354.26 Undesirable Results.
[36] TH&Co, 2021. Update to the Groundwater Flow Model of the Tule Subbasin. Prepared for the Tule Subbasin Technical Advisory Committee. Dated July 29, 2021. Attachment 3 to the Tule Subbasin Coordination Agreement.
[37] TH&Co, 2020. Groundwater Flow Model of the Tule Subbasin. Prepared for the Tule Subbasin Technical Advisory Committee. Dated January 2020. Attachment 3 to the Tule Subbasin Coordination Agreement.

(relative to 2022) transitional pumping schedules resulting from the analysis are summarized in Table 3. These pumping schedules resulted in the model-estimated land subsidence and Lower Aquifer groundwater levels shown in Appendices C and D. While the simulations allowed for some overdraft pumping between 2024 and 2040, the volume of overdraft pumping was reduced in half in the Lower Tule River Irrigation District and Pixley Irrigation District GSAs. Overdraft pumping in the Tri-County Water Authority GSA (TCWA) was reduced by 10,000 acre-ft/yr. The TCWA reduction was applied in the TCWA North Management Area. It is noted that reductions in pumping reflected in the forecasted land subsidence charts and Lower Aquifer groundwater level hydrographs in Appendices C and D were not aquifer specific. Pumping well locations and perforation intervals are, for the most part, a data gap. As additional data are collected on the location and construction of wells in the subbasin, it is anticipated that the representativeness of forecasted land subsidence and groundwater levels will improve.

Forecasted land subsidence rates at selected RMS sites are shown in Appendix C. Except for three RMS sites, land subsidence rates are forecast to slow and eventually reduce to near zero across almost all of the subbasin by 2040. Two exceptions to this are LTRID TSS L01 located in the north-central part of the subbasin and TSMW-5L located in the southwest part of the subbasin. These results indicate that enhanced management actions will likely be necessary in these areas to manage land subsidence within the goals of the subbasin. The GSAs in which these wells are located will be implementing a land subsidence management plan to ensure that future land subsidence will be limited within the goals presented herein. The cause of forecasted land subsidence after 2040 at the third location (25S/26E-09C01), located in the south-central part of the subbasin, is unclear. Land subsidence rates at this location have historically been relatively low and rates into the future are not predicted to exceed one foot between 2020 and 2040. Future monitoring, data collection and analysis will inform the management actions (if any) needed to reduce land subsidence rates at this location within the goals of the subbasin.

Forecasted changes in groundwater levels in RMS wells for the Lower Aquifer are provided in Appendix D. Lower Aquifer groundwater levels at all locations are projected to stabilize or rise between 2024 and 2040. The forecasted rise in groundwater levels in the Lower Aquifer is needed to meet both the Lower Aquifer groundwater level goals as well as land subsidence goals. At some locations, Lower Aquifer groundwater levels are forecasted to decline slightly after 2040. Some of this decline may be due to the influence of climate change factors incorporated into the forecast. Nonetheless, groundwater levels remain above the SMC goals through the planning horizon and ongoing monitoring and adaptive demand management and/or projects can be employed to ensure that land subsidence is minimized into the future.

12 Summary and Conclusions

The analysis of land subsidence and Lower Aquifer groundwater level SMC presented herein has resulted in the following conclusions:

- The Tule Subbasin GSAs have identified the land uses and infrastructure types that could be impacted by land subsidence.
- The GSAs have collectively identified the significant and unreasonable land subsidence conditions throughout the subbasin that they seek to avoid.
- The GSAs have developed cumulative subsidence MTs to avoid significant and unreasonable conditions.
- The GSAs have quantified undesirable results to avoid significant and unreasonable subsidence conditions.
- Throughout most of the Tule Subbasin, the revised allowable subsidence is less than previously published in the 2022 GSPs, which should reduce the risk of impacts to land uses and infrastructure.
- The GSAs have quantified the subsidence rates necessary to meet cumulative subsidence goals and incorporated those rates as interim milestones. Exceedance of interim milestone rates will trigger management actions to ensure that land subsidence goals are met.
- For potential impacts that cannot be foreseen, the GSAs have incorporated land subsidence mitigation into the Tule Subbasin Mitigation Program.
- The GSAs have established Lower Aquifer groundwater level MTs that are consistent with the subsidence goals.
- The subsidence and Lower Aquifer groundwater level SMC have been vetted through a public stakeholder process that has included NGO groups, including Community Water Center, Self Help Enterprises, the Central California Environmental Justice Network, and The Leadership Council.

Summary of Land Uses and Infrastructure in the Tule Subbasin Vulnerable to Land Subsidence and Criteria for Defining Significant and Unreasonable Conditions

Land Use/ Infrastructure	Potential Impacts	Criteria for Significant and Unreasonable Impacts	Basis for Significance Criteria
Friant-Kern Canal	Loss of Delivery Capacity Canal Cracking	An unmitigated reduction in flow capacity as defined by the Middle Reach Capacity Correction Project design flow rates for the Friant-Kern Canal should those flow rates be achieved after construction of the FKC Middle Reach Capacity Correction Project as defined in the Record of Decision cited below.	Agreement with FWA re: Canal Restoration Costs
Local Canals	Loss of Delivery Capacity Canal Cracking	Loss of Delivery Capacity or Damage to Canals that Cannot Be Mitigated by the Canal Owners	Correspondence with: GSA Growers Lower Tule River Irrigation District Pixley Irrigation District Tule River Association
Water Delivery Pipelines	Loss of Pipeline Capacity Due to Exceedance of Pipeline Pressure Ratings Damage to Pipelines from Differential Subsidence	Loss of Pipeline Delivery Capacity or Exceedance of Pipeline Pressure Ratings that Cannot be Mitigated	Correspondence with: Delano-Earlimart Irrigation District Saucelito Irrigation District Terra Bella Irrigation District Porterville Irrigation District City of Porterville

Summary of Land Uses and Infrastructure in the Tule Subbasin Vulnerable to Land Subsidence and Criteria for Defining Significant and Unreasonable Conditions

Land Use/ Infrastructure	Potential Impacts	Criteria for Significant and Unreasonable Impacts	Basis for Significance Criteria
Flood Control	Increased Flood Risk in Areas Adjacent to Stream Channels During Extreme Runoff Events	Loss of Land Uses Due to Flooding Caused by Land Subsidence from Groundwater Pumping Occurring After 2015. Cumulative Land Subsidence Limited to 7 ft Along the Western Tule River and 5 ft Along the Western Deer Creek.	Correspondence with: GSA Growers Lower Tule River Irrigation District Tule River Association Deer Creek Stormwater District Alpaugh Irrigation District Tulare County Flood Control District California High Speed Rail Burlington Northern/Santa Fe Railroad California Department of Water Resources AMEC, 2017; HSR DEIR
	Increased Flood Risk of Infrastructure Due to Differential Land Subsidence In and Near Tulare Lake	Loss of Function of a Structure or Facility from Flooding Caused by Land Subsidence Occurring After 2015. Cumulative Land Subsidence Limited to 7 ft in the Northwestern Tule Subbasin.	
Wells	Well Casing Damage or Collapse	The Point At Which Well Damage from Land Subsidence Prevents the Use of the Well Requiring Repair or Replacement that Cannot Be Mitigated (14 ft).	Correspondence with: GSA Growers with Wells City of Porterville City of Tipton (Engineer) Well Casing Supplier Local Well Drillers Self Help Enterprises
Other Infrastructure	Uneven Settlement Resulting in Structural Damage	The Point at Which Damage and/or Loss of Functionality of a Structure or Facility Occurs to the Extent that the Structure or Facility Cannot Function or Operate Without Repair or Replacement	Correspondence with: City of Porterville Tulare County Resources Management Agency California High Speed Rail Burlington Northern/Santa Fe Railroad

Planning-Level Levee Mitigation Cost Estimates

Area	Segment	Length (ft)	Pre-existing Levees[1]	Number of Levees	Cost per Cubic Foot of Levee[2]	Land Subsidence since 2020[3] (ft)	Estimated Residual Land Subsidence[4] (ft)	Scenario 1 (No More Transitional Pumping)					Scenario 2 (Reaching updated 2024 MT)					Scenario 3 (Reaching 2020 GSP MT)				
								Subsidence due to Future Pumping[5] (ft)	Scenario 1 Minimum Threshold (ft)	Additional Levee Height Required (ft)	Cross-sectional Area Required[6] (ft^2)	Cost Per Segment[7]	Subsidence due to Future Pumping[8] (ft)	Scenario 2 Minimum Threshold (ft)	Additional Levee Height Required (ft)	Cross-sectional Area Required[6] (ft^2)	Cost Per Segment[7]	Subsidence due to Future Pumping[9] (ft)	Scenario 3 Minimum Threshold (ft)	Additional Levee Height Required (ft)	Cross-sectional Area Required[6] (ft^2)	Cost Per Segment[7]
Tule River	1	14,000	yes	2	$0.68	2.3	2	0	4.3	0	0	$0	3	7.0	0	0	$0	7	11.6	4	132	$2,514,000
	2	11,000	yes	2	$0.68	2.9	2	0	4.3	0	0	$0	2	7.0	0	0	$0	4	8.8	1	27	$404,000
	3	14,300	no	2	$0.68	2.3	2	0	4.3	2	18	$350,000	3	7.0	5	75	$1,458,000	3	7.4	5	75	$1,458,000
	4	21,000	no	2	$0.68	1.8	2	0	4.3	2	18	$514,000	3	6.7	5	75	$2,142,000	2	6.3	4	52	$1,486,000
	5	20,100	no	2	$0.68	2.2	2	0	4.3	2	18	$492,000	2	6.4	4	52	$1,422,000	2	6.3	4	52	$1,422,000
	6	6,100	yes	2	$0.68	2.4	2	0	4.3	0	0	$0	2	6.7	0	0	$0	4	7.9	1	27	$224,000
											Tule River Subtotal	$1,400,000				Tule River Subtotal	$5,000,000			Tule River Subtotal	$7,500,000
Deer Creek	1	16,100	no	2	$0.68	1.8	2	0	4.3	2	18	$394,000	2	5.9	4	52	$1,138,000	5	9.0	7	133	$2,912,000
	2	7,500	no	0	$0.68	2.0	2	0	4.3	2	18	$0	2	6.2	4	52	$0	4	8.4	6	102	$0
	3	7,900	no	0	$0.68	1.6	2	0	4.3	2	18	$0	3	6.1	5	75	$0	4	7.9	6	102	$0
											Deer Creek Subtotal	$400,000				Deer Creek Subtotal	$1,100,000			Deer Creek Subtotal	$2,900,000

Notes:

[1] Pre-existing levees are assumed to be 5 ft tall and thus require less raising.

[2] The basis for planning-level costs are based on conversations with Engineers at LTRID.

[3] Approximate average subsidence along the length of the segment, from January 2020 through September 2023 using DWR InSAR data.

[4] 2 feet of residual subsidence is assumed to occur once groundwater levels stabilize.

[5] Land subsidence due to future groundwater pumping does not exist due to a theoretical halting of pumping.

[6] The cross-sectional area of a levee is assumed to be a trapezoid. Height = Additional Levee Height Required (ft). Top Width = 5 ft. Base = (4 * height) + 5 ft.
i.e. If the additional height required is 2 ft, the cross-sectional area that levee would be (5 ft + ((4 * 2) + 5)) ft / 2) * 2 ft = 18 ft^2

[7] Cost = Length x Cross-sectional area x Cost per Cubic Foot of Levee.
i.e. Length = 100 ft. Cross-sectional area = 18 ft^2. Cost per Cubic Foot of Levee = $0.68. Therefore, 100 ft * 18 ft^2 * $0.68 ft^{-3} = $1,224

[8] Land subsidence due to future pumping is based on the updated Minimum Thresholds for the cumulative amount of allowable land subsidence set in 2024.

[9] Land subsidence due to future pumping is based on the previous Minimum Thresholds for the cumulative amount of allowable land subsidence set in 2020.

Planned Transitional Pumping by GSA

Water Year	Eastern Tule GSA[1]		LTRID GSA			Pixley ID GSA			DEID GSA	TCWA			Alpaugh GSA		Kern-Tulare WD GSA
	2020 and 2024 GSP Plan Description	Numerical Annual Transitional Pumping for Model	2020 GSP Plan Description	2024 GSP Accelerated Rampdown Description	Numerical Annual Transitional Pumping for Model	2020 GSP Plan Description	2024 GSP Accelerated Rampdown Description	Numerical Annual Transitional Pumping for Model	2020 and 2024 GSP Plan Description	2020 GSP Plan Description	2024 GSP Accelerated Rampdown Description	Numerical Annual Transitional Pumping for Model	2020 and 2024 GSP Plan Description	Numerical Annual Transitional Pumping for Model	2024 Plan Description
2019/20	90% of over-pumping[2]	100%	2.0 af/ac Over Cons. Use Target	N/A	100%	Fallow 5,000 acres; Remaining no change	N/A	100%	No Change/ Sustainable	100% of over-pumping	N/A	100%	Reduce cropped area by 880 acres; 80% of overpumping	100%	No Change/ Sustainable
2020/21		90%			98%			98%				100%		98%	
2021/22		90%			95%			95%				100%		96%	
2022/23		90%			93%			93%				100%		94%	
2023/24		90%		50% Accelerated Rampdown	45%		50% Accelerated Rampdown	45%				100%		92%	
2024/25	80% of over-pumping	80%	1.5 af/ac Over Cons. Use Target		44%	Fallow 5,000 acres; Remaining 1.5 af/ac Over Cons. Use Target[3]		44%		Reduce pumping 10,000 af/yr	Reduce pumping by additional 10,000 af/yr	91%		90%	
2025/26		80%			43%			43%				82%		88%	
2026/27		80%			42%			42%				73%		86%	
2027/28		80%			41%			41%				64%		84%	
2028/29		80%			40%			40%				55%		82%	
2029/30	30% of over-pumping	30%	1.0 af/ac Over Cons. Use Target		35%	Fallow 5,000 acres; Remaining 1.0 af/ac Over Cons. Use Target		35%				45%	50% of overpumping	80%	
2030/31		30%			30%			30%				36%		73%	
2031/32		30%			25%			25%				27%		65%	
2032/33		30%			20%			20%				18%		58%	
2033/34		30%			15%			15%				9%		50%	
2034/35	Sustainable	0%	0.5 af/ac Over Cons. Use Target		12%	Fallow 5,000 acres; Remaining 0.5 af/ac Over Cons. Use Target		12%		Sustainable		0%	20% of overpumping	43%	
2035/36		0%			9%			9%				0%		35%	
2036/37		0%			6%			6%				0%		28%	
2037/38		0%			3%			3%				0%		20%	
2038/39		0%			0%			0%				0%		0%	
2039/40+	Sustainable	0%	Sustainable	Sustainable	0%	Sustainable	Sustainable	0%		Sustainable		0%	Sustainable	0%	

Notes:

[1]Land Subsidence Management Area subject to additional pumping restrictions.

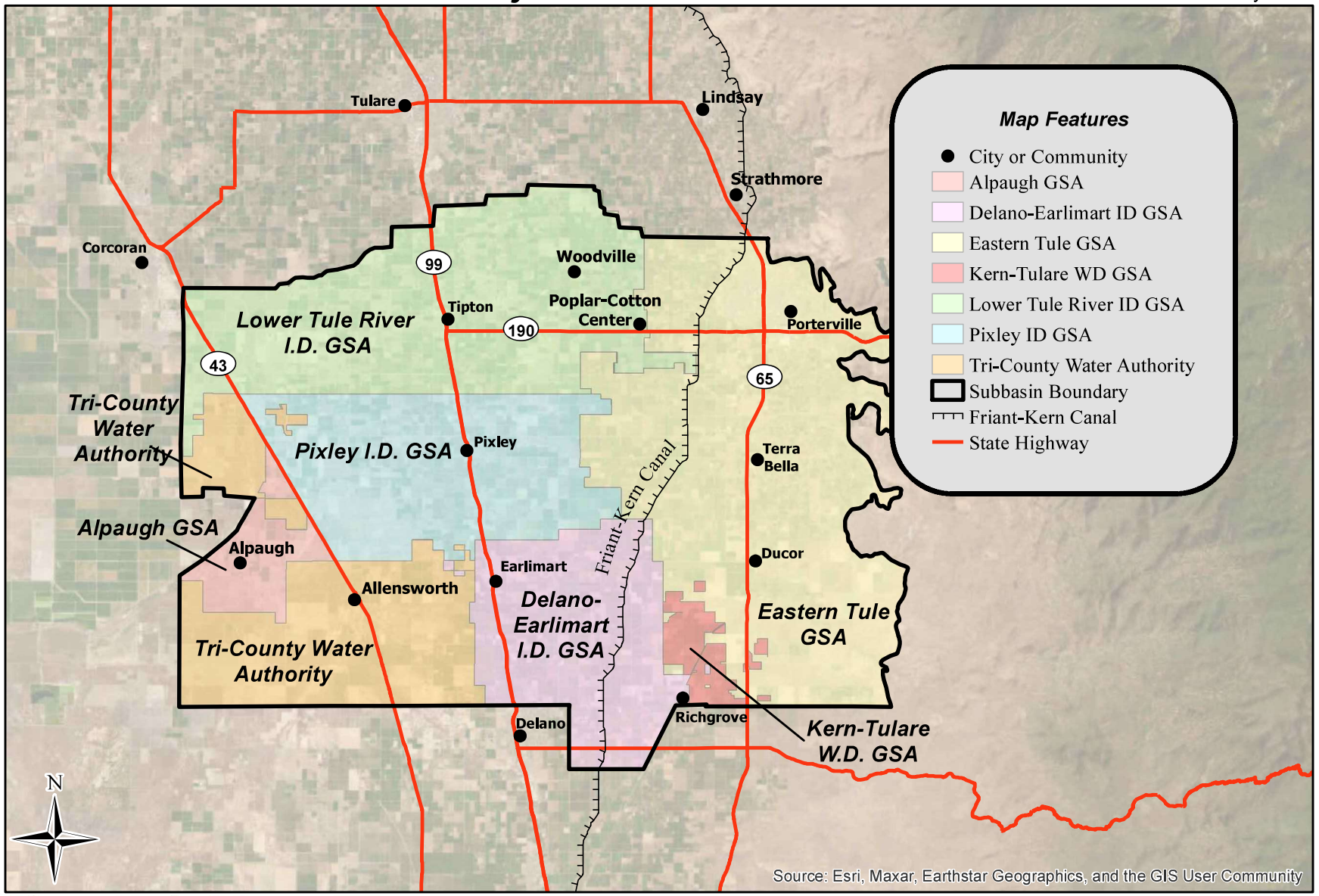
[2]Over-pumping means pumping in excess of the consumptive use target

[3]Over consumptive use target means over pumping

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

July 2024

Tule Subbasin Technical Advisory Committee



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0 2.5 5 10 Miles

NAD 83 State Plane Zone 4

GSA Boundaries

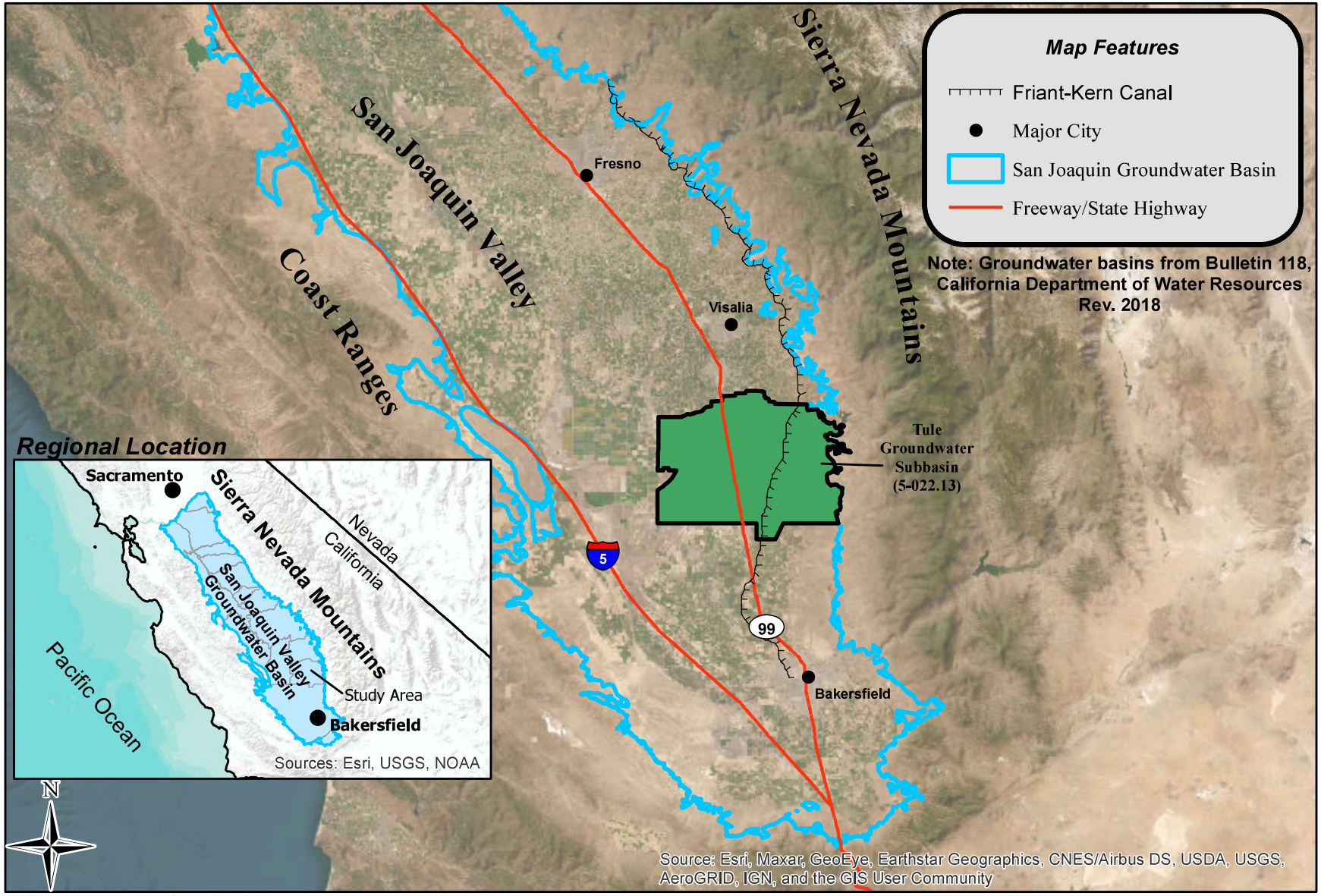
Figure 1

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Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

July 2024

Tule Subbasin

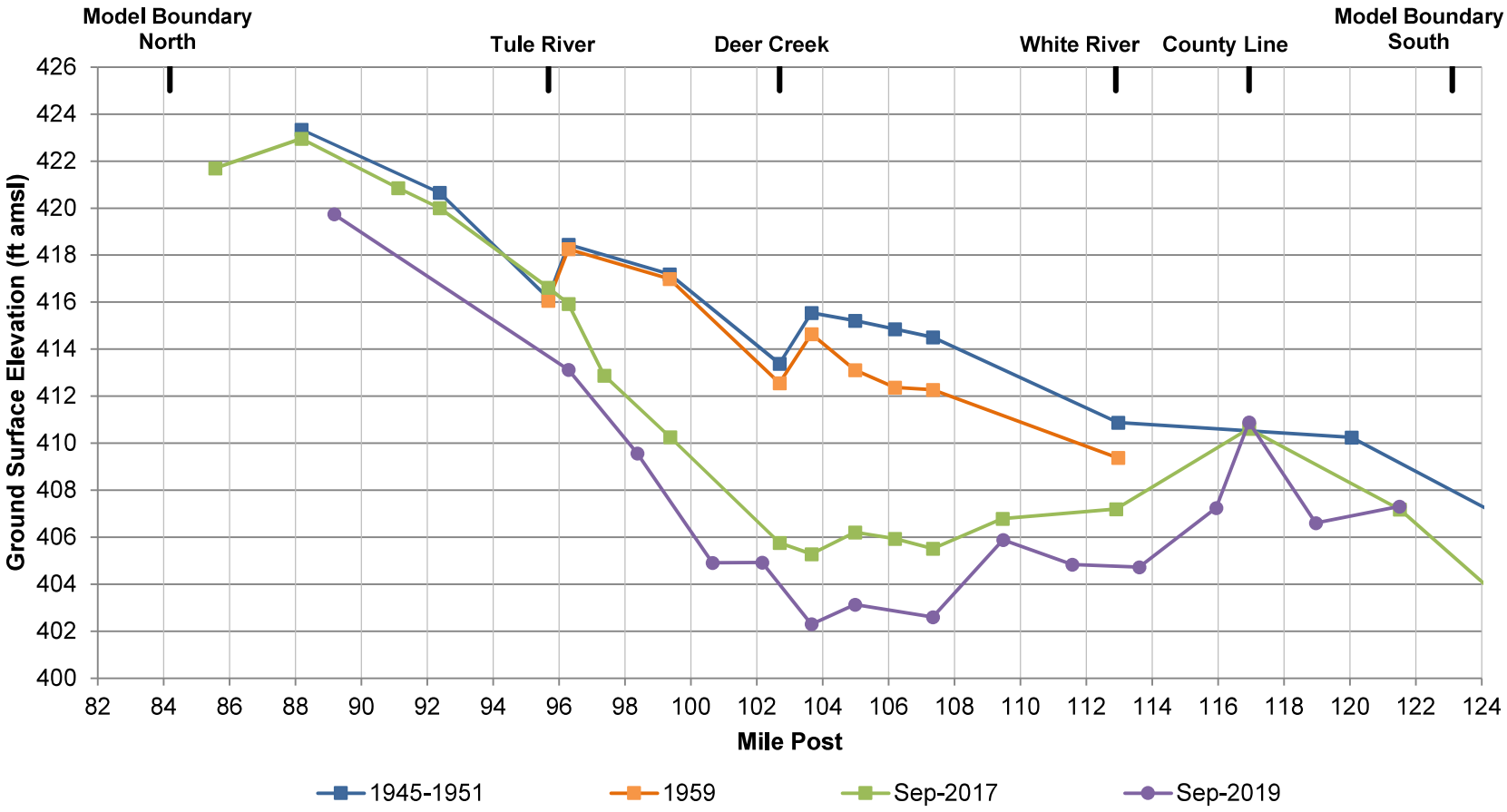


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Groundwater Consulting

0 10 20 40
Miles
NAD 83 State Plane Zone 4

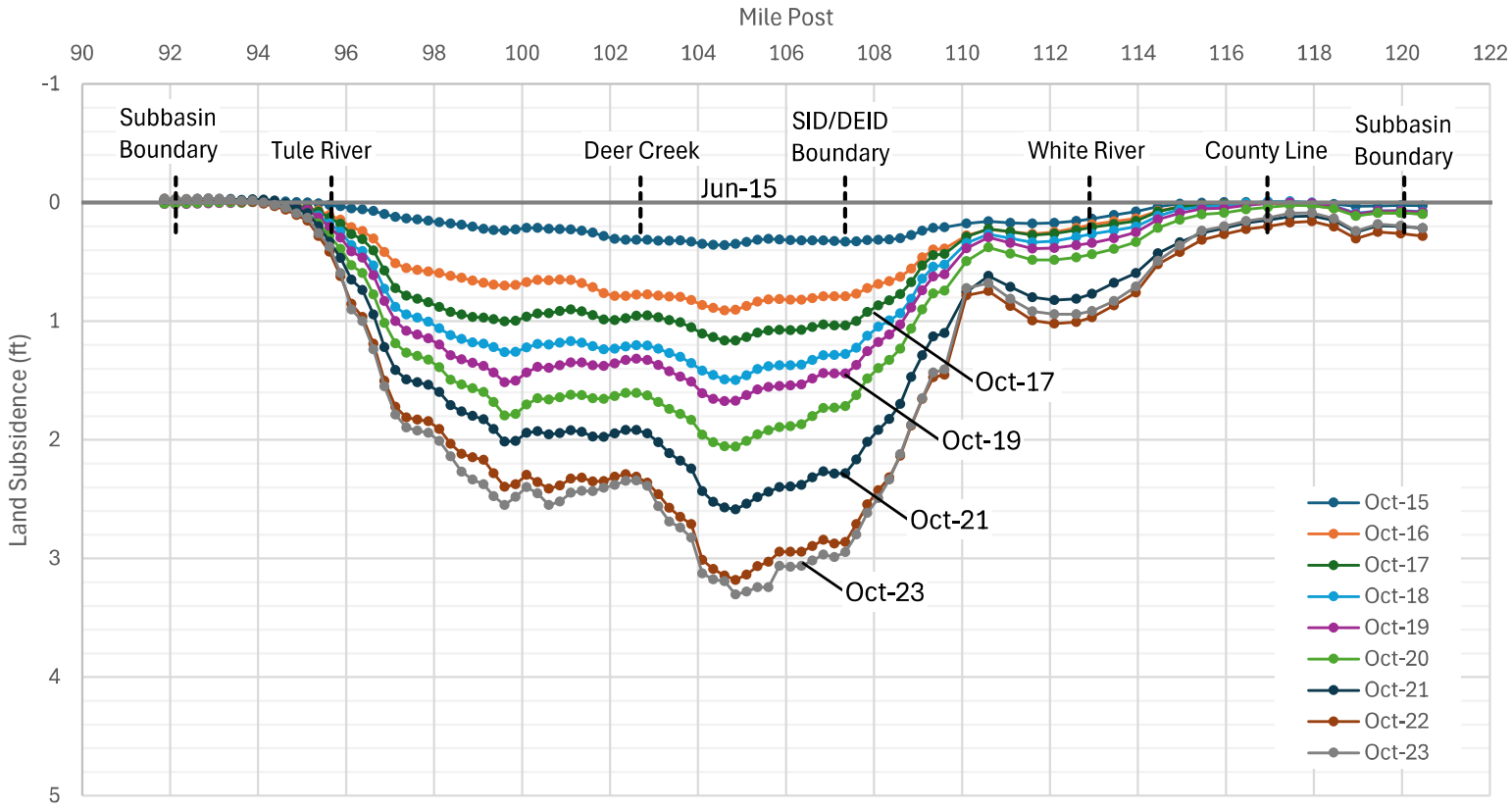
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Regional Map
Figure 3

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



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

Friant-Kern Canal Profile with InSAR Land Subsidence
June 2015 through October 2023



Notes:

"Oct" = October 1, representative of the end of the Water Year

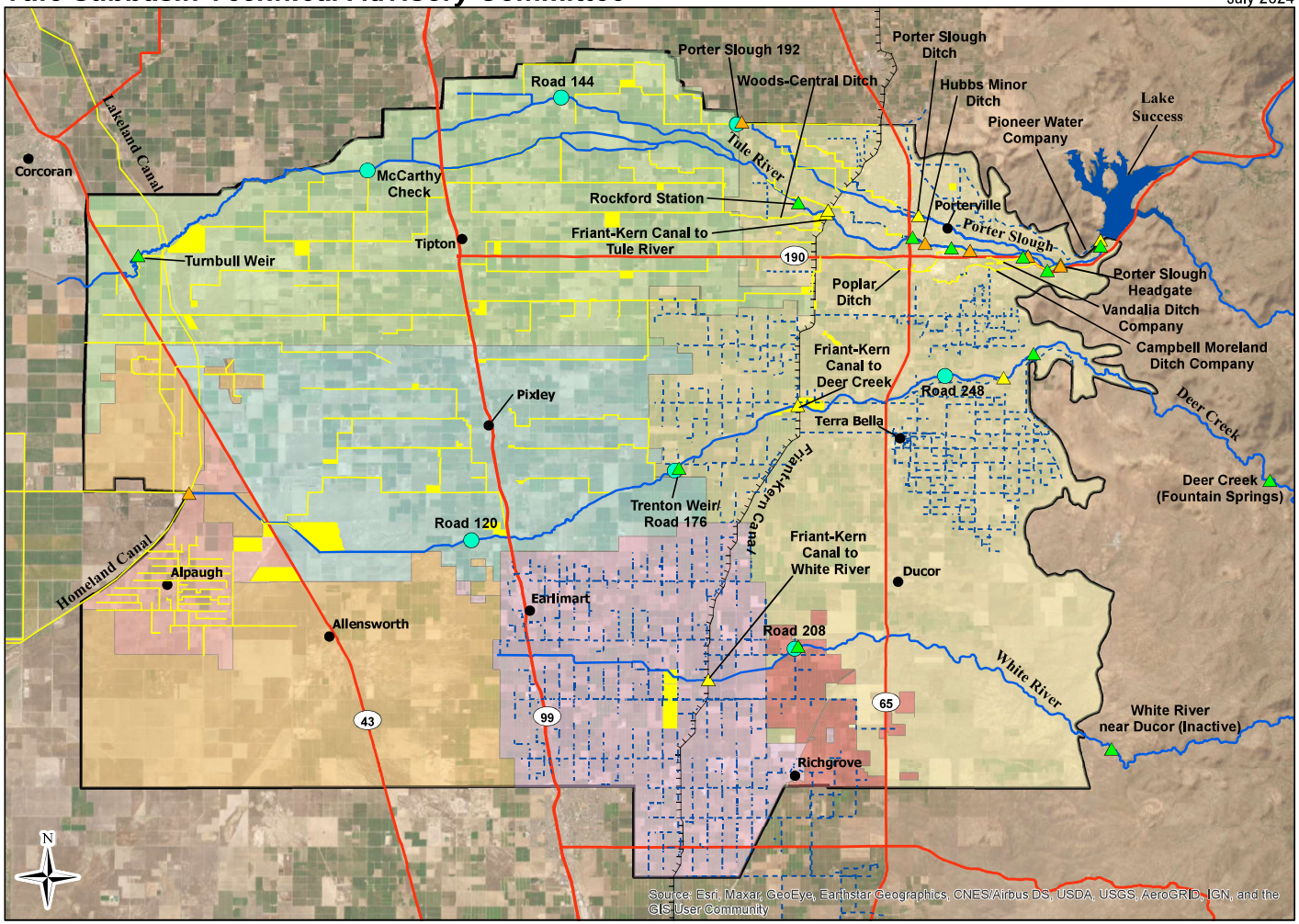
All values relative to 13-Jun-15

InSAR data from https://gis.water.ca.gov/arcgisimg/rest/services/SAR

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Diversion Headgate
- Diversion Gage
- Instream Gage
- QM
- City or Community
- Canal
- Pipe
- Major Hydrologic Feature
- Friant-Kern Canal
- Recharge Basin
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority
- Subbasin Boundary
- Freeway/State Highway

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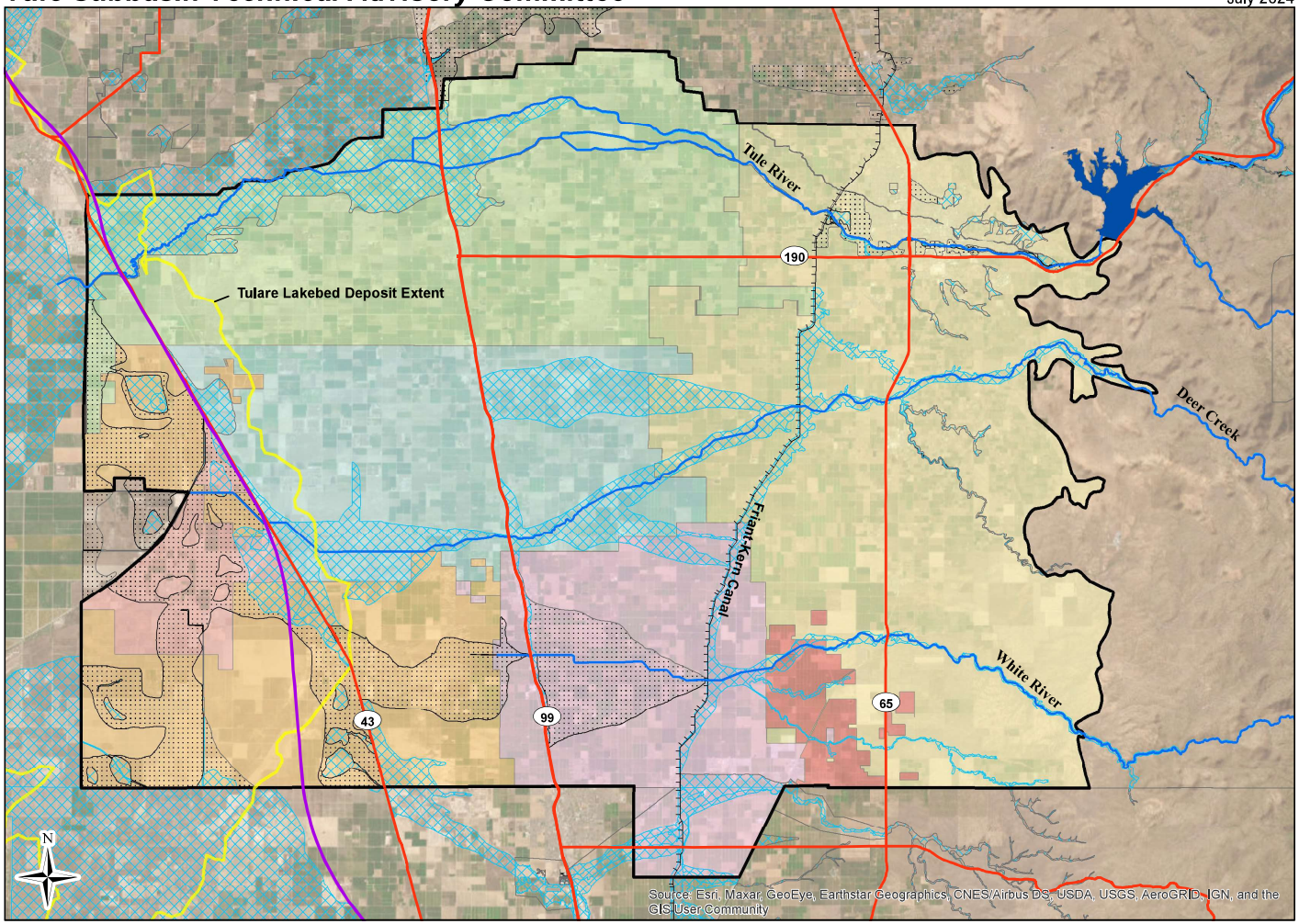
Gravity-Driven Water Conveyance Infrastructure

Figure 6

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Simplified FEMA Flood Hazard Area*
  - 1% Annual Chance Flood Area
  - 0.2% Annual Chance Flood Area
  - Outside 0.2% Chance Flood Area
- Tulare Lakebed Deposit Extent
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority
- California High Speed Rail
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature
- Subbasin Boundary

*Simplified data shown for illustrative purposes only. Not official National Flood Insurance Program (NFIP) reference.

Data modified from County Federal Emergency Management Agency (FEMA) maps.
https://www.fema.gov/flood-maps/national-flood-hazard-layer

Lake Deposits from California Geological Survey
Geologic Atlas of California Map No. 002
1:250,000 scale, Compiled by A.R. Smith, 1964
and Geologic Atlas of California Map No. 005,
1:250,000 scale, Compiled by: R.A. Matthews and J.L. Burnett

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Simplified FEMA Flood Hazard Areas

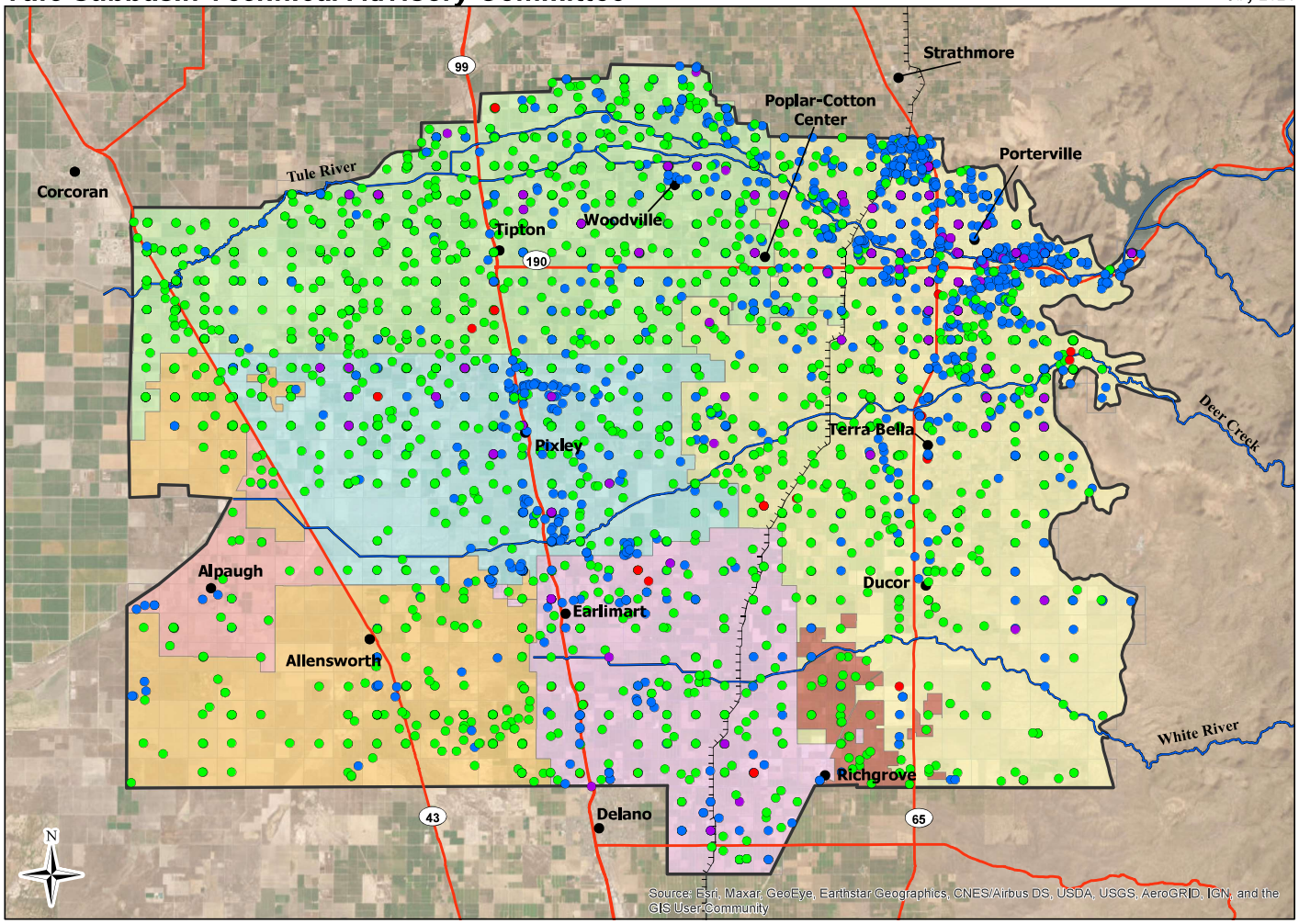
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Figure 7

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Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Domestic Well
- Agricultural Well
- Industrial Well
- Unknown Well
- City or Community
- Major Hydrologic Feature
- State Highway/Major Road
- Friant-Kern Canal
- Subbasin Boundary
- Alpaugh GSA
- Delano-Earlimart I.D. GSA
- Eastern Tule GSA
- Kern-Tulare GSA
- Lower Tule River I.D. GSA
- Pixley I.D. GSA
- Tri-County Water Authority GSA

0 2.5 5 10 Miles

NAD 83 State Plane Zone 4

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All USGS and OSCWR Wells Under Consideration

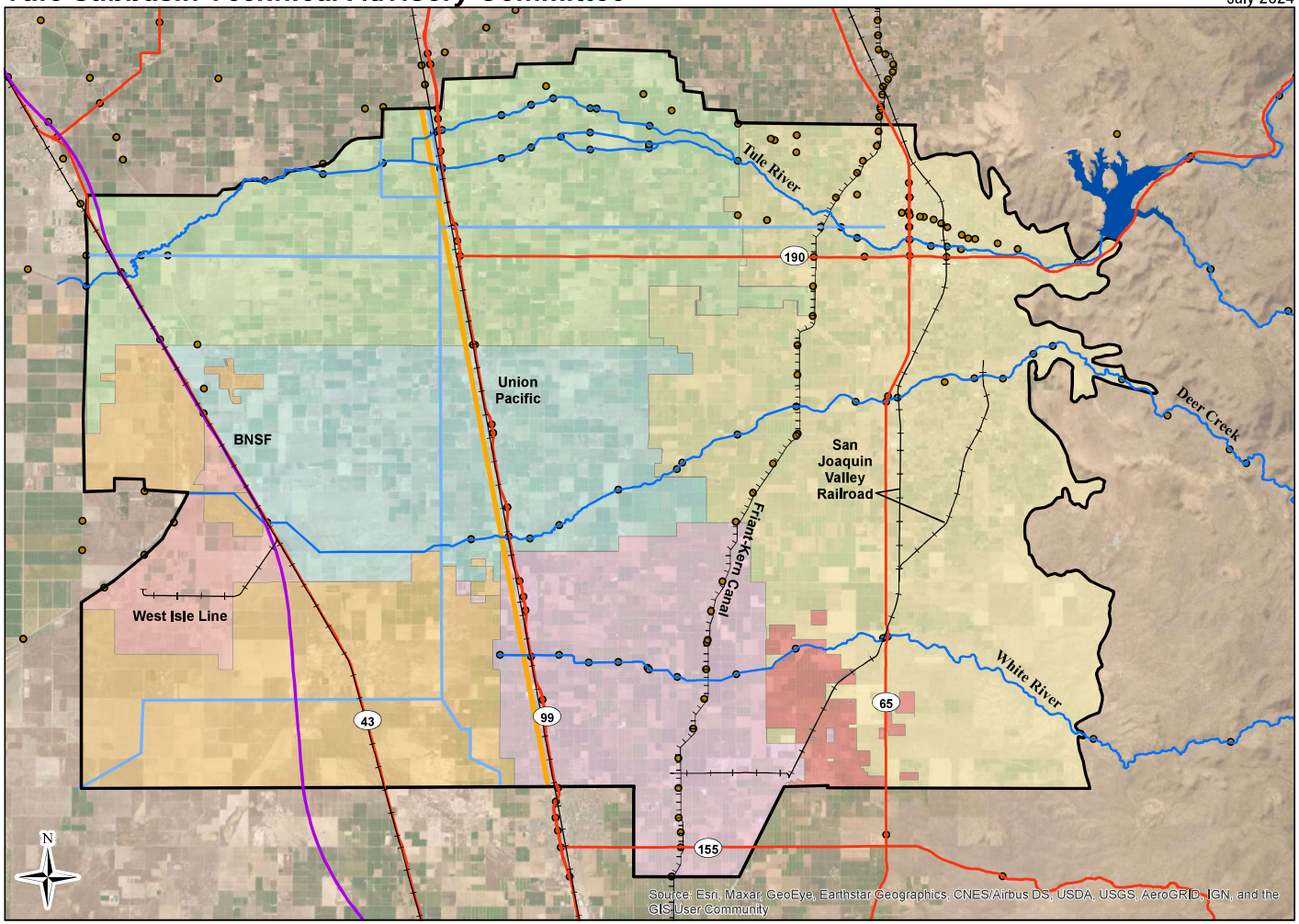
Figure 8

Note: The well data comes from the USGS, 07 2023 and the OSCWR database
https://www.sciencebase.gov/catalog/item/64958d73d34ef77fcb01dc8f

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Local Bridge
- Railroad
- California High Speed Rail
- Gas Transmission Pipeline
- Hazardous Liquid Pipeline
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature
- Subbasin Boundary
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority

Railroads from Caltrans.

Bridges from the US Department of Transportation, National Bridge Inventory.

Pipelines from the National Pipeline Mapping System (NPMS). Data shown for illustrative purposes only. https://pvnpms.phmsa.dot.gov/PublicViewer/

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State Highways, Railroads, Pipelines, and Bridges

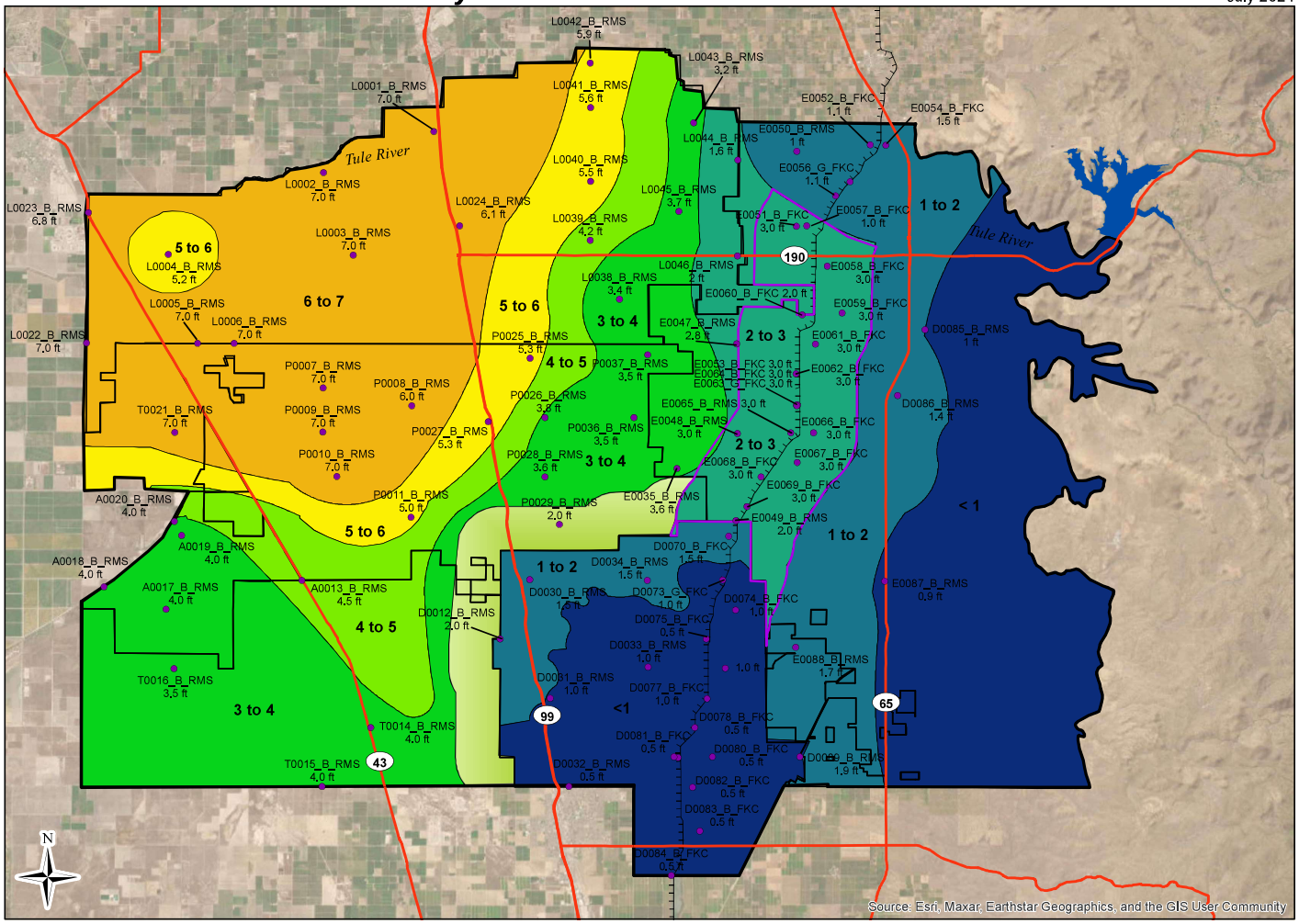
Figure 9

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Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

Cumulative Land Subsidence Minimum Threshold (ft)

- <1
- 1 to 2
- 4 to 5
- 3 to 4
- 2 to 3
- 5 to 6
- 6 to 7

Preliminary DEID Perimeter Buffer Zone*

Minimum Threshold at RMS (ft)

Friant-Kern Canal

State Highway

ETGSA Land Subsidence Management Area

GSA Boundary

Minimum Threshold values relative to 2020.

*The preliminary buffer zone has been identified as an area where focused projects and management actions are needed to avoid land subsidence in the zone that could impact DEID pipelines. The zone is preliminary because the data and analysis needed to define the extent as well as the projects and management actions needed to protect DEID pipelines are not available at this time (this is a data gap). In the meantime, the GSAs are coordinating to implement more frequent land subsidence monitoring as well implementing a land subsidence management plan to avoid impacts to DEID's pipelines until the analysis can be completed.

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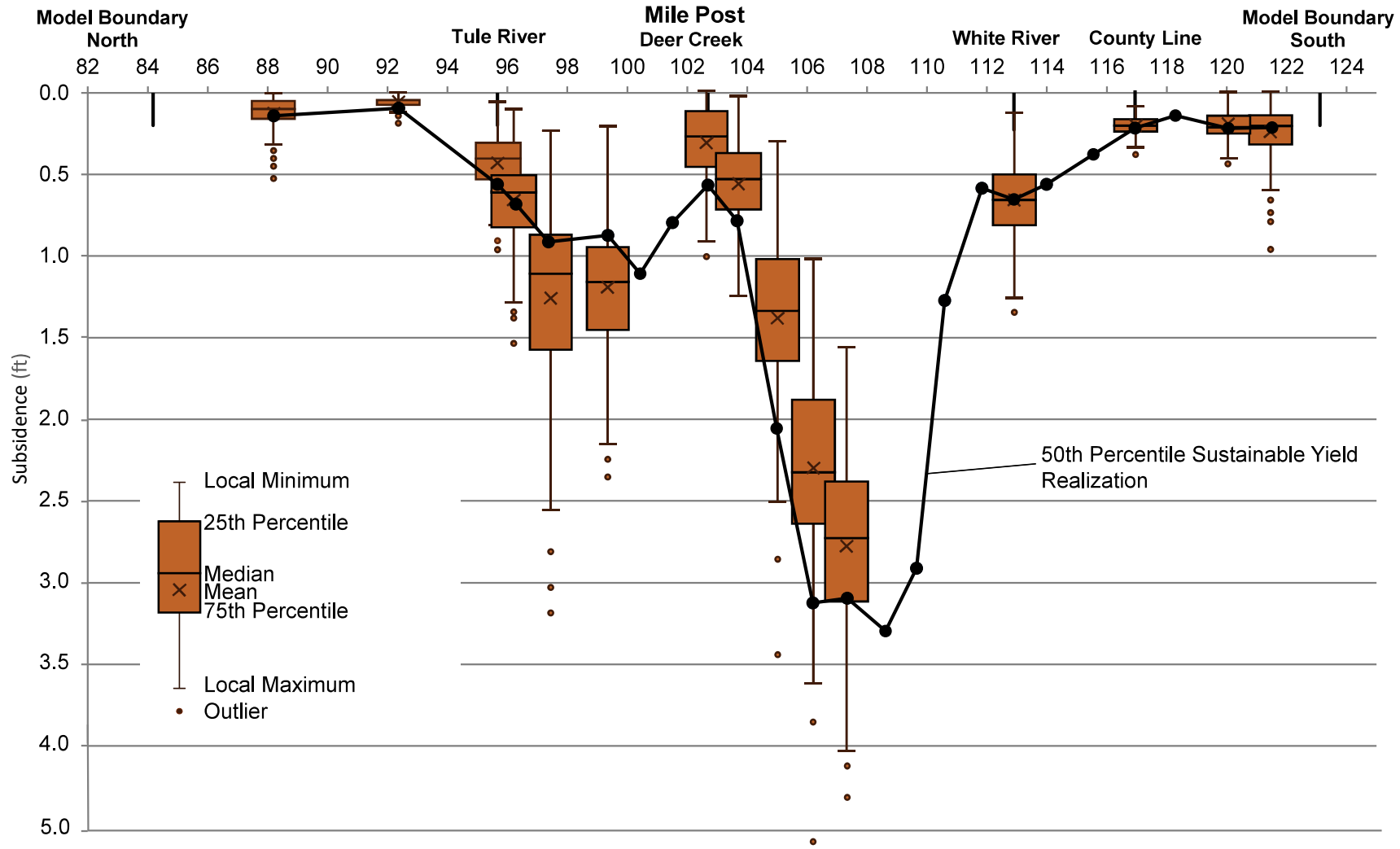
Minimum Threshold - Land Subsidence

Figure 10

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Figure 11

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



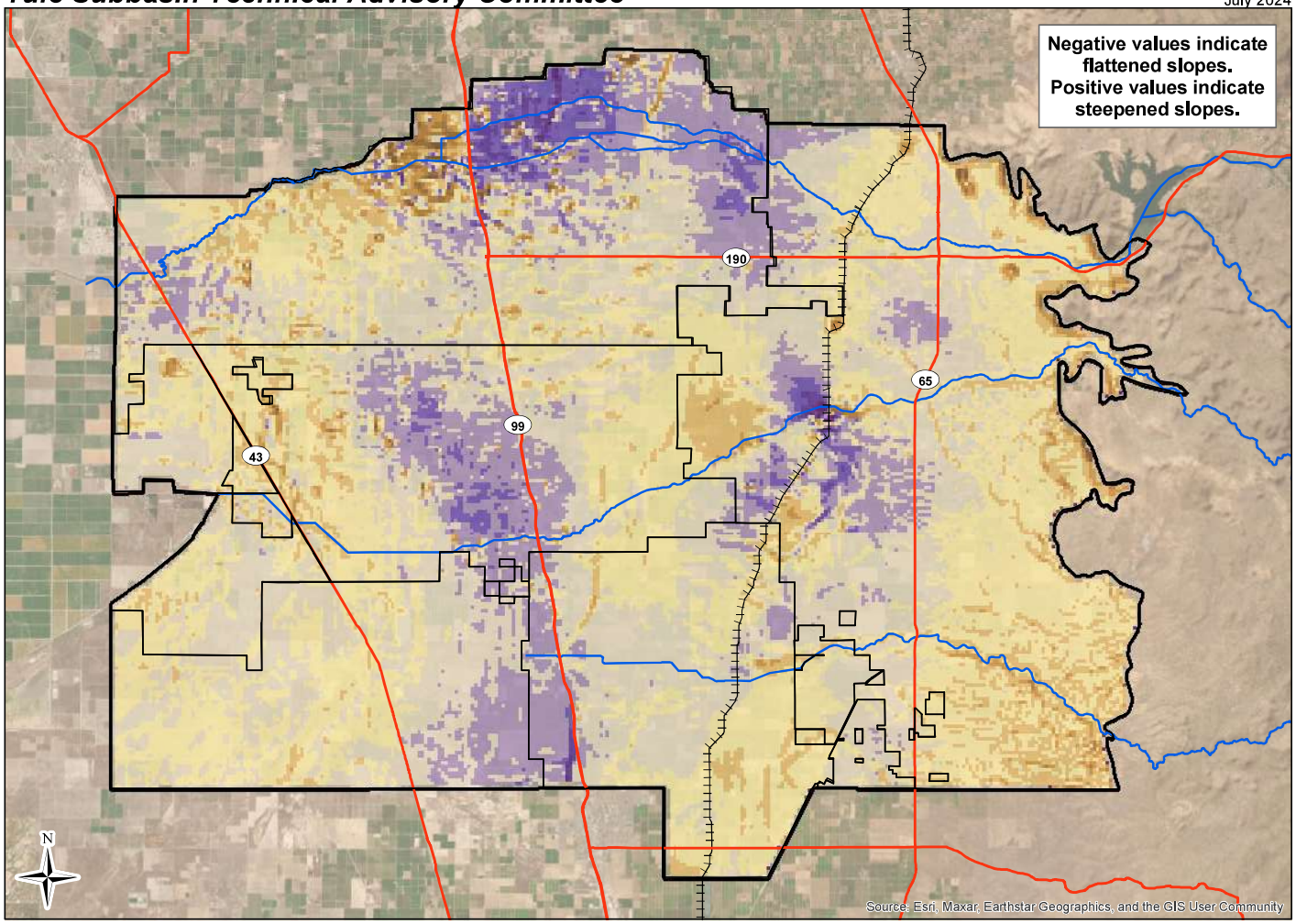
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Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

July 2024



0 2 4 8 Miles

NAD 83 State Plane Zone 4

Map Features

Change in Land Surface Slope (ft/mi)

- < -1
- -1 to -.08
- -0.8 to -0.6
- -0.6 to -0.4
- -0.4 to -0.2
- -0.2 to 0.0
- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- > 1
- GSA Boundary
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature

Note: This map shows estimated change in land surface slope at the subsidence minimum thresholds relative to 2022 conditions.

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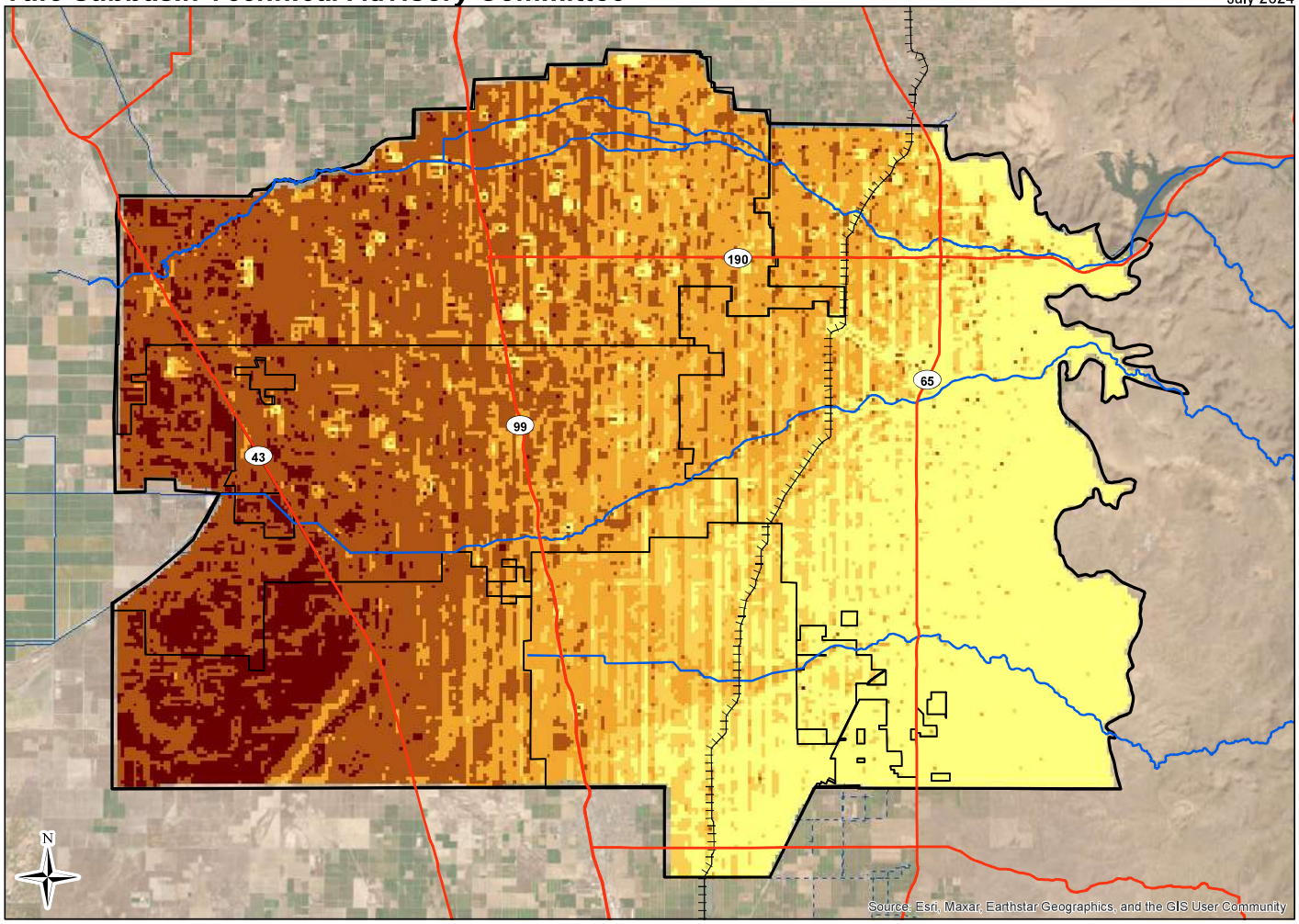
Estimated Change in Land Surface Slope 2022 Minimum Threshold

Figure 12

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



0 2 4 8 Miles

NAD 83 State Plane Zone 4

Map Features

Land Surface Slope (ft per mile)

- 0 to 1
- 1 to 5
- 5 to 10
- 10 to 15
- > 15
- GSA Boundary
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature
- Canal
- Pipe

Note: The estimated 2020 Land Surface Slope based on interpolated 2020 land surface Digital Elevation Model (DEM).

Land subsidence from January 2020 to April 2021 was added to the USGS LiDAR DEM from April 2021 to estimate the Jan 2020 land surface DEM."

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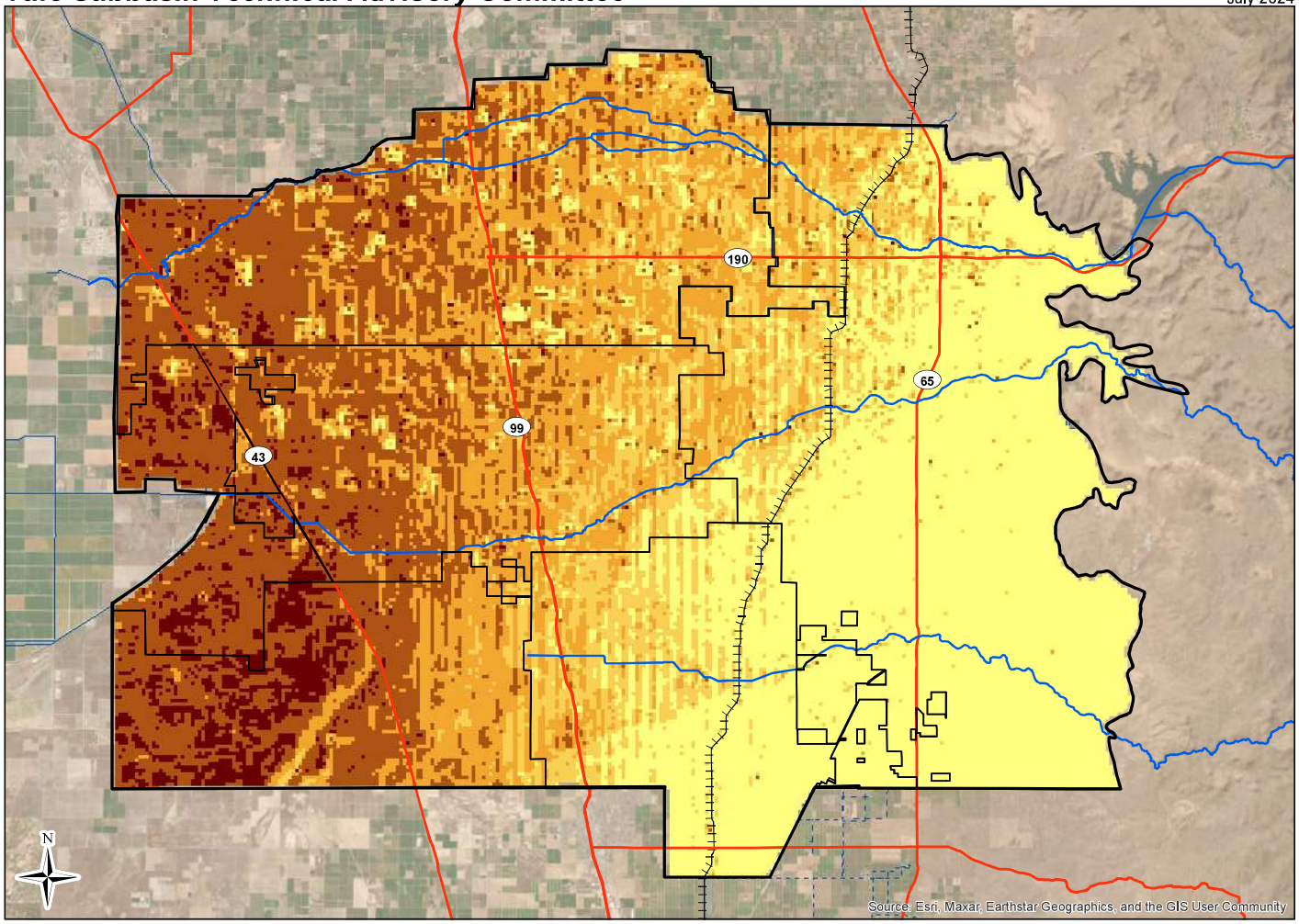
Estimated 2020 Land Surface Slope

Figure 13

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

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Map Features

Land Surface Slope (ft per mile)

- 0 to 1
- 1 to 5
- 5 to 10
- 10 to 15
- > 15
- GSA Boundary
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature
- Canal
- Pipe

0 2 4 8 Miles

NAD 83 State Plane Zone 4

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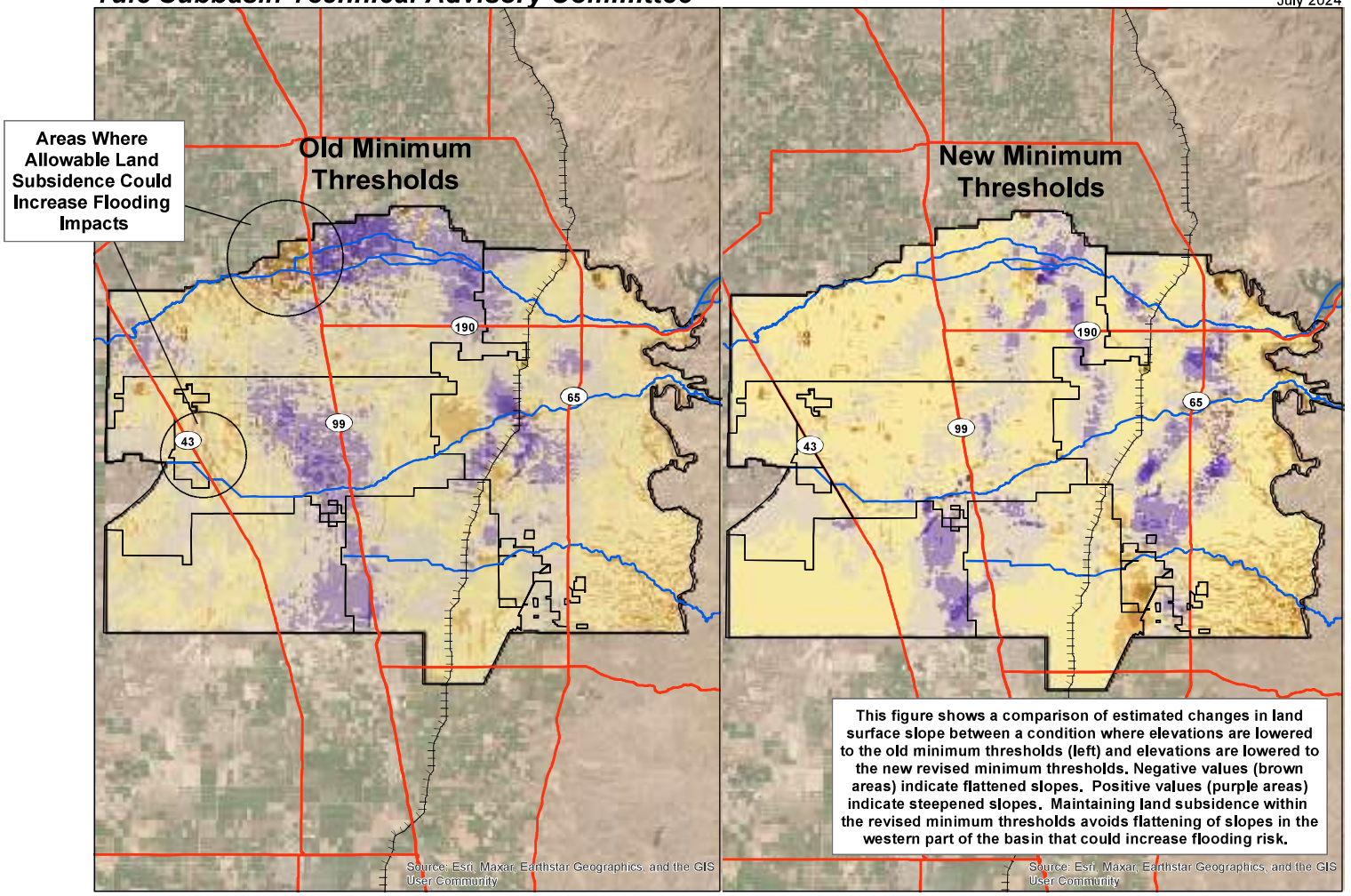
Estimated Land Surface Slope at the Updated Land Subsidence Minimum Thresholds

Figure 14

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

July 2024



This figure shows a comparison of estimated changes in land surface slope between a condition where elevations are lowered to the old minimum thresholds (left) and elevations are lowered to the new revised minimum thresholds. Negative values (brown areas) indicate flattened slopes. Positive values (purple areas) indicate steepened slopes. Maintaining land subsidence within the revised minimum thresholds avoids flattening of slopes in the western part of the basin that could increase flooding risk.

Map Features

Change in Land Surface Slope (ft/mi)

- < -1
- -1 to -.08
- -0.8 to -0.6
- -0.6 to -0.4
- -0.4 to -0.2
- -0.2 to 0.0
- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1
- > 1
- GSA Boundary
- State Highway
- Friant-Kern Canal
- Major Hydrologic Feature

0 3.5 7 14 Miles

NAD 83 State Plane Zone 4

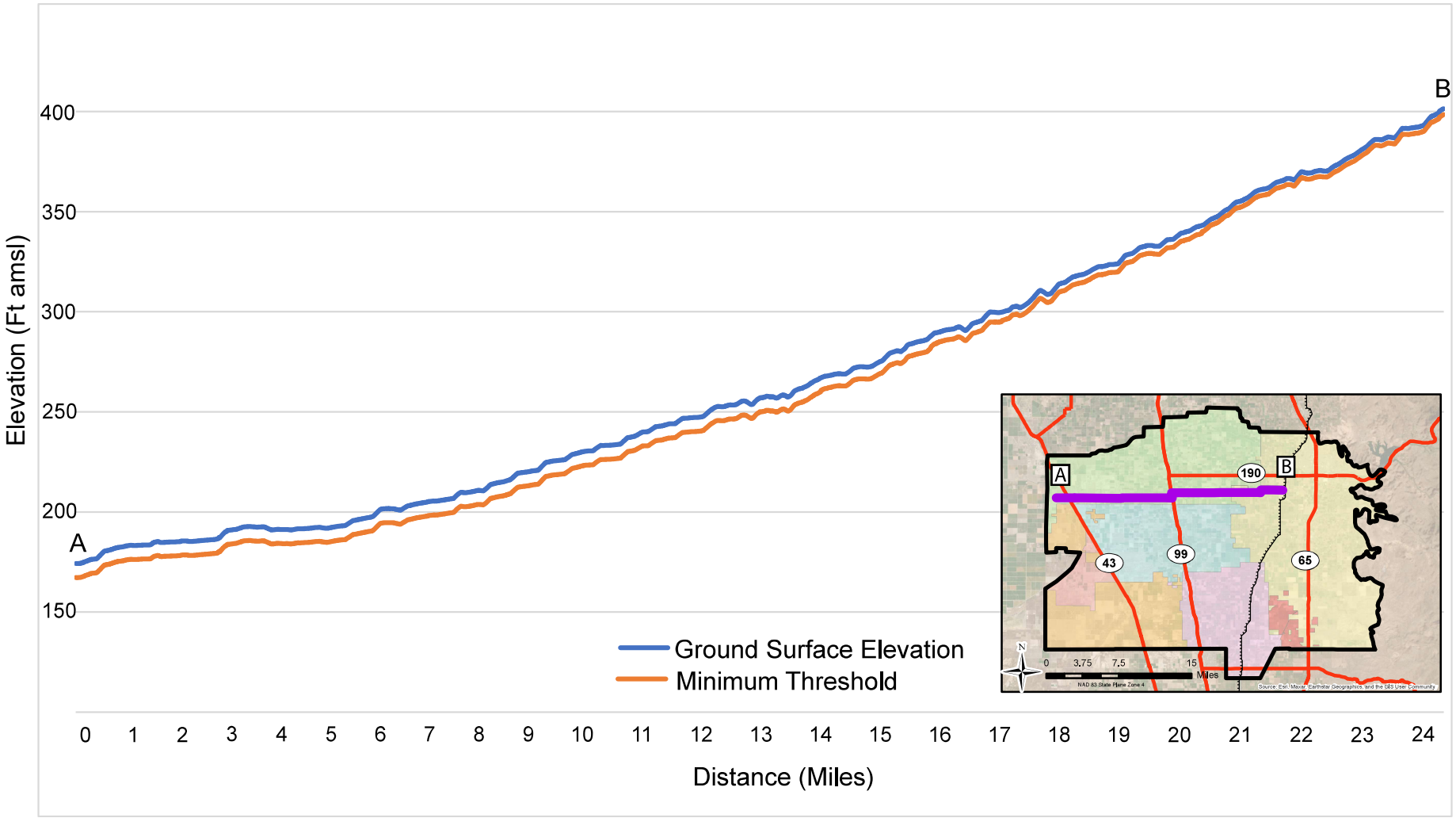
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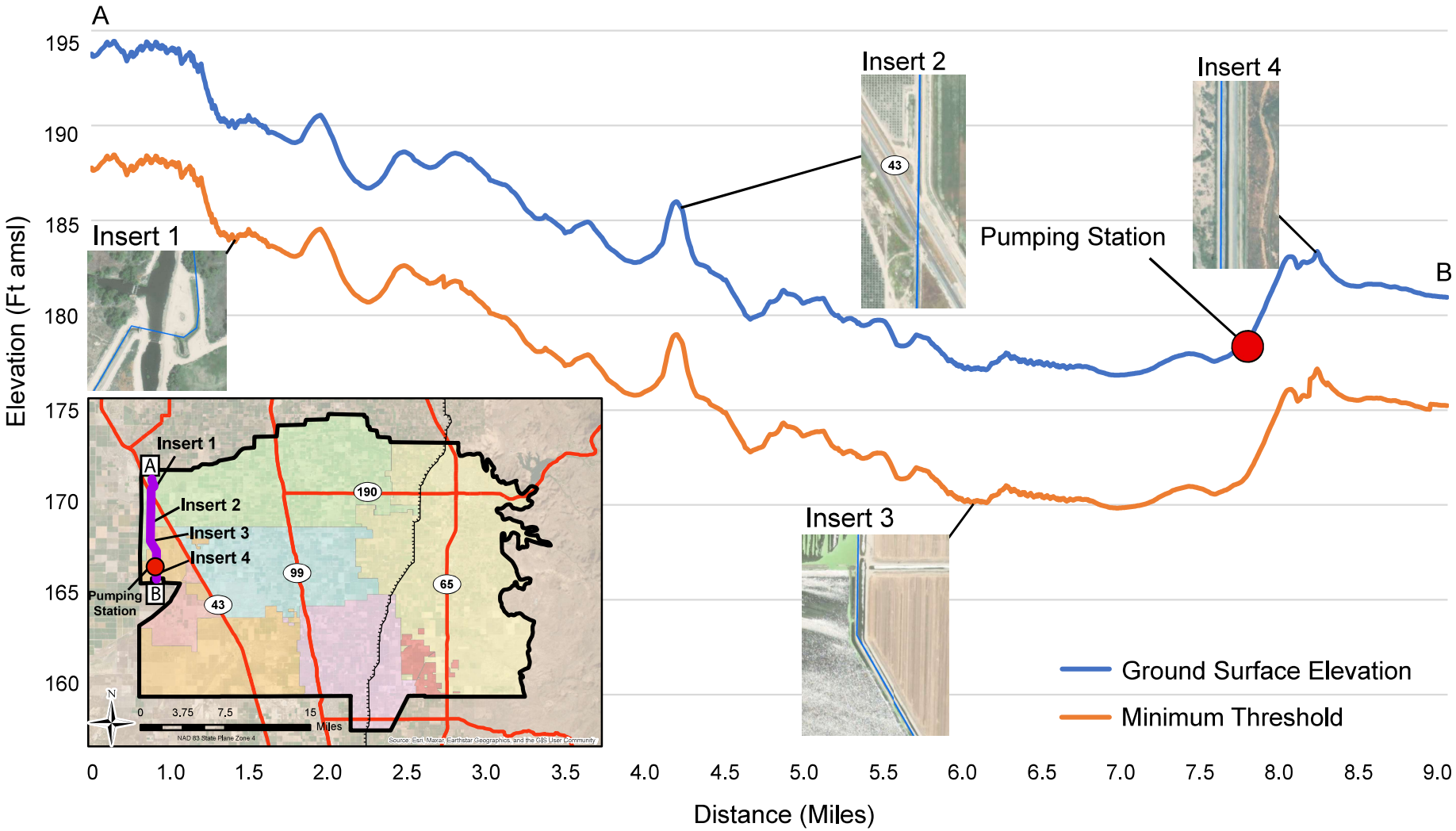
Difference in Projected Land Surface Slope Between Old and New Minimum Thresholds

Figure 15

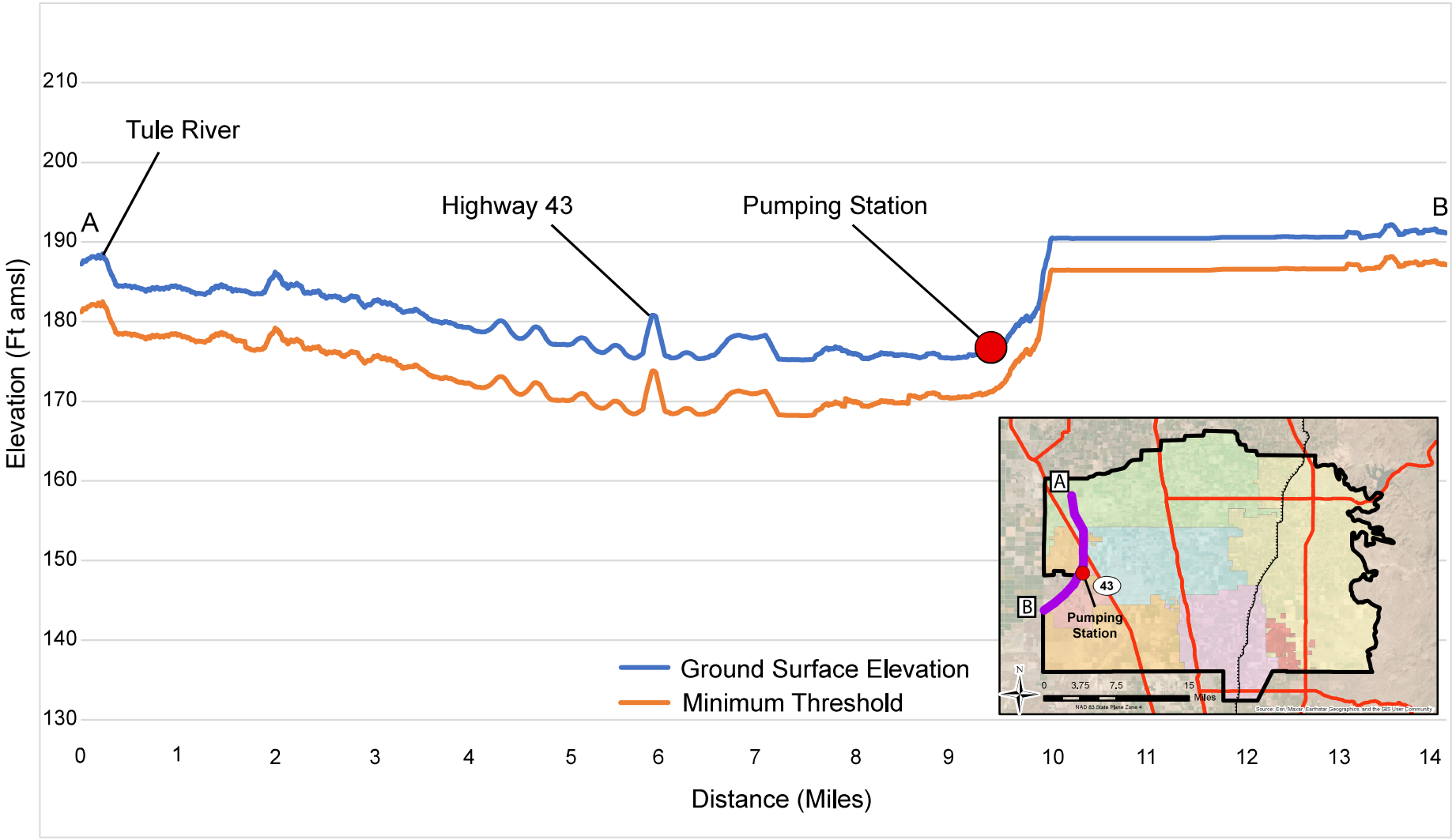
Elevation Profile of the Beshears Ditch



Elevation Profile of the Taylor Ditch



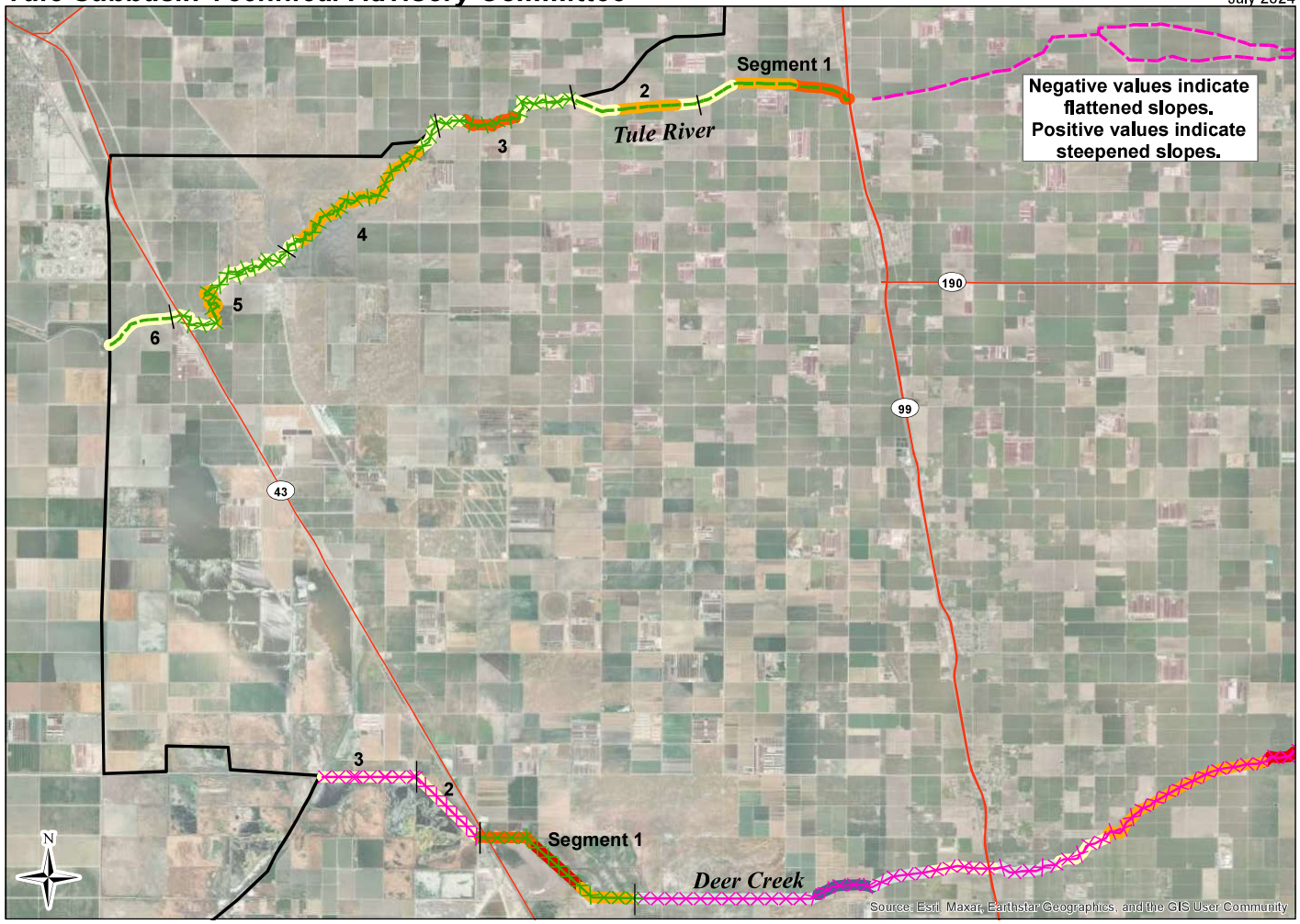
Elevation Profile of the Homeland Canal



Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

July 2024



Map Features

Change in slope (ft/mi)

- -0.31 to -0.3
- -0.3 to -0.2
- -0.2 to -0.1
- -0.1 to 0
- 0 to 0.1
- 0.1 to 0.2
- 0.2 to 0.25
- Exisiting Levee - No Modifications Anticipated
- Exisiting Levee - Raising Anticipated
- No Exisiting Levee - Construction Anticipated
- No Exisiting Levee - No Modifications Anticipated
- State Highway
- Subbasin Boundary

Note: Differences in ground elevation slope between the 2020 Ground Surface Elevation and 2040 Minimum Threshold estimates range from -0.31 to 0.25 ft per mile (negative = flatter) in areas of concern on the Tule River and Deer Creek.

Levee segments are broken up based on three factors with potential to be catalysts for flodding:
1) Differences in subsidence since 2015 seen in LiDAR images
2) Estimated changes in GSE slope between 2020 and 2040 MTs
3) Preexisting levees

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Levee Slopes and Reccomendations

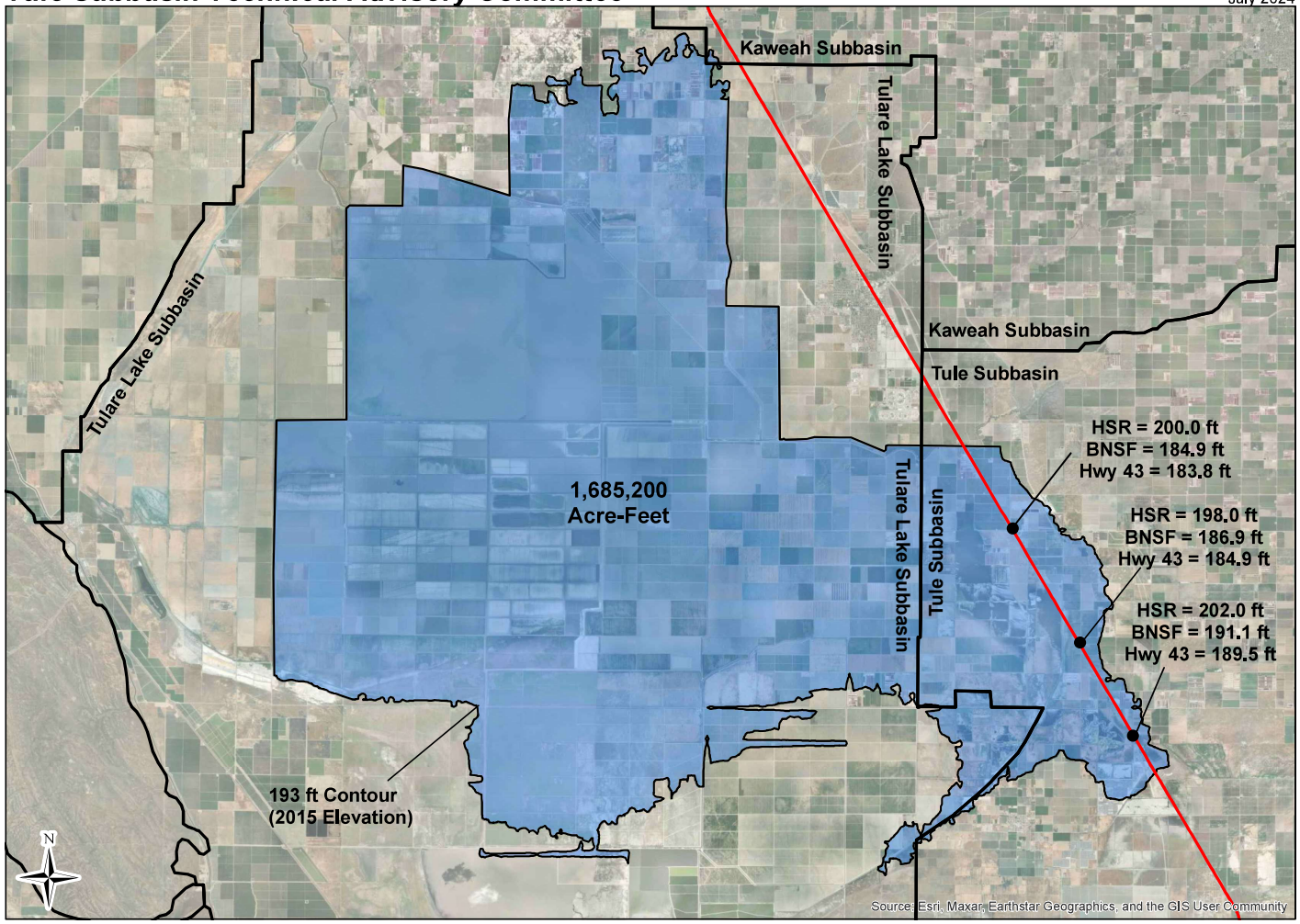
Thomas Harder & Co.
Groundwater Consulting

Figure 19

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

July 2024



0 1.5 3 6 Miles

NAD 83 State Plane Zone 4

Map Features

- Subbasin Boundary
- Transportation Corridor
- 100 year Flood at 2015 GSE (193 ft amsl)

High Speed Rail (HSR) elevations are projected construction elevations.

Burlington Northern Santa Fe (BNSF) track elevations based on 2023 elevations raised by difference in ground surface elevation between 2015 and 2023 due to subsidence.

Hwy 43 elevations based on 2021 elevations raised by difference in ground surface elevation between 2015 and 2021 due to subsidence.

All elevations in feet above mean sea level (ft amsl).

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Groundwater Consulting

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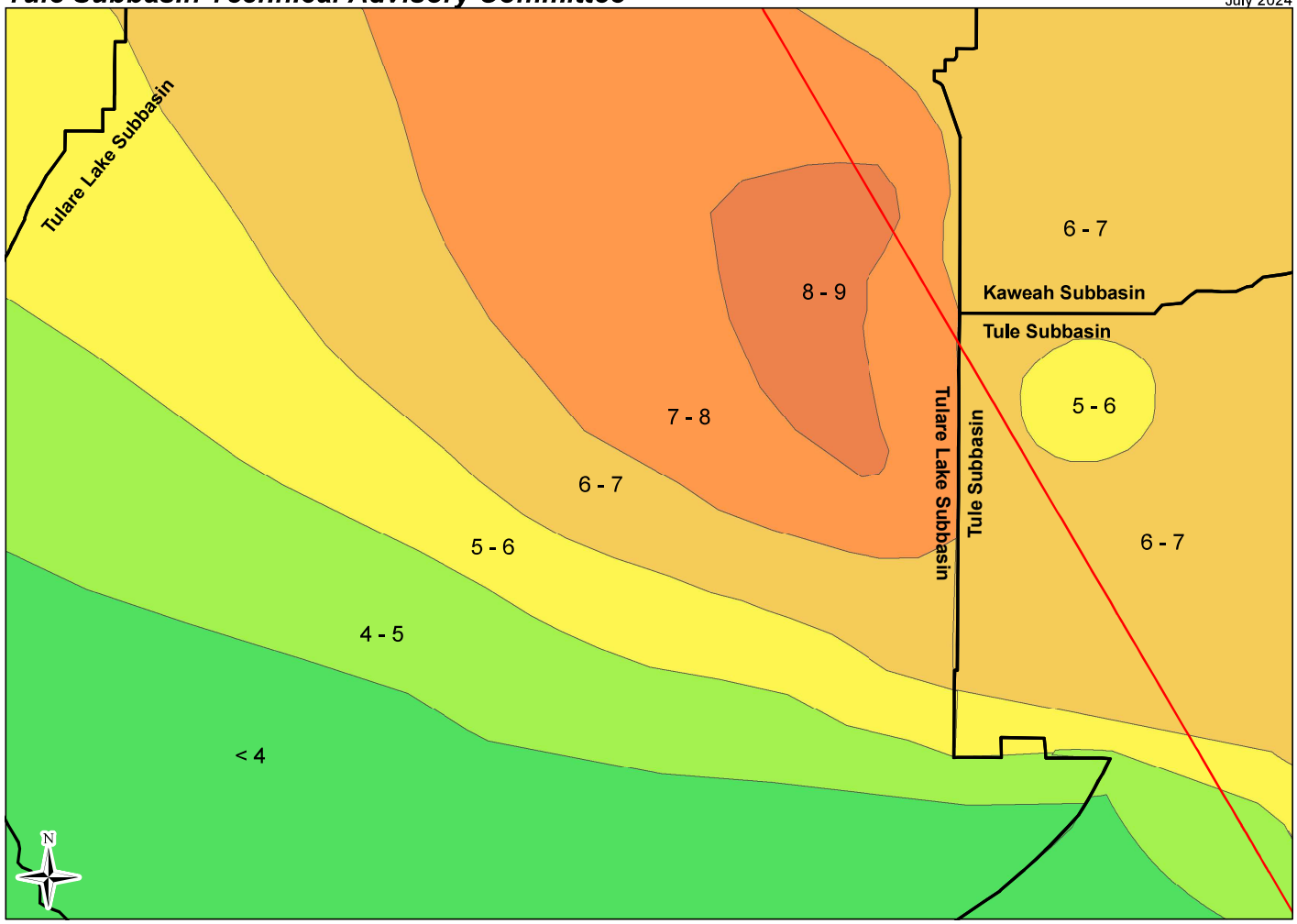
Tulare Lake 100-Year Flooding Extent at 2015 Ground Surface Elevations

Figure 20

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

Cumulative Land Subsidence Minimum Threshold (ft)

- < 4
- 4 to 5
- 5 to 6
- 6 to 7
- 7 to 8
- 8 to 9
- Transportation Corridor
- Subbasin Boundary

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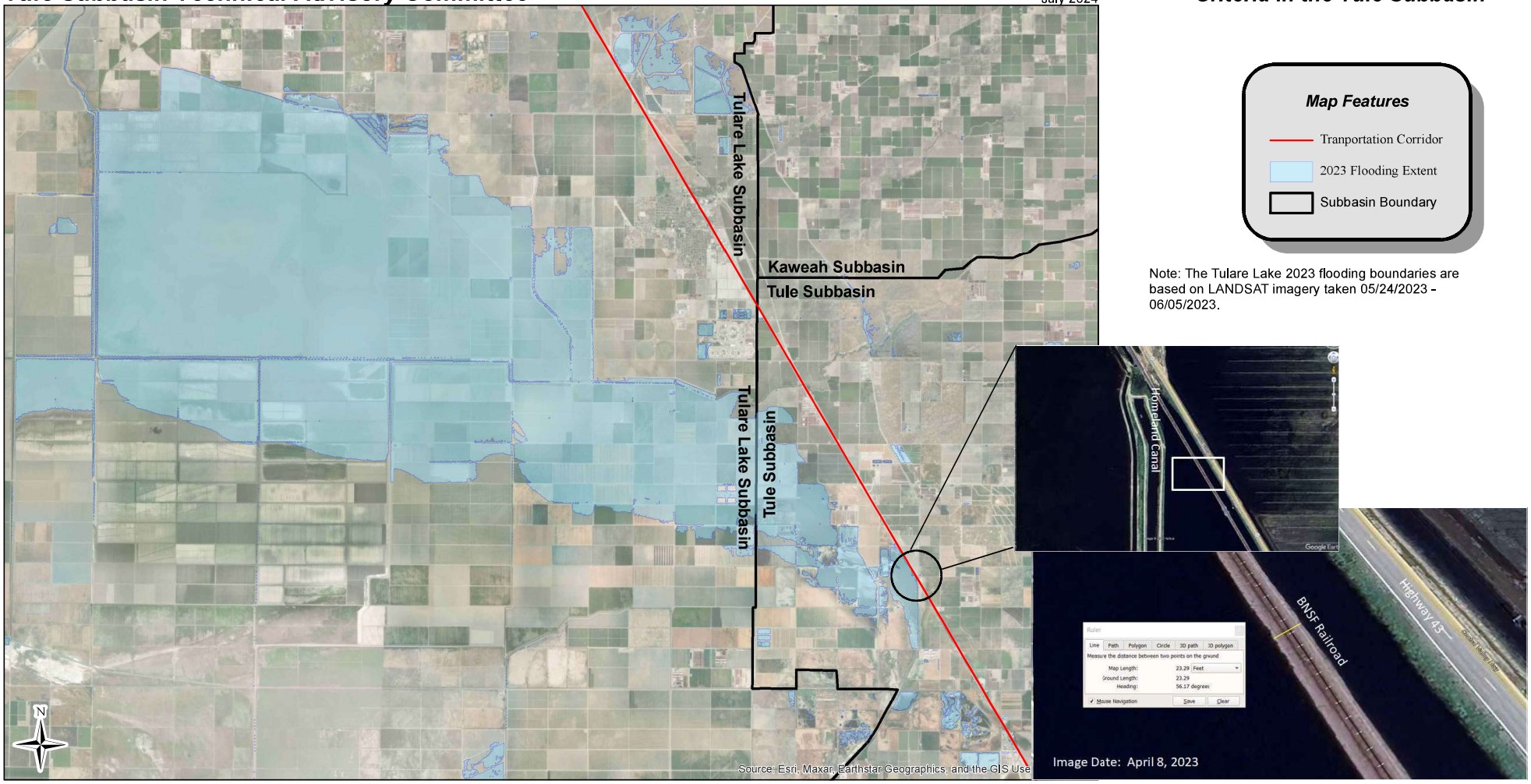
Projected Minimum Thresholds for Tule, Kaweah and Tulare Lake

Figure 21

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin

Tule Subbasin Technical Advisory Committee

July 2024



Map Features

- Tranportation Corridor
- 2023 Flooding Extent
- Subbasin Boundary

Note: The Tulare Lake 2023 flooding boundaries are based on LANDSAT imagery taken 05/24/2023 - 06/05/2023.

Thomas Harder & Co.
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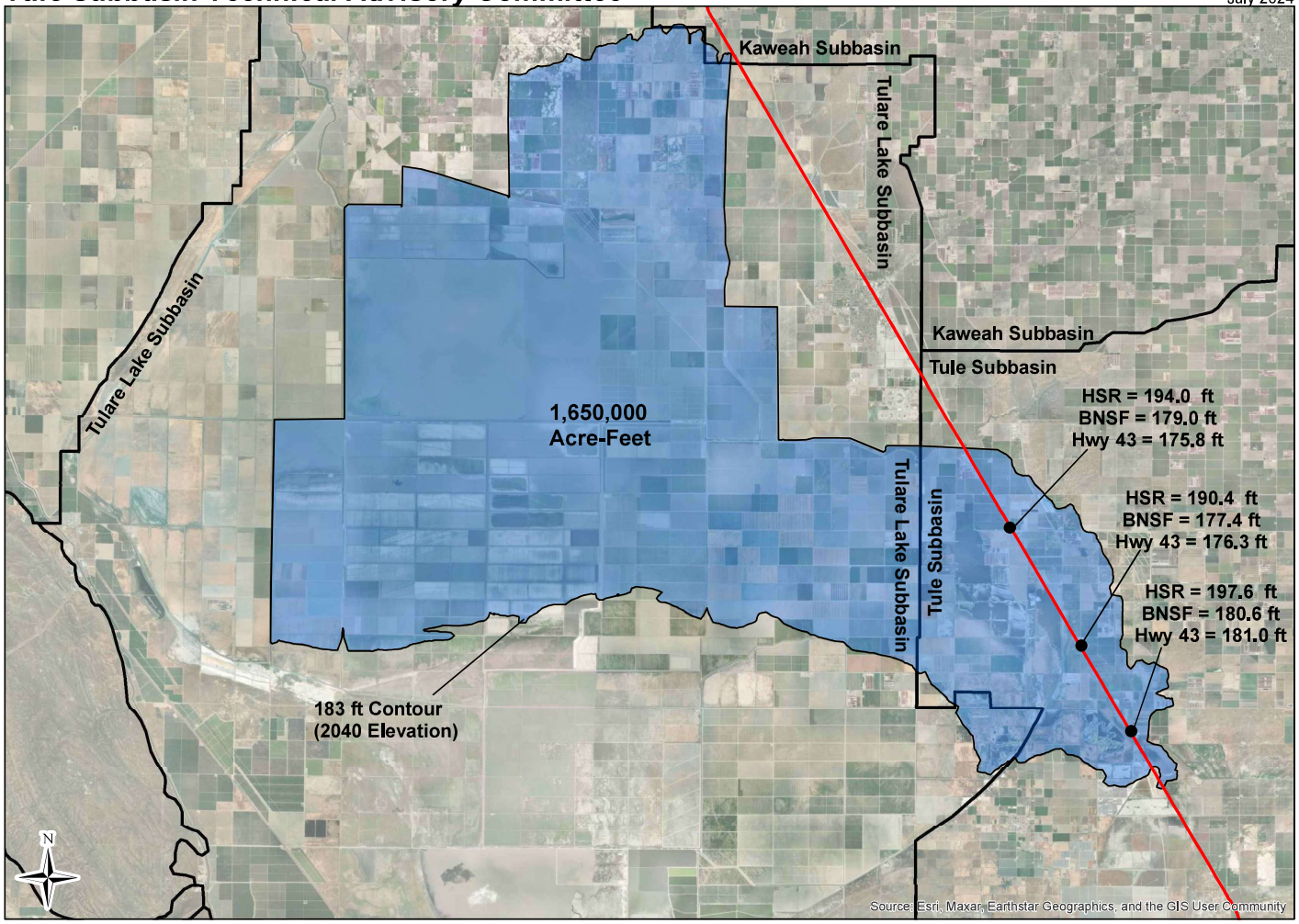
Extent of Tulare Lake Flooding In 2023

Figure 22

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



0 1.5 3 6 Miles

NAD 83 State Plane Zone 4

Map Features

- Subbasin Boundary
- 100 year Flood at Estimated 2040 GSE (183' amsl)
- Transportation Corridor

High Speed Rail (HSR) elevations based on planned elevations lowered by projected subsidence from 2023 to 2040.

Burlington Northern Santa Fe (BNSF) track elevations based on 2023 elevations lowered by difference in ground surface elevation between 2023 to 2040 due to projected subsidence.

Hwy 43 elevations based on 2021 elevations lowered by difference in ground surface elevation between 2021 to 2040 due to projected subsidence.

All elevations in feet above mean sea level (ft asml).

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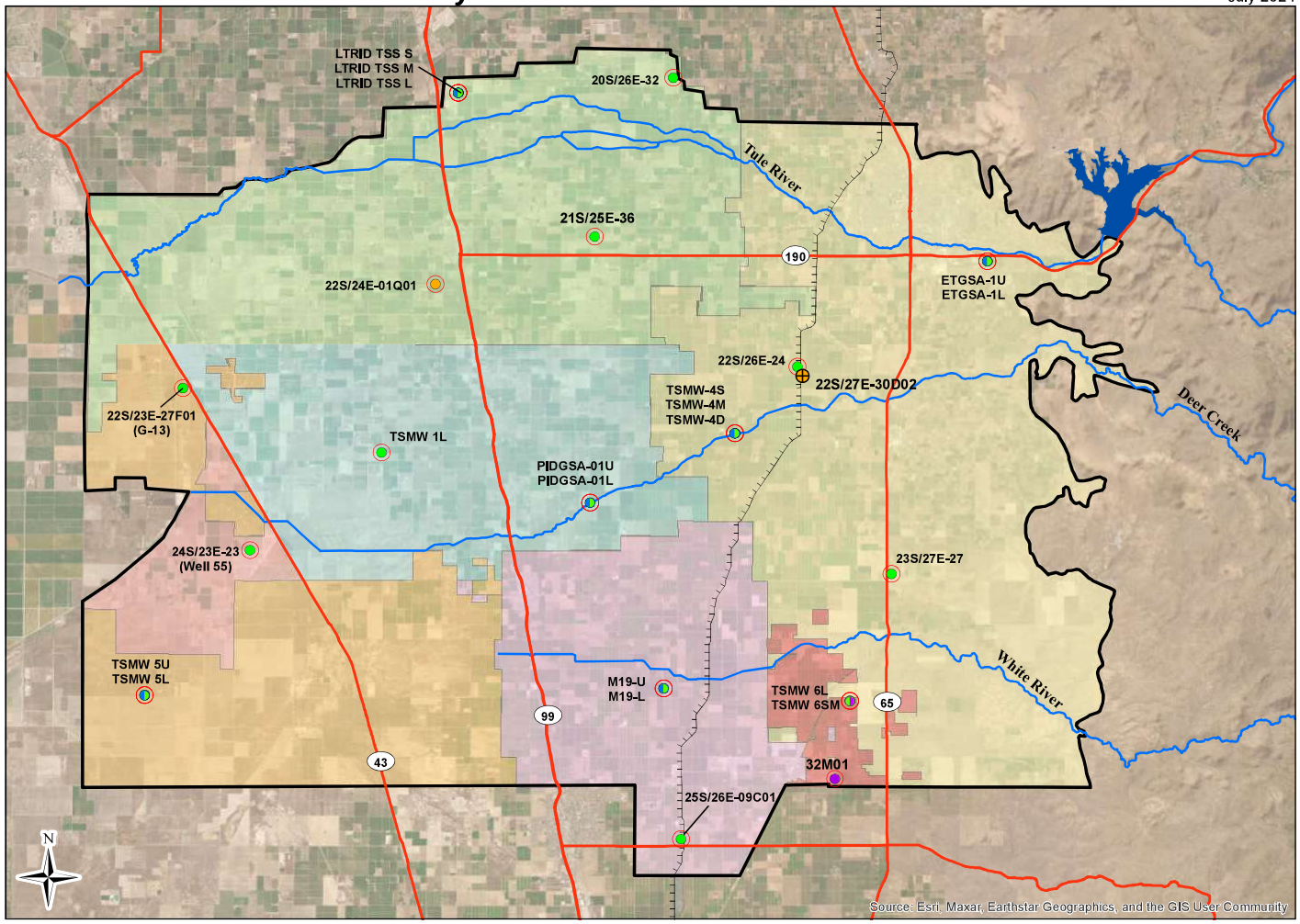
Tulare Lake 100-Year Flooding Extent at Projected 2040 Ground Surface Elevations

Figure 23

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Upper Aquifer RMS Well
- Lower Aquifer RMS Well
- Composite Aquifer RMS Well
- Santa Margarita Aquifer RMS Well
- USGS Extensometer
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority
- Major Hydrologic Feature
- CA_Aq_&_Frian-Kern_Canal
- State Highway
- Subbasin Boundary

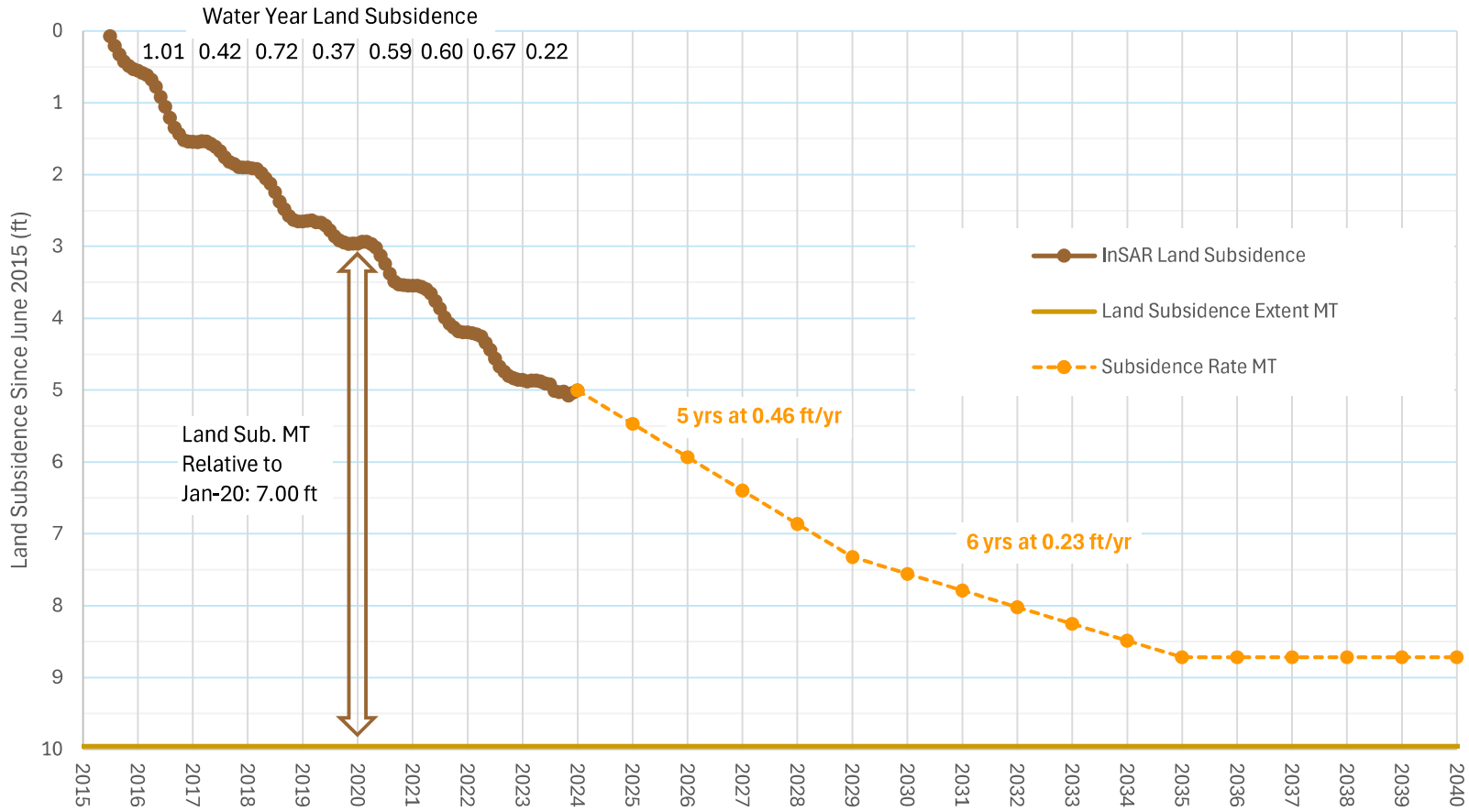
DRAFT-FINAL

Thomas Harder & Co.
Groundwater Consulting

Lower Aquifer Groundwater Level RMS Wells

Figure 24

TSMW-01L (PID GSA) Lower Land Subsidence Rates



Notes:

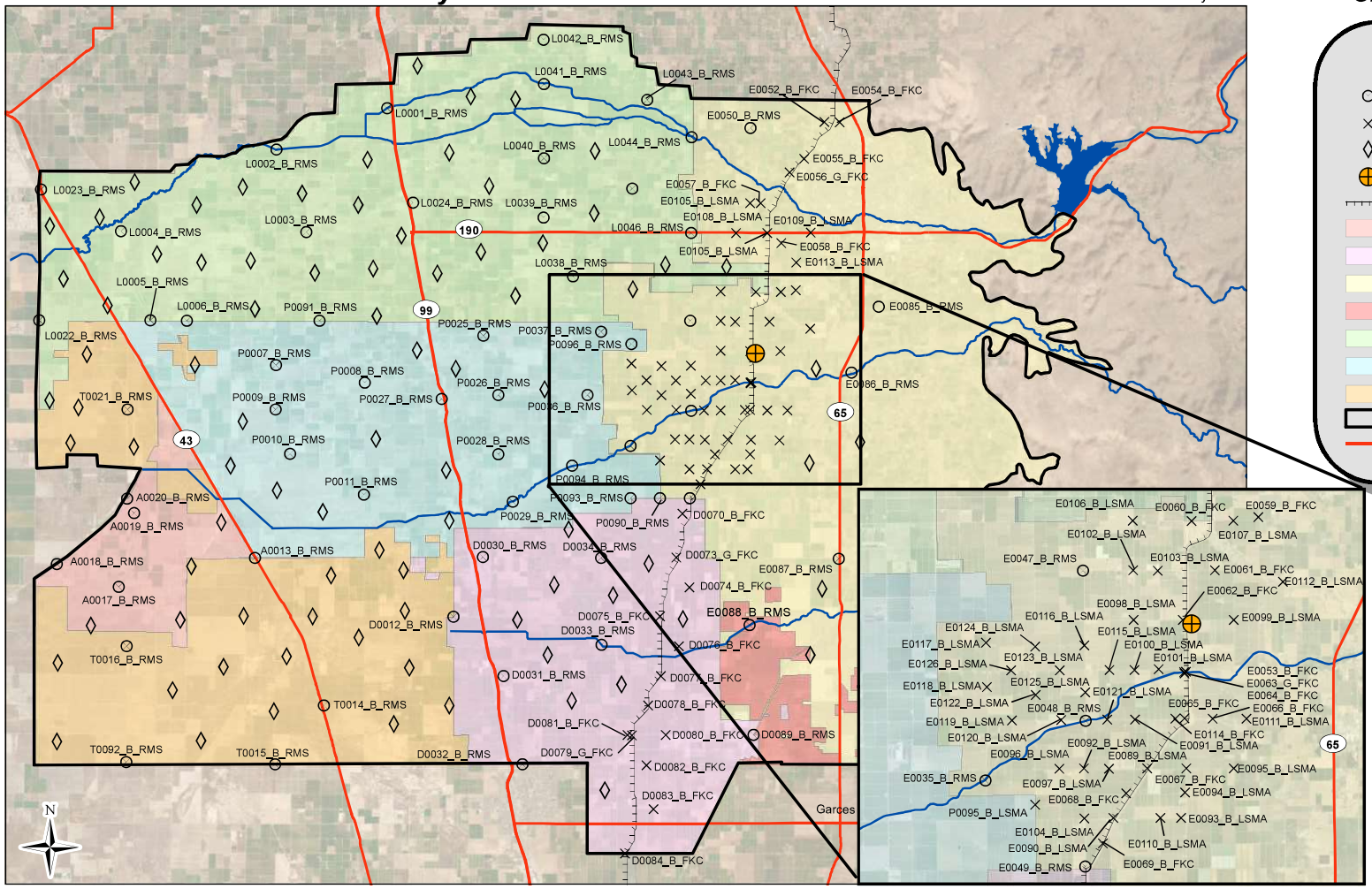
ft amsl = feet above mean sea level

Reference point elevation = 224.39 ft amsl

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Land Surface Elevation Benchmark RMS
- Land Surface Elevation Benchmark
- InSAR Monitoring Point
- USGS Extensometer
- Friant-Kern Canal
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority
- Subbasin Boundary
- State Highway

DRAFT-FINAL

Land Surface Elevation and Subsidence Monitoring Network

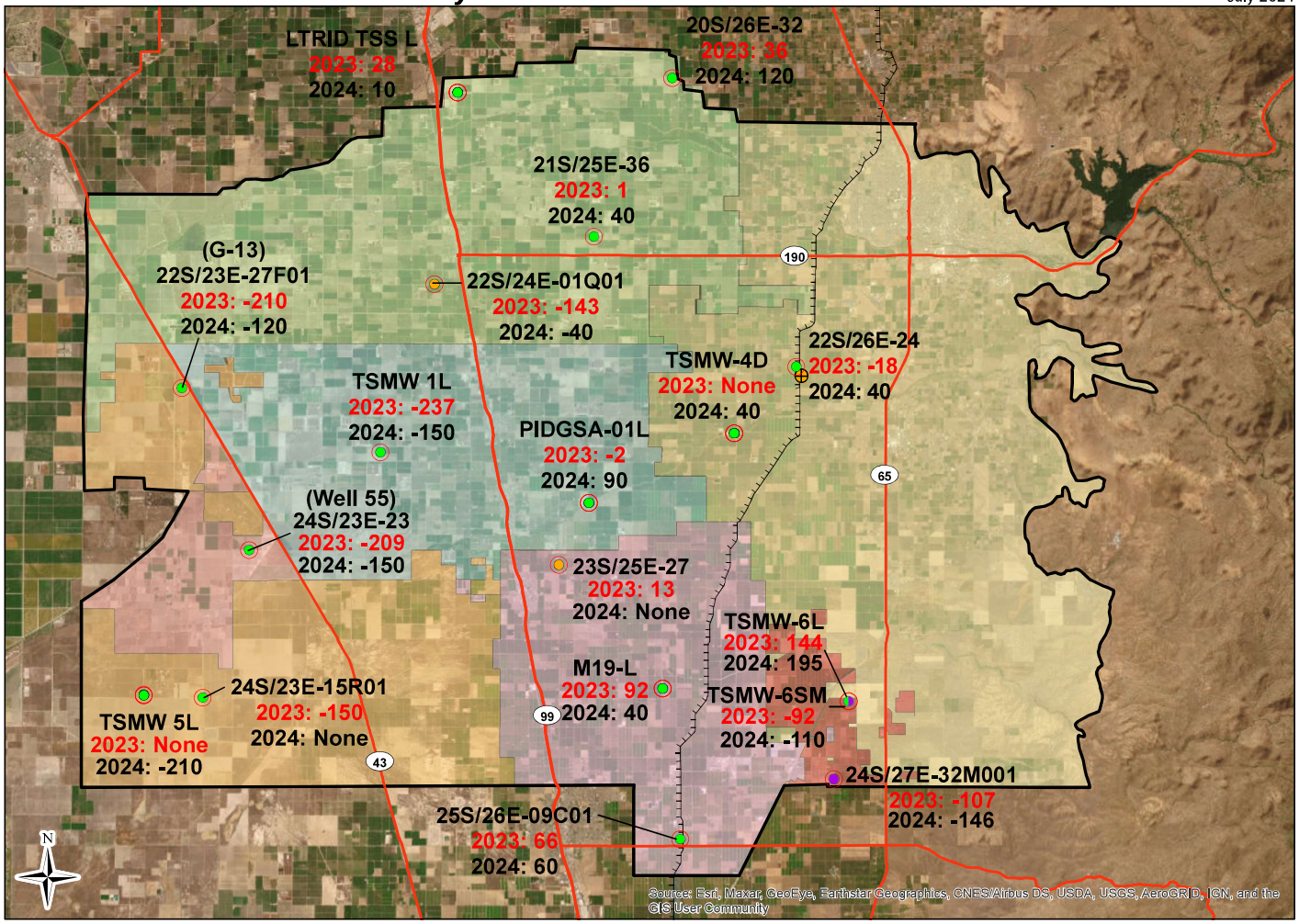
Figure 26

Thomas Harder & Co.
Groundwater Consulting

Tule Subbasin Technical Advisory Committee

July 2024

Technical Support for Land Subsidence Sustainable Management Criteria in the Tule Subbasin



Map Features

- Lower Aquifer RMS Well
- Composite Aquifer RMS Well
- Santa Margarita Aquifer RMS Well
- USGS Extensometer
- Friant-Kern Canal
- State Highway
- Alpaugh GSA
- Delano-Earlimart ID GSA
- Eastern Tule GSA
- Kern-Tulare WD GSA
- Lower Tule River ID GSA
- Pixley ID GSA
- Tri-County Water Authority
- Subbasin Boundary

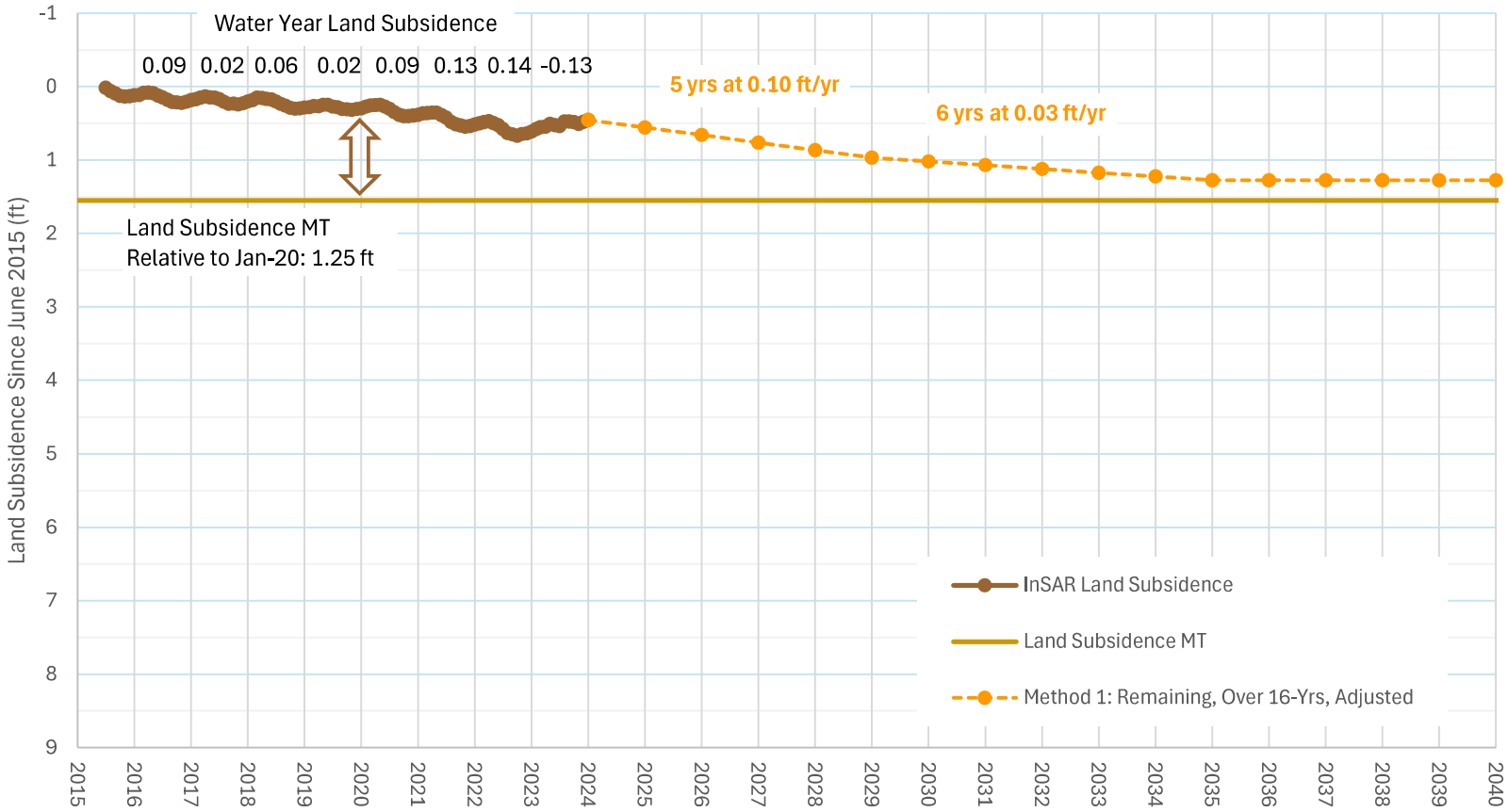
DRAFT-FINAL

Thomas Harder & Co.
Groundwater Consulting

Lower Aquifer Groundwater Level Minimum Thresholds

Figure 27

TSMW-6SM (KTWD GSA) Land Subsidence Rates

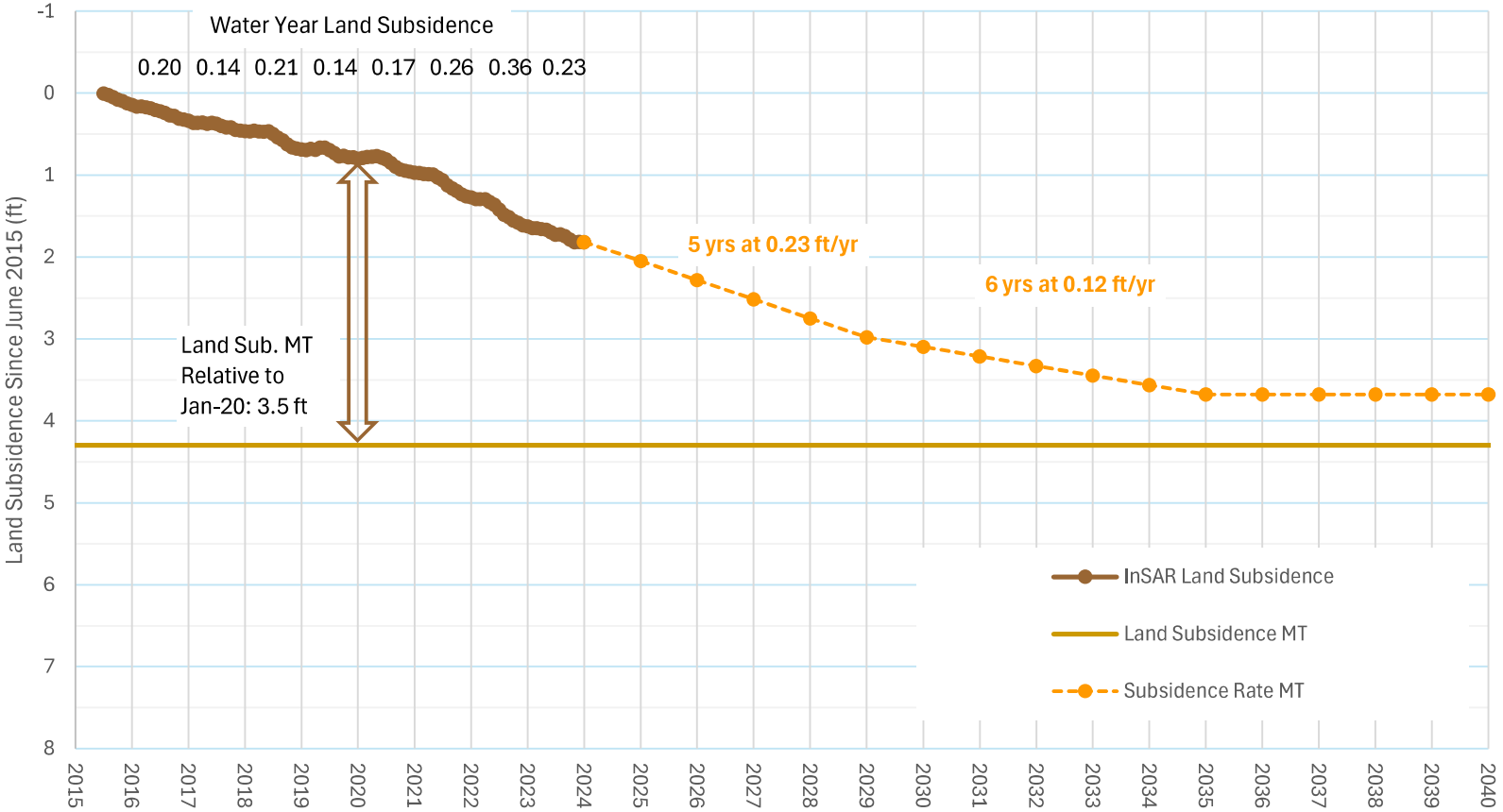


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 520 ft amsl

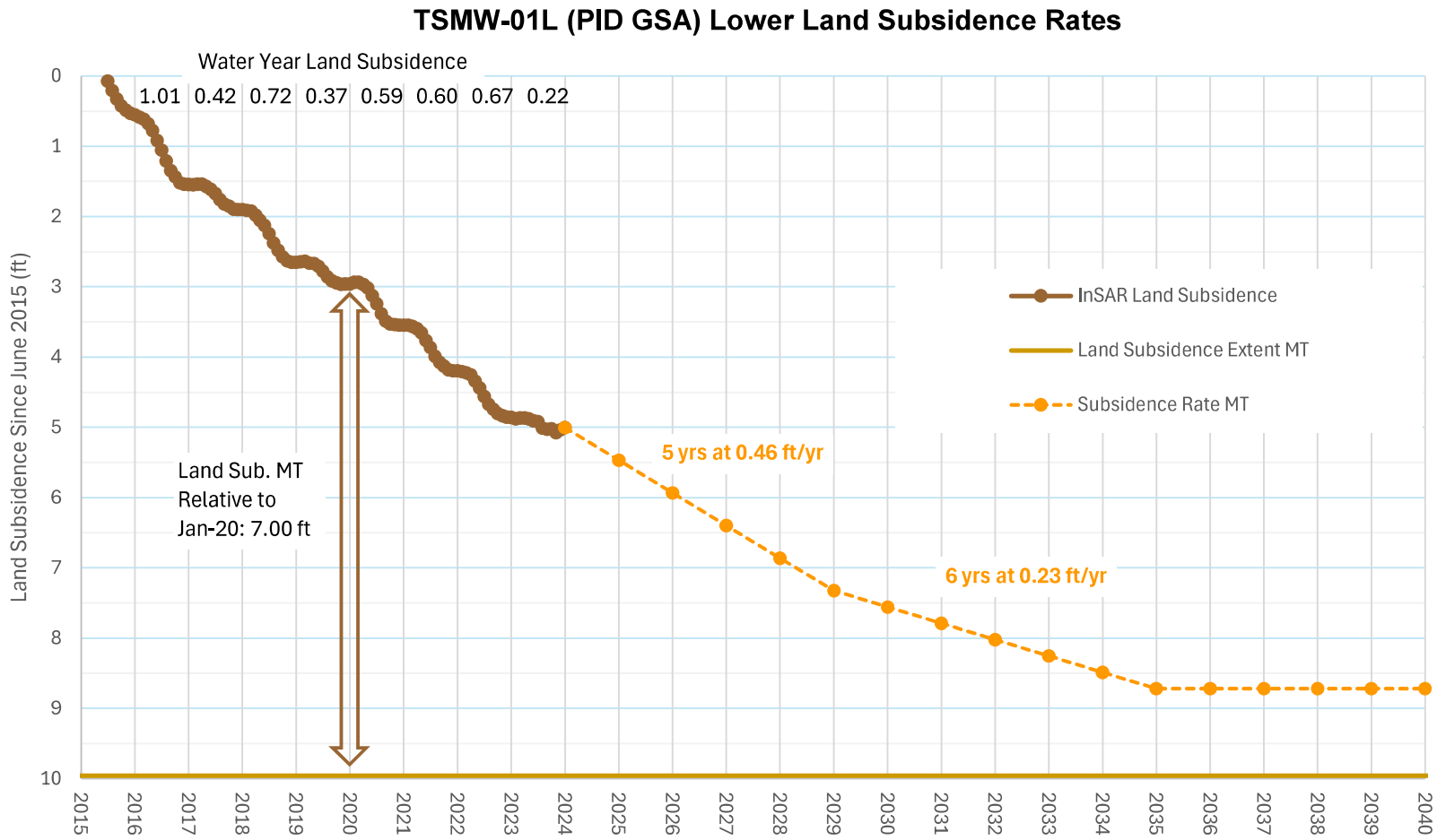
TSMW-5L (TCWA) Land Subsidence Rates



Notes:

ft amsl = feet above mean sea level

Reference point elevation = 198 ft amsl

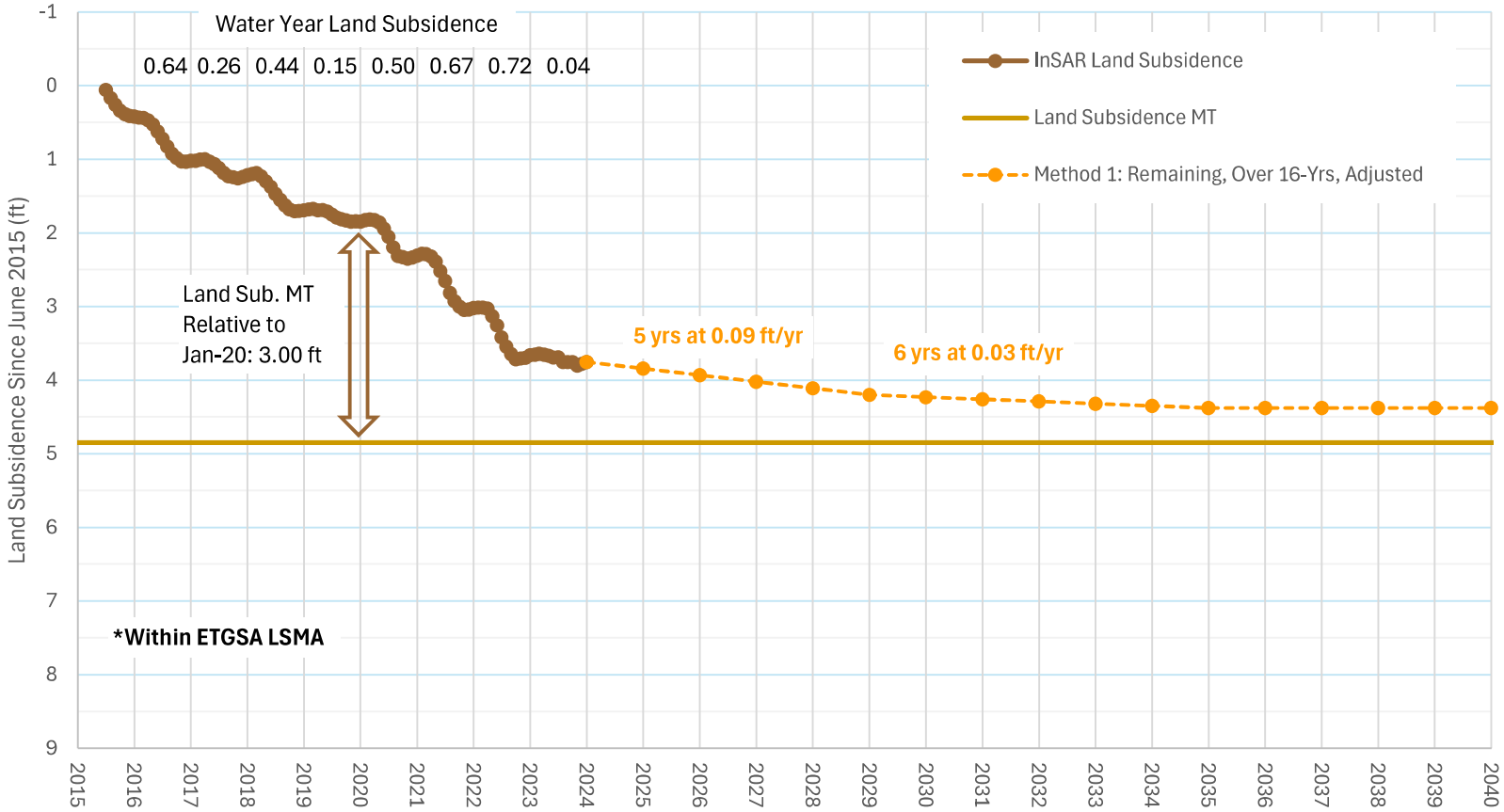


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 224.39 ft amsl

TSMW-4D (ETGSA) Land Subsidence Rates

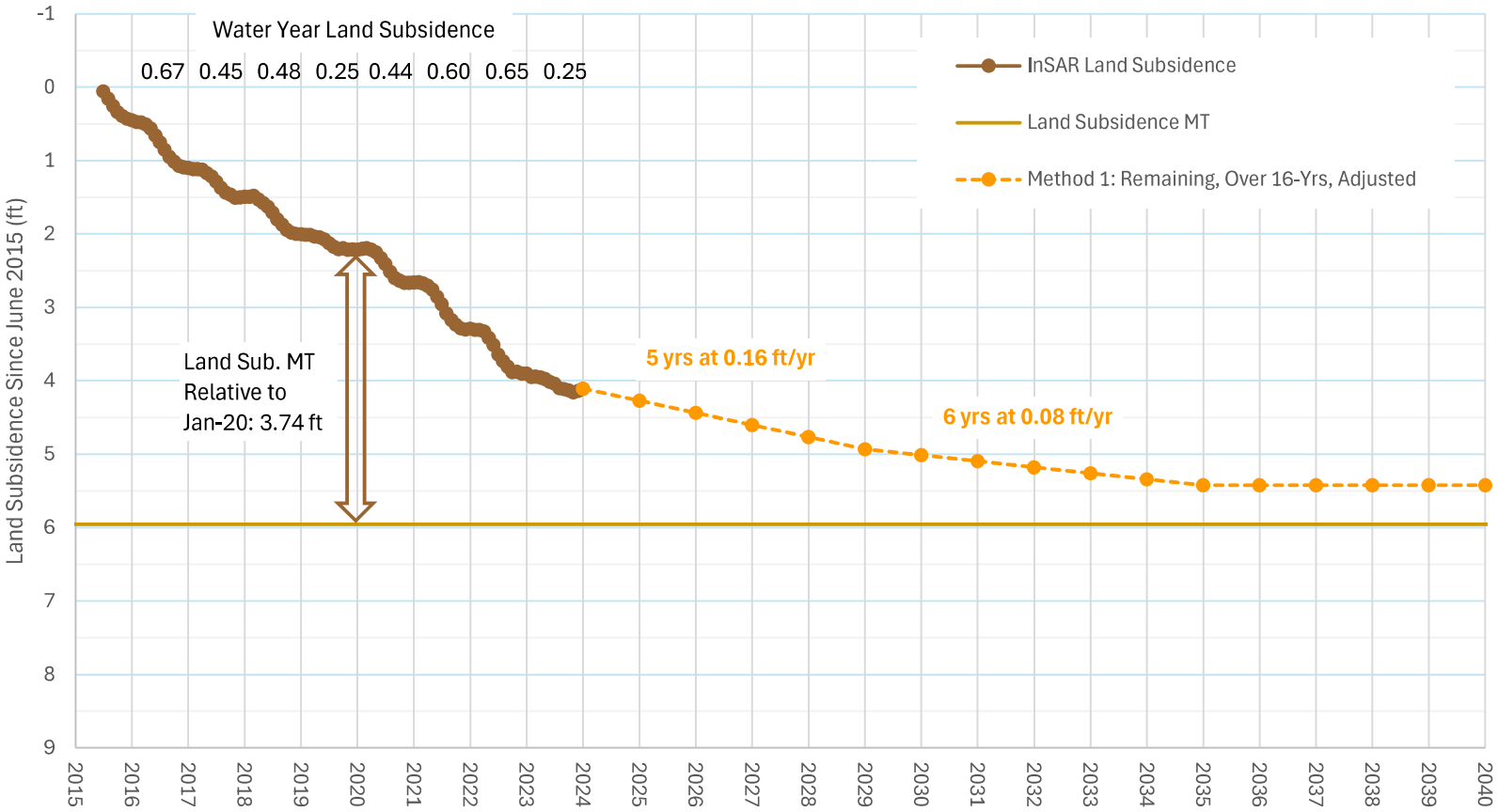


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 369.05 ft amsl

PIDGSA-01D (PID GSA) Land Subsidence Rates

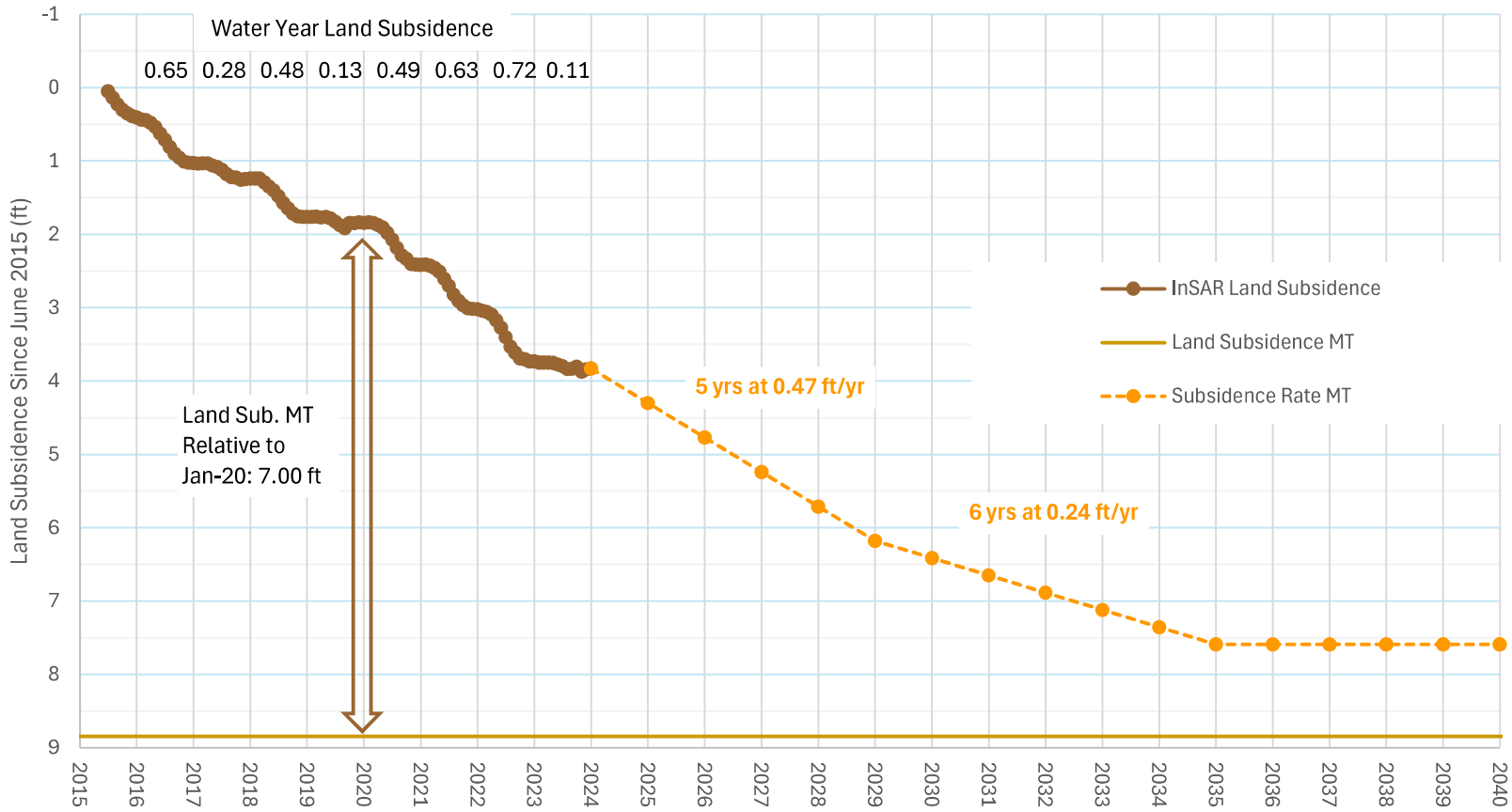


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 299.56 ft amsl

LTRID TSS L (LTRID GSA) Land Subsidence Rates

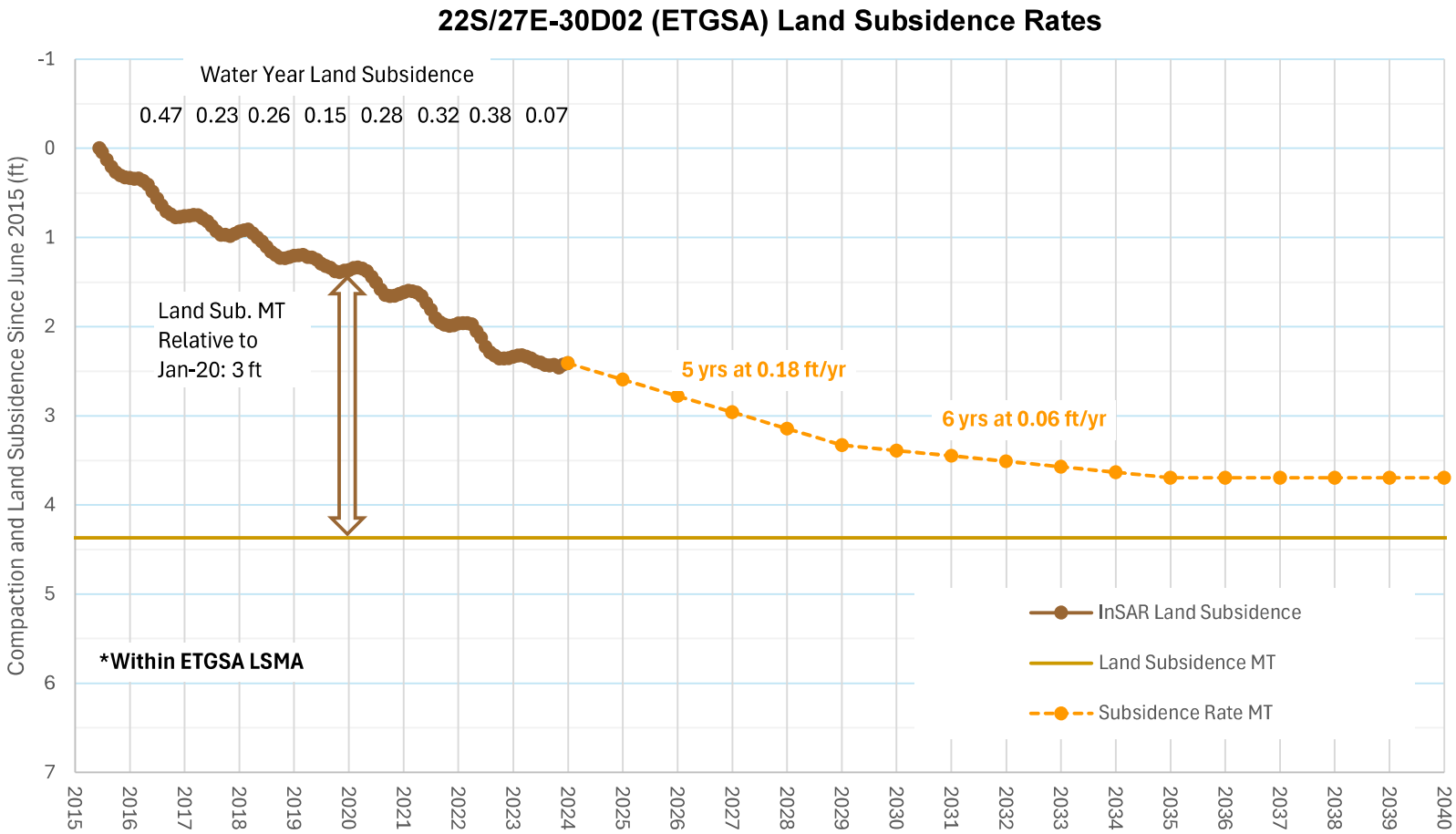


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 264 ft amsl

Also known as LTRID-01D

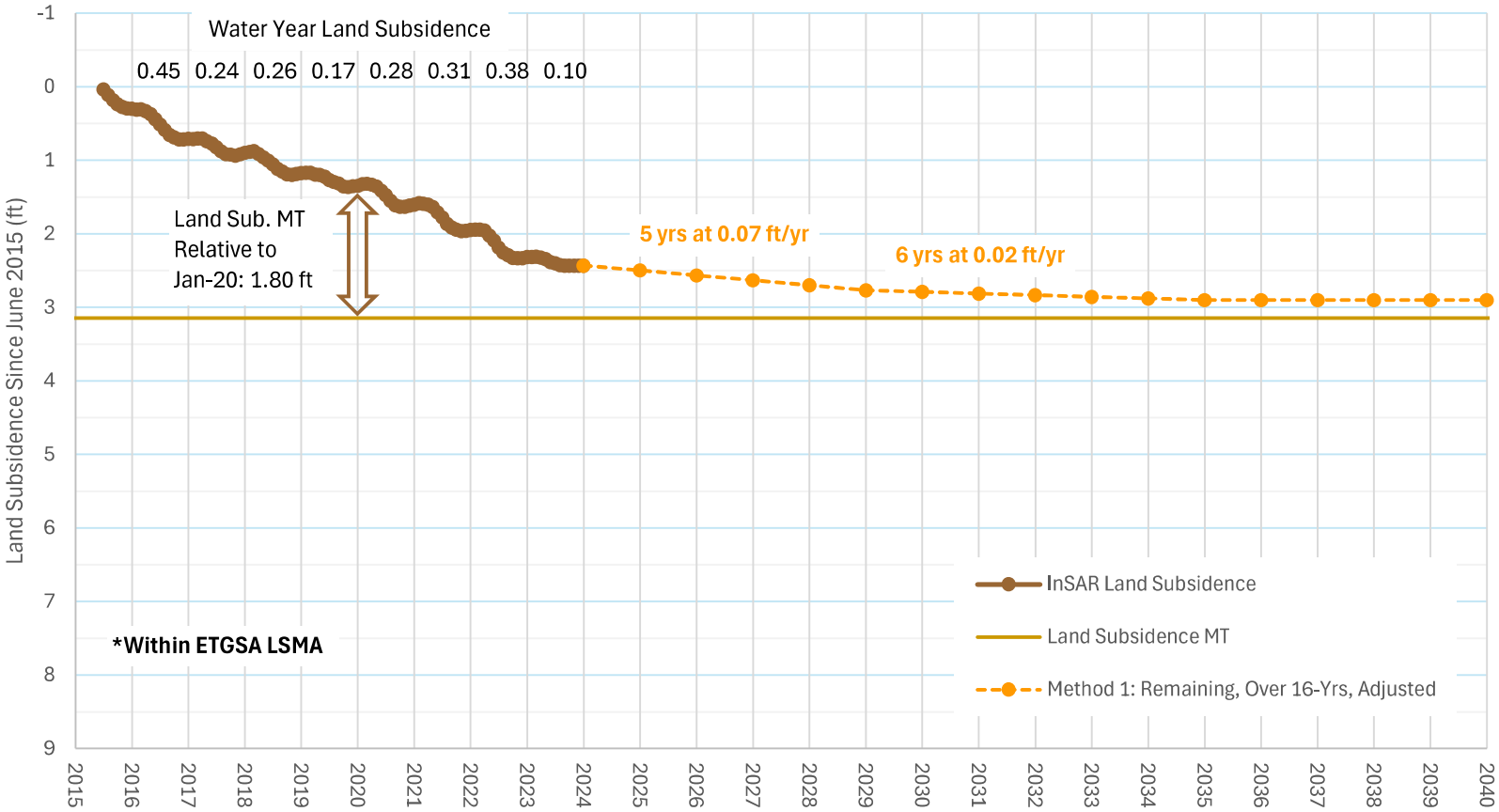


Notes:

ft amsl = feet above mean sea level

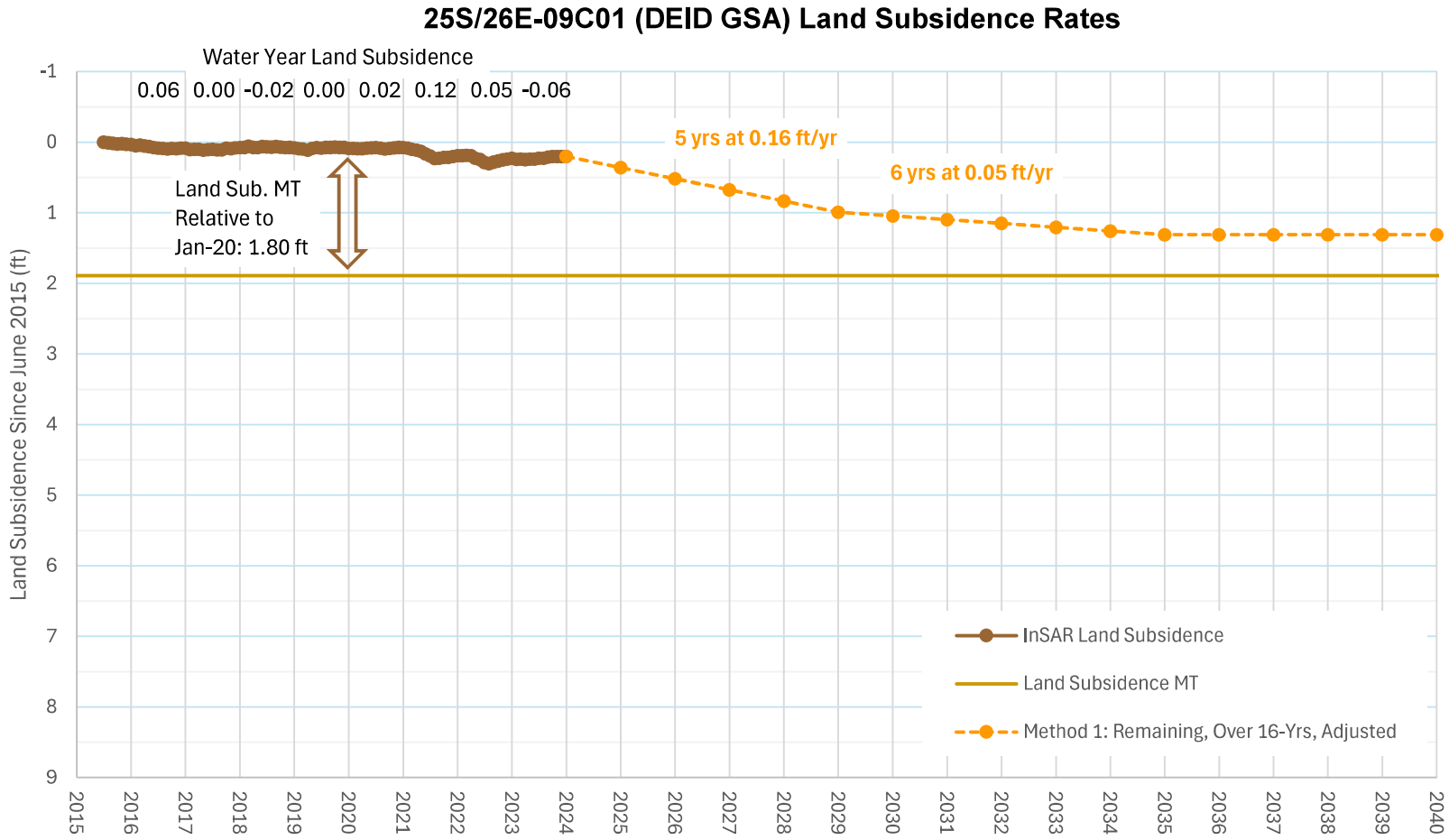
Extensometer depth 1,180 ft bgs and screened interval 1,083 to 1,180 ft bgs.

22S/26E-24 (ETGSA) Land Subsidence Rates



Notes:

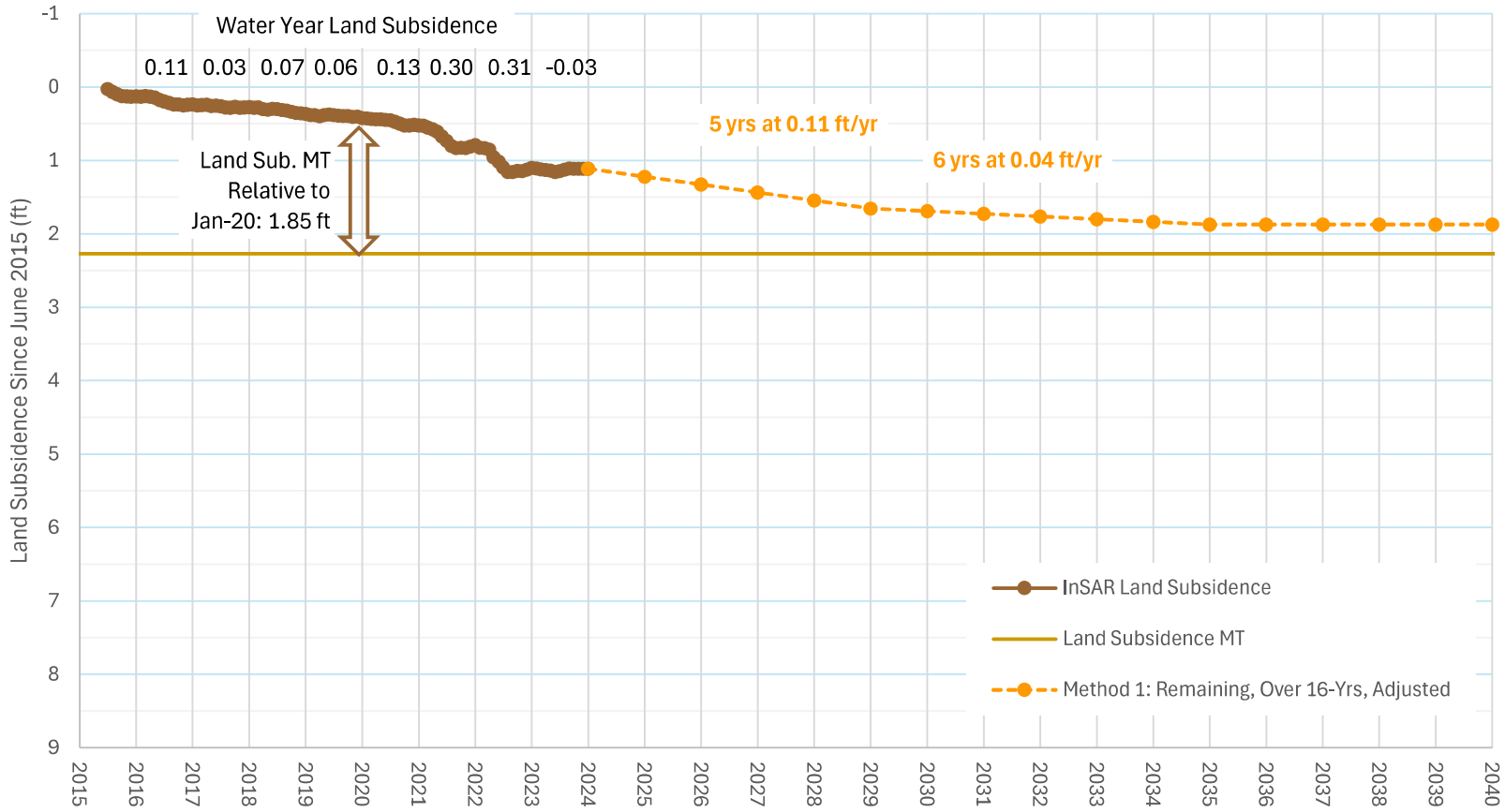
ft amsl = feet above mean sea level



Notes:

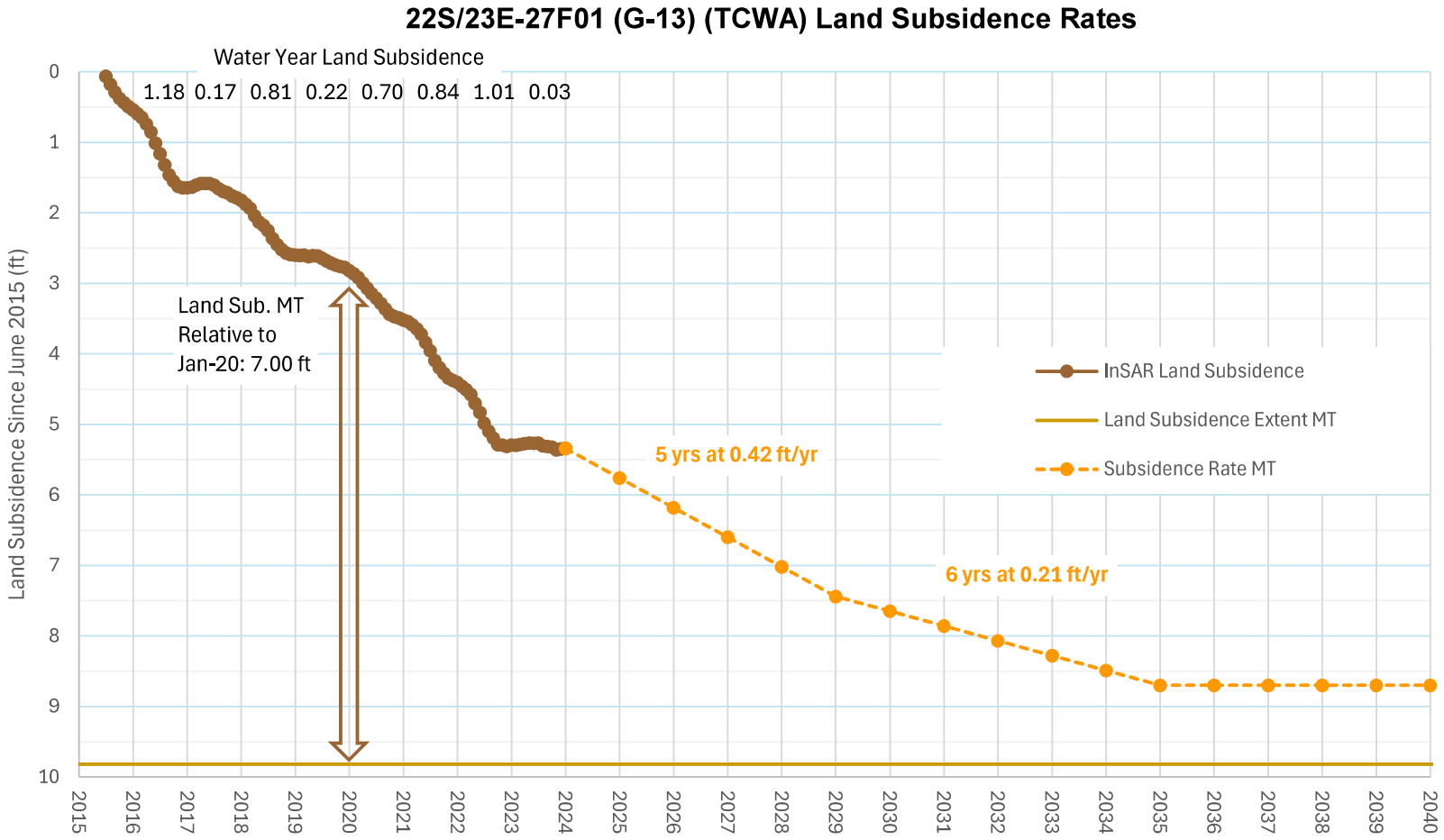
ft amsl = feet above mean sea level

M19 Deep (DEID GSA) Land Subsidence Rates



Notes:

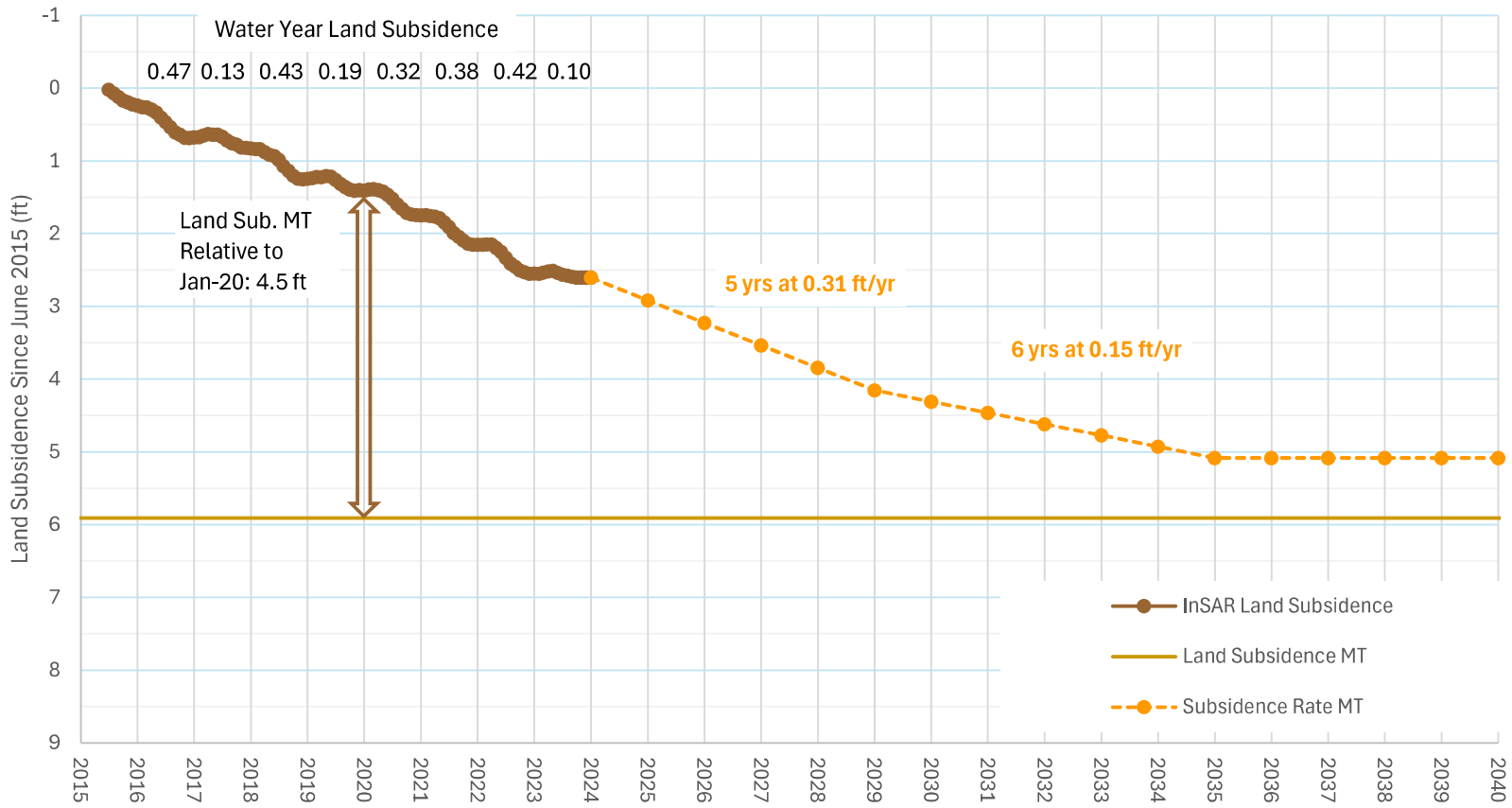
ft amsl = feet above mean sea level



Notes:

ft amsl = feet above mean sea level

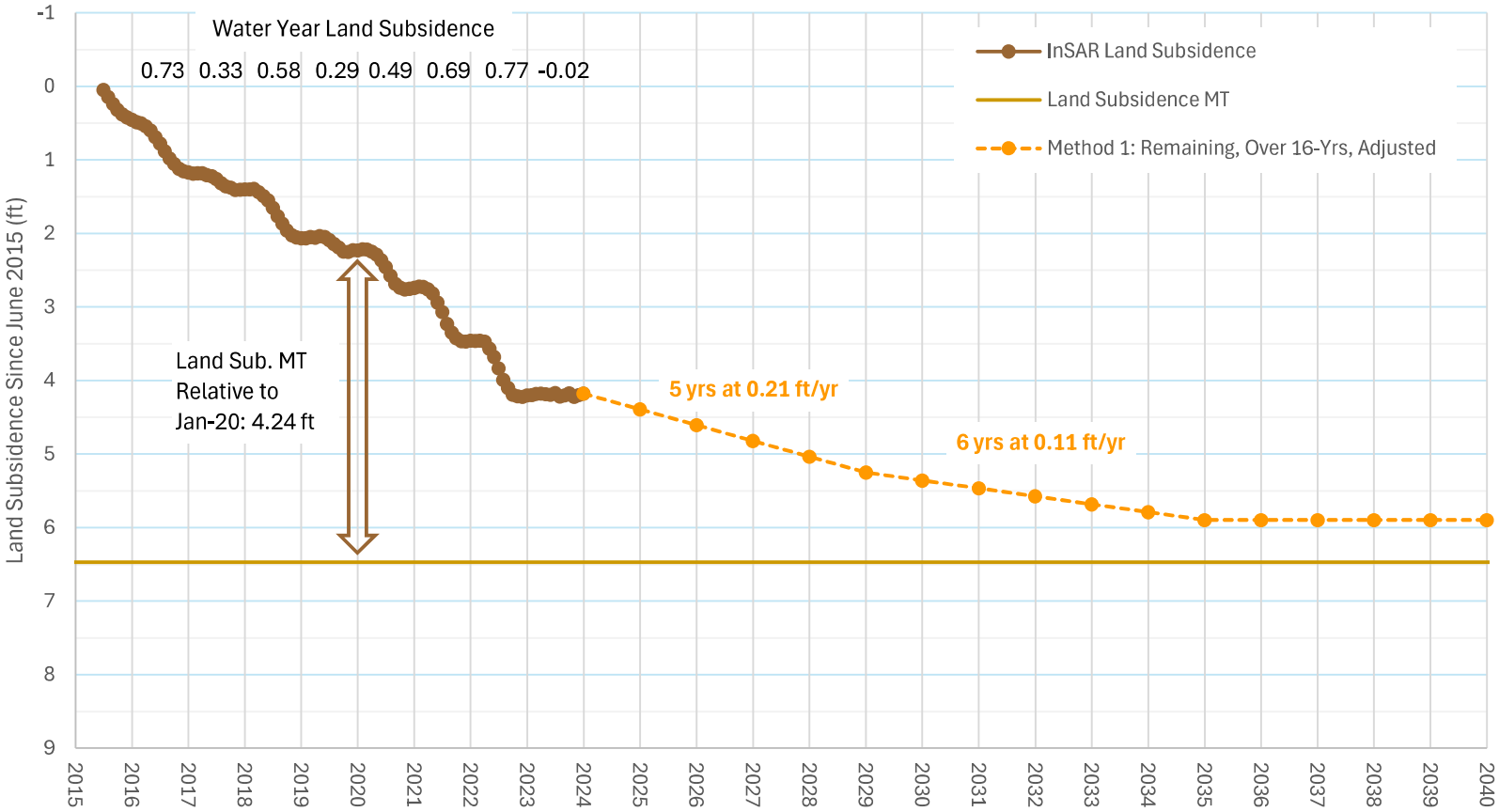
24S/23E-23 (Well 55) (AID GSA) Land Subsidence Rates



Notes:

ft amsl = feet above mean sea level

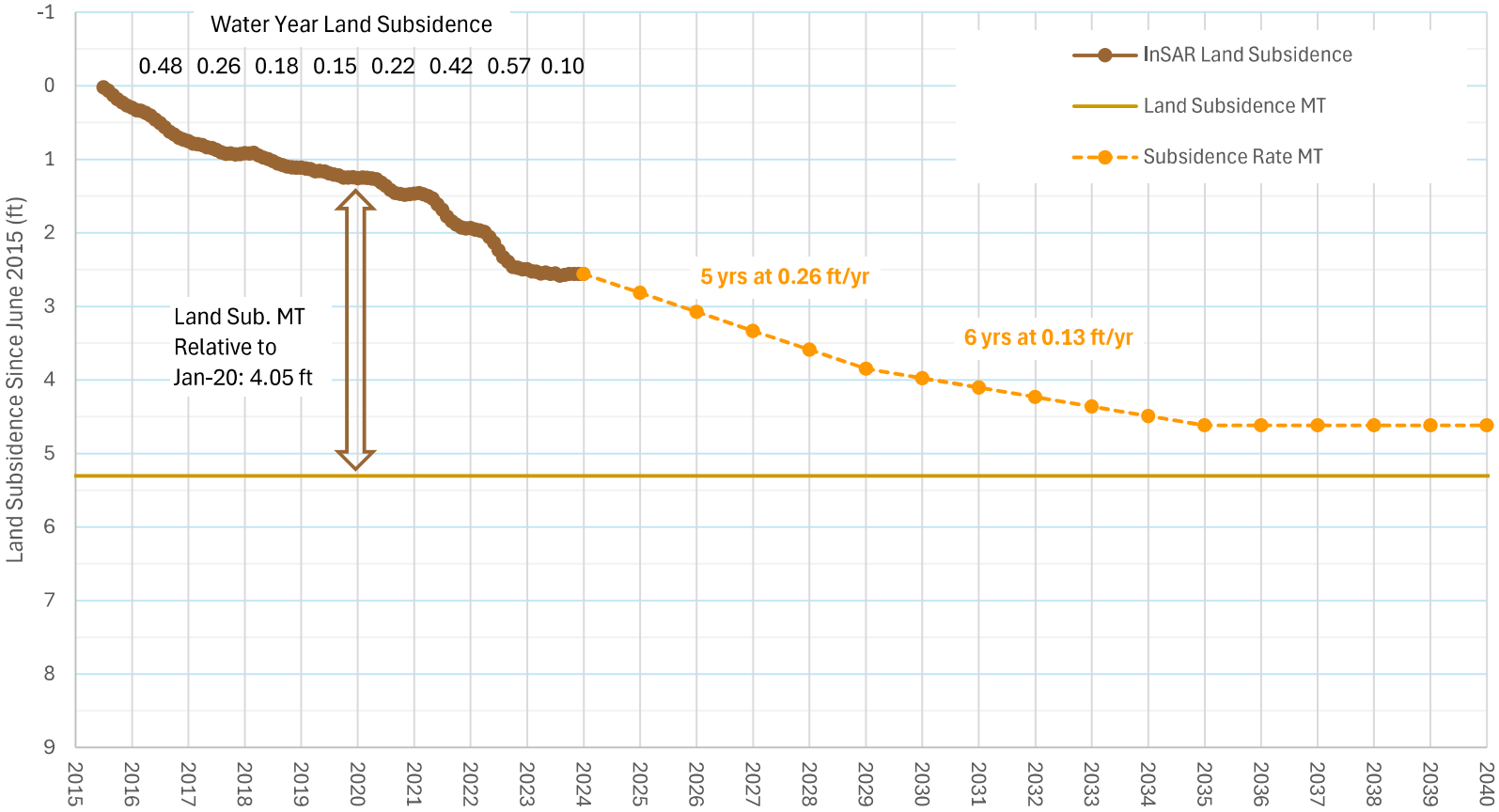
21S/25E-36 (LTRID GSA) Land Subsidence Rates



Notes:

ft amsl = feet above mean sea level

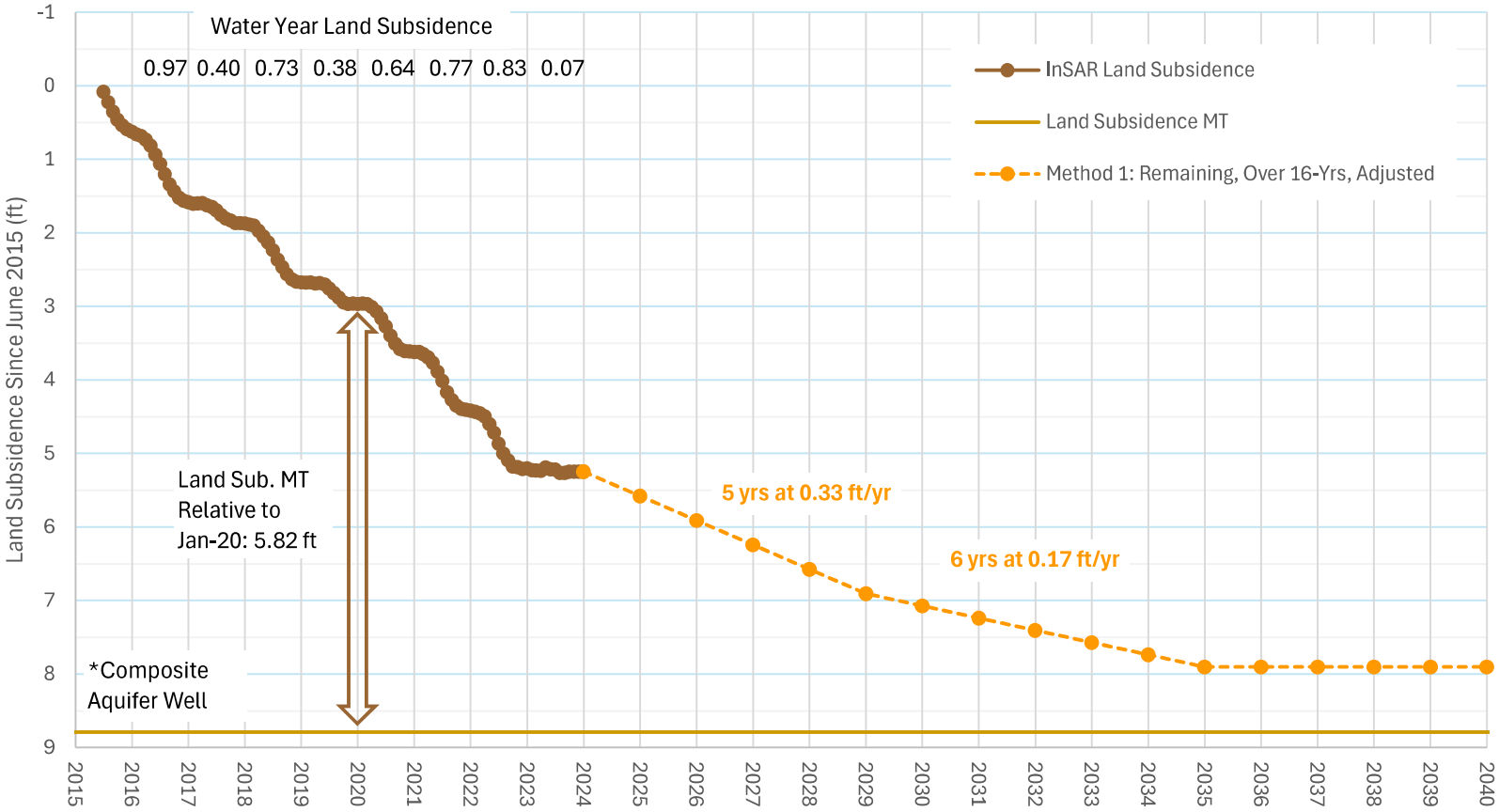
20S/26E-32 (LTRID GSA) Land Subsidence Rates



Notes:

ft amsl = feet above mean sea level

22S/24E-01Q01 (LTRID GSA) Land Subsidence Rates

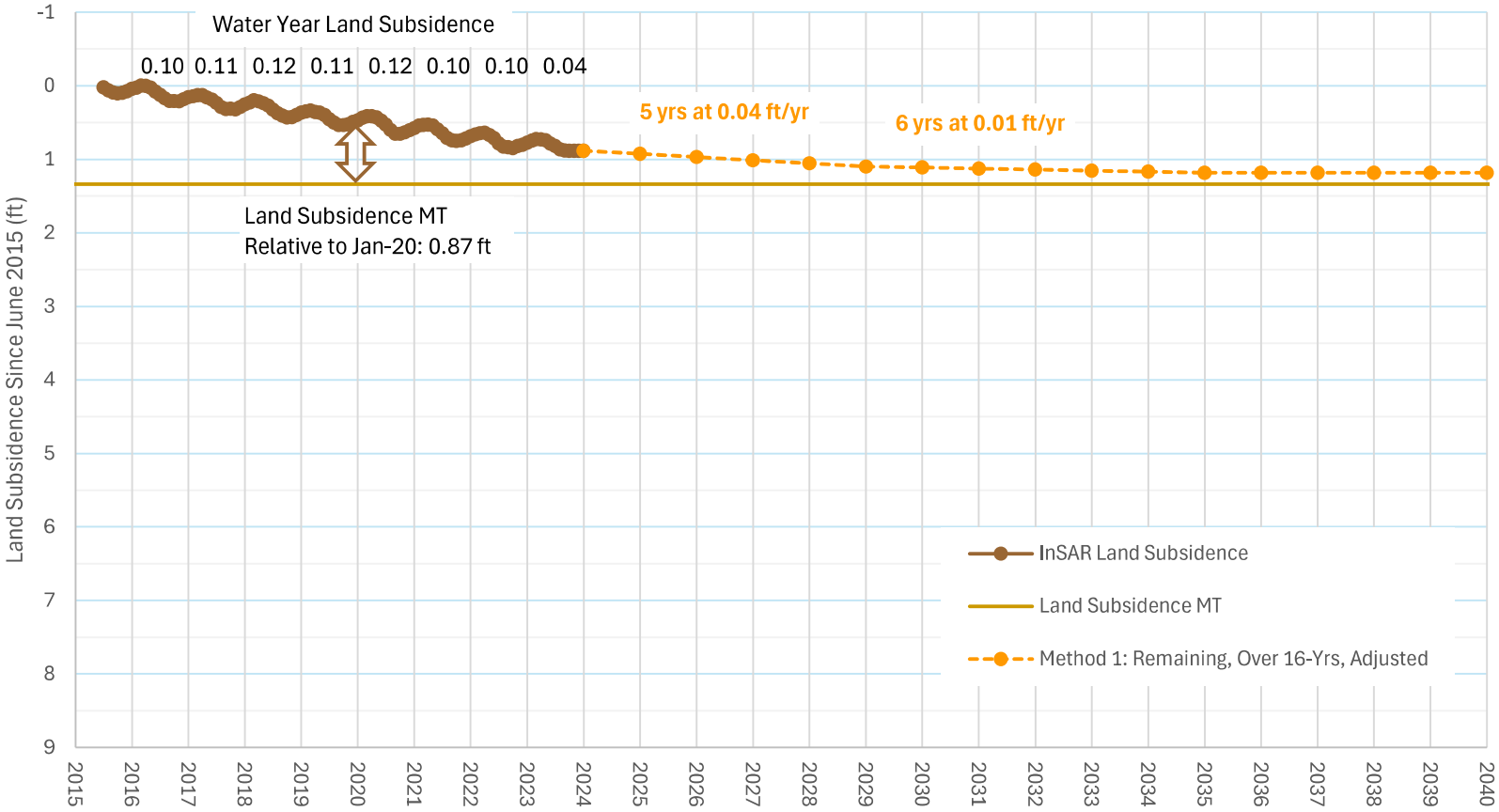


Notes:

ft amsl = feet above mean sea level

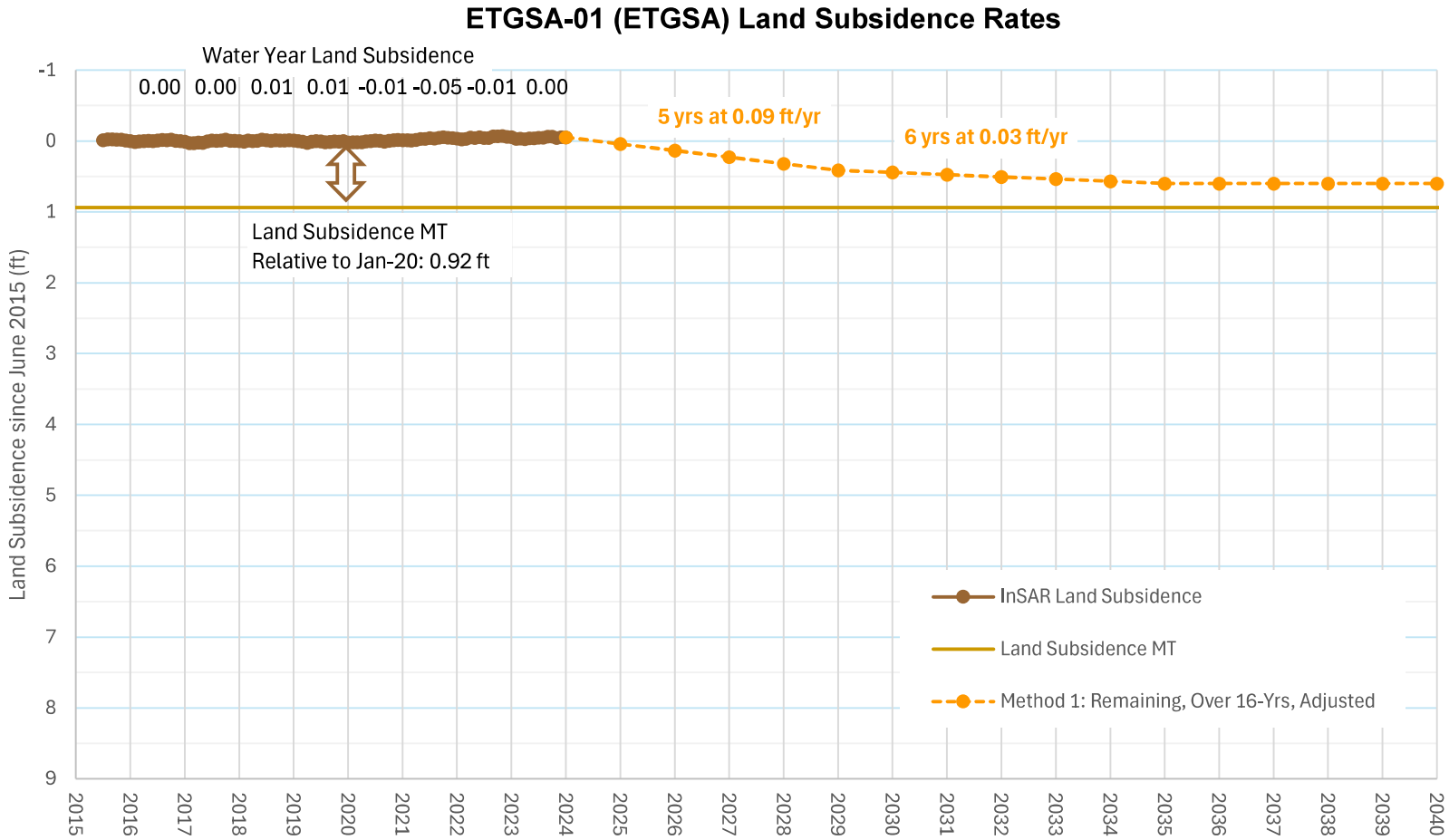
Composite aquifer well.

23S/27E-27 (ETGSA) Land Subsidence Rates



Notes:

ft amsl = feet above mean sea level

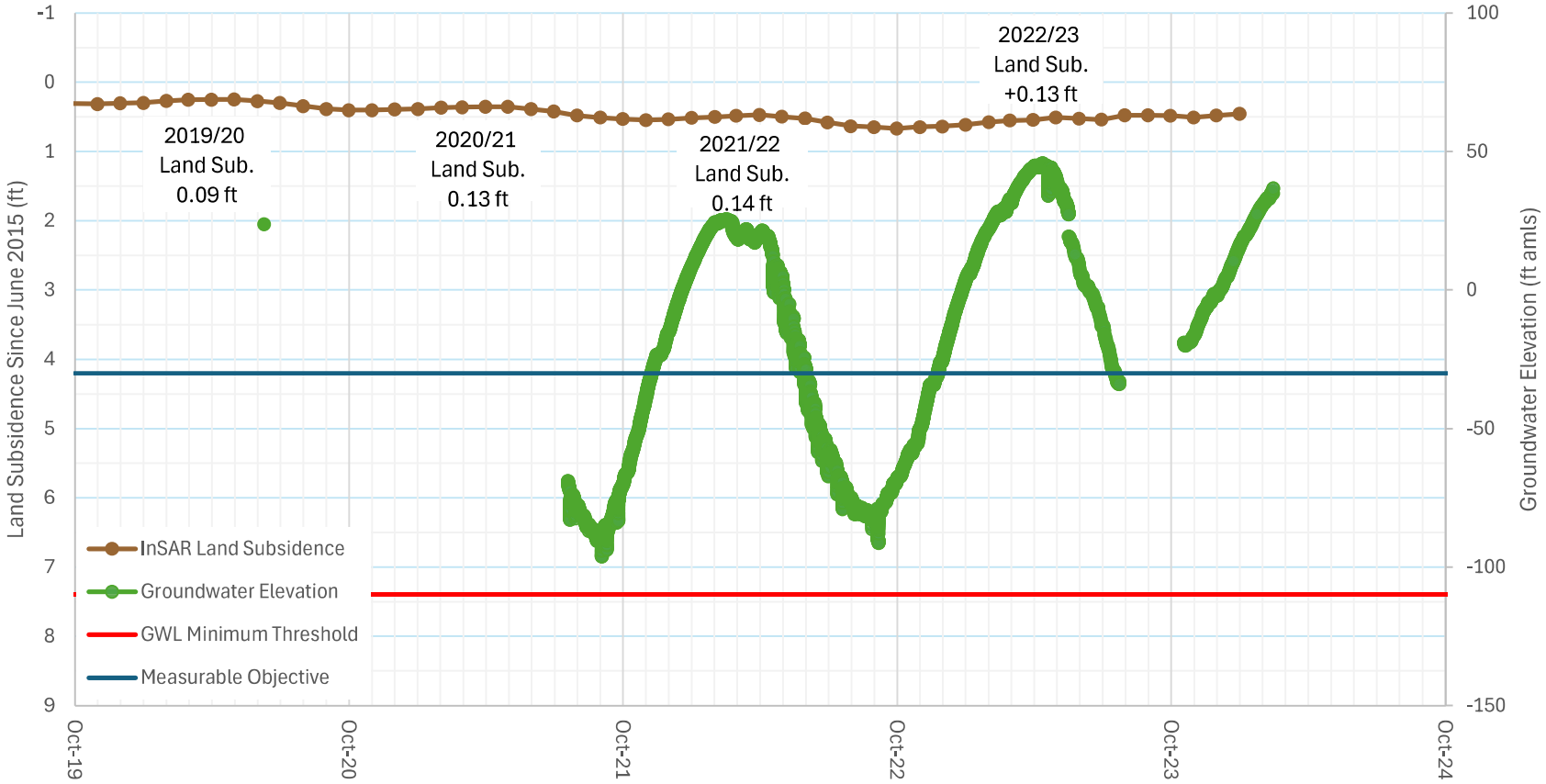


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 478.14 ft amsl

Santa Margarita Aquifer Groundwater Level Minimum Threshold and Measurable Objective TSMW-6SM

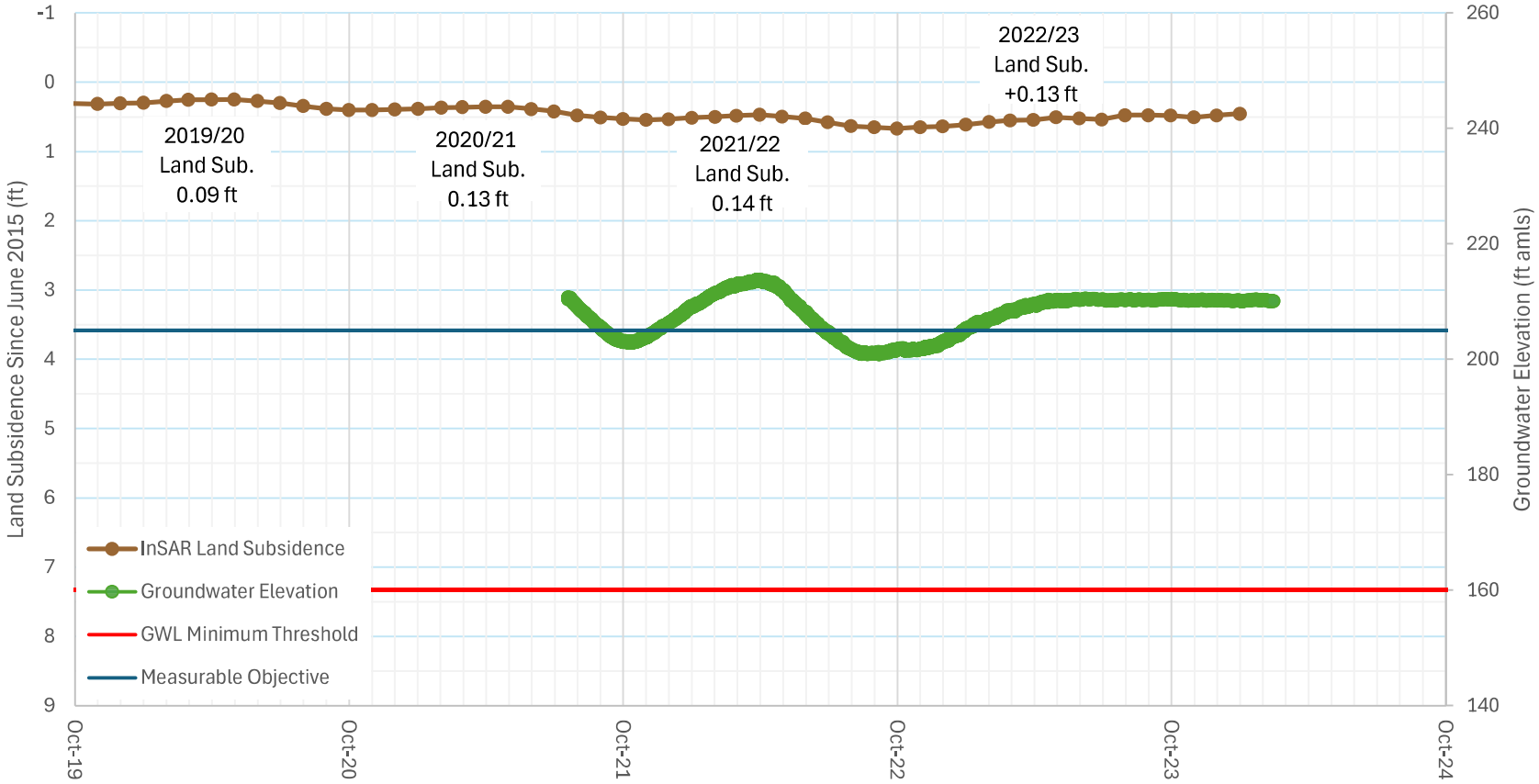


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 516.55 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective TSMW-6L

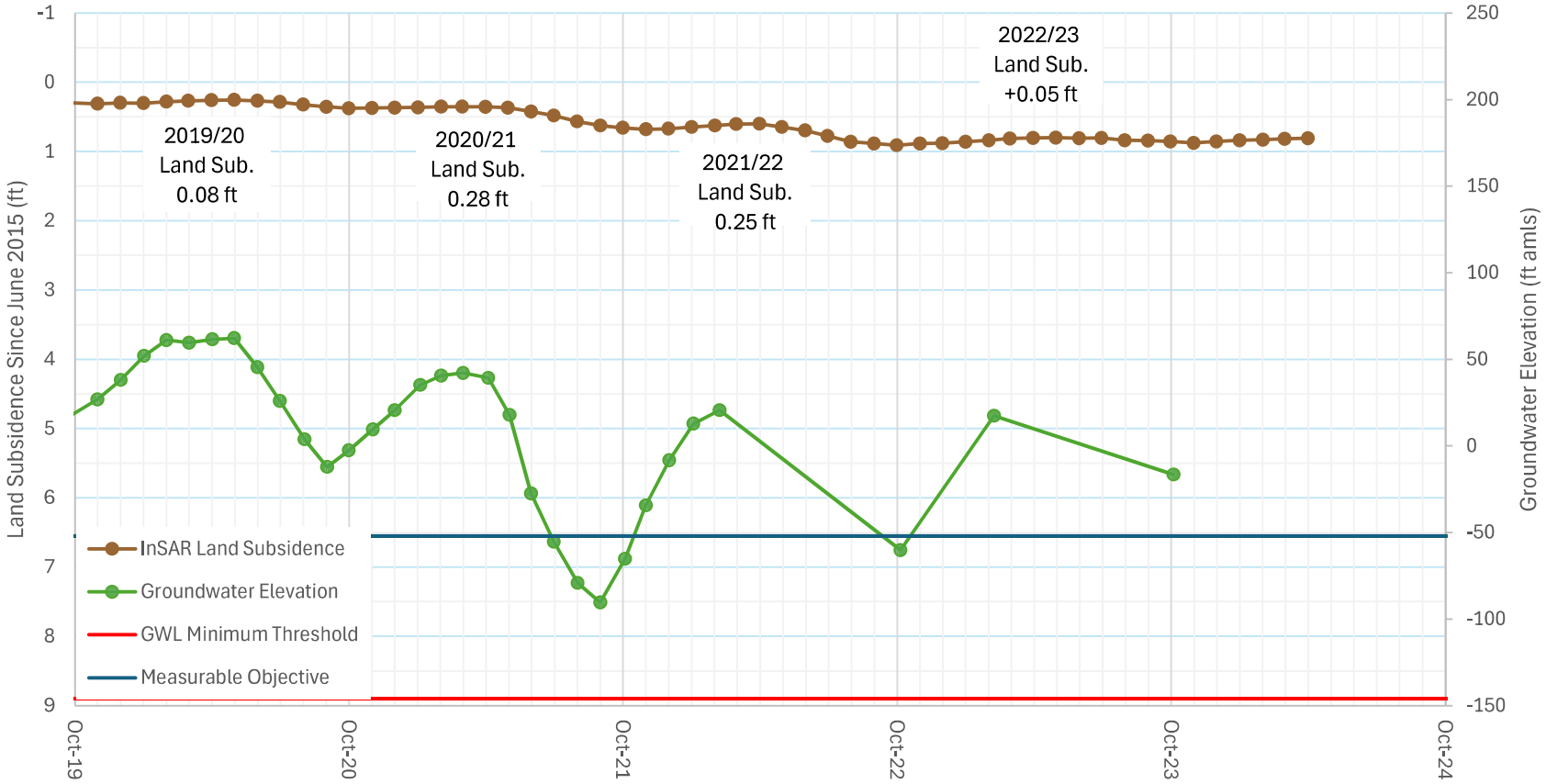


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 519.34 ft amsl

Santa Margarita Aquifer Groundwater Level Minimum Threshold and Measurable Objective 24S/27E-32M01

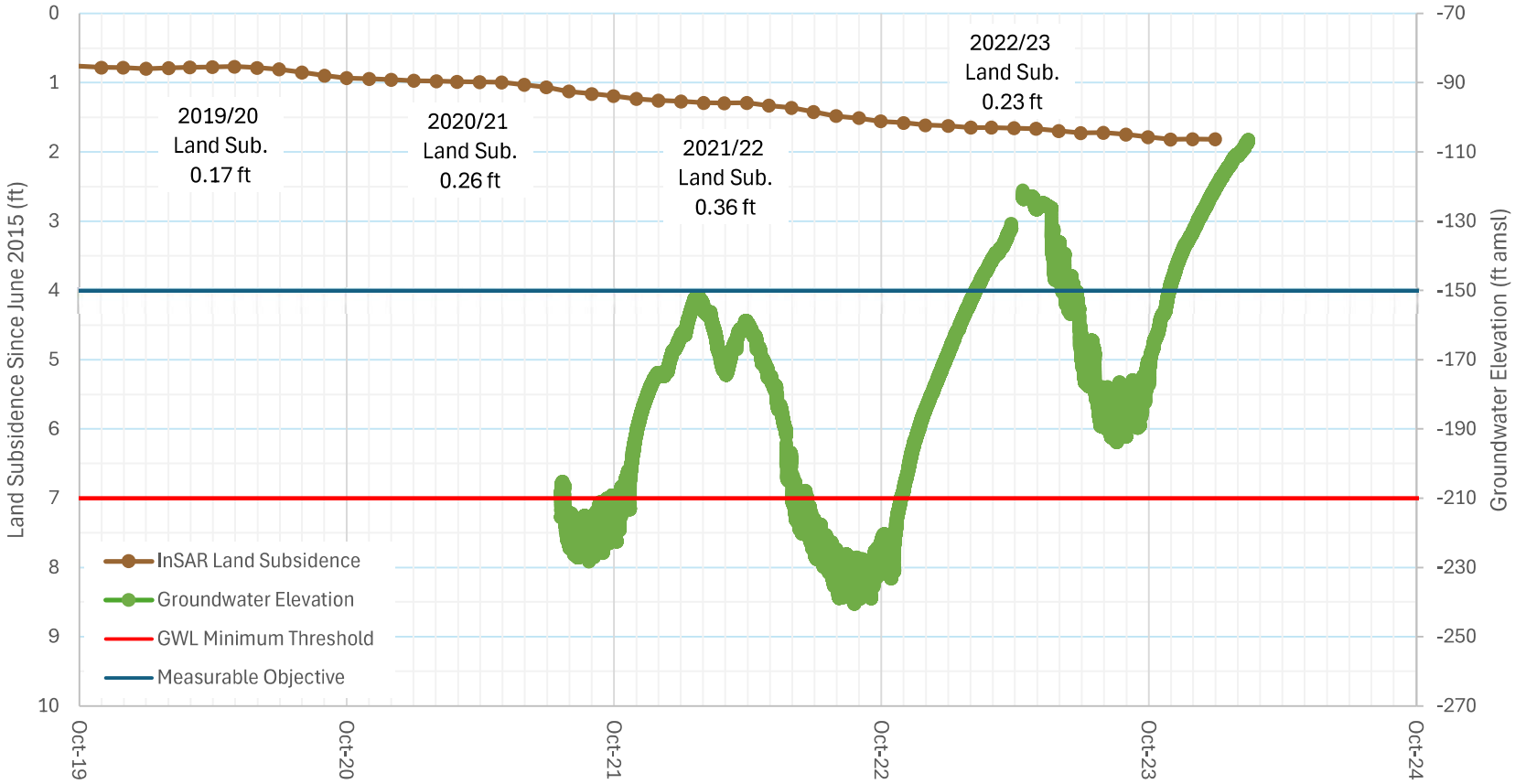


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 536.31 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective TSMW-5L

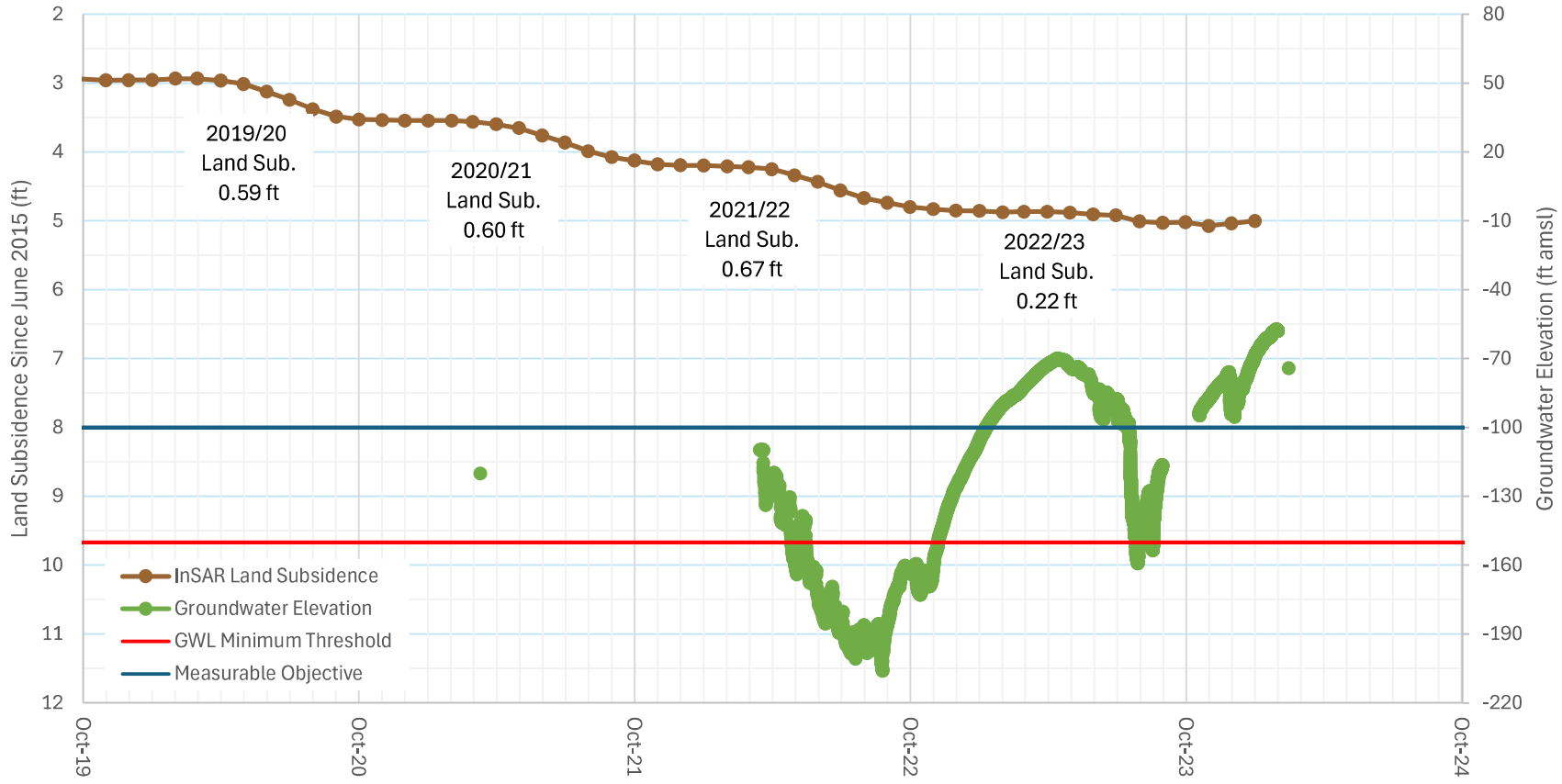


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 200 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective TSMW-01L

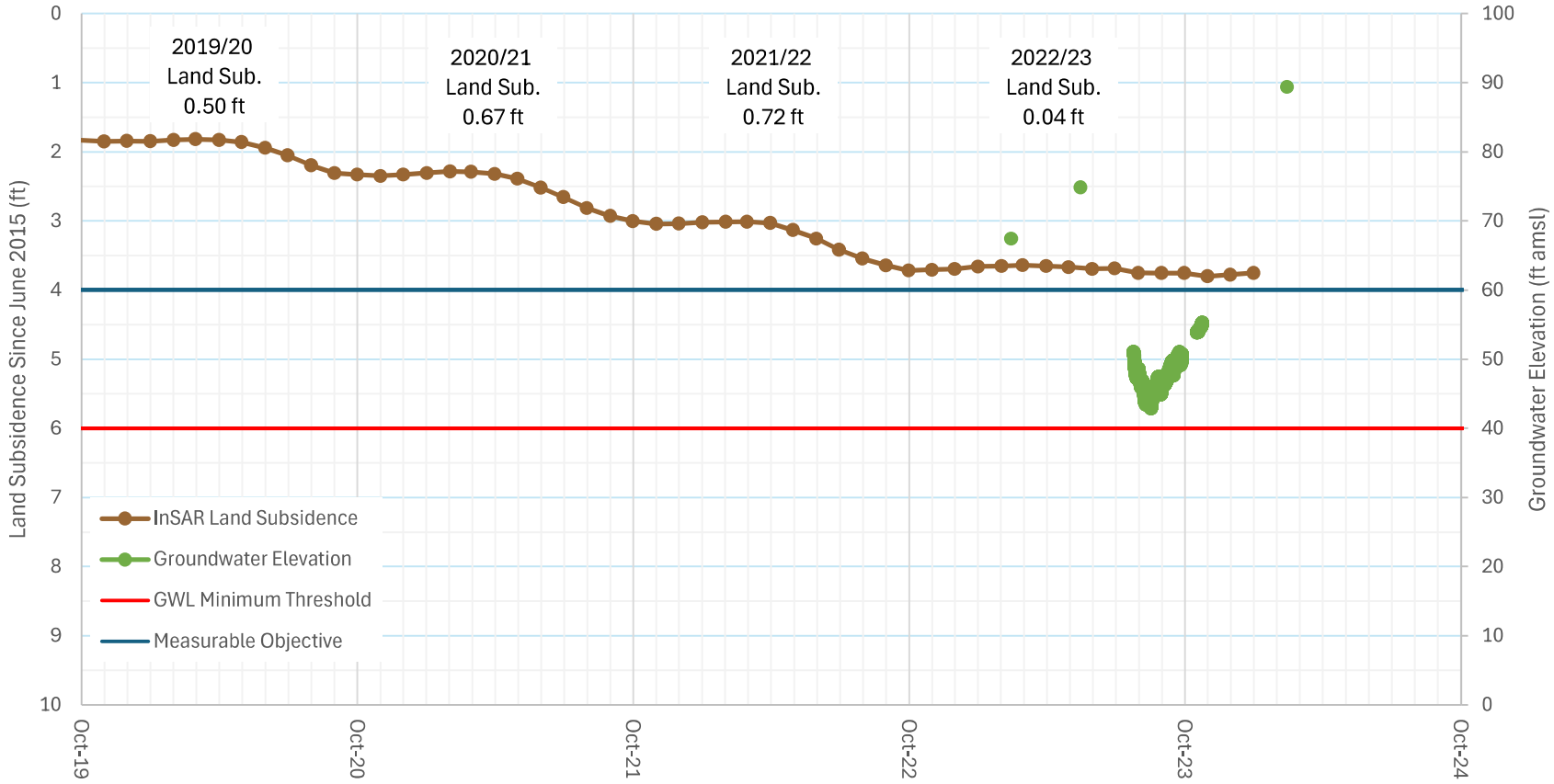


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 224.39 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective TSMW-4D

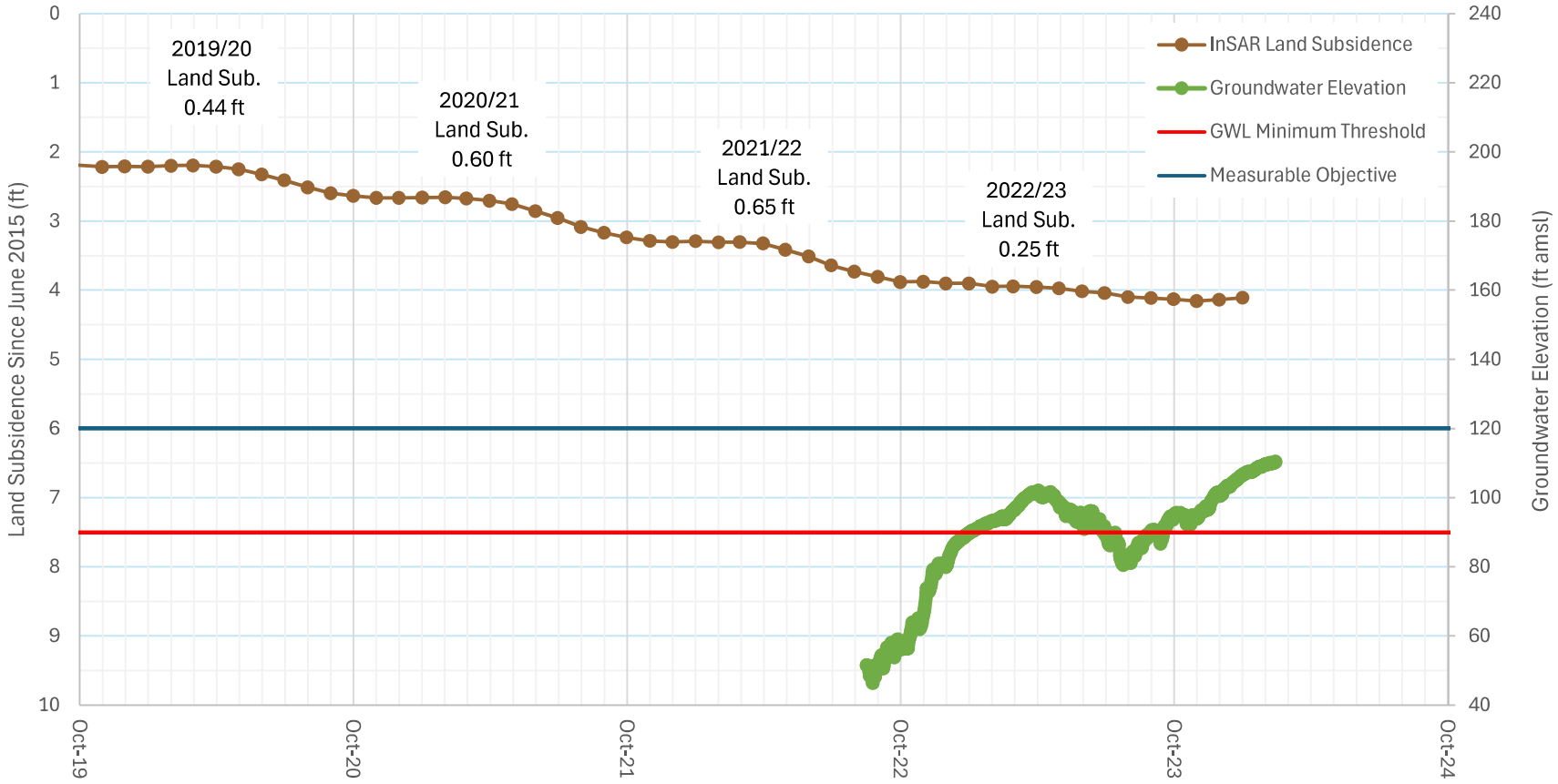


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 369.05 ft amsl

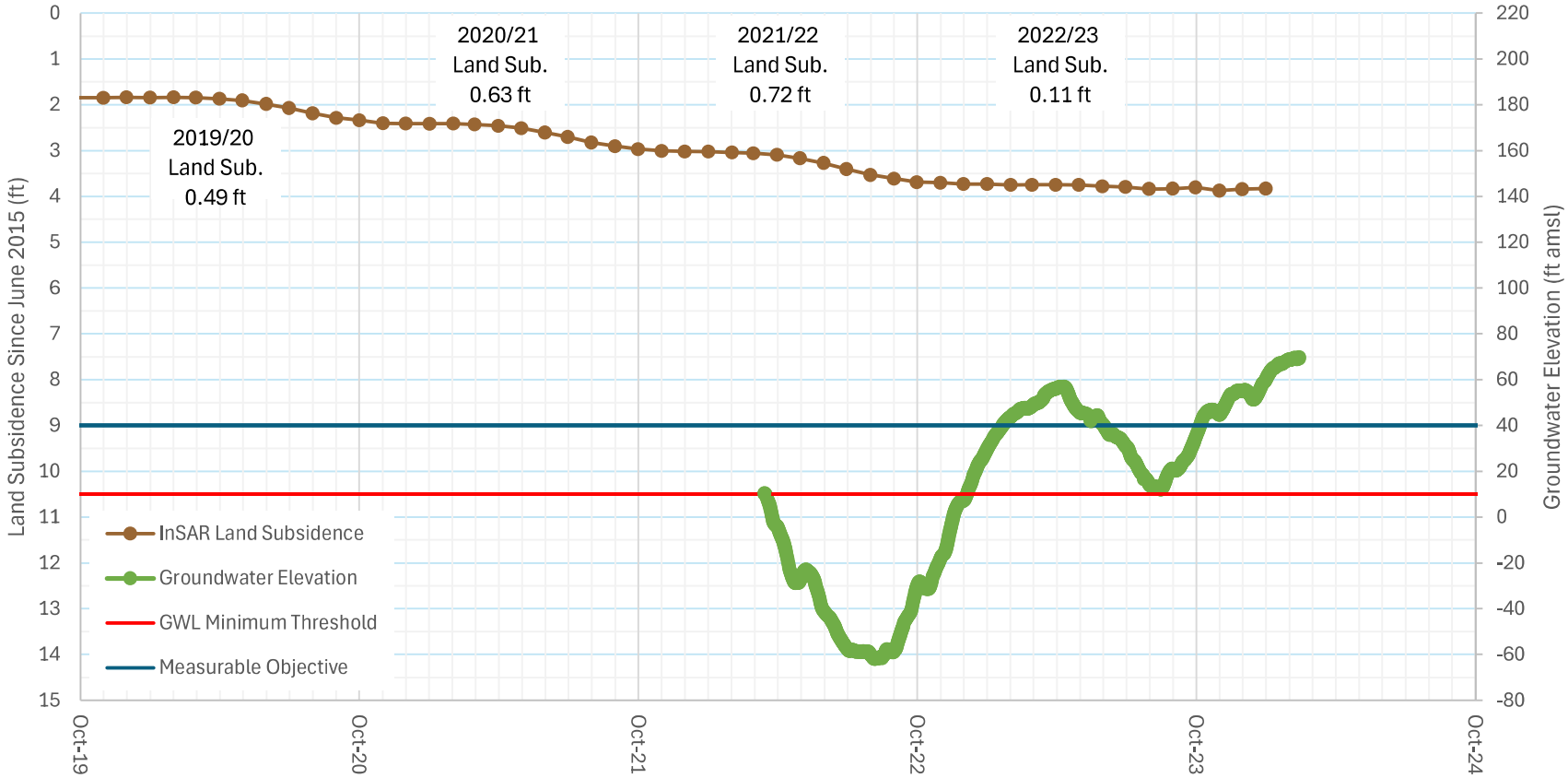
Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective
PIDGSA-01D



Notes:

ft amsl = feet above mean sea level
Reference point elevation = 299.56 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective LTRID-01D

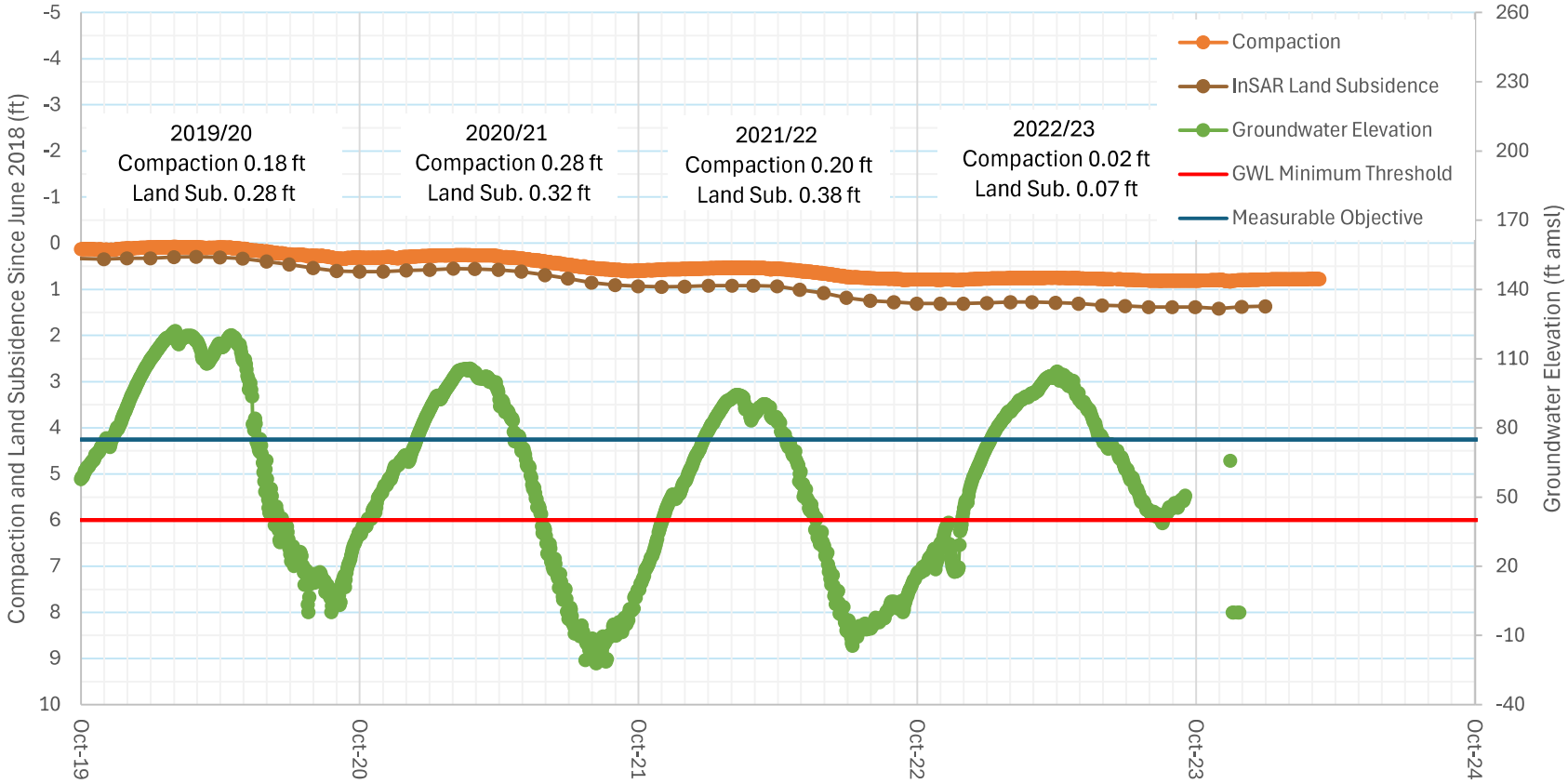


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 264 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 22S/27E-30D02

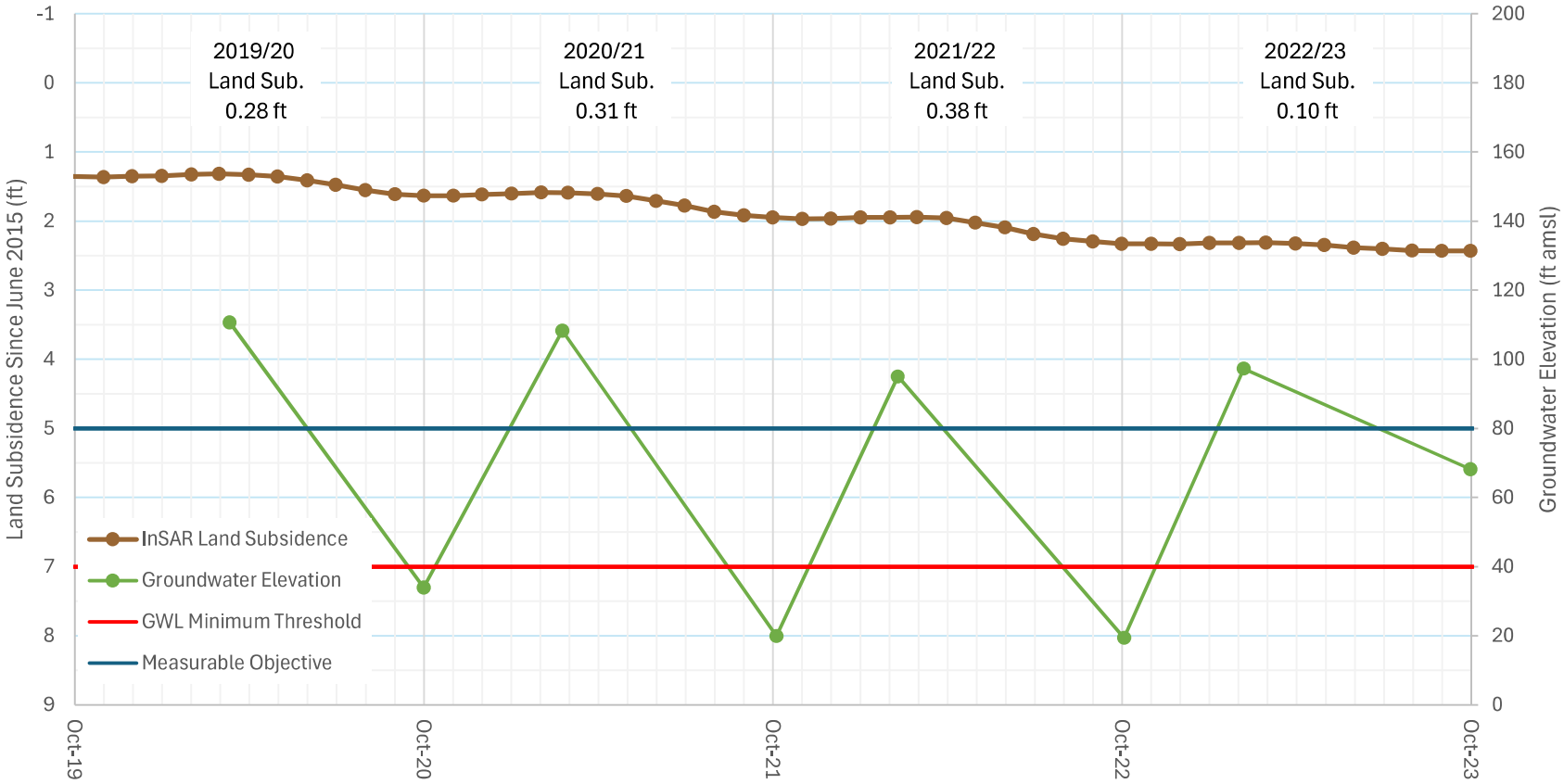


Notes:

ft amsl = feet above mean sea level

Extensometer depth 1,180 ft bgs and screened interval 1,083 to 1,180 ft bgs.

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective
22S/26E-24

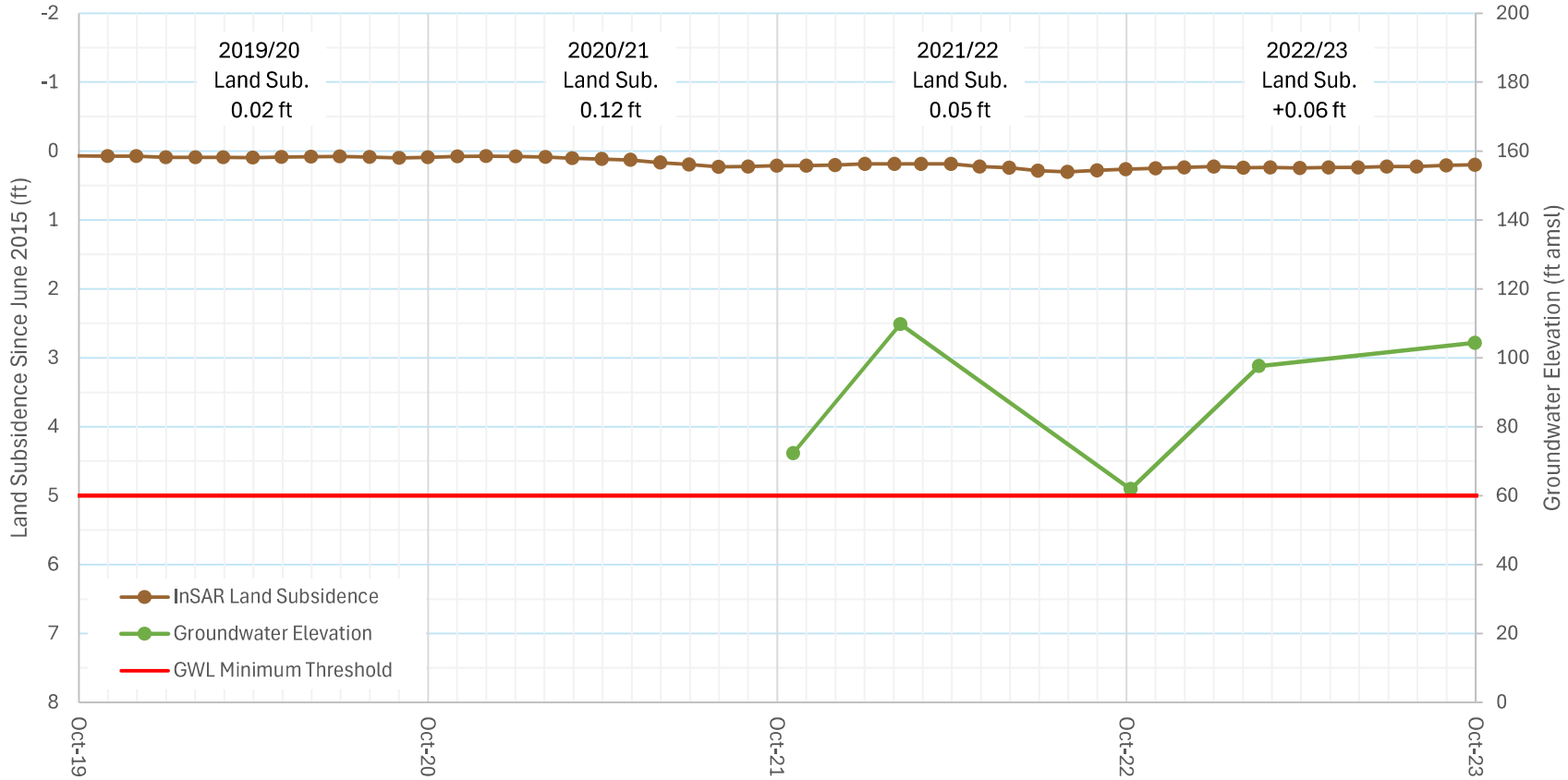


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 397.5 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 25S/26E-09C01

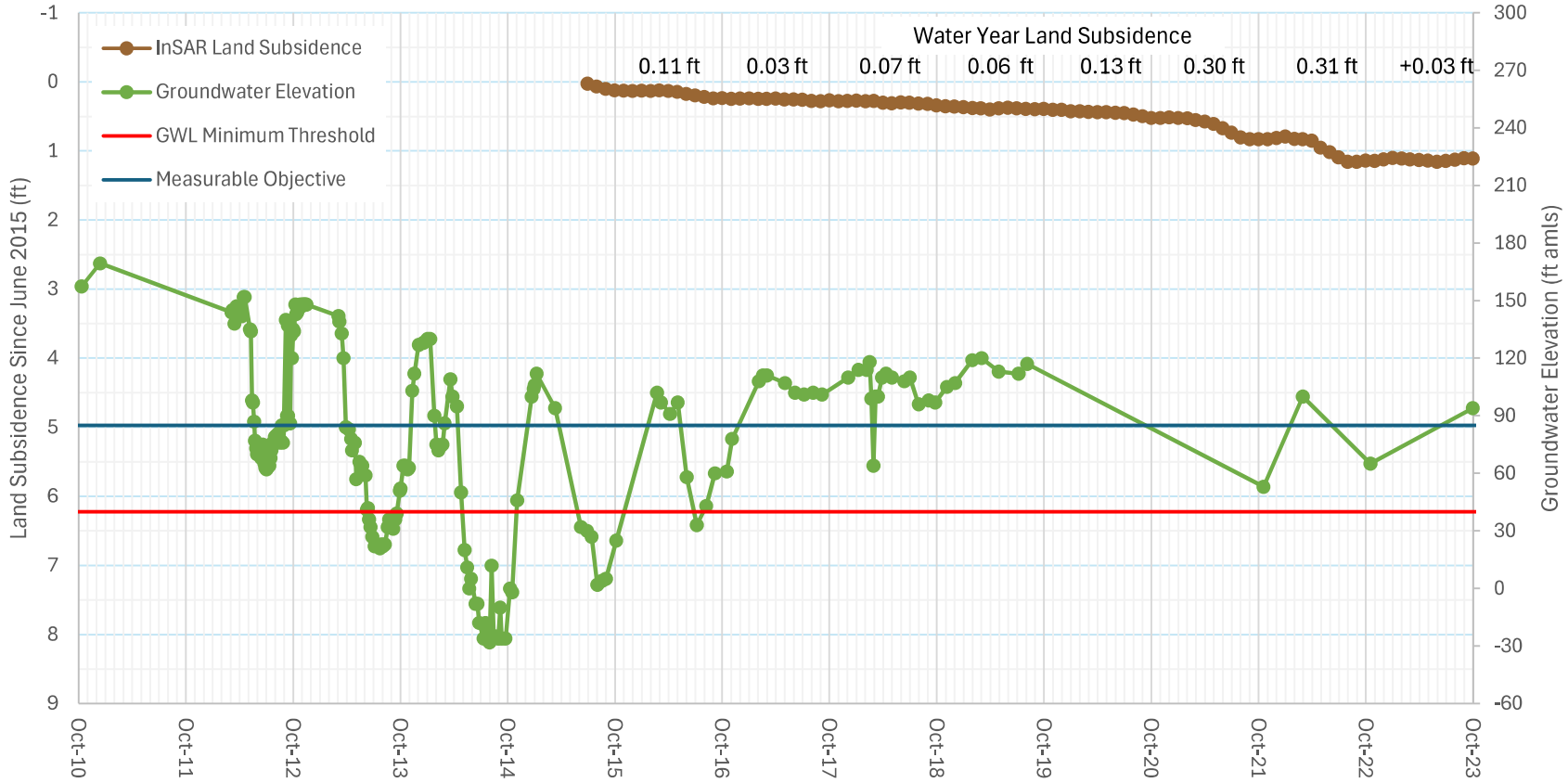


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 399 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective M19

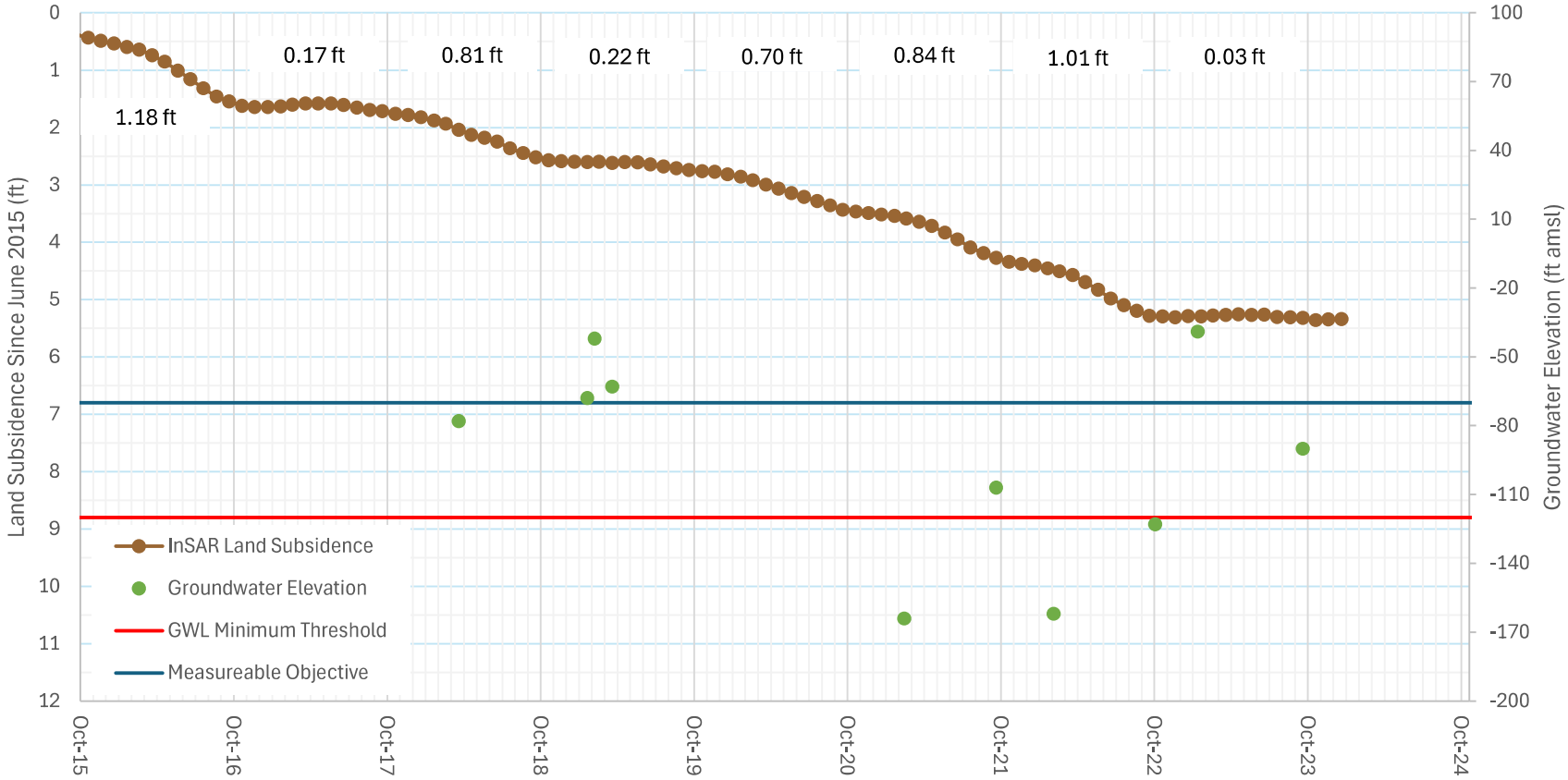


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 373 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 22S/23E-27F01 (G-13)

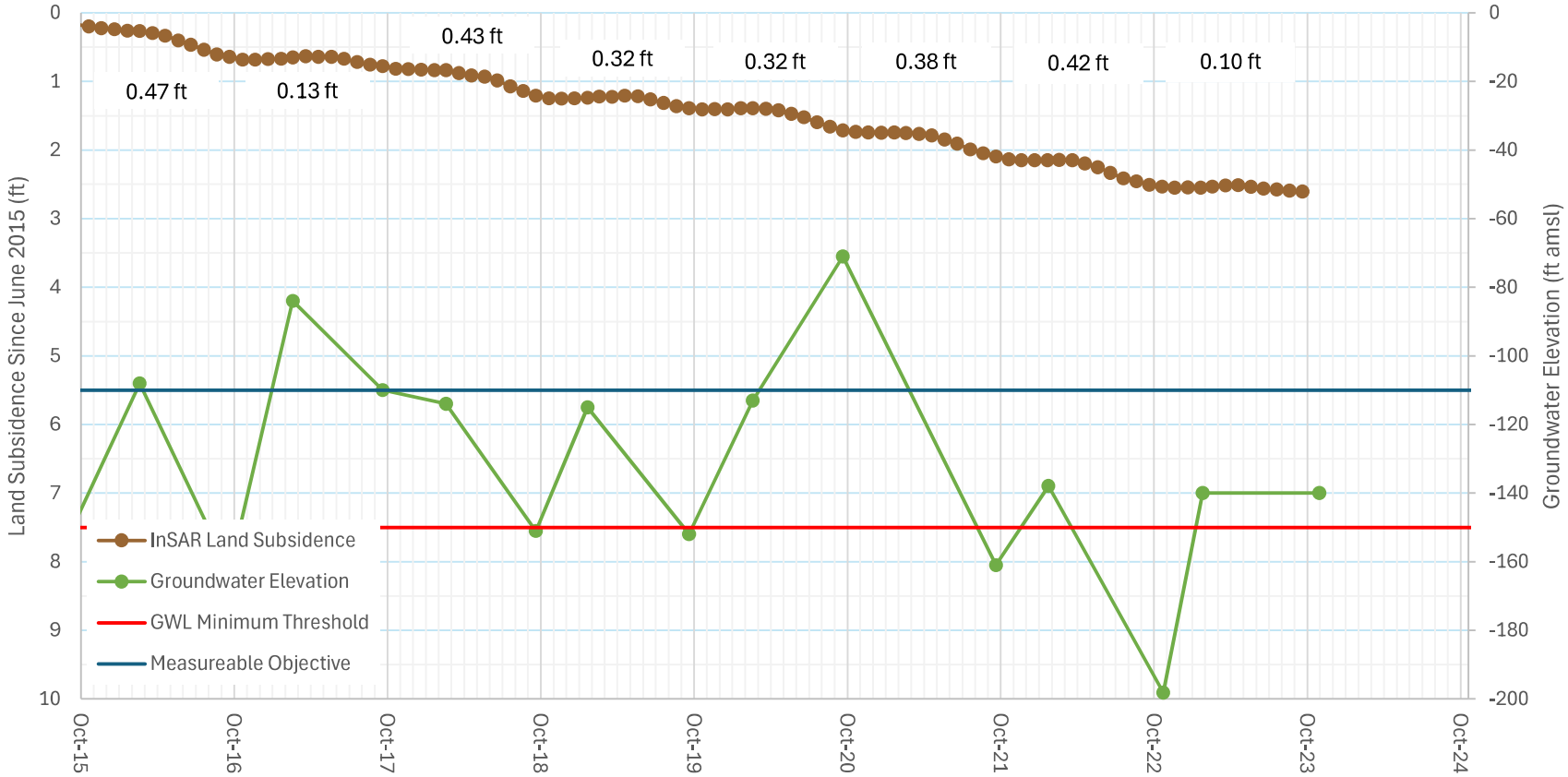


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 201 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 24S/23E-23 (Well 55)

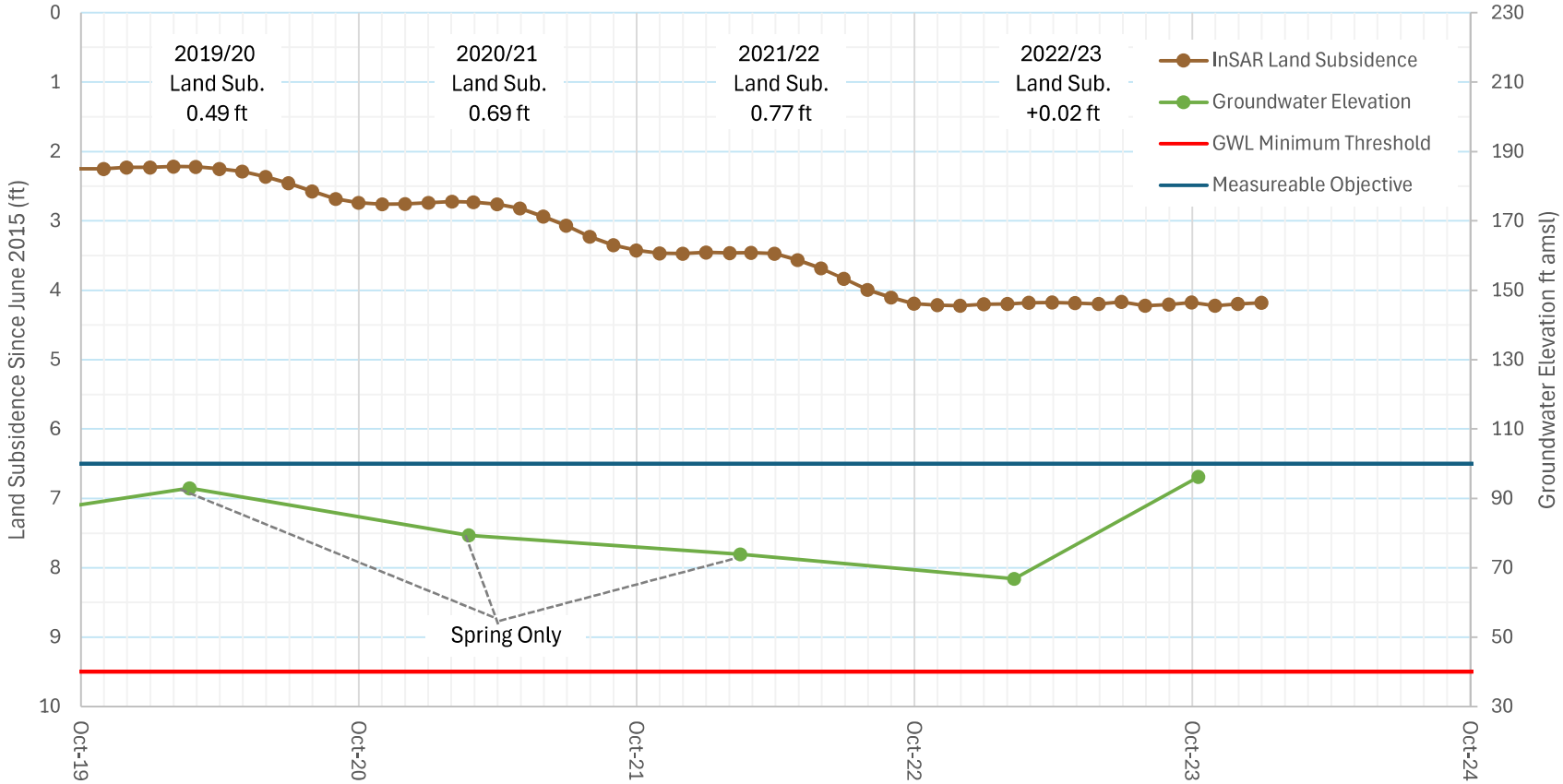


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 200 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 21S/25E-36

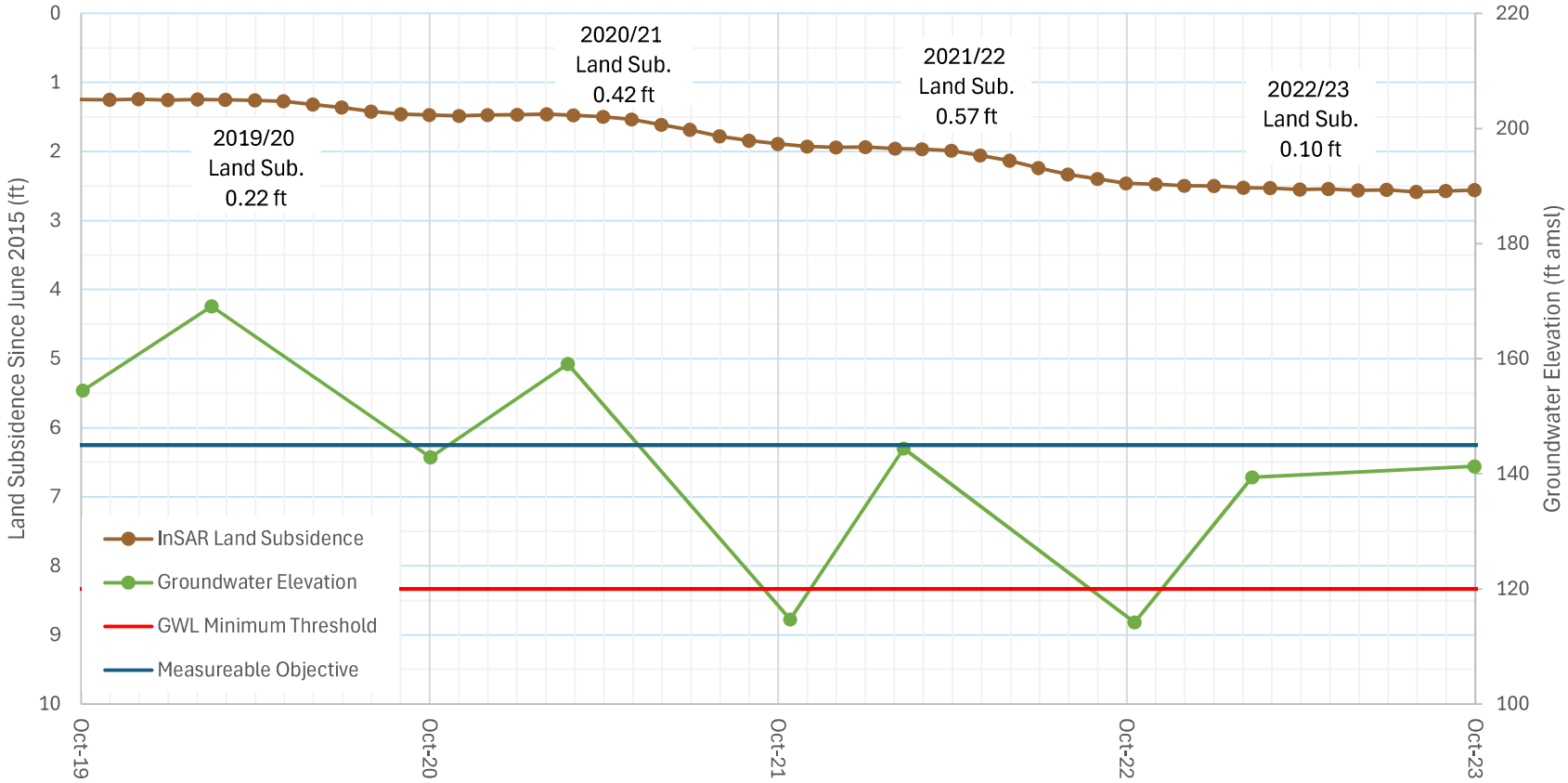


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 312.7 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective 20S/26E-32

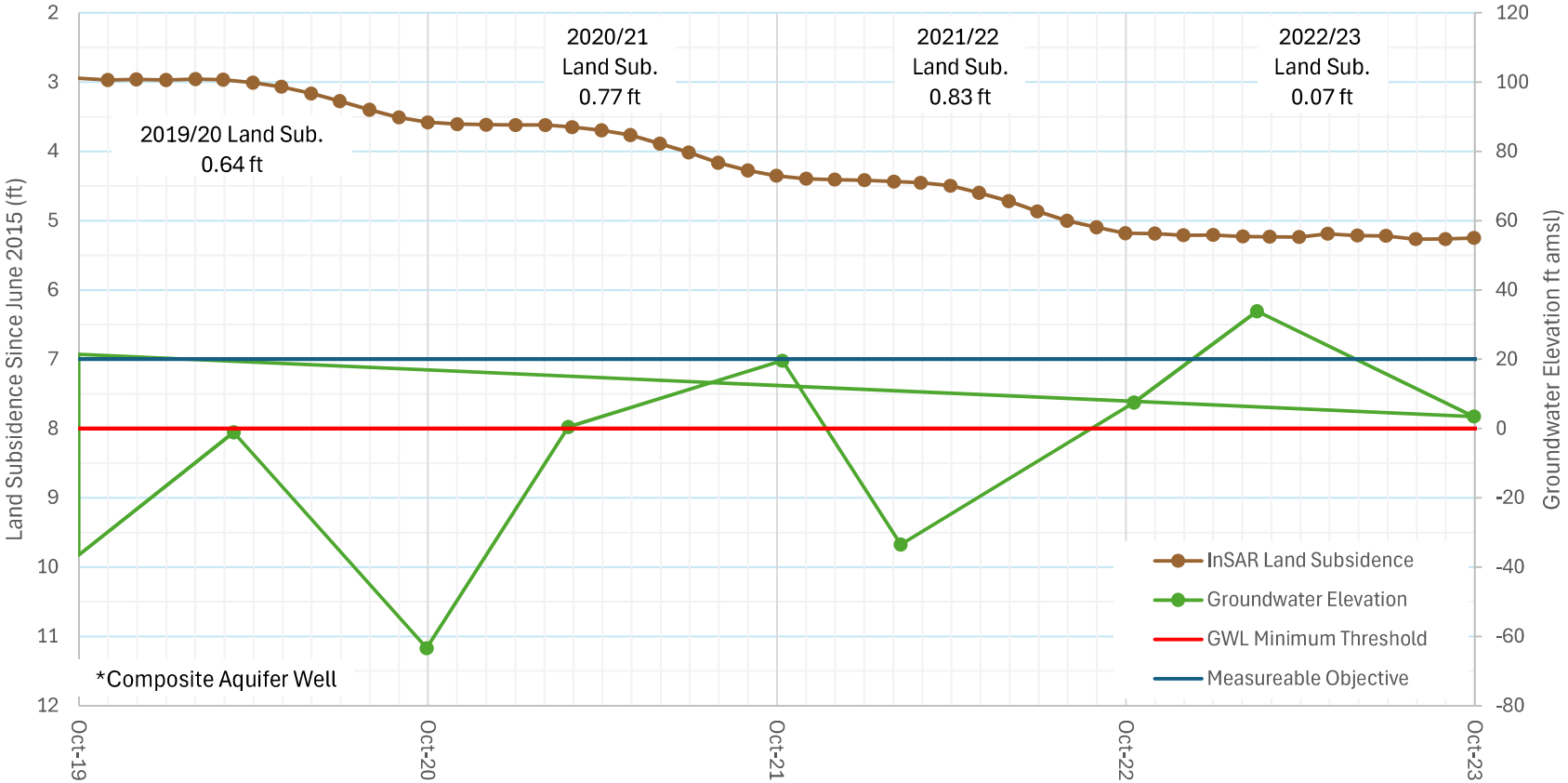


Notes:

ft amsl = feet above mean sea level

Reference point elevation = 330 ft amsl

Lower Aquifer Groundwater Level Minimum Threshold and Measurable Objective
22S/24E-01Q01

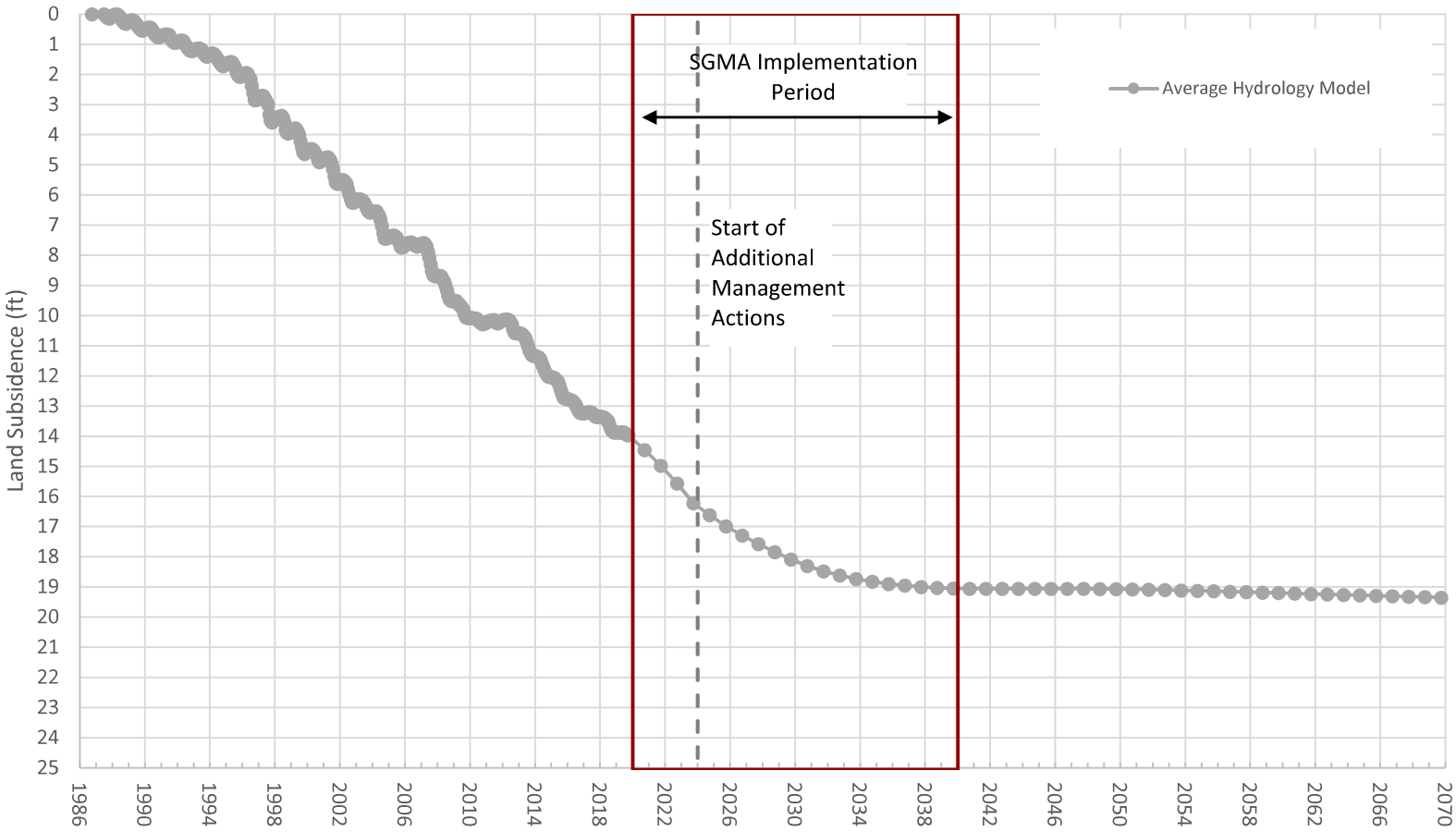


Notes:

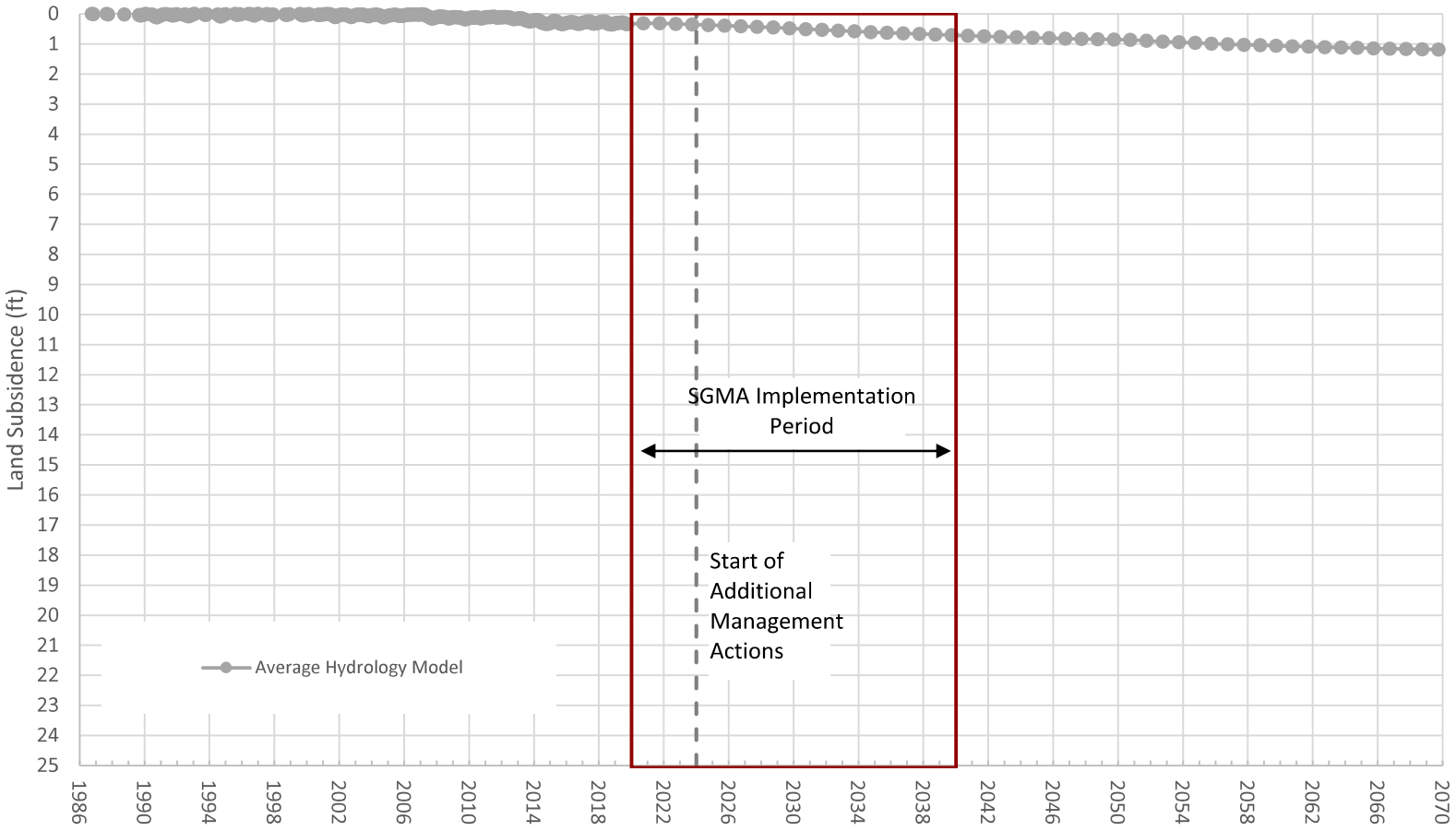
ft amsl = feet above mean sea level

Composite aquifer well.

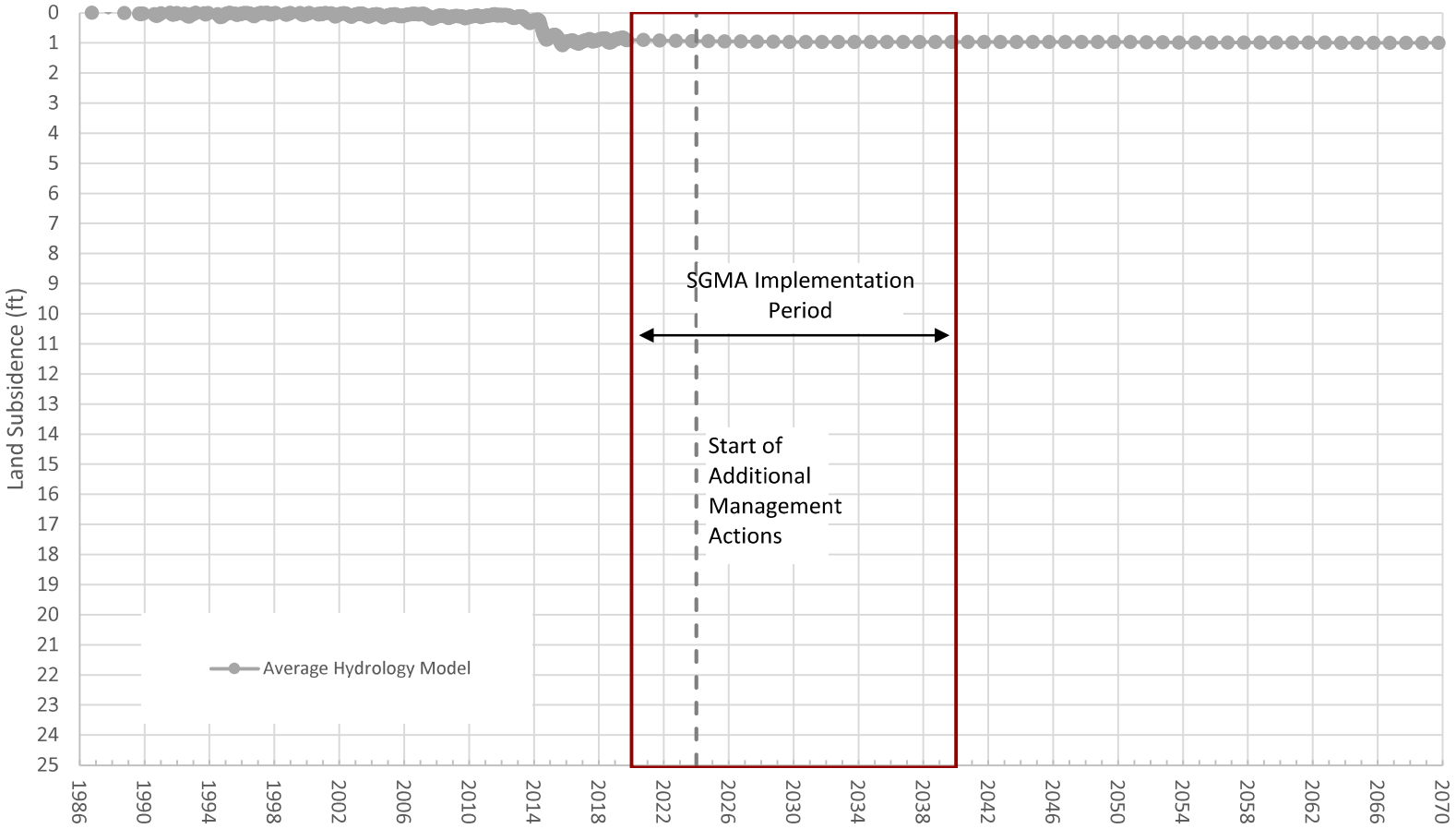
Model-Generated Land Subsidence
24S/23E-23 (Well 55), Alpaugh ID GSA



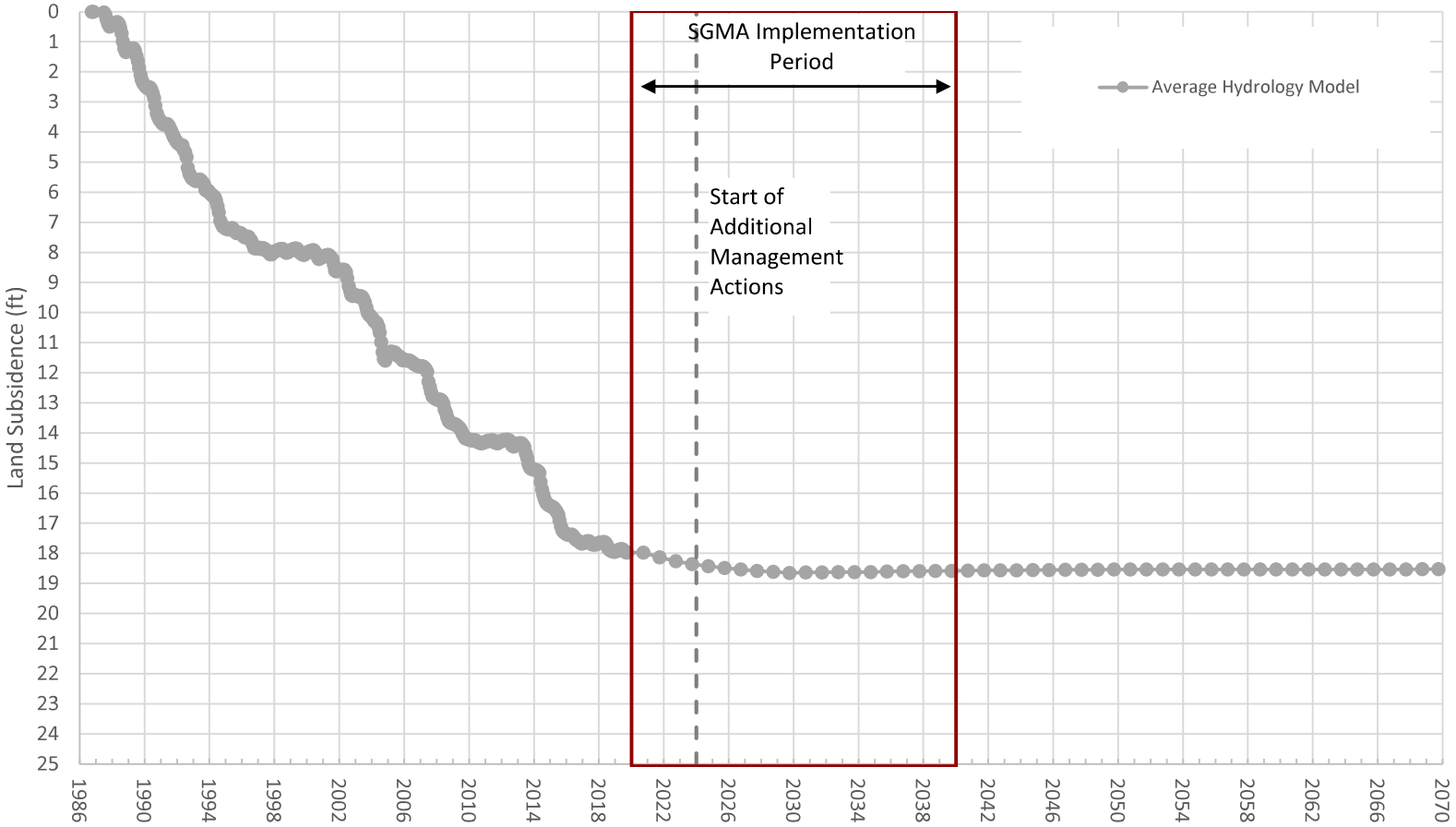
Model-Generated Land Subsidence
25S/26E-09C01, DEID GSA



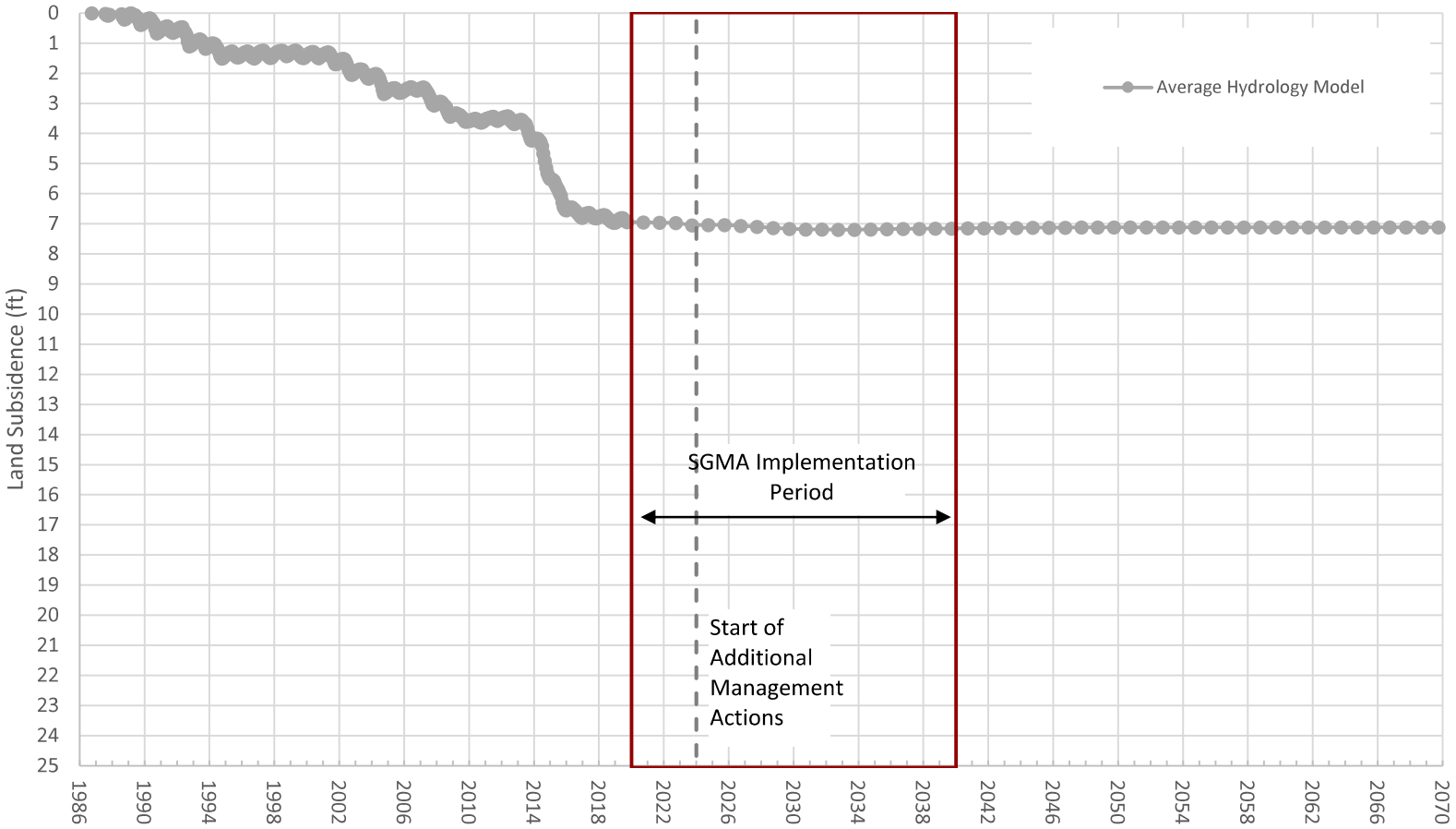
Model-Generated Land Subsidence
M19-L, DEID GSA



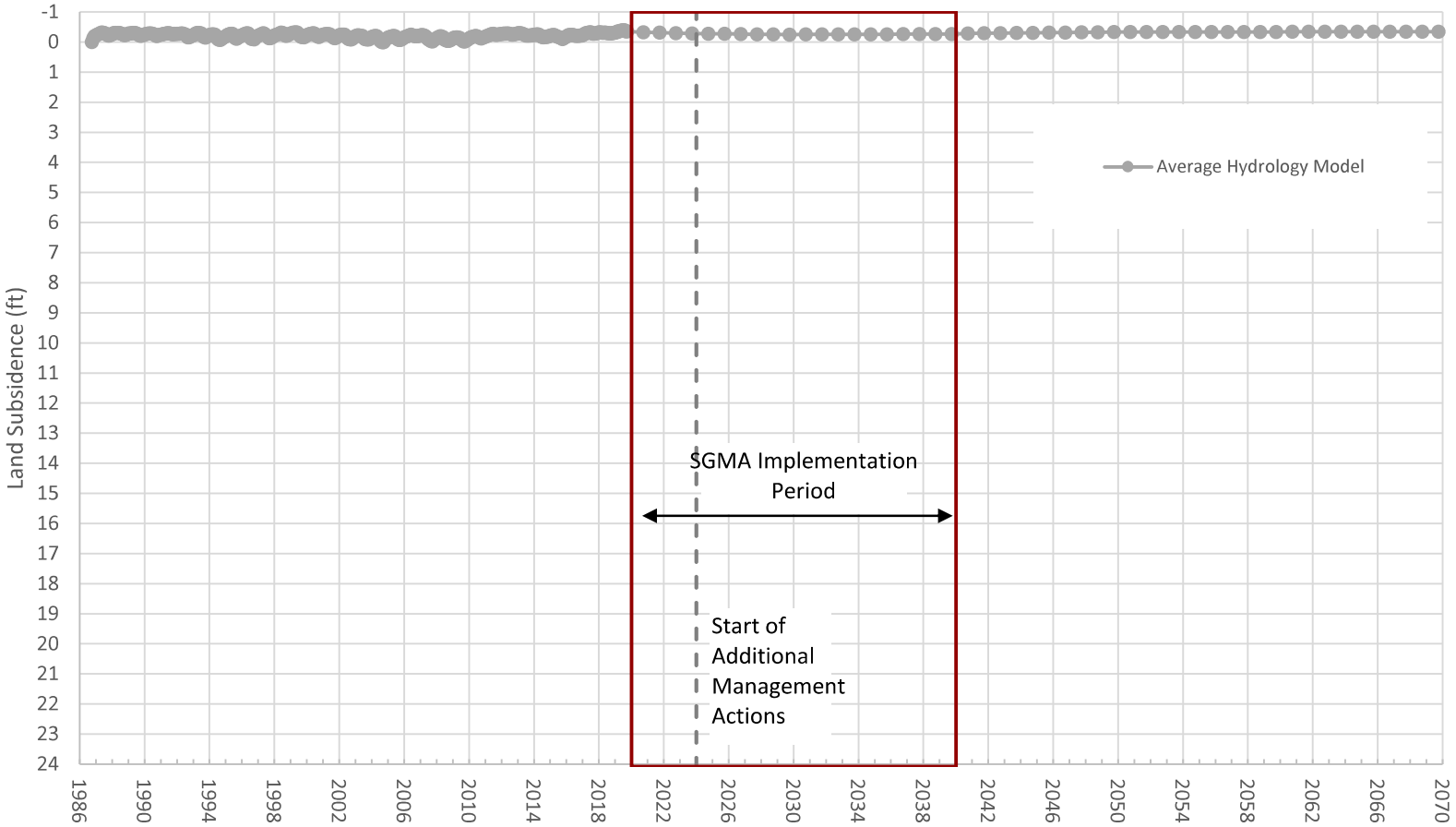
Model-Generated Land Subsidence 22S26E-24, ETGSA



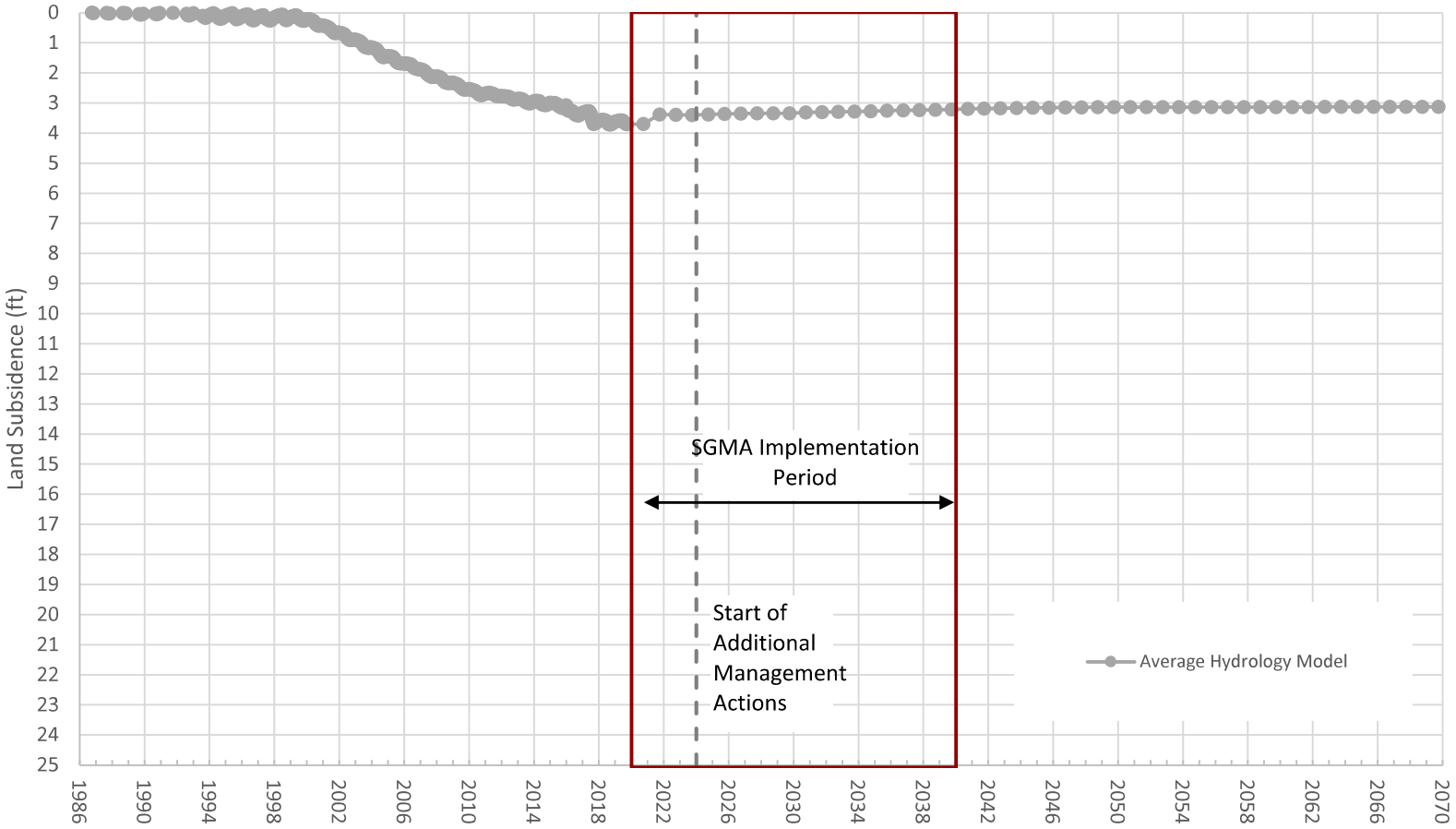
Model-Generated Land Subsidence
TSMW-4D, ETGSA



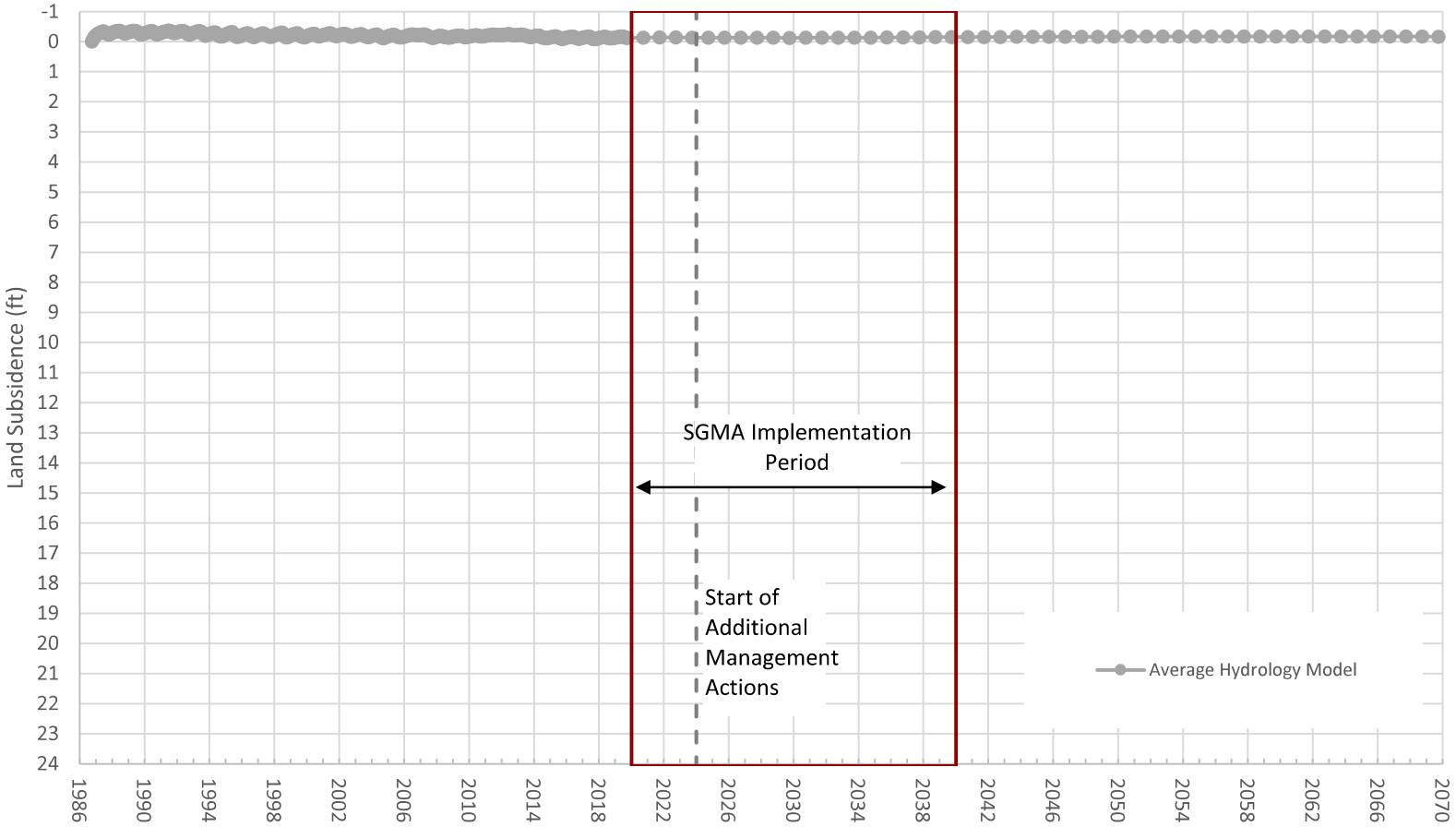
Model-Generated Land Subsidence
ETGSA-01L, ETGSA



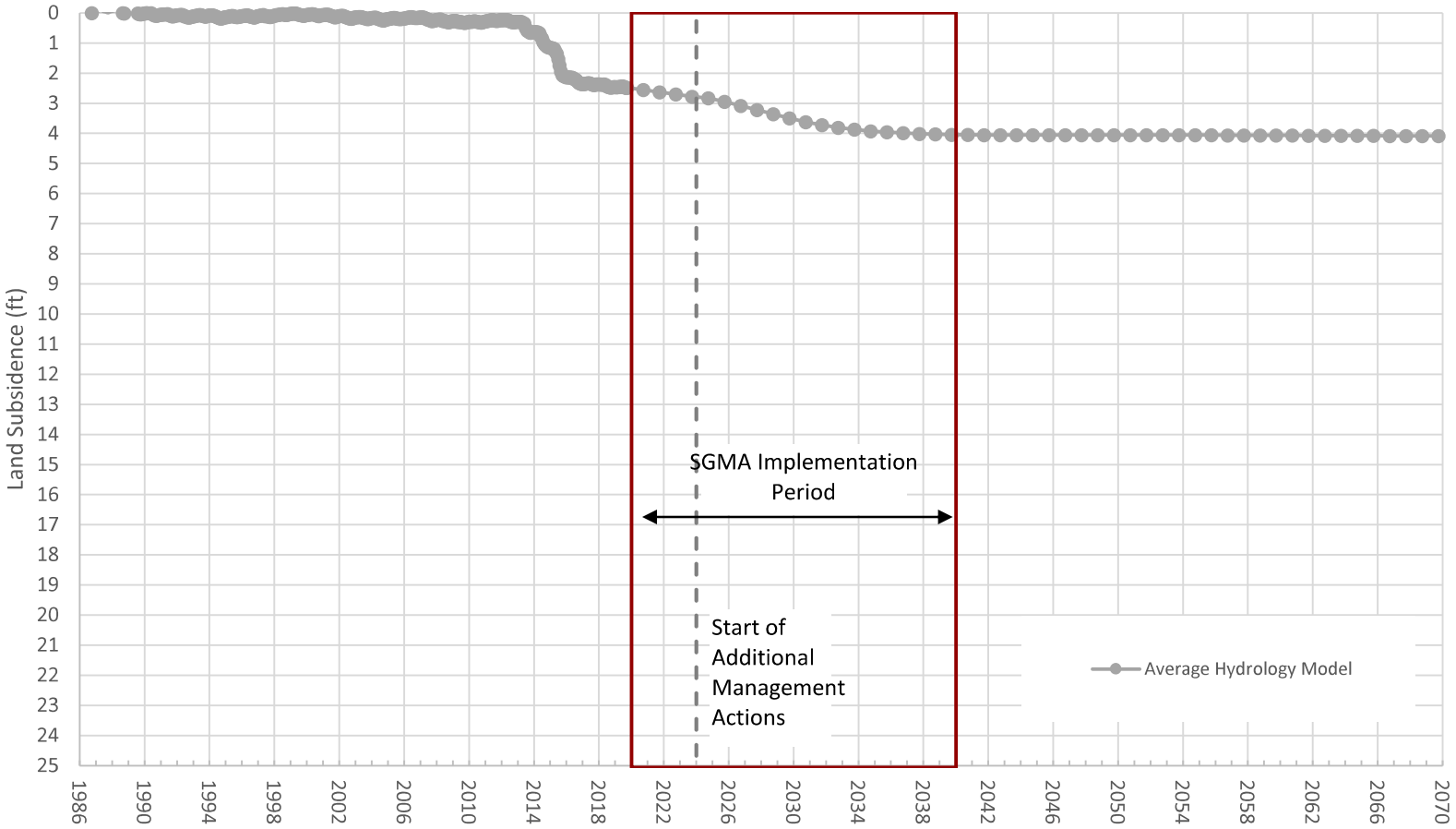
Model-Generated Land Subsidence
23S/27E-27, ETGSA



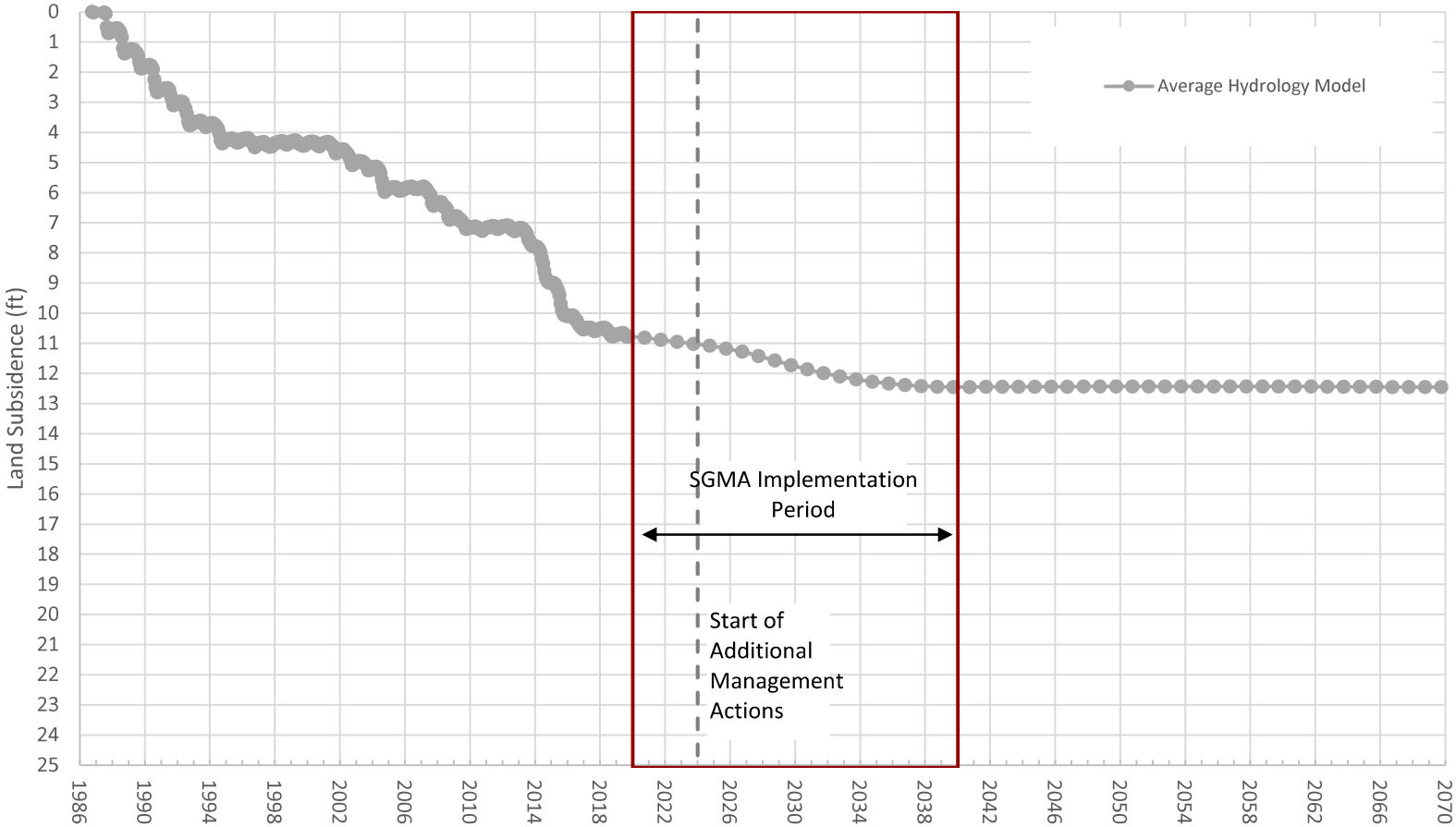
Model-Generated Land Subsidence
TSMW-6L, KTWD GSA



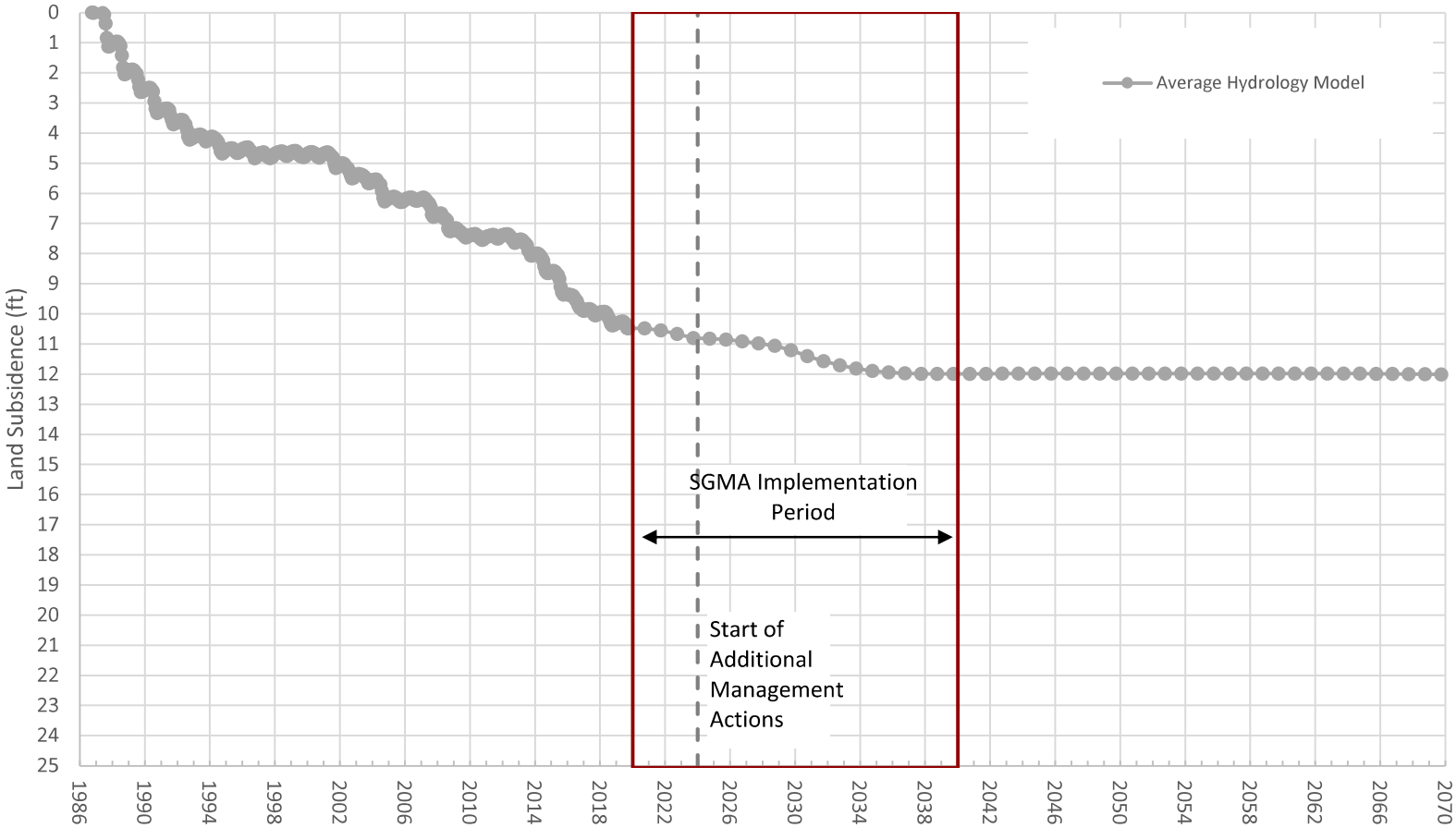
Model-Generated Land Subsidence
20S/26E-32, LTRID GSA



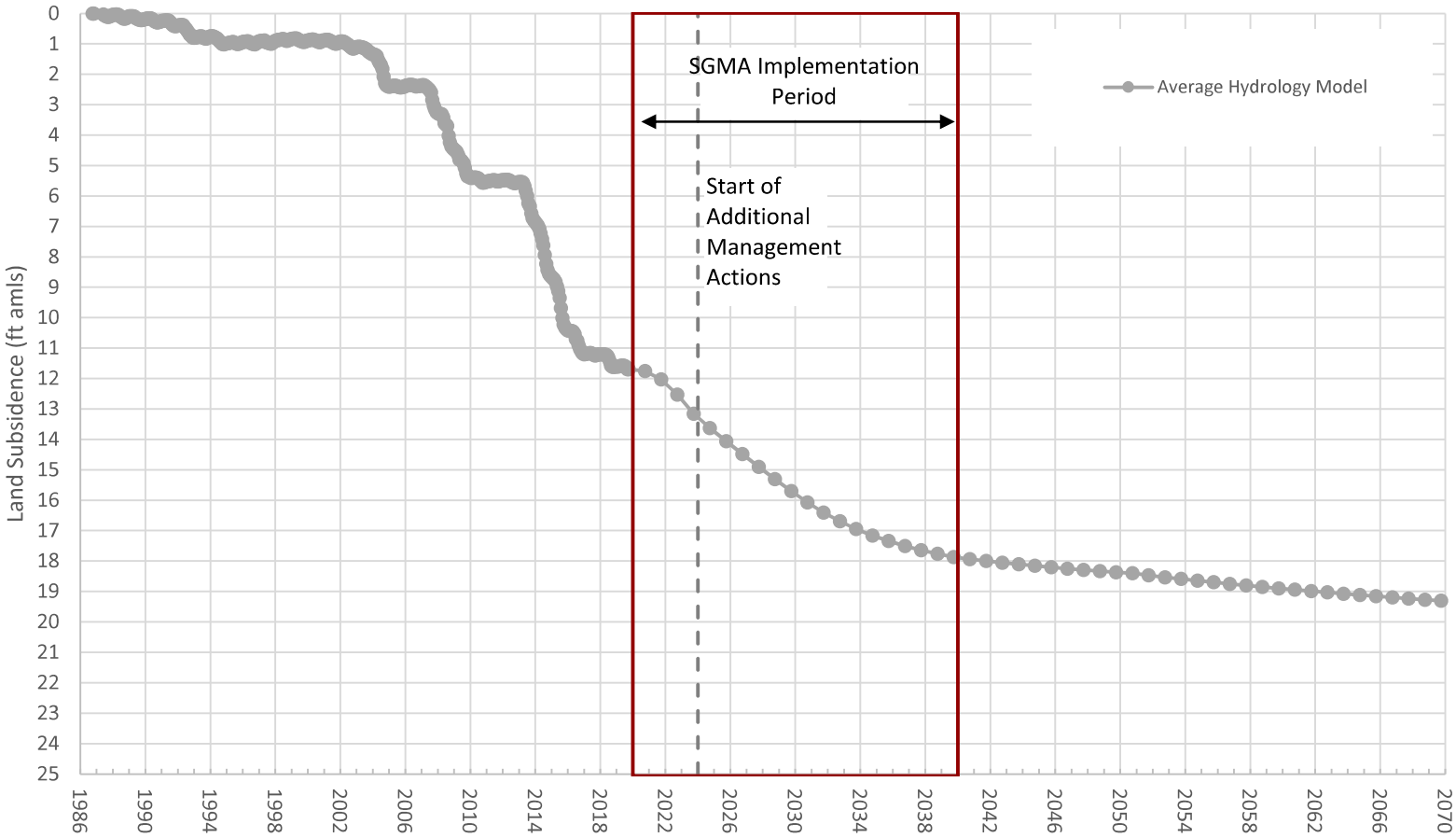
Model-Generated Land Subsidence 21S/25E-36, LTRID GSA



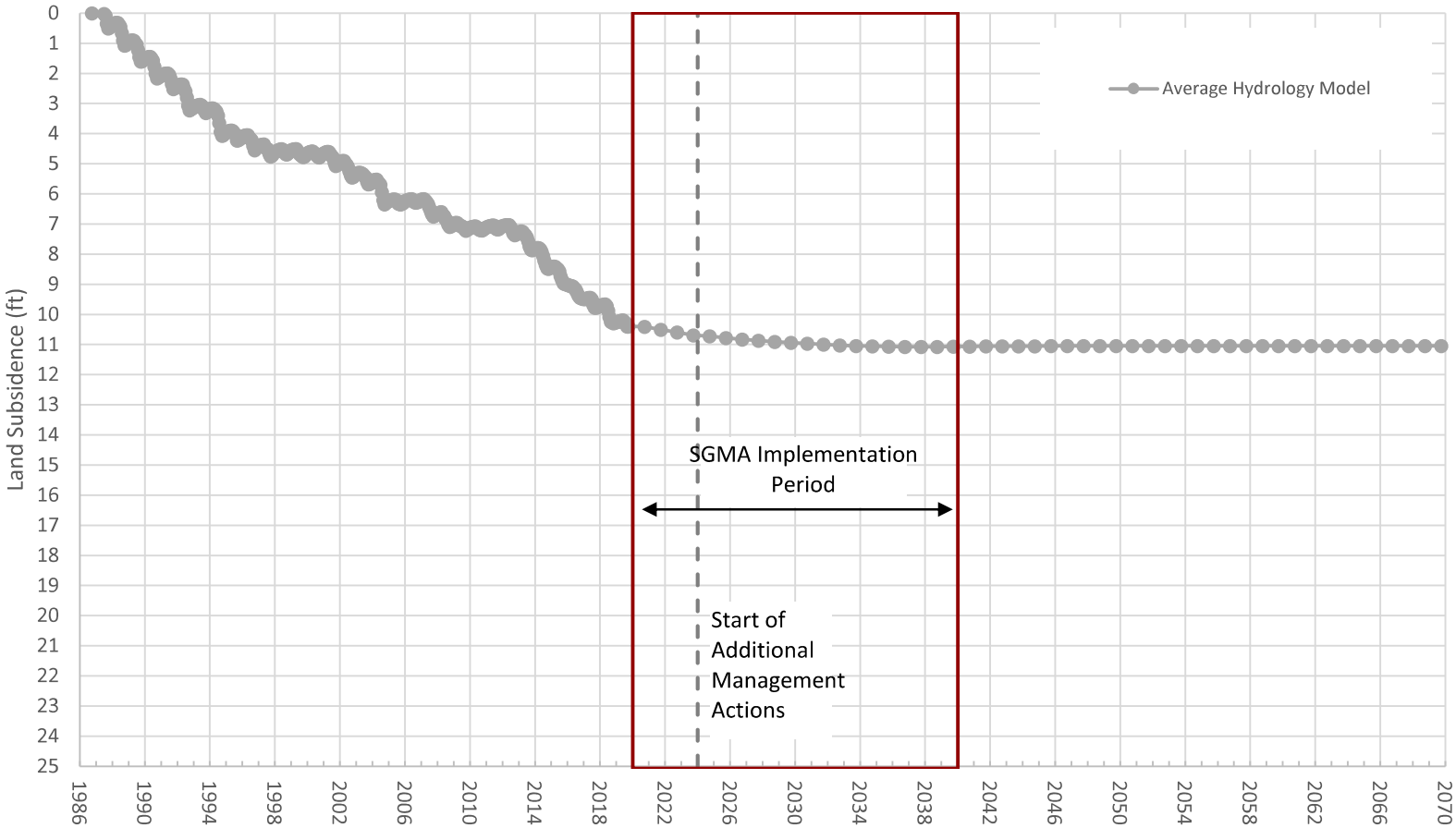
Model-Generated Land Subsidence 22S/24E-01Q01, LTRID GSA



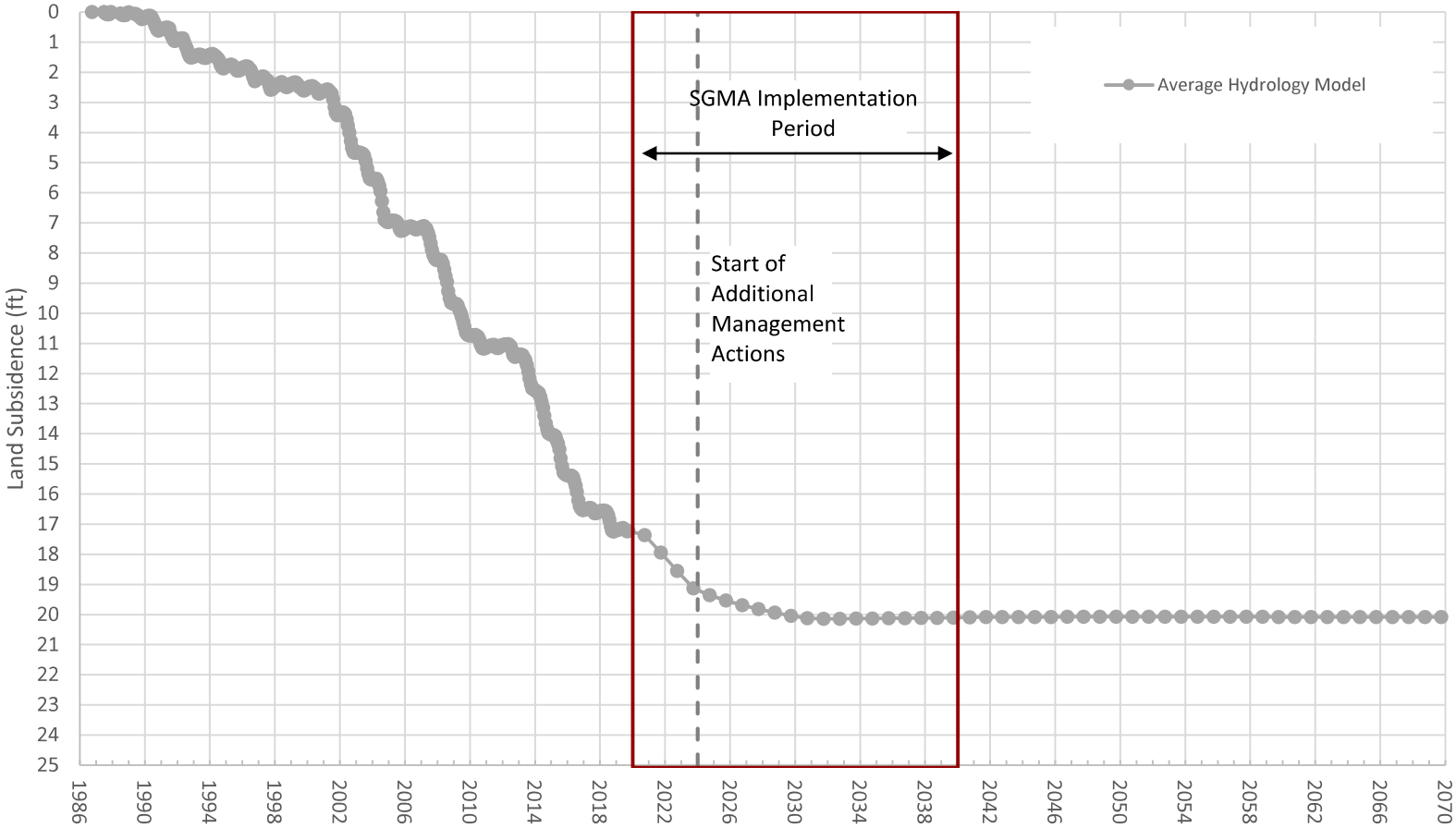
Model-Generated Land Subsidence
LTRID TSS L, LTRID GSA



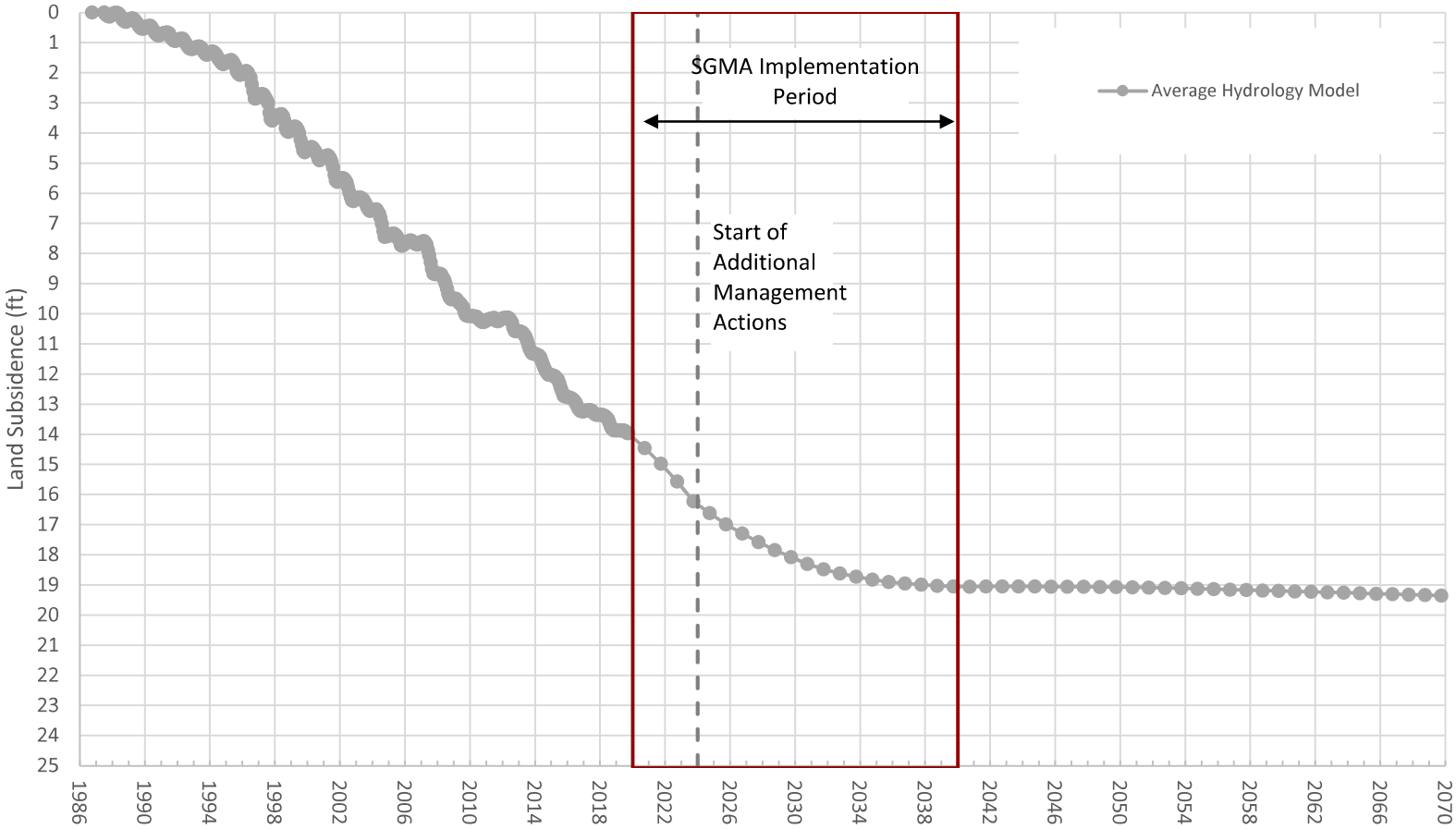
Model-Generated Land Subsidence PIDGSA-01L, Pixley ID GSA



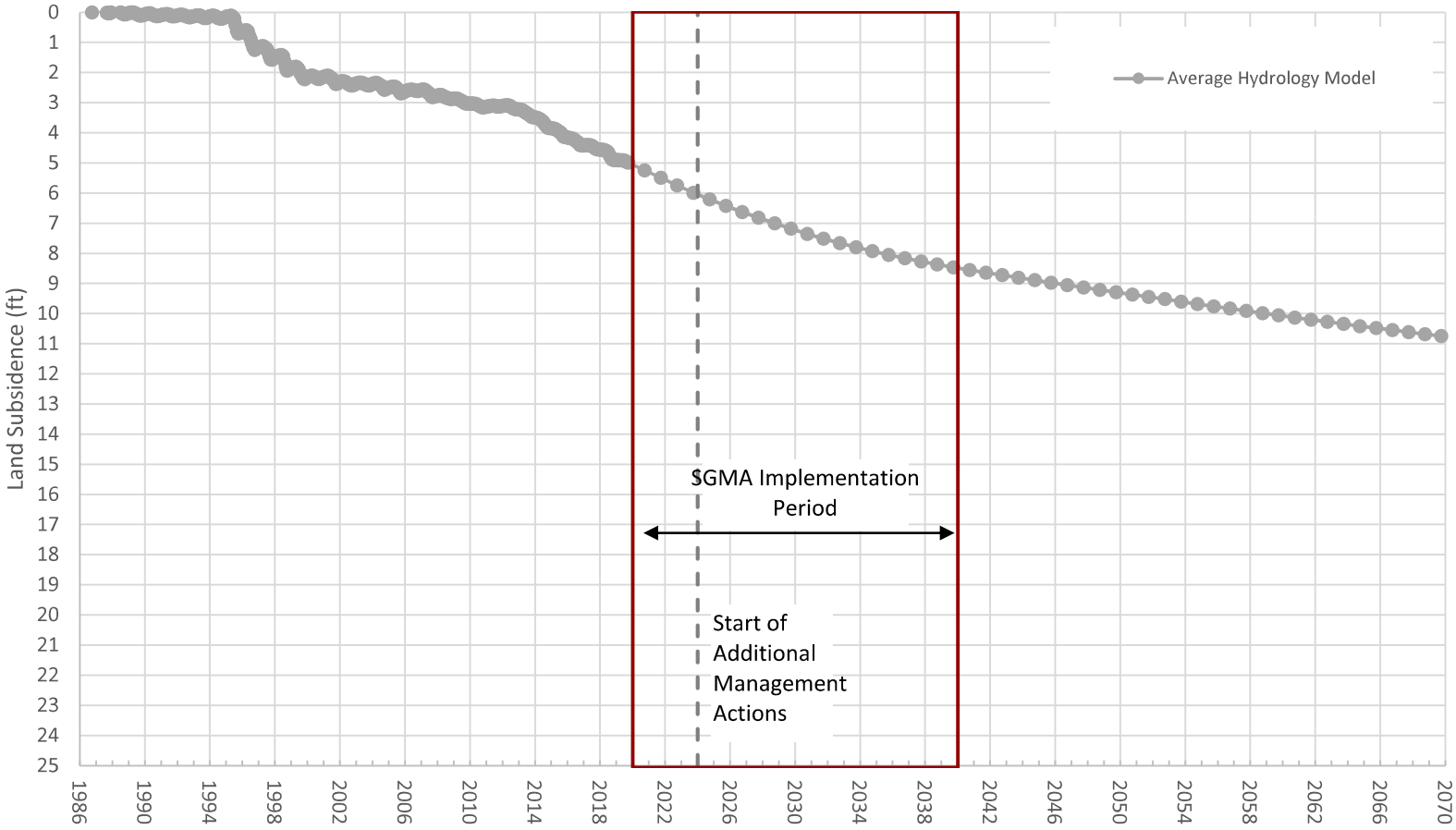
Model-Generated Land Subsidence
TSMW-1L, Pixley ID GSA



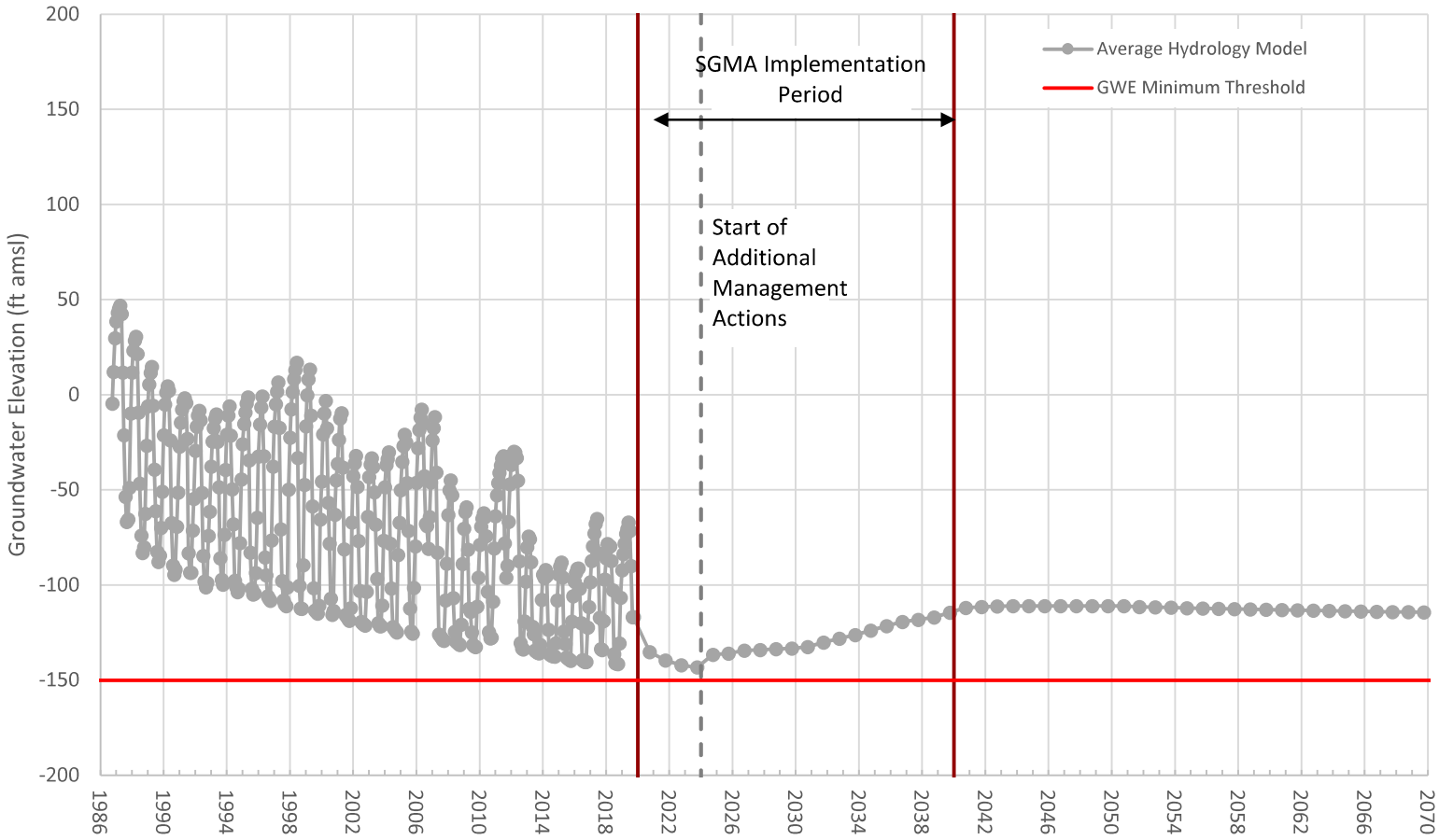
Model-Generated Land Subsidence 22S/23E-27F01_G, TCWA GSA



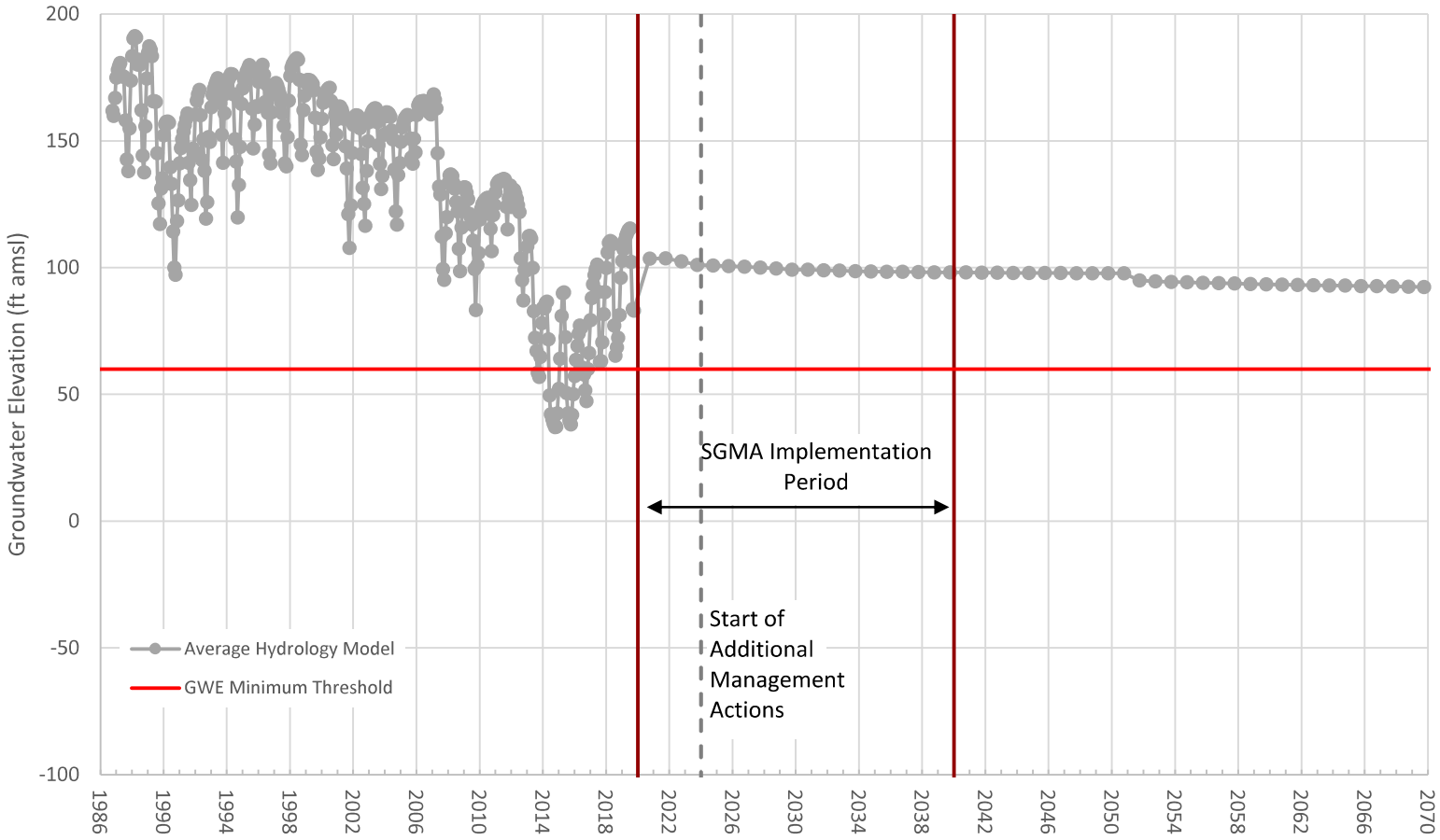
Model-Generated Land Subsidence TSMW-5L, TCWA GSA



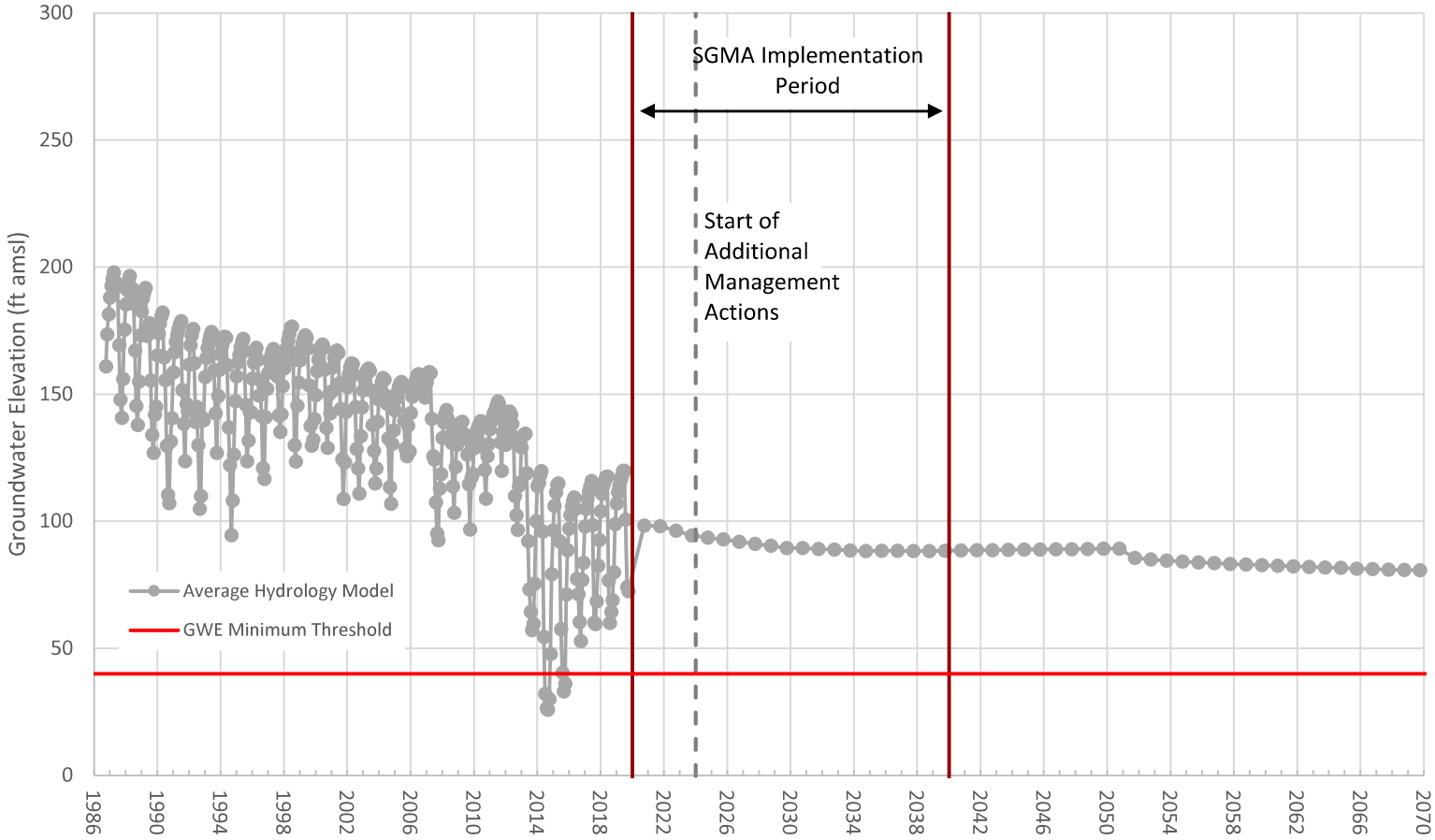
Model-Generated Lower Aquifer Groundwater Level 24S/23E-23 (Well 55), Alpaugh ID GSA



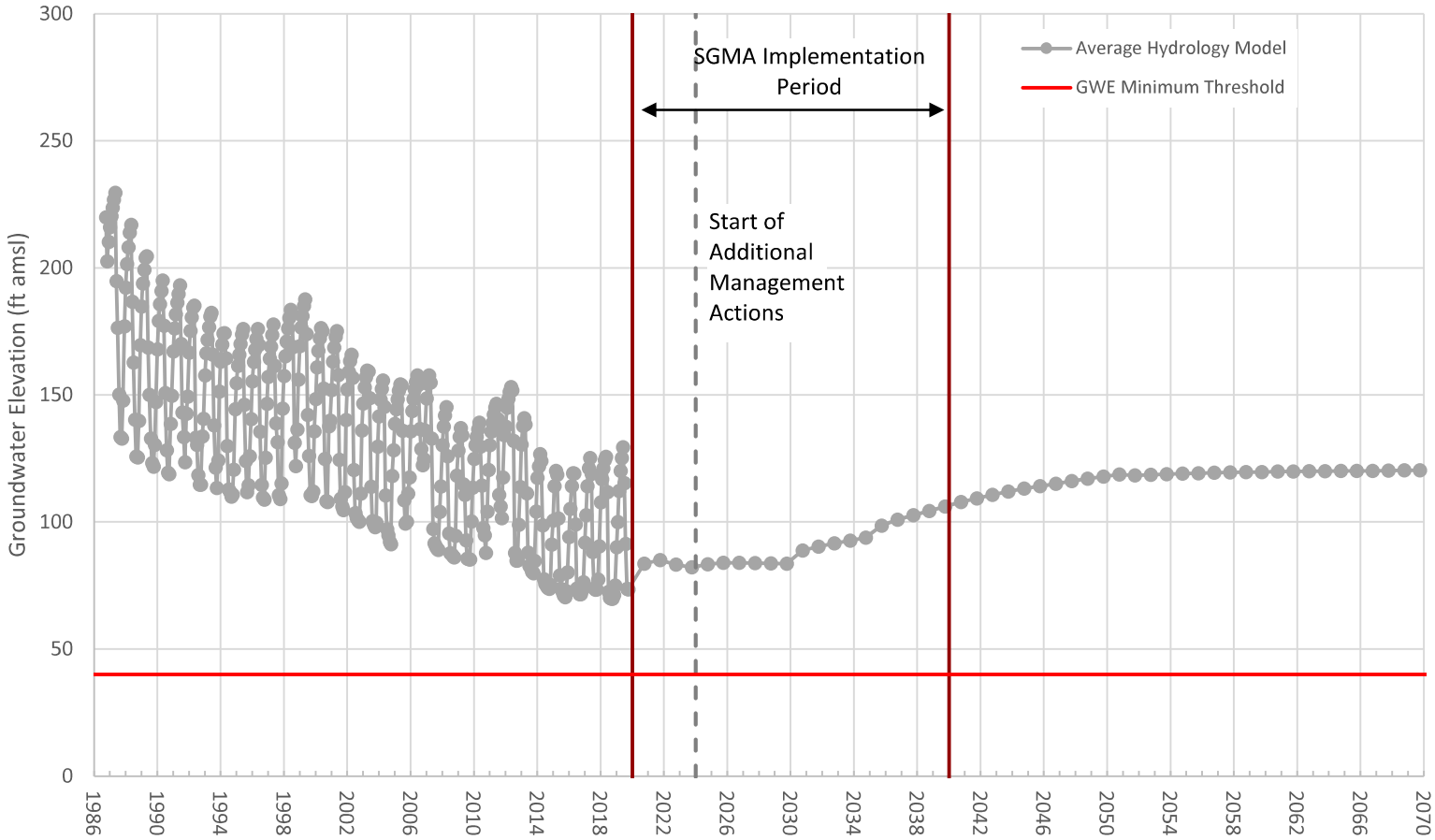
Model-Generated Lower Aquifer Groundwater Level 25S/26E-09C01, DEID GSA



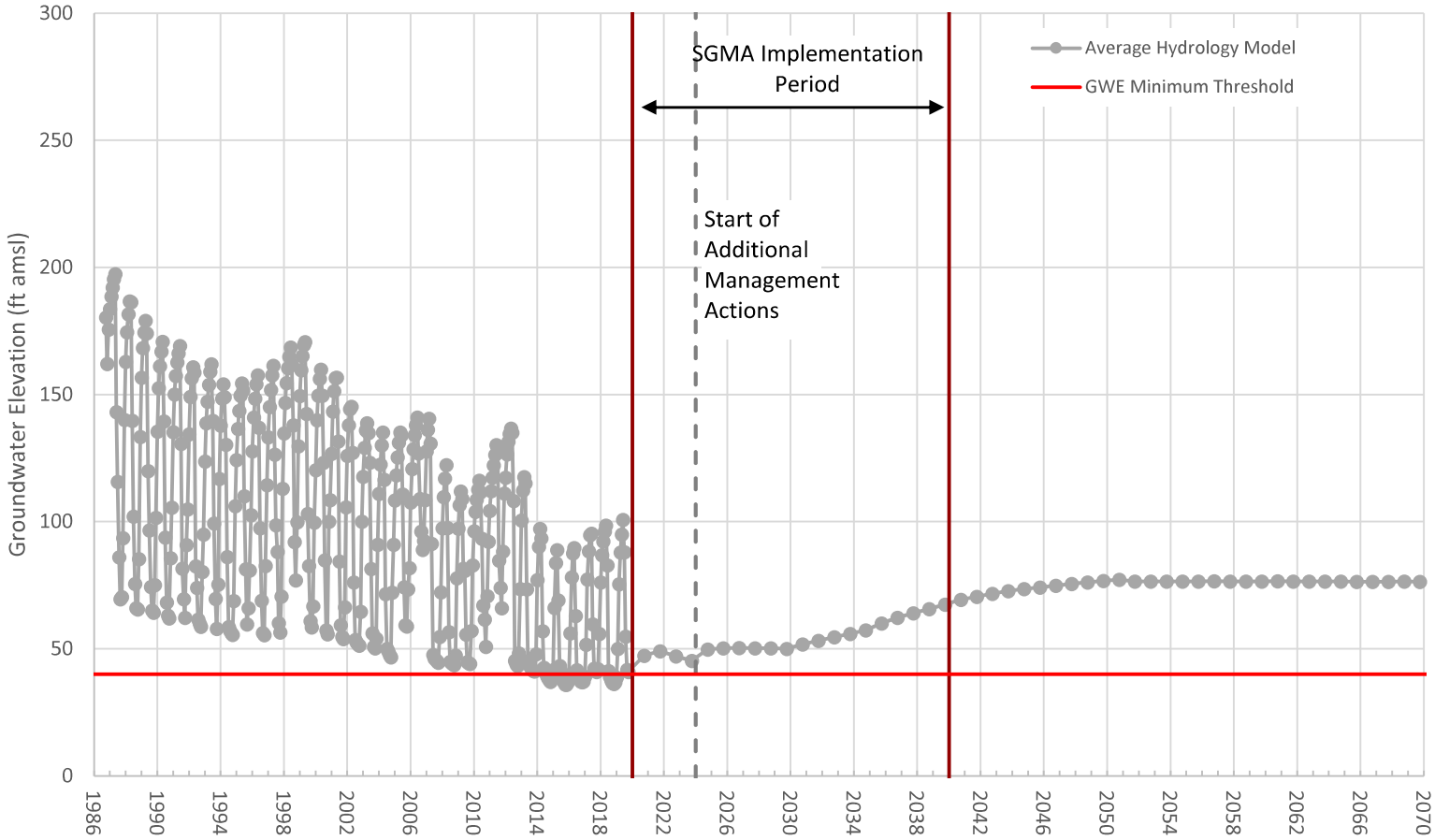
Model-Generated Lower Aquifer Groundwater Level M19-L, DEID GSA



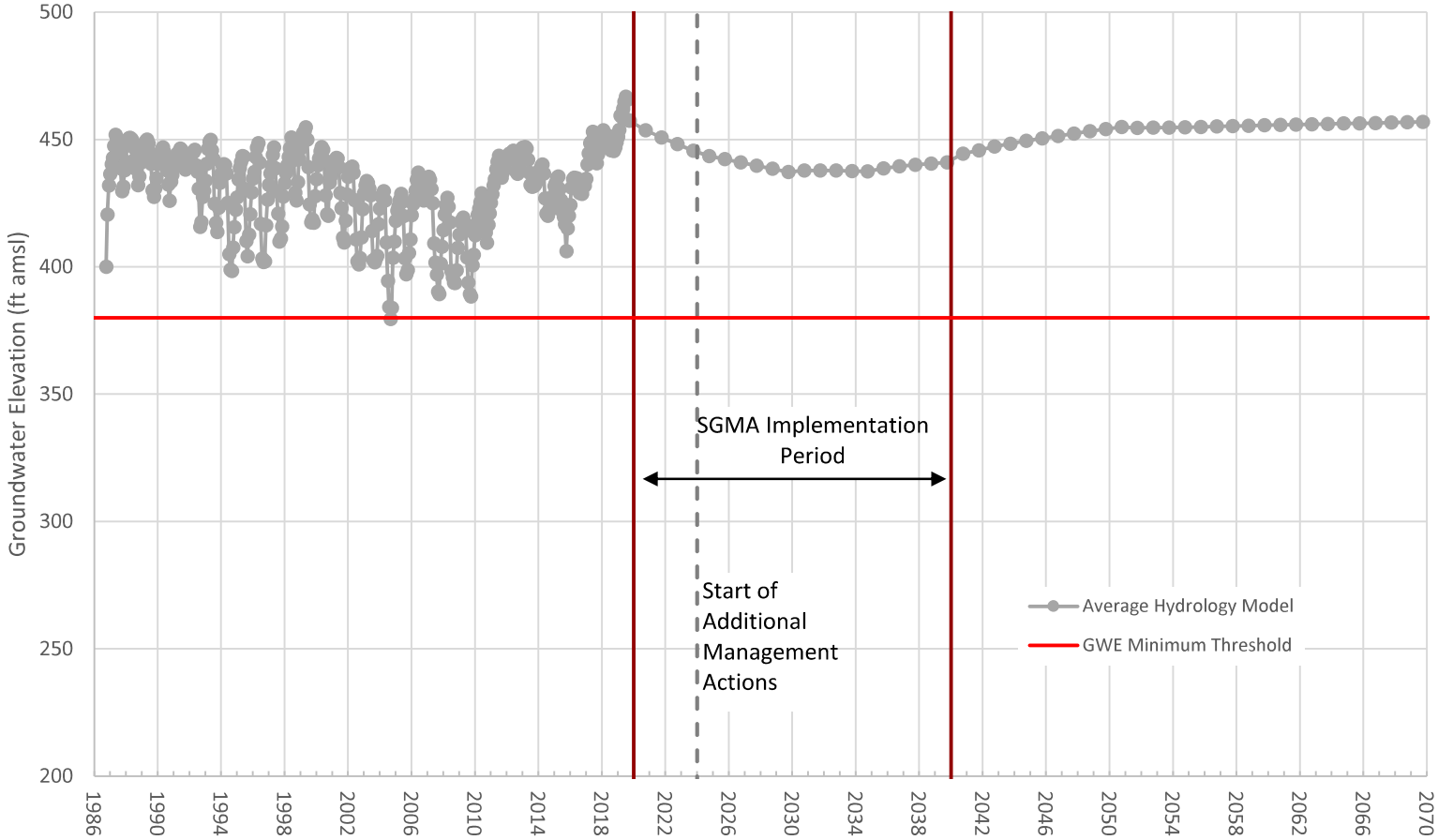
Model-Generated Lower Aquifer Groundwater Level 22S/26E-24, ETGSA



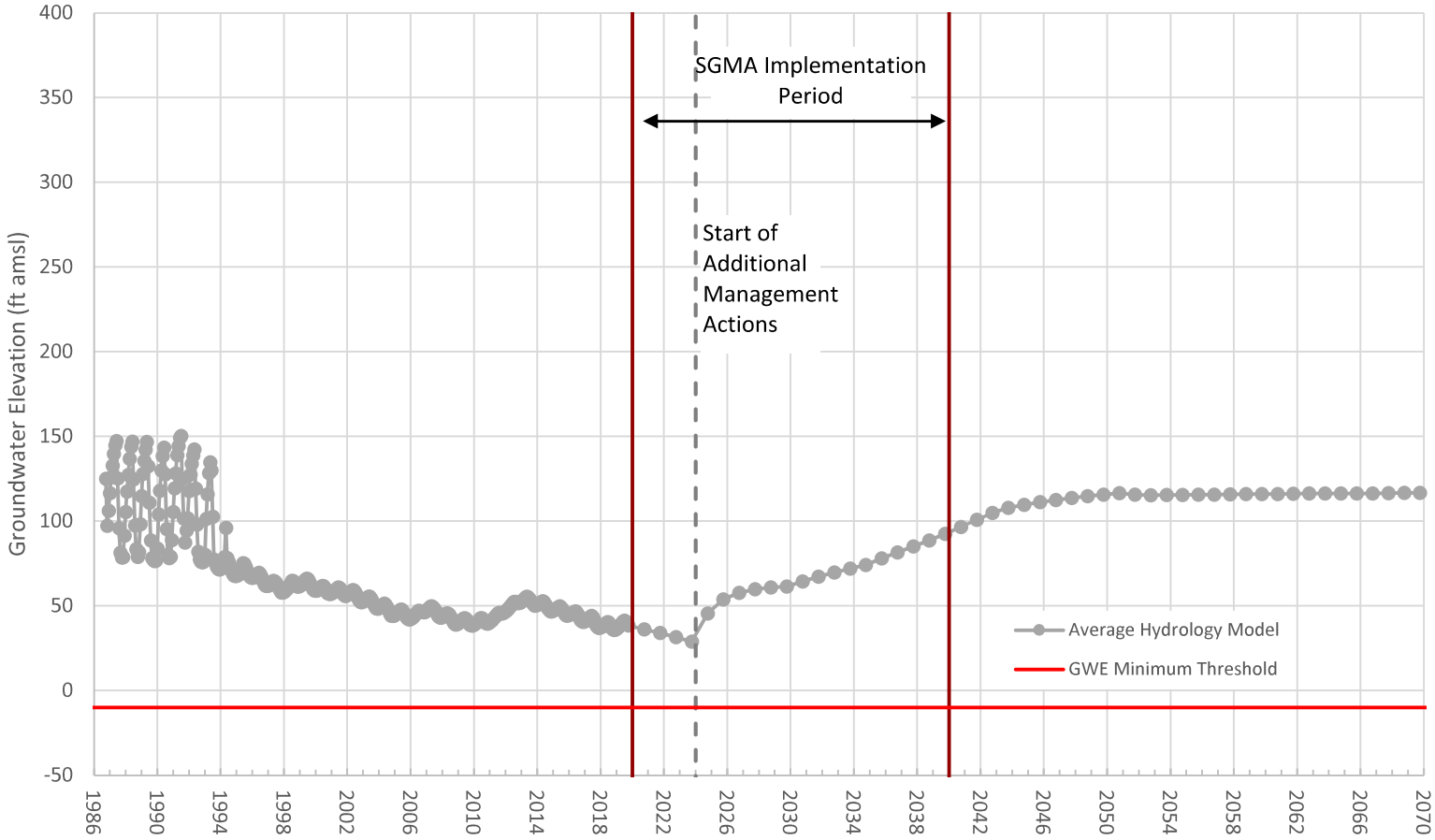
Model-Generated Lower Aquifer Groundwater Level TSMW-4D, ETGSA



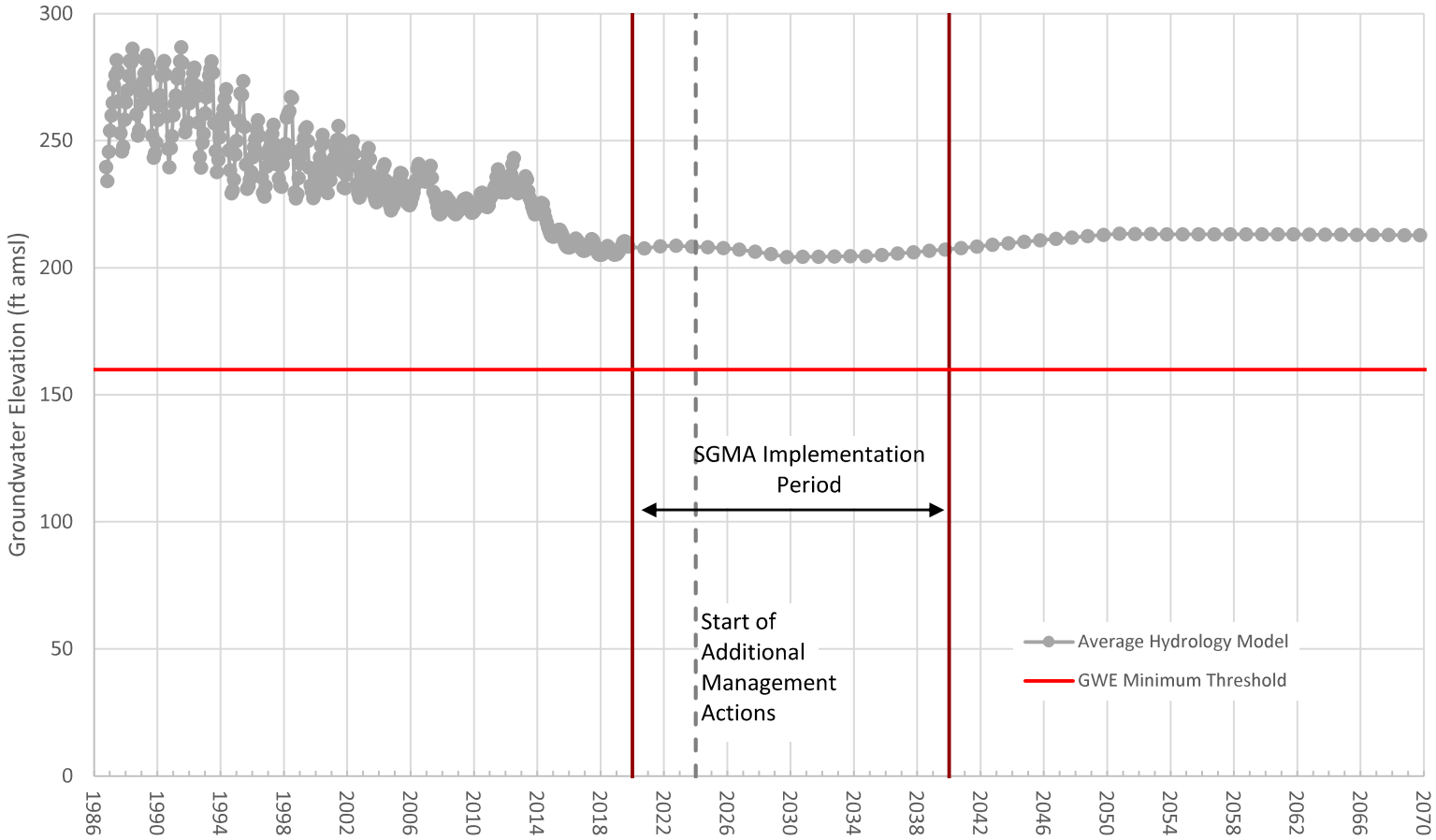
Model-Generated Lower Aquifer Groundwater Level ETGSA-01L, ETGSA



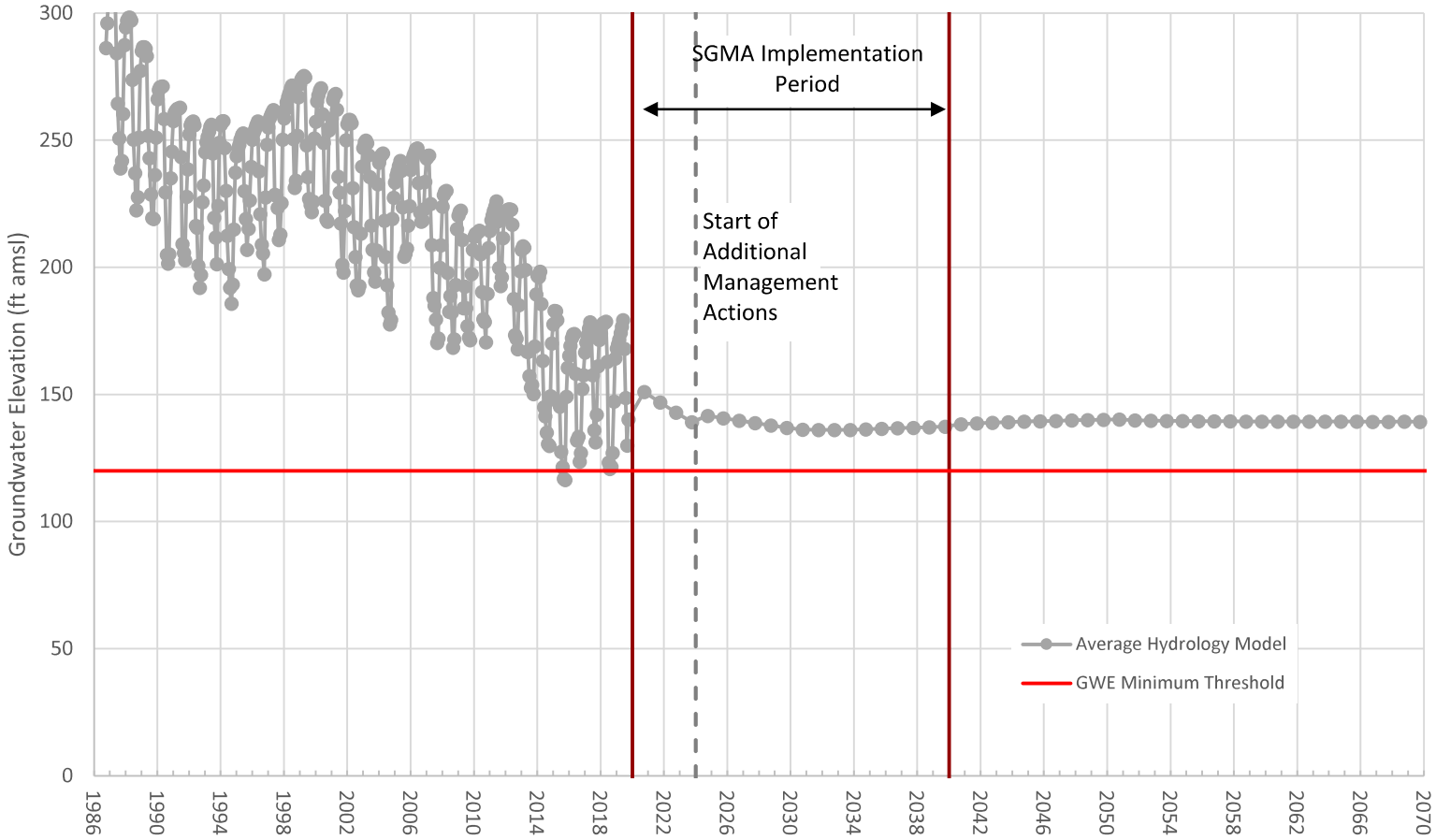
Model-Generated Lower Aquifer Groundwater Level 23S/27E27, ETGSA



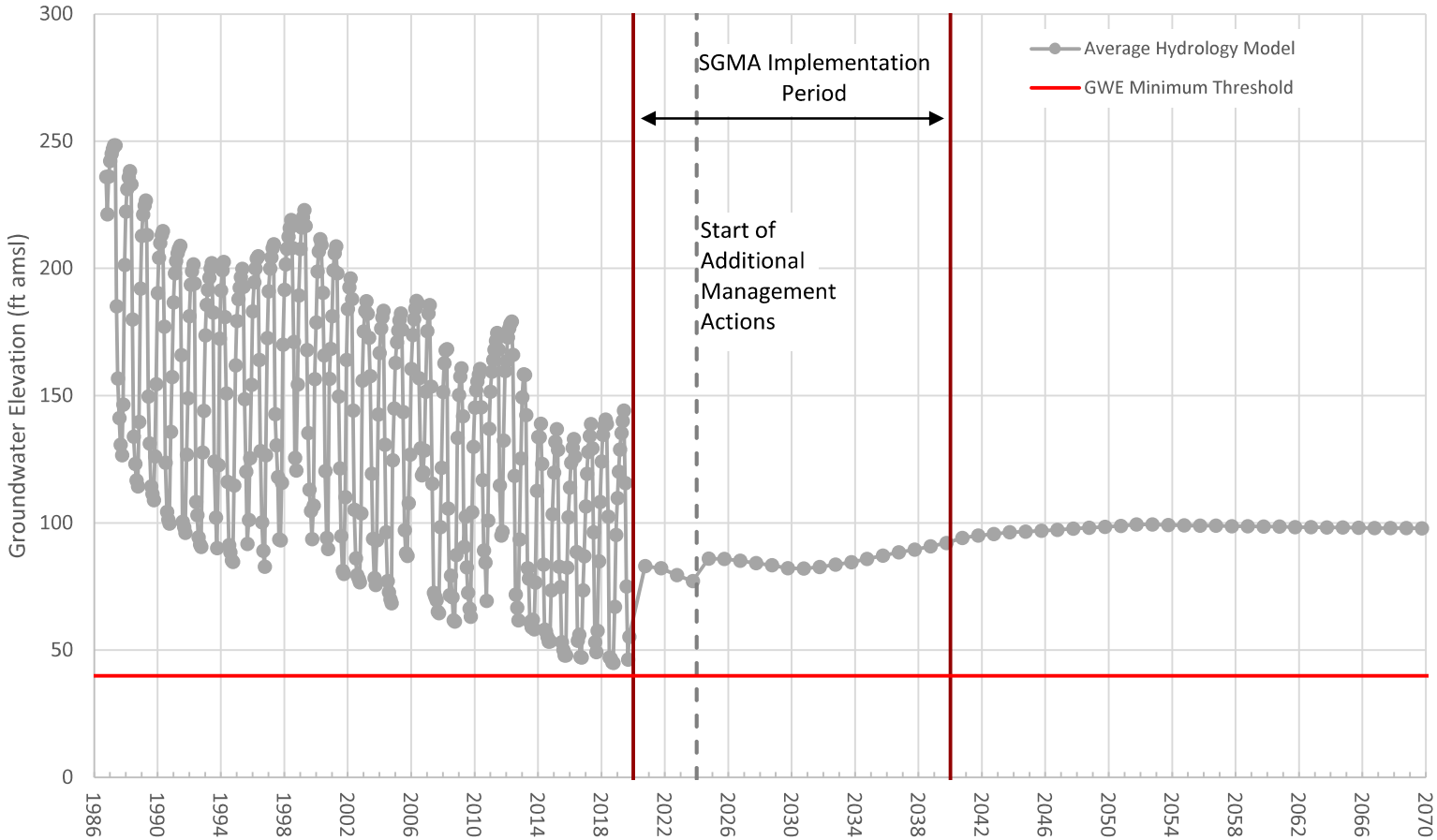
Model-Generated Lower Aquifer Groundwater Level TSMW-6L, KTWD GSA



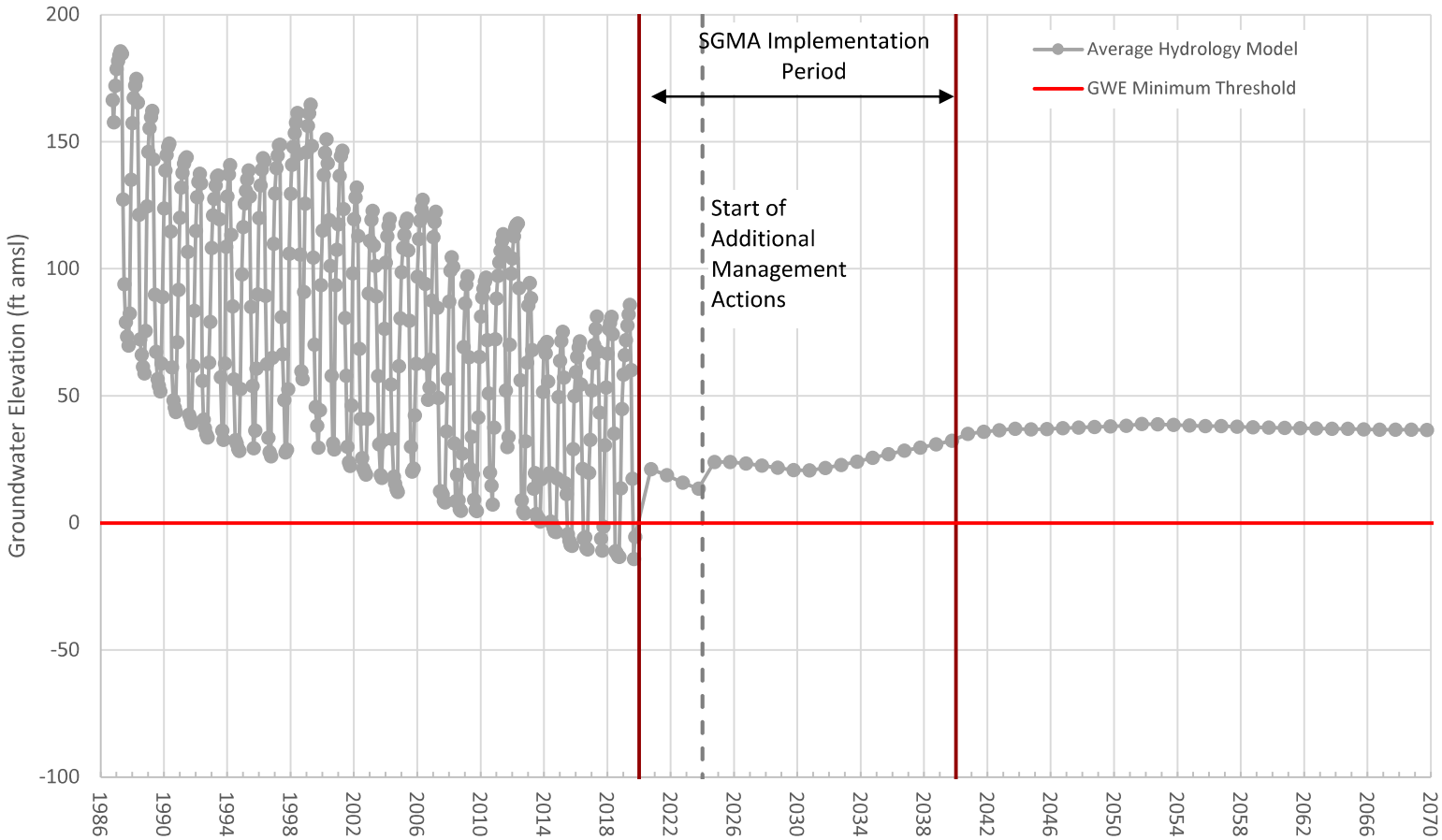
Model-Generated Lower Aquifer Groundwater Level 20S/26E-32, LTRID GSA



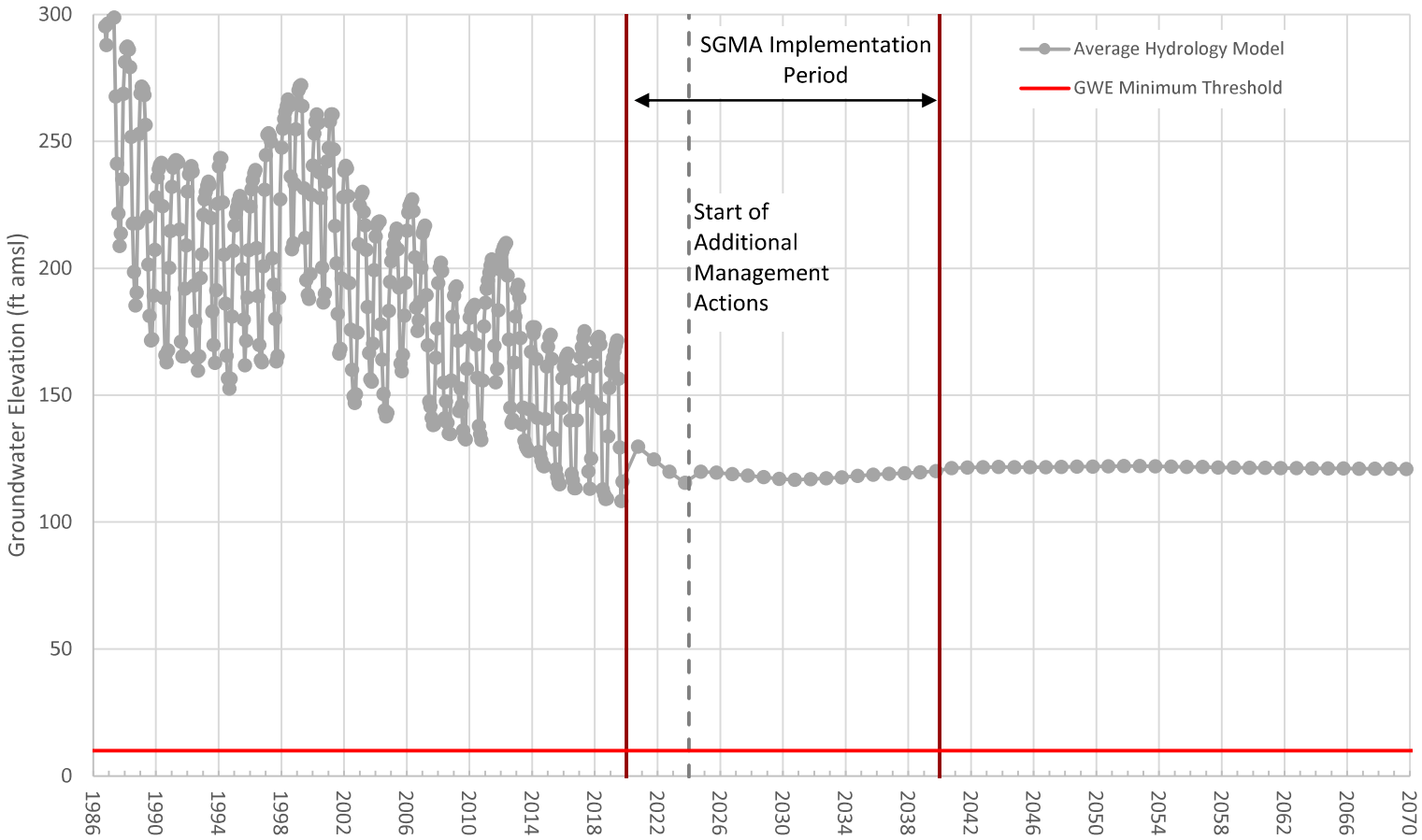
Model-Generated Lower Aquifer Groundwater Level 21S/25E-36, LTRID GSA



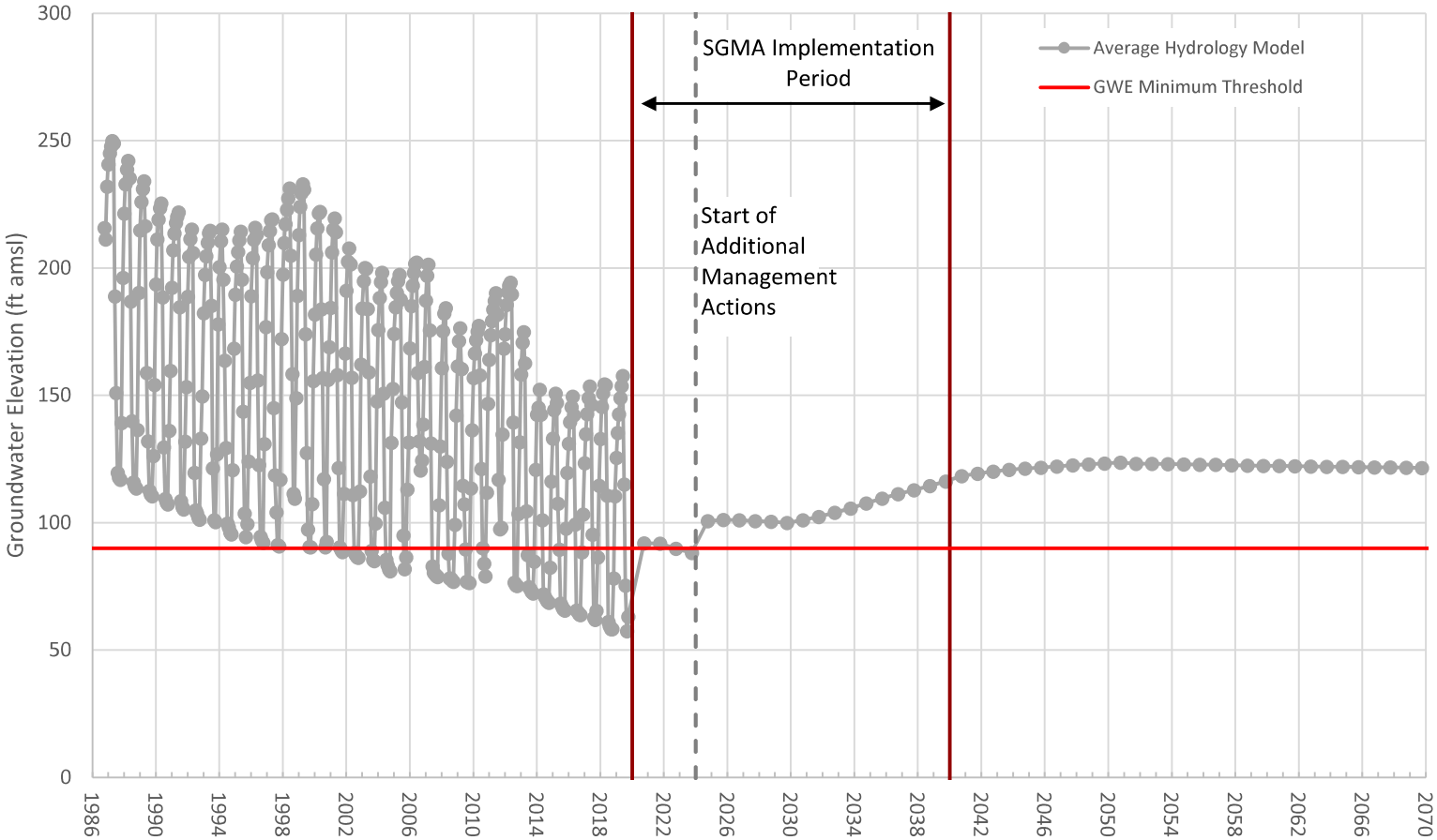
Model-Generated Lower Aquifer Groundwater Level 22S/24E-01Q01, LTRID GSA



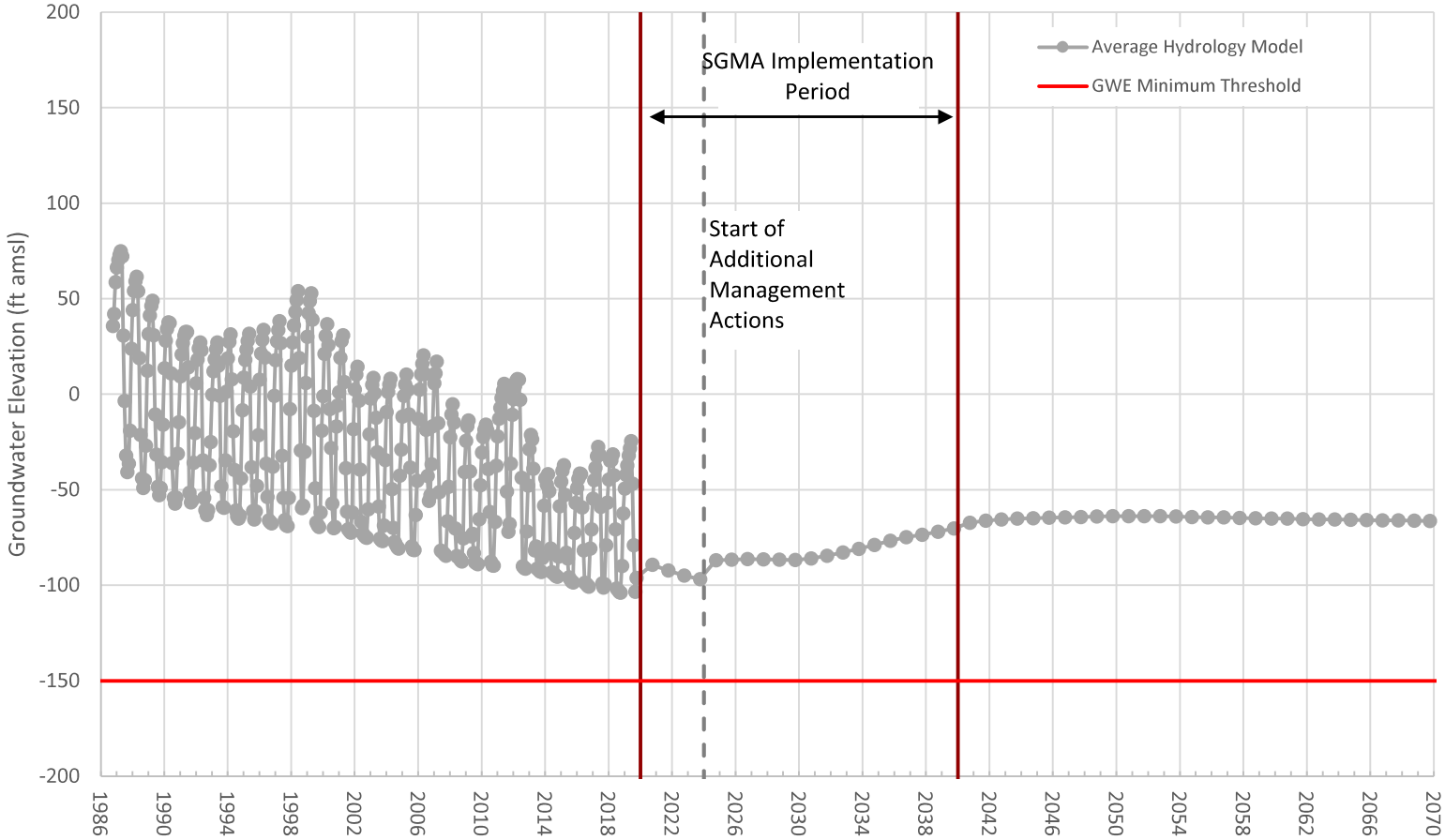
Model-Generated Lower Aquifer Groundwater Level
LTRID TSS L, LTRID GSA



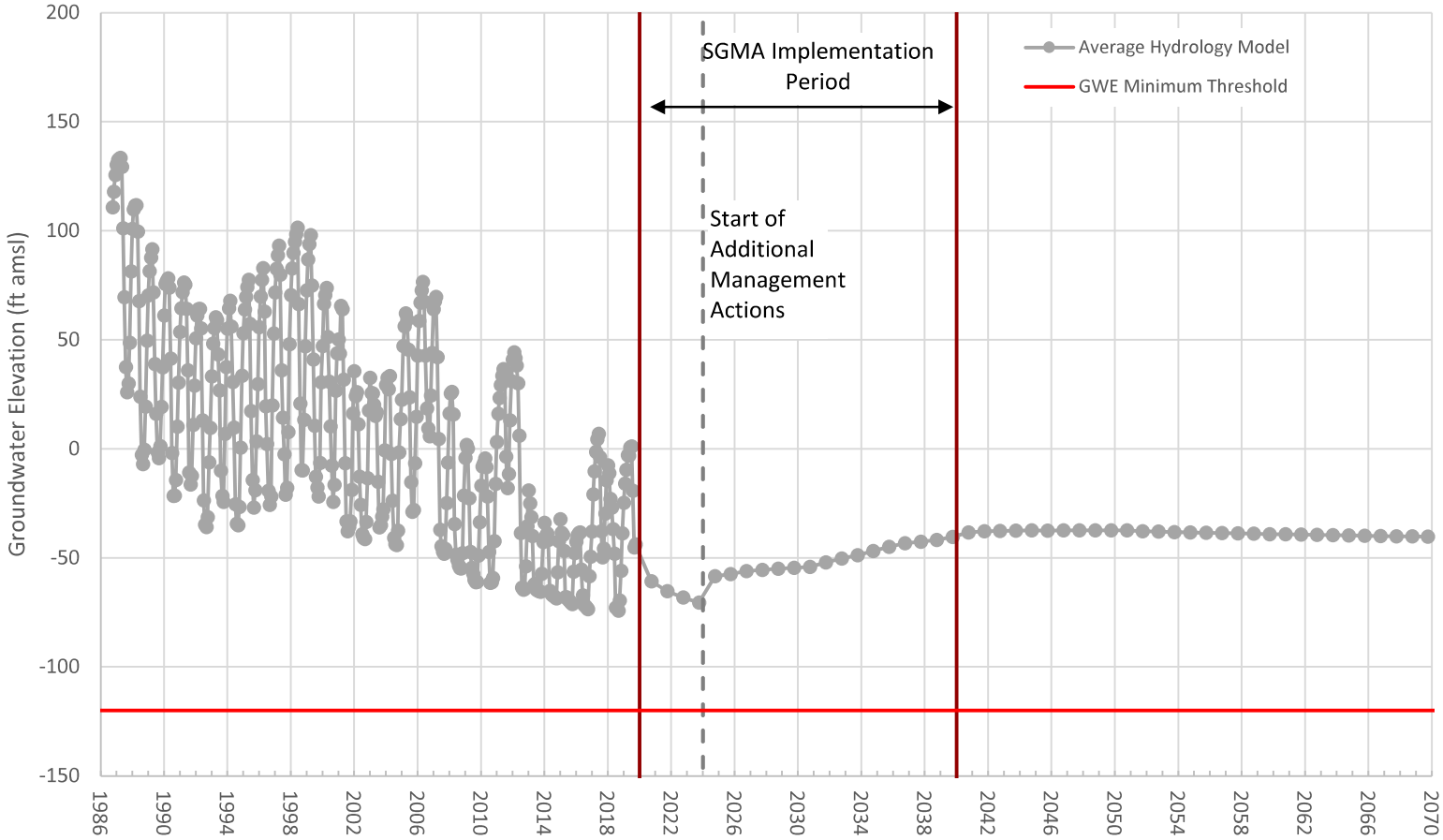
Model-Generated Lower Aquifer Groundwater Level
PIDGSA-01L, Pixley ID GSA



Model-Generated Lower Aquifer Groundwater Level TSMW 1L, Pixley ID GSA



Model-Generated Lower Aquifer Groundwater Level 22S/23E-27F01 (G-13), TCWA GSA



Model-Generated Lower Aquifer Groundwater Level TSMW-5L, TCWA GSA

