Appendix 5E

Technical Approach for Developing Subsidence Sustainable Management Criteria in the Kaweah Subbasin

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Technical Approach for Developing Subsidence Sustainable Management Criteria in the Kaweah Subbasin

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ACRONYMS & ABBREVIATIONS

1-D Model	1-Dimensional Compaction Numerical Model
DWR	California Department of Water Resources
EKGSA	East Kaweah Groundwater Sustainability Agency
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
InSAR	Interferometric Synthetic Aperture Radar
SGMA	Sustainable Groundwater Management Act
SMC	Sustainable Management Criteria
Subbasin	Kaweah Subbasin
TID	Tulare Irrigation District
USGS	United States Geological Survey

1 INTRODUCTION

This technical report describes the methodology for developing land subsidence sustainable management criteria (SMC) for the San Joaquin Valley - Kaweah Subbasin (Subbasin). The revisions are in response to the California Department of Water Resources' (DWR) incomplete determination of the 3 Groundwater Sustainability Plans (GSPs) submitted in January 2020 (DWR, 2022). The 3 GSPs are implemented by 3 Groundwater Sustainability Agencies (GSAs) covering the entirety of the Subbasin: East Kaweah GSA, Greater Kaweah GSA, and Mid-Kaweah GSA.

DWR provided a staff report with a statement of findings explaining the incomplete determination for the Subbasin GSPs. The staff report states, "the Plan does not define sustainable management criteria for subsidence in the manner required by Sustainable Groundwater Management Act (SGMA) and the GSP Regulations." DWR's findings specified the following:

- Because Mid-Kaweah and Greater Kaweah did not define subsidence criteria based on conditions that would substantially interfere with land surface uses and users in the Subbasin, Department staff have no basis for evaluating whether continued subsidence predicted by the Plans (potentially 15 feet in the next 20 years in the southwest portion of the Subbasin) would cause significant and unreasonable impacts to land surface uses.
- The East Kaweah GSP better comports with expectations based on the GSP Regulations to develop sustainable management criteria for subsidence. The East Kaweah GSP states that an undesirable result would occur if there were "significant loss of functionality of a structure or a facility to the point that, due to subsidence, the feature cannot be operated as designed requiring either retrofitting or replacement." The East Kaweah GSP identified the Friant-Kern Canal as critical infrastructure for users in the GSA area and determined that a loss of more than 10% of its capacity would be unacceptable. The East Kaweah GSP identified that subsidence over 9.5 inches cumulatively would result in the 10% loss in capacity and, therefore, used 9.5 inches of cumulative subsidence as the minimum threshold.
- The differences between Greater Kaweah and East Kaweah GSPs creates the potential for inconsistency in groundwater management between the Subbasins GSPs. A portion of the Greater Kaweah GSP area bisects the East Kaweah GSP area in the vicinity of the Friant Kern Canal. Greater Kaweah's subsidence minimum thresholds in this area allow for 1.0 to 1.2 inches per year of subsidence, or 20 to 24 inches cumulatively over the 20-year implementation period. Neither the East Kaweah nor the Greater Kaweah GSPs nor the Subbasin Coordination Agreement explain how up to 24 inches of subsidence in the

Greater Kaweah area can be accommodated without interfering with the 9.5-inch limit set by East Kaweah to protect the conveyance capacity of the Friant-Kern Canal. The GSPs will need to reconcile this apparent discrepancy.

DWR's recommended corrective actions include the following:

- Mid-Kaweah and Greater Kaweah must define sustainable management criteria for land subsidence in the manner required by SGMA and the GSP Regulations. The GSAs should develop criteria, including minimum thresholds, measurable objectives, interim milestones, and undesirable results based on the amount of subsidence that would substantially interfere with land surface uses. Developed criteria should be supported with information on the effects of subsidence on land surface beneficial uses and users and the amount of subsidence that would substantially interfere with those uses and users.
- Greater Kaweah also must explain how their minimum thresholds in the vicinity of identified critical infrastructure (i.e., the Friant Kern Canal) will not substantially interfere with the Canal's use (identified by East Kaweah GSA as an undesirable result). Address how the amount of potential cumulative subsidence allowed for by Greater Kaweah's subsidence rates, which currently exceeds the amount identified by East Kaweah that would cause an undesirable result, are compatible or provide revised rates for the eastern portion of the Subbasin that are compatible.

The GSAs were given up to 180 days from the receipt of DWR's staff report to address the deficiencies for land subsidence SMC. This document and the GSP revisions fulfill that purpose.

1.1 General Approach Used to Develop Sustainable Management Criteria

The general approach described herein focuses on estimating future total subsidence over various time horizons and addressing potential damage to water conveyance infrastructure and deep wells. No reliable direct correlation between total subsidence and well collapse has been found. Significant and unreasonable impacts to deep wells are based on commonly used well designs that accommodate subsidence. In the future, should more detailed and local information become available on damage to wells caused by subsidence, this information would be used to re-evaluate the impact of subsidence on well infrastructure.

1.2 Data Sources

In response to DWR comments, the GSAs reviewed the data sources and methods used to select subsidence SMCs. Information and tools used for establishing revised subsidence SMC include:

- Groundwater level monitoring in the Subbasin 1999-2021
- Historical Interferometric Synthetic Aperture Radar (InSAR) measured subsidence data
- Local subsidence benchmark monitoring data
- Possible future groundwater elevations based on revised minimum thresholds
- A 1-Dimensional Compaction Numerical Model (1-D Model) developed by Stanford University researchers
- A subsidence spreadsheet prediction tool developed for the GSAs to simplify and extrapolate subsidence predictions from 1-D Model to the rest of the Subbasin
- Water conveyance infrastructure locations

2 METHODOLOGY USED TO ESTIMATE FUTURE SUBSIDENCE

The methodology presented in this section estimates the total future subsidence that is the basis for setting minimum thresholds. Total subsidence is the annual sum of active subsidence caused by the most recent year's lowering of groundwater levels and any residual subsidence from previous years. The method uses historical groundwater elevations, historical subsidence measurements, the 1-D subsidence model, a subsidence spreadsheet prediction tool, and revised chronic lowering of groundwater levels minimum thresholds to establish estimated rates of total future maximum (worst-case) subsidence.

The 1-D model was built and calibrated using the following data and approach:

- An initial model was developed using Fall groundwater levels to simulate historical subsidence between 1999 and 2021.
- The model was calibrated against 2015 to 2021 subsidence data collected using InSAR available from DWR.
- The model was extended from 2021 through 2070 using minimum thresholds as the ultimate groundwater elevations.
    - Chronic lowering of groundwater levels minimum thresholds described in Appendix 5A are used to estimate a groundwater elevation trend between 2021 and 2040.
    - The minimum threshold "worst-case" groundwater elevations are held stable in the model between 2040 and 2070.

The 1-D model results are used to develop a simplified subsidence spreadsheet prediction tool to extrapolate the 1-D model predictions to other areas in the Subbasin. The subsidence predictions from the spreadsheet tool are used to evaluate the impact that subsidence might have on conveyance infrastructure if groundwater levels stabilize in 2040 at the chronic lowering of groundwater levels minimum thresholds.

2.1 1-Dimensional Compaction Numerical Model

A 1-D Model developed by Stanford University researchers (Lees *et al.*, 2022) estimates subsidence in two locations in and adjacent to the Subbasin. Stanford University researchers calibrated historical subsidence at the South Hanford and Tulare Irrigation District (TID) Sites, shown on Figure 1 (Lees *et al.*, 2022). Only the results from the South Hanford Site are published by Lees (2022). Stanford researchers used the calibrated 1-D Model to estimate the amount of future subsidence through 2070 at the two sites if groundwater elevation declines to the minimum thresholds.

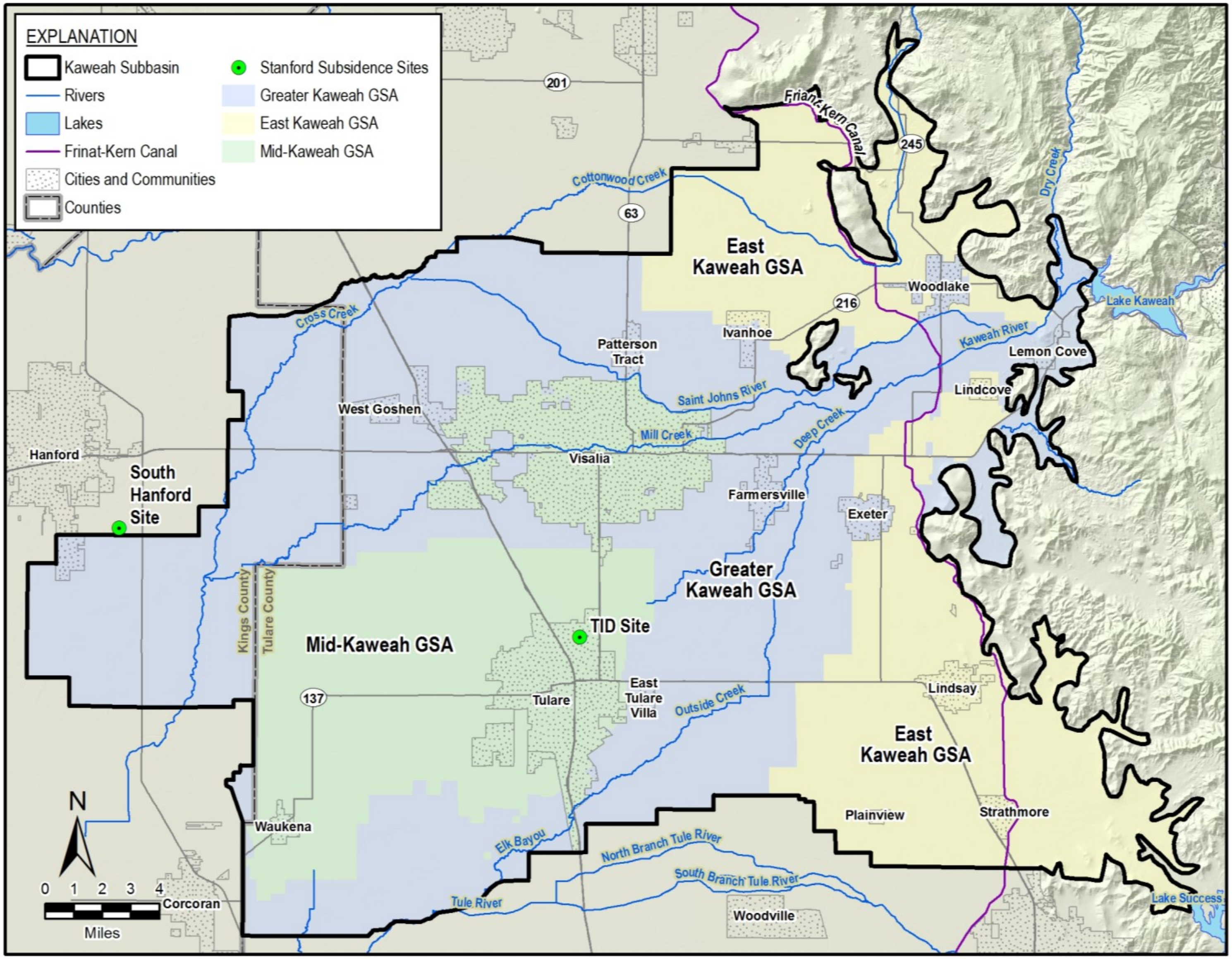

Figure 1. Subsidence Prediction Locations, derived from Lees *et al.*, 2022

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2.1.1 Data Sources and Equations

The 1-D Model is built using governing equations for clay compaction with reduction in groundwater head. The equations were originally described in the late 1970s in a United States Geological Survey report (Helm, 1975). The Lees *et al.* (2022) model uses the number and thickness of various clay layers from geophysical logs, historical groundwater elevation data, and historical subsidence estimates from 1952 to 2017 to build and calibrate a model to match subsidence observations. Multiple physical parameters are adjusted to assess sensitivity and uncertainty and develop a range of potential solutions. The calibration results in reasonable values for vertical hydraulic conductivity, specific storage, initial stress, aquifer depth, and the residual timescale for subsidence (Lees *et al.*, 2022).

2.1.2 1-D Model Results

The 1-D model results show significant residual subsidence related to overdraft in the Subbasin is expected to occur for many decades following stabilization of groundwater elevations (Lees *et al.*, 2022). Most compaction, about 90 to 94% at the South Hanford site, occurs in the lower aquifer below the Corcoran Clay.

The model's subsidence predictions for the worst case of groundwater elevations declining and stabilizing at the minimum thresholds are shown on Figure 2 for the South Hanford site and Figure 3 for the TID site. The blue lines on these figures show historical and predicted shallow aquifer groundwater elevations. The red lines on these figures show historical and predicted deep aquifer groundwater elevations. These lines demonstrate how groundwater elevations equilibrate at minimum thresholds beginning in 2040. The yellow line on these figures is the model-estimated subsidence, and the green dots are the measured subsidence from InSAR data.

Predicted subsidence at the South Hanford site is about 27 feet from 2020 to 2040 and about 18 feet from 2040 to 2070, for a total future subsidence of 45 feet. Predicted subsidence at the TID site is about 13 feet from 2020 to 2040 and about 8 feet from 2040 to 2070, for a total future subsidence of 21 feet. Models for both sites show residual subsidence continuing for decades after groundwater elevations stabilize in 2040. Figure 2 and Figure 3 do not show expected subsidence, but rather the maximum subsidence under worst-case conditions.

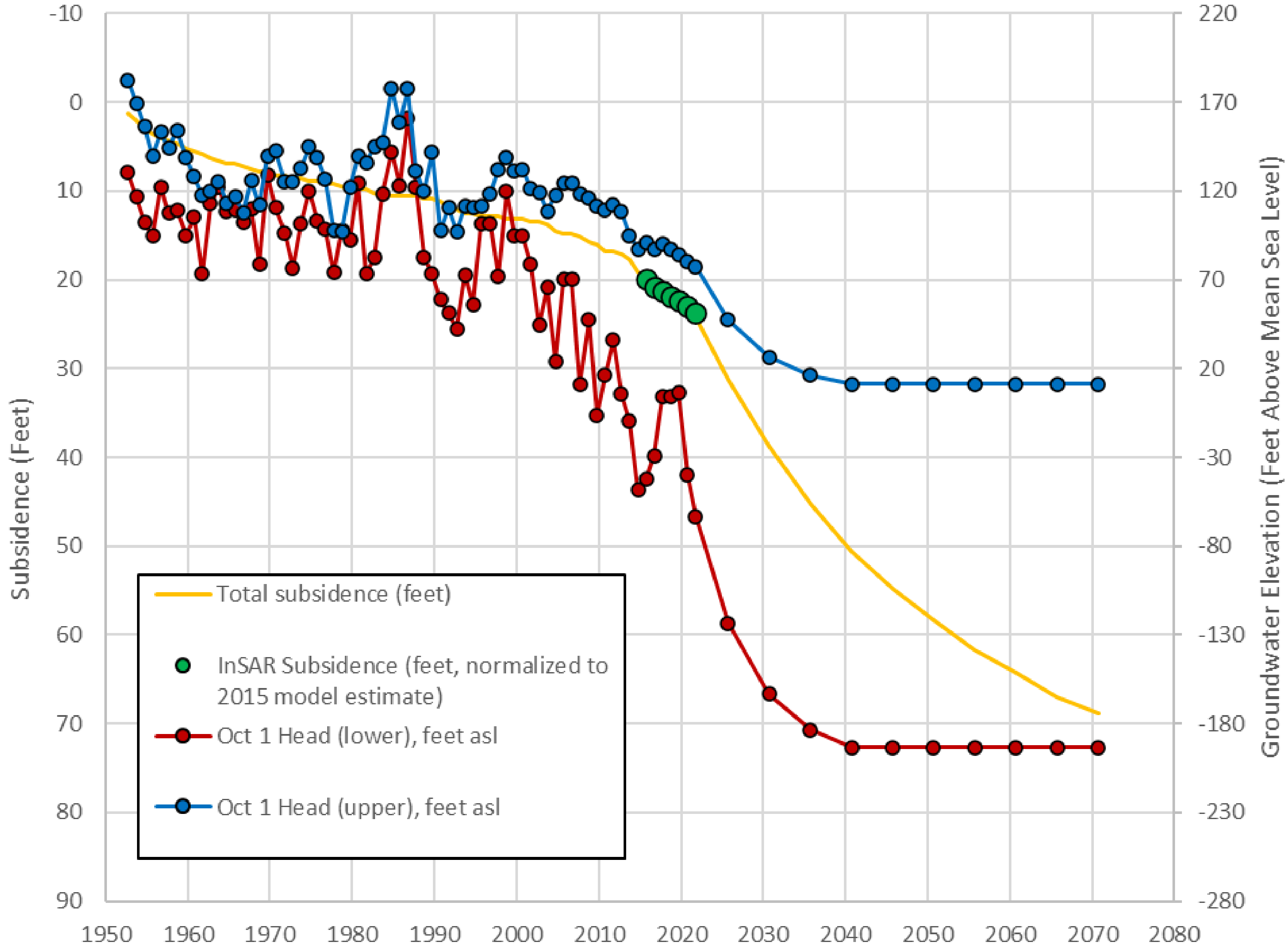


Figure 2. South Hanford Site Subsidence and Groundwater Elevation Time-Series, derived from Lees *et al.*, 2022

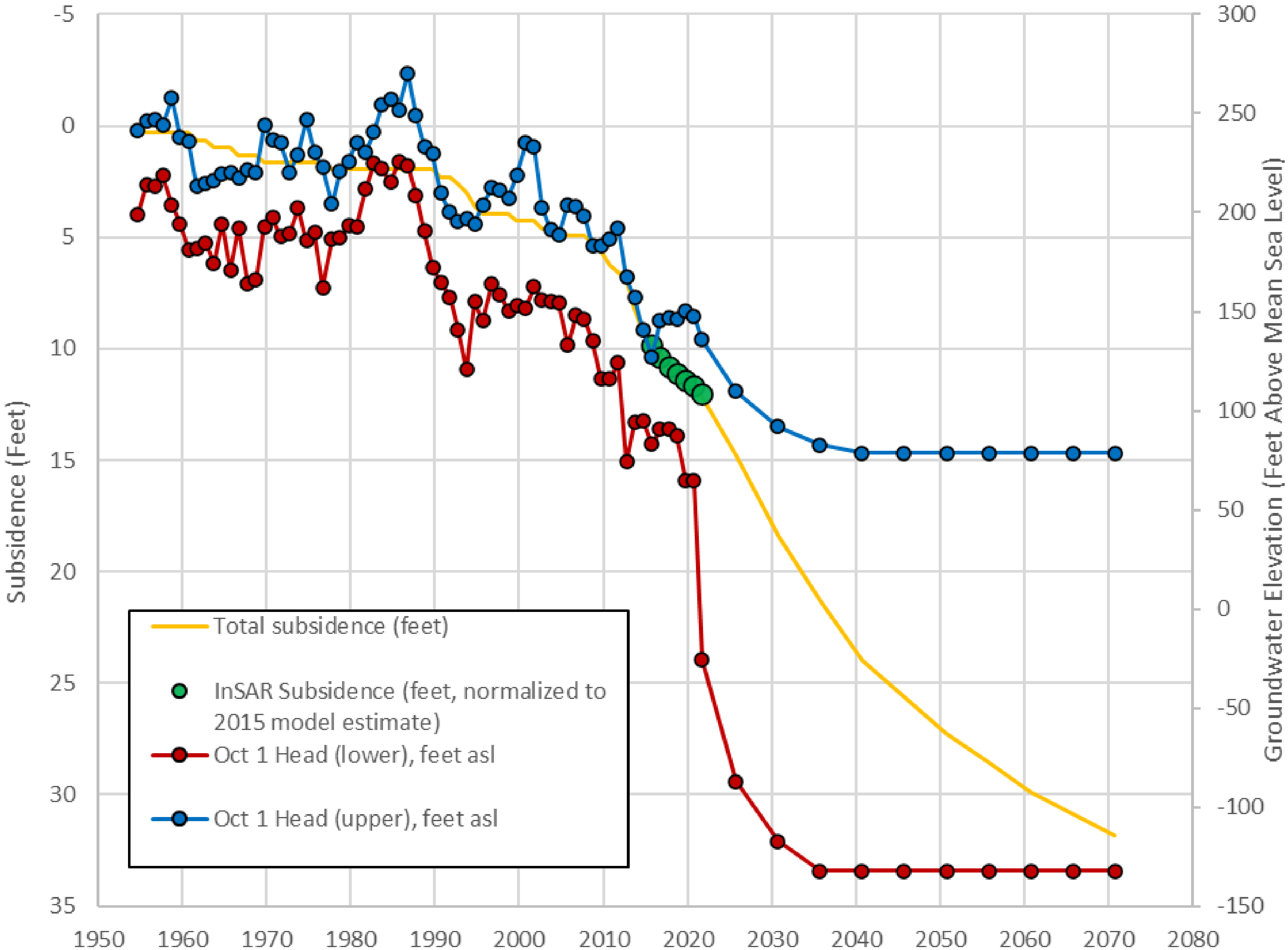


Figure 3. TID Site Subsidence and Groundwater Elevation Time-Series, derived from Lees *et al.*, 2022

2.1.3 Subsidence Spreadsheet Prediction Tool

Results from the 1-D Model are used to develop a simple spreadsheet tool to predict subsidence spatially throughout the Subbasin. A grid of 77 points plotted at 2-mile intervals is used to extrapolate the 1-D Model subsidence predictions (Figure 4). This grid is chosen to align with the United States Geological Survey's (USGS) textural model of the San Joaquin Valley (Faunt, 2009). The spreadsheet tool is used to predict subsidence at each point from 2020 to 2040, and from 2040 to 2070 based on historical groundwater elevation trends and chronic lowering of groundwater levels minimum thresholds provided by the GSAs.

2.1.4 Spreadsheet Tool Data Sources

The parameters in the spreadsheet tool are historical groundwater elevation, groundwater elevation minimum threshold, and estimated clay thickness. Fall groundwater elevation from the GSP groundwater model for years 1999 through 2017 and recent manual measurements in 2021 are used to estimate annual groundwater elevations. Groundwater elevation time series are compiled for the Lower and Upper Aquifer Systems in areas where the Corcoran Clay is present and for the Single Aquifer System in areas where Corcoran Clay is absent. An initial estimate of fine sediment thickness is derived from the USGS' textural model of the San Joaquin Valley. The textural model lumps silts and clays and therefore overestimates total clay thickness.

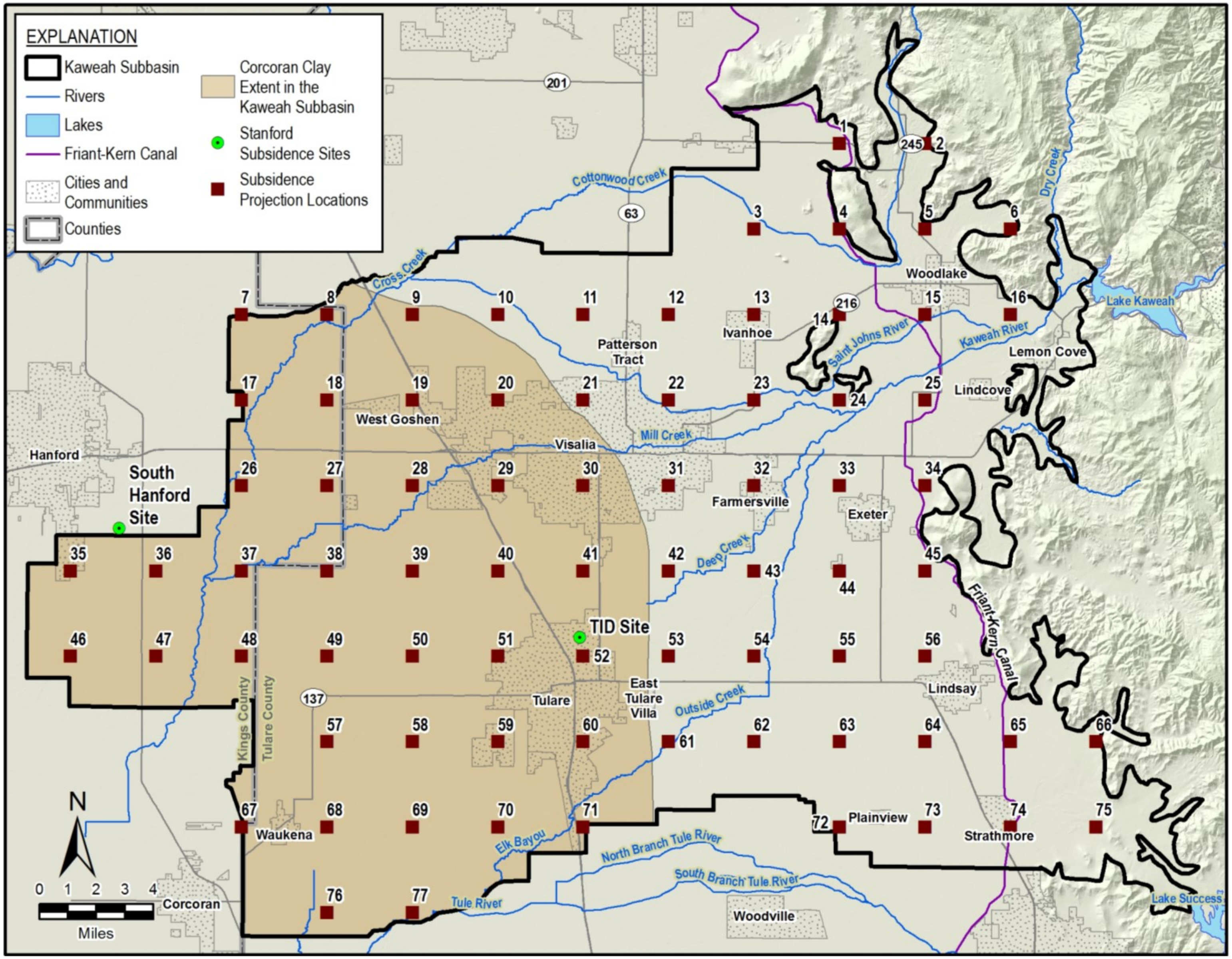


Figure 4. Subsidence Prediction Locations

2.1.5 Equations to Extrapolate Subsidence Across the Subbasin

A simplified set of equations is developed to extrapolate subsidence predicted from the 1-D Models for the South Hanford and TID sites to other locations with less refined data. An identical set of equations and variables are matched in the spreadsheet tool to the 1-D Model results at both the South Hanford and TID sites, only changing clay thickness to reflect site specific clay thickness at each site from geophysical logs.

A simplified equation for cumulative subsidence (Equation 1) is developed using scaling factor (Equation 2) and residual subsidence (Equation 3). These equations are empirical approximations of the more complex, physically based set of compaction equations described in Lees *et al*., 2022 and Helm, 1975:

Equation 1

$$Cumulative\ Subsidence = (Overdraft \times scaling\ factor) + \sum_{0}^{n} residual\ subsidence_{(n)}$$

Equation 2

$$Scaling\ factor = total\ clay\ thickness^2 \times scaling\ coefficient$$

Equation 3

$$Residual\ subsidence_{(n)} = Active\ subsidence_{(n)} \times residual\ subsidence\ factor$$

Where n is the number of previous years of subsidence.

2.1.5.1 Equation 1: Cumulative Subsidence

$$Cumulative\ Subsidence = (Overdraft \times scaling\ factor) + \sum_{0}^{n} residual\ subsidence_{(n)}$$

The cumulative subsidence estimate is the sum of active subsidence from overdraft in the current year and residual subsidence from overdraft in all prior years. Active subsidence for the current year is calculated only if groundwater levels drop below the previously lowest measured groundwater levels.

Subsidence is influenced by groundwater levels in both the Upper and Lower Aquifer Systems. Lees *et al.* estimated that 93% of subsidence is related to overdraft in the Lower Aquifer System, and 7% of subsidence is related to overdraft in the Upper Aquifer System. Therefore, active subsidence is calculated for each aquifer and then weighted according to the percentages identified by Lees *et al*., 2022. In the Single Aquifer System area where the Corcoran Clay is not present, 7% of overdraft is assumed to contribute to subsidence because the Single Aquifer System is unconfined, like the Upper Aquifer System. Consequently, overdraft in the Single Aquifer System does not appear to cause as much subsidence as overdraft below the Corcoran Clay. This is supported by very little historical subsidence east of the Corcoran Clay observed in InSAR data from 2015 to 2022 (DWR InSAR data), or in DWR data from 1954 to 2006 (DWR TRE Altamira data), despite some observed historical overdraft.

2.1.5.2 Equation 2: Scaling Factor

$$Scaling\ factor = total\ clay\ thickness^2 \times scaling\ coefficient$$

A consistent scaling factor was applied to equation 1 by using a single scaling coefficient throughout the Subbasin and varying the total clay thickness. The clay thickness for South Hanford and TID sites was assigned using geophysical logs collected during well installations. Clay thickness was adjusted at other sites to calibrate the model as discussed in Section 2.1.7. The scaling coefficient is fit to the South Hanford and TID site data and held constant for the 77 prediction sites. This coefficient simplifies the governing differential equation described in Lees *et al*., 2022, that incorporates vertical hydraulic conductivity, storage coefficient, and the sum of squared individual clay layer thicknesses.

2.1.5.3 Equation 3: Residual Subsidence

$$Residual\ subsidence_{(n)} = Active\ subsidence_{(n)} \times residual\ subsidence\ factor$$

A simplified equation was developed to account for residual subsidence from previous years' active subsidence. The equation multiplies the active subsidence in any previous year by a residual subsidence factor that decreases over time. The equation is designed to add a lesser amount of residual subsidence over time as the effects of past overdraft diminish. The residual subsidence factor, shown on Figure 5, was fit to the 1-D Model data for South Hanford and TID sites and then applied throughout the Subbasin.

As an example, Figure 5 shows that after 50 years, only 20% of the active subsidence from the first year is added to the total subsidence calculation. Lees *et al*. (2022) and other research on subsidence has found that residual subsidence can occur for long periods, even after groundwater elevations stabilize. For example, at the South Hanford site, Lees *et al*. predicted that significant subsidence occurs for at least 64 years after overdraft stops and groundwater elevations are held constant. This long residual subsidence is due to much slower head equilibration and compaction in thick clay interbeds. Lees *et al.* acknowledges that this approach is conservative as they expect that the compressibility of clays will reduce over time as clays near ultimate compaction.

2.1.6 Spreadsheet Tool Development

Figure 6 shows how calculations from the spreadsheet tool fit the model used by Lees *et al*. for the South Hanford and TID sites. The results from Lees *et al*. are shown in yellow, and the results from the spreadsheet tool are shown in blue.

As shown on Figure 6, the spreadsheet tool is calibrated to groundwater elevation and subsidence from 1954 to 2017 to present. The 1954 to 1998 groundwater level and subsidence data are available at the South Hanford and TID sites, but not throughout the Subbasin. Subsidence predictions throughout the Subbasin were therefore based only on groundwater elevation data available from 1999 to 2021 and future estimated groundwater levels.

To demonstrate the effect of limiting the groundwater level data in the spreadsheet tool to data collected between 1999 and 2021, the fit between the spreadsheet tool using only data between 1999 and 2021 at the TID and South Hanford sites is shown with the Lees *et al*. results on Figure 7. The results on Figure 7 are not as accurate as the results using the more extensive groundwater elevation dataset from 1954 to 2017, shown on Figure 6. This is because residual subsidence from overdraft prior to 1999 is not accounted for in the Figure 7 results. However, Figure 7 shows that the error in the spreadsheet diminishes over time, suggesting the spreadsheet model remains valid for estimating long-term subsidence.

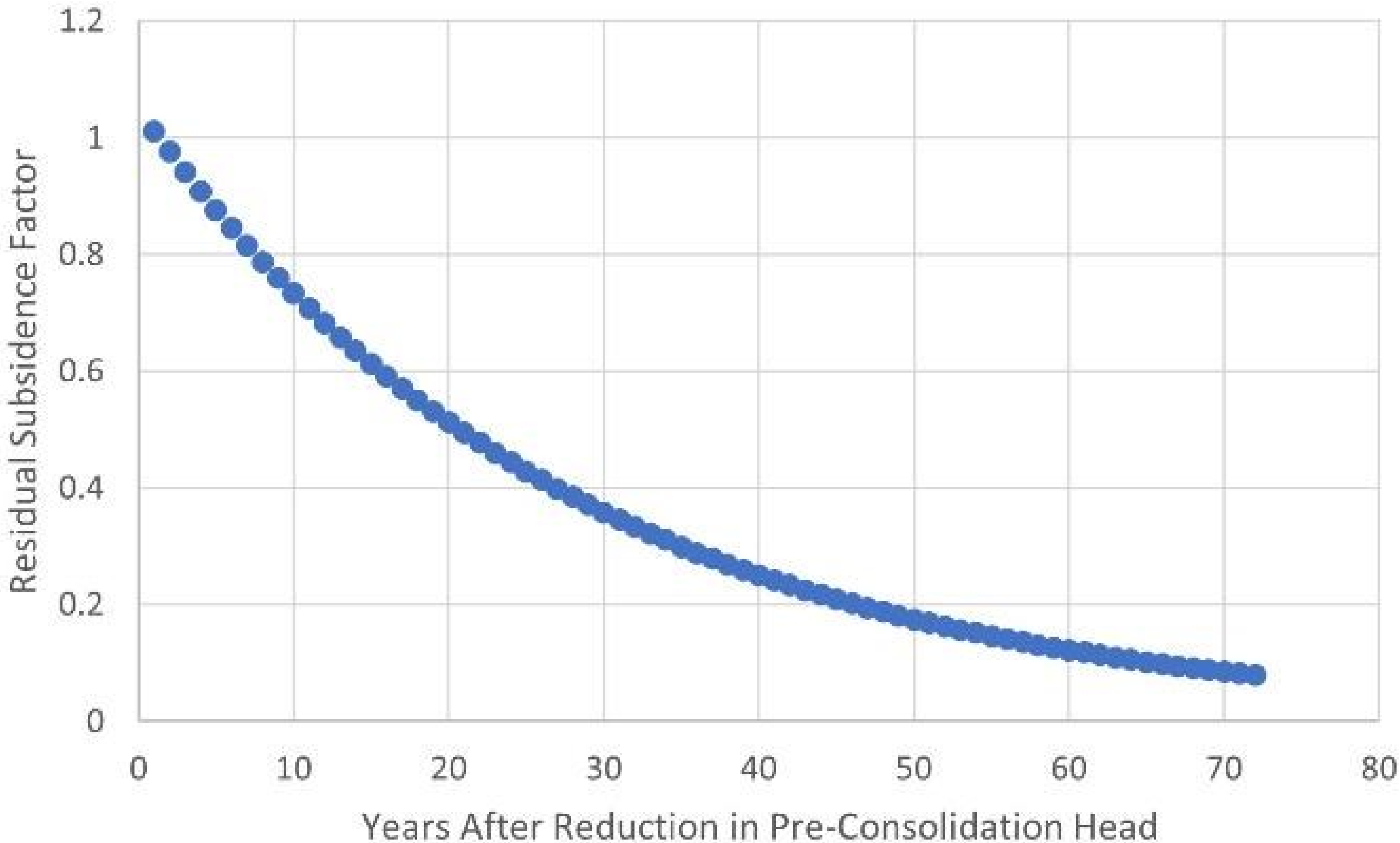
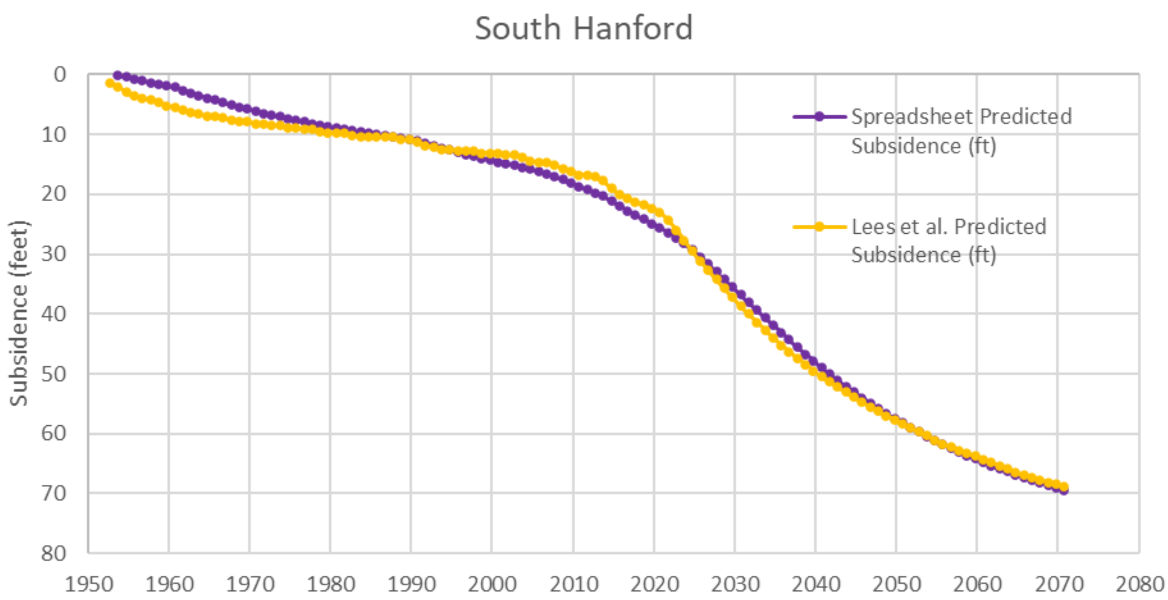


Figure 5. Residual Subsidence Factors for Years After Reduction in Pre-Consolidated Head



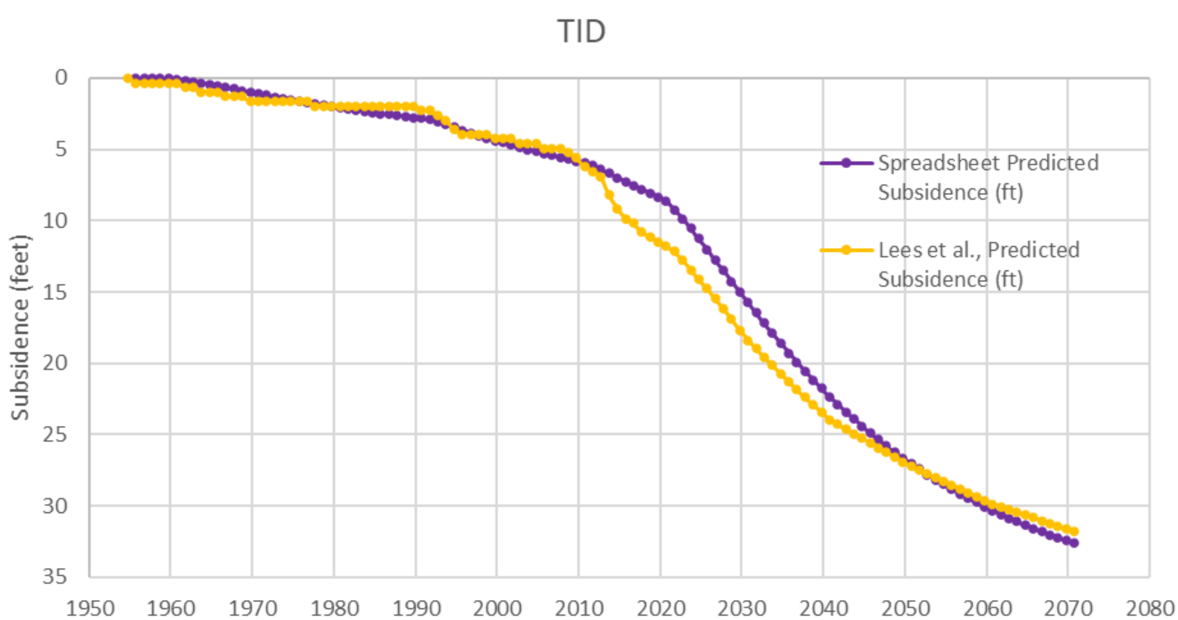
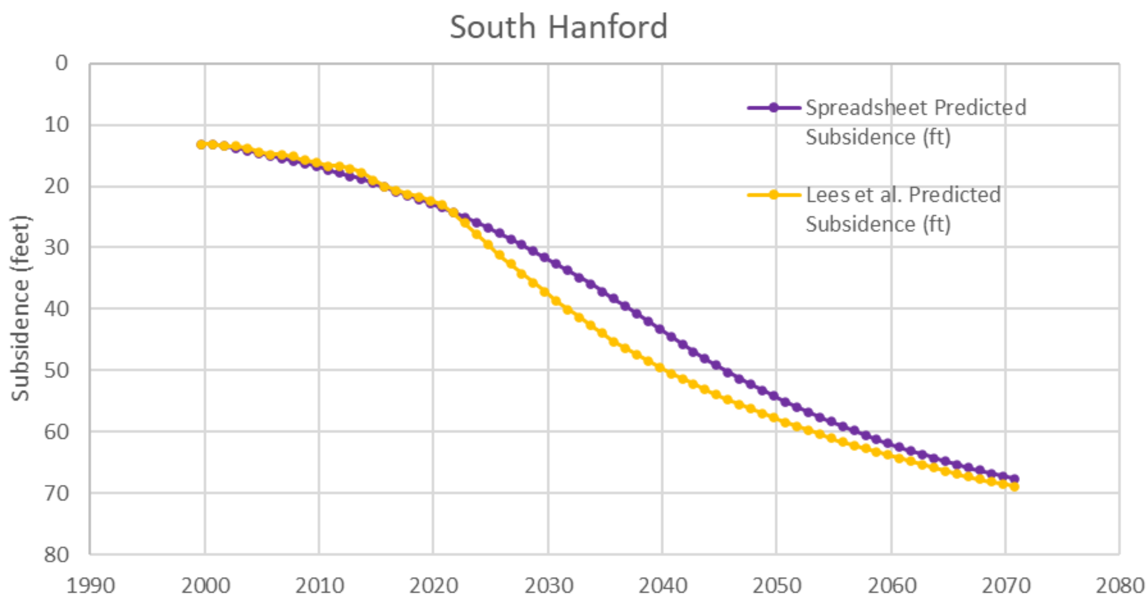


Figure 6. Spreadsheet and Model Predicted Subsidence at South Hanford and TID Sites, 1954-2070



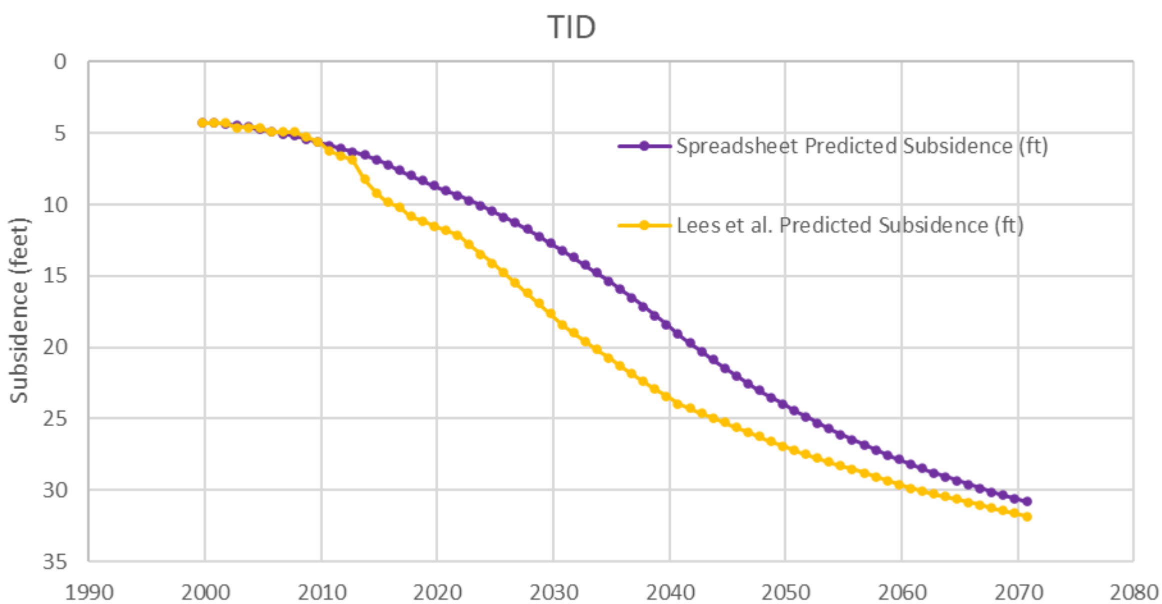


Figure 7. Spreadsheet and Model Predicted Subsidence at South Hanford and TID Sites, 1999-2070

2.1.7 Spreadsheet Tool Calibration

Total clay thickness is adjusted to calibrate the spreadsheet tool to match subsidence measured by InSAR between 2015 and 2021. The calibrated clay thickness is shown on Figure 8. This figure represents the total clay thickness, not the thickness of specific clay layers such as the Corcoran Clay. A comparison of the InSAR measured subsidence and calibrated model predicted subsidence is shown on Figure 9. Where subsidence was greatest in the western portion of the Subbasin, the model was calibrated to estimate slightly less subsidence than the InSAR data to account for underprediction shown on Figure 7. InSAR measured little to no subsidence in the eastern portion of the Subbasin where the Corcoran Clay is absent. The spreadsheet tool is not developed to estimate elastic subsidence or increase in land surface elevation when groundwater elevations increase, so subsidence in the eastern portion of the Subbasin may be slightly overestimated by this simplified approach.

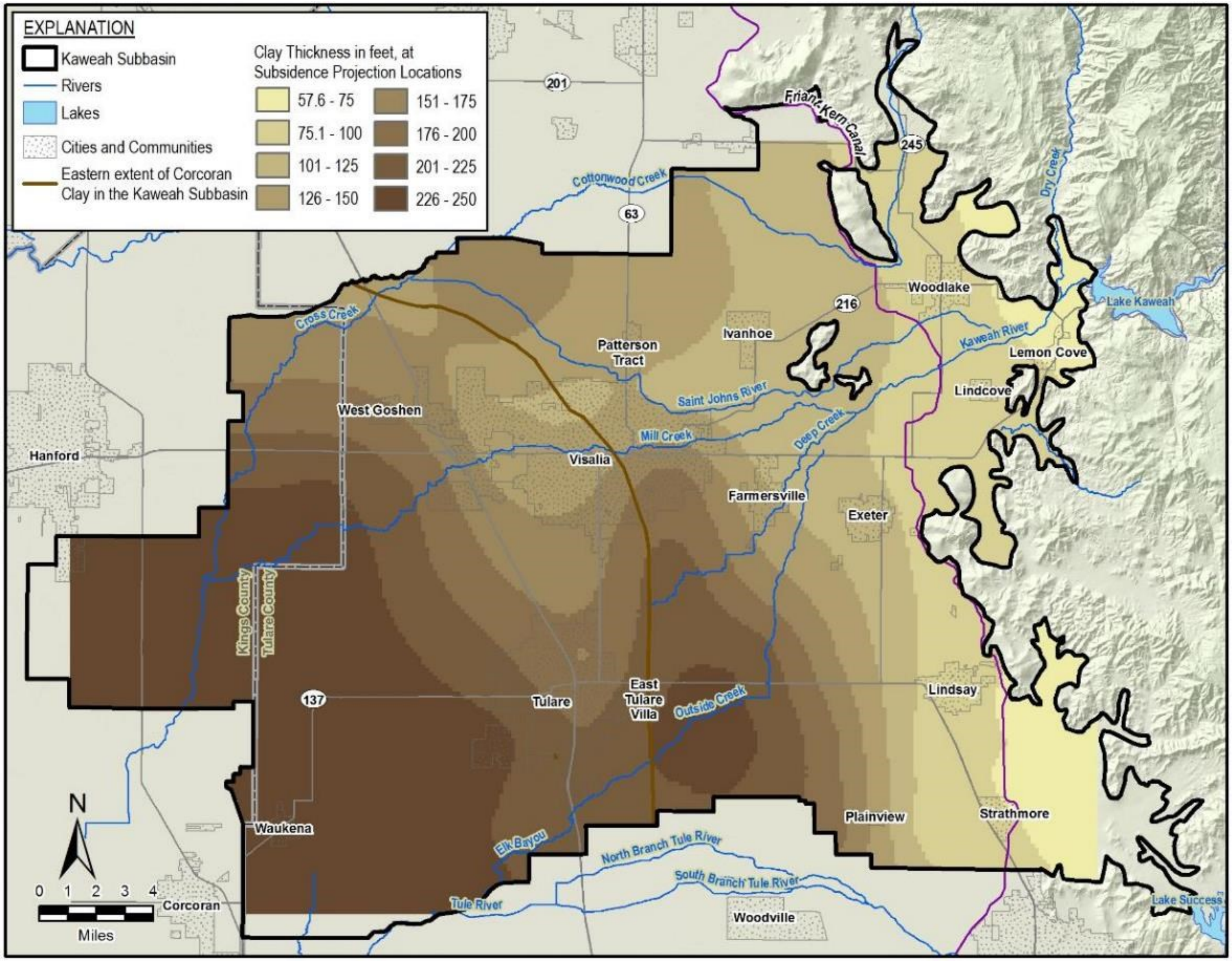


Figure 8. Clay Thickness from Spreadsheet Tool Calibration

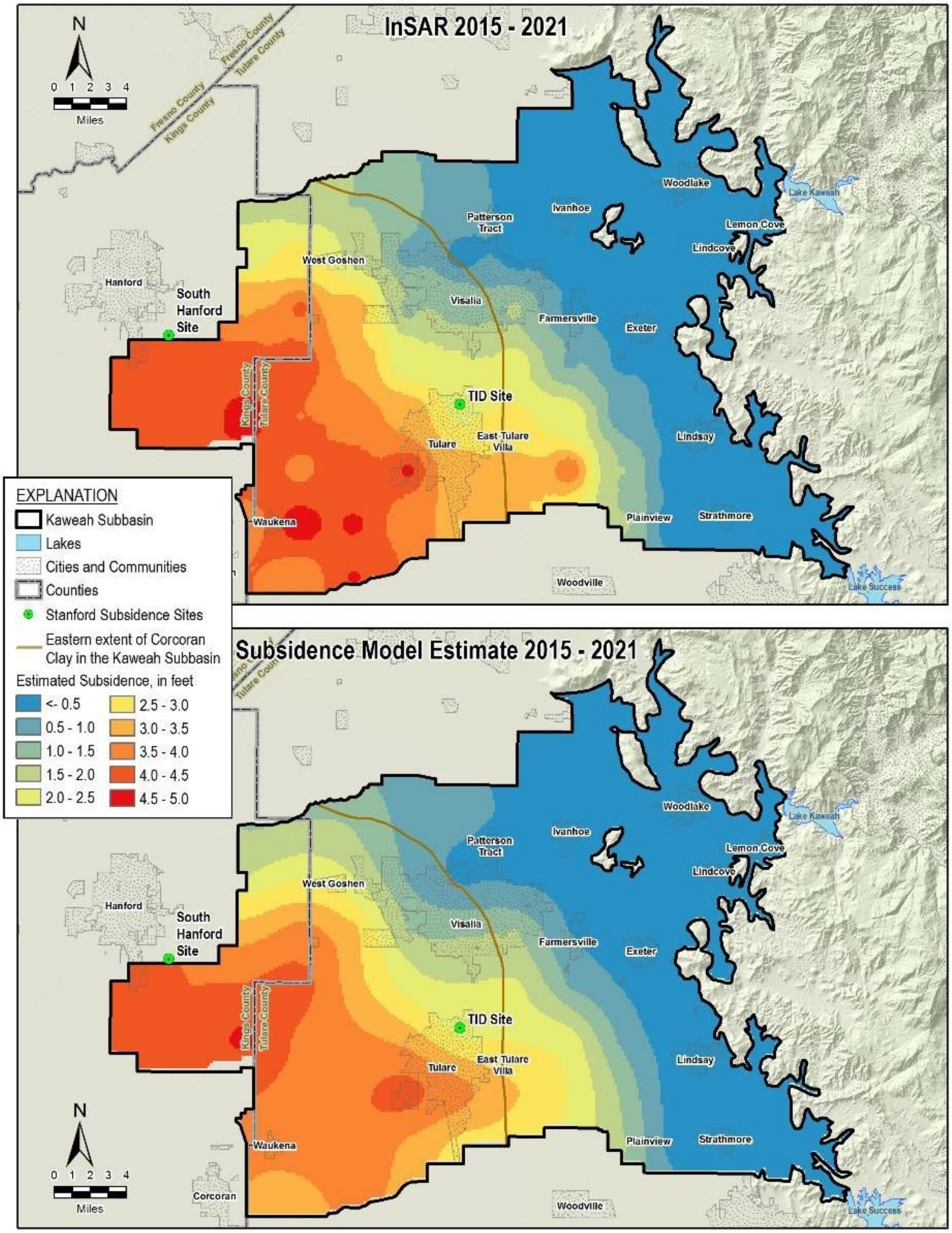


Figure 9. Subsidence from InSAR (top) Compared to Spreadsheet Model Estimate from 2015 to 2021 (bottom)

2.1.8 Spreadsheet Tool Results

Subsidence in the Subbasin is projected using the spreadsheet tool to continue over the SGMA planning and implementation horizon. This is substantiated by the results published by Lees *et al*., 2022, which estimates up to 10 feet of subsidence will occur at the South Hanford site even if groundwater level declines are halted immediately.

2.1.8.1 Subsidence at Groundwater Elevation Minimum Thresholds

If groundwater elevations decrease and stabilize at the minimum threshold, up to 20.2 feet of subsidence could occur between 2020 and 2040 (1 foot/year) as shown on Figure 10. Up to 22.9 feet of subsidence could occur between 2040 and 2070 (0.76 feet/year) as shown on Figure 11. These results are similar to the 1-D model results at the South Hanford site, which predicts approximately 27 feet of subsidence between 2020 and 2040, and 18 feet of subsidence from 2040 to 2070.

All subsidence between 2040 and 2070 is residual subsidence. The model assumes that the Subbasin achieves sustainability in 2040, and no new subsidence is activated over the ensuing 30 years. The subsidence shown on Figure 11 is the cumulative result of progressively less subsidence every year since 2040.

Figure 12 shows that Subbasin-wide subsidence could range between less than 1 foot and 43.1 feet over the full 50-year planning and implementation horizon. This equates to subsidence rates up to 10.4 inches per year. The greatest subsidence is located near the South Hanford site. Very little subsidence is predicted to occur along the eastern edge of the Subbasin.

Subsidence is measured in the Subbasin at a series of subsidence monitoring points, shown on Figure 13. The estimated subsidence when groundwater elevations stabilize at the minimum thresholds is shown for each subsidence measuring point in Table 1 as both a total subsidence and an equivalent subsidence rate.

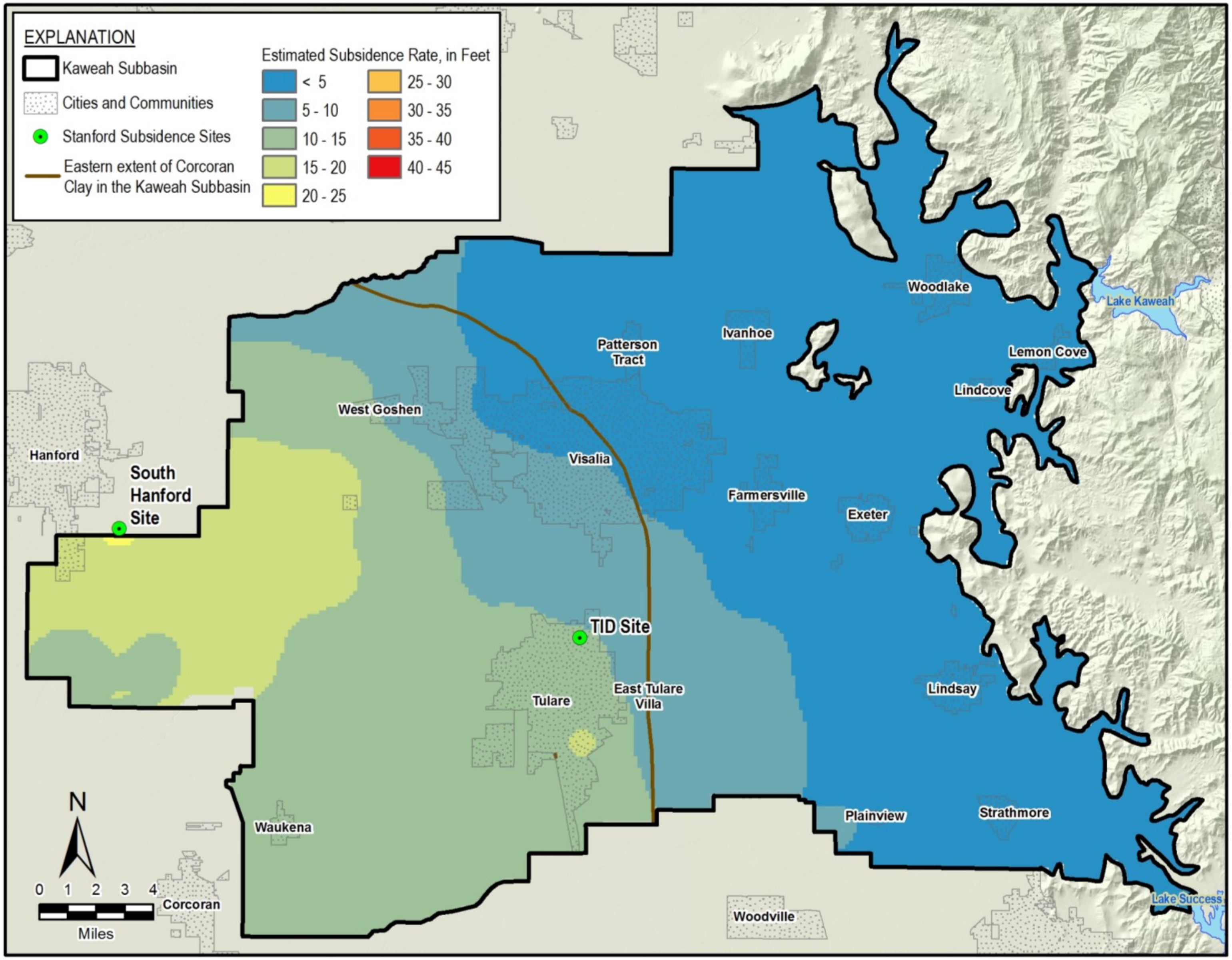


Figure 10. Spreadsheet Tool Estimated 2020 to 2040 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

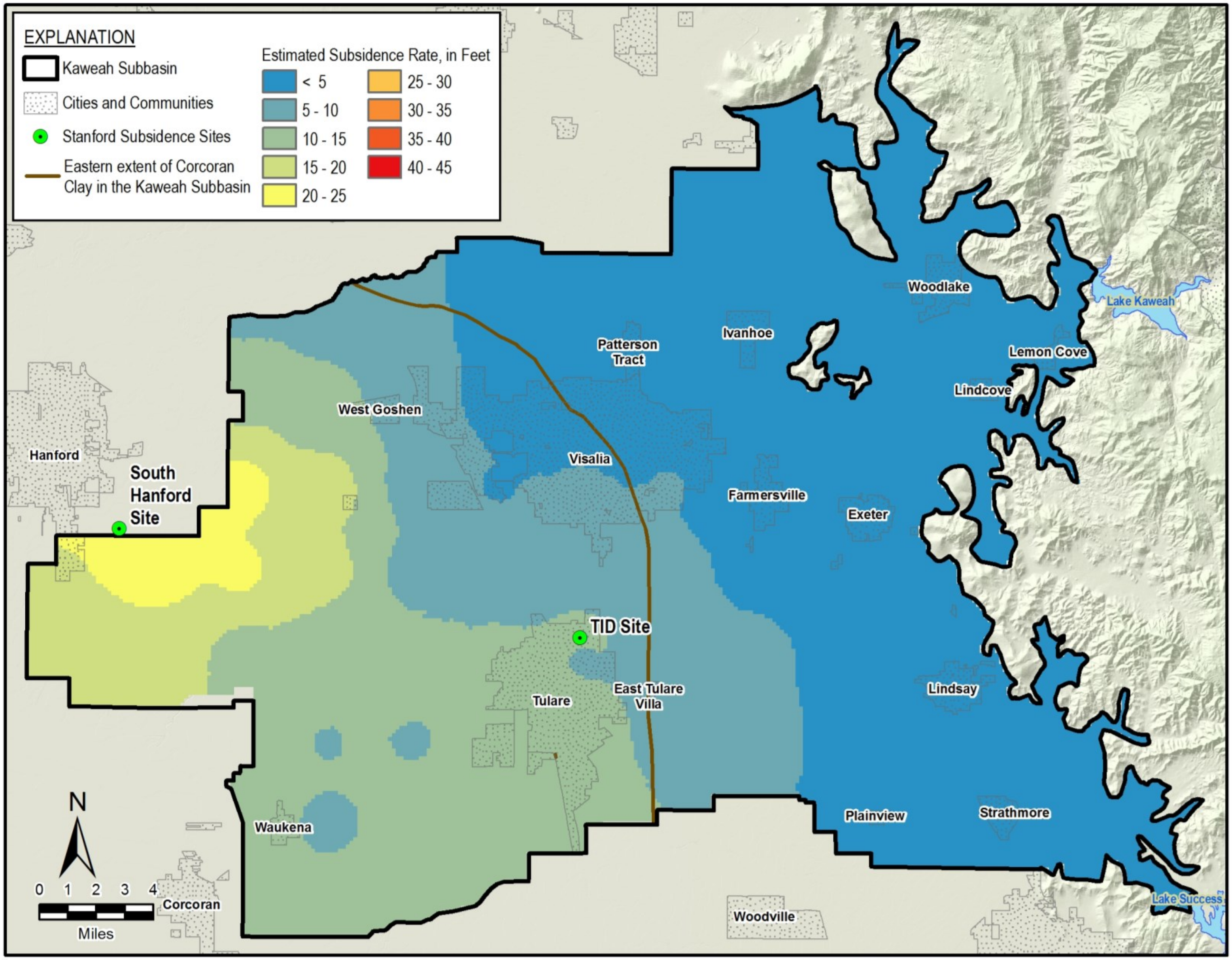


Figure 11. Spreadsheet Tool Estimated 2040 to 2070 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

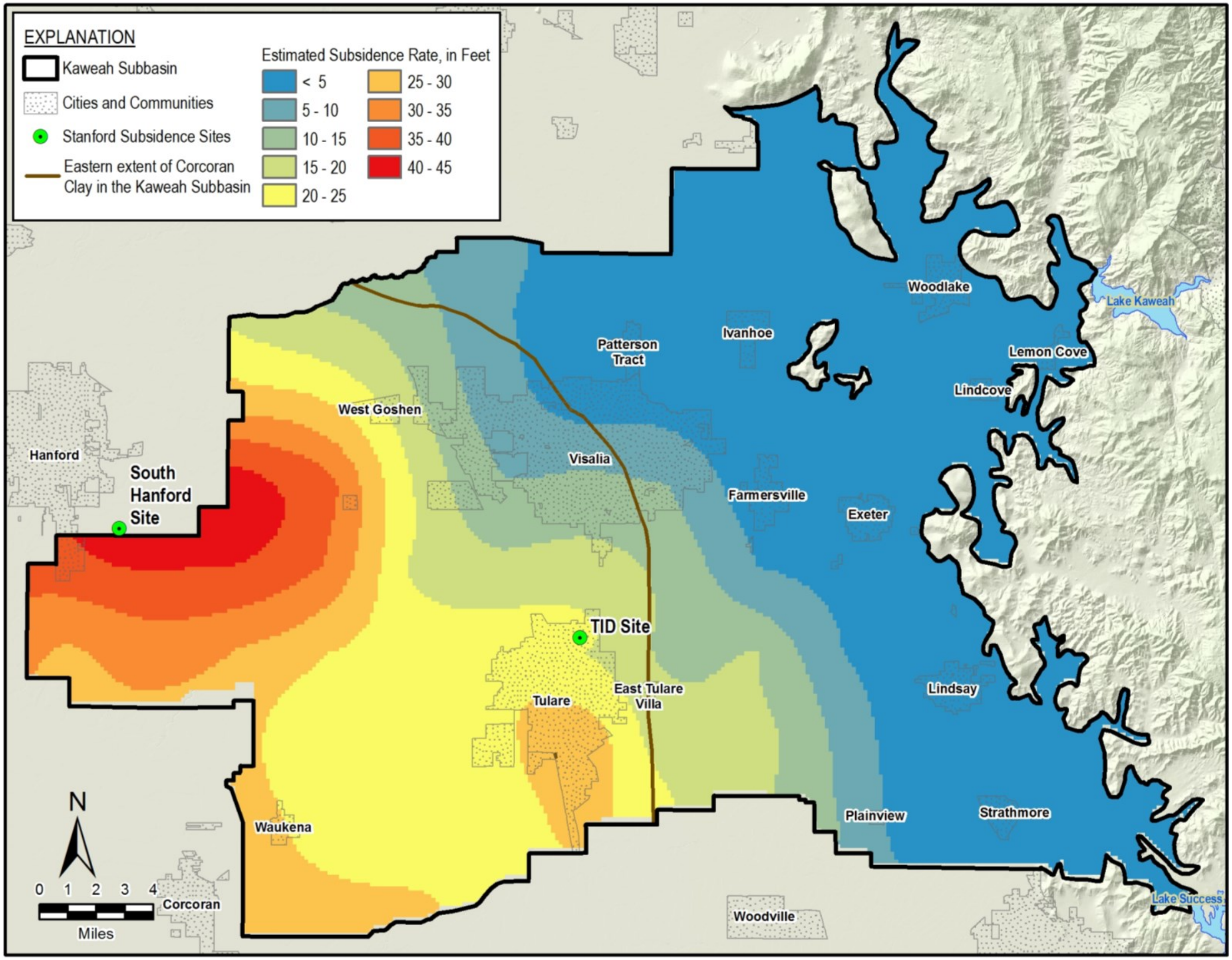


Figure 12. Spreadsheet Tool Estimated 2020 to 2070 Subsidence when Groundwater Levels Stabilize at Minimum Thresholds

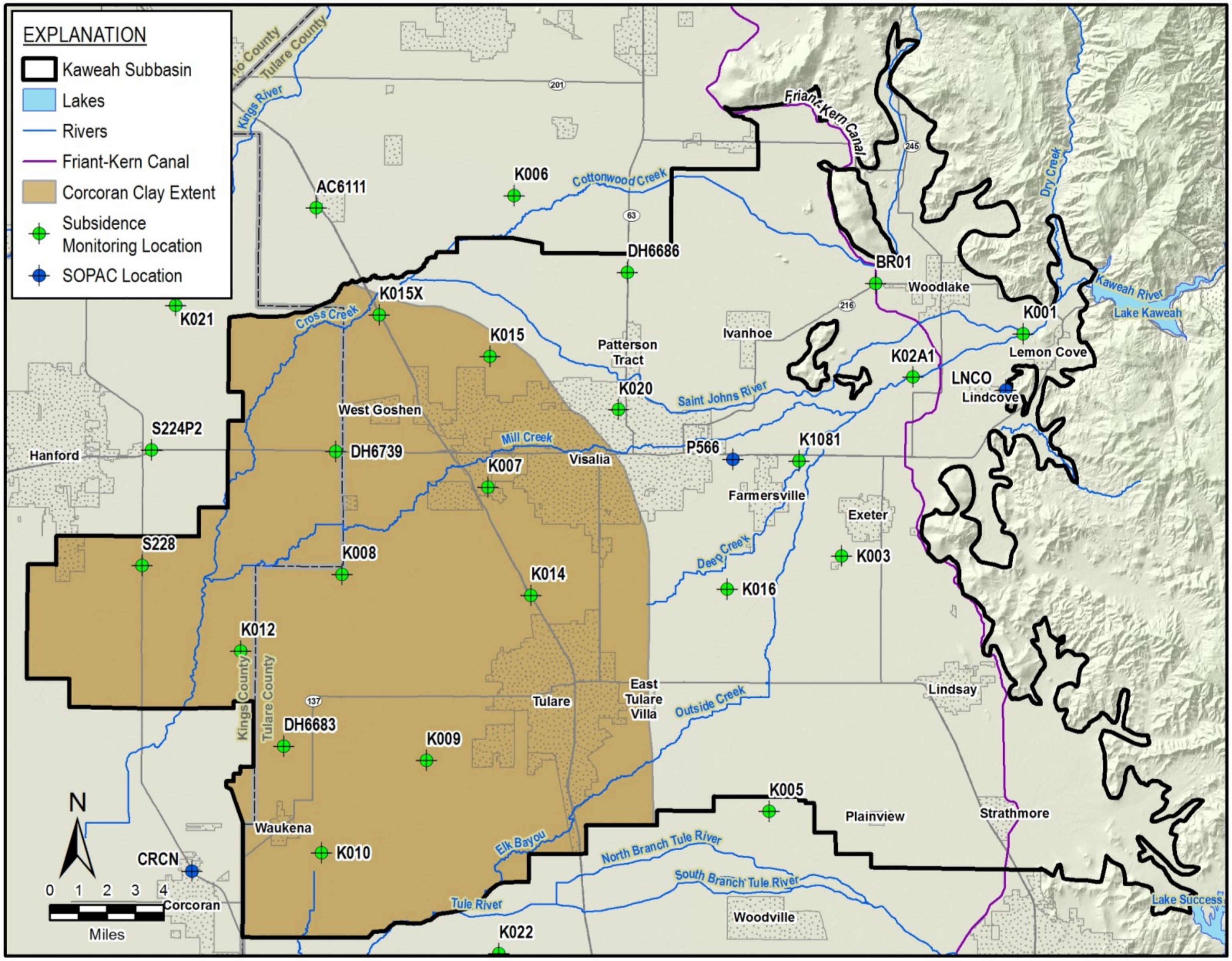


Figure 13. Subsidence Monitoring Points in and Around the Kaweah Subbasin

Table 1. Estimated Subsidence at Subbasin Monitoring Points when Groundwater Levels Stabilize at Minimum Thresholds

Subsidence Monitoring Point	2020 to 2040		2040 to 2070		2020 to 2070	
	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)
BR01	0.2	0.3	0.1	0.2	0.1	0.5
DH6683	7.6	12.7	4.4	10.9	5.7	23.6
DH6686	0.9	1.6	0.8	1.9	0.8	3.5
DH6739	9.5	15.9	6.1	15.2	7.5	31.1
K001	0.1	0.2	0.1	0.2	0.1	0.4
K003	0.7	1.2	0.6	1.4	0.6	2.6
K007	3.9	6.6	2.0	5.0	2.8	11.6
K008	9.8	16.3	6.2	15.5	7.6	31.8
K009	6.7	11.1	3.9	9.9	5.0	21.0
K010	7.9	13.2	4.3	10.9	5.8	24.0
K012	10.3	17.2	5.0	12.6	7.1	29.8
K014	5.9	9.9	3.7	9.2	4.6	19.1
K015	2.1	3.5	1.3	3.2	1.6	6.7
K015X	4.5	7.5	2.5	6.3	3.3	13.8
K016	2.6	4.4	2.1	5.2	2.3	9.5
K020	1.1	1.9	0.9	2.2	1.0	4.0
K02A1	0.1	0.2	0.1	0.2	0.1	0.4
K1081	0.3	0.5	0.1	0.4	0.2	0.9
P566	0.9	1.4	0.6	1.6	0.7	3.0
S228	10.8	18.0	9.0	22.5	9.7	40.5

2.1.8.2 Subsidence at Groundwater Elevation Measurable Objectives

If groundwater elevations decrease and stabilize at the measurable objectives in 2040, up to 18.9 feet of subsidence could occur between 2020 and 2040, as shown on Figure 14. Up to 16 feet of subsidence could occur between 2040 and 2070 as shown on Figure 15.

All subsidence between 2040 and 2070 is residual subsidence. The model assumes that the Subbasin achieves sustainability at the measurable objectives in 2040, and no new subsidence is activated over the ensuing 30 years. The subsidence shown on Figure 15 is the cumulative result of progressively less subsidence every year since 2040.

Figure 16 shows that subbasin-wide subsidence could range between less than 0.02 feet and 34.8 feet over the full 50-year planning and implementation horizon. This equates to subsidence rates of between 0.005 and 8.3 inches per year. The greatest subsidence is located near the South Hanford site and very little subsidence is predicted to occur along the eastern edge of the Subbasin.

The estimated subsidence when groundwater elevations stabilize at the measurable objective is shown for each of the subsidence measuring points in Table 2 as both a total subsidence and an equivalent subsidence rate.

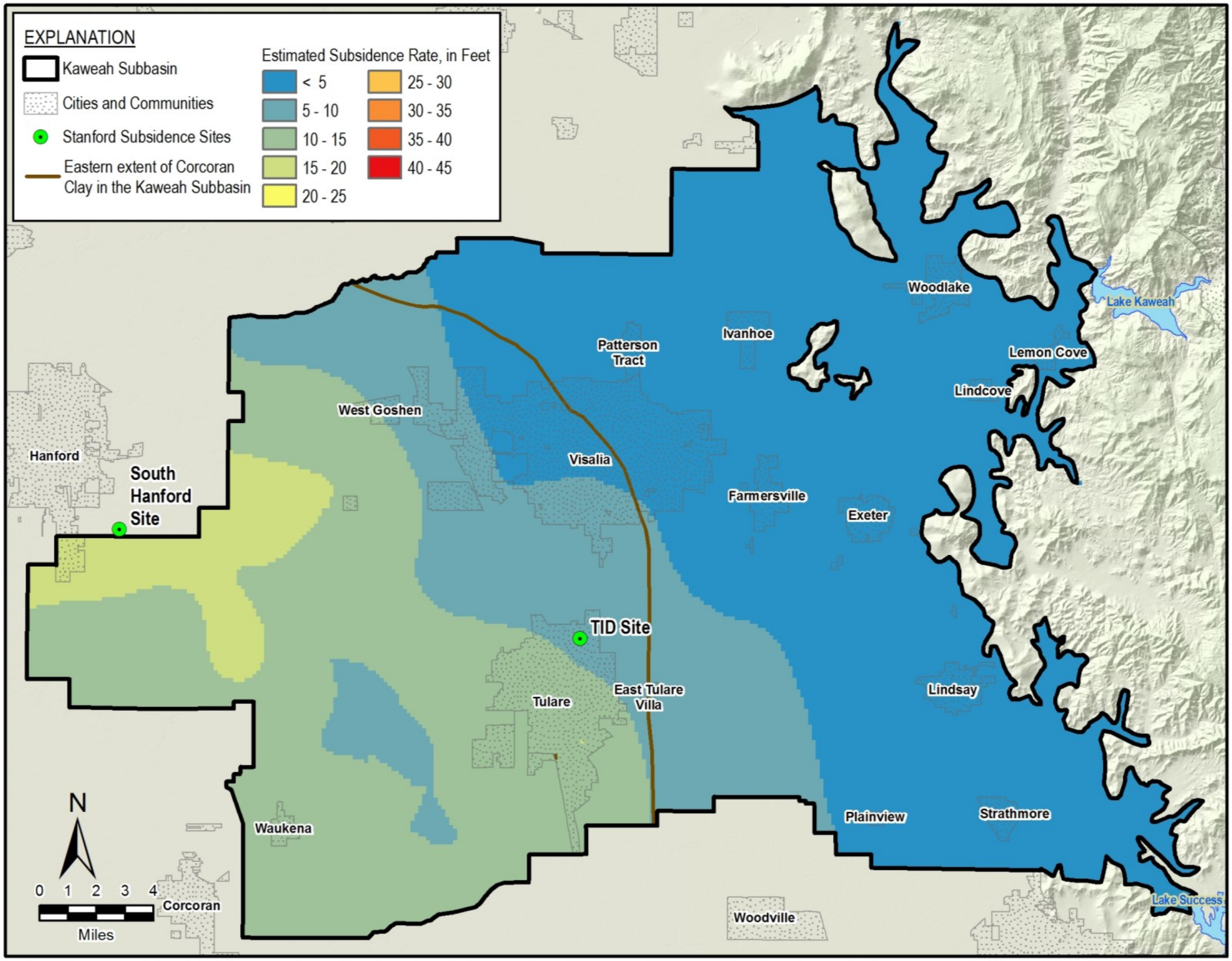


Figure 14. Spreadsheet Tool Estimated 2020 to 2040 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

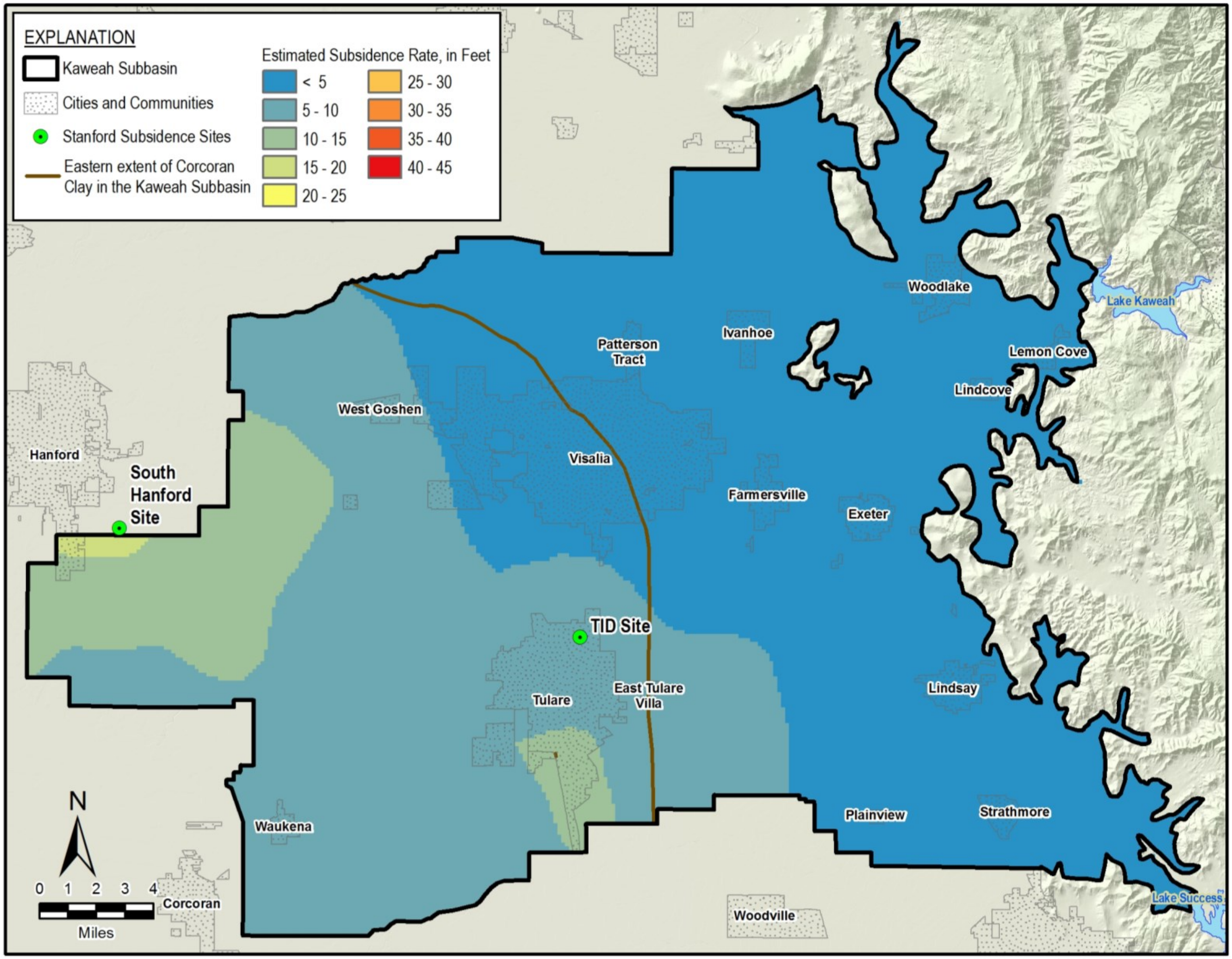


Figure 15. Spreadsheet Tool Estimated 2040 to 2070 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

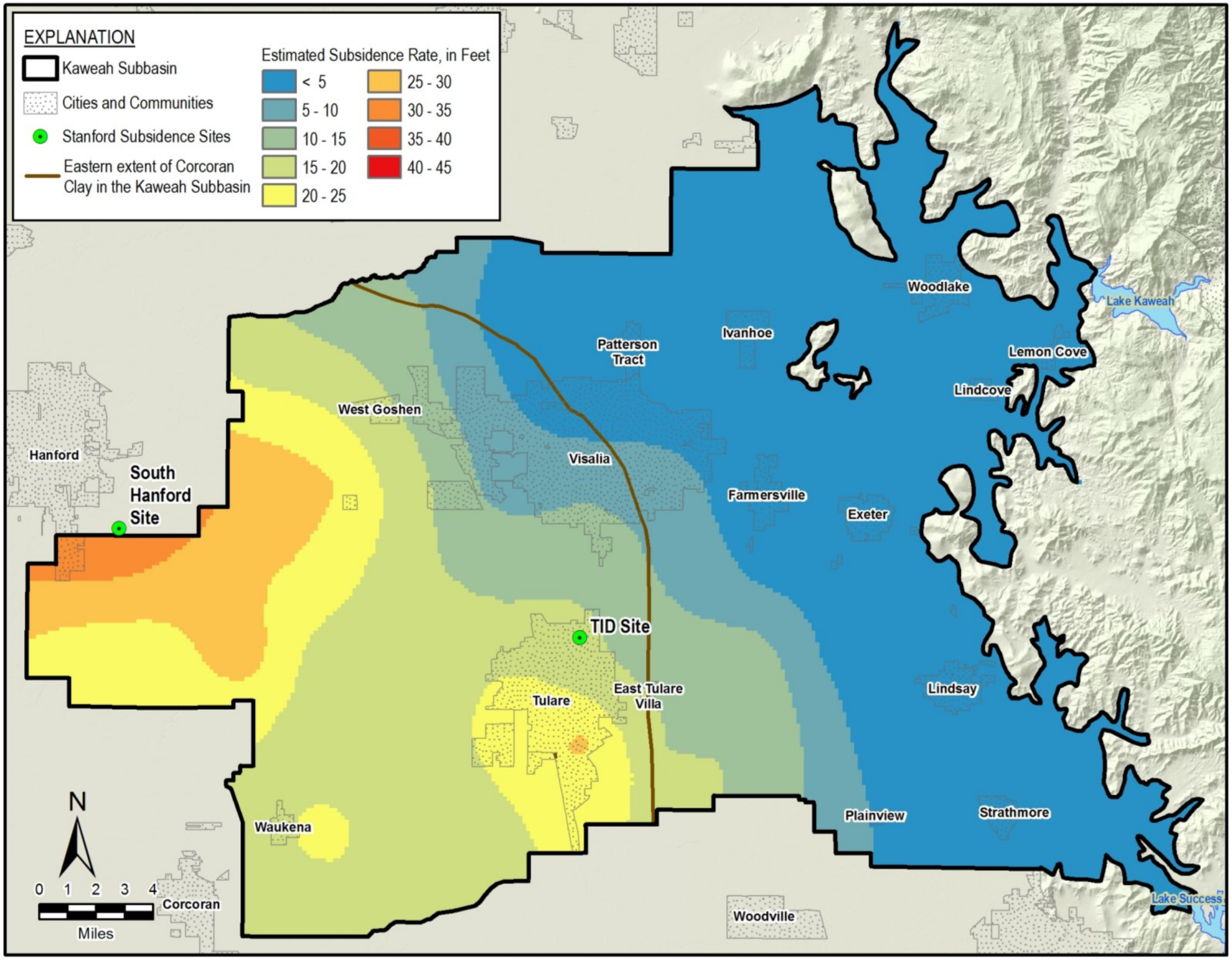


Figure 16. Spreadsheet Tool Estimated 2020 to 2070 Subsidence when Groundwater Levels Stabilize at Measaurable Objectives

Table 2. Estimated Subsidence at Subbasin Monitoring Points when Groundwater Levels Stabilize at Measurable Objectives

Subsidence Monitoring Point	2020 to 2040		2040 to 2070		2020 to 2070	
	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)	Annual Subsidence (inch/year)	Total Subsidence (feet)
BR01	0.2	0.3	0.1	0.2	0.1	0.5
DH6683	6.8	11.4	3.0	7.5	4.5	18.9
DH6686	0.8	1.3	0.4	1.0	0.5	2.3
DH6739	8.1	13.4	3.7	9.2	5.4	22.6
K001	0.1	0.2	0.1	0.2	0.1	0.4
K003	0.6	1.0	0.3	0.7	0.4	1.7
K007	3.3	5.6	1.4	3.5	2.2	9.1
K008	7.8	12.9	3.4	8.5	5.1	21.4
K009	6.0	9.9	2.7	6.9	4.0	16.8
K010	7.3	12.1	3.3	8.1	4.9	20.3
K012	9.8	16.4	4.4	11.0	6.6	27.4
K014	5.2	8.7	2.4	6.0	3.5	14.7
K015	1.9	3.1	0.8	2.1	1.2	5.2
K015X	4.3	7.1	2.0	5.1	2.9	12.2
K016	2.3	3.8	1.2	3.0	1.6	6.8
K020	0.9	1.5	0.5	1.2	0.7	2.7
K02A1	0.1	0.2	0.1	0.1	0.1	0.4
K1081	0.3	0.6	0.1	0.3	0.2	0.9
P566	0.8	1.4	0.4	1.1	0.6	2.5
S228	9.8	16.4	5.8	14.4	7.4	30.8

2.2 Impact of Subsidence on Conveyance Infrastructure

Infrastructure in the Subbasin that may be affected by subsidence include roads, bridges, gas and water pipelines, power lines, canals, ditches, flood control waterways, railroad tracks, and wells. Although InSAR data show that up to 5 feet of subsidence has occurred in the Subbasin between 2015 and 2021, a survey of local infrastructure impacts indicated there has been no widespread damage caused by subsidence other than damage noted to water conveyance infrastructure and groundwater wells.

Subsidence predictions from the spreadsheet tool described in Section 2.1.8 are used to evaluate potential impacts to water conveyance infrastructure in the Subbasin, including subsidence along the Friant-Kern Canal and other important conveyance infrastructure described below. Water conveyance infrastructure including the Friant-Kern Canal and other important local conveyance is shown on Figure 17.

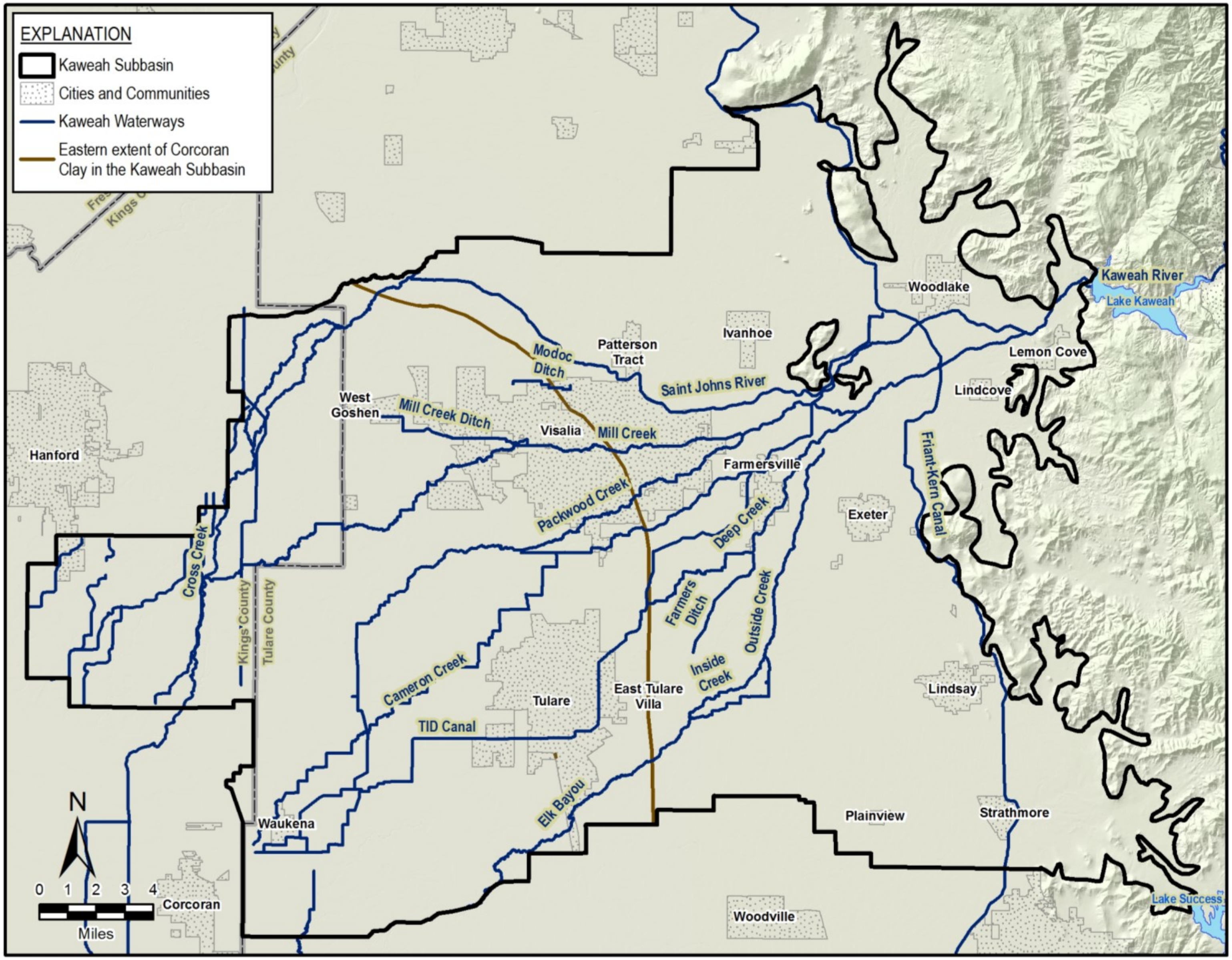


Figure 17. Conveyance Infrastructure Locations

2.2.1 Friant-Kern Canal

The East Kaweah Groundwater Sustainability Agency (EKSGA) identified the Friant-Kern Canal as the sole conveyance infrastructure in their portion of the Subbasin with potential to experience significant and unreasonable impacts due to subsidence. The EKGSA determined that a 10% loss of capacity would be significant and unreasonable. Using canal cross section and elevation data, EKGSA estimated that approximately 10 inches of total subsidence in the Subbasin would reduce the canal carrying capacity by 10%. This equates to a 50-year subsidence rate of 0.2 inches per year.

The subsidence spreadsheet tool was used to estimate the maximum subsidence along the Friant-Kern Canal. Figure 18 shows the maximum predicted subsidence along the Friant-Kern canal between 2020 and 2040 when groundwater levels are held at minimum thresholds. The maximum subsidence is 0.69 feet, or 0.41 inches per year. Figure 19 shows the maximum predicted subsidence between 2040 and 2070 when groundwater levels are held at minimum thresholds. The maximum subsidence is 0.69 feet, or 0.28 inches per year. Figure 20 shows the maximum predicted subsidence between 2020 and 2070 when groundwater levels are held at minimum thresholds. The maximum subsidence is 1.4 feet, or 0.34 inches per year.

Figure 21 shows the maximum predicted subsidence along the Friant-Kern Canal between 2020 and 2040 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.55 feet, or 0.33 inches per year. Figure 22 shows the maximum predicted subsidence between 2040 and 2070 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.39 feet, or 0.16 inches per year. Figure 23 shows the maximum predicted subsidence between 2020 and 2070 when groundwater levels are held at measurable objectives. The maximum subsidence is 0.94 feet, or 0.23 inches per year.

Estimated subsidence along the Friant-Kern Canal is greatest where it enters and leaves the Subbasin, which suggests there may be boundary errors in the analysis. These estimates at the boundaries are not considered reliable. Except for the boundaries, the greatest subsidence is estimated where the canal abuts the foothills in the middle of the Subbasin near the City of Exeter. The subsidence at this point is likely the maximum reliable subsidence from this analysis and is shown in Table 3. To date, very little subsidence has been noted in this area, as discussed in Section 2.1.7. Therefore, based on the model results, 10 inches (or 0.83 feet) of subsidence is possible, but not likely to occur and no significant impacts from subsidence to the Friant-Kern Canal are anticipated in the Subbasin.

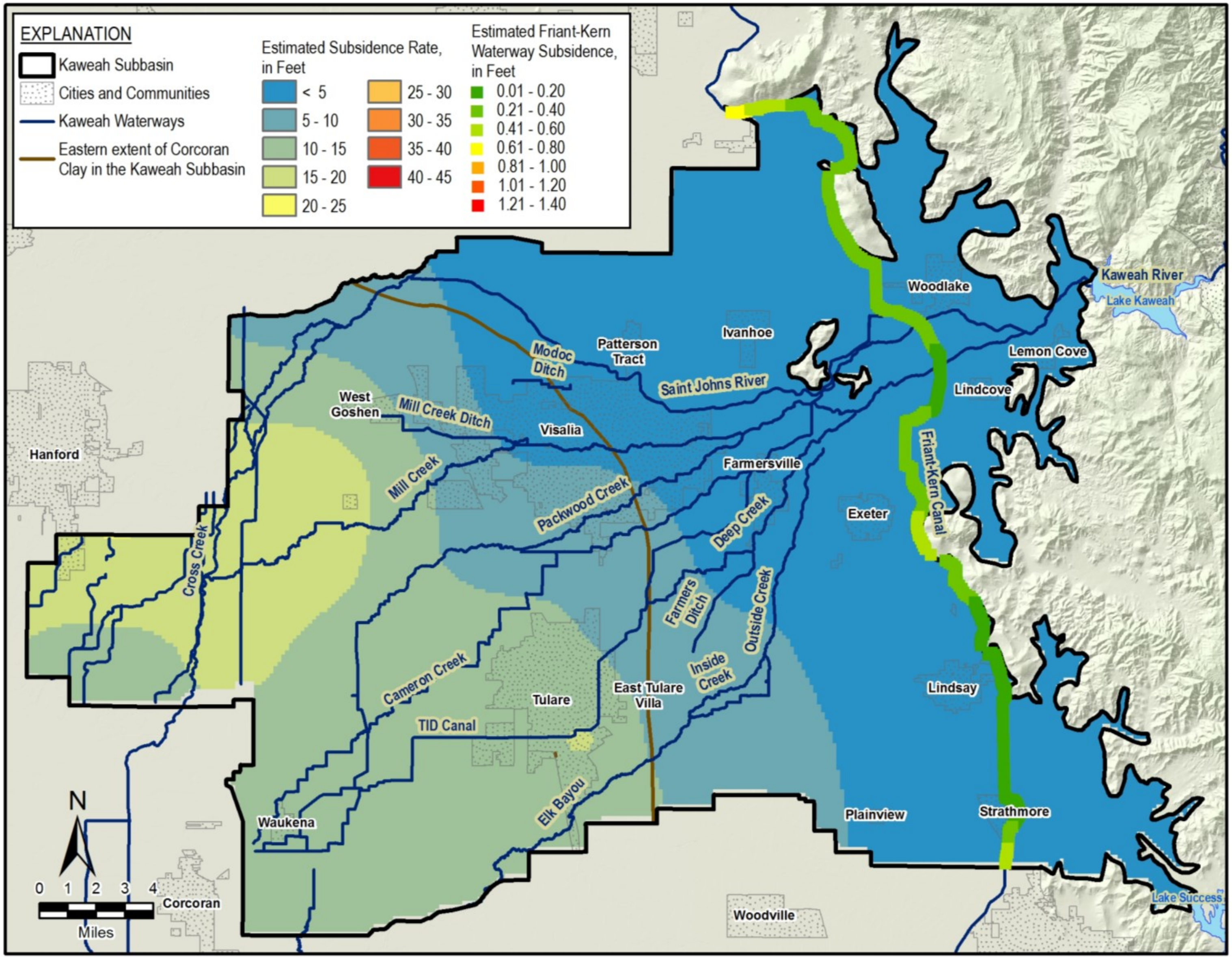


Figure 18. Estimated 2020 to 2040 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

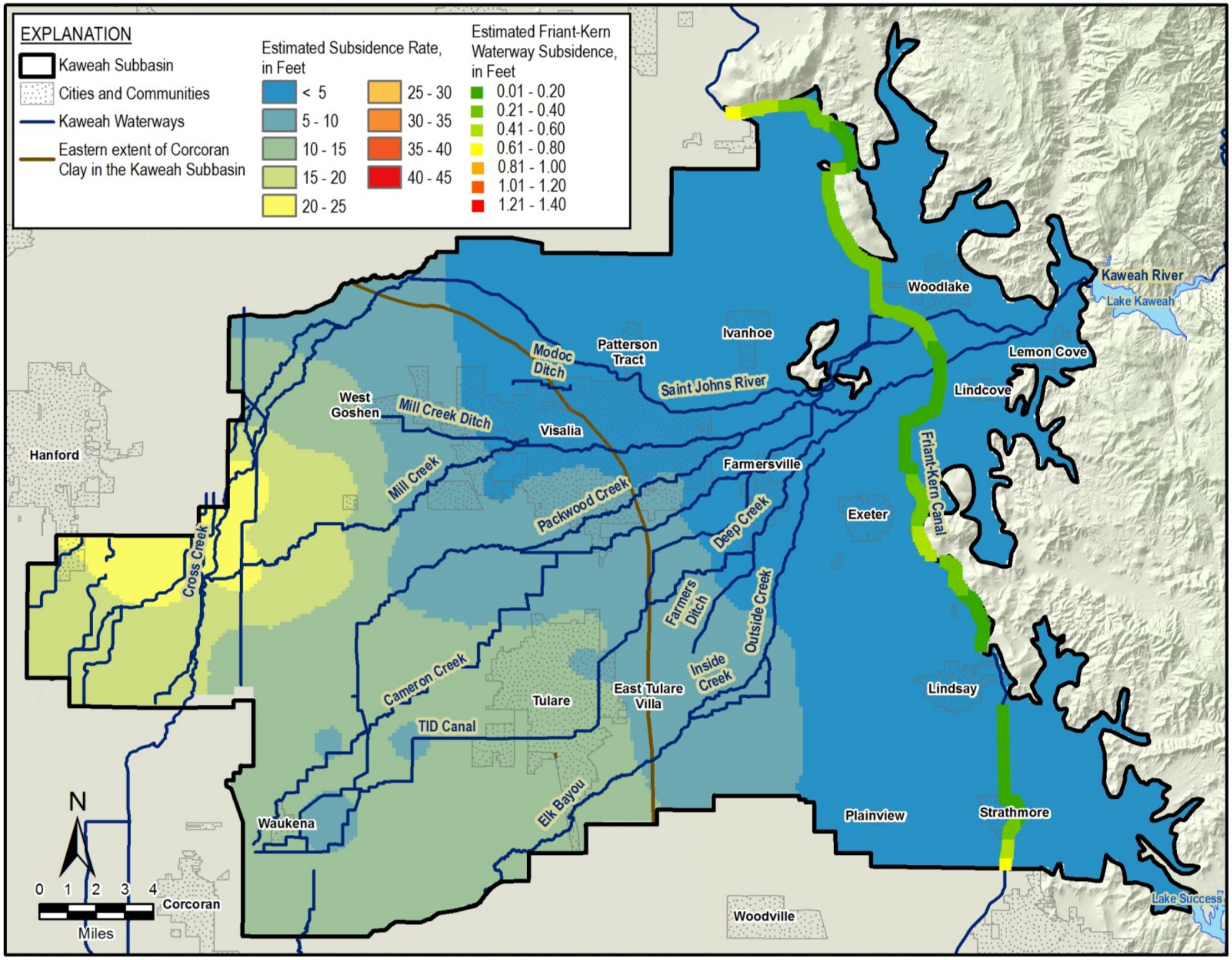


Figure 19. Estimated 2040 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

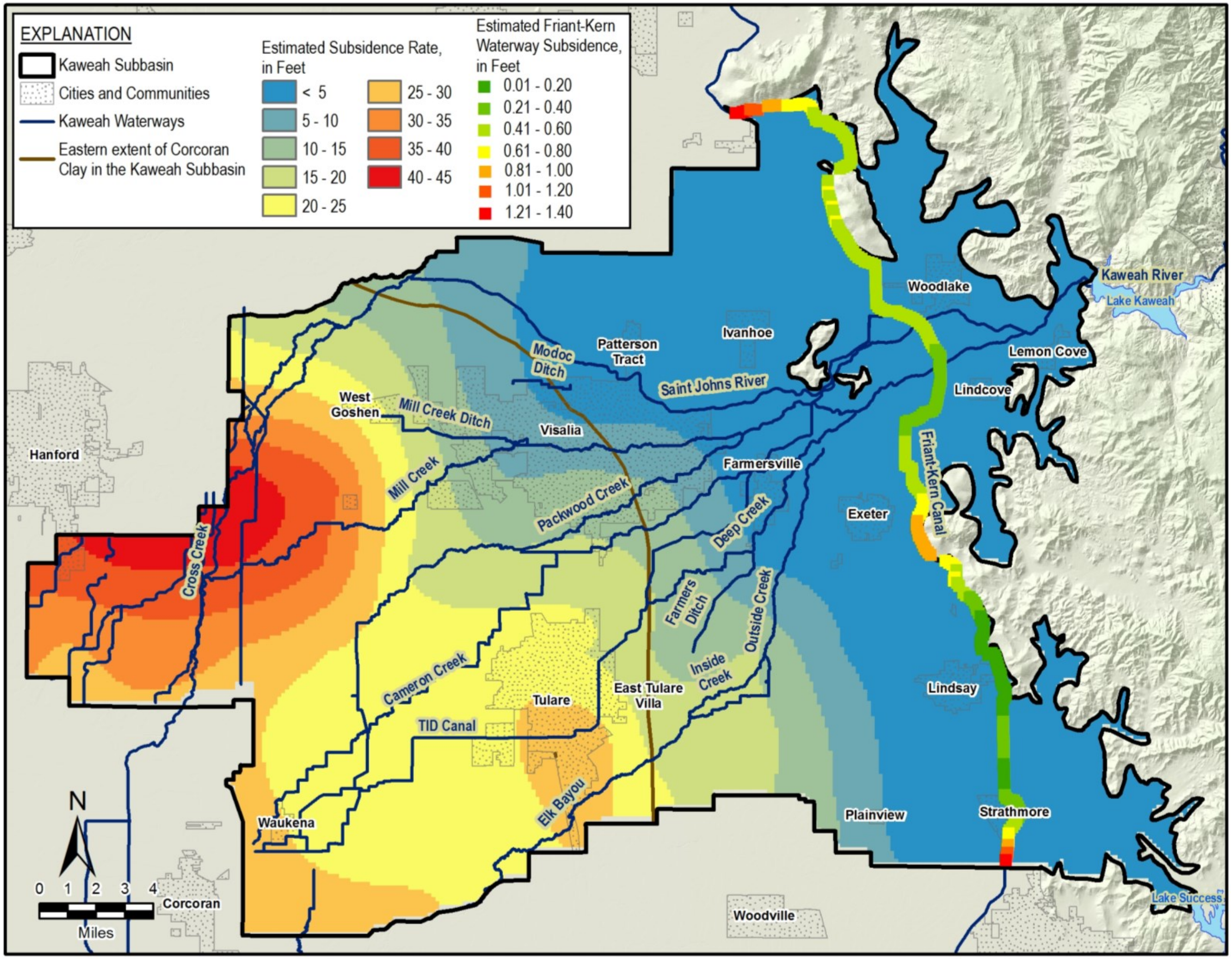


Figure 20. Estimated 2020 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Minimum Thresholds

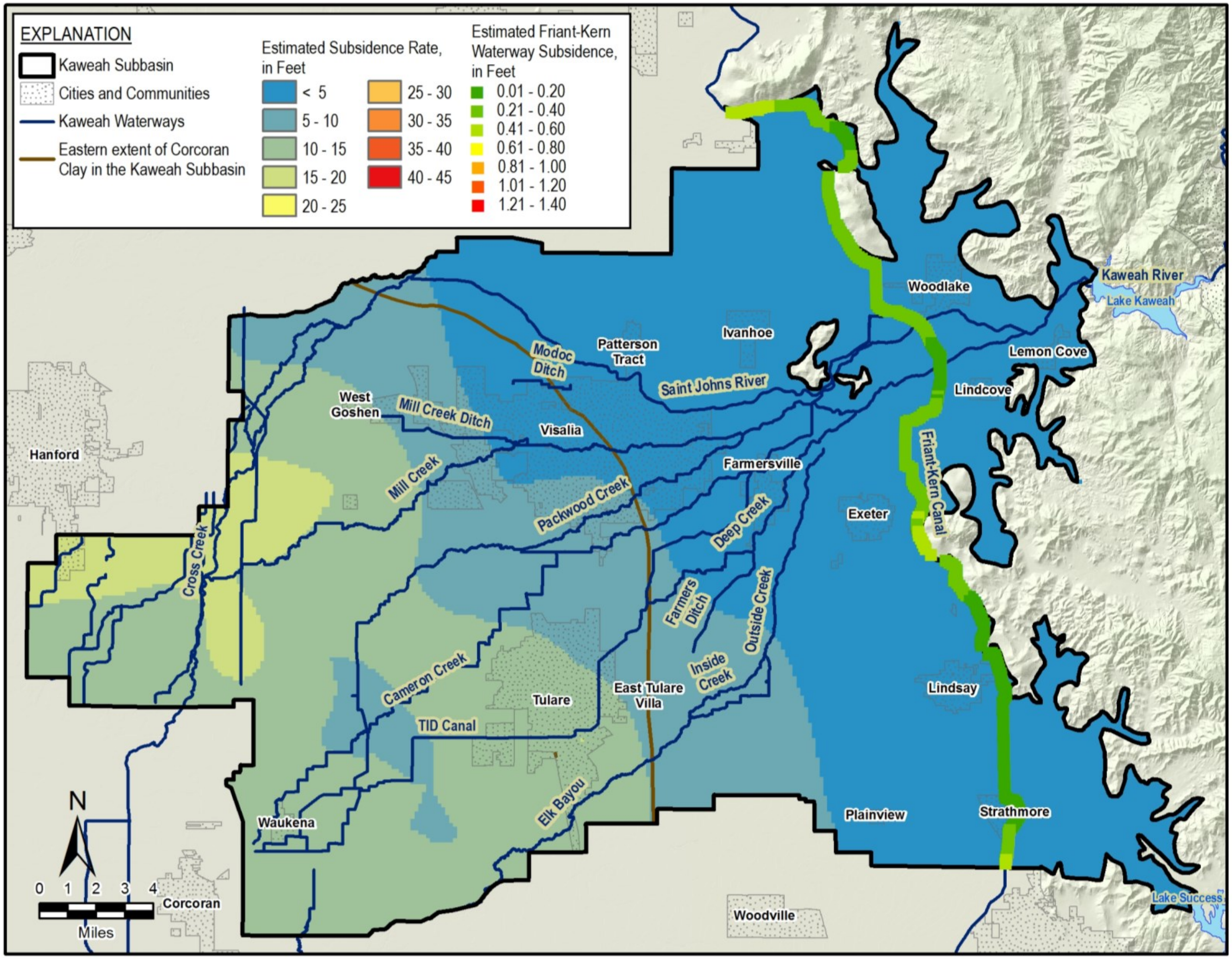


Figure 21. Estimated 2020 to 2040 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

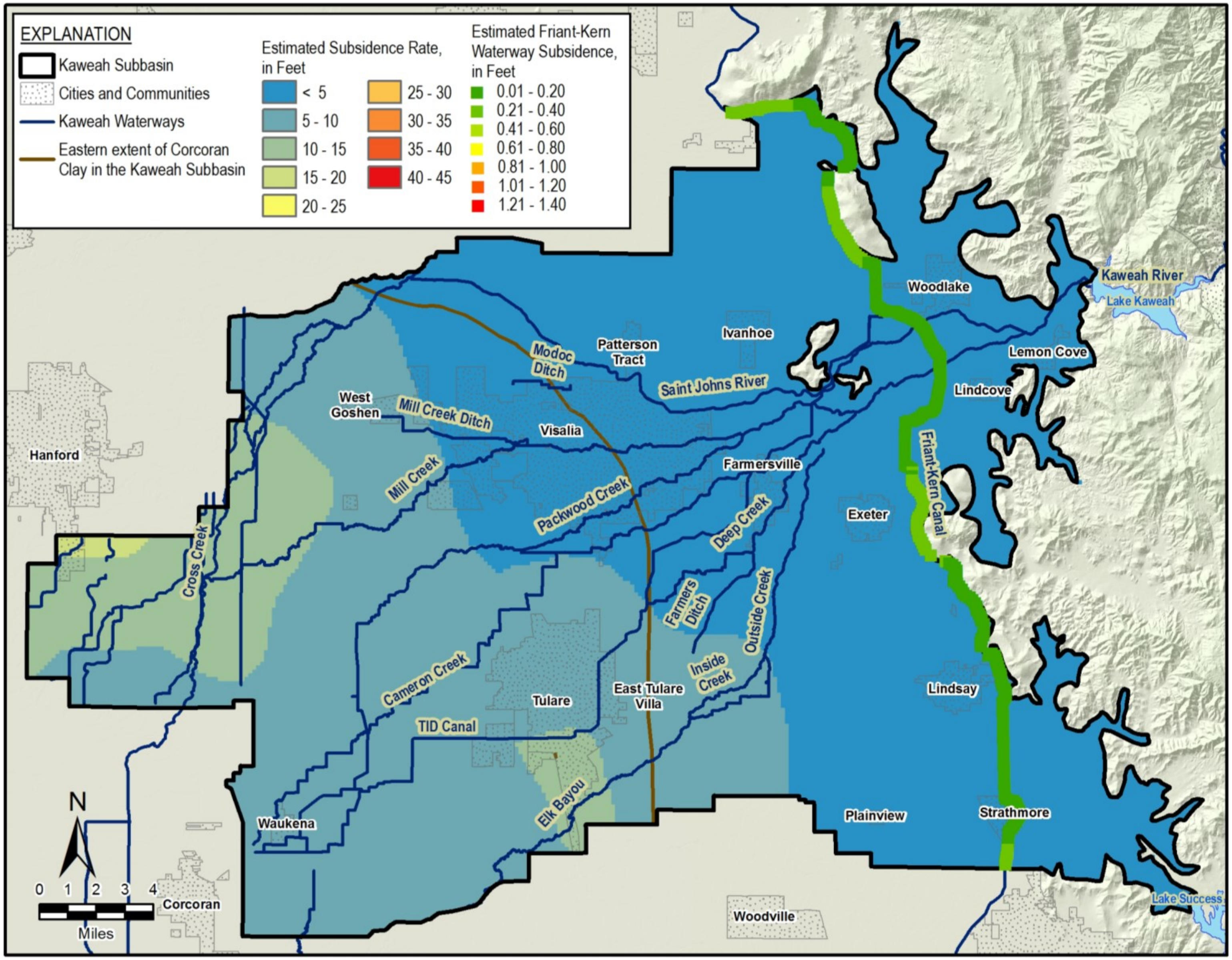


Figure 22. Estimated 2040 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

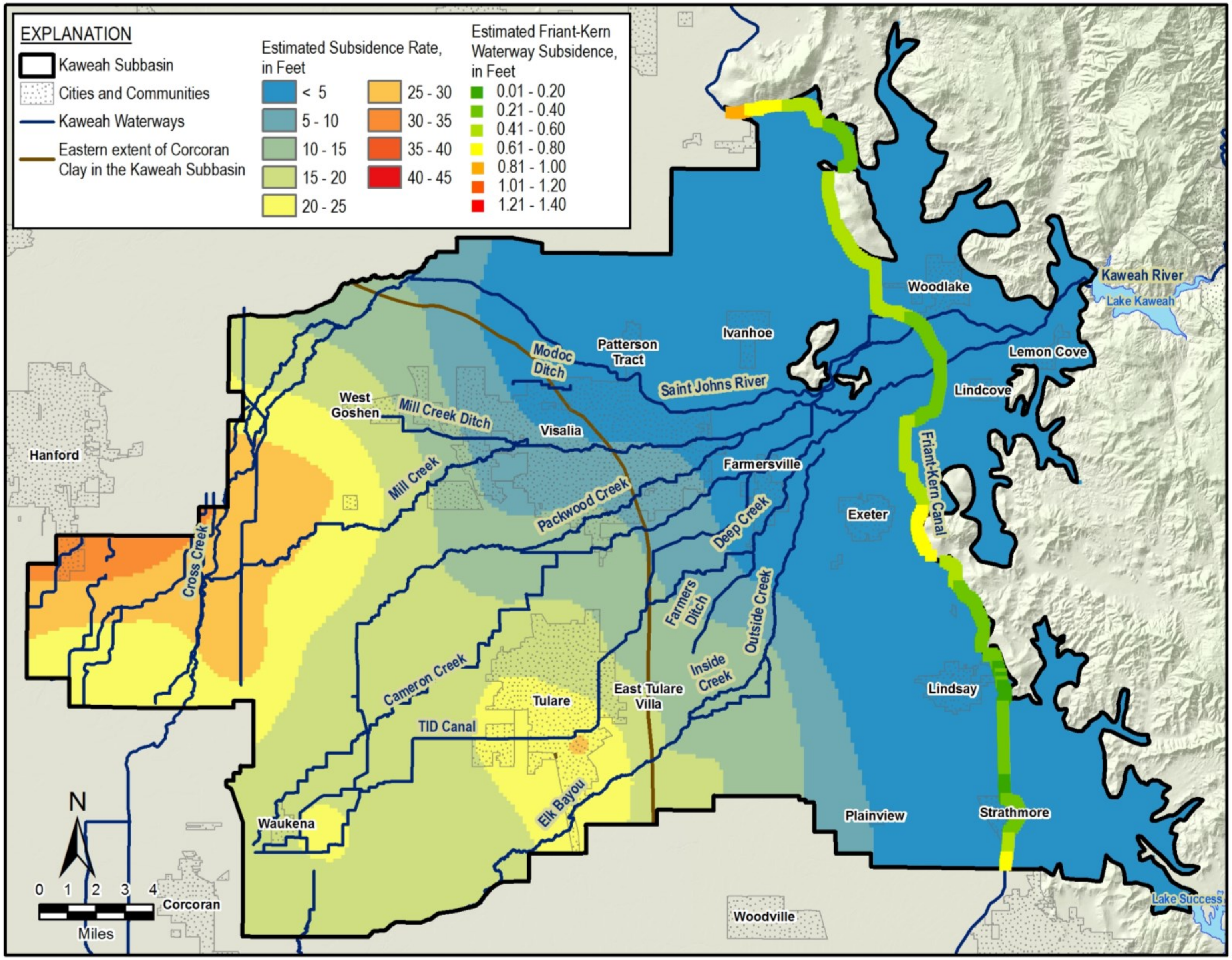


Figure 23. Estimated 2020 to 2070 Subsidence in Along Friant-Kern Canal when Groundwater Levels Stabilize at Measurable Objectives

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Table 3. Maximum Estimated Subsidence Along the Friant-Kern Canal Near Exeter

Time Period	Total Subsidence (feet)	Equivalent Subsidence Rate (inch/yr)
Groundwater Levels Stabilize at Minimum Thresholds		
2020 to 2040	0.50	0.30
2040 to 2070	0.43	0.17
2020 to 2070	0.93	0.22
Groundwater Levels Stabilize at Measurable Objectives		
2020 to 2040	0.42	0.25
2040 to 2070	0.26	0.10
2020 to 2070	0.68	0.16

2.2.2 Conveyance Infrastructure

The capacity of water conveyance infrastructures other than the Friant-Kern canal is impacted only if they subside more upstream than downstream, because the subsidence flattens the conveyance gradient and causes a reduction in capacity. The GSAs determined that a 10% loss of capacity in any of these conveyances would be significant and unreasonable.

Based on experience with the TID main canal, the 10% loss of capacity is equated to differential subsidence where a waterway's upstream subsidence is 1 foot more than its downstream subsidence over 1.5 miles. Each major waterway is analyzed using the total subsidence maps shown in Section 2.1.8, and greater than 1 foot of differential subsidence over 1.5 miles is predicted on 11 conveyance reaches.

Figure 24 through Figure 26 show the locations of conveyance infrastructure that would potentially be significantly impacted for various levels of subsidence. Figure 24 through Figure 26 show which conveyance infrastructures may be significantly impacted if groundwater levels are held at minimum thresholds. Figure 27 through Figure 29 show which conveyance infrastructures may be significantly impacted if groundwater levels are held at measurable objectives. These figures show the number and extent of conveyance infrastructure that should be included in the GSA's mitigation plans.

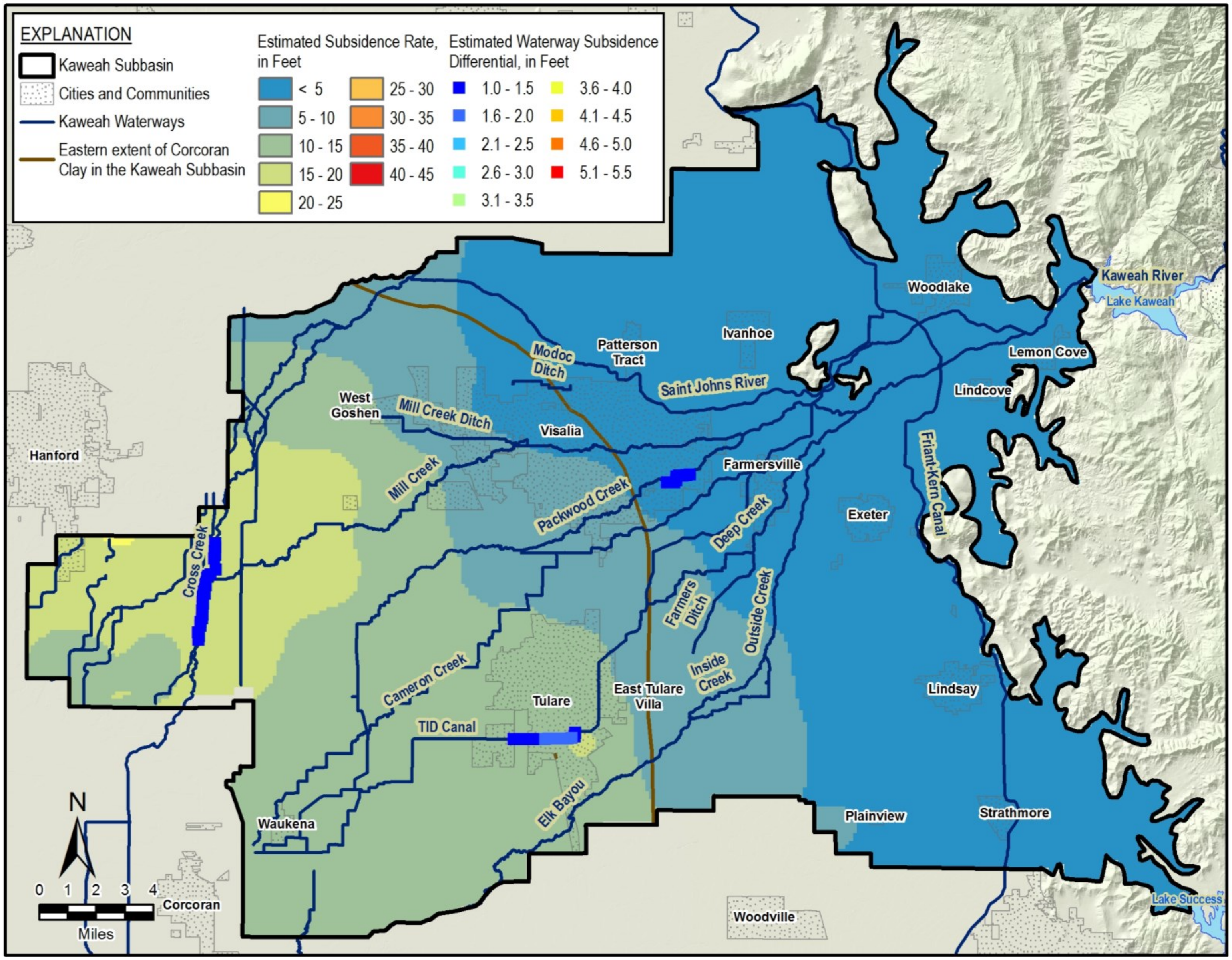

Figure 24. Estimated 2020 to 2040 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

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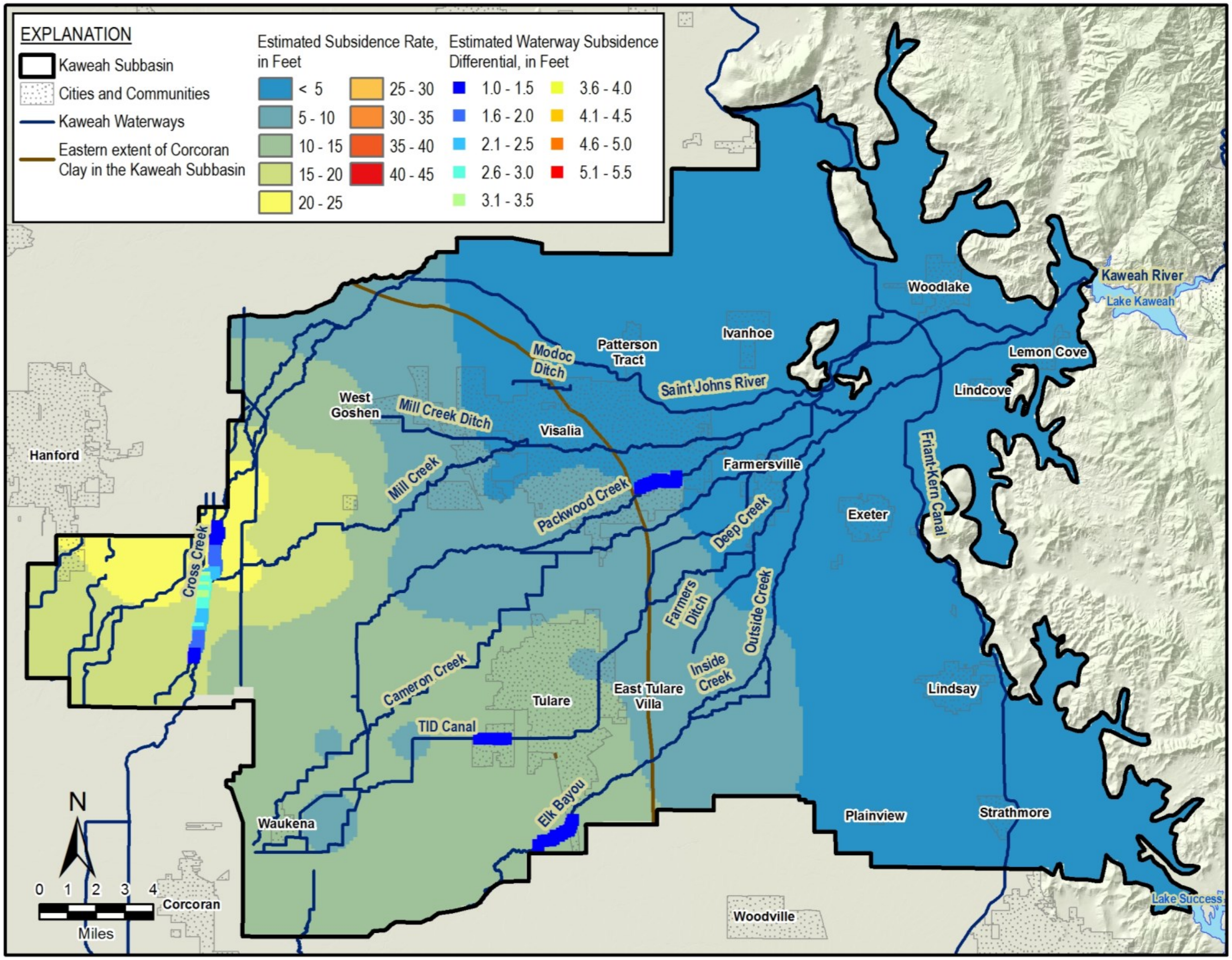

Figure 25. Estimated 2040 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

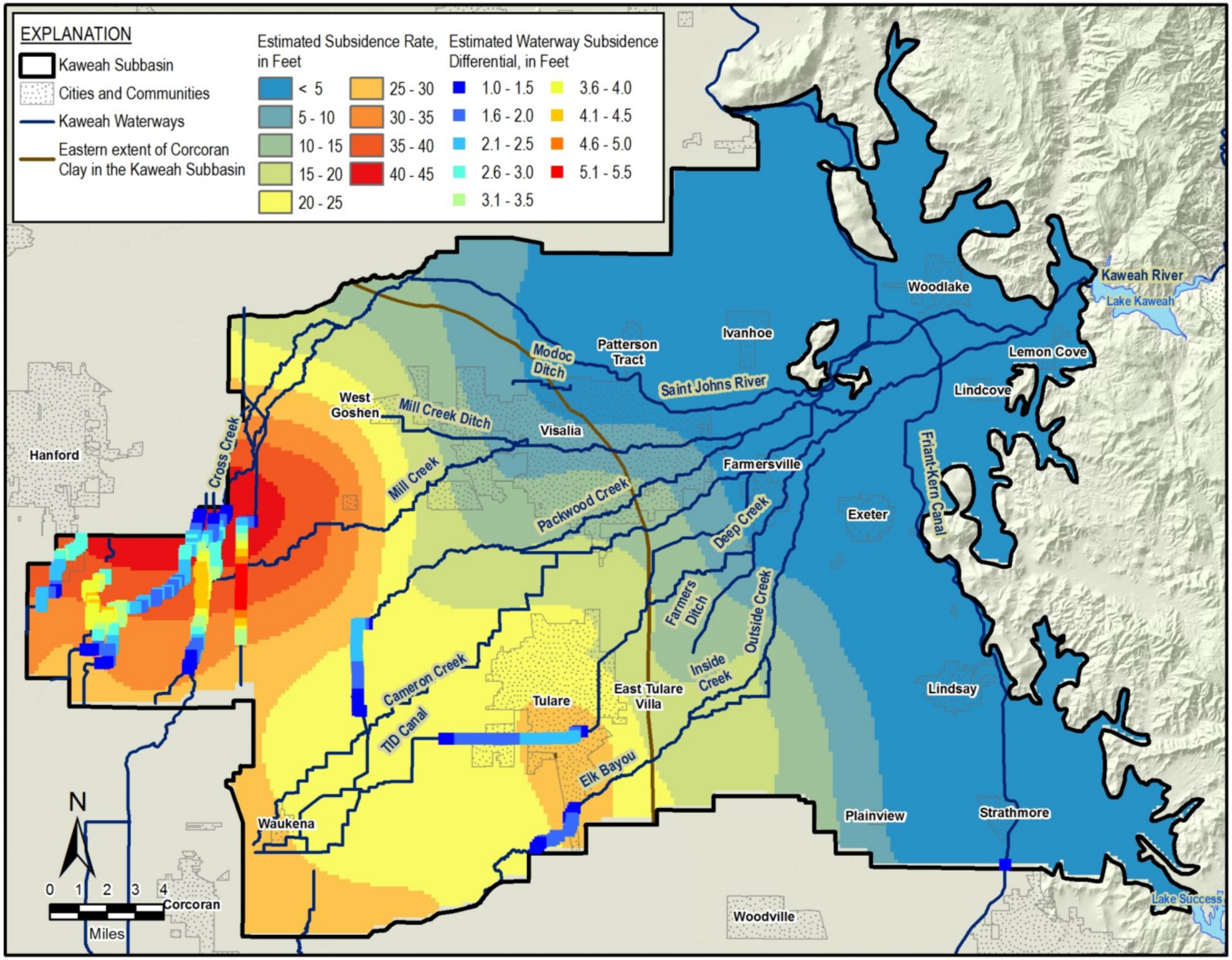

Figure 26. Estimated 2020 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Minimum Thresholds

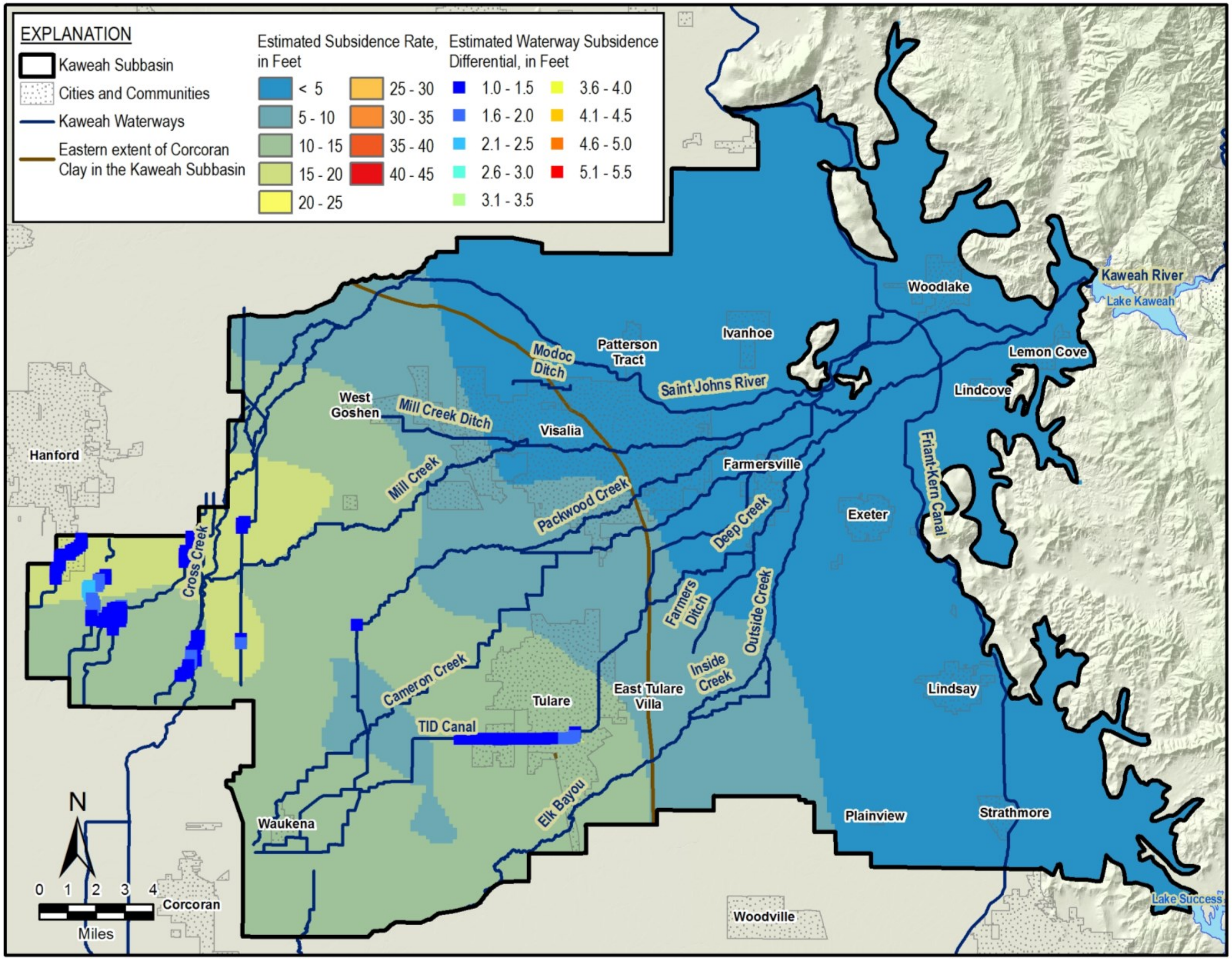

Figure 27. Estimated 2020 to 2040 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

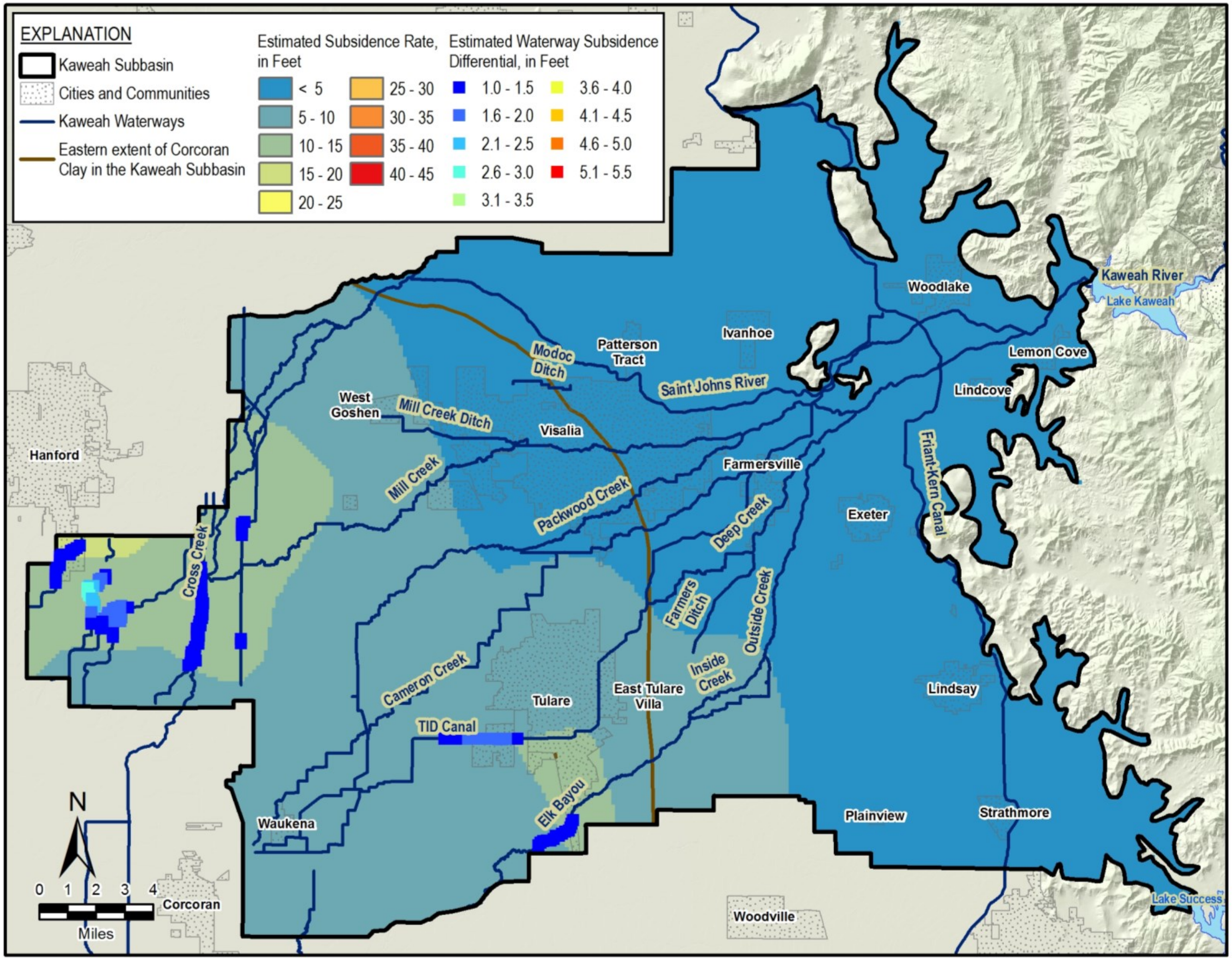

Figure 28. Estimated 2040 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

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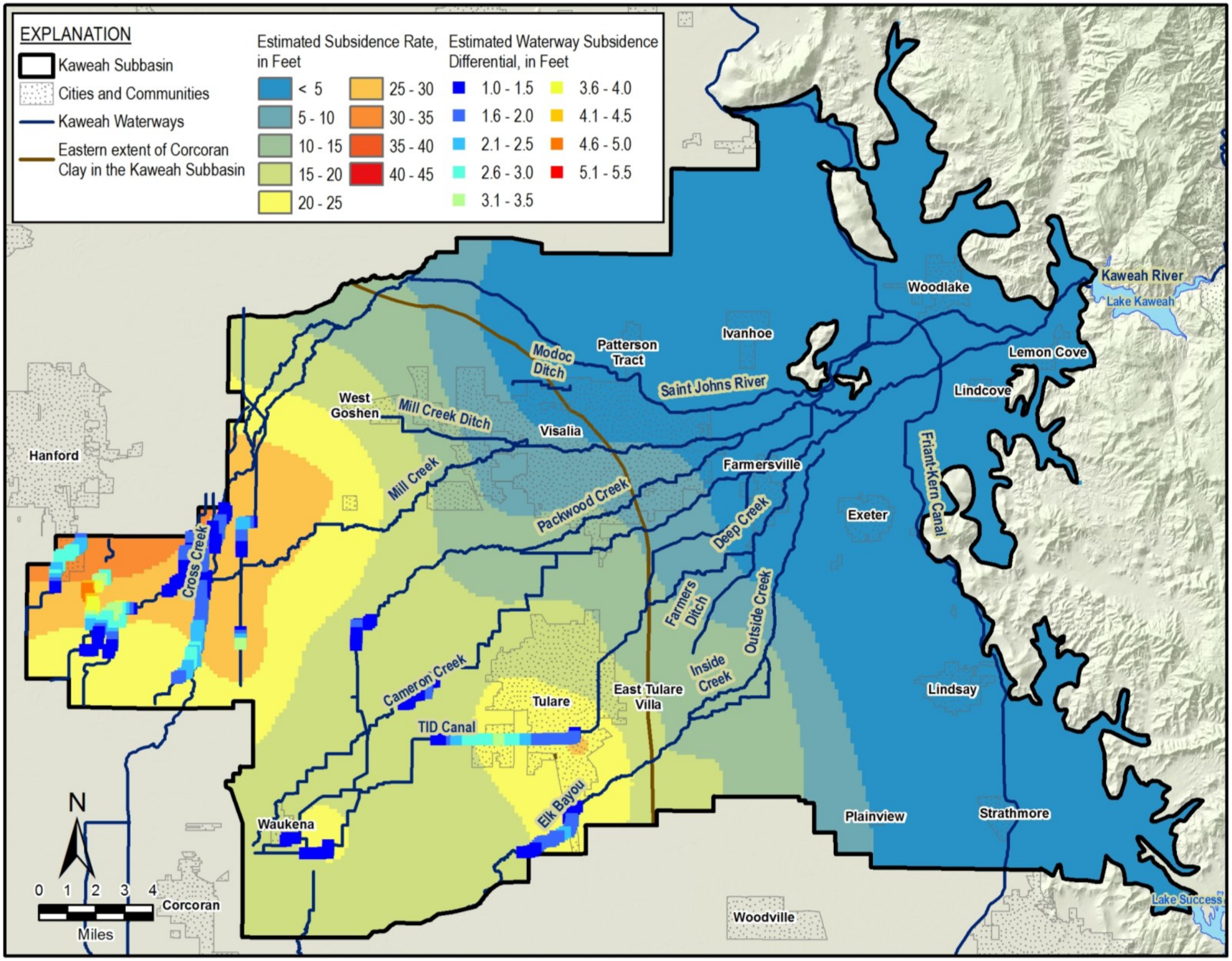

Figure 29. Estimated 2020 to 2070 Subsidence Impacts to Conveyance Infrastructure when Groundwater Levels Stabilize at Measurable Objectives

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