

TECHNICAL MEMORANDUM

DATE: December 15, 2021 Project No.: 18-1-132

TO: Jeff Barry, GSI Water Solutions, Inc.

FROM: William L. Halligan, PG

SUBJECT: **Revised Subsidence Vulnerability, Santa Clarita Valley Water Agency, Santa Clara River Valley Basin, East Subbasin**

INTRODUCTION

According to the U.S. Geological Survey (USGS), land subsidence is a phenomenon found across the United States, affecting the land surface of over 17,000 square miles in 45 states (Galloway et al., 1999). Land subsidence in California is commonly a result of fluid withdrawal (oil or groundwater). The principal causes of land subsidence are compaction of fine-grained subsurface materials (caused by reduction in hydraulic head affecting the physical structure and orientation of clay minerals and drainage of organic soils). Subsidence can occur in two forms, elastic (temporary) and inelastic (permanent). Impacts from subsidence are primarily related to infrastructure, such as roadways, pipelines, railroad tracks, etc.

GEOLOGIC AND GROUNDWATER CONDITIONS

When discussing the potential for land subsidence, it is important to consider the type of geologic materials that exist and if they may be susceptible to subsidence, along with factors that can create the conditions for subsidence such as groundwater extraction or oil extraction.

Out of the two primary water production aquifers in the Santa Clara River Valley Basin, East Subbasin (Subbasin), the Saugus Formation contains some silt and clay beds occurring predominantly in the central portion of the Subbasin in the vicinity of the Whittaker-Bermite site. The lateral extent of these clay beds has not been fully documented, however, review of available well logs, geophysical logs and other information indicates these beds may be confined to the Whittaker-Bermite site area and west of the site in the vicinity of Saugus Formation wells Saugus 1 and 2, V201, V205, V206, and V207. A schematic depiction of these units is illustrated in **Figure 1**.

The hydrostratigraphic units in the central portion of the Subbasin in the Saugus Formation correspond to alternating coarse and fine-grained beds with the coarse-grained units being relatively thick compared to the fine-grained units and identified as the SI, SIII, SV, SVII, and SVIII units while the fine-grained beds are relatively thin in comparison and designated as the SII, SIV, and SVI units. The coarse-grained units are generally about 200 to 600 feet thick and are generally not susceptible to compaction. This is because the structure of the

coarse-grained materials (sand and gravel) do not compact with declines in groundwater elevations like silts and clays.

The silt and clay beds are not laterally continuous throughout the Saugus Formation. In the western portion of the Subbasin in the vicinity of wells V206 and V207, analysis of lithology indicates that clay beds are minimal at the V206 site. Identification of clay beds at depths greater than 1,200 feet exist at the V207 site, however, that well is not constructed at those depths and projections of groundwater levels in the V206 and V207 area are expected to be similar to historical levels during normal years, however, will decline up to a maximum of approximately 150 feet below historical levels during short term droughts of one to five years (**Appendix A**). There are plans to construct and operate four new wells in the vicinity of V206 and V207 in the future. The simulated future low water levels described above include pumping from these not-yet constructed wells. The geology at the locations of these future wells are not known and will be evaluated once those wells are constructed to assess the potential for subsidence near the future wells.

As discussed further below, periods of historical low groundwater elevations were followed by periods of groundwater elevation recovery. Further, some evidence of subsidence exists, but the cause or causes are not clear. Also, impacts to infrastructure from subsidence have not been observed. Through the last nineteen years of reviewing and reporting on the geology and water resources in the Basin (Luhdorff and Scalmanini, 2019), there has not been evidence of chronic groundwater level declines that would contribute to subsidence (Luhdorff and Scalmanini, 2019).

Logs of production and monitoring wells were evaluated to identify areas where the Saugus Formation contains clay beds that could potentially undergo compaction should a pronounced and extended decline in groundwater elevations occur. Analysis of historical geologic cross sections was also conducted (CH2M HILL, 2004) that resulted in the identification of an area of the Subbasin where the Saugus Formation was subdivided into distinct hydrostratigraphic units, separated by three primary fine-grained confining units (CH2M Hill, 2004). As discussed above, this geographic location is in the central portion of the Basin where the Whittaker-Bermite site and production wells Saugus 1, Saugus 2, V201, and V205 are located. The three confining units, SII, SIV, and SVI (CH2M Hill, 2004; Luhdorff and Scalmanini, 2013) are each approximately 50 to 100 feet thick and composed of silts and clays with some coarse-grained materials as estimated from a review of geologic cross sections, well completion reports, and geophysical logs.

Should groundwater levels in the confined Saugus Formation substantially decline over an extended period where compressible layers are present along with decreases in the potentiometric head and associated decrease in pore pressure, some degree of compaction of these clay materials could occur resulting in subsidence. However, these three fine-grained units are at depths that are several hundreds of feet below the potentiometric head in the Saugus Formation when observing both historical Saugus Formation groundwater levels and projected elevations based on model simulations (**Appendix A**). These clay units are not as extensive in the western portion of the Saugus Formation in the vicinity of V206 and V207 and pinch out (become very thin) toward the South Fork area of the Subbasin where wells NC12 and NC13 are present. As mentioned, data on the occurrence of clay beds in the vicinity of the four new Saugus Formation wells near the Magic Mountain area is not known as the exact location of these wells has not been finalized nor the borings drilled.

Land Surface and Groundwater Elevation Monitoring Data

Land surface elevation monitoring data is available from three separate sources. UNAVCO operates a network of continuous global positioning system (CGPS) sites throughout California and has two sites in the Subbasin outside the margin of the Alluvial valley floor. The second source of data is from the European Space Agency in the form of INSAR data that is available through DWR. The third source of data is from Los Angeles County Department of Public Works (LACDPW) through its network of survey benchmarks throughout the Subbasin. There is also groundwater elevation monitoring conducted by SCV Water from selected wells in the Subbasin including Wells V201, V205, V205M, Saugus 1, and Saugus 2. The locations of these wells are depicted in **Figure 2**.

UNAVCO CGPS

As of February 2020, land surface elevation is being monitored at two continuous global positioning system (CGPS) sites in the Basin as reported by UNAVCO (<http://www.unavco.org/data/data.html>). Data collection has been ongoing since the early 2000's with daily measurements.

The locations of the UNAVCO CGPS sites along with historic vertical displacement data are presented in **Figure 3**. The relatively stable trend of these plots indicate that long-term subsidence is not occurring. Since the beginning of data collection in the early 2000's at both UNAVCO locations, the net vertical displacement is positive (0.05 ft) at the CTDM site and zero at the SKYB site. This means that the land surface has risen (positive displacement) or stayed the same. In any given year, the vertical displacement is generally less than 0.05 feet, with the exception of 2006 to 2007 at the SKYB site. Within the context of complex southern California geology, the elevation change (less than 0.2 feet vertical change over the last 20 years) seen at the two UNAVCO stations is likely due to tectonic activity since these stations are located north of the San Gabriel fault in locations where minimal groundwater extraction occurs.

DWR ESA INSAR

Land surface elevation data was also obtained from the Department of Water Resources SGMA Data viewer. The TRE Altamira InSAR Dataset contains vertical displacement data from June 2015 through September 2019. These data were collected by the European Space Agency Sentinel-1A satellite and processed by TRE Altamira. The dataset covers more than 200 groundwater basins across the state at a resolution of approximately 100 square meters (almost 1,100 square feet). Vertical displacement for the winter-to-winter period from 2015/2016 through 2018/2019 period over the entire Subbasin from the TRE Altamira InSAR dataset is presented in **Figure 4**. Vertical displacement values in the Subbasin ranged between -0.25 and +0.25 feet. In the central area of the Subbasin in the vicinity of wells V201, V205, Saugus 1, and Saugus 2 the range of displacement was smaller (0.025 to 0.032 feet). To avoid accounting for elastic (temporary) compaction without recognizing corresponding elastic rebound, it is best to evaluate subsidence from a comparison of data collected in the winter or early spring to avoid incorporating elastic or temporary subsidence that can vary season to season and from year to year. Because the satellite data was developed from a summer to early fall time frame, it likely is not a reliable starting and ending date to evaluate inelastic or permanent subsidence. In addition, the resolution of satellite data for subsidence monitoring is not as accurate as ground-based data collection. GPS

benchmark monitoring locations such as those maintained by UNAVCO generally have an accuracy of approximately 0.05 feet, while satellite data from the DWR website via the European Space Agency has an error that is approximately 0.02 feet greater than global positioning system measurements.

Los Angeles County Department of Public Works Benchmark Surveys

The Los Angeles County Department of Public Works (LACDPW) has a network of over one hundred benchmarks in the Subbasin as part of a larger survey network in Los Angeles County (<http://dpw.lacounty.gov/sur/BenchMark/>). LACDPW reportedly surveys these benchmarks approximately every six years. The surveys began in 1978 and the most recent survey in the Subbasin was conducted in 2018. These benchmarks are located in the “Newhall Quad.” The Index of benchmarks contained in this quad are depicted in **Figure 5** and the specific benchmarks in the vicinity of existing Saugus Formation wells are presented in **Table 1**.

Ideally land surface data from 1978 to the present could be precisely compared to each successive survey event, but this is not practical because vertical datums changed between 1993 and 1995. Land surface elevation data from 1995, 2009, and 2018 for these benchmarks were evaluated to determine the magnitude of subsidence that occurred over this time period because the elevations were measured using the same NAVD88 vertical datum required by DWR. The benchmark surveys measured prior to 1995 in 1978, 1983, and 1993 were measured using the older and different NGVD29 vertical datum.

Benchmark measurements are recorded to the nearest thousandths of a foot reflect a basic accuracy of ± 0.017 feet per mile (LADPW, 2018). Between 1995 and 2018, benchmarks located near the Saugus Formation production wells in the western and central area of the Subbasin had recorded changes in land surface elevations that ranged from -0.179 to +0.011 feet over the 23-year period between 1995 and 2018 (**Table 1**).

Groundwater elevations in the Saugus Formation historically were most depressed in the early 1990s during the highest amount of pumping from the Saugus Formation. The 1995 dataset was collected by LADPW about one or two years after the peak decline in Saugus Formation groundwater levels. The 1993 benchmark survey was collected using a different vertical datum than the 1995 making it difficult to compare the 1993 to 1995 surveys in order to see if the peak Saugus pumping could be correlated with land surface elevation changes. Generally, the examination of LADPW benchmark data indicates that many factors are contributing to the very small amount of land elevation shifts that have occurred over time. These factors include tectonic influences from this seismically active area of California, the time of year each benchmark survey was collected (meaning it is difficult to determine if land surface changes are elastic or inelastic), and groundwater pumping. LADPW data was also reviewed outside of the areas where these Saugus Wells are located. Positive and negative ground surface elevation changes can be seen in areas away from Saugus Wells, including north of the San Gabriel Fault. In the future, with the implementation of a basin-wide subsidence monitoring program, correlations of groundwater pumping to changes in land surface elevations will be better understood. The yearly rate of subsidence that occurred between 1995 and 2018 was 0.008 feet per year given the maximum subsidence of -0.179 feet noted above. That annual average rate is less than the accuracy of the benchmark surveying equipment and is negligible.

Summary of Land Surface Elevation Data Sets

The data that has been available for review has provided the following understanding of the occurrence of changes in land surface elevations over time as summarized in **Table 2**. From the period spanning 1995 to 2018, LADPW benchmark survey data in the vicinity of the Saugus Formation wells show changes in land surface elevations that have ranged from -0.179 to +0.011 feet over 23 years from 1995 to 2018 with an average annual rate of -0.008 feet per year to less than 0.001 feet per year. The InSAR ground surface elevation data for the three-year period from 2015/16 to 2018/19 in the central portion of the Subbasin where clay beds are most prevalent, the magnitude of subsidence was 0.025 to 0.032 feet or approximately 0.008 to 0.010 feet per year over that very short time frame. The UNAVCO benchmark data showed either no change in land surface elevation over the past 20 years or a rise of 0.05 feet, equating to an annual rise of 0.002 feet per year. The locations of the UNAVCO stations are north of the San Gabriel fault where no large-scale municipal pumping occurs from the Saugus Formation, thereby the changes in land surface elevations are likely the result of the regions seismic activity.

Table 2: Subsidence Datasets

Dataset	Time Period	Range of Elevation Change (ft)	Annual Rate of Elevation Change (ft/yr)
UNAVCO CGPS	CTDM: 2001-Present	+0.05	+0.003
	SKYB: 2006-Present	+0.00	+0.00
DWR ESA INSAR	2015-2020	-0.025 to +0.028	-0.0017 to +0.0056
LA County DPW Benchmark Surveys	1995-2018	-0.179 to +0.011	-0.0078 to +0.00048

Historical Saugus Formation Groundwater Elevations

Evaluation of groundwater elevation data from the area of the Subbasin where projected groundwater levels during normal years are expected to have the greatest declines as compared to historical elevations (Appendix A) were evaluated. This area is located in the central area of the Subbasin in the vicinity of five wells (Saugus 1, Saugus 2, V201, V205, and V205M). This also corresponds to the area that has the most pronounced evidence of fine-grained clay beds (see discussion of geology above).

Analysis of historical groundwater level data indicated that data was collected beginning in the early 1990s and into 2020, however, only one of the five wells (V201) had a complete dataset for this period while the other four wells had partial datasets (**Appendix A**). Data from Saugus 1 and Saugus 2 are not available after 2011 due to the well repair that impacted the sounding tubes. However, the data from these two wells is valuable because the data (coupled with data from well V201) capture the period (1993) when

groundwater levels in the Saugus Formation declined to historic lows. The historic low was brief and was not maintained.

Projected Saugus Formation Pumping

The hydrographs in Appendix A were prepared using results from the Subbasin numerical model and show historical groundwater level data along with projected (future) groundwater elevations. The comparison of the projected and historical data at each well allows one to see simulated future groundwater levels, including during normal periods and drought periods. The future water levels are representative of “full build-out land use conditions” that include the sustained operation of wells V201 and V205 (in part for perchlorate removal), along with additional source capacity for extraction of groundwater from the Saugus Formation in the V206 and V207 area of the Subbasin that would allow SCV Water to extract approximately 35,000 acre feet per year during multiple dry years.

Central Area

Projections of Saugus Formation groundwater pumping volumes in the central area (Saugus 1 and 2, V201, V205) are expected to be higher than historical amounts during normal *and* dry years. Groundwater model simulations of future normal year conditions (Saugus 1 and 2, V201) indicate groundwater levels will be maintained approximately 100 to 150 feet lower in normal years than in the past, with some shorter-term decreases in water level beyond these during drought.

Western Area

Projections of Saugus Formation groundwater pumping in the western area (V206, V207 and four to-be-constructed Saugus wells) are expected to be higher than historical amounts during dry years. Groundwater model simulations of future conditions (V 206 and 207) indicate groundwater levels will be similar to historical normal year levels, but in drought years are projected to be approximately 100 to 150 feet lower than in the past.

Conclusions

The potential for subsidence to occur is driven by many factors as described above, however, the presence of significant clay beds coupled with a significant length of time (years) of sustained groundwater elevations at or below historic lows is one component necessary for inelastic land subsidence (permanent land subsidence) to occur.

Evidence of Past Land Subsidence Caused by Groundwater Extraction

A review of past groundwater elevations show that chronic decline in water levels has not taken place. A review of three different land surface elevation data sets provide good information about elevations over time, but do not suggest clear evidence of groundwater pumping caused subsidence. Land surface elevations have varied across the Subbasin, resulting in some areas showing increases in land surface elevations and other areas exhibiting decreases, dependent on the time frame and location that the datasets cover. The data indicates that many factors appear to contribute to changes in land surface elevations. These factors include:

- The Subbasin being located in a tectonically active area,
- Time of year data is collected and whether it includes the effects of elastic subsidence on the land surface elevation data,
- Frequency of data collection, and;
- Analysis and characterization of the occurrence of significant clay beds and potential for compaction.

Potential Future Land Subsidence

The potential for subsidence in the various areas of the Subbasin to occur in the future is difficult to predict or quantify based on the datasets evaluated and documented above. Groundwater elevations in the future, in particular at full build out, will be lower than in the past. In some areas, groundwater elevations will be lower than past drought water elevations (western area), and in other cases groundwater elevations will be lower both in normal and drought conditions (central area). The central area appears to contain more compressible fine grained layers than the west and because of these factors, there may be a potential for future subsidence, but it is difficult to predict, and should be monitored.

Further, these fine-grained materials are at depths that are several hundreds of feet below the potentiometric head in the Saugus Formation when observing both historical Saugus Formation groundwater levels and projected elevations based on model simulations (**Appendix A**). This fine-grained unit placement is considered a more favorable condition than physically dewatering clays as the groundwater potentiometric surface becomes lower. These clay units are not as extensive in the western portion of the Saugus Formation in the vicinity of V206 and V207 and pinch out (become very thin) toward the South Fork area of the Subbasin where wells NC12 and NC13 are present. As mentioned above, data on the occurrence of clay beds in the vicinity of the four new Saugus Formation wells near the Magic Mountain area is not known as the exact location of these wells has not been finalized nor the borings drilled.

Approach to Establish a Preliminary Subsidence Minimum Threshold

In order to develop the minimum threshold for subsidence in the GSP, a methodology was developed to approximately estimate the magnitude of subsidence that may occur in the planning and implementation period of the GSP. There was a short period of time between the winter of 2015/2016 to winter 2018/2019 where a comparison of observed land surface elevation from DWR's InSAR dataset could be compared to groundwater level declines in the area of the Basin where clay beds exist in the Saugus Formation and where the potential for future subsidence is the most probable as a result of increased pumping. As described above, the central portion of the Basin in the vicinity of well V-201 is where groundwater levels are predicted by the groundwater model to be lowest in future. In this area, a groundwater level decline of 15 feet was measured between winter of 2015/2016 and winter of 2018/2019. The InSAR data showed a corresponding reduction in ground surface elevation of approximately 0.032 feet. If the change in ground surface elevation shown in the InSAR data is actually related to groundwater extraction, this equates to approximately 0.01 feet of subsidence per 5 feet of groundwater elevation decline. As stated previously, it is not known if the observed reduction in ground surface elevation is related to pumping or to tectonics.

It is anticipated that groundwater elevations could be lower in the future as the Basin Operating Plan is implemented at full build out of the Basin to meet future demands during extended drought periods. The groundwater flow model was used to estimate future groundwater levels in the Basin. The approximate difference between long term average historic groundwater levels observed in well V-201 and future projected groundwater levels is estimated to be on the order of 150 feet. When considering historical low groundwater levels (e.g., 1993) measured at well V-201, the difference between measured groundwater levels and the predicted lowest dry year/drought groundwater levels in the future is approximately 70 feet. Depending on which of the two water level differences that are used, the approximate amount of subsidence that could occur in the future ranges between 0.3 feet of subsidence for the 150 feet of groundwater level decline to approximately 0.14 feet for the 70 feet of decline. This estimate assumes that the InSAR measured reduction in land surface elevation used in the calculations is a direct result of groundwater extraction, which may not be the case. It is also not known over what timeframe this estimated subsidence might occur since it is understood that subsidence effects can be delayed and because the rate of subsidence can be affected by the duration that groundwater levels are below the historical low.

Based on this evaluation, the minimum threshold for subsidence has been preliminarily set at a rate of 0.1 feet in any single year with a maximum subsidence of 0.5 feet over any 5-year period. Due to the considerable uncertainty associated with estimating subsidence rates in the Basin and the lack of a complete data set from which to estimate subsidence, the GSA plans to conduct robust subsidence monitoring and consider adjusting thresholds should monitoring data indicate that this is advisable and warranted.

Data Gaps and Next Steps

Some areas in California that have a history of subsidence (California's Central Valley) and impacts on infrastructure have existing subsidence monitoring networks that can be used to correlate subsidence to groundwater pumping and changes in groundwater elevations.

The East Subbasin has not had a history of impacts on infrastructure related to subsidence in general, regardless of the cause, and therefore, an organized subsidence monitoring program has not been developed. This lack of sufficient historical subsidence data collection has resulted in a large degree of uncertainty in identifying past causes of land surface elevation changes.

With the current uncertainty about the potential for future groundwater extraction to cause land subsidence, a robust monitoring program has been developed and described in the GSP to monitor land surface elevations utilizing the existing subsidence monitoring programs above, but with additional data collection by the SCV GSA. These data will allow for the GSA to determine if land surface elevation changes can be correlated with groundwater extraction and if the changes are elastic or inelastic. Data will be evaluated to help manage groundwater pumping in the Saugus Formation to minimize the impacts of subsidence should it occur.

REFERENCES

CH2M Hill, 2004. Conceptual Hydrogeology Technical Memorandum, Eastern Santa Clara Subbasin Groundwater Study. June 2004.

Galloway, et. Al., 1999. Land Subsidence in the United States. United States Geological Survey, Circular 1182.

Helm 1977, Estimating parameters of compacting fine-grained interbeds within a confined aquifer system by a one-dimensional simulation of field observations, in Land subsidence symposium: Proceedings of the second International Symposium on Land Subsidence, December 13-17, 1976: International Association of Hydrological Sciences, IAHS-AISH Publication series, no. 121, p. 145-156.

Los Angeles County Department of Public Works (LACDPW), 2018. Newhall Quad Benchmarks 2018 Adjustment. 2018.

Luhdorff and Scalmanini, 2013. Updated Draft Task 1 Historical Data Analysis, Restoration of Valencia Water Company Well V201, Santa Clarita Valley, California. December 23, 2013.

Luhdorff and Scalmanini, 2019. 2018 Santa Clarita Valley Water Report, Santa Clarita Valley Water Agency, Los Angeles County Waterworks District 36. May 2019.

Figures

Figure 1. Saugus Hydrostratigraphic Units Schematic

Figure 2. Saugus Formation Well Locations

Figure 3. UNAVCO Continuous GPS Station Locations

Figure 4. TRE Alameda InSAR Dataset (October 2018 – October 2019)

Figure 5. Newhall Quad Benchmark Index

APPENDIX A

Groundwater Elevation Hydrographs, Historical and Projected GSI Water Solutions