TODD GROUNDWATER

July 9, 2020

DRAFT MEMORANDUM

To: Turlock Subbasin Joint Technical Advisory Committees (TACs)

From: Phyllis Stanin, Vice President/Principal Geologist

Re: Consideration of the Land Subsidence Sustainability Indicator
Turlock Subbasin GSP

Over the last several months, the joint TACs have been discussing technical information on the six sustainability indicators as defined in the Sustainable Groundwater Management Act (SGMA). In June, the joint TACs considered the land subsidence sustainability indicator as it relates to the Turlock Subbasin. During that discussion, the joint TAC members requested the technical team to prepare a memorandum on this indicator summarizing GSP requirements, issues relating to the Turlock Subbasin, and examples of how other subbasins in the Central Valley had defined Undesirable Results.

This draft memorandum has been prepared to facilitate ongoing discussions on the inelastic land subsidence sustainability indicator. The memorandum does not provide all GSP regulatory requirements nor does it contain a full description of the mechanisms of land subsidence and groundwater conditions in the Turlock Subbasin. Rather, key technical issues and regulations are summarized for the purposes of assisting the joint TACs with selection of appropriate sustainable management criteria and GSP monitoring strategies.

GSP REQUIREMENTS AND BEST MANAGEMENT PRACTICES

In its definition of undesirable results, SGMA identifies six sustainability indicators, which describe potential adverse groundwater conditions as summarized below.

SGMA Sustainability Indicators

					
Chronic Lowering of Water Levels	**Reduction of Groundwater in Storage**	**Degraded Water Quality**	**Seawater Intrusion**	**Inelastic Land Subsidence**	**Depletion of Inter-connected Surface Water**

The sustainability indicator for land subsidence addresses the potential for inelastic (i.e., permanent) subsidence of the ground surface caused by groundwater extraction. Adverse impacts associated with this process have been documented in other areas of California experiencing land subsidence including:

- Damage to infrastructure including foundations, roads, bridges, or pipelines.
- Loss of conveyance in canals, streams, or channels.
- Diminished effectiveness of levees.
- Collapsed or damaged well casings.
- Land fissures.

The SGMA definition of undesirable results for this indicator is stated as follows: "Significant and unreasonable land subsidence *that substantially interferes with surface land uses*." 10721.x(5), *emphasis added*). The inclusion of "surface land uses" links the definition to the adverse impacts listed above. Damage to critical infrastructure could readily interfere with surface land use.

GSP regulations require the quantification of a minimum threshold (MT) to signal the likelihood of undesirable results. Metrics for the land subsidence MT involve the rate and extent of subsidence; where water levels can be linked to that rate and extent, a designated water level at representative monitoring sites can be used as a proxy. The MT must also consider the land uses and property interests that have been affected or are likely to be affected by permanent land subsidence.

In its Best Management Practices (BMP) on Sustainable Management Criteria (DWR, 2017), DWR lists technical questions to consider in establishing an MT for the land subsidence sustainability indicator:

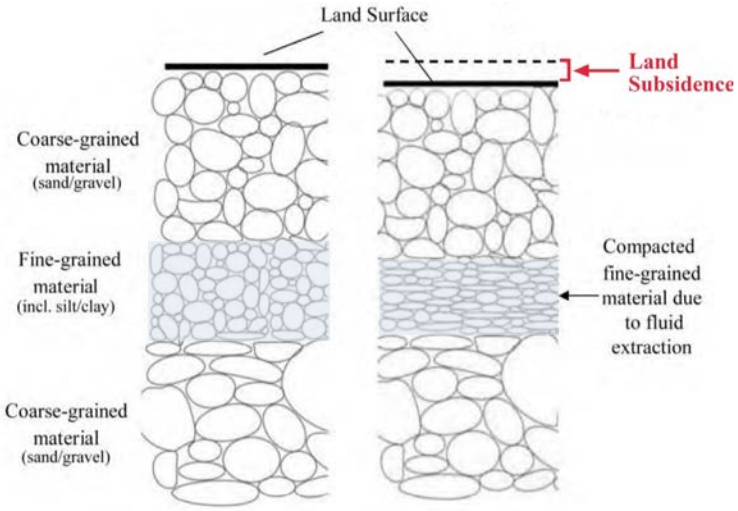
- Do principal aquifers contain sediments susceptible to subsidence?
- What are the historical, current, and projected groundwater levels, particularly the historical lows?
- What is the historical rate and extent of subsidence?
- What are the land uses and property interests in areas susceptible to subsidence?
- Where are infrastructure/facilities in areas susceptible to subsidence?
- What are the adjacent subbasin's MTs for this indicator?

The mechanism of land subsidence and key questions listed above are addressed briefly for the Turlock Subbasin in the following section.

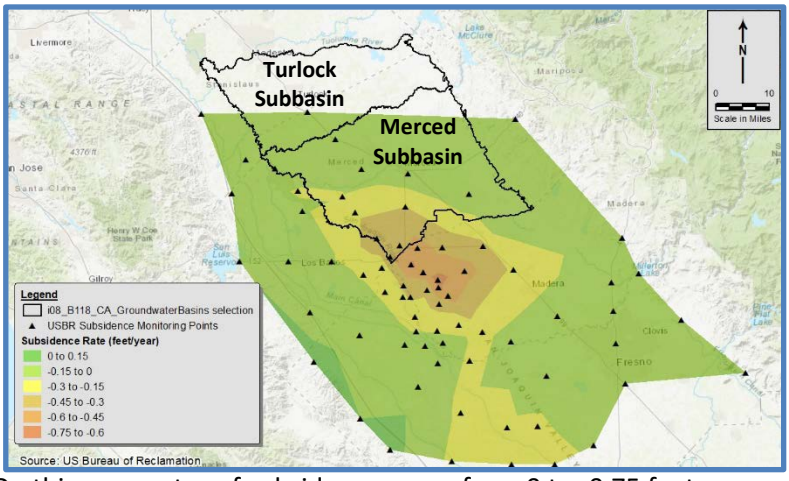
INELASTIC LAND SUBSIDENCE IN THE TURLOCK SUBBASIN

The joint TACs have reviewed the mechanisms of elastic and inelastic land subsidence related to groundwater extraction in several meetings (most recently on June 25, 2020) and have also reviewed technical information provided in draft sections of the GSP Basin Setting.

In brief, water level declines associated with pumping cause a decrease in water pressure in the pore space (pore pressure) of the aquifer system (Galloway, et al., 1999). This pressure can cause the aquifer system to deform, resulting in the re-arrangement and compaction of fine-grained sediments such as clay.[1] As the sediments compact, the ground surface can sink, as illustrated by the diagram.



Land subsidence in the San Joaquin Valley has been documented for more than 90 years and recent investigations using satellite imagery indicate continuing problems in some areas. Much of the deformation and related inelastic land subsidence in the Central Valley is associated with compaction of the Corcoran Clay. This regional aquitard is a clay-rich lacustrine deposit that occurs throughout the Valley, including beneath the western portion of the Turlock Subbasin (extending from the San Joaquin River to a few miles east of Highway 99). Most of this regional subsidence occurs south of the Turlock Subbasin as indicated on the map prepared by the U.S. Bureau of Reclamation below. Investigations cite the dewatering of the Corcoran Clay as a primary mechanism for inducing land subsidence in the San Joaquin Valley.



Rates of historical subsidence are shown on the map with higher rates indicated in the southern Merced Subbasin and the adjacent subbasin to the south (i.e., Chowchilla Subbasin, boundaries not shown). Subsidence extends south of this map into additional subbasins. On this map, rates of subsidence range from 0 to -0.75 feet per year (9 inches per year). As indicated on the map, the data that extends into the Turlock Subbasin indicates negligible to

[1] Although extraction of groundwater by pumping wells causes a more complex deformation of the aquifer system than discussed herein, the simplistic concept of vertical compaction is often used to illustrate the land subsidence process (Galloway, et al., 1999; LSCE et al., 2014).

small rates of land subsidence from 0 to -0.15 feet per year (0 to 1.8 inches per year). More recent satellite imagery data[2] from DWR indicates areas of potential small vertical displacement of the land surface in the Turlock Subbasin; however, additional ground-truthing is required to determine if the displacement is actual land subsidence and if so, whether it is elastic or inelastic. A decrease in water levels from groundwater pumping can cause a small elastic compaction in both coarse- and fine-grained sediments that recovers as water levels rise and the effective stress returns to its initial value. Because elastic deformation is relatively minor and fully recoverable, it is not considered an impact.

Impacts associated with subsidence have not been identified in the Turlock Subbasin. This is likely due to the lack of significant water level declines in the western Subbasin that could cause compaction of the Corcoran Clay. Nonetheless, the potential for future land subsidence in this area could occur if future water level declines were sufficient to induce compaction of the Corcoran Clay.

EXAMPLES OF OTHER UNDESIRABLE RESULTS

It is difficult to determine how best to define undesirable results and select appropriate sustainable management criteria in the Turlock Subbasin because undesirable results relating to inelastic land subsidence is not occurring and has not occurred. To facilitate this process, definitions of undesirable results for the land subsidence indicator from several GSPs[3] in critically-overdrafted basins were reviewed.

A definition of undesirable results from the Merced Subbasin seems particularly relevant to the Turlock Subbasin because of similar geology and land uses in the areas of highest land subsidence potential (i.e., western Subbasin). Merced Subbasin's undesirable result definition is provided below.

> An undesirable result for land subsidence would be a significant and unreasonable reduction in the viability of the use of infrastructure over the planning and implementation horizon of this GSP. Land subsidence that substantially interferes with surface land uses causes damage to public and private infrastructure (e.g., roads and highways, flood control, canals, pipelines, utilities, public buildings, residential and commercial structures). The main conveyance facility that has the potential to be damaged or have reduced flood conveyance capacity due to subsidence is the Eastside Bypass, located in the southwest corner of the Merced Subbasin.
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> Exceedances of minimum threshold rates of land subsidence at three or more monitoring sites (out of four) for two consecutive years, where both years are categorized hydrologically as below normal, above normal, or wet, will

[2] Interferometric synthetic-aperture radar (referred to as InSAR) data published by DWR online (https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#landsub).
[3] It is noted that these GSPs have not yet been approved by DWR.

quantitatively indicate that the Subbasin has reached undesirable results for land subsidence.

Additional examples of undesirable results definitions related to land subsidence were reviewed for consideration by the joint TACs. Subbasins on the east side of the southern San Joaquin Valley with areas of subsidence related to the Corcoran Clay were prioritized. Selected definitions are provided as **Attachment 1** to this memorandum.

MONITORING METHODS FOR LAND SUBSIDENCE

A multi-faceted approach to land subsidence monitoring could be implemented in the Turlock Subbasin. A combination of several monitoring strategies could maximize coverage and provide some redundancy to better identify potential land subsidence before surface land use or infrastructure is impacted. Several screening methods would provide a cost effective manner for incorporation into the GSP monitoring network.

As illustrated on the map shown on page 3, the U.S. Bureau of Reclamation surveys a network of more than 70 control points across the San Joaquin Valley twice annually to monitor land subsidence. Since 2011, monitoring has included one location in the Turlock Subbasin near the City of Turlock. These data are reported in geodetic network reports and can be accessed online (http://www.restoresjr.net/science/subsidence-monitoring/). Additional information could be obtained regarding use of the station and future monitoring. If determined to be appropriate, these data could be accessed on a semi-annual basis and incorporated into the GSP monitoring program. In addition, DWR has entered into a contract with TRE Altamira to process and publish online InSAR data to assist GSAs with land subsidence monitoring. If appropriate, those data could serve as a cost effective method of evaluating subsidence within the Turlock Subbasin to optimize future monitoring. If publicly-available data are determined to be insufficient, additional surveyed benchmarks or continuous-recording GPS stations can also be considered.

Finally, water level MTs may be selected to be protective of future land subsidence impacts and serve as a proxy for monitoring rates of subsidence. If water levels are maintained at or near historic low levels, the risk of future subsidence could be mitigated. At a minimum, GSAs should consider management actions that control water levels within the extent of the Corcoran Clay to avoid dewatering of the aquitard.

ATTACHMENT 1:
EXAMPLES OF UNDESIRABLE RESULTS DEFINITIONS
SELECTED GROUNDWATER SUSTAINABILITY PLANS (GSPs)
SOUTHERN SAN JOAQUIN VALLEY

Chowchilla Subbasin

The cause of basin groundwater conditions that would result in significant and unreasonable land subsidence is excessive overall average annual groundwater pumping and other outflows from the subbasin that exceed average annual inflows and results in groundwater levels below historic lows in areas that have already experienced significant impacts to infrastructure (i.e., the Western Management Area) …Significant and unreasonable land subsidence results in significant impacts to infrastructure.

…For the Western Management Area of the Subbasin, significant continued subsidence that impacts infrastructure is unacceptable. To address the inherent data uncertainty, undesirable results for subsidence in the Western Management Area are defined by having more than 50 percent of Western Manager Area Lower Aquifer RMS[4] exceeding their respective MTs for the same two consecutive fall readings (i.e., 4 of the current 7 RMS for the Lower Aquifer in the Western Management Area). Historical water level data and modeling results indicate that a significant shift in pumping from the Lower Aquifer to the Upper Aquifer will be necessary to achieve land subsidence MT thresholds. In addition, several successful recharge projects and overall demand reduction…will also be need to meet subsidence minimum thresholds. …Minimum thresholds were established based on not going below historical groundwater elevations.

Greater Kaweah Subbasin

Undesirable results associated with subsidence are caused by over-pumping or minimal groundwater recharge during drought periods such that groundwater levels fall and remain below minimum thresholds. Over-pumping and lack of recharge are area specific, and some GSA areas experience greater adverse impacts than others. Over-pumping during drought periods, which may result in new lows in terms of groundwater elevations, is of particular concern based on current scientific understanding of subsidence trends in this region. Regional correlation of groundwater levels versus subsidence trends remain difficult to ascertain because groundwater levels occur at a local scale and subsidence occurs at a broader/regional scale.

The primary criteria and metric will be the annual rate of reduction in land surface elevation and areal extent of such elevation changes. An undesirable result will occur when one-third of all Subbasin subsidence monitoring sites exceed their respective minimum thresholds. In addition, GSGSA will evaluate cumulative subsidence at each of the interim milestones as

[4] Representative Monitoring Sites

described in Section 5. The water-level sustainability indicator will be considered for differential land subsidence although the current body of knowledge relative to subsidence and local and regional declines in water levels is limited. As set forth in Section 5.3.6, subsidence rates that represent minimum thresholds have been identified that reflect recent historical rates in the GKGSA region. Within the eastern portions of the Subbasin, the East Kaweah GSA has established minimum thresholds using a metric tied to loss of conveyance capacity in the Friant-Kern Canal which traverses from north to south through that GSA.

Mid Kaweah GSP

Undesirable results associated with subsidence are caused by over-pumping or nominal groundwater recharge operations during drought periods such that groundwater levels fall and remain below minimum thresholds. Over-pumping and lack of recharge is area specific, and some GSA Management Areas experience greater adverse impacts than others. Over-pumping during drought periods, which may result in new lows in terms of groundwater elevations, is of particular concern based on current scientific understanding of subsidence trends in this region. Local correlations of water levels v. subsidence trends remain difficult to quantify and pinpoint with existing data because of the lack of pumping depth and volume information at specific wells and wellfields. While the basin setting and other reference information in the plan relates subsidence to water levels, in our basin it remains a data gap that will be filled over time through collection of data from our land surface subsidence monitoring network.

The primary criteria and metric will be the annual rate of reduction in land surface elevation and areal extent of such elevation changes. An undesirable result will occur when one-third of the Subbasin's subsidence monitoring sites exceed their respective minimum thresholds. In addition, MKGSA will evaluate cumulative subsidence at each of the interim milestones as described in Section 5.

Tulare Lake Subbasin

The majority of the Subbasin has some subsidence but it has not caused undesirable results, or the subsidence has been mitigated. Should land subsidence exceed the MTs at either of both of the RMSs, the subsidence will be considered significant and unreasonable. At this point, the GSAs will evaluate the cause of the subsidence. If subsidence originates from outside the GSP area, the impacted GSAs will coordinate with relevant GSAs in the other subbasins to address the issue. There is an understanding that there is subsidence in areas adjacent to the Subbasin and efforts will be made to determine if conditions outside of the Subbasin are creating impacts within the Subbasin.

(MOs and MTs were selected as feet of cumulative subsidence since 1990 and included a MT of 11.5 feet, Tables 4-2 and 4-3).