APPENDIX A: GSP ASSESSMENT STAFF REPORT, SAN JOAQUIN VALLEY – MERCED SUBBASIN (NO. 5-022.04)

CALIFORNIA DEPARTMENT OF WATER RESOURCES
SUSTAINABLE GROUNDWATER MANAGEMENT OFFICE
715 P Street, 8th Floor | Sacramento, CA 95814 | P.O. Box 942836 | Sacramento, CA 94236-0001

August 4, 2023

Hicham Eltal
Merced Irrigation District
744 W. 20th Street
Merced, CA 95340
heltal@mercedid.org

RE: Approved Determination of the Revised Groundwater Sustainability Plan Submitted for the San Joaquin Valley – Merced Subbasin

Dear Hicham Eltal,

The Department of Water Resources (Department) has evaluated the resubmitted groundwater sustainability plan (GSP) for the San Joaquin Valley – Merced Subbasin in response to the Department's incomplete determination on January 28, 2022 and has determined the GSP is approved. The approval is based on recommendations from the Staff Report, included as an exhibit to the attached Statement of Findings, which describes that the groundwater sustainability agencies (GSAs) have taken sufficient action to correct deficiencies identified by the Department and the Merced GSP satisfies the objectives of the Sustainable Groundwater Management Act (SGMA) and substantially complies with the GSP Regulations. The Staff Report also proposes recommended corrective actions that the Department believes will enhance the GSP and facilitate future evaluation by the Department. The Department strongly encourages the recommended corrective actions be given due consideration and suggests incorporating all resulting changes to the GSP in the future.

Recognizing SGMA sets a long-term horizon for GSAs to achieve their basin sustainability goals, monitoring progress is fundamental for successful implementation. GSAs are required to evaluate their GSP at least every five years and whenever the Plan is amended, and to provide a written assessment to the Department. Accordingly, the Department will evaluate approved GSPs and issue an assessment at least every five years. The Department will initiate the first periodic review of the Merced Subbasin GSP no later than January 28, 2025.

Please contact Sustainable Groundwater Management staff by emailing sgmps@water.ca.gov if you have any questions related to the Department's assessment or implementation of your GSP.

Thank You,

Paul Gosselin

Paul Gosselin
Deputy Director
Sustainable Groundwater Management

Attachment:

1. Statement of Findings Regarding the Determination of Approval of the Merced Subbasin Groundwater Sustainability Plan (August 4, 2023)

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

STATEMENT OF FINDINGS REGARDING THE APPROVAL OF THE SAN JOAQUIN VALLEY – MERCED SUBBASIN GROUNDWATER SUSTAINABILITY PLAN

The Department of Water Resources (Department) is required to evaluate whether a submitted groundwater sustainability plan (GSP or Plan) conforms to specific requirements of the Sustainable Groundwater Management Act (SGMA or Act), is likely to achieve the sustainability goal for the basin covered by the Plan, and whether the Plan adversely affects the ability of an adjacent basin to implement its GSP or impedes achievement of sustainability goals in an adjacent basin. (Water Code § 10733.) The Department is directed to issue an assessment of the Plan within two years of its submission. (Water Code § 10733.4.) If a Plan is determined to be Incomplete, the Department identifies deficiencies that preclude approval of the Plan and identifies corrective actions required to make the Plan compliant with SGMA and the GSP Regulations. The GSA has up to 180 days from the date the Department issues its assessment to make the necessary corrections and submit a revised Plan. (23 CCR § 355.2(e)(2)). This Statement of Findings explains the Department's decision regarding the revised Plan submitted by the Merced Irrigation-Urban Groundwater Sustainability Agency, Merced Subbasin Groundwater Sustainability Agency, and Turner Island Water District Groundwater Sustainability Agency #1 (GSAs or Agencies) for the San Joaquin Valley – Merced Subbasin (Subbasin) (Basin No. 5-022.04).

Department management has discussed the Plan with staff and has reviewed the Department Staff Report, entitled Sustainable Groundwater Management Program Groundwater Sustainability Plan Assessment Staff Report, attached as Exhibit A, recommending approval of the GSP. Department management is satisfied that staff have conducted a thorough evaluation and assessment of the Plan and concurs with staff's recommendation and all the recommended corrective actions. The Department therefore **APPROVES** the Plan and makes the following findings:

A. The initial Plan for the basin submitted by the GSA for the Department's evaluation satisfied the required conditions as outlined in § 355.4(a) of the GSP Regulations (23 CCR § 350 et seq.), and Department Staff therefore evaluated the initial Plan.

B. On January 28, 2022, the Department issued a Staff Report and Statement of Findings determining the initial GSP submitted by the Agencies for the Subbasin to be incomplete, because the GSP did not satisfy the requirements of SGMA, nor did it substantially comply with the GSP Regulations. At that time, the Department provided corrective actions in the Staff Report that were intended to address the deficiencies that precluded approval. Consistent with the GSP Regulations, the Department provided the Agencies with up to 180 days to address the deficiencies detailed in the Staff Report. On July 26, 2022, within the 180 days provided to remedy the deficiencies identified in the Staff Report related to the Department's initial incomplete determination, the Agencies resubmitted a revised 2022 GSP to the Department for evaluation. When evaluating a revised GSP that was initially determined to be incomplete, the Department reviews the materials (e.g., revised or amended GSP) that were submitted within the 180-day deadline and does not review or rely on materials that were submitted to the Department by the GSA after the resubmission deadline. Part of the Department's review focuses on how the Agencies have addressed the previously identified deficiencies that precluded approval of the initially submitted Plan. The Department shall find a Plan previously determined to be incomplete to be inadequate if, after consultation with the State Water Resources Control Board, the Department determines that the Agencies have not taken sufficient actions to correct the deficiencies previously identified by the Department. (23 CCR § 355.2(e)(3)(C).) The Department shall approve a Plan previously found to be incomplete if the Department determines the Agencies have sufficiently addressed the deficiencies that precluded approval. The Department may evaluate other components of the Plan, particularly to assess whether revisions to address deficiencies may have affected other components of a Plan or its likelihood of achieving sustainable groundwater management and may offer recommended corrective actions to deal with any issues of concern.

C. The Department's Staff Report, dated January 28, 2022, identified the deficiencies that precluded approval of the initially submitted Plan. After thorough evaluation of the revised Plan, the Department makes the following findings regarding the sufficiency of the actions taken by the Agencies to correct those deficiencies:

   1. <u>Deficiency 1</u>: The corrective action advised the Agencies to address several aspects of the Plan's discussion, analyses, and justification of groundwater level, subsidence, and interconnected surface waters sustainable management criteria and potential impacts to beneficial uses and users. The Department found that management approach described in the initial GSP of coupling minimum thresholds and measurable objectives with a definition of undesirable results that disregards minimum threshold exceedances in all years except consecutive below normal, above normal, or wet years (non-dry years) was inconsistent with the objectives of SGMA and that the Plan lacked specific projects and management actions the Agencies would implement to offset drought-year groundwater level declines. The Department also found the Plan lacked sufficient explanation for how their approach avoids undesirable

results for subsidence and interconnected surface waters sustainable management criteria, how the Agencies will address drinking water impacts caused by continued overdraft, how the Agencies will assess groundwater quality degradation allowed via the minimum thresholds, and how the Agencies will coordinate with appropriate groundwater users, water quality regulatory agencies and programs.

The 2023 Staff Report associated with the revised Plan indicates that the Agencies have taken sufficient actions to correct this deficiency such that, at this time, although the Staff Report includes recommended corrective actions to further align this aspect of the Plan with the GSP Regulations, the Department no longer finds the deficiency to preclude approval, and further finds that the Agencies have the ability to achieve the sustainability goal for the basin on SGMA timelines, and that the Department will be able to periodically monitor and evaluate the likelihood of Plan implementation to achieve sustainability.

2. Deficiency 2: The corrective action advised the Agencies to address the Plan's discussion supporting the selection of chronic lowering of groundwater levels sustainable management criteria. The initial GSP did not provide sufficient discussion on apparent or potential discrepancies between the stated rationale for minimum thresholds versus the results of multiple studies and lacked explanation on other drinking water users that may rely on shallow wells considered in the Agencies' site-specific thresholds.

   The 2023 Staff Report indicates that the Agencies have taken sufficient actions to correct this deficiency such that, at this time, although the Staff Report includes recommended corrective actions to further align this aspect of the Plan with the GSP Regulations, the Department finds Plan approval is not precluded, that the Agencies have the ability to achieve the sustainability goal for the basin on SGMA timelines, and that the Department will be able to periodically monitor and evaluate the likelihood of Plan implementation to achieve sustainability.

3. Deficiency 3: The corrective action advised the Agencies to address the Plan's discussion supporting the selection of land subsidence sustainable management criteria. The initial GSP did not provide sufficient information to support the selection of land subsidence management criteria for critical infrastructure, and rates of delayed or residual compaction used to inform minimum thresholds or measurable objectives. The Department also found the minimum thresholds and measurable objectives for land subsidence indicated in the initial Plan did not reflect the intent of SGMA that subsidence be avoided or minimized once sustainability is achieved

and the Plan lacked explanation on how the implementation of projects and management actions will achieve the long-term avoidance or minimization of subsidence without exceeding the tolerable amount of cumulative subsidence.

The 2023 Staff Report indicates that the Agencies have taken sufficient actions to correct this deficiency such that, at this time, although the Staff Report includes recommended corrective actions to further align this aspect of the Plan with the GSP Regulations, the Department finds Plan approval is not precluded, that the Agencies have the ability to achieve the sustainability goal for the basin on SGMA timelines, and that the Department will be able to periodically monitor and evaluate the likelihood of Plan implementation to achieve sustainability.

D. The Plan satisfies the required conditions as outlined in § 355.4(a) of the GSP Regulations (23 CCR § 350 et seq.):

1. The Plan was complete, meaning it generally appeared to include the information required by the Act and the GSP Regulations sufficient to warrant a thorough evaluation and issuance of an assessment by the Department. (23 CCR § 355.4(a)(2).)

2. The Plan, either on its own or in coordination with other Plans, appears to cover the entire Basin sufficient to warrant a thorough evaluation. (23 CCR § 355.4(a)(3).)

E. The general standards the Department applied in its evaluation and assessment of the Plan are: (1) “conformance” with the specified statutory requirements, (2) “substantial compliance” with the GSP Regulations, (3) whether the Plan is likely to achieve the sustainability goal for the Subbasin within 20 years of the implementation of the Plan, and (4) whether the Plan adversely affects the ability of an adjacent basin to implement its GSP or impedes achievement of sustainability goals in an adjacent basin. (Water Code § 10733.) Application of these standards requires exercise of the Department’s expertise, judgment, and discretion when making its determination of whether a Plan should be deemed “approved,” “incomplete,” or “inadequate.”

The statutes and GSP Regulations require Plans to include and address a multitude and wide range of informational and technical components. The Department has observed a diverse array of approaches to addressing these technical and informational components being used by GSAs in different basins throughout the state. The Department does not apply a set formula or criterion that would require a particular outcome based on how a Plan addresses any one of SGMA’s numerous informational and technical components. The Department finds that affording flexibility and discretion to local GSAs is consistent with the standards identified above; the state policy that sustainable groundwater management is best achieved locally through the development, implementation, and updating of local plans and programs (Water Code § 113); and the Legislature's express intent under SGMA that groundwater basins be managed through the actions of local governmental agencies to the greatest extent feasible, while minimizing state intervention to only when necessary to ensure that local agencies manage groundwater in a sustainable manner. (Water Code § 10720.1(h)). The Department's final determination is made based on the entirety of the Plan's contents on a case-by-case basis, considering and weighing factors relevant to the particular Plan and Subbasin under review.

F. In making these findings and Plan determination, the Department also recognized that: (1) The Department maintains continuing oversight and jurisdiction to ensure the Plan is adequately implemented; (2) the Legislature intended SGMA to be implemented over many years; (3) SGMA provides Plans 20 years of implementation to achieve the sustainability goal in a Subbasin (with the possibility that the Department may grant GSAs an additional five years upon request if the GSA has made satisfactory progress toward sustainability); and, (4) local agencies acting as GSAs are authorized, but not required, to address undesirable results that occurred prior to enactment of SGMA. (Water Code §§ 10721(r); 10727.2(b); 10733(a); 10733.8.)

G. The Plan conforms with Water Code §§ 10727.2 and 10727.4, substantially complies with 23 CCR § 355.4, and appears likely to achieve the sustainability goal for the Subbasin.

   1. The sustainable management criteria and the GSP's goal to achieve sustainable groundwater management on a long-term average basis by increasing recharge and/or reducing groundwater pumping, while avoiding undesirable results are sufficiently justified and explained. The Plan relies on credible information and science to quantify the groundwater conditions that the Plan seeks to avoid and provides an objective way to determine whether the Basin is being managed sustainably in accordance with SGMA. (23 CCR § 355.4(b)(1).)

   2. The Plan demonstrates a thorough understanding of where data gaps exist (e.g., understanding depletions of interconnected surface water) and demonstrates a commitment to eliminate those data gaps. The GSP intends to address these data gaps by expanding the existing monitoring network. However, the Department provides recommended corrective actions that identify where additional data gaps exist within the hydrogeologic conceptual model and monitoring network. Filling these known data gaps, and others described in the Plan, should lead to the refinement of the GSAs' monitoring networks, the Subbasin's water model,

and sustainable management criteria to better inform and guide future adaptive management strategies. (23 CCR § 355.4(b)(2).)

3. The sustainable management criteria and projects and management actions are commensurate with the level of understanding of the Subbasin setting. The projects and management actions described in the Plan provide a feasible approach to achieving the Subbasin's sustainability goal and should provide the GSAs with greater versatility to adapt and respond to changing conditions and future challenges during GSP implementation, particularly due to the addition of a Domestic Well Mitigation Program. (23 CCR § 355.4(b)(3).)

4. The Plan provides an explanation of how the various interests of groundwater uses and users in the Subbasin were considered in developing most of the sustainable management criteria and how those interests would be impacted by the established minimum thresholds at this time. The Department has provided a recommended corrective action asking the GSAs to fill data gaps and address the interests of groundwater uses and users impacted by the sustainable management criteria and established minimum thresholds for interconnected surface water and will continue to monitor the GSAs' progress towards addressing these concerns as Plan implementation proceeds. (23 CCR § 355.4(b)(4).)

5. The Plan's proposed projects and management actions appear feasible at this time and, if implemented expeditiously, appear capable of preventing undesirable results and ensuring that the Subbasin is managed within its sustainable yield on SGMA timelines. The Department will continue to monitor Plan implementation and reserves the right to change its determination if projects and management actions are not implemented or appear unlikely to prevent undesirable results or unlikely to achieve sustainability within SGMA timeframes. (23 CCR § 355.4(b)(5).)

6. The Plan includes a reasonable assessment of overdraft conditions and includes reasonable means to mitigate overdraft, if present. (23 CCR § 355.4(b)(6).)

7. the Department has insufficient evidence to conclude the Plan will adversely affect the ability of the adjacent basins to implement their GSPs or impede achievement of their sustainability goals. The Department will continue to monitor these conditions as Plan implementation proceeds. While no discussion was included on the potential impacts to adjacent basins, the Plan's water budget included subsurface outflows and inflows estimates between the adjacent subbasins. (23 CCR § 355.4(b)(7).)

8. Because a single plan was submitted for the Subbasin, a coordination agreement was not required. (23 CCR § 355.4(b)(8).)

9. The Merced Irrigation-Urban Groundwater Sustainability Agency, the Merced Subbasin Groundwater Sustainability Agency, and Turner Island Water District Groundwater Sustainability Agency #1, collectively referred to as "GSAs", developed a Memorandum of Understanding (MOU) that provides the basis for the agreement to work together to develop and implement a GSP for the Merced Subbasin. Given the legal authority and financial resources of the GSAs and the additional authorities granted the GSAs under SGMA, the Department concludes the GSAs likely have the legal authority and financial resources necessary to implement the Plan. (23 CCR § 355.4(b)(9).)

10. Through review of the Plan and consideration of public comments, the Department determines that the GSAs adequately responded to comments that raised credible technical or policy issues with the Plan, sufficient to warrant approval of the Plan at this time. The Department also notes that the recommended corrective actions included in the Staff Report are important to addressing certain technical or policy issues that were raised and, if not addressed before future, subsequent plan evaluations, may preclude approval of the Plan in those future evaluations. (23 CCR § 355.4(b)(10).)

H. In addition to the grounds listed above, DWR also finds that:

1. The Plan provides an assessment conducted by the GSAs which evaluated potential impacts to beneficial uses and users based on the established sustainable management criteria. The assessment, sufficient to warrant approval of the Plan at this time, estimated the potential impacts of reaching the minimum thresholds on representative wells by evaluating the wells with available historical measurements. However, the Department provides a recommended corrective action in the Staff Report calling for the Agencies to provide further details of the analysis used to evaluate potential impacts to domestic wells due to planned overdraft during the initial period of GSP implementation before achieving the sustainability goal. The Department developed its GSP Regulations consistent with and intending to further the human right to water policy (Water Code § 106.3) through implementation of SGMA and the Regulations, primarily by achieving sustainable groundwater management in a basin. By ensuring substantial compliance with the GSP Regulations, the Department has considered the state policy regarding the human right to water in its evaluation of the Plan. (23 CCR § 350.4(g).)

2. The Plan acknowledges and identifies interconnected surface waters within the Subbasin. The GSAs propose to use chronic groundwater level sustainable management criteria as proxy for the depletions of interconnected surface water sustainability indicator, however, the Department recognizes that many data gaps related to interconnected surface water exist within the Subbasin. The GSAs should fill data gaps, evaluate additional modeling data, and coordinate with agencies and interested parties to understand beneficial uses and users that may be impacted by depletions of interconnected surface water caused by groundwater pumping. Future updates to the Plan should aim to improve the sustainable management criteria as more information and improved methodologies become available.

3. The California Environmental Quality Act (Public Resources Code § 21000 *et seq*.) does not apply to the Department's evaluation and assessment of the Plan.

Accordingly, the revised GSP submitted by the Agencies for the Merced Subbasin is hereby **APPROVED.** The recommended corrective actions identified in the Staff Report will assist the Department's future review of the Plan's implementation for consistency with SGMA and the Department therefore recommends the Agencies address them by the time of the Department's periodic review, which is set to begin on January 29, 2025, as required by Water Code § 10733.8. Failure to address the Department's Recommended Corrective Actions before future, subsequent plan evaluations, may lead to a Plan being determined incomplete or inadequate.

Signed:

Karla Nemeth, Director
Date: August 4, 2023

Exhibit A: Groundwater Sustainability Plan Assessment Staff Report – San Joaquin Valley – Merced Subbasin (August 4, 2023)

State of California
Department of Water Resources
Sustainable Groundwater Management Program
Groundwater Sustainability Plan Assessment
Staff Report

Groundwater Basin Name:	Merced Subbasin (No. 5-022.04)
Submitting Agencies:	Merced Irrigation-Urban Groundwater Sustainability Agency, Merced Subbasin Groundwater Sustainability Agency, and Turner Island Water District Groundwater Sustainability Agency #1
Submittal Type:	Revised Plan in response to Incomplete Determination
Submittal Date:	July 26, 2022
Recommendation:	Approve
Date:	August 4, 2023

On July 26, 2022, the Merced Irrigation-Urban Groundwater Sustainability Agency, Merced Subbasin Groundwater Sustainability Agency, and Turner Island Water District Groundwater Sustainability Agency #1 (GSAs or Agency) submitted the *Merced Subbasin Groundwater Sustainability Plan – Revised July 2022* (GSP or Plan) for the Merced Subbasin (Subbasin or Basin) to the Department of Water Resources (Department) in response to the Department's incomplete determination on January 28, 2022,[1] for evaluation and assessment as required by the Sustainable Groundwater Management Act (SGMA)[2] and GSP Regulations.[3] On January 28, 2022, the Department determined the *Merced Subbasin Groundwater Sustainability Plan – November 2019 (2019 Plan)* incomplete. After evaluation and assessment, Department staff conclude the GSAs have taken sufficient actions to correct deficiencies identified by the Department; however, Department staff have recommended additional corrective actions, which staff recommend the GSA should address by the Plan's first periodic evaluation.[4]

Overall, Department staff believe the Plan contains the required components of a GSP; demonstrates a thorough understanding of the Basin based on what appears to be the best available science and information; sets reasonable and supported sustainable management criteria to prevent undesirable results as defined in the Plan; has a

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[1] Water Code § 10733.4(b); 23 CCR § 355.4(a)(4); *Incomplete Determination of the 2020 Merced Subbasin Groundwater Sustainability Plan*, Department of Water Resources, January 28, 2022. https://sgma.water.ca.gov/portal/service/gspdocument/download/7782.
[2] Water Code § 10720 *et seq*.
[3] 23 CCR § 350 *et seq*.
[4] 23 CCR § 356.4.

reasonable monitoring network; and proposes a set of projects and management actions that, if successfully implemented, are likely to achieve the sustainability goal defined for the Basin.[5] Department staff will continue to monitor and evaluate the Basin's progress toward achieving the sustainability goal through annual reporting[6] and future periodic evaluations of the GSP and its implementation. Department staff recommend approval of the Plan subject to recommended corrective actions described herein.

This assessment includes six sections:

- **Section 1 – Summary**: Provides an overview of the Department Staff's assessment and recommendations.
- **Section 2 – Evaluation Criteria**: Describes the legislative requirements and the Department's evaluation criteria.
- **Section 3 – Required Conditions**: Describes the submission requirements of a response to an incomplete determination to be evaluated by the Department.
- **Section 4 – Deficiency Evaluation**: Provides an assessment of whether and how the contents included in the GSP submittal addressed the deficiencies identified by the Department in the initial incomplete determination.
- **Section 5 – Plan Evaluation:** Provides a detailed assessment of the contents included in the GSP organized by each Subarticle outlined in the GSP Regulations.
- **Section 6 – Staff Recommendation:** Includes the staff recommendation for the Plan and any recommended corrective actions.

[5] 23 CCR § 354.24.
[6] 23 CCR § 356.2.

1 SUMMARY

Department staff conclude the GSAs took sufficient action to correct the deficiencies previously identified. Accordingly, Department staff recommend **approval** of the Plan for the Merced Subbasin, along with recommended corrective actions described in this Staff Report, which Department staff recommend be addressed by the next periodic evaluation to further improve Plan implementation and achievement of basin sustainability in accordance with SGMA timelines.

The GSAs have identified areas for improvement of its Plan (e.g., addressing data gaps related to hydrogeological conceptual model, groundwater conditions, and water budgets, incorporating new information into the numerical model, and expanding monitoring networks). Department staff concur that those items are important and recommend that the GSAs address them as soon as possible. Department staff have also identified additional recommended corrective actions designed to address shortcomings of the Plan, as described in this Staff Report, that the GSAs should address by the next periodic Plan evaluation. The recommended corrective actions generally focus on the following:

1) Implementation of the Domestic Well Mitigation Program and evaluating impacts to water quality because of continued overdraft during GSP implementation before the sustainability goal is achieved.
2) Evaluating potential impacts to domestic wells because of continued overdraft during GSP implementation before the sustainability goal is achieved.
3) Identification of total cumulative subsidence tolerable by critical infrastructure and revision to how the level of uncertainty is accounted for in the definition of sustainable management criteria of land subsidence.
4) Investigation of wells pumping from below the bottom of the basin.
5) Establishment of sustainable management criteria for groundwater storage.
6) Explaining and justifying the selection of the sustainable management criteria for degradation of water quality, particularly with respect to constituents of concern and undesirable results and minimum thresholds.
7) Working towards establishing sustainable management criteria for the interconnected surface water sustainability indicator.
8) Filling of data gaps within the groundwater levels monitoring network.
9) Provide an explanation of how the timing and quantified benefits of project and management actions will be conducted to reach sustainability by 2040.

Addressing these recommended corrective actions, provided in Section 6 of this Staff Report, will be important to demonstrate, on an ongoing basis, that implementation of the Plan is likely to achieve the sustainability goal.

2 EVALUATION CRITERIA

The Department evaluates whether a Plan conforms to the statutory requirements of SGMA[7] and is likely to achieve the basin's sustainability goal,[8] whether evaluating a basin's first Plan,[9] a Plan previously determined incomplete,[10] an amended Plan,[11] or a GSA's periodic evaluation to an approved Plan.[12] To achieve the sustainability goal, each version of the Plan must demonstrate that implementation will lead to sustainable groundwater management, which means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.[13] The Department is also required to evaluate, on an ongoing basis, whether the Plan will adversely affect the ability of an adjacent basin to implement its groundwater sustainability program or achieve its sustainability goal.[14]

The Plan evaluated in this Staff Report is a revision of the 2019 Plan, which was evaluated by the Department and found to be incomplete. An incomplete Plan is one which Department staff identify as containing one or more deficiencies that preclude its initial approval. Deficiencies may result from supporting information that is insufficiently detailed or analyses that are insufficiently thorough or unreasonable, or where Department staff determine it is unlikely the GSA(s) in the basin/subbasin could achieve the sustainability goal under the proposed Plan. After GSAs have been afforded up to 180 days to address the deficiencies and based on the GSAs' efforts, the Department can either approve[15] the Plan or determine the Plan inadequate.[16]

The Department's evaluation and assessment of a revised or amended Plan, subsequent to the initial Plan being found to be incomplete, as presented in this Staff Report, continues to follow Article 6 of the GSP Regulations[17] to determine whether the Plan, with revisions or additions prepared by the GSA, complies with SGMA and substantially complies with the GSP Regulations.[18] As stated in the GSP Regulations, "substantial compliance means that the supporting information is sufficiently detailed and the analyses sufficiently thorough and reasonable, in the judgment of the Department, to evaluate the Plan, and the Department determines that any discrepancy would not materially affect the

[7] Water Code §§ 10727.2, 10727.4, 10727.6.
[8] Water Code § 10733; 23 CCR § 354.24.
[9] Water Code § 10720.7.
[10] 23 CCR § 355.2(e)(2).
[11] 23 CCR § 355.10.
[12] 23 CCR § 355.6.
[13] Water Code § 10721(v).
[14] Water Code § 10733(c).
[15] 23 CCR §§ 355.2(e)(1).
[16] 23 CCR §§ 355.2(e)(3).
[17] 23 CCR § 355 *et seq*.
[18] 23 CCR § 350 *et seq*.

ability of the Agency to achieve the sustainability goal for the basin, or the ability of the Department to evaluate the likelihood of the Plan to attain that goal."[19]

When reviewing a revised or amended Plan that was previously determined to be incomplete, Department staff primarily assess whether the GSA(s) have taken sufficient actions to correct any deficiencies identified by the Department.[20] A Plan approval does not signify that Department staff, were they to exercise the professional judgment required to develop a Plan for the basin, would make the same assumptions and interpretations as those contained in the revised Plan, but simply that Department staff have determined that the modified assumptions and interpretations relied upon by the submitting GSA(s) are supported by adequate, credible evidence, and are scientifically reasonable. Assessment of a revised or amended Plan previously determined to be incomplete may involve the review of new information presented by the GSA(s), including models and assumptions, and a reevaluation of that information based on scientific reasonableness. In conducting its assessment, Department staff does not recalculate or reevaluate technical information or perform its own geologic or engineering analysis of that information.

The recommendation to approve a Plan previously determined to be incomplete is based on a determination that the GSA(s) have taken sufficient actions (e.g., amended or revised the Plan) to correct the deficiencies previously identified by the Department that precluded earlier approval.

3 REQUIRED CONDITIONS

For a Plan that the Department determines to be incomplete, the Department identifies corrective actions to address those deficiencies that preclude approval of the Plan as initially submitted. The GSAs in a basin, whether developing a single GSP covering the basin or multiple GSPs, must attempt to address those corrective actions within the time provided, not to exceed 180 days, for the Plan to be evaluated by the Department.

3.1 INCOMPLETE RESUBMITTAL

GSP Regulations specify that the Department shall evaluate a revised GSP in which the GSAs have taken corrective actions within 180 days from the date the Department issued an incomplete determination to address deficiencies.[21]

The Department issued the incomplete determination on January 28, 2022. The GSAs submitted a revised GSP to the Department on July 26, 2022, in compliance with the 180-day deadline.

[19] 23 CCR § 355.4(b).
[20] 23 CCR §§ 355.2(e)(3)(C).
[21] 23 CCR § 355.4(a)(4).

4 DEFICIENCY EVALUATION

As stated in Section 355.4 of the GSP Regulations, a basin "shall be sustainably managed within 20 years of the applicable statutory deadline consistent with the objectives of the Act." The Department's assessment is based on a number of related factors including whether the elements of a GSP were developed in the manner required by the GSP Regulations, whether the GSP was developed using appropriate data and methodologies and whether its conclusions are scientifically reasonable, and whether the GSP, through the implementation of clearly defined and technically feasible projects and management actions, is likely to achieve a tenable sustainability goal for the basin.

In its initial incomplete determination, the Department identified deficiencies in the Plan which precluded the Plan's approval in January 2022.[22] In January 2022 the GSAs were given 180 days to take corrective actions to remedy the identified deficiencies. Consistent with the GSP Regulations, Department staff have evaluated the revised 2022 Plan to determine if the GSAs have taken sufficient actions to correct the deficiencies.

4.1 DEFICIENCY 1. THE GSP LACKS SUFFICIENT JUSTIFICATION FOR IDENTIFYING THAT UNDESIRABLE RESULTS FOR CHRONIC LOWERING OF GROUNDWATER LEVELS, LAND SUBSIDENCE, AND DEPLETION OF INTERCONNECTED SURFACE WATERS CAN ONLY OCCUR IN CONSECUTIVE NON-DRY WATER YEAR TYPES.

4.1.1 Corrective Action 1

The Department defined the following corrective actions related to the water year type criteria specified for undesirable results in the Incomplete Determination issued on January 28, 2022:

a) *Department staff believe the management approach described in the GSP, which couples minimum thresholds and measurable objectives that account for operational flexibility during dry periods with a definition of undesirable results that disregards minimum threshold exceedances in all years except consecutive below normal, above normal, or wet years, to be inconsistent with the objectives of SGMA. Therefore, the GSAs should remove the water-year type requirement from the GSP's undesirable result definition.*

b) *The GSP should be revised to include specific projects and management actions the GSAs would implement to offset drought-year groundwater level declines.*

c) *The GSAs should thoroughly explain how their approach avoids undesirable results for subsidence and depletion of interconnected surface waters, as SGMA*

[22] *Incomplete Determination of the 2020 Merced Subbasin Groundwater Sustainability Plan*, Department of Water Resources, January 28, 2022.
https://sgma.water.ca.gov/portal/service/gspdocument/download/7782.

does not include an allowance or exemption for those conditions to continue in periods of drought.

d) *The GSAs should revise the GSP to describe how they would address drinking water impacts caused by continued overdraft during the period between the start of GSP implementation and achieving the sustainability goal. If the GSP does not include projects or management actions to address those impacts, the GSP should contain a thorough discussion, with supporting facts and rationale, explaining how and why the GSAs determined not to include specific actions to mitigate drinking water impacts from continued groundwater lowering below pre-SGMA levels.*

e) *The GSP should be revised to explain how the GSAs will assess groundwater quality degradation in areas where further groundwater level decline, below historic lows, is allowed via the minimum thresholds. The GSAs should further describe how they will coordinate with the appropriate groundwater users, including drinking water, environmental, and irrigation users as identified in the GSP. The GSAs should also discuss efforts to coordinate with water quality regulatory agencies and programs in the Subbasin to understand and develop a process for determining if continued lowering of groundwater levels is resulting in degraded water quality in the Subbasin during GSP implementation.*

4.1.2 Evaluation

To address the identified deficiencies, the GSAs have supplemented portions of the Plan related to the use of consecutive non-dry water year types in the definition of undesirable results for chronic lowering of groundwater levels, land subsidence, and depletion of interconnected surface waters. Specifically, descriptions supporting undesirable results, projects and management actions, and other factors related to drought-years have been further detailed and/or revised.

4.1.2.1 Undesirable Results (1a)

The Department's Incomplete Determination notified the GSAs that the management approach described in the 2019 GSP of coupling minimum thresholds and measurable objectives with a definition of undesirable results that disregards minimum threshold exceedances in all years except consecutive below normal, above normal, or wet years (non-dry years), was inconsistent with the objectives of SGMA. In response to component 1a of the corrective action, the GSAs removed the water-year type requirement of two consecutive non-dry years from the GSP's undesirable results definition for chronic lowering of groundwater levels,[23] land subsidence,[24] and depletion of interconnected surface waters by proxy of groundwater levels. The 2022 Plan now states that undesirable results for chronic lowering of groundwater levels occur when November groundwater levels at greater than 25 percent of representative monitoring wells (at least 6 of 21) fall

[23] Merced Subbasin 2022 GSP Redline, Section 3.3.1, pp. 247-248.
[24] Merced Subbasin 2022 GSP Redline, Section 3.7.1, p. 265.

below their minimum thresholds for two consecutive years.[25] Department staff conclude that the removal of the water year type aspect of the undesirable result has addressed component 1a of the corrective action.

4.1.2.2 Projects and Management Actions to Offset Drought-Year Declines (1b)

Because of the original definition of undesirable results, the Department's Incomplete Determination stated "the GSP does not present specific detail for how projects and management actions, in conjunction with the proposed chronic lowering of groundwater levels sustainable management criteria, will offset drought-related groundwater reductions and avoid significant and unreasonable impacts when groundwater levels identified as minimum thresholds are potentially exceeded for an extended period of time in the absence of two consecutive non-dry years." In addition to removing the water-year type component of the undesirable results definition for chronic lowering of groundwater levels, minimum thresholds have been revised from the construction depth of the shallowest domestic well within a 2-mile radius to the fall 2015 groundwater level measurement available recorded at each representative monitoring well.[26] Although the 2022 Plan does not provide details of specific new projects to offset drought-year groundwater level declines, because the GSAs have updated the definition of undesirable results for chronic lowering of groundwater levels to remove the water-type and updated their minimum threshold values, Department staff believe component 1b of the corrective action has been addressed.

4.1.2.3 Subsidence and Depletion of Interconnected Surface Waters (1c)

The Department's Incomplete Determination notified the GSAs that while SGMA states that overdraft resulting in groundwater level or groundwater storage declines during periods of drought could be managed with increases during other periods, SGMA does not extend this premise to land subsidence and depletions of interconnected surface water. Component 1c of the corrective action stated that the GSAs should thoroughly explain how their approach avoids undesirable results for subsidence and depletion of interconnected surface waters. The Plan did not provide revisions describing how undesirable results for subsidence and depletion of interconnected surface waters would be avoided with the water-year type requirement of two consecutive non-dry years. Instead, the GSAs removed the water-year type requirement of two consecutive non-dry years from the GSP's undesirable result definition for chronic lowering of groundwater levels,[27] land subsidence,[28] and depletion of interconnected surface waters by proxy of groundwater levels. Department staff believe component 1c of the corrective action has been addressed by the GSAs because the Plan no longer uses the water-year type requirement of two consecutive non-dry years in the definition of undesirable results for

[25] Merced Subbasin 2022 GSP Redline, Section 3.3.1, pp. 247-248.
[26] Merced Subbasin 2022 GSP Redline, Section 3.3.2, p. 250.
[27] Merced Subbasin 2022 GSP Redline, Section 3.3.1, pp. 247-248.
[28] Merced Subbasin 2022 GSP Redline, Section 3.7.1, p. 265.

land subsidence and depletion of interconnected surface waters (by proxy of groundwater levels).

4.1.2.4 Addressing Drinking Water Impacts Caused by Continued Overdraft (1d)

The Department's Incomplete Determination letter notified the GSAs that SGMA requires GSAs to consider the interests of all groundwater beneficial uses and users and to implement their GSPs to mitigate overdraft conditions.[29] Component 1d of the corrective action stated that GSAs should revise the GSP to describe how they would address drinking water impacts caused by continued overdraft during the period between the start of GSP implementation and achieving the sustainability goal. In response, the Plan includes details stating that the GSAs will lead the development of a Domestic Well Mitigation Program to respond to adverse impacts experienced by domestic well users located in areas where post-2015 regional overdraft conditions are causing declining groundwater levels that interfere with groundwater production or quality.[30] The Plan describes that through a Proposition 218 election, scheduled for July 19, 2022,[31] the Merced Subbasin GSA is establishing a fund with a maximum annual collection of $200,000 and a total maximum of $800,000 that will provide "a portion of the near-term funding for the to-be-defined mitigation program." The Plan also states that coordination with other GSAs, including roles and responsibilities, will be completed by 2025 and that potential mitigation measures of the Domestic Well Mitigation Program may include, but are not limited to: bottled water delivery, setting pumps deeper, water treatment, connection to public water systems and other actions.[32]

Department staff believe the establishment of this mitigation program and the Proposition 218 funding demonstrates the GSAs' commitment to addressing drinking water impacts. However, the Plan indicates Domestic Well Mitigation Program will not be initiated until there is demonstrated need. In Section 4.2.2 of this Staff Report, Department staff articulate the need for the Plan to identify the impacts to beneficial uses and users during Plan Implementation. Given that the Plan identifies interim milestones below historical lows and below the minimum thresholds, Department staff recommend the Domestic Well Mitigation Program should be in place and initiated prior to the need so as not to delay implementation if impacts occur. Based on staff evaluation in Section 4.2.2, the GSA should describe whether the Domestic Well Mitigation Program corresponds with the projected impacts to beneficial uses and users. As Plan implementation carries out, the GSA should monitor the implementation need for the program and assess if additional funding beyond the $800,000 is needed to further mitigation or other approaches. Department staff also encourage the GSAs to review the Department's April 2023 guidance document titled *Considerations for Identifying and Addressing Drinking Water Well Impacts*

[29] 23 CCR §§ 355.4(b)(4), 355.4(b)(6).
[30] Merced Subbasin 2022 GSP Redline, Section 6.2.3, pp. 325-328.
[31] Water Year 2022 Annual Report states it passed under the Compliant Funding Mechanism for Phase 1.
[32] Merced Subbasin 2022 GSP Redline, Section 6.2.3, pp. 325-326.

guidance to assist its Program implementation.[33] (See Recommended Corrective Action 1a)

4.1.2.5 Degradation of Groundwater Quality (1e)

The Department's Incomplete Determination notified the GSAs that the GSP does not explain how groundwater level declines allowed by the established minimum thresholds relate to the degradation of water quality and that the GSAs should explain how they will coordinate with groundwater users and agencies to assess groundwater quality degradation in areas where further groundwater level decline, below historic lows, is allowed via the minimum thresholds. In response and as described in Section 4.2.2 below, the Plan describes that the minimum thresholds for groundwater levels have been revised to correspond to 2015 groundwater elevations and the measurable objectives are at November 2011 groundwater levels.[34] However, the GSAs intend to manage the Subbasin with interim milestones set below 2015 levels and below historical lows at certain representative monitoring sites.[35] The Plan describes that a potential water quality concern with groundwater level declines is that dewatering of portions of an aquifer can cause the migration of low-quality groundwater or changes in aquifer chemistry. The Plan explains that groundwater quality degradation is "not expected in the long-term" as a result of the "short-term nature" of potentially limited declines below 2015 elevations (i.e., meeting the interim milestones in 2025 and 2030) because of the GSAs' desire to operate at the measurable objectives groundwater levels, which are expected to be above 2015 groundwater elevations by 2040.[36] The Plan describes that groundwater quality impacts will be assessed using the groundwater quality minimum threshold for salinity and groundwater quality monitoring coordination activities including monthly reviews of data from GeoTracker and other entities, quarterly check-ins with existing monitoring programs, review of monitoring reports, and meetings with the Regional Water Quality Control Board, Merced County Division of Environmental Health, and the Eastern San Joaquin Water Quality Coalition.

While Department staff regard the revised minimum thresholds to 2015 groundwater levels to be a significant improvement relative to the 2020 Plan, the GSAs have not thoroughly explained the impacts on water quality by operating the basin below historical lows during Plan implementation prior to reaching sustainability. The Plan does not describe how impacts of potential degradation of groundwater that may occur during Plan implementation with the anticipation that groundwater levels will drop below historic lows and could persist in the Subbasin even if groundwater levels return to 2015 groundwater levels. The Plan describes coordination with water quality regulatory agencies and programs, but has not described how coordination with appropriate groundwater users, including water, environmental, and irrigation users will be conducted and how such coordination will be utilized to address groundwater quality degradation, should it occur

[33] https://water.ca.gov/Programs/Groundwater-Management/Drinking-Water-Well
[34] Merced Subbasin 2022 GSP Redline, Section 3.3.2, p. 250 and Section 3.3.3, p. 253.
[35] Merced Subbasin 2022 GSP Redline, Section 3.6.2, p. 262.
[36] Merced Subbasin 2022 GSP Redline, Section 3.6.2, p. 262; Appendix F.

during Plan implementation. Department staff do not regard these remaining issues as sufficiently serious to preclude approval at this time, but staff recommend the GSAs describe how potential impacts to degradation of groundwater quality will be managed. (See Recommended Corrective Action 1b).

4.1.3 Conclusion

Overall, Department staff believe the GSAs have taken sufficient action to address deficiencies identified. Staff conclude that the removal of the requirement of having consecutive non-dry water year types in the definition of undesirable results for chronic lowering of groundwater levels, land subsidence, and depletion of interconnected surface waters allows the GSAs to manage the Subbasin as intended by SGMA. The Plan also provides a description of the drinking water impacts caused by continued overdraft. However, as highlighted in the recommended corrective actions, the GSP should include additional supporting technical details and clarification by the next periodic evaluation.

4.2 Deficiency 2. The GSP does not provide sufficient information to support the selection of chronic lowering of groundwater levels sustainable management criteria.

4.2.1 Corrective Action 2

The Department defined the following corrective actions related to the chronic lowering of groundwater levels sustainable management criteria deficiency in the Incomplete Determination issued on January 28, 2022:

a) *As required by the GSP Regulations, the GSP must provide a description of how the minimum thresholds may affect the interests of beneficial uses and users of groundwater or land uses and property. In particular, the GSAs should address the apparent or potential discrepancies between the stated rationale for the minimum thresholds versus the results of multiple studies showing a potentially significant number of well impacts if groundwater levels are operating near those minimum thresholds. Furthermore, the GSAs should explain whether other drinking water users that may rely on shallow wells, such as public water systems and state small water systems, were considered in the GSAs' site-specific thresholds. If not, the GSAs should conduct outreach with those users and incorporate their shallow wells, as applicable, into the site-specific minimum thresholds and measurable objectives.*

4.2.2 Evaluation

The Department's Incomplete Determination notified the GSAs that public comments and publicly available reports analyzing the effects of the groundwater level minimum thresholds proposed in the 2019 GSP on well infrastructure, indicated the potential for more than 1,000 domestic wells to go dry at those thresholds.[37]

In response to the corrective action, the GSAs revised the chronic lowering of groundwater levels minimum thresholds from the construction depth of the shallowest domestic well within a 2-mile radius of a representative monitoring well to the fall 2015 groundwater level measurement recorded at each representative monitoring well.[38] The Plan explains that the groundwater level minimum thresholds based on fall 2015 groundwater levels are consistent with the avoidance of significant and unreasonable impacts to other sustainability indicators.[39] The Plan explains that the minimum thresholds will keep groundwater elevations generally above levels that have been experienced in the past, and that impacts to shallow well users and other beneficial users of groundwater will generally not exceed what has historically been experienced in the Subbasin.[40] Furthermore, the Plan states that minimum thresholds established at fall 2015 groundwater levels are consistent with the avoidance of significant and unreasonable impacts for subsidence, water quality, and depletions of interconnected surface water.

In revising the sustainable management criteria for chronic lowering of groundwater levels, the GSAs also revised the measurable objectives and the interim milestones. The measurable objectives were changed from projected average future groundwater levels for years 2040 to 2090 in the 2019 Plan, to the fall 2011 groundwater levels at representative wells with available data in the 2022 Plan; wells without available groundwater level data were calculated using estimates of historical groundwater levels in November 2011 from the Merced Water Resources Model.[41] Interim milestones have been revised, raised approximately 80 feet from the previous values; however, when examining the hydrographs provided, Department staff note they are frequently below historical lows.[42] The GSAs have conducted a modeling analysis using the revised groundwater level minimum thresholds (2015 water levels) to understand impacts to beneficial uses and users, specifically domestic well users, and state that there is no indication that a domestic well mitigation program would be necessary.[43] The Plan does not provide the results of this analysis to further explain why the GSAs believe the mitigation program would not be necessary.

[37] See public comments submitted to the Department on the SGMA Portal from the State Water Resources Control Board, which concluded between 395 to 1,195 domestic wells outside or above the Corcoran Clay could go dry at the minimum thresholds. A study by a group affiliated with UC Davis found 415 wells could go dry at the minimum threshold (see Table 3 in the paper: Bostic, Darcy; Kristen Dobbin; Rich Pauloo; Jessica Mendoza; Michael Kuo; Jonathon London. 2020. *Sustainable for Whom? The Impact of Groundwater Sustainability Plans on Domestic Wells*. UC Davis Center for Regional Change).
[38] Merced Subbasin 2022 GSP Redline, Section 3.3.2, p. 250.
[39] Merced Subbasin 2022 GSP Redline, Section 3.3.2, pp. 250-251.
[40] Merced Subbasin 2022 GSP Redline, Section 3.3.2, p. 250.
[41] Merced Subbasin 2022 GSP Redline, Section 3.3.3, pp. 253-254.
[42] Merced Subbasin 2022 GSP Redline, Table 3-1, p. 257.
[43] Merced Subbasin 2022 GSP Redline, Section 6.2.3, p. 325.

The corrective action associated with Deficiency 2 also indicted the GSAs should explain whether other drinking water users that may rely on shallow wells, such as public water systems and state small water systems, were considered in the GSAs' site-specific thresholds. To address the remaining portion of the corrective action, the GSAs used Merced County's electronic well permitting database to determine the shallowest domestic or public water system well depth within five miles (revised from two in the 2019 Plan) of each representative monitoring well and evaluate the impact of the revised minimum thresholds.[44]

Overall, while the GSP does not articulate the specific impacts to beneficial uses and users of groundwater and land uses and property during this time, it is apparent to Department staff that the Plan intends for the Subbasin to experience undesirable results related to groundwater levels prior to reaching sustainability in 2040. Given that the interim milestones are now higher than the previous minimum thresholds, Department staff assume the impacts are less than originally described in the Incomplete Determination Staff Report.[45] Furthermore, the Plan states that the GSAs recognize the importance of access to safe drinking water and, as described in Section 4.1.2.4 of this Staff Report, are establishing a Domestic Well Mitigation Program that would implement mitigation measures for domestic wells dewatered by regional declines in groundwater levels.[46]

Department staff believe that establishing minimum thresholds at 2015 groundwater levels and the implementation of a well mitigation program to be reasonable means of mitigating overdraft to achieve sustainability by 2040. However, Department staff note the GSAs intend to continue overdraft before 2040 based on the revised interim milestones, which after examining the hydrographs provided, are frequently below historical lows.[47] While SGMA and the GSP Regulations does not preclude undesirable results during Plan implementation, undesirable results cannot remain or continue after 20 years of Plan implementation. Department staff are concerned because impacts to other sustainability indicators (such as subsidence and water quality) will not recover in the same manner that groundwater levels can. Department staff believe that additional assessment is needed to understand the impacts to beneficial uses and users from continued overdraft, including what impacts may result if groundwater levels reach the revised interim milestones in 2025 and 2030, prior to reaching sustainability in 2040. This would include an analysis of how many wells may go dry during Plan implementation, for how long they may go dry, and the impacts to land uses and property interests. Department staff recommend the GSAs provide an impact analysis identifying the anticipate wells that may go dry during Plan implementation and explanation of how the mitigation program will be

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[44] Merced Subbasin 2022 GSP Redline, Section 3.3.2, p. 251.
[45] https://sgma.water.ca.gov/portal/gsp/assessments/9.
[46] Merced Subbasin 2022 GSP Redline, Section 3.3.1, p. 248.
[47] Merced Subbasin 2022 GSP Redline, Section 3.3.3, pp. 253-256.

applied during the period of time in which the Subbasin will be operating below minimum thresholds. (See Recommended Corrective Action 2)

4.2.3 Conclusion

At this time, Department staff believe the GSAs have taken sufficient action to address the deficiency identified. The Plan's revised minimum thresholds and measurable objectives for the chronic lowering of groundwater levels appear to Department staff to be a notable improvement for the protection of shallow wells since the revised minimum thresholds have been increased by an average of 106 feet. Department staff believe that the details provided in the Plan regarding the Domestic Well Mitigation Program show improved efforts to consider the beneficial uses and users of drinking water. Staff conclude that the Plan provides a sufficient assessment to support the selection of chronic lowering of groundwater levels sustainable management criteria. However, as highlighted in the recommended corrective action, the Plan should further describe the impacts to groundwater users.

4.3 Deficiency 3. The GSP does not provide sufficient information to support the selection of land subsidence sustainable management criteria.

4.3.1 Corrective Action 3

The Department defined the following corrective actions related to the land subsidence deficiency in the Incomplete Determination issued on January 28, 2022:

a) *The GSAs should identify the amount of subsidence that can be tolerated by critical infrastructure during the implementation of the GSP. This identification should be supported by information on the effects of subsidence on land surface and groundwater beneficial uses and users, and the amount of subsidence that would substantially interfere with those uses and users.*

b) *If, pending resolution of this corrective action, rates of delayed or residual compaction are used to inform minimum thresholds or measurable objectives, then information should be provided to substantiate those rates, or explanation should be provided for how those rates will be evaluated as a data gap.*

c) *The GSAs should revise their minimum thresholds and measurable objectives for land subsidence to reflect the intent of SGMA that subsidence be avoided or minimized once sustainability is achieved. The GSAs should explain how the 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 (i.e., less than substantial interference).*

4.3.2 Evaluation

To address the identified deficiency, the GSAs have supplemented portions of the Plan related to the selection of land subsidence sustainable management criteria. Specifically, how these criteria would affect the amount of tolerable subsidence by critical infrastructure, rates of delayed or residual compaction, and avoiding or minimizing subsidence have been further detailed and/or revised.

To address the deficiency, the Plan establishes revised minimum thresholds to not allow subsidence, amending the minimum thresholds from a subsiding rate of -0.75 feet per year (ft/yr) to 0 ft/yr. The Plan also identifies a total uncertainty of subsidence to be -0.16 ft/yr, meaning any amount of subsidence less than -0.16 ft/yr would be considered within the uncertainty of measurement and considered 0 ft/yr. The Plan states that this minimum threshold is consistent with the sustainable management criteria for groundwater levels which seeks to keep levels above 2015 conditions by 2040. The GSAs also revised the measurable objective rate from -0.25 ft/yr to 0 ft/yr. The Plan allows for minimum threshold exceedances throughout the duration of the implementation phase with the proposed interim milestones, which were revised from a consistent -0.25 ft/yr to -0.75 ft/yr by 2025 (which the 2022 GSP states is slightly higher than actual subsidence rates experienced in the Subbasin between 2011 and 2018), to -0.5 ft/yr by 2030, and -0.25 ft/yr by 2035.[48]

4.3.2.1 Amount of Tolerable Subsidence by Critical Infrastructure (3a)

The Department’s Incomplete Determination notified the GSAs that the 2019 GSP the amount of subsidence that can be tolerated by critical infrastructure is necessary to properly identify what would be significant and unreasonable because it would substantially interfere with land surface and groundwater beneficial uses and users.

To address component 3a of the corrective action, the Plan identifies the Eastside Bypass (located in the southwest corner of the Subbasin) as the largest conveyance facility that has the potential to be damaged or have reduced flood conveyance capacity due to subsidence within the Subbasin.[49] The Plan adds that the San Joaquin River Restoration Program’s 2020 Channel Capacity Report[50] analyzed the impacts of projected total subsidence, from 2016 through 2031, on the flow capacity of the Middle Eastside Bypass and that by 2031, three reaches will be impacted by subsidence with indirect impacts on a fourth reach.[51] In 2020, levee improvements were implemented in one of the three reaches of the Middle Eastside Bypass to resolve flow capacity concerns which eliminated the projected 2031 subsidence impacts in this particular reach. Considering that the Plan does not provide details regarding levee improvements for the other two

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[48] Merced Subbasin 2022 GSP Redline, Section 3.7.2, pp. 265-268.
[49] Merced Subbasin 2022 GSP Redline, Section 3.7.1, p. 265.
[50] Department of Water Resources, 2020. Channel Capacity Report, 2020 Restoration Year, Appendix B - Evaluation of the Effects of Future Subsidence on Capacity up to 2,500 cfs in Reach 4A and Middle Eastside Bypass. Retrieved from https://www.restoresjr.net/wp-content/uploads/2020/02/Appendix-B_508.pdf
[51] Merced Subbasin 2022 GSP Redline, Section 2.2.5, p. 183.

reaches of the Middle Eastside Bypass, Department staff have concerns about impacts to beneficial uses and users resulting further subsidence.

While Department staff are encouraged by the updated sustainable management criteria, the Plan still does not identify a total amount of subsidence which would be considered significant and unreasonable. The interim milestones established allow for more than 7.5 feet of subsidence by 2040. Based on the minor amount of subsidence anticipated between now and 2025, Department staff believe this does not preclude approval at this time. However, given that the Plan intends to both experience minimum threshold exceedances, which may likely result in undesirable results related to water levels and project that subsidence will be 0 ft/yr only by and after 2040, Department staff recommend identifying the total cumulative subsidence for critical infrastructure by the periodic evaluation. (See Recommended Corrective Action 3a).

4.3.2.2 Rates of Delayed or Residual Compaction (3b)

The Department's Incomplete Determination letter notified the GSAs that delayed or residual compaction rates should be substantiated with data and analyses or provide an explanation that details how those rates will be evaluated as a data gap. In response to component 3b of the corrective action, the GSAs revised minimum thresholds[52] and measurable objectives[53] to 0 ft/yr. Because of this attempt by the GSAs to avoid subsidence (with a zero tolerance), it does not appear to Department staff that the GSAs used rates of delayed or residual compaction to inform the development of minimum thresholds and measurable objectives. However, the Plan does state that revised interim milestones are based on an expectation of "continuing"–which Department staff interpret to mean delayed or residual–compaction, due to historical dewatering of the aquifer.[54] Additionally, the Plan allows for minimum threshold exceedances during Plan implementation as indicated above with the proposed interim milestones.

Although SGMA and the GSP Regulations indicate that for a basin to be sustainably managed the basin experience no undesirable results only after 20 years of plan implementation. Unlike other indicators, SGMA calls for subsidence to be avoided or minimized.[55] This does mean that undesirable results from subsidence during plan implementation are not allowable, because undesirable results that occur during plan implementation may still exist and persist to 2040 and beyond. For instance, subsidence that occurs during early Plan implementation that causes lasting impacts to infrastructure, like flood control structures, that substantially interferes with the infrastructure's operations and utility in 2040 and beyond, constitutes an undesirable result under SGMA and would indicate that the basin is not being sustainably managed. Department staff believe that the Plan's revisions to the land subsidence sustainable management criteria with the goal of arresting subsidence is consistent with the intent of SGMA and component

[52] Merced Subbasin 2022 GSP Redline, Section 3.7.2, p. 267.
[53] Merced Subbasin 2022 GSP Redline, Section 3.7.3, pp. 267-268.
[54] Merced Subbasin 2022 GSP Redline, Section 3.7.3, p. 268.
[55] Water Code § 10720.1(e).

3b of the corrective action has been sufficiently addressed. However, because of the Plan's continued allowance of minimum threshold exceedances during the implementation period (i.e., allowing subsidence at the interim milestone rates) due to planned overdraft, along with documentation of potential impacts of subsidence on the Middle Eastside Bypass, Department staff believe that this is not consistent with the intent of SGMA to avoid or minimize subsidence. The Plan should include additional details describing measures that consider and disclose the current and potentially lasting impacts of subsidence on land uses and groundwater beneficial uses and users as described above in Recommended Corrective Action 3a.

4.3.2.3 Avoiding or Minimizing Subsidence with Sustainable Management Criteria (3c)

The Department's Incomplete Determination letter stated the GSAs should revise their minimum thresholds and measurable objectives for land subsidence to reflect the intent of SGMA that subsidence be avoided or minimized once sustainability is achieved, and that the GSAs should explain how the implementation of the projects and management actions is consistent with both achieving long-term avoidance or minimization of subsidence and with not exceeding the tolerable amount of cumulative subsidence (i.e., less than substantial interference). In response to component 3c of the corrective action, as described above, the GSAs revised minimum thresholds[56] and measurable objectives[57] to 0 ft/yr and will ramp down at each interim milestone to 0 ft/yr. The Plan describes that the 2025 interim milestone is slightly higher than actual subsidence rates experienced between 2011 and 2018 in the Subbasin and that subsequent interim milestones are reduced as projects and management actions are implemented.[58]

In the establishment of the minimum threshold, the Plan describes the application of a level of uncertainty to measurements, claiming that the survey measurements have a vertical accuracy of plus or minus 2.5 centimeters. The Plan proposes adding these uncertainty values so that when two measurements are taken the Agencies consider the total uncertainty in subsidence to be 5 centimeters, which equals approximately -0.16 ft/yr. By this rationale, the Plan assumes that subsidence values less than 0.16 ft/yr are within the uncertainty of measurement and considered to be compliant with the minimum threshold of 0 ft/yr.[59] Department staff believe this approach, involving the compounding of uncertainty values, to be inconsistent with standard practices. When multiple measurements are taken at the same location, they are being compared to the same baseline measurement and, in turn, have the same single level of uncertainty. While it's understandable that there be an allowance for a level of uncertainty, it appears the Plan allows for the continued subsidence if the rate is less than 0.16 ft/yr. Department staff recommend the Plan revise its application of the level of uncertainty as it relates to

[56] Merced Subbasin 2022 GSP Redline, Section 3.7.2, pp. 265-267.
[57] Merced Subbasin 2022 GSP Redline, Section 3.7.3, pp. 267-268.
[58] Merced Subbasin 2022 GSP Redline, Section 3.7.3, p. 268.
[59] Merced Subbasin 2022 GSP Redline, Section 3.7.3, p. 267.

subsidence measurements according to standard professional practices. (See Recommended Corrective Action 3b)

The Plan states the Above Corcoran Sustainable Management Criteria Adjustment Consideration Management Action will assist in avoiding declines in groundwater levels below historical levels, which in turn will reduce the risk of subsidence. This management action will redirect pumping from the “Below Corcoran Clay” principal aquifer to "Above Corcoran Clay” principal aquifer.[60] Principal Aquifers are described in further detail in Section 5.2.1 of this Staff Report. The proposed management action would modify the groundwater level sustainable management criteria for all or a portion of the “Above Corcoran Clay” Principal Aquifer in order mitigate subsidence impacts by directing pumping from the Below Corcoran Clay Principal Aquifer to the Above Corcoran Clay. The Plan states that because much of the Above Corcoran Clay Principal Aquifer has historically had lower levels of water use, minimum thresholds are likely to be high and describes that because the aquifer does not have many domestic wells and is not considered to contribute to subsidence, sustainable management criteria for chronic lowering of groundwater levels could be revised. The Plan states that if this management action were to be selected, it would take place prior to 2025 through the submittal of a revised GSP (which Department Staff assume the GSAs mean the periodic evaluation) and that recharge projects may be considered “for pairing with increased pumping from above the clay.”[61]

Department staff believe the changes to the minimum threshold and measurable objectives are good steps taken by the Agencies to reach sustainability and address component 3c of the corrective action; however, given the adjustments to the interim milestones Department staff encourage the Agencies to address the recommended corrective actions.

4.3.3 Conclusion

Overall, Department staff believe the GSAs have taken sufficient action to address the deficiency identified. Staff conclude that the zero tolerance for land subsidence minimum thresholds and measurable objectives is commensurate with the understanding of SGMA. However, the recommended corrective actions should be considered by the next periodic evaluation for further advancement of the sustainable management criteria. Department staff have also provided evaluation of the monitoring network, in Section 5.4 of this Staff Report, for the Subbasin based on the changes made to the sustainable management criteria.

[60] Merced Subbasin 2022 GSP Redline, Section 3.7.3, p. 327.
[61] Merced Subbasin 2022 GSP Redline, Section 6.2.4, pp. 327-328.

5 PLAN EVALUATION

As stated in Section 355.4 of the GSP Regulations, a basin "shall be sustainably managed within 20 years of the applicable statutory deadline consistent with the objectives of the Act." The Department's assessment is based on a number of related factors including whether the elements of a GSP were developed in the manner required by the GSP Regulations, whether the GSP was developed using appropriate data and methodologies and whether its conclusions are scientifically reasonable, and whether the GSP, through the implementation of clearly defined and technically feasible projects and management actions, is likely to achieve a tenable sustainability goal for the basin.

The Department staff's evaluation of the likelihood of the Plan to attain the sustainability goal for the Basin is provided below. Department staff consider the information presented in the Plan to satisfy the general requirements of the GSP Regulations.

5.1 ADMINISTRATIVE INFORMATION

The GSP Regulations require each Plan to include administrative information identifying the submitting Agency, describing the plan area, and demonstrating the legal authority and ability of the submitting Agency to develop and implement a Plan for that area.[62]

The Plan was developed jointly by the Merced Irrigation-Urban Groundwater Sustainability Agency, the Merced Subbasin Groundwater Sustainability Agency, and Turner Island Water District Groundwater Sustainability Agency #1. The GSAs developed a Memorandum of Understanding (MOU) that provides the basis for the agreement of the three GSAs to work together to develop and implement a GSP for the Merced Subbasin.[63] The GSAs were guided by recommendations from a Coordination Committee and Stakeholder Advisory Committee.

The Plan estimates implementation will cost between $1.2 million and $1.6 million per year with projects and management actions costing an estimated $22.9 million.[64] The Plan describes that the GSAs will develop a financing plan for the overall implementation of the GSP; financing options under consideration by the GSAs include pumping fees, assessments, loans, and grants; and that costs for project implementation will be shared based on project beneficiaries. The costs of overall GSP administration are expected to be shared by the three GSAs consistent with the cost share in the MOU.

The description of the Plan Area consists of details related to the area covered by the Plan, boundaries of agencies, land use designations, water use, density of wells, water monitoring programs, and land use plans. The majority of the Subbasin is covered by the Merced Irrigation-Urban GSA and the Merced Subbasin GSA with a minor portion

[62] 23 CCR § 354.2 *et seq*.
[63] Merced Subbasin 2019 GSP, Section 1.1.3, p. 28.
[64] Merced Subbasin 2019 GSP, Section 1.1.3.3, p. 31.

covered by the Turner Island Water District GSA-1.[65] The Subbasin is bordered to the north by the Turlock Subbasin, to the south by the Chowchilla Subbasin, to the west by the Delta-Mendota Subbasin, and to the east by the Sierra Nevada foothills.[66] The Plan describes that land use patterns in the Subbasin are dominated by agricultural uses. Federal and State lands associated with wildlife refuge areas are primarily on the western part of the Subbasin along the San Joaquin River.[67] A map showing the Subbasin and adjacent subbasins is shown in Figure 1 below.

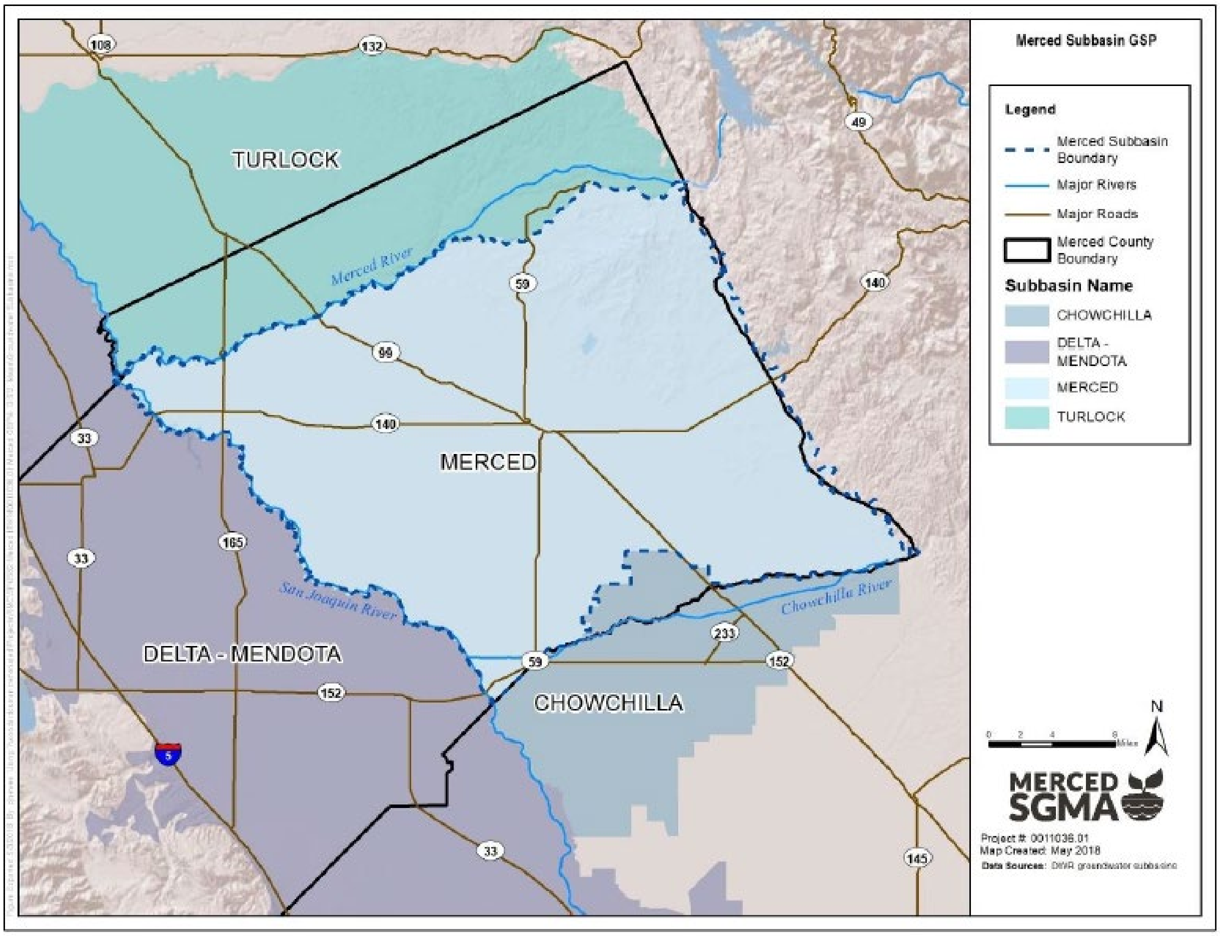

Figure 1. Merced Subbasin Location Map

The Plan provides a general description of existing land use plans, surface water supply, and demands in the Subbasin.[68] In particular, the Plan describes that in 2015, Merced County implemented a new well permitting program for any new, replacement, back-up, and De Minimis well construction.[69] Program applicants must provide information about groundwater elevation estimates, land elevation estimates, land subsidence rate

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[65] Merced Subbasin 2019 GSP, Figure 1-5, p. 44.
[66] Merced Subbasin 2019 GSP, Figure 1-2, p. 41.
[67] Merced Subbasin 2019 GSP, Figure 1-7, p. 46.
[68] Merced Subbasin 2019 GSP, Section 1.2.2.4, pp. 53-54 and Section 1.2.3, pp. 58-64.
[69] Merced Subbasin 2019 GSP, Section 1.2.3.3, p. 65.

estimates, depth to Corcoran Clay, and other basic well characteristics. The new well permitting program does not allow groundwater to be “exported”, meaning used outside of the same basin from which it is extracted, without an exemption claim.

Beneficial uses and users of groundwater include: municipalities, utilities, or other public water districts that provide groundwater as a drinking water supply; agricultural purveyors; individual private supply wells; and the environment.[70] Department staff assume that the use of “private” supply wells, introduced elsewhere in the GSP to include “agricultural-private” and “urban-private”,[71] is interchangeable with “domestic” well use in the GSP. For the environment, the Plan states that the U.S. Fish & Wildlife Service operates several wildlife refuges/management areas in the Subbasin that are supported by groundwater, and that there are additional wetlands and other groundwater-dependent ecosystems throughout the Subbasin.[72]

The Plan provides a list of public meetings where the GSP was discussed from January 2018 through June 2019, including GSA board meetings, Coordination Committee meetings, stakeholder advisory committee meetings, and public workshops. Public comments received during Plan development including meeting notes from the Stakeholder Advisory Committee, Coordination Committee, and Public Workshops are included in Appendix B of the GSP.[73] Public comments regarding the Plan were reviewed, categorized, and addressed in Appendix O of the GSP.[74] Attachments to Appendix O include public comment letters and comments from the joint boards meeting, documented in the meeting minutes.

The Plan describes that as part of the decision-making process, the GSAs were guided by a Coordination Committee that is composed of up to four representatives from each GSA and appointed by each respective GSA Board. The Coordination Committee and GSA Board were also informed by a Stakeholder Advisory Committee which consisted of community representatives who reviewed groundwater conditions, management issues and needs, and projects and management actions to improve sustainability in the Subbasin. The 23 Stakeholder Advisory Committee members were selected by the Coordination Committee and approved by the GSAs to represent the broad interests and geography in the region.[75] The Plan describes that public engagement was promoted with the formation of a Stakeholder Engagement Strategy to conduct outreach and develop engagement throughout the GSP development process.[76] Active public participation was encouraged by accepting public comments at GSA Board meetings, forming a Stakeholder Advisory Committee, developing a website, coordinating disadvantaged community outreach efforts, issuing news releases and providing translation

[70] Merced Subbasin 2019 GSP, Section 1.2.5.1, p. 66.
[71] Merced Subbasin 2019 GSP, Table 2-16, pp. 202-203.
[72] Merced Subbasin 2019 GSP, Section 1.2.5.1, pp. 66-68.
[73] Merced Subbasin 2019 GSP, Appendix B, pp. 376-574.
[74] Merced Subbasin 2019 GSP, Appendix O, pp. 1118-1284.
[75] Merced Subbasin 2019 GSP, Section 1.2.5.5.1, p. 71.
[76] Merced Subbasin 2019 GSP, Section 1.2.5.2, p. 68 and Appendix N, pp. 1094-1117.

(interpretation) services at public workshops. The Plan describes that the GSAs intend to inform the public about the status of projects and Plan implementation by providing opportunities for public participation, access to GSP information online, and by coordinating with entities that conduct outreach to disadvantaged communities.[77]

Overall, Department staff believe the GSAs have thoroughly described agency information, plan area, and notice and communication process, in substantial compliance with the GSP Regulations.

5.2 Basin Setting

The GSP Regulations require information about the physical setting and characteristics of the basin and current conditions of the basin, including a hydrogeologic conceptual model; a description of historical and current groundwater conditions; and a water budget accounting for total annual volume of groundwater and surface water entering and leaving the basin, including historical, current, and projected water budget conditions.[78]

5.2.1 Hydrogeologic Conceptual Model

The GSP Regulations require a descriptive hydrogeologic conceptual model of the basin that includes a written description supported by cross sections and maps.[79] The hydrogeologic conceptual model is a non-numerical model of the physical setting, characteristics, and processes that govern groundwater occurrence within a basin, and represents a GSA's understanding of the geology and hydrology of the basin that support the geologic assumptions used in developing mathematical models, such as those that allow for quantification of the water budget.[80]

The Plan provides a description of the hydrogeologic conceptual model for the Merced Subbasin that is based on existing geologic and hydrogeologic studies. The Plan describes that the Subbasin is in the San Joaquin Valley, a broad structural trough approximately 200 miles long and up to 70 miles wide. The Plan describes that the Subbasin is bounded by the foothills of the Sierra Nevada Mountain range on the east and other groundwater subbasins of the Central Valley to the north, south, and west.[81]

The Plan describes that the Subbasin consists of unconsolidated deposits and underlying consolidated sedimentary rocks of the Valley Springs Formation and the Mehrten Formation.[82] The Corcoran Clay, a bed of laterally extensive reduced (blue/grey) silt and clay, is described by the GSP as a key feature that restricts vertical groundwater flow in

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[77] Merced Subbasin 2019 GSP, Section 1.2.5.5.2, p. 71.
[78] 23 CCR § 354.12 *et seq*.
[79] 23 CCR § 354.12 *et seq*.
[80] DWR Best Management Practices for the Sustainable Management of Groundwater: Hydrogeologic Conceptual Model, December 2016: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-3-Hydrogeologic-Conceptual-Model_ay_19.pdf.
[81] Merced Subbasin 2019 GSP, Section 2.1.6.1, p. 111.
[82] Merced Subbasin 2019 GSP, Table 2-8, p. 125.

the Subbasin. The Plan provides a map that depicts that the Corcoran Clay occurs at depths of approximately 200 feet in the western portion of the Subbasin, becoming shallower eastward until it pinches out at a depth of approximately 75 feet, generally corresponding to the pathway of Highway 99.[83]

The Plan identifies the bottom of the Subbasin as the lowest elevation of fresh water, as previously mapped based on well measurements of specific conductance of less than 3,000 micromhos per centimeter.[84] Data provided by the Plan show that in most parts of the Subbasin, the base of fresh water is deeper than 500 feet with some wells extending deeper than the bottom of the Subbasin. The Plan describes that based on a well depth analysis from March 2018 and the Merced County's well permit database, 56 wells extend below what the GSP identifies as the bottom of the Subbasin.[85] The GSP states there is no data available to show that these wells are active but does not indicate that obtaining such data through surveys or ground truthing is impossible. If any of these wells are active, their pumping could impact the groundwater management of the Subbasin. Department staff therefore recommend the GSAs further investigate these wells and confirm to what extent they are active. If these wells are active, then the GSAs should determine their groundwater extractions and account for that activity in the Plan, which may result in a reassessment of the bottom of the Basin. (See Recommended Corrective Action 4)

The Plan states that the Merced Groundwater Basin Groundwater Management Plan Update (2008) identified five different aquifer systems (a fractured bedrock aquifer, the Mehrten Formation, a confined aquifer, an intermediate "leaky" aquifer, and a shallow unconfined aquifer) in the Subbasin.[86] The GSP states that for practical purposes, these five aquifer systems are combined into three principal aquifers, (1) the Above Corcoran Clay, (2) Below Corcoran Clay, and (3) Outside Corcoran Clay.[87] The Plan describes that the Above Corcoran Clay Principal Aquifer includes all aquifers that exist above the Corcoran Clay Aquitard, namely the Intermediate Leaky-Aquifer and the Shallow Unconfined Aquifer (where it overlies the Corcoran Clay).[88] The Below Corcoran Clay Principal Aquifer is described to include all aquifers that exist below the Corcoran Clay Aquitard, namely the Confined Aquifer and any portion of the Mehrten Formation, Valley Springs formation, or Fractured Bedrock system that underlies the Corcoran Clay. Outside the Corcoran Clay includes Fractured Bedrock, Mehrten Formation, Intermediate Leaky-Aquifer, and the Shallow Unconfined Aquifer.[89]

[83] Merced Subbasin 2019 GSP, Section 2.1.7.2, p. 124 and Figure 2-37, p. 128.
[84] Page, R. W. (1973). *Base of Fresh Ground Water (approximately 3,000 micromhos) in the San Joaquin Valley, California.* Hydrologic Atlas 489.
[85] Merced Subbasin 2019 GSP, Section 2.1.6.2, p. 114.
[86] Merced Subbasin 2019 GSP, Section 2.1.7.1, pp. 115-117.
[87] Merced Subbasin 2019 GSP, Section 2.1.7, p. 114.
[88] Merced Subbasin 2019 GSP, Section 2.1.7.2, p. 124.
[89] Merced Subbasin 2019 GSP, Table 2-8, p. 125.

The description of the hydrogeologic conceptual model in the GSP substantially complies with the requirements outlined in the GSP Regulations. While Department staff have provided a recommended corrective action to further investigate potential pumping from below the bottom of the basin, at this time, this Plan section is described in sufficient detail, and appears to be based on the best information and science available at the time the GSP was prepared.

5.2.2 Groundwater Conditions

The GSP Regulations require a written description of historical and current groundwater conditions for each of the six sustainability indicators and groundwater dependent ecosystems.[90]

In describing historical groundwater conditions, the Plan states that long-term groundwater elevations in the Subbasin are declining and that during the period from 1996 to 2015 (identified as representative hydrologic conditions), groundwater levels decreased annually on average by 1.3 feet for the Above Corcoran Clay Principal Aquifer, 2.4 feet for the Below Corcoran Clay Principal Aquifer, and 1.2 feet from the Outside Corcoran Clay Principal Aquifer.[91] The GSP provides two hydrographs of wells with multiple discrete completion depths for each of the three Subbasin's principal aquifers: (1) Above Corcoran Clay[92], (2) Below Corcoran Clay[93], and (3) Outside Corcoran Clay.[94] Based on Department staff's assessment of the well screen intervals and depth to Corcoran Clay provided by the GSP, the hydrographs depict vertical gradients within the principal aquifers.

The Plan provides a detailed and descriptive graph depicting annual and cumulative change in groundwater in storage by water year type, along with annual groundwater use for the period of 1996 to 2015.[95] The graph depicts that during wet years, change in storage increased, but during all other water year types (above normal, below normal, dry, and critical), change in groundwater in storage decreased; corresponding to an overall cumulative decrease of approximately 3 million acre-feet of storage. The Plan estimates that groundwater storage for the Subbasin as of 2015 was 45.3 million acre-feet.[96]

The GSP identifies the naturally-occurring water quality constituents of concern in the Subbasin as arsenic and uranium, and the water quality constituents of concern in the Subbasin related to human activity as salinity, nitrate, hexavalent chromium, petroleum hydrocarbons (such as benzene and Methyl Tertiary Butyl Ether (MTBE)), pesticides (such as Dibromochloropropane (DBCP), ethylene dibromide (EDB), 1,2,3-

[90] 23 CCR § 354.16(a-f).
[91] Merced Subbasin 2019 GSP, Section 2.2.1.1, p. 132.
[92] Merced Subbasin 2019 GSP, Figures 2-55 and 2-56, p. 148.
[93] Merced Subbasin 2019 GSP, Figures 2-51 and 2-52, p. 146.
[94] Merced Subbasin 2019 GSP, Figures 2-53 and 2-54, p. 147.
[95] Merced Subbasin 2019 GSP, Figure 2-58, p. 150.
[96] Merced Subbasin 2019 GSP, Section 2.2.2, p. 149.

trichloropropane (TCP)), solvents (such as tetrachloroethylene (PCE), trichloroethylene (TCE)), and emerging contaminants (such as perfluorooctantoic acid (PFOA), perfluorooctanesulfonic acid (PFOS)), with nitrate identified as the most widespread issue with a direct impact on public health. Salinity, measured as TDS, is described by the Plan as an issue due to the widespread nature of the problem and difficulty of management given increases in salinity because of both urban and agricultural use. The Plan provides maps of the concentrations for the constituents of concern, developed based on the monitoring network data collected within the Subbasin.[97]

The GSP states that seawater intrusion is not a potential risk in the Subbasin, as the Subbasin is not near any seawater source.[98]

The GSP describes land subsidence as a significant issue in the southwestern portion of the Subbasin and in the neighboring Delta-Mendota and Chowchilla Subbasins and states that the subsidence is likely caused by groundwater extraction from below the Corcoran Clay.[99] GSP Maps based on United States Bureau of Reclamation San Joaquin River Restoration Program Subsidence Control Points identify that the most subsidence is occurring in the southwestern portion of the Subbasin with rates averaging up to 0.45 ft/yr (December 2011 to December 2017) with a maximum annual rate of subsidence rate of 0.67 ft/yr (December 2012 to December 2013).

The Plan describes that the Merced Water Resources Model was used to identify interconnected surface waters and identifies interconnected surface waters for the Merced River, San Joaquin River and tributaries to both rivers.[100] Presence of interconnected surface waters are identified predominantly on the northwestern portion of the Subbasin within the Above Principal Corcoran Clay Principal Aquifer, with a small portion of interconnected streams for the Merced River within the Outside Corcoran Clay Principal Aquifer.[101] Department staff found some conflicting statements related to the amount of depletions occurring. The Plan states that stream depletions were not calculated and that there are no known field studies of interconnected surface water systems within the Subbasin, but also later states Model results estimate additional 16,000 acre-feet per year of depletions on the Merced River, 10,000 acre-feet per year on the San Joaquin River, and 12,000 acre-feet per year on the combined system of canals and smaller streams.[102] Timing of the depletions is not identified.

The GSP depicts likely groundwater dependent ecosystems in the northwestern portion of the Subbasin, at the confluence of the Merced and San Joaquin River, with likely groundwater dependent ecosystems also in the southwestern portion of the Subbasin.[103] The GSP describes that the identification of groundwater dependent ecosystems was

[97] Merced Subbasin 2019 GSP, Section 2.2.4, p. 151-180.
[98] Merced Subbasin 2019 GSP, Section 2.2.3, p. 150.
[99] Merced Subbasin 2019 GSP, Section 2.2.5, p. 180.
[100] Merced Subbasin 2019 GSP, Figure 2-10, p. 89 and Section 2.2.6, p. 186.
[101] Merced Subbasin 2019 GSP, Figure 2-10, p. 89 and Figure 2-41, p. 134.
[102] Merced Subbasin 2019 GSP, Section 2.2.6, p. 186; p. 261.
[103] Merced Subbasin 2019 GSP, Figure 2-87 and Figure 2-88, pp. 191-192.

performed in two steps: (1) identifying the types of plants that are often associated with accessing groundwater using the Natural Communities Commonly Associated with Groundwater (NCCAG) database, and (2) by identifying if those plants are dependent on groundwater, or if they can access alternate water supplies.[104] The GSP also describes five categories of NCCAG areas that were not identified (i.e., excluded) as groundwater dependent ecosystems: (1) areas with depth to groundwater greater than 30 feet in Spring 2015, (2) managed wetlands with supplemental water deliveries, (3) areas adjacent to irrigated fields, (4) NCCAG areas within 300 feet of losing streams, and (5) vernal pool complexes. Additional consideration was taken by the GSAs to analyze additional GDEs not included by the NCCAG through review of aerial photographs and comparison to external databases. The GSP provides maps of additional GDEs in the Subbasin.[105]

The Department received and considered several public comments related to interconnected surface water and groundwater dependent ecosystems, expressing concern with the methods and approaches taken to identify the connected systems. Department staff believe the GSAs have taken thorough steps in identifying the presence of interconnected surface water and groundwater dependent ecosystems; what the GSAs have provided is substantially compliant with the GSP Regulations and the issues raised are not of concern at this time.

Overall, Department staff conclude the Plan sufficiently describes the historical and current groundwater conditions throughout the Subbasin, provides sufficient maps, and the information included in the Plan substantially complies with the requirements outlined in the GSP Regulations.

5.2.3 Water Budget

The GSP Regulations require a water budget for the basin that provides an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the basin, including historical, current, and projected water budget conditions, and the change in the volume of water stored, as applicable.[106]

The GSP identifies water budgets for historical, current, projected, and sustainable conditions utilizing the Merced Water Resources Model, a fully integrated surface and groundwater flow model covering approximately 1,500 square miles of the Merced Groundwater Region, which fully encompasses the Merced Subbasin, plus the Dry Creek watershed North of the Merced River and the section of Chowchilla Water District north of the Chowchilla River.[107] Outflows from the groundwater system are identified by the GSP to streams, land surface system, subsurface outflow, and from agricultural and urban use.[108] Outflows from the groundwater system for managed wetlands were not separately provided by the GSP, noting that managed wetlands and habitat areas are

[104] Merced Subbasin 2019 GSP, Section 2.2.7, p. 187.
[105] Merced Subbasin 2019 GSP, Section 2.2.7, pp. 187-192.
[106] 23 CCR § 354.18.
[107] Merced Subbasin 2019 GSP, Section 2.3.2, p. 195.
[108] Merced Subbasin 2019 GSP, Table 2-17, pp. 204-205.

recognized as additional areas that have unique water use characteristics and that values for applied surface water and applied groundwater are aggregated into larger categories such as local, riparian or agricultural.[109]

The water budget provides details of total surface water entering and leaving the basin by source type, inflows to and outflows from the groundwater system, and change in the annual volume of groundwater in storage. The GSP states that greater outflows than inflows (2005 to 2015) lead to an average annual decrease (for historical conditions water budget) in groundwater storage of 192,000 acre-feet per year, while the projected conditions water budget has an estimated deficit in groundwater storage of 82,000 acre-feet per year, and the sustainable conditions water budget has a zero change in storage.[110]

A "sustainable yield water budget" was developed by the GSAs, which the GSP states is "intended to estimate future conditions of supply, demand, and aquifer response to implementation of sustainable conditions in the Subbasin."[111] The sustainable yield water budget was developed using the "sustainable conditions scenario" of the Merced Water Resources Model. The GSP describes that the sustainable yield water budget is based on the Projected Conditions Baseline and is modeled with lower groundwater production resulting from an estimated reduction in agricultural and urban demand. The GSP states that "to achieve a net-zero change in groundwater storage over a 50-year planning period (water years 2041 to 2090), agricultural and urban groundwater demand would need to be reduced by approximately ten percent, if no new water supply projects are implemented".[112] It should be noted that per the GSP Regulations, the Subbasin must achieve sustainability within 20 years of Plan adoption and maintain sustainability for the 50-year planning and implementation horizon.[113] Based on the sustainable yield water budget analysis, the sustainable yield of the basin is approximately 570,000 acre-feet per year.

Department staff conclude the historical, current, and projected water budgets included in the Plan substantially comply with the requirements outlined in the GSP Regulations. The GSP provides the required historical, current, and future accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the Basin including an estimate of the sustainable yield of the Basin and projected future water demands.

5.2.4 Management Areas

The GSP Regulations provide the option for one or more management areas to be defined within a basin if the GSA has determined that the creation of the management areas will facilitate implementation of the Plan. Management areas may define different minimum

[109] Merced Subbasin 2019 GSP, Table 2-16, p. 203.
[110] Merced Subbasin 2019 GSP, Table 2-17, p. 205.
[111] Merced Subbasin 2019 GSP, Section 2.3.5, pp. 217-218.
[112] Merced Subbasin 2019 GSP, Section 2.3.5, pp. 217-218.
[113] 23 § 350.4(f).

thresholds and be operated to different measurable objectives, provided that undesirable results are defined consistently throughout the basin.[114] The Plan does not include the use of management areas for the Subbasin.

5.3 Sustainable Management Criteria

The GSP Regulations require each Plan to include a sustainability goal for the basin and to characterize and establish undesirable results, minimum thresholds, and measurable objectives for each applicable sustainability indicator, as appropriate. The GSP Regulations require each Plan to define conditions that constitute sustainable groundwater management for the basin including the process by which the GSA characterizes undesirable results and establishes minimum thresholds and measurable objectives for each applicable sustainability indicator.[115]

5.3.1 Sustainability Goal

The Sustainability Goal of the Merced Subbasin is to "[a]chieve sustainable groundwater management on a long-term average basis by increasing recharge and/or reducing groundwater pumping, while avoiding undesirable results."[116] The GSP states that the sustainability goal will be achieved by "allocating a portion of the estimated Subbasin sustainable yield to each GSA and coordinating the implementation of programs and projects to increase both direct and in-lieu groundwater recharge, which will, in turn, increase the groundwater and / or surface water available to each GSA."

5.3.2 Sustainability Indicators

Sustainability indicators are defined as any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results.[117] Sustainability indicators thus correspond with the six undesirable results – chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon, significant and unreasonable reduction of groundwater storage, significant and unreasonable seawater intrusion, significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies, land subsidence that substantially interferes with surface land uses, and depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water[118] – but refer to groundwater conditions that are not, in and of themselves, significant and unreasonable. Rather, sustainability indicators refer to the effects caused by changing groundwater conditions that are monitored, and for which criteria in the form of minimum thresholds are established by the agency to define when the effect becomes significant and unreasonable, producing an undesirable result.

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[114] 23 CCR § 345.20.
[115] 23 CCR § 354.22 *et seq*.
[116] Merced Subbasin 2019 GSP, Section 3.1, p. 241.
[117] 23 CCR § 351(ah).
[118] Water Code § 10721(x).

The following subsections consolidate three facets of sustainable management criteria: undesirable results, minimum thresholds, and measurable objectives. Information, as presented in the Plan, pertaining to the processes and criteria relied upon to define undesirable results applicable to the basin, as quantified through the establishment of minimum thresholds, are addressed for each sustainability indicator. However, a GSA is not required to establish criteria for undesirable results that the GSA can demonstrate are not present and are not likely to occur in a basin.[119]

5.3.2.1 Chronic Lowering of Groundwater Levels

The GSP Regulations require the minimum threshold for chronic lowering of groundwater levels to be the groundwater elevation indicating a depletion of supply at a given location that may lead to undesirable results.[120]

In the January 2022 Incomplete Determination, the Department identified two deficiencies related to the sustainable management criteria of chronic lowering of groundwater levels. The GSAs revised this portion of the Plan, and Department staff evaluate this sustainability indicator in Section 4.1 and Section 4.2 of this Staff Report. As described above, Department staff have provided recommended corrective actions based on the changes the Agencies have made to the sustainable management criteria for this sustainability indicator.

5.3.2.2 Reduction of Groundwater Storage

The GSP Regulations require the minimum threshold for the reduction of groundwater storage to be a total volume of groundwater that can be withdrawn from the basin without causing conditions that may lead to undesirable results. Minimum thresholds for reduction of groundwater storage shall be supported by the basin's sustainable yield, calculated based on the basin's historical trends, water year type, and projected water use.[121]

The GSP states that reduction of groundwater storage is not an applicable sustainability indicator because significant and unreasonable reduction of groundwater storage is not present and not likely to occur in the Subbasin.[122] The GSP identifies that based on groundwater storage in the Subbasin of 45 million acre-feet (as of 2015), it would not be reasonable to expect the available groundwater in storage to be exhausted, based on an estimated overdraft rate of approximately 0.3 percent per year over the period of 1996-2015., This results in a cumulative reduction of groundwater storage of 3 million acre-feet (approximately 6 percent of total).[123]

In order to not establish sustainable management criteria for a sustainability indicator (deem it not applicable), an Agency must demonstrate that an undesirable result for that sustainability indicator is not present and not likely to occur in a basin.[124] Department staff

[119] 23 CCR § 354.26(d).
[120] 23 CCR § 354.28(c)(1).
[121] 23 CCR § 354.28(c)(2).
[122] Merced Subbasin 2019 GSP, Section 3.4, p. 251.
[123] Merced Subbasin 2019 GSP, Section 3.4, p. 251.
[124] 23 CCR § 354.26(d).

conclude that Agencies have not satisfied this requirement and, therefore, it is not reasonable for the Agencies to not establish sustainable management criteria for the reduction of groundwater storage in the Subbasin. This Subbasin is considered critically overdrafted and the GSAs intend to operate the Subbasin at water levels below historical lows prior to reaching sustainability in 2040; further substantiating the GSAs inability to dismiss this sustainability indicator. Annual reports submitted to the Department indicate the basin has at times exceeded the approximate overdraft rate of 0.3 percent per year. Because groundwater levels are closely correlated with groundwater storage and those levels are being closely monitored, Department staff do not believe this shortcoming to preclude approval at this time; however, Department staff recommend sustainable management criteria for reduction of groundwater storage be established in accordance with the GSP Regulations by the periodic evaluation. (See Recommended Corrective Action 5).

5.3.2.3 Seawater Intrusion

The GSP Regulations require the minimum threshold for seawater intrusion to be defined by a chloride concentration isocontour for each principal aquifer where seawater intrusion may lead to undesirable results.[125]

The GSP does not develop sustainable management criteria for seawater intrusion. The GSP states that seawater intrusion is not a potential risk in the Merced Subbasin because the Subbasin is not near any seawater source.[126] This assessment presented in the GSP is reasonable to Department staff.

5.3.2.4 Degraded Water Quality

The GSP Regulations require the minimum threshold for degraded water quality to be the degradation of water quality, including the migration of contaminant plumes that impair water supplies or other indicator of water quality as determined by the Agency that may lead to undesirable results. The minimum thresholds shall be based on the number of supply wells, a volume of water, or a location of an isocontour that exceeds concentrations of constituents determined by the Agency to be of concern for the basin. In setting minimum thresholds for degraded water quality, the Agency shall consider local, state, and federal water quality standards applicable to the basin.[127]

As described in Section 5.2.2, the GSAs have identified several constituents of concern for the Subbasin but have established sustainable management criteria for only TDS. The GSP describes the primary naturally-occurring water quality constituents of concern in the Subbasin as arsenic and uranium, and the primary water quality constituents of concern related to human activity as salinity (total dissolved solids (TDS)), nitrate, hexavalent chromium, petroleum hydrocarbons (such as benzene and Methyl Tertiary Butyl Ether (MTBE), pesticides (such as Dibromochloropropane (DBCP), ethylene

[125] 23 CCR § 354.28(c)(3).
[126] Merced Subbasin 2019 GSP, Section 3.5, p. 251.
[127] 23 CCR § 354.28(c)(4).

dibromide (EDB), 1,2,3-trichloropropane (TCP)), solvents (such as tetrachloroethylene (PCE), trichloroethylene (TCE)), and emerging contaminants (such as perfluorooctantoic acid (PFOA), perfluorooctanesulfonic acid (PFOS)).[128] The Plan states that GSAs and stakeholders determined that "salinity is the only constituent of concern currently known to be directly tied to groundwater management activities" in the Subbasin.[129] The Plan states that for the other constituents of concern, "thresholds are not established because there is no demonstrated local correlation between fluctuation in groundwater elevations and/or flow direction and concentrations of the constituents," "the GSAs have no authority to limit the loading of nutrients or agrochemicals," and "GSAs are not responsible and do not have authority for containment or cleanup" of sites under cleanup orders set by state or federal agencies.[130] The other constituents of concern are considered by the GSAs as water quality issues without a causal nexus in the Subbasin. The GSAs' stance regarding their lack of authority to manage based on a causal nexus does not consider the potential for degraded groundwater to migrate toward previously unimpacted areas due to GSA groundwater management activities. Because the GSAs have legal authority to regulate groundwater pumping, which affects hydraulic gradients and groundwater flow, the GSA can monitor for and influence the migration of groundwater and has the responsibility to prevent unimpacted areas from becoming significantly and unreasonably impacted by constituents of concern.[131]

Given the constituents of concern for the Subbasin and the ability of groundwater management to cause degradation of water quality, Department staff recommend the GSAs provide additional justification and explanation for how the other constituents of concern will be managed and monitored, and how impacts to beneficial uses and users will be addressed, should there be degradation of water quality during plan implementation when the Subbasin expects to lower of groundwater elevations. Department staff believe that the GSAs should consider developing sustainable management criteria for additional water quality constituents (see Recommended Corrective Action 6a).

The Plan establishes sustainable management criteria for degraded water quality for TDS. The Plan states that "undesirable results for degraded water quality would be impacts caused by groundwater extractions and other SGMA groundwater management activities in the Subbasin that cause significant and unreasonable reduction in the long-term viability of domestic, agricultural, municipal, or environmental uses over the planning and implementation horizon of this GSP" and defines an undesirable result "is considered to occur during GSP implementation when at least 25% of representative monitoring wells (6 of 22 sites) exceed the minimum threshold for degraded water quality for two consecutive years.[132] This is an increase from 5 of 19 sites because the 2022 Plan

[128] Merced Subbasin 2019 GSP, Section 2.2.4, pp. 150-151.
[129] Merced Subbasin 2019 GSP, Section 3.6.1, p. 251.
[130] Merced Subbasin 2022 GSP Redline, Section 3.6.2, p. 253.
[131] 23 CCR 354.28(c)(4).
[132] Merced Subbasin 2022 GSP Redline, Section 3.6.1, pp. 259-260.

increased the number of representative monitoring sites from 19 to 22 due to improvements made by the Eastern San Joaquin Water Quality Coalition to the to the Groundwater Quality Trend Monitoring.

In establishing the minimum threshold for salinity (as TDS), the Plan states that State and federal regulations on impacts to drinking water and agricultural beneficial uses were considered. The California secondary drinking water standard recommended maximum contaminant level for TDS is 500 milligrams per liter (mg/L) with an upper limit of 1,000 mg/L, and a short-term limit of 1,500 mg/L.[133] For agricultural uses, TDS below 1,200 mg/L at a 90% crop yield potential is the limit in the Subbasin. Given these considerations and the water quality trends across the Subbasin, the Plan states that areas which have experienced TDS concentrations more than 1,000 mg/L are not considered to be undesirable; therefore, the Plan defines the minimum threshold for salinity as TDS concentration of 1,000 mg/L and the measurable objective as TDS concentration of 500 mg/L.[134]

Department staff conclude the GSP has not provided sufficient rationale for establishing the minimum threshold at 1,000 mg/L for TDS given that levels beyond 500 mg/L would exceed the secondary maximum contaminant level and could have adverse impacts to the long-term viability of domestic and municipal beneficial uses and users over the planning and implementation horizon. Department staff recommend that the GSAs provide further rationale for establishing minimum thresholds which exceed the TDS maximum contaminate level for drinking water standard. (See Recommended Corrective Action 6b). While Department staff understand that the GSP proposes management that would raise groundwater elevations to 2015 levels by 2040, as previously discussed in Section 4.1.2.5, impacts from potential or projected groundwater levels during GSP implementation to water quality are also not fully explained and Department staff have provided a recommended corrective action in that Section as well.

5.3.2.5 Land Subsidence

SGMA defines the undesirable result for subsidence to be significant and unreasonable land subsidence that substantially interferes with surface land uses, caused by groundwater conditions occurring throughout the basin.[135] The GSP Regulations require the minimum threshold for land subsidence to be the rate and extent of subsidence that substantially interferes with surface land uses and may lead to undesirable results.[136] Minimum thresholds for subsidence shall be supported by the identification of land uses and property interests that have been affected or are likely to be affected by land subsidence in the basin, including an explanation of how the Agency has determined and considered those uses and interests, and the Agency’s rationale for establishing minimum thresholds in light of those effects and maps and graphs showing the extent and rate of

[133] Merced Subbasin 2019 GSP, Section 3.6.2, p. 254.
[134] Merced Subbasin 2019 GSP, Section 3.6.2, p. 255.
[135] Water Code § 10721(x)(5).
[136] 23 CCR § 354.28(c)(5).

land subsidence in the basin that defines the minimum threshold and measurable objectives.[137]

In the January 2022 Incomplete Determination, the Department identified deficiencies related to the sustainable management criteria of land subsidence. The GSAs revised this portion of the Plan and Department staff provide evaluation for this sustainability indicator in Section 4.1 and Section 4.3 of this Staff Report. As described above, Department staff have provided recommended corrective actions based on the changes the Agencies have made to the sustainable management criteria for this sustainability indicator.

5.3.2.6 Depletions of Interconnected Surface Water

SGMA defines undesirable results for the depletion of interconnected surface water as those that have significant and unreasonable adverse impacts on beneficial uses of surface water and are caused by groundwater conditions occurring throughout the basin.[138] The GSP Regulations require that a Plan identify the presence of interconnected surface water systems in the basin and estimate the quantity and timing of depletions of those systems.[139] The GSP Regulations further require that minimum thresholds be set based on the rate or volume of surface water depletions caused by groundwater use, supported by information including the location, quantity, and timing of depletions, that adversely impact beneficial uses of the surface water and may lead to undesirable results.[140]

The Department's January 28, 2022 incomplete determination identified a deficiency related to the definition of undesirable results for depletions of interconnected surface water can only occur in consecutive non-dry water year types. Section 4.1.2.3 summarizes the changes made to the Plan and provides the Department staff's evaluation. The Plan defines "undesirable results for depletions of interconnected surface water in the Merced Subbasin could include depletions that result in reductions in flow or levels of major rivers and streams that are hydrologically connected to the basin such that the reduced surface water flow or levels have a significant and unreasonable adverse impact on beneficial uses of the surface water within the Subbasin over the planning and implementation horizon of this GSP."[141] The Plan proposes to use groundwater levels as a proxy for depletion of interconnected surface water and relies on the sustainable management criteria for groundwater levels.[142]

The Plan attempts to justify the use of groundwater as a proxy for depletions of interconnected surface water due to groundwater extractions by noting the existence of challenges associated with directly measuring streamflow depletions, concluding that,

[137] 23 CCR §§ 354.28(c)(5)(A-B).
[138] Water Code § 10721(x)(6).
[139] 23 CCR § 354.16(f).
[140] 23 CCR § 354.28(c)(6).
[141] Merced Subbasin 2019 GSP, Section 3.8.1, p. 259.
[142] Merced Subbasin 2019 GSP, Section 3.8.1, p. 260.

because of these challenges, and because of what the Plan claims to be a significant correlation between groundwater levels and depletions, groundwater levels can be used as a proxy for depletions of interconnected surface water. The Plan argues that this approach is supported by Department guidance. [143] However, Department Guidance and the GSP Regulations specify that the use of groundwater elevations as a proxy for other sustainability indicators is appropriate when the GSA can demonstrate the reasonableness of doing so. The Plan refers to challenges associated with directly measuring streamflow depletions, but this does not constitute evidence in support of using groundwater elevations as a proxy. The Plan claims a correlation between groundwater elevations and surface flow depletions, but the Plan does not demonstrate how those elevations serve as a proxy for quantifying the effect of groundwater extractions on those depletions, which is the focus of this sustainability indicator. Based on the information presented in the Plan, Department staff do not agree the proxy has been substantiated, nor has sufficient technical analysis been presented to correlate depletions with groundwater levels. Furthermore, even if the Plan had provided that substantiation, given that the Plan intends to operate the Subbasin below the 2015 groundwater level minimum thresholds, Department staff would have concerns about the impact of doing so on the effectiveness of that proxy measurement.

The GSP states that groundwater modeling results were analyzed to estimate the volume of depletions associated with groundwater levels. The GSP reports that its modeling results indicate that groundwater extraction causes an estimated 16,000 AFY of depletions on the Merced River, 10,000 AFY on the San Joaquin River, and 12,000 AFY on the combined system of canals and smaller streams. However, the Plan does not describe the amount of depletion of interconnected surface water due to groundwater extraction that would be considered significant and unreasonable.[144] Furthermore, the GSP states that a hypothetical scenario was simulated to select groundwater levels that would constitute an undesirable result based on the groundwater level minimum threshold criteria, which is based on an exceedance of minimum thresholds of 25 percent of representative wells. Department staff assume the model was not updated with the revised sustainable management criteria for groundwater levels because there are no changes between the original submittal and the 2022 Plan to the above-mentioned depletion values.[145]

Despite its shortcomings, because of how the Plan has been amended to limit worsening conditions in the basin, Department staff consider the near-term risk to the beneficial uses and users of surface water from increased depletion due to groundwater extraction to be low. As a result, Department staff do not consider the shortcoming of the current plan to preclude approval. Department staff understand that quantifying depletions of interconnected surface water from groundwater extractions is a complex task that likely requires developing new, specialized tools, models, and methods to understand local

[143] Merced Subbasin 2019 GSP, Section 3.8.1, p. 260.
[144] Merced Subbasin 2019 GSP, Section 3.8.1, p. 261.
[145] Merced Subbasin 2022 GSP Redline, Section 3.8.1, p. 270.

hydrogeologic conditions, interactions, and responses. The GSP has identified the use of a model to quantify depletions due to groundwater extractions. Department staff advise that at this stage in SGMA implementation GSAs address deficiencies related to interconnected surface water depletion where GSAs are still working to fill data gaps related to interconnected surface water and where these data will be used to inform and establish sustainable management criteria based on timing, volume, and depletion as required by the GSP Regulations (see Recommended Corrective Action 7a).

The Department will continue to support GSAs in this regard by providing, as appropriate, financial, and technical assistance to GSAs, including the development of guidance describing appropriate methods and approaches to evaluate the rate, timing, and volume of depletions of interconnected surface water caused by groundwater extractions. Once the Department's guidance related to depletions of interconnected surface water is publicly available, GSAs, where applicable, should consider incorporating appropriate guidance approaches into their future periodic evaluations to the GSP (see Recommended Corrective Action 7a). GSAs should consider availing themselves of the Department's financial or technical assistance, but in any event must continue to fill data gaps, collect additional monitoring data, and implement strategies to better understand and manage depletions of interconnected surface water caused by groundwater extractions and define segments of interconnectivity and timing within their jurisdictional area (See Recommended Corrective Action 7b). Furthermore, GSAs should coordinate with local, state, and federal resources agencies as well as interested parties to better understand the full suite of beneficial uses and users that may be impacted by pumping induced surface water depletion (See Recommended Corrective Action 7c).

5.4 Monitoring Network

The GSP Regulations describe the monitoring network that must be developed for each basin including monitoring objectives, monitoring protocols, and data reporting requirements. Collecting monitoring data of a sufficient quality and quantity is necessary for the successful implementation of a groundwater sustainability plan. The GSP Regulations require a monitoring network of sufficient quality, frequency, and distribution to characterize groundwater and related surface water conditions in the basin and evaluate changing conditions that occur through implementation of the Plan.[146]

The GSP presents monitoring networks for chronic lowering of groundwater levels (and depletions of interconnected surface water by proxy), degraded water quality, and land subsidence sustainability indicators.

The GSP groundwater level monitoring network includes 50 wells, of which 21 are designated as representative wells with established minimum thresholds, measurable objectives, and interim milestones.[147] In looking at the monitoring network established for

[146] 23 CCR § 354.32.
[147] Merced Subbasin 2022 GSP Redline, Section 4.5.4, p. 279.

groundwater levels and the subsidence monitoring network, Department staff are concerned the GSAs will not be able to monitor subsidence adequately. Figure 2 shows the representative sites used by the Agencies to monitor for subsidence within the Subbasin. Figure 3 shows the water levels monitoring network and the data gap areas, including the wells which are monitoring Above Corcoran Clay layer and Below Corcoran Clay layer. The GSP states that there is a data gap along the western edge of the Subbasin and that installing wells along this area would help improve the understanding of subsurface groundwater flow between adjacent subbasins, depletions of interconnected surface waters, subsidence, and connection between principal aquifers. The GSP also states that there are plans to add wells for the Above and Below Corcoran Principal Aquifers in the southwesterly portion of the Subbasin and wells in the northwestern portion of the Subbasin.[148] While the GSP states data gap areas #2 and #3 and a plan to fill these data gaps will be submitted within two years of Plan approval, Department staff believe efforts on filling these data gaps are crucial for the Subbasin's management of subsidence with the presence of the Corcoran Clay and the GSAs' intentions to operate the basin below historical lows. It's unclear to Department staff how the implementation of the Above Corcoran Sustainable Management Criteria Adjustment Consideration Management Action will be able to accomplish its goal given the data gaps. Department staff recommend the GSAs prioritize filling these data gaps and describing how filling these data gaps will assist in the successful implementation of the Above Corcoran Sustainable Management Criteria Adjustment Consideration Management Action. (See Recommended Corrective Action 8)

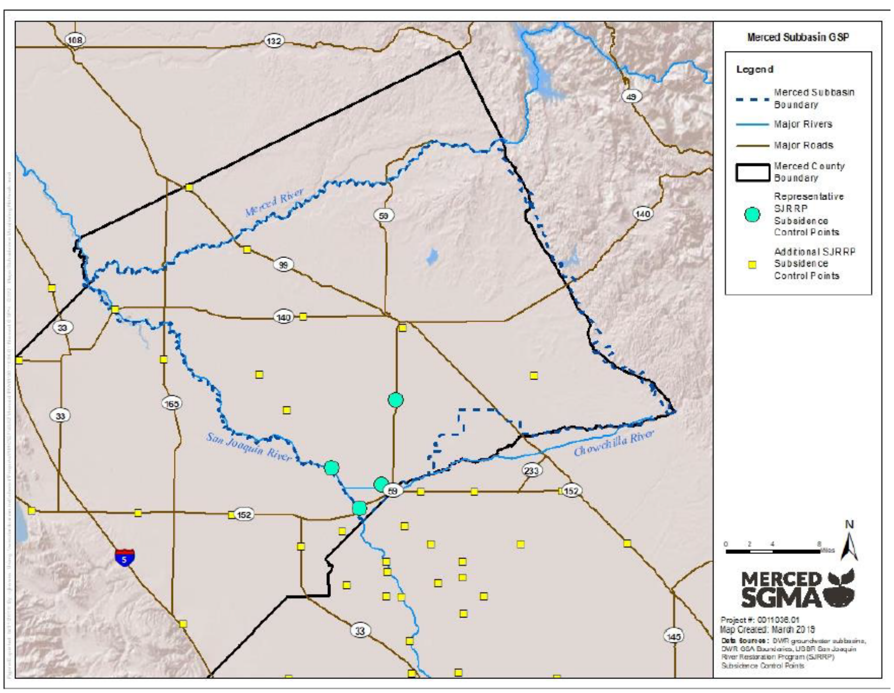

Figure 2: Subsidence Monitoring Network[149]

[148] Merced Subbasin 2019 GSP, Section 4.5.7, pp. 277-278.
[149] Merced Subbasin 2022 GSP Redline, Figure 4-8, p. 291.

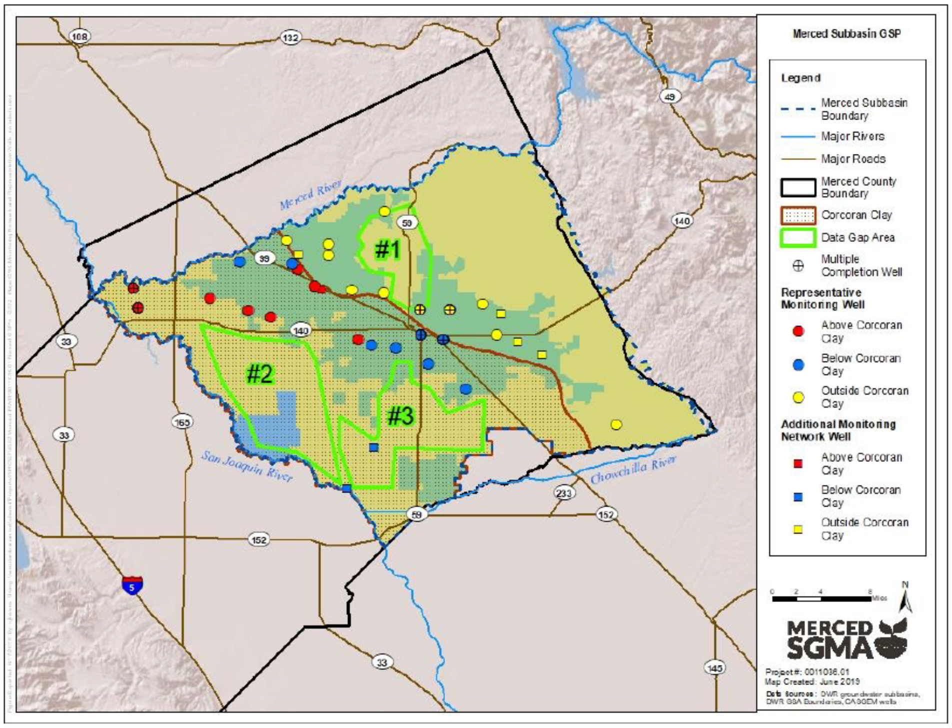

Figure 3: Groundwater Levels Monitoring Network and Data Gaps[150]

The Plan describes that the groundwater quality monitoring network consists of 284 wells for a broader spectrum of constituents, of which 19 are designated as representative monitoring wells with established sustainable management criteria for TDS.[151] Of the 284 wells in the monitoring network, five are monitored through the East San Joaquin Water Quality Coalition Groundwater Quality Trend Monitoring program and 279 wells are from the municipal public water system. The 19 representative monitoring wells include five domestic wells denoted by the GSP as "principal wells," which the East San Joaquin Water Quality Coalition selected as meeting Central Valley Regional Water Quality Control Board waste discharge requirements and can be accessed for annual sampling, and 14 public water system wells denoted by the GSP as "complementary wells."[152] The Plan details that an additional three wells were added to the existing five "principal wells" wells, bringing the total number of representative wells to 22.[153] The Plan states there are few monitoring wells closer to the San Joaquin River and Mariposa County and many wells used for monitoring do not have construction information, and to reduce data gaps, additional wells are planned to be added to the network and that efforts will be made to obtain additional well construction information.[154]

To provide regional context for subsidence, the Merced Subbasin subsidence monitoring network includes 71 subsidence control points (that are monitored semiannually by the

[150] Merced Subbasin 2022 GSP Redline, Figure 4-6, p. 277.
[151] Merced Subbasin 2019 GSP, Table 3-2, p. 256.
[152] Merced Subbasin 2019 GSP, Section 3.6.2, p. 255.
[153] Merced Subbasin 2022 GSP Redline, Section 4.8.4 and Table 4-7, pp. 290-292.
[154] Merced Subbasin 2019 GSP, Section 4.8.8, p. 289.

United States Bureau of Reclamation for the San Joaquin River Restoration Program). Although most are outside of the Subbasin boundary, 10 of the monitoring points are within the Subbasin, four of which are in the southern portion of the Subbasin and are selected as representative monitoring sites with established minimum thresholds and measurable objectives.[155] The GSP states that the monitoring network provides adequate spatial coverage of land subsidence monitoring density to assess subsidence rates of the Subbasin, but that there is a data gap regarding the depth at which subsidence is occurring. The GSP states that subsidence is thought to be caused by groundwater extraction below the Corcoran Clay and compaction of clays below the Corcoran Clay and recommends that one or more extensometers be installed to understand the depth at which subsidence is occurring, which the GSP states is included in the Project and Management Actions section.[156]

Monitoring of depletion of interconnected surface water monitoring is conducted using groundwater levels as proxy.[157] As described in Section 5.3.2.6, the Plan has not demonstrated that the use of groundwater elevations is a suitable proxy for quantifying depletions of interconnected surface water due to groundwater extraction. Based on the Department's evaluation of sustainable management criteria for depletion of interconnected surface water and the recommended corrective actions provided, changes to the monitoring network are inherently expected to fill data gaps and should be commensurate with the improved level of understanding of the basin setting.

The description of the monitoring networks for groundwater levels, groundwater quality, and land subsidence included in the Plan substantially comply with the requirements outlined in the GSP Regulations. Overall, the Plans describe in sufficient detail monitoring networks that promote the collection of data of sufficient quality, frequency, and distribution to characterize groundwater and related surface water conditions in the Subbasin and evaluate changing conditions that occur through Plan implementation. The GSP provides a reasonable explanation for the conclusion that the monitoring networks are supported by the best available information and data and are designed to ensure adequate coverage of sustainability indicators. The GSP also describes existing data gaps and the steps that will be taken to fill data gaps and improve the monitoring network. Department staff consider the information presented in the Plan to satisfy the general requirements of the GSP Regulations regarding monitoring network.

5.5 Projects and Management Actions

The GSP Regulations require a description of the projects and management actions the GSAs have determined will achieve the sustainability goal for the basin, including projects and management actions to respond to changing conditions in the basin.[158]

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[155] Merced Subbasin 2019 GSP, Section 4.9, pp. 290-294.
[156] Merced Subbasin 2019 GSP, Section 4.9.6 and Section 4.9.7, p. 294.
[157] Merced Subbasin 2022 GSP Redline, Section 4.10, pp. 304-308.
[158] 23 CCR § 354.44 et seq.

The Plan lays out the projects which were selected through a process which included stakeholder and coordination committees and the public. Projects were prioritized based on things such as addressing disadvantaged communities, data gaps, basinwide benefits, subsidence, recharge, conveyance, drinking water, water for habitat, monitoring, reporting, and data modeling, incentives to reduce pumping, beyond planning phase, dedicated funding mechanism, and prioritized by at least one GSA. From this prioritization, 12 projects were shortlisted for implementation and 39 projects are reserved for possible future implementation.[159] The shortlisted projects are as follows:

- Project 1: Planada Groundwater Recharge Basin Pilot Project
- Project 2: El Nido Groundwater Monitoring Wells
- Project 3: Meadowbrook Water System Intertie Feasibility Study
- Project 4: Merquin County Water District Recharge Basin
- Project 5: Merced Irrigation District to Lone Tree Mutual Water Company Conveyance Canal
- Project 6: Merced Integrated Regional Water Management Region Climate Change Modeling
- Project 7: Merced Region Water Use Efficiency Program
- Project 8: Merced Groundwater Subbasin Light Detection and Ranging (LIDAR)
- Project 9: Study for Potential Water System Intertie Facilities from Merced Irrigation District to Le Grand Athlone Water District and Chowchilla Water District
- Project 10 Vander Woude Dairy Offstream Temporary Storage
- Project 11: Mini-Big Conveyance Project
- Project 12: Streamlining Permitting for Replacing Sub-Corcoran Wells

Project 11 is scheduled for completion in 2026. Project 1 is scheduled to for completion by December 2023. All other projects should be complete by now.

The Plan proposes a total of four managements actions including an allocation framework, demand management, a mitigation program, and adjustments to aquifer pumping. The management actions are as follows:

(1) Initial Groundwater Allocation Framework: This consists of allocating the sustainable yield of native groundwater within the basin to each GSA and establish groundwater extraction limits. The GSAs intend to further refine and develop this framework prior to implementation. The Plan intends to have allocations phase-in between 2025-2035, with full implementation and

[159] Merced Subbasin 2022 GSP Redline, Table 6-3, p. 330 and Table 6-5, pp. 345-349.

enforcement by 2040. Approximately 440,000 acre-feet per year of native groundwater is said to be available for allocation.[160]

(2) Merced Subbasin GSA Groundwater Demand Reduction Management Action: This consists of a demand reduction program to gradually reduce pumping in a consistent annual rate during plan implementation to reach the Native Groundwater allocation objective by 2040. The Merced Subbasin GSA may utilize a trading market, establish a fee structure tied to extracted volumes, and establishing easement or contract programs to pay for reduced groundwater use.[161]

(3) Domestic Well Mitigation Program: This management action is a new addition in the Plan. Staff provided a summary of this program in Section 4.1.2.4.[162]

(4) Above Corcoran Sustainable Management Criteria Adjustment Consideration: This management action is a new addition in the Plan. Staff provided a summary of this management action in Section 4.3.2.3.[163]

While not included as part of the active project and management actions, the Plan provides special studies and issues that the GSAs intend to consider during periodic evaluation.[164] Department staff encourage the GSAs to provide a robust discussion of all the potential projects, special studies, and issues that get resolved that come to fruition in during Plan implementation to be include in the periodic evaluation.

The GSP has presented a large, diverse suite of projects and management actions, which Department staff believe are substantially compliant with the GSP Regulations. However, the GSP has not fully described how the timing and quantified benefits of the project and managements actions will allow the Subbasin to reach sustainability by 2040 and Department staff conclude this information is beneficial to be included in the periodic evaluation. It's unclear how the Subbasin groundwater levels will reach the interim milestones with the completion of the 12 projects by 2026. Department staff also conclude additional explanation of the Above Corcoran Sustainable Management Criteria Adjustment Consideration management action should be provided to explain how the transfer of pumping from the Below Corcoran Clay aquifer to the Above Corcoran Clay aquifer will avoid impacts to the sustainability indicators. As mentioned above in Section 5.2.2, the Plan acknowledges that groundwater levels have declined in that Above Corcoran Clay aquifer, therefore, the explanation should fully describe the implementation of this management action. The Department staff recommend the GSAs provide a robust discussion explaining how the implementation of the projects and management actions will restore groundwater levels up to the measurable objective by 2040. (See Recommended Corrective Action 9).

[160] Merced Subbasin 2022 GSP Redline, Section 6.2.1, pp. 319-323.
[161] Merced Subbasin 2022 GSP Redline, Section 6.2.2, pp. 324-325.
[162] Merced Subbasin 2022 GSP Redline, Section 6.2.3, pp. 325-327.
[163] Merced Subbasin 2022 GSP Redline, Section 6.2.3, pp. 327-328.
[164] Merced Subbasin 2022 GSP Redline, Section 7.8, p. 360-362.

5.6 Consideration of Adjacent Basins/Subbasins

SGMA requires the Department to "…evaluate whether a groundwater sustainability plan adversely affects the ability of an adjacent basin to implement their groundwater sustainability plan or impedes achievement of sustainability goals in an adjacent basin."[165] Furthermore, the GSP Regulations state that minimum thresholds defined in each GSP be designed to avoid causing undesirable results in adjacent basins or affecting the ability of adjacent basins to achieve sustainability goals.[166]

The Merced Subbasin has three adjacent basins, the Turlock Subbasin, Delta-Mendota Subbasin, and the Chowchilla Subbasin, are all high-priority and required to be managed under a GSP. The Delta-Mendota Subbasin and Chowchilla Subbasins are critically overdrafted and currently have inadequate plans that the Department has referred to the State Water Resources Control Board under Chapter 11 of SGMA. The Plan states that the GSAs are coordinating with adjacent basins under a memorandum of understanding with GSAs from the Chowchilla Subbasin, are developing a memorandum of understanding with GSAs in the Delta-Mendota Subbasin, and under a memorandum of intent with GSAs in the Turlock Subbasin. Additionally, the Plan states that there is inter-subbasin modeling coordination with the Chowchilla Subbasin to provide consistency in the way minimum thresholds are determined.[167] However, the Plan does not include a discussion of its potential impacts to the Turlock Subbasin, Delta-Mendota Subbasin, and the Chowchilla Subbasins.

Based on information available at this time, Department staff have insufficient evidence to conclude that groundwater management in the Merced Subbasin will adversely affects the implementation of a plan or impede achievement of sustainability goals in an adjacent basin. Department staff will continue to review periodic evaluations to the Plan and annual reports to assess whether implementation of the Merced Subbasin GSP is potentially impacting adjacent basins.

5.7 Consideration of Climate Change And Future Conditions

The GSP Regulations require a GSA to consider future conditions and project how future water use may change due to multiple factors including climate change.[168]

Since the GSP was adopted and submitted, climate change conditions have advanced faster and more dramatically. It is anticipated that the hotter, dryer conditions will result in a loss of 10% of California's water supply. As California adapts to a hotter, drier climate, GSAs should be preparing for these changing conditions as they work to sustainably manage groundwater within their jurisdictional areas. Specifically, the Department encourages the GSAs to explore how the proposed groundwater level thresholds have

165 Water Code § 10733(c).
166 23 CCR § 354.28(b)(3).
167 Merced Subbasin 2019 GSP, Section 3.9, p. 262.
168 23 CCR § 354.18.

been established in consideration of groundwater level conditions in the Subbasin based on current and future drought conditions. The Department encourages the GSAs to also explore how groundwater level data from the existing monitoring network will be used to make progress towards sustainable management of the Subbasin given increasing aridification and effects of climate change, such as prolonged drought. Lastly, the Department encourages the GSAs to continually coordinate with the appropriate groundwater users, including but not limited to domestic well owners and state small water systems, and the appropriate overlying county jurisdictions developing drought plans and establishing local drought task forces [169] to evaluate how the GSAs' groundwater management strategy aligns with drought planning, response, and mitigation efforts within the Subbasin.

6 STAFF RECOMMENDATION

Department staff believe sufficient action has been taken by the GSAs to address the deficiencies previously identified by the Department. Department staff recommend **APPROVAL** of the Plan with the required and recommended corrective actions listed below. The Plan conforms with Water Code Sections 10727.2 and 10727.4 of SGMA and substantially complies with the GSP Regulations. Implementation of the Plan will likely achieve the sustainability goal for the Merced Subbasin. The GSAs have identified several areas for improvement of its Plan and Department staff concur that those items are important and should be addressed as soon as possible. Department staff have also identified recommended corrective actions related to groundwater levels, groundwater storage, water quality, and depletion of interconnected surface water. These recommended corrective actions do not preclude Plan approval at this time as they do not appear to prevent the GSAs from implementing important elements of the current Plan, are capable of being concurrently addressed in sufficient time to update or revise the Plan (or management under the Plan) as appropriate with new information before the next periodic evaluation so that the GSA can adjust the Basin management as needed to achieve sustainability within 20 years of Plan implementation. Addressing these recommended corrective actions will be important to demonstrate that implementation of the Plan is and continues to be likely to achieve the sustainability goal. The recommended corrective actions include:

RECOMMENDED CORRECTIVE ACTION 1

a) Given that the Plan identifies interim milestones below minimum thresholds and historical lows, Department staff recommend the Domestic Well Mitigation Program be in place and initiated prior to the need so as not to delay implementation should impacts occur. Based on staff evaluation in Section 4.2.2, the GSAs should describe whether the Domestic Well Mitigation Program

[169] Water Code § 10609.50.

corresponds with the projected impacts to beneficial uses and users. As Plan implementation carries out, the GSAs should monitor the mitigation carried out by the Program and assess if additional funding beyond the $800,000 is needed for additional mitigation or other approaches. Department staff also encourage the GSAs to review the Department's April 2023 guidance document titled *Considerations for Identifying and Addressing Drinking Water Well Impacts* guidance to assist its Program implementation.[170] The GSAs should provide progress updates via annual reports and periodic evaluations.

b) The GSAs are aware that the lowering of groundwater levels can cause degradation of groundwater water. Department staff recommend the GSAs describe how potential impacts to degradation of groundwater quality will be managed, including how coordination with groundwater users, including water, environmental, and irrigation users will be conducted and how such coordination will be utilized to address groundwater quality degradation, should it occur during Plan implementation.

Recommended Corrective Action 2

Department staff recommend that additional assessment be conducted to understand the impacts to beneficial uses and users from continued overdraft, including what impacts may result if groundwater levels reach the revised interim milestones in 2025 and 2030, prior to reaching sustainability in 2040. This would include an analysis of how many wells may go dry during Plan implementation, for how long they may go dry, and the impacts to land uses and property interests. As discussed in Recommended Corrective Action 1a, a through explanation of how the mitigation program will be applied during the period of time in which the Subbasin will be operating below minimum thresholds should also be included.

Recommended Corrective Action 3

Department staff recommend the following as it relates to subsidence:

a) The GSAs should identify the total cumulative subsidence tolerable by critical infrastructure. The Plan should also include additional details describing measures that consider and disclose the current and potentially lasting impacts of subsidence on land uses and groundwater beneficial uses and users.

b) The GSAs should revise its application of the level of uncertainty as it relates to subsidence measurements according to standard professional practices. Establishment of sustainable management criteria should not allow for subsidence in perpetuity.

[170] https://water.ca.gov/Programs/Groundwater-Management/Drinking-Water-Well

Recommended Corrective Action 4

Department staff recommend the GSAs further investigate the 56 wells which are said to be drilled below the bottom of the basin and confirm to what extent they are active. If these wells are active, then the GSAs should determine their groundwater extractions and account for that activity in the Plan.

Recommended Corrective Action 5

Department staff recommend sustainable management criteria for reduction of groundwater storage be established in accordance with the GSP Regulations by the periodic evaluation.

Recommended Corrective Action 6

Department staff recommend the following related to degraded water quality:

a) The GSAs should provide additional justification and explanation for how water quality constituents of concern, other than TDS, will be managed and monitored, and how impacts to beneficial uses and users will be addressed should there be degradation of water quality during plan implementation when the Subbasin expects to lower of groundwater elevations. The GSAs should consider developing sustainable management criteria for additional water quality constituents.

b) The GSAs should provide additional detail and analysis to support its selection of the proposed TDS minimum thresholds and measurable objectives for the degraded water quality sustainability indicator, while properly characterizing groundwater quality for constituents of concern. The GSAs should provide further rationale for establishing minimum thresholds which exceed the TDS maximum contaminate level for drinking water standard.

Recommended Corrective Action 7

Department staff understand that estimating the location, quantity, and timing of stream depletion due to ongoing, Subbasin-wide pumping is a complex task; however, it is critical for the Department's ongoing and future evaluations of whether GSP implementation is on track to achieve sustainable groundwater management. The Department plans to provide guidance on methods and approaches to evaluate the rate, timing, and volume of depletions of interconnected surface water and support for establishing specific sustainable management criteria in the near future. This guidance is intended to assist GSAs to sustainably manage depletions of interconnected surface water.

In addition, the GSA should work to address the following items by the first periodic evaluation:

a. Work to establish undesirable results, minimum thresholds, and measurable objectives consistent with the GSP Regulations. Measurable objectives are to use the same metric used for minimum thresholds, including quantifying the location, quantity, and timing of depletions of interconnected surface water due to groundwater extraction. Consider utilizing the interconnected surface water guidance, as appropriate, when issued by the Department.

b. Continue to fill data gaps, collect additional monitoring data, and implement the current strategy to manage depletions of interconnected surface water and define segments of interconnectivity and timing. The monitoring network should be updated to reflect any corresponding changes and approaches.

c. Prioritize collaborating and coordinating with local, state, and federal regulatory agencies as well as interested parties to better understand the full suite of beneficial uses and users that may be impacted by pumping induced surface water depletion within the GSA's jurisdictional area.

RECOMMENDED CORRECTIVE ACTION 8

Department staff recommend the GSAs fill data gaps in the groundwater level monitoring network and describe how filling these data gaps will assist in the successful implementation of the Above Corcoran Sustainable Management Criteria Adjustment Consideration Management Action.

RECOMMENDED CORRECTIVE ACTION 9

Department staff recommend the GSAs provide a robust discussion explaining how the implementation of the projects and management actions will restore groundwater levels up to the measurable objective by 2040. This discussion should also include additional explanation of the Above Corcoran Sustainable Management Criteria Adjustment Consideration management action and how the transfer of pumping from the Below Corcoran Clay aquifer to the Above Corcoran Clay aquifer will avoid impacts to the sustainability indicators.

APPENDIX B: DATA REPORT FOR SURVEY AREA 5 – MERCED, TURLOCK AND MODESTO GROUNDWATER BASINS

THE CALIFORNIA DEPARTMENT OF WATER RESOURCES' STATEWIDE AIRBORNE ELECTROMAGNETIC SURVEY PROJECT

DATA REPORT FOR SURVEY AREA 5
MERCED, TURLOCK AND MODESTO GROUNDWATER SUBBASINS

RAMBØLL

Eclogite Consulting

GEI Consultants

SKYTEM

RAS REALtime Aquifer Services

HydroGeophysics Group AARHUS UNIVERSITY

Sinton Helicopters

CALIFORNIA AIRBORNE ELECTROMAGNETIC SURVEYS MERCED, TURLOCK AND MODESTO GROUNDWATER SUBBASINS

Project name	California Airborne Electromagnetic Surveys for the Merced, Turlock and Modesto Groundwater Subbasins
Project no.	1690021880, Work Order 05
Recipient	California Department of Water Resources – Sustainable Groundwater Management Office
Document type	Report
Version	1
Date	April 15, 2023
Prepared by	Ahmad-Ali Behroozmand, Chris Petersen, Julián Consoli, Ian Gottschalk, Max Halkjaer, Paul Thorn, Peter Thomsen, Frederik Christensen and Mikkel Toftdal
Checked by	Timothy K. Parker
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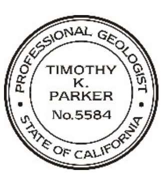
Description	This is a data report describing the acquisition, processing, inversion and lithology transform for the AEM survey conducted in the Merced, Turlock and Modesto Groundwater Subbasin. In addition, the report provides a description of the well data collected along the planned flight lines and the projects data management system.



Timothy K. Parker, PG

04/15/2023
Date

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LIST OF ABBREVIATIONS AND ACRONYMS

ACT	Accumulated Clay Thickness
AEM	Airborne Electromagnetic
CF	Clay Fraction
DMS	Data Management System
DOI	Depth of Investigation
DWR	Department of Water Resources
EC	Electrical Conductivity
EM	Electromagnetics
GAMA	Groundwater Ambient Monitoring and Assessment
GIS	Geographic Information System
GPS	Global Positioning System
GSP	Groundwater Sustainability Plan
km	Kilometer
L	Liter
m	Meter
mg	Milligrams
OSWCR	Online System for Well Completion Reports
PLSS	Public Land Survey System
QA	Quality Assurance
QC	Quality Control
SGMA	Sustainable Groundwater Management Act
SR	State Route
SWRCB	State Water Resources Control Board
TDS	Total Dissolved Solids
TEM	Time-domain (or Transient) Electromagnetics
USCS	Unified Soils Classification System

ACKNOWLEDGEMENTS

DWR would like to acknowledge the AEM Survey project partners including the Merced, Turlock and Modesto Basin Groundwater Sustainability Agency (GSA), California Geologic Survey, California Department of Fish and Wildlife, California Department of Food and Agriculture, California State Water Resources Control Board, and United States Geologic Survey. This project was funded through the California Drought, Water, Parks, Climate, Coastal Protection and Outdoor for all Fund (Senate Bill 5, Proposition 68).

PROJECT TEAM

The project team for the AEM Survey covering the Merced, Turlock and Modesto includes:

Ramboll – responsible for coordination of the contractors, onsite geophysicist during data acquisition, data processing and inversion, lithology model, initial hydrostratigraphic model, reporting and quality control of deliverables.

GEI – collected and compiled well data into the data management system and assisted in report preparation.

SkyTEM – coordinated the AEM surveys field operation, providing the AEM equipment and leading the field work.

Sinton Helicopters – provide helicopter, pilots, AEM instrumentation and flew the AEM survey.

AECOM – assisted DWR with outreach to the local GSA's and authorities, plan the location of the flight lines, assisting with the initial collection of well data from the GSA's.

Eclogite – digitized well lithology and geophysical logs.

RealTime Aquifer Services – provided additional geophysical logs in digital format.

Aarhus University, Denmark – assisted with the lithology model and the initial hydrostratigraphic model.

AEM Data Report and Use Disclaimer

0. EXECUTIVE SUMMARY

Regional airborne geophysical surveys are being conducted by the California Department of Water Resources (DWR) and its contractors in all of the state's high- and medium-priority groundwater basins to collect data on the geometry and geologic properties of the underlying aquifer systems that provide groundwater to local communities (Figure 0-1). The focus of this report is the Merced, Turlock and Modesto Groundwater Subbasins geophysical survey (Figure 0-1). The regional geophysical surveys, which use the airborne electromagnetics (AEM) technique, have been compared to an MRI to see beneath the ground surface. The AEM data and products from the surveys are being provided to assist local water managers and the state as they implement the Sustainable Groundwater Management Act (SGMA) to manage groundwater for long term sustainability. The AEM surveys are funded by voter-approved Proposition 68, and all the data from the surveys are being made publicly available online.

Figure 0-1 SGMA high- and medium-priority basins in California. The Merced, Turlock and Modesto Groundwater Subbasins are colored red.

The AEM survey technique utilizes a helicopter flying approximately 80 kilometers per hour (50 miles per hour), with the geophysical equipment suspended below, mounted on a large hexagonal frame about 30 meters (100 feet) above the ground surface (Figure 0-2). The AEM equipment sends a pulsating weak electromagnetic signal into the ground and measures the response, which provides an electrical resistivity profile of the earth's geological layers and structures down to depths of as much as 300 meters (1,000 feet). Aquifer systems consist of (1) aquifers typically composed of sands and gravels that have high resistivities, and (2) aquitards composed of silt and clays that have low resistivities, so the resistivity profiles help in mapping the overall aquifer systems dimensions and extent. The AEM survey data is analyzed in detail, correlated with data from nearby wells, and modeled to produce subsurface maps of the resistivity, lithology, and an initial hydrostratigraphic model.

Figure 0-2 Helicopter towing the hexagonal SkyTEM system while collecting AEM data during the survey.

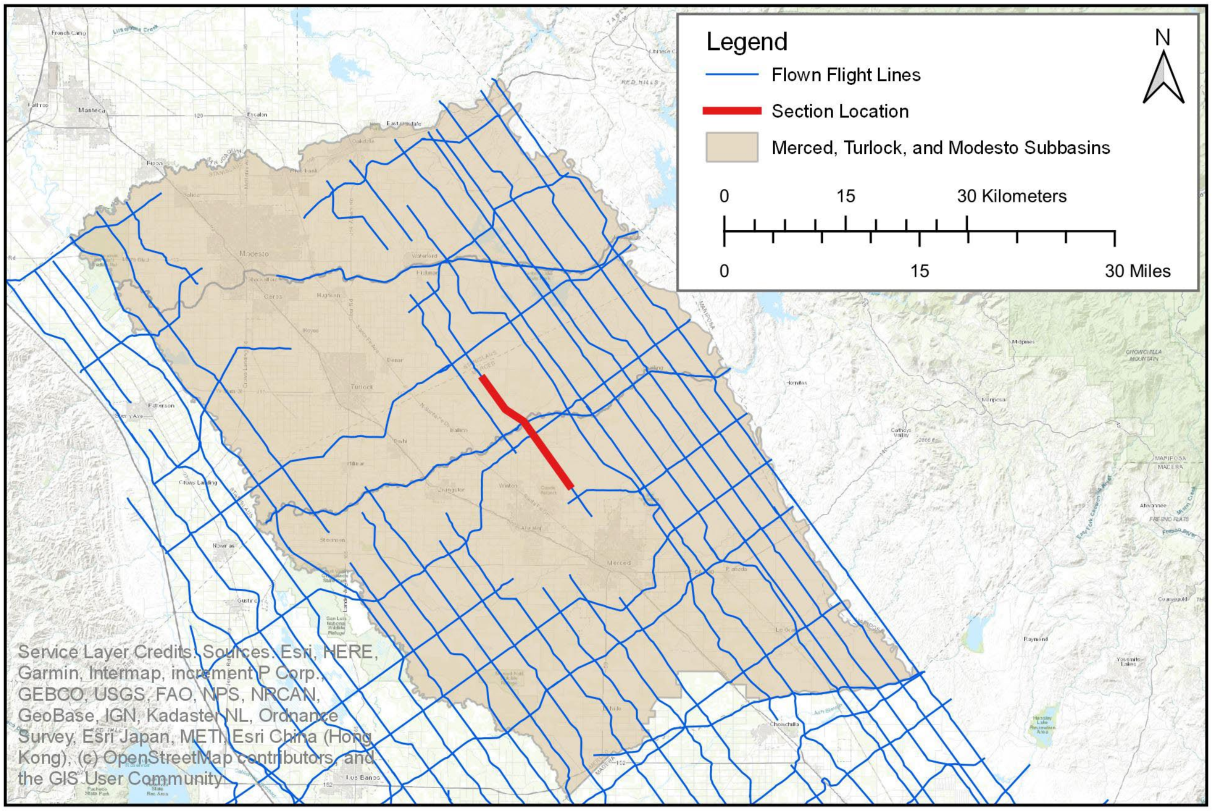

Figure 0-3 Outline of the Merced, Turlock and Modesto Groundwater Subbasins and the completed AEM Survey Area 5 flight lines. The red line shows the location of the vertical profile shown in Figure 0-4.

Merced, Turlock and Modesto subbasins AEM Survey

The Merced, Turlock and Modesto Groundwater Subbasin survey was conducted in March and April 2022, totaling 1,487.8 line-kilometers (km) (929.9 line-miles). Prior to the survey, public outreach was conducted, providing information on the survey to local residents, media and law enforcement agencies. Both during and after AEM data acquisition, measures were taken to ensure acceptable data quality. This included daily AEM system tests, evaluation of the unprocessed AEM data, and conducting repeat AEM lines to ensure the reproducibility of the collected data.

Well lithology and oil and gas geophysical logs located along the AEM flight lines were compiled to provide additional data to support and ground-truth the surveys, with the objective of obtaining two high-quality lithology logs in each of the Public Land Survey System one-mile square sections that the flight lines cross. High-quality lithology logs are defined as having a verified location accuracy of less than 50 meters (m) (164 feet [ft]), wells that are at least 30 m (98 ft) deep and have an average description interval of less than 30 m (98 ft). In total, there were 1,181 high-quality lithology logs and 122 geophysical logs compiled. Groundwater levels and water quality data (as total dissolved solids [TDS]), both of which can affect the subsurface resistivity, were also compiled.

The AEM data was then processed to filter out potential noise in the data and, if necessary, remove the data where interference is too great to effectively filter. Potential sources for noise in the data includes electric power transmission lines, railroads, pipelines, and any significant metallic objects. Subsequent to AEM data processing, resistivity models were produced that in general, provide profiles indicative of coarse-grained (sands and gravels) and fine-grained (silts and clays), represented by higher and lower resistivities, respectively. Two types of models were produced: a smooth resistivity model, showing the gradual resistivity transition with depth, and sharp resistivity model, where subsurface boundaries are inferred from the AEM data. Figure 0-4 shows a vertical resistivity section with the 30-layer sharp resistivity model (top section).

The AEM modeled resistivity was then processed, combining the detailed high-quality well lithologic data with information on the spatial heterogeneity from the resistivity to provide an interpretation of lithology. In the first step of the process, the well lithology data descriptions were aggregated into either (1) coarse or (2) fine material classifications. Then computer-based numerical calculations using an inversion algorithm were preformed to iteratively compare the modeled resistivity with the simplified lithology from the lithology log data to produce a model of the coarse fraction thickness consistent with the lithology log coarse fraction thickness. The second section on Figure 0-4 shows the interpretation of the coarse fraction thickness along the AEM flight line.

The resistivity and coarse fraction data were combined to produce an initial hydrostratigraphic model for the subbasins, designating areas or layers of the subsurface having similar hydrogeologic properties. This was done utilizing a clustering algorithm, where the relationship between resistivity and coarse fraction were divided into groups with similar properties. As resistivity and coarse fraction is inherently related to the earth's hydrogeological properties, each group of datapoints represents an individual hydrostratigraphic unit. The datapoints were then plotted on the profiles to produce an initial hydrostratigraphic model, containing 5 separate groups based on the resistivity and coarse fraction along the flight line.

The resistivity models will be useful for local groundwater management agencies to refine hydrogeologic conceptual models and groundwater flow models. This may also assist in the identification of recharge areas and interconnected surface water.

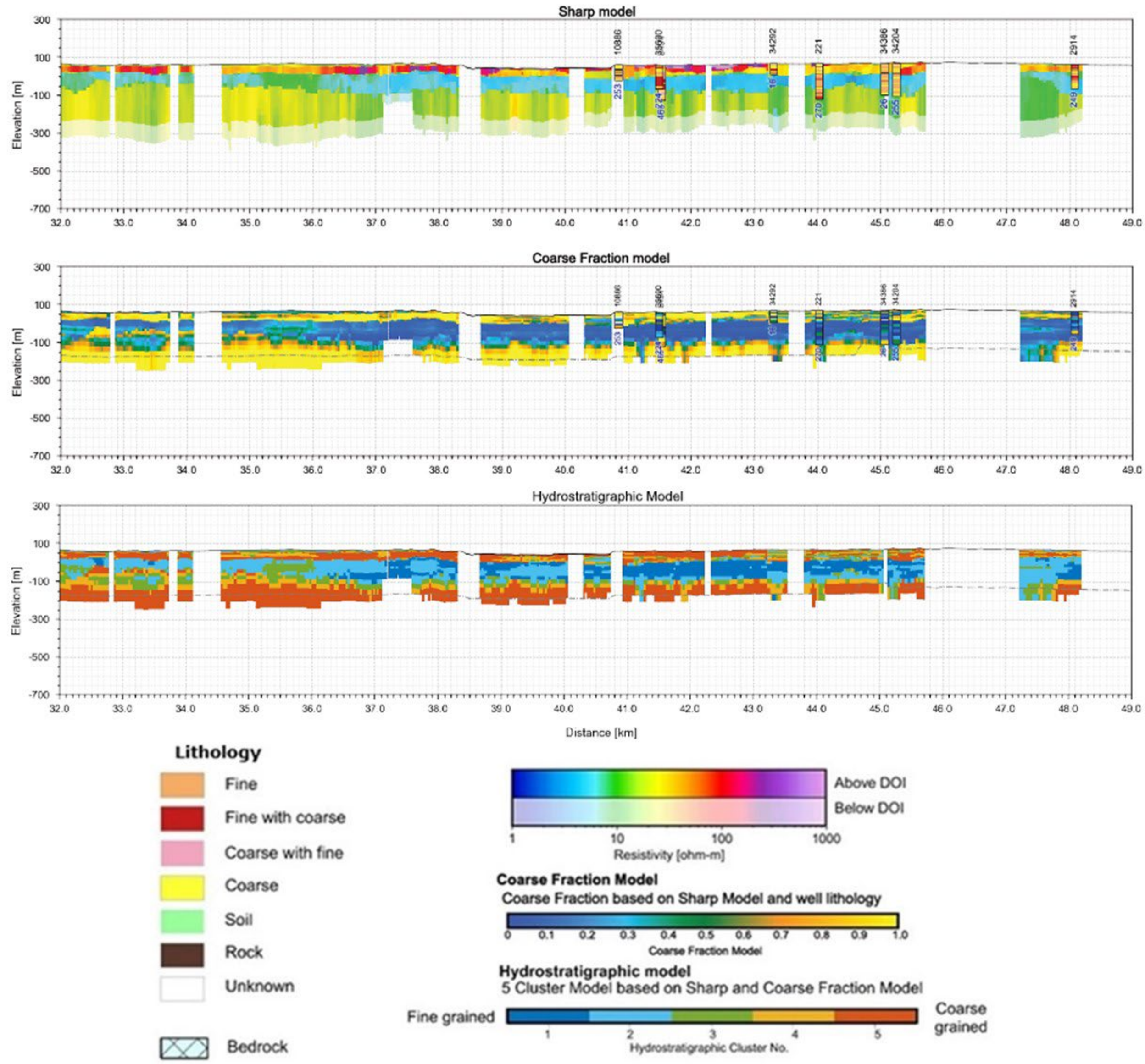

Figure 0-4 Vertical resistivity section series from a AEM flight line in the survey area. The top section shows the 30-layer sharp resistivity model, the middle section shows the coarse fraction model, and the bottom section shows the initial hydrostratigraphic model. The location of the section is shown on Figure 0-3.

1. INTRODUCTION

The California Department of Water Resources (DWR) is currently conducting airborne electromagnetic (AEM) surveys in California's high- and medium-priority groundwater basins. The data from the surveys are collected in order to assist local water managers as they implement their respective groundwater sustainability plans (GSPs) to comply with the Sustainable Groundwater Management Act (SGMA) to sustainably manage groundwater.

An electromagnetic (EM) survey is a geophysical technique conducted from the land surface or the air that measures the electrical properties of the earth's subsurface materials. AEM is an airborne EM technique that includes a large hexagonal frame containing the geophysical equipment suspended by cable beneath a helicopter about 100 feet (ft) above the ground surface along a defined flight path. During the survey, the system sends a weak pulsating electromagnetic signal that penetrates up to around 300 meters ([m] 1,000 ft) into the earth. The returning signal pulse is picked up by receivers in the frame. The data collected provides a measurement of the electrical resistivity of the different geological strata, providing information on the distribution of coarse-grained and fined-grained materials in the subsurface as well as groundwater salinity.

This report presents information on the AEM survey conducted in the Merced, Turlock and Modesto Groundwater Subbasins of the San Juaquin Valley Groundwater Basin. The subbasins are located in the northeastern part of the San Joaquin Valley and designated either high- or medium-priority by the state (Figure 1-1). The report provides full documentation of the data collection, processing and analysis, including the methods used, results, uncertainty and quality control.

1.1 Overview of the California State-wide AEM Survey

The DWR has a long history of data collection, monitoring, and reporting to support characterizing California's groundwater basins. *California's Groundwater*, DWR Bulletin 118, Update 2020 (DWR 2020) is the State's official publication on the occurrence and nature of groundwater in California. The publication defines the groundwater basin boundaries and features current knowledge of groundwater resources including information on the location, characteristics, use, management status, and conditions for each of the State's 10 hydrologic regions. With the passage of SGMA in 2014, there is an increased need for local and state agencies and the public to better understand groundwater basin characteristics in order to make informed management decisions to achieve sustainability in the next two decades.

The objective of the Proposition 68 funded AEM survey program is to support the State's continued effort to improve groundwater basin characterization and to provide groundwater sustainability agencies (GSAs) and interested parties with a regional and statewide dataset, which GSAs can utilize as one way to support the technical requirements of DWR's Groundwater Sustainability Plan (GSP) Regulations and SGMA. The data collection effort will provide essential information about subsurface hydrogeologic characteristics of groundwater basins that will reduce uncertainty and could improve the potential for successful implementation of GSPs and groundwater recharge projects. The focus of the AEM surveys is all of California's high- and medium-priority groundwater basins (Figure 1-1) where data collection is feasible, as these are the groundwater basins that are required to develop GSPs and achieve long-term sustainability within 20 years under SGMA.

1.1.1 DWR AEM Survey Flight Line Planning

DWR conducts the AEM survey flight line planning with input from local, state and federal agencies and then transmits the flight line plan to Ramboll for execution. The AEM survey flight lines are developed with the goal of collecting high-quality data that are beneficial to local, state, and federal agencies by supporting basin characterization and the implementation of SGMA. The steps to developing the survey flight lines are described below.

Step 1: An approximate 2-mile by 8-mile grid was first oriented to capture large-scale hydrogeologic features within the surveyed area, with input from DWR's Region Office staff. Large-scale hydrogeologic features that were considered included aquifer structures, geologic bedding and buried feature orientations, faults, and presence of brackish to saline groundwater.

Step 2: For a combination of safety considerations and potential for noise in the collected data, flight lines were modified to avoid, or minimize the interaction with, the following:

- Urban areas
- Structures containing people or confined livestock
- Oil and gas well fields
- Highways
- Transmission lines
- Railroads
- Pipelines
- Vineyards (most vines are supported by metal posts)

Step 3: Flight lines were modified to incorporate important areas identified by GSAs and state and federal agencies.

Step 4: The flight lines were finally modified to be co-located with existing high-quality lithology or geophysical data gathered from public databases or provided from the GSAs.

Figure 1-1 Map of California showing the SGMA medium- and high-priority basins, highlighted in blue. The Merced, Turlock and Modesto Groundwater Subbasins, the subject of this report, are colored red.

Step 5: The flight lines were transmitted to the consultant team, where they are further examined by SkyTEM and Ramboll to adjust for potential infrastructure interference and safety considerations.

All flight line planning was conducted using ArcGIS, and publicly available data was utilized when available.

1.1.2 Statewide AEM Survey Planning and Coordination

Coordination and engagement with a wide range of organizations helps to ensure that the end use of the high-value AEM data is optimized to support sustainable groundwater management activities. In addition, this provides benefits to a range of state, federal, and Tribal government hydrogeologic and geologic related projects. For each priority groundwater basin to be surveyed, DWR coordinates and engages with local, state, federal agencies, and Tribal governments (where present) to develop the survey design to meet a broad number of objectives. DWR also provides ongoing coordination, communication and public outreach throughout the process to support the AEM project logistics and to ensure the community is informed of the activities, as outlined below.

<u>Local Coordination</u>
DWR coordinates with local GSAs within each groundwater basin planned for an AEM survey to identify important areas within their basin where they want to ensure that AEM data is collected. For many GSAs, this include areas of known data gaps, areas being considered for groundwater recharge or other projects, or areas critical to GSP implementation.

<u>Local Data Request</u>
DWR also requests that the local basin GSAs share high-quality, digitized lithology or geophysical logs (that are not currently available in state databases) with DWR to support the AEM data interpretation. Integration of existing lithology and geophysical logs supports and reduces the uncertainty in the interpretation of the AEM data and is incorporated into the groundwater basin flight line planning process (described in Section 3.1)

<u>State and Federal Agency Coordination</u>
DWR is collaborating and coordinating with the state and federal agencies listed below that may benefit from the AEM data to support other state- and federal-related interests, such as fault and seismic hazard mapping, canal and aqueduct maintenance, land subsidence, managed aquifer recharge, and groundwater modeling. DWR solicits input on flight line planning, requests area maps and descriptions and provides updates on the AEM survey program status and schedule.

State Agencies

- California Department of Fish and Wildlife
- California Department of Food and Agriculture
- California Department of Water Resources
- California Geological Survey
- State Water Resources Control Board

Federal Agencies

- United States Bureau of Reclamation
- United States Geological Survey

Tribal Government Engagement

DWR elected not to survey Tribal Trust Lands (as defined by the United States Bureau of Indian Affairs) unless the Tribe within the surveyed basin indicates that data collection and publication is acceptable.

DWR engages with Tribes within the surveyed basin through meetings and letters to Tribal leaders with information about the AEM project and an invitation to elect to join the surveys. DWR will only survey Tribal Trust Lands (as defined by the United States Bureau of Indian Affairs) if the specific Tribe(s) within the basin to be surveyed indicates that data collection and publication is acceptable. Notifications of surveys are provided in lieu of invitations if data collection over the Tribal Trust Land is not possible due to technical limitations. Technical limitations can be caused by the proximity of a potential survey area to urban areas, buildings, or electromagnetic noise sources, like infrastructure and other metallic features.

The AEM Survey Schedule webpage (https://gis.water.ca.gov/app/AEM-schedule) provides a map showing the AEM survey progress and locations of federally recognized Tribal Trust Lands and the surveyed basins.

1.1.3 AEM Survey Public Outreach

Prior to initiating the surveys within a groundwater basin, DWR conducts outreach to the public to provide an overview of the project and to notify interested parties of the upcoming work. Conducting outreach is a priority for DWR to ensure that the public is comfortable with the low-flying helicopter and is aware of the importance of the project. DWR’s public outreach plan in each survey area includes the following activities:

- Posting a social media announcement on DWR’s LinkedIn and Twitter pages and sharing with local GSAs to be re-posted on their social media websites.
- Providing a press release to local media outlets to be shared with their subscribers; interviews were also conducted by DWR staff when requested.
- Sending notification letters (in English and Spanish) via United States Postal Services to parcel owners within a 500-m buffer beneath the planned flight path.

These public outreach activities were conducted within one month prior to the start of the AEM survey in the Merced, Turlock and Modesto Groundwater Subbasin.

Ramboll, SkyTEM, and Sinton Helicopters conducted outreach to county law enforcement to notify them of the planned AEM surveys and to provide background information about the project. The following sheriff offices were contacted via mail and telephone:

- Stanislaus County Sheriff
- Merced County Sheriff

1.2 Merced, Turlock and Modesto AEM Survey

For the Merced, Turlock and Modesto Groundwater Subbasin survey, shown on Figure 1-2, a total of 1,487.8 line-kilometer(929.9 line-miles) was acquired from March 13 to April 3. During the survey, on a daily basis the acquired AEM survey data was downloaded from the AEM instrumentation, initially checked for quality, and uploaded to a secure server for storage and subsequent analysis.

Parallel to the collection and processing of the AEM data, well information along the flight lines was gathered and compiled in a project data management system. The well data collected includes lithology, geophysical logs, water level measurements and water quality measurements (total dissolved solids [TDS]). The processed and inverted AEM resistivity data were then analyzed in combination with the well data, providing information on how resistivity relates to lithology. This report provides a summary and documentation of the listed tasks, including the methods used, results, uncertainty, and quality control.

1.3 Basin Geology

This report has a focus on the AEM data collected in the Merced, Turlock and Modesto subbasins. However, the basin-specific hydrogeology determines the resistivity distribution in the subsurface; therefore, a very basic hydrogeological description of the Merced, Turlock and Modesto Groundwater Subbasins is included in this section, providing the general background for this section. For more information, please see the descriptions in Bulletin 118 (https://water.ca.gov/programs/groundwater-management/bulletin-118) as well as the GSPs submitted for the subbasins (https://sgma.water.ca.gov/portal/gsp/status).

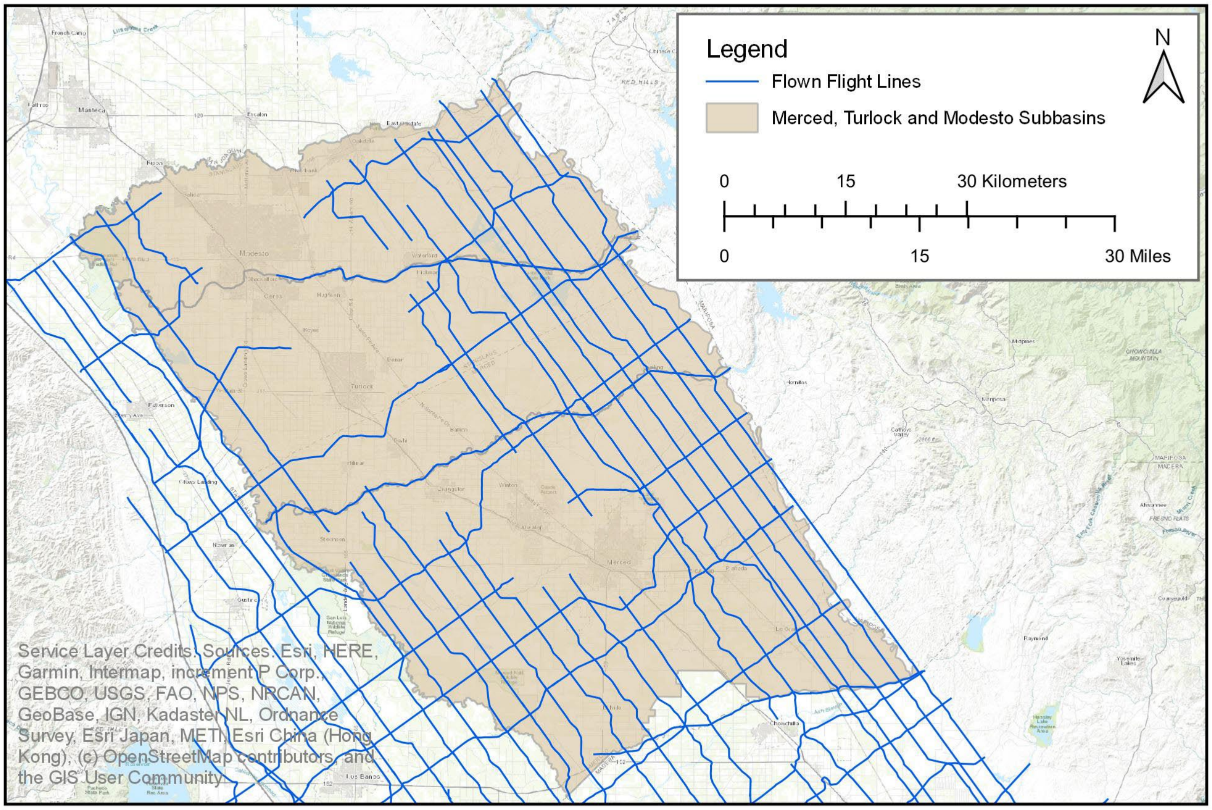

Figure 1-2 Map showing the Survey Area 5 flight lines completed in the Merced, Turlock and Modesto Groundwater Subbasins, shown in brown.

The surficial geology of the three subbasins is generally similar and predominantly composed of Quaternary alluvium with fans of older alluvium contacting the crystalline rock of the foothills along the eastern margins of the subbasins (CGS, 2010). The primary water bearing units of the subbasins include unconsolidated Pliocene to Holocene continental deposits and alluvium deposits, as well as consolidated sandstone, breccia, conglomerate, tuff siltstone and claystone deposits of Miocene to Pliocene age (DWR, 2003). The Corcoran Clay, a significant impermeable clay unit in the region, partially confines some of these water bearing units (DWR, 2003).

1.4 Report Contents and Appendices

The data report for the Merced, Turlock and Modesto Groundwater Subbasin survey is divided up into a main body and 11 appendices. The purpose of the main report is to provide a general overview of the activities conducted and a basic description of the methodology and results. The main report is divided into six sections. The first section includes an introduction to the California statewide AEM survey and the specific survey for the Merced, Turlock and Modesto Groundwater Subbasin. Section 2 gives a brief description of the geography and hydrogeology. Section 3 provides a description of the data collection, including the acquisition of the AEM data as well as the gathering of well data along the planned flight lines. Section 4 presents the AEM processing and inversion methods, results, and uncertainty. Section 5 provides the methodology and results of the lithology model, and Section 6 includes the methodology and results of the lithostratigraphic model.

The report appendices provide detailed technical documentation of all the activities conducted including survey methodology, results and quality control measures undertaken before, during, and upon completion of the AEM surveys, and include:

- Appendix 1 - Detailed description and presentation of the well data gathered along the planned flight lines, a description of the data management system, and the quality control checks of the collected well data included in the data management system.
- Appendix 2 - Technical details on the acquisition and quality control of the AEM data.
- Appendix 3 - Technical details of the processing and inversion of the AEM data, including methodology, results, uncertainty and quality control.
- Appendix 4 - Technical details of lithology model.
- Appendix 5 – Technical details of the development of the initial hydrostratigraphic model.
- Appendix 6 – Profile atlas containing the smooth resistivity model and the total magnetic intensity.
- Appendix 7 – Profile atlas containing the 30-layer sharp inversion model, the 4-layer model and the resistivity uncertainty analysis.
- Appendix 8 – Profile atlas showing the lithology model results and lithology model uncertainty.
- Appendix 9 – Profile atlas showing the initial hydrostratigraphic model results and cluster model uncertainty index.
- Appendix 10 - Resistivity maps, broken out for specific elevation intervals and as depth intervals.
- Appendix 11 - Description of the deliverables.

2. HYDROGEOLOGIC DATA ACQUISITION AND COMPILATION

Lithologic data, resistivity logs, water level measurements, and water quality (TDS) measurements from wells were assembled for the Merced, Turlock and Modesto Groundwater Subbasins. The data was compiled along the planned flight lines before they were flown. This data was then quality control checked and assembled into a data management system (DMS) for this project. This section provides a brief description of the results for the collection of the well data. A detailed description of the data compilation process and results is presented in Appendix 1.

2.1 Well Lithology Logs

For this project, the contractual objective was to obtain a minimum of two “best available” lithology logs from available well completion reports for each Public Land Survey System (PLSS) one-mile square section the flight lines cross. Best available lithology logs are defined as logs which can be accurately located within 50 m (165 feet [ft]), and that contain high-quality lithologic descriptions based on the detail in both the description and discretization. A lithology log is considered high-quality if the log’s descriptions extend more than 30 m (100 ft) below ground surface (bgs), and the average description interval is less than 30 m (100 ft) (i.e., there are at least one lithologic description for every 30 m on average); otherwise, it is considered a low-quality lithology log.

In total, the planned flight lines cross 1,091 PLSS sections, as shown on Figure 2-1. There are a total of 1,181 high-quality lithology logs distributed across 571 PLSS sections that the flight lines cross. There are 311 sections that contain two or more high-quality lithology logs, 260 sections that contain only one high-quality log, and 520 sections that contain no high-quality logs. In total, there are 155 sections that contain only low-quality logs and 365 sections that do not contain any lithology logs. Of the 1,181 high-quality lithology logs, 596 were obtained directly from the local agencies, 206 were digitally available from the DWR Online System for Well Completion Reports (OSWCR) database, and 379 were digitized for this project (as described in Appendix 1).

Note that in Figure 2-1, the flight lines cross into adjacent subbasins. These subbasins are also part of the survey area but are covered in a separate report.

The well lithology log data was added to the project DMS. The lithologic descriptions in the DMS were then standardized with regards to their different descriptors. They were then simplified into two basic classifications: fine or coarse. Appendix 1 contains additional details on the lithologic standardization process. The data entered into the DMS was quality control checked with regards to the well placement and lithology transcription. All wells digitized by the project team were quality control checked. A random control check of 10% of the wells provided by local agencies and from the OSWCR database was then conducted.

2.2 Well Geophysical Logs

For this project, high-quality electrical resistivity logs were compiled from wells from the California Geologic Energy Management Division (CalGEM) database that are within the PLSS sections in which the flight lines cross. High-quality electrical resistivity logs are defined as being located with an accuracy of 50 m (165 ft), with measurements over the interval of 0 to 300 m (1,000 ft) below ground surface, and that have a hard copy log image of sufficient quality to be digitized. However, logs that were more than 40-years old or within an oil field were not included due to the changing hydrological conditions in the basin over time (potential changes in water levels and groundwater salinity), and the metal infrastructure within oil fields that interfere with the AEM survey signal. In the study area, there were 7 resistivity logs in the CalGEM database within the PLSS sections which met the criteria.

Geophysical logs were also compiled for the DMS by RealTime Aquifer Services (RAS), a part of the contractor team, as well as by AECOM via the local agencies. RAS provided 112 geophysical logs located within PLSS sections crossed by a flight line, and the local agencies provided 3.

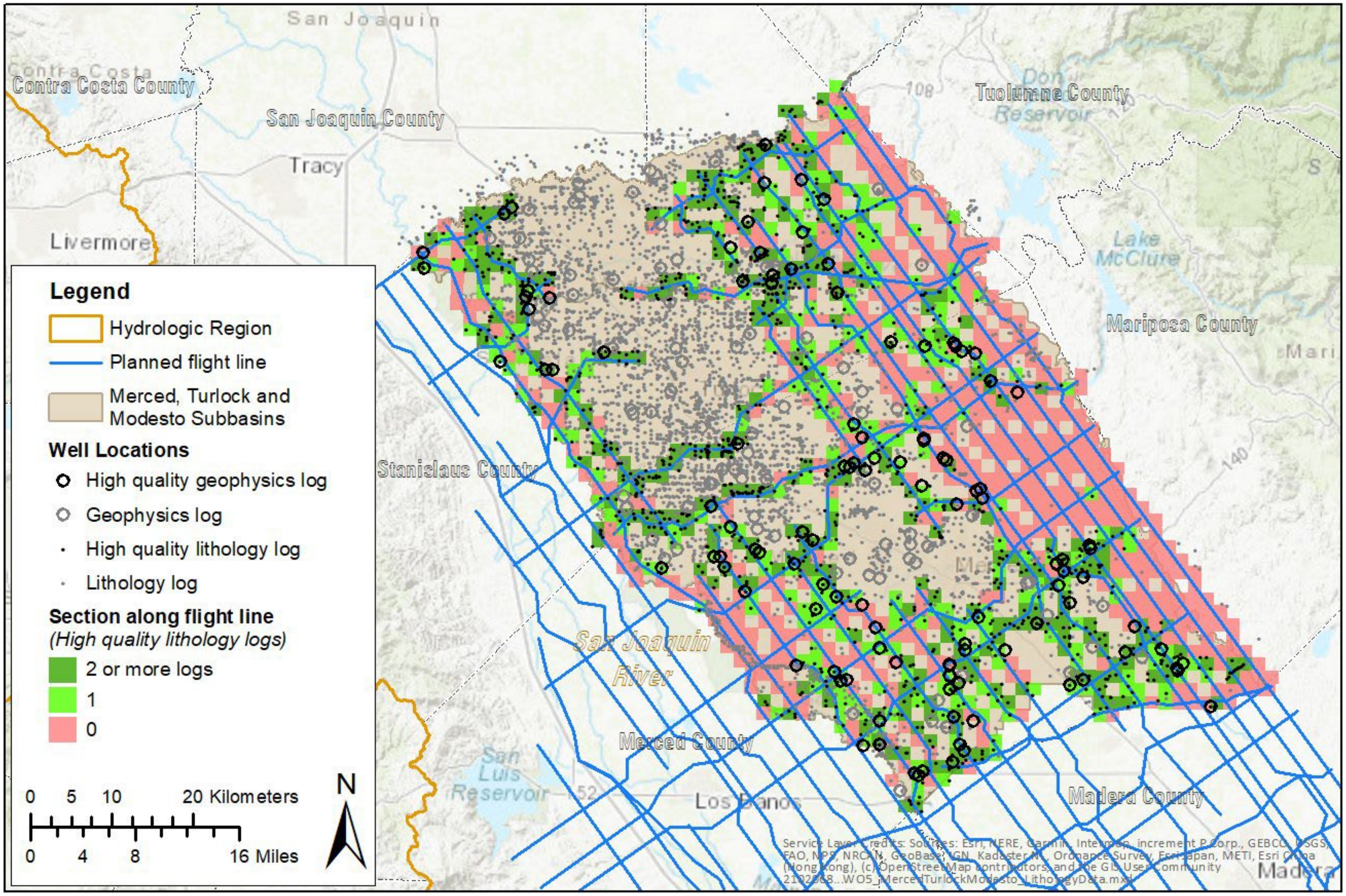

Figure 2-1 The location of well lithology and geophysical logs used in the AEM survey. The map shows the flight lines in blue and the wells within the PLSS sections that the flight lines cross. The sections with two or more high-quality lithology logs are shown in dark green, sections with one high-quality log in light green, and sections without high-quality logs as light red.

2.3 Groundwater Occurrence

Information on the depth to groundwater is important in the interpretation of geophysical data because the electrical resistivity of subsurface lithologies differs between unsaturated and saturated conditions. Understanding the depth to groundwater supports the AEM data inversion process. Figure 2-2 shows depths to groundwater for select wells in the study area. For more detailed information on groundwater occurrence see the GSP for the basins.

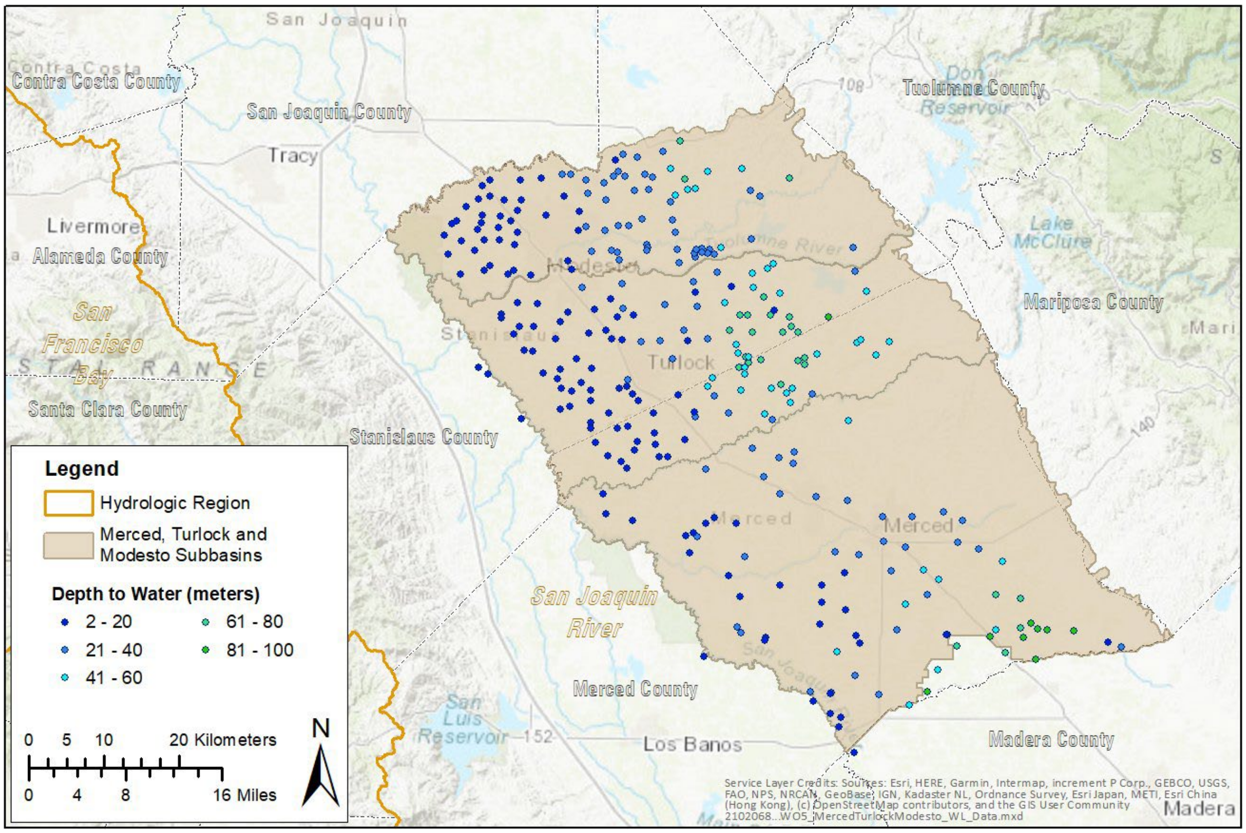

Figure 2-2 A map showing the depths to groundwater in the survey area for measured in select wells between 2019 and 2022.

2.4 Total Dissolved Solids in Groundwater

Groundwater quality is important to geophysical interpretation because electrical conductivity varies depending on the dissolved constituents in groundwater. This can vary by depth, aquifer, and geographic location within a groundwater basin. A measure of the amount of dissolved constituents is recorded in total dissolved solids (TDS) concentrations. In addition to TDS measurements, electrical conductivity (EC) is often measured directly. TDS and EC vary proportionally to one another. Both measurements were assembled from the State Water Resources Control Board's (SWRCB) Groundwater Ambient Monitoring and Assessment (GAMA) system. The GAMA system is the most comprehensive, readily available, and reliable water quality dataset. It includes data collected from various federal, state, and local programs. This dataset is being updated by the state as new water quality data is reported to the state for compliance monitoring.

Figure 2-3 shows available water quality data throughout the study area. For sites with concurrent TDS and EC measurements, TDS was used. TDS and EC vary proportionally to each other, but the conversion factor (from EC in micromhos per centimeter to TDS in milligrams per liter [mg/L]) depends on the specific constituents within the sample and can range from 0.5 to 0.75 (Rusydi 2018). For plotting purposes, an average conversion factor of 0.6 was used. TDS values within the study area range from less than 800 mg/L to up to 6,400 mg/L.

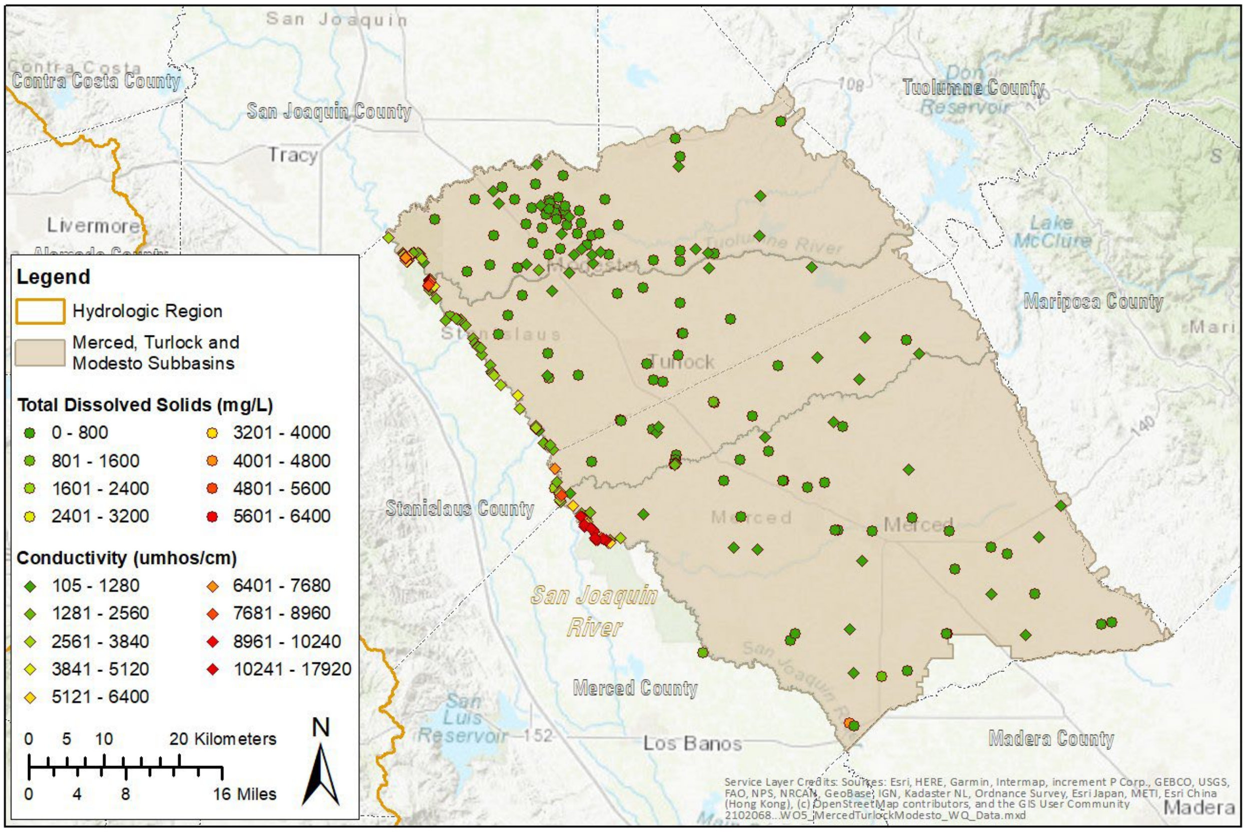

Figure 2-3 Map showing the TDS and electrical conductivity measured in select wells in the survey area between 2001 and 2018.

3. AIRBORNE ELECTROMAGNETICS SURVEY

3.1 Basin AEM Survey Methodology, Objectives and Flight Line Planning

This section introduces the methodology used for the AEM data acquisition, describes survey objectives, and discusses procedures taken for flight planning.

3.1.1 AEM Survey Methodology

The AEM survey method being used is a time-domain or transient electromagnetic method, known as TEM. The TEM methods are based on the principle of inducing electrical currents into the subsurface and receiving Earth's response over a short period of time. The TEM-instrumentation consists of a transmitter loop, two receiver coils, two inclinometers, two altimeters, and two differential global positioning system (DGPS) units (for more information, see Appendix 2).

During each transient measurement, direct current is initiated through the transmitter loop. After a short time, the current is abruptly turned off. This abrupt turn-off induces electrical currents (called eddy currents) in the subsurface, which in return, generates secondary magnetic fields that decay with time. The decaying magnetic fields are measured using the receiver coil as a voltage timeseries, also referred to as a sounding. An optimization algorithm, called inversion, is then applied to the processed data to yield estimates of the subsurface resistivity structure, called resistivity models.

The TEM system can be deployed on the ground surface for stationary measurements or carried on moving platforms such as sleds, boats or, in the case of AEM, carried by a helicopter or airplane. Figure 3-1 provides an image of the actual AEM system, operated by SkyTEM Surveys, and helicopter, owned by Sinton Helicopters, being used in the DWR AEM statewide surveys.

An example of a single sounding of AEM data in the study area and corresponding resistivity model of the subsurface is shown in Figure 3-2. During the inversion, the entire AEM dataset is inverted together and the resistivity model for each sounding is constrained. This is done by introducing a dependency in between models for neighboring soundings, as discussed in Section 4 and Appendix 3.

More information on the physical principles of the TEM method can be found in Ward and Hohmann (1988) and Schamper et al. (2013) and in Appendix 2. A detailed description of the SkyTEM/AEM system used in this survey can be found in Section 3.2.1 and Appendix 2.

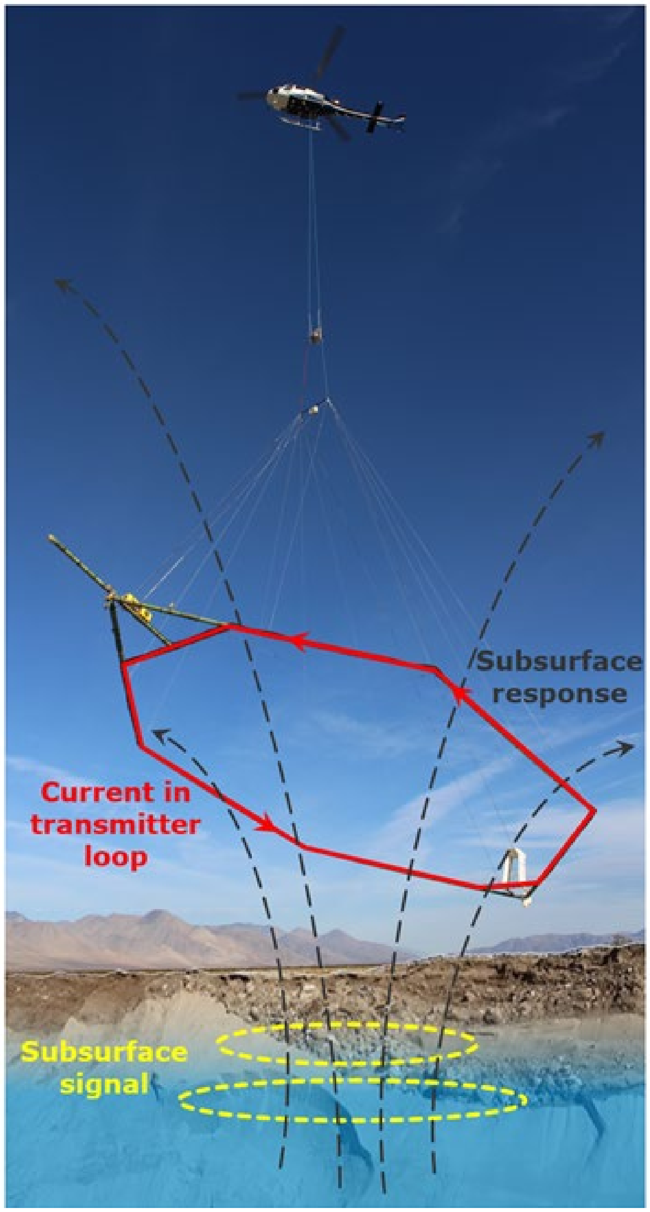

Figure 3-1 Figure showing the Airborne Electromagnetic Survey Schematic including the transmitter loop (current in red), subsurface signal (in yellow), and subsurface response (in dashed black lines) which is picked up by the system receiver. Note: the illustration does not include primary magnetic fields.

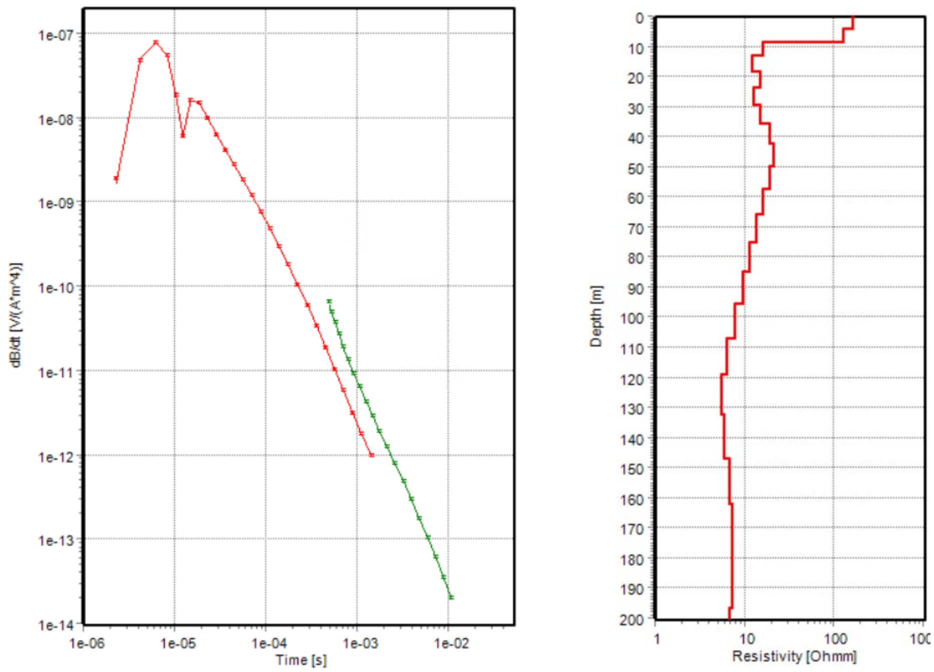

Figure 3-2 An example of a single sounding of acquired AEM data (change in magnetic field as a function of time) shown on the left-hand side with Low Moment (red) and High Moment (green) transmitter data, and a corresponding resistivity model showing the modeled resistivity from the ground surface to a depth of 200 m (650 ft).

3.1.2 Merced, Turlock and Modesto Groundwater Subbasin AEM Survey Flight Line Planning

The planned flight lines for the AEM survey were prepared by DWR as discussed in Section 1.1.2, and provided to Ramboll for execution. Ramboll, SkyTEM and Sinton Helicopters conducted a review of the planned flight lines on aerial photos from Google Earth and aeronautical charts to identify possible safety considerations in relation to:

- Built up areas which will need to be diverted around
- Trees and forested areas which the pilot will need to climb in elevation or divert around
- Towers, power lines, and other infrastructure that the pilot will need to climb in elevation or divert around
- Major roads which the pilot will need to navigate around
- Restricted air space
- Restricted areas due to endangered species

A proposed flight line plan was then prepared incorporating the safety review of the DWR-planned flight lines and landing zone bases (small airports) that were identified for survey logistics, equipment checks and data downloads, and fueling. The safety considerations and proposed flight line plan were presented to DWR for final review, and subsequently approved for execution.

Figure 3-3 shows a map of the planned flight lines along with the land use within the Merced, Turlock and Modesto Groundwater Subbasins. During flight line execution, Sinton Helicopters sometimes had to diverge slightly from the planned flight lines while flying based on visual observation of potential safety issues such as the presence of people, livestock or other safety hazards (shown in Figure 3-5).

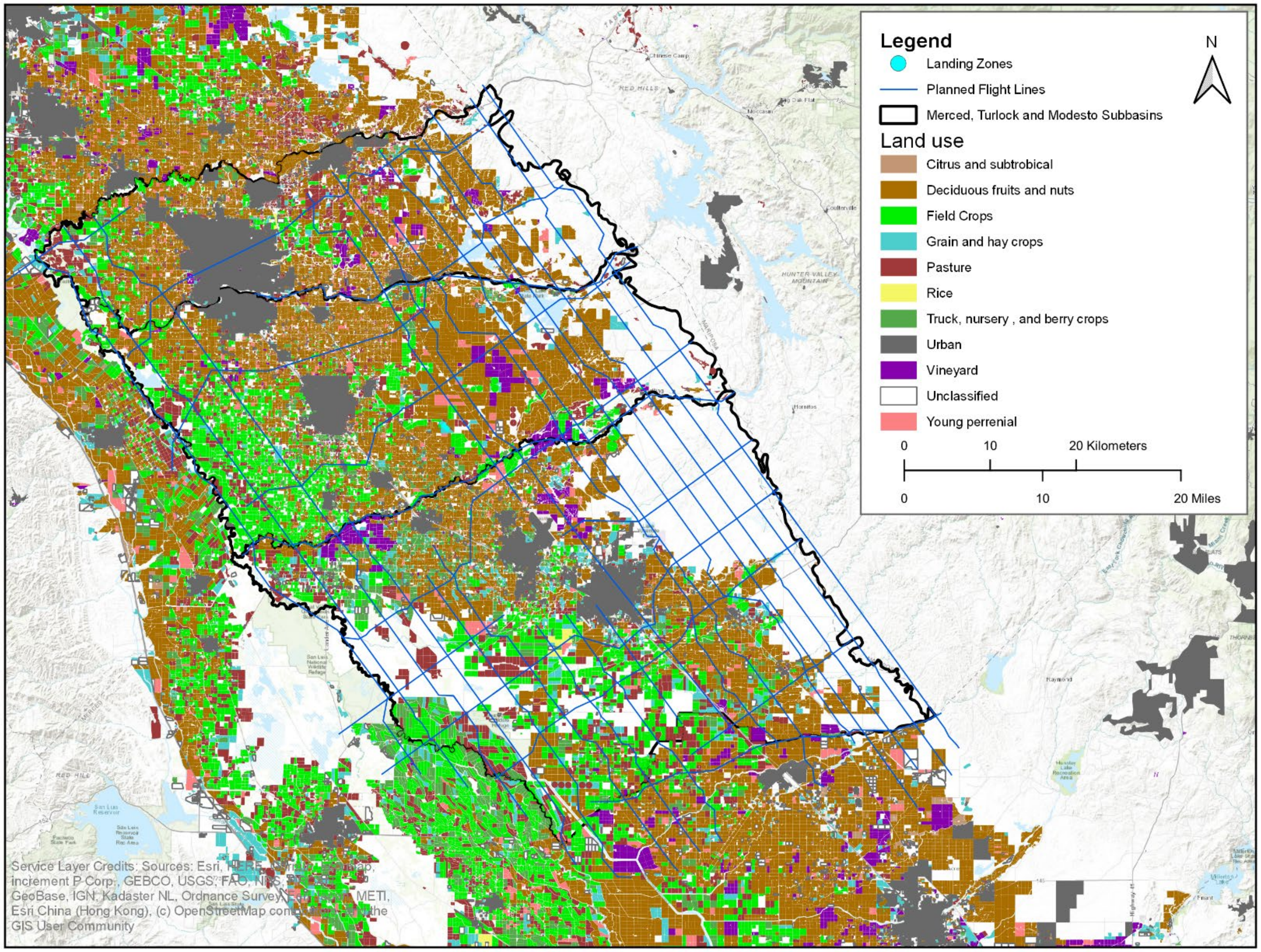

Figure 3-3 A map showing the planned flight lines (dark blue), the landing zones (light blue circle) and the surrounding land use types. Urban areas are shown in grey, vineyards are in purple, and the remaining areas are various types of agriculture.

3.2 Basin AEM Survey

3.2.1 Basin AEM Survey Equipment and Instrumentation

The helicopter-borne SkyTEM312M time-domain electromagnetic system was used during this survey. Throughout this report, the terms SkyTEM, SkyTEM312M, and AEM are used synonymously to indicate the geophysical survey equipment.

The AEM system is carried as a sling load, suspended 30 m (98 ft) beneath the helicopter and flown 30-50 m (98-164 ft) above the land surface (Figure 3-4) while flying at a groundspeed of 80-100 kph (50–62 mph). The system is designed for hydrogeological, environmental, and mineral investigations. The SkyTEM312M system has a transmitter loop area of 342 m^2 (3,681 ft^2) contained within a hexagonal frame towed beneath the helicopter.

In addition to acquiring electromagnetic data, which provides information about the resistivity structure of the subsurface, the system also collects magnetic data, which is primarily used for mapping magnetic anomalies, fractures, and faults. Auxiliary data is also recorded and include Global Positioning System (GPS) data for positional accuracy, the pitch and roll of the system, laser altimeter data for elevation, and video for a record of the ground surface along the flight path. A more comprehensive description of the TEM methodology can be found in Appendix 2.

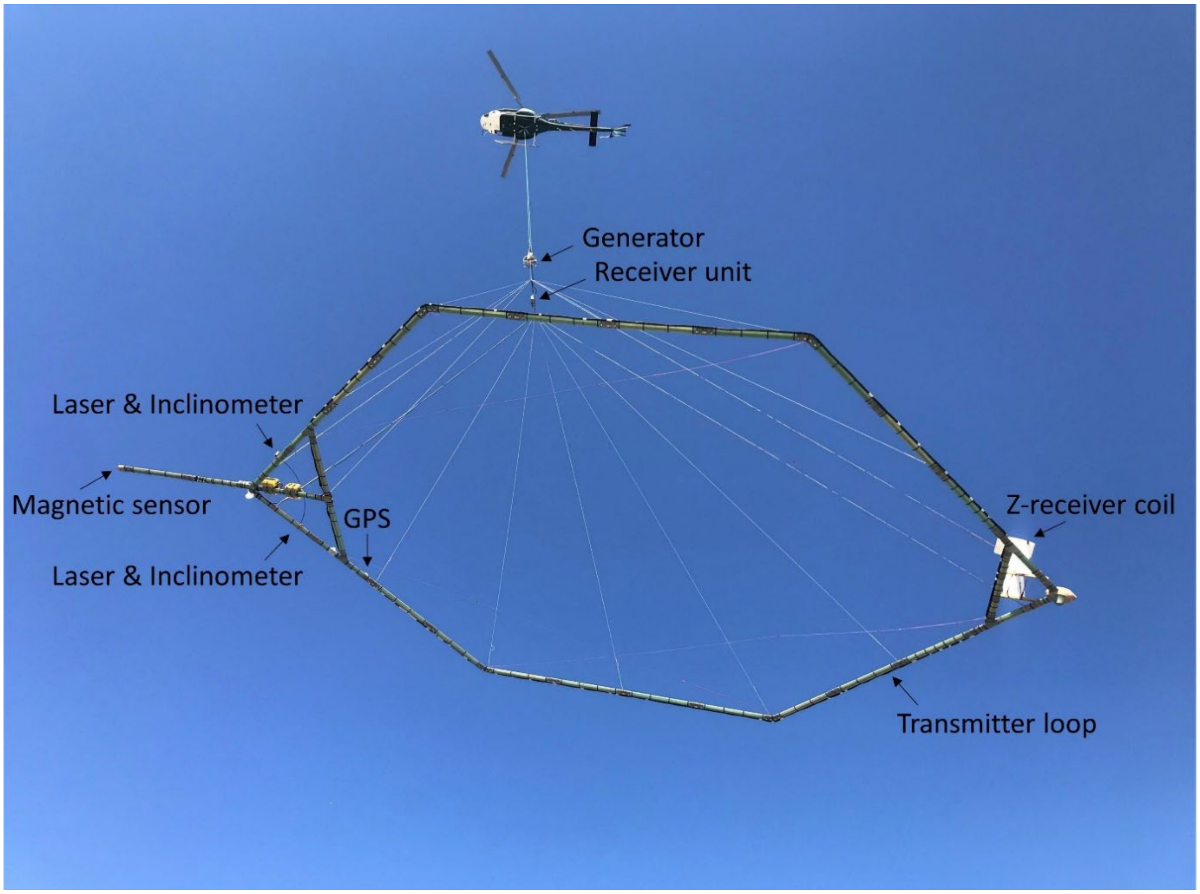

Figure 3-4 AEM Equipment and instrumentation configuration. The picture shows the helicopter towing the hexagonal transmitter loop. The front of the loop contains the GPS, laser, inclinometer and magnetic sensor. At the back of the loop is the Z-receiver coil. Suspended between the transmitter loop and the helicopter are the generator and receiver unit.

3.2.2 Landing Zones

Multiple locations were used as landing zone bases throughout the survey. These included New Coalinga Municipal Airport from March 13 to 17, Reedley Municipal Airport from March 17 to 19, Madera Municipal Airport from March 19 to 26 and Turlock Airport from March 26 to April 3, see Figure 3-5.

3.2.3 Basin AEM Survey Data Acquisition

The AEM survey was carried out between March 13 to April 2, 2022. A total of 1,487.8 line-km (929.9 line-miles) of data was acquired.

Before, during and after the acquisition of the AEM data, several measures were taken to ensure that the AEM system functioned properly, and the quality of the acquired data was acceptable. During the initial on-site SkyTEM system set-up phase, very high-altitude tests, waveform, configuration settings and null positions were checked in collaboration with SkyTEM to ensure that the configuration and specifications were as agreed upon in the contract.

During the survey, SkyTEM provided daily updates, including a map of daily production, high-altitude test, raw electromagnetic, magnetic, and reference line data (see Appendix 2), which was quality control checked on a daily basis by Ramboll. The quality of the data evaluated daily during the Merced, Turlock and Modesto Groundwater Subbasin survey was all found to be acceptable.

Figure 3-5 shows the actual flown flight lines compared with the planned flight lines. In general, it was not necessary to deviate significantly from the planned flight lines in the Merced, Turlock and Modesto Groundwater Subbasins. Figure 3-6 shows three photos of the AEM array during data acquisition in the Merced, Turlock and Modesto Groundwater Subbasins.

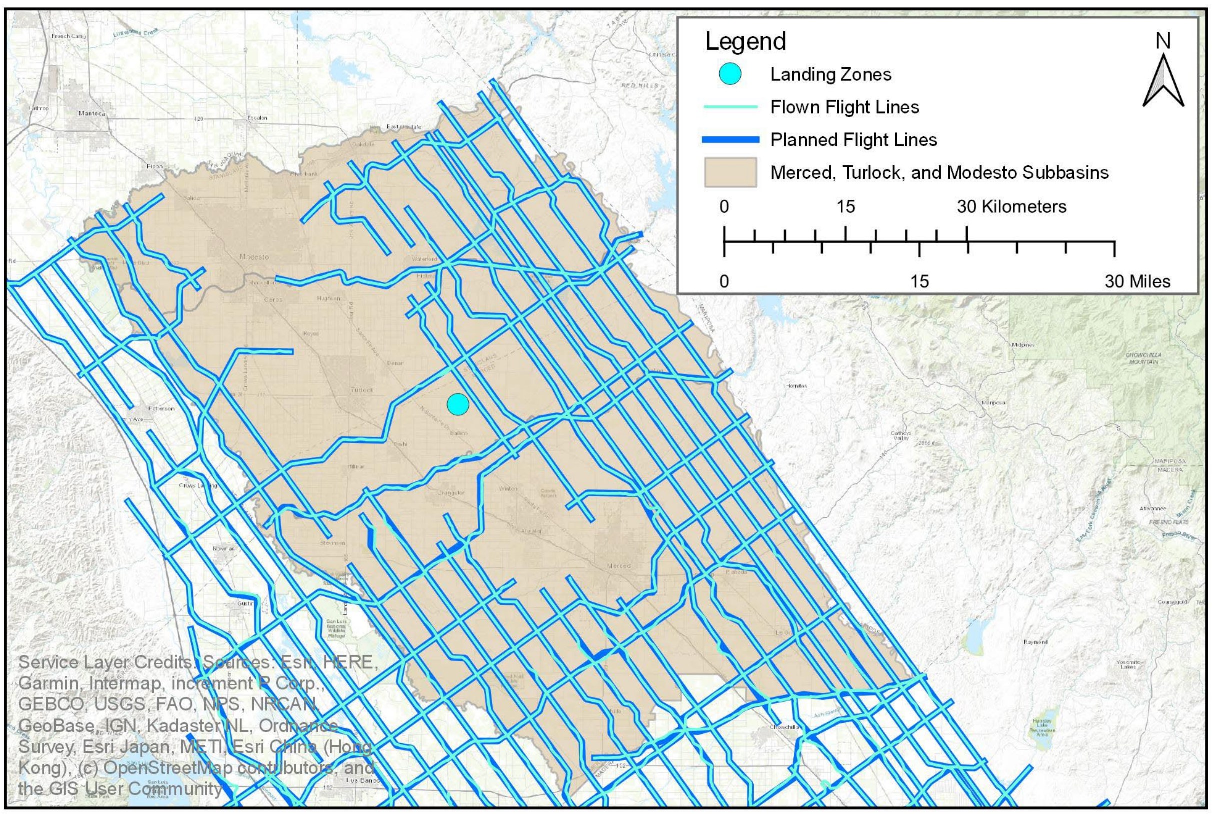

Figure 3-5 Map showing the planned and flown flight lines in the Merced, Turlock and Modesto Groundwater Subbasin. The planned flight lines are shown as the thicker dark blue lines and the actual flown lines are superimposed on top as thin light blue lines. The light blue dots show the location of the landing zone bases for the flights conducted in the area.

Figure 3-6 Photos of the AEM flights in the Merced, Turlock and Modesto Groundwater Subbasins.

3.2.4 Reference Lines

Reference lines are flight lines that are repeated, with the purpose to compare the initial and repeated flight line results to ensure the reproducibility of the AEM system during the survey to validate instrument performance, to identify any potential drift and to document the stability of the data processing and inversion algorithms. One or more reference lines were flown during each production day during the survey, which resulted in a total of 21 reference lines in two locations ranging from ~ 1,450 m to ~ 1,750 m (4,750 to 5,740 ft) in length.

The results of the reference lines demonstrate that the AEM system was not affected by drift or instrumentation issues. It also showed that the processing and inversion schemes were consistent, and the results demonstrate that the data is highly repeatable. More information and the results of the reference lines can be found in Appendix 2.

4. AEM DATA PROCESSING, INVERSION, AND RESULTS

The AEM dataset acquired during the survey comprises a set of voltage time series, which is the response signal resulting from the electromagnetic pulses produced by the AEM transmitter loop. Auxiliary data (e.g., GPS and height measurements) are also acquired. To obtain quantitative information on the subsurface resistivity from the raw AEM data, the data must go through the steps of processing and inversion. Processing refers to actions that prepare the data for inversion, including the removal of noisy or coupled AEM data, and the application of averaging filters to the data. Filters are applied to obtain usable, noise-free data and optimize lateral resolution. Inversion refers to the numerical optimization algorithm that identifies the subsurface resistivity distribution that agrees with the AEM data. Here, we present an overview of the processing and inversion, as well as a selection of the resulting resistivity models. A more thorough review of the processing and inversion is presented in Appendix 3, and the full set of resistivity models resulting from the processing and inversion steps are shown in Appendix 6.

4.1 AEM Data Processing and Inversion

After the raw (electromagnetic & auxiliary) data were checked for quality, they were imported into the Aarhus Workbench software for data processing and inversion. Which comprised the following steps:

1. Process auxiliary data (e.g., GPS, height)
2. Process AEM data automatically and manually
3. Run inversion on the AEM data
4. Calculate the depth of investigation from AEM data
5. Run uncertainty analysis on AEM data

4.1.1 Data Processing

The first data to be processed are the auxiliary data: these data include pitch and roll (tilt) data, transmitter height data, and GPS data. The tilt and transmitter height data affect the raw AEM measurement and must be accounted for during the inversion. The GPS data are needed to relate each measurement with its correct geographic position. Each type of auxiliary data was quality control checked before being used in the inversion. To relate the resistivity models to the topography of the landscape, a terrain elevation was assigned to each electromagnetic sounding using a digital elevation model (DEM). For more information about these steps see Appendix 3.

Next, the raw AEM data (voltage timeseries) were processed to prepare for inversion. The AEM system continuously makes electromagnetic measurements, which results in approximately 25-35 measurements per kilometer along each flight line. The AEM data processing comprises an automatic and a manual component. The automatic processing requires selection of appropriate filters and other parameters. After automatic processing, the data are manually reviewed for noise, as well as interference from infrastructure, such as powerlines or pipes. The distance of AEM data locations to human-made structures was considered, and portions of the dataset were selectively removed. The AEM data processing is an iterative process, which requires revisiting the data after each step, and again after provisional inversion results are visualized. Detailed information about the voltage timeseries data processing steps and settings are provided in Appendix 3.

4.1.2 Inversion

Once the auxiliary and AEM data was processed, the data was used to produce resistivity models through inversion. The inversion is an iterative optimization, where the resistivity model at each location where AEM data were acquired (i.e., each sounding) along each flight line, is used to calculate synthetic AEM data. These synthetic AEM data are compared to the processed AEM data acquired during the survey. The misfit between the observed and synthetic data is used as a criterion to update the resistivity model, and the process is repeated. While minimizing the data misfit, the employed inversion scheme enables applying vertical constraints (i.e., between the resistivity values of adjacent layers) and spatial constraints (i.e., along and between flight lines), to allow the migration of information to nearby AEM data. Once the synthetic AEM data match the acquired AEM data within a specified tolerance, the resistivity model is considered final.

All AEM data were inverted simultaneously using the spatially constrained inversion (SCI) approach (Viezzoli et al., 2008), which accounts for all model parameters, AEM data and spatial constraints. The system setup information (AEM equipment metrics) is used during the inversion when calculating the synthetic AEM data. The inversion algorithm requires user input on specific values, including the depth discretization of the resistivity model (i.e., the estimate of the subsurface resistivity structure), the initial estimate of resistivity values, and horizontal and vertical constraints. Each value is selected based on the AEM system setup, depth interval of interest, and background geologic information of the study area; multiple inversions may be run on the same dataset to find the optimal values for these input values. Typically, two to three inversions are run on the dataset to 1) finalize the processing of the data (e.g., by removing noisy or coupled data that appear in the inversion result) and 2) obtain final input values for the inversion. Detailed information of the inversion approach can be found in Auken et al. (2015) and Appendix 3.

4.1.2.1 Inversion Schemes

Using the SCI approach with a different setup, the AEM data can be inverted to result in different types of resistivity-depth models. The following inversion schemes were used in this study:

- Smooth inversion: in this scheme, many layers (20 to 30) are used in the model, where each layer thickness is larger than that of the layer above it. Each layer thickness remains fixed during iterations of the inversion, but the resistivity value of each layer is allowed to vary. Using spatial constraints, resistivity values are restricted to stay within a factor of neighboring resistivity values, resulting in smoothly varying resistivity-depth models.

- Few-layer inversion: in this scheme, a small number of layers (typically 3 to 6) are used in the model; both the resistivity and thickness of each layer are allowed to vary during the inversion. The few-layer inversion can represent sharp boundaries in the subsurface, unlike the smooth inversion. The few-layer inversion is used in this project for the uncertainty analysis since the uncertainty in the thickness and depth of each layer can be analyzed (unlike in the smooth and sharp inversions).
- Sharp inversion: Like the smooth inversion, the sharp inversion uses many layers. Like the few-layer inversion, the sharp inversion is favorable when expecting sharp layer boundaries. However, unlike the smooth inversion, the sharp inversion is designed to support both gradual and abrupt changes in resistivity values (Vignoli et al., 2015). Furthermore, the sharp inversion overcomes the limitation in the few-layer inversion of setting a small, constant number of layers in the inversion over a large survey area, where conditions are likely to change spatially. Because of these advantages, the results from the sharp inversion were used to develop the lithology model and initial hydrostratigraphic model.

For detailed description of the three inversion schemes, see Appendix 3.

4.1.2.2 Depth of Investigation

The resistivity models resulting from each inversion were used to calculate the depth of investigation (DOI). The DOI is dependent upon the geology, water quality and data quality: areas with thick conductive clays and saline water will typically have a shallower DOI than sands and fresh water. The DOI gives an indication of the depth to which a resistivity-depth model can be considered reliable, and below which there is an elevated uncertainty. Since the AEM method is a diffusive method, it is not possible to define an exact DOI, below which there is no useful information on the resistivity structure. Thus, resistivity information below the DOI still may be useful, but interpretation of resistivity values below the DOI is cautioned. In this study, the DOI was calculated using sensitivity information output from the inversion, following the approach presented by Christiansen et al. (2012). More information about the DOI can be found in Appendix 3. The resulting DOI varies throughout the survey area; a histogram of all DOI values can be seen in Figure 4-1. In the central part of the survey area, the DOI is typically 200 to 350 m (650 to 1,150 ft), while along the east side of the survey area in the foothills of the Sierra Nevada, it is typically much lower, between 50 and 150 m (150 to 500 ft).

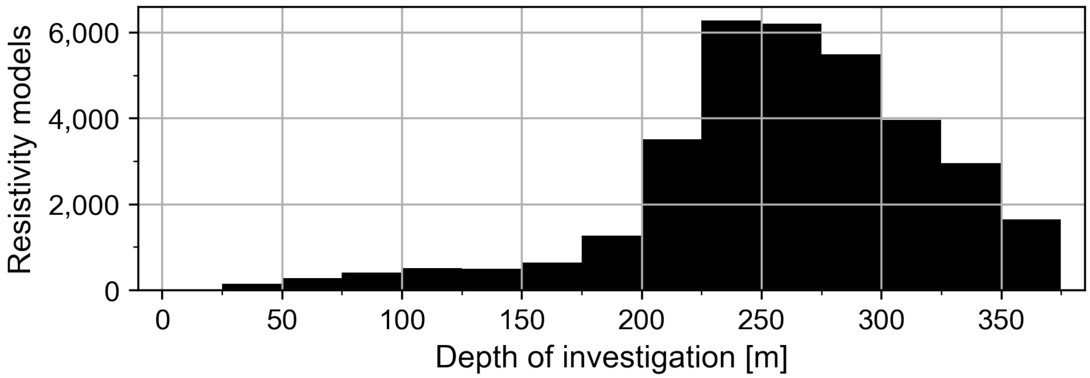

Figure 4-1 Depth of investigation histogram for all resistivity models in the smooth inversion. Most resistivity models have a DOI between 200 and 350 m (656 and 1,148 ft).

4.1.2.3 Inversion Uncertainty Analysis

The acquired AEM data is affected by environmental noise, both natural and anthropogenic, which is presented as the standard deviation, or error bars, on the data. The uncertainty in the raw AEM data propagates through the inversion to the parameters of the output resistivity models. In the case of the smooth and sharp inversions, the parameters with associated uncertainty are resistivity values for all layers of the model. The few-layer inversion, which allows the thickness of each layer to vary, has two additional parameters with associated uncertainty: the layer thickness and depth to the bottom of each layer.

For the employed inversion approaches, the model parameter uncertainties are estimated based on the *a posteriori* model covariance matrix and presented as normalized standard deviation factors (STDFs). The STDFs are classified in different intervals, ranging from very well determined parameters (low STDFs) to undetermined parameters (high STDFs). For details about the calculation of the model parameter uncertainties and how to read the uncertainty sections, see Appendix 3. The uncertainty analysis sections for the few-layer model, corresponding with the resistivity sections, are presented in Appendix 3, Section 8.3. The uncertainty analyses for the smooth and sharp models are provided as tables and databases described in Appendix 11.

4.2 Selected Results

The resistivity models resulting from the inversion of AEM data can be presented as vertical sections or as plan-view maps. In this section, selected results of each are illustrated.

A color scale was developed to illustrate the resistivity models as vertical sections and plan-view maps. On each resistivity color scale, cool colors (blues, greens) represent lower resistivity values, while warm colors (reds, purples) represent higher resistivity values. For the resistivity models in this survey, an interval of 3-300 ohm-m was used to illustrate structural variations across the survey area. The color scale is shown in Figure 4-2 through Figure 4-10.

The entire set of vertical sections are presented in Appendix 6 and Appendix 7: Appendix 6 presents the results of the smooth inversion, and Appendix 7 presents the results of the sharp inversion, few-layer inversion, and the uncertainty analysis. In this section as well as in the appendices, the data displayed in the vertical sections are projected onto vertical planes, the location of which is defined by a profile line. These profile lines are based on the planned flight lines to keep each profile with as few turns as possible. Each profile is up to 17 km (10.6 mi), and a 1 km (0.6 mi) overlap is applied to adjacent profiles along the same flight line.

The entire set of plan-view resistivity maps are shown in Appendix 10. In this section, as well as in Appendix 10, the plan-view maps display horizontal "slices", where each slice is the average resistivity over a vertical interval, defined by either depth or elevation.

4.2.1 Vertical Resistivity Sections

In this section, four vertical model-sections (Figure 4-2 through Figure 4-5) across the surveyed area are provided to illustrate the geographical variations with a focus on how the generated resistivity models compare to well lithology logs, geophysical logs (e-logs), and water levels. Detailed geologic structures are evident along the sections. In addition, an example of model uncertainties calculated for a specific flight section is illustrated in Figure 4-6.

4.2.1.1 Section 201600, Distance Interval 0-17 km

Figure 4-2 shows a section spanning 17 km (10.6 mi) in the Merced subbasin. Several lithology logs, water level and water quality measurements, and one geophysical resistivity log can be seen along the section. Throughout the bottom of the section, a low-resistivity layer is present, while in the top half of the section, a transition can be seen from layered higher resistivity structure on the left to a layered structure of lower resistivity on the right. The borehole lithology data similarly show more coarse sediment on the left side of the section than on the right.

4.2.1.2 Section 201700, Distance Interval 0-17 km

Figure 4-3 shows a 17 km (10.6 mi) long section intersecting the Merced subbasin, southwest of Atwater. Approximately 3 km east of Section 201600 (Figure 4-2), this section shows a similarly layered system on the right side of the section; here, however, the higher resistivity layers near the ground surface and at approximately -50 m elevation take on notably higher resistivity values (yellows, oranges) than do the same layers in Figure 4-2 (greens, yellows), indicating a gradual change in the electrical properties of the subsurface.

4.2.1.3 Section 201900, Distance Interval 16-33 km

Figure 4-4 shows a section, 17 km (10.6 mi) long, crossing the Merced and Chowchilla Groundwater Subbasins, showing predominantly lower (blues) resistivity values dipping gently toward the southeast. Multiple geophysical resistivity logs can be seen along the profile with excellent correlation with the resistivity values derived by AEM data.

4.2.1.4 Section 202100, Distance Interval 16-33 km

Figure 4-5 shows a 17 km (10.6 mi) long section in the Turlock Groundwater Subbasin, where, through most of the section, a thin, high resistivity (red) layer, followed by a region of higher resistivity (yellow, orange). At the bottom of the left side of the section, a transition can be seen to lower resistivity values with depth, reflected by the deep borehole resistivity log.

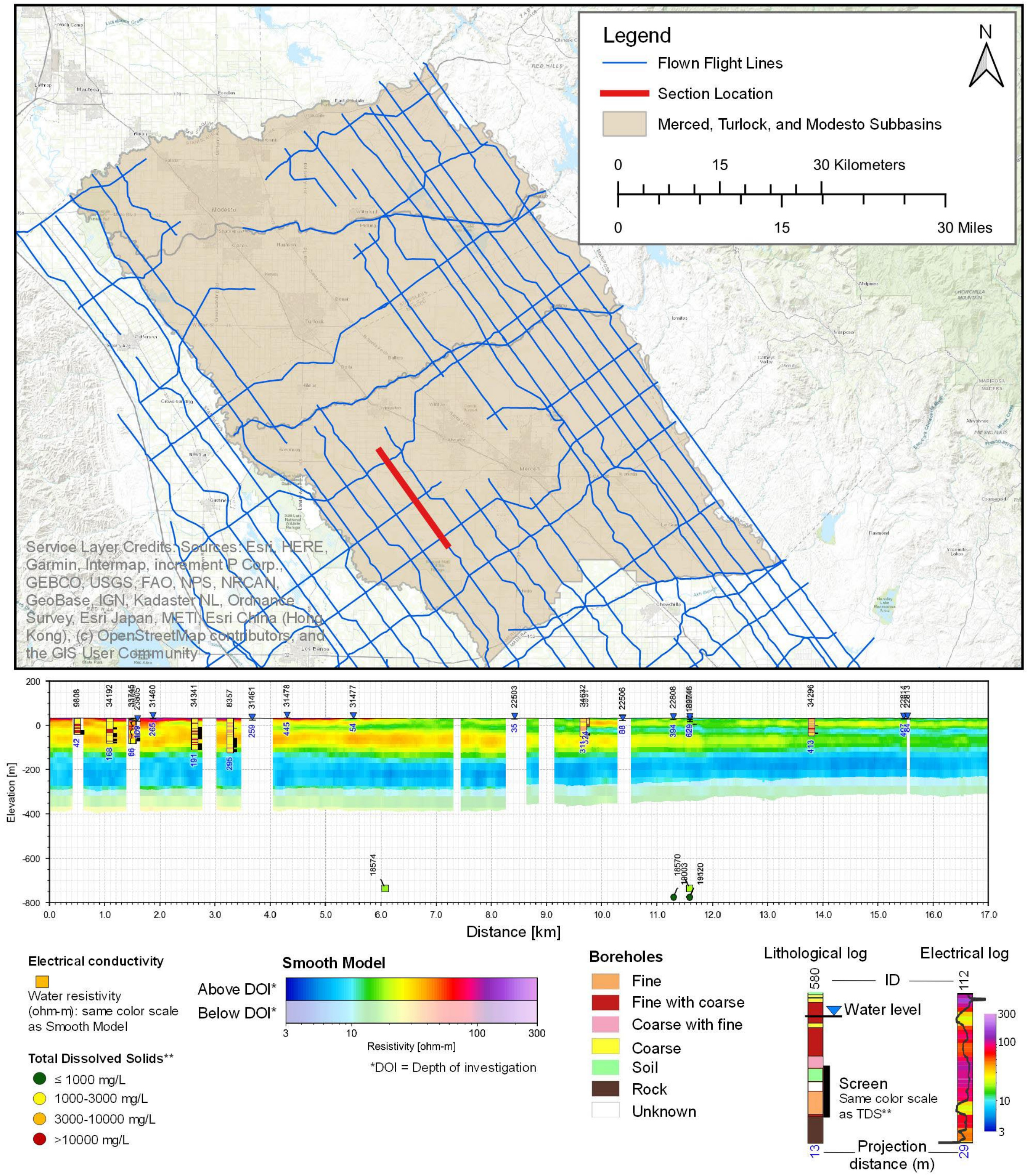

Figure 4-2 Resistivity along Section 201600, distance interval 0-17 km. The location of the section is shown as the red line in the top panel, while the vertical resistivity section from north to south is shown in the bottom panel. Faded colors near the bottom of the cross-section represent resistivity values below the DOI. Lithology data (colored rectangles) and water level measurements (blue triangles) measured from nearby boreholes are projected onto the section, with the well IDs shown above and the projection distance shown below the borehole.

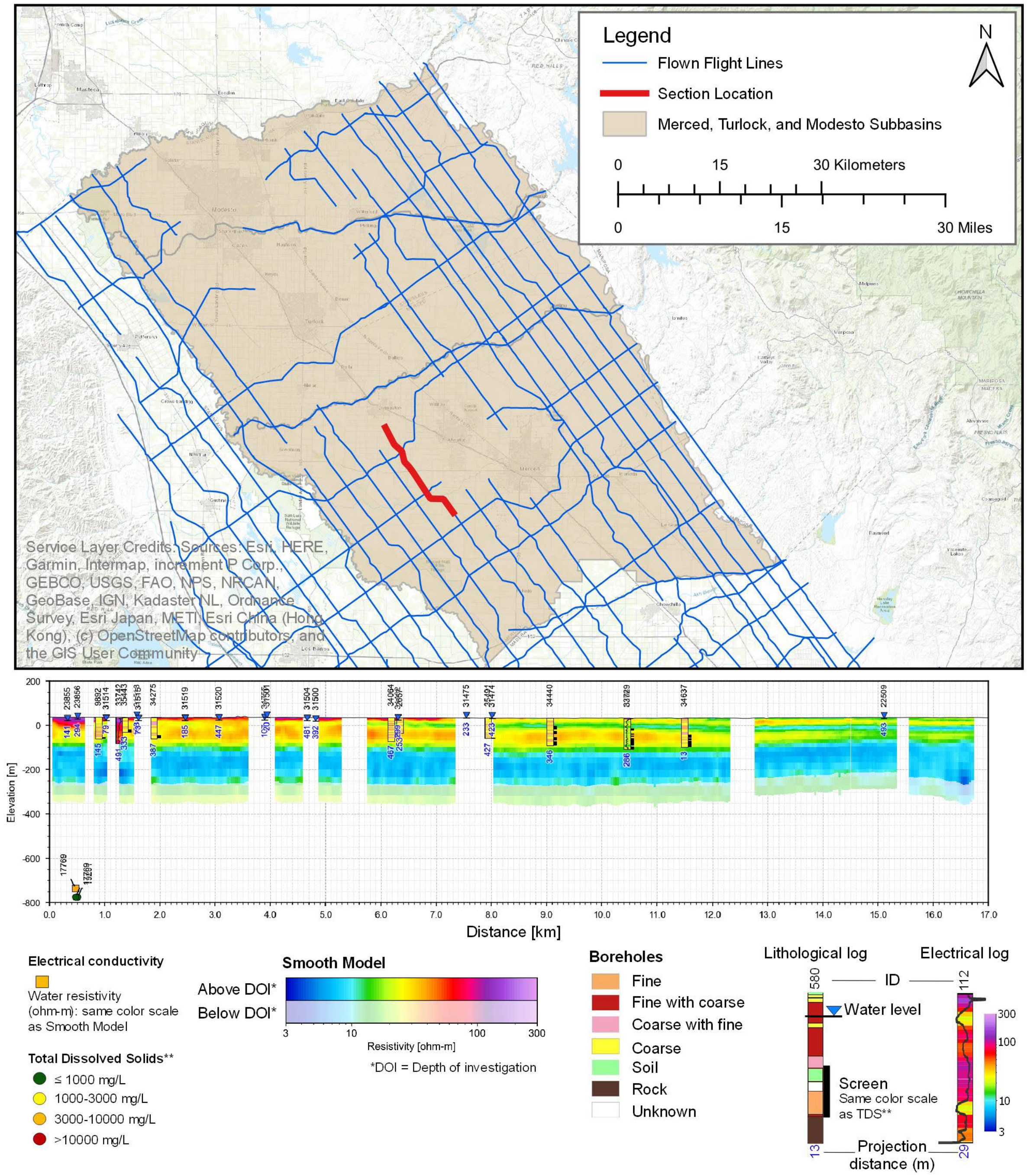

Figure 4-3 Resistivity along Section 201700, distance interval 0-17 km. The location of the section is shown as the red line in the top panel, while the vertical resistivity section from north to south is shown in the bottom panel. Faded colors near the bottom of the cross-section represent resistivity values below the DOI. Lithology data (colored rectangles) and water level measurements (blue triangles) measured from nearby boreholes are projected onto the section, with the well IDs shown above and the projection distance shown below the borehole.

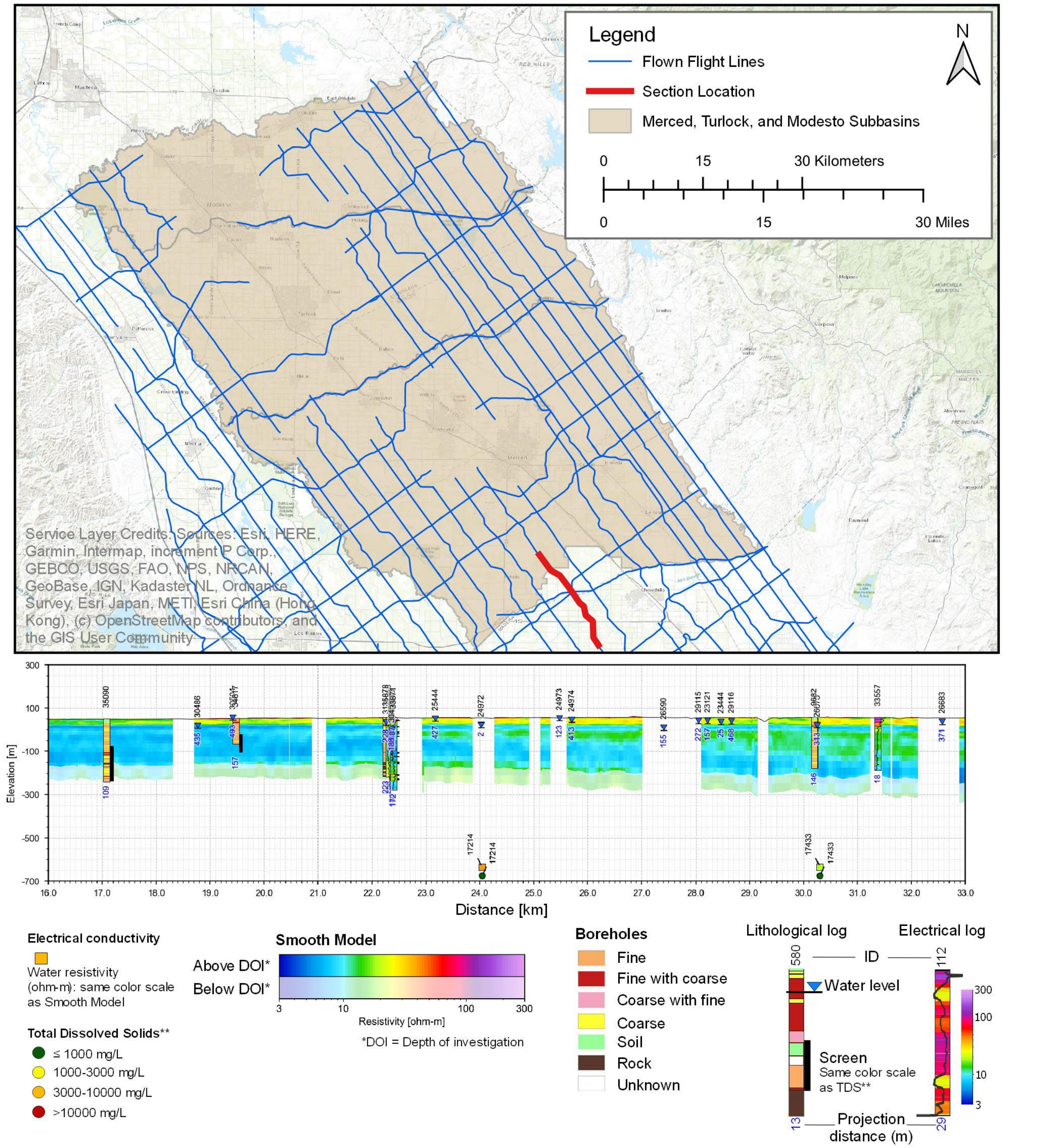

Figure 4-4 Resistivity along Section 201900, distance interval 16-33 km. The location of the section is shown as the red line in the top panel, while the vertical resistivity section from north to south is shown in the bottom panel. Faded colors near the bottom of the cross-section represent resistivity values below the DOI. Lithology data (colored rectangles) and water level measurements (blue triangles) measured from nearby boreholes are projected onto the section, with the well IDs shown above and the projection distance shown below the borehole.

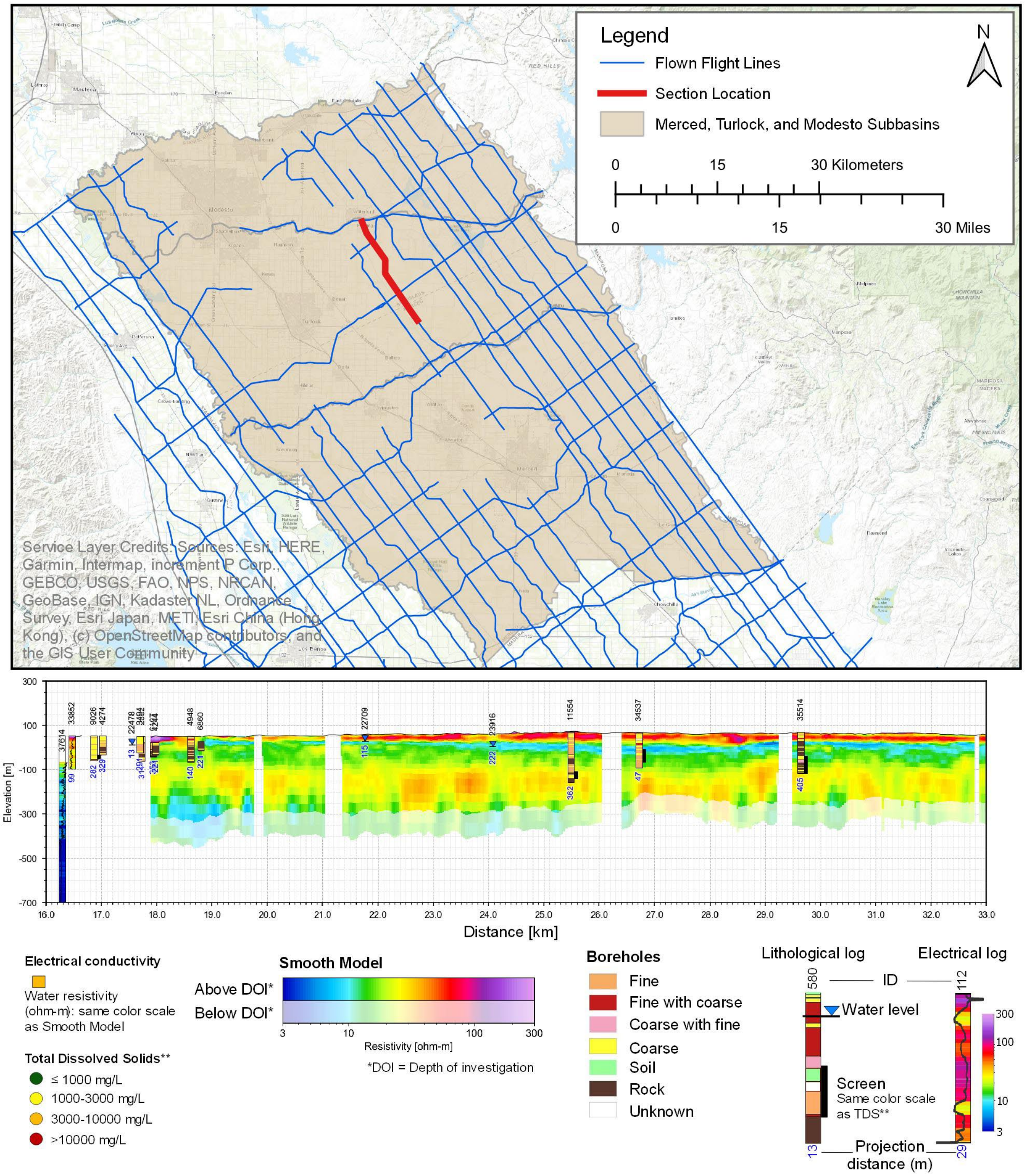

Figure 4-5 Resistivity along Section 202100, distance interval 16-33 km. The location of the section is shown as the red line in the top panel, while the vertical resistivity section from north to south shown in the bottom panel. Faded colors near the bottom of the cross-section represent resistivity values below the DOI. Lithology data (colored rectangles) and water level measurements (blue triangles) measured from nearby boreholes are projected onto the section, with the well IDs shown above and the projection distance shown below the borehole.

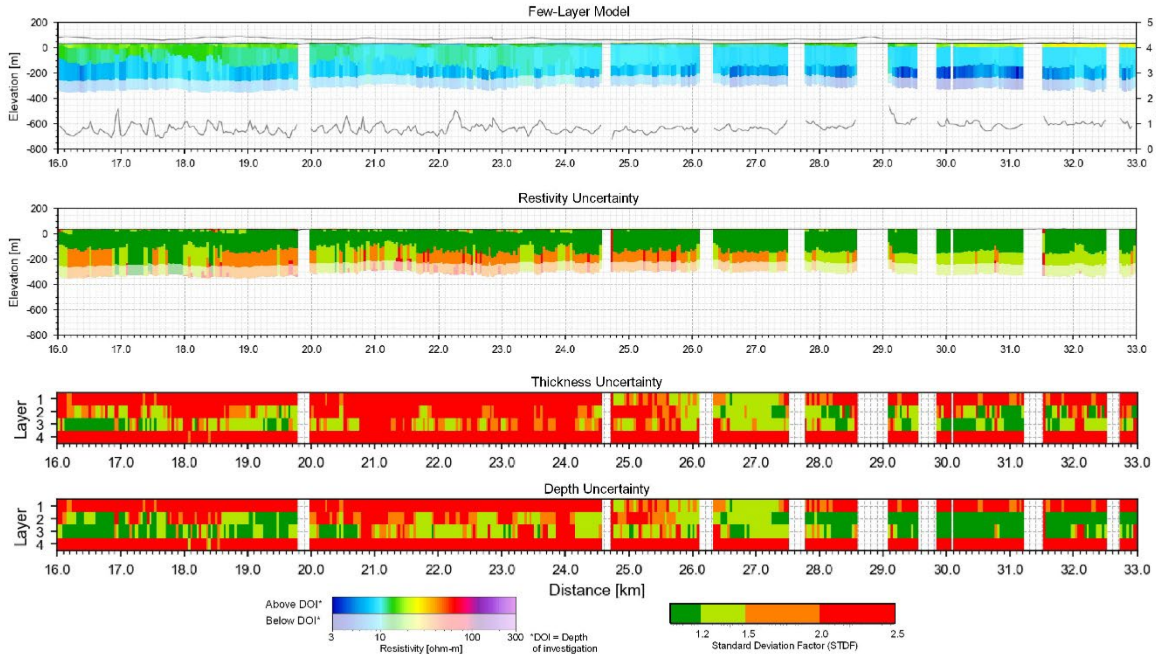

Figure 4-6 Few-layer model and associated uncertainty along Section 201600, distance interval 16-33 km. The top panel shows the few-layer resistivity model used for sensitivity analysis of the model parameters. Uncertainty for the resistivity of each layer is shown in panel 2. Uncertainty for the thickness of the top three layers is shown in panel 3, and the uncertainty for the depth to the bottom of the top three layers is shown in panel 4.

4.2.2 Mean Resistivity Plan-View Maps

Four representative plan-view maps of horizontal slices along the flight lines are displayed at different depth and elevation intervals in Figure 4-7 through Figure 4-10. These maps illustrate detailed structures and provide insight into variations across the surveyed area at each interval.

Figure 4-7 illustrates the mean resistivity over the depth interval 0-5 m (0-16 ft) below ground surface. Within this shallow depth interval, resistivity values vary over short lateral distance; however, regional trends can also be identified: higher resistivity values are present in the central part and eastern edge of the study area, while lower resistivity values can be found in the south and west.

Figure 4-8 shows the mean resistivity in the depth interval 30-60 m (100-200 ft) below ground surface. At this depth interval, most resistivity values have shifted lower in comparison to those shown in Figure 4-7, with the exception of the eastern edge of the study area, along the foothills.

Figure 4-9 shows the mean resistivity values in the elevation interval 0 to -20 m (0 to -65 ft) above mean sea level (amsl). At this elevation, the spatial distribution of resistivity values is similar to that of Figure 4-8, as that depth interval is similar to the 0 to -20 m elevation within the floor of the Central Valley. Differences emerge along the eastern edge of the study area, where, at this elevation interval, the subsurface is more conductive than shown Figure 4-8.

Figure 4-10 shows the mean resistivity in the elevation interval -80 m to -100 m (-260 to -330 ft) amsl. Within this elevation interval, resistivity values have shifted lower in comparison to those shown in Figure 4-9.

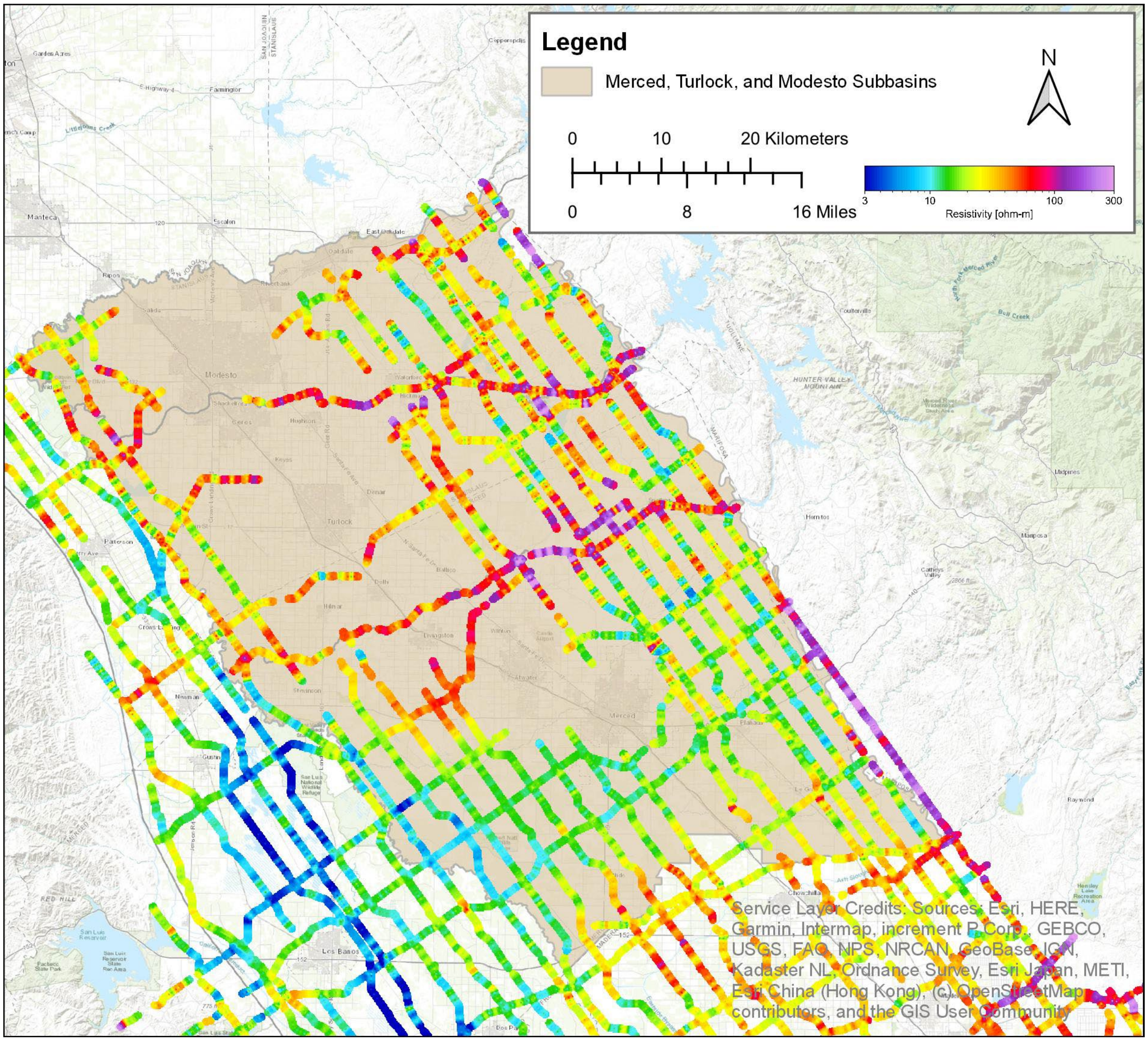

Figure 4-7 Mean resistivity plan-view map in the depth interval 0-5 m (0-16 ft) bgs. The colors represent the resistivity, with blue colors representing the lower resistivities, below 10 ohm-m, the yellow and green colors representing the moderate resistivities (between 10 and 50 ohm-m), the orange and red colors representing the higher resistivities (over 50 ohm-m), and purples representing the highest resistivities (above 100 ohm-m).

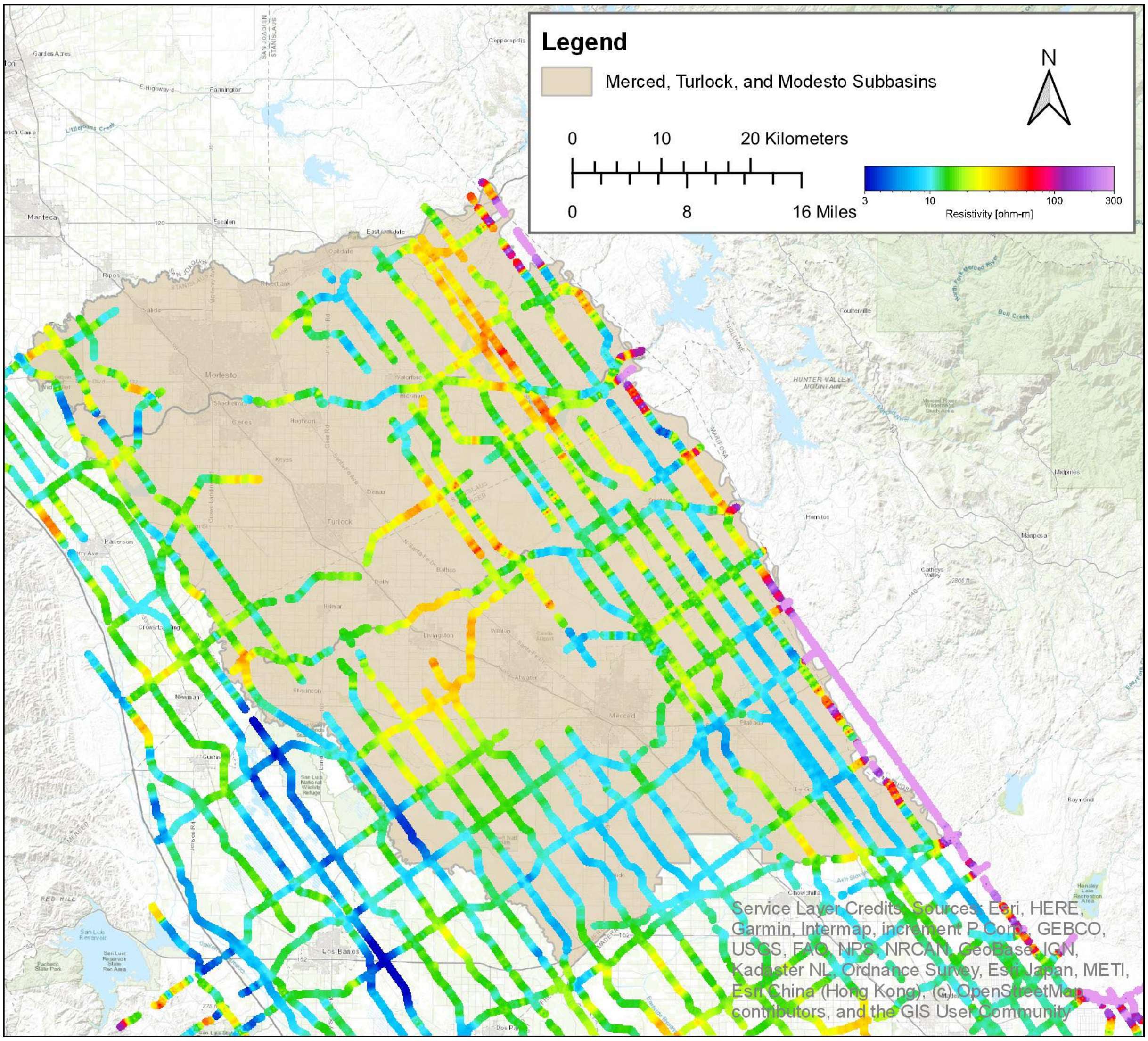

Figure 4-8 Mean resistivity plan-view map in the depth interval 30-60 m (100-200 ft) bgs. The colors represent the resistivity, with blue colors representing the lower resistivities, below 10 ohm-m, the yellow and green colors representing the moderate resistivities (between 10 and 50 ohm-m), the orange and red colors representing the higher resistivities (over 50 ohm-m), and purples representing the highest resistivities (above 100 ohm-m).

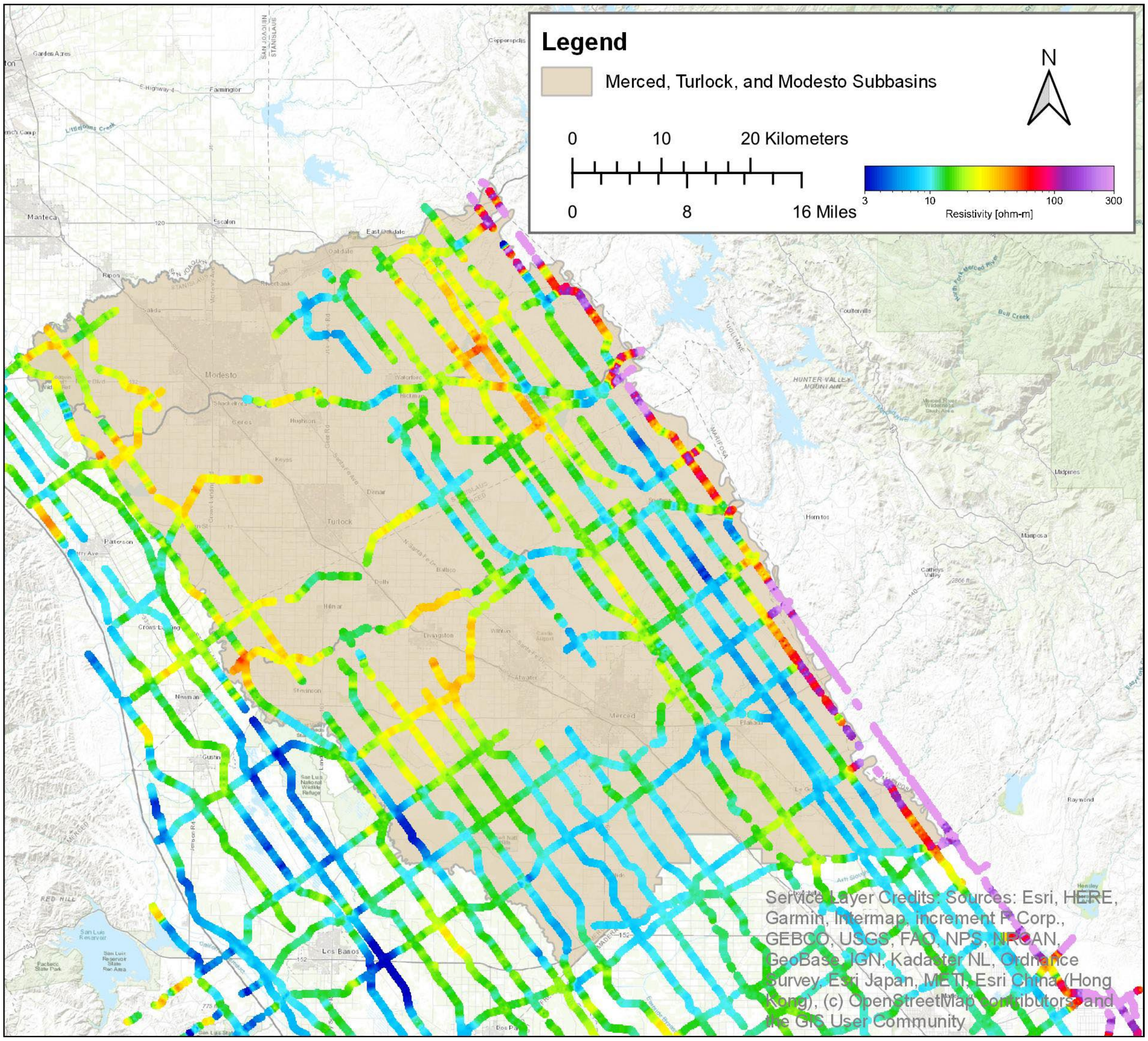

Figure 4-9 Mean resistivity plan-view map in the elevation interval 0 to -20 m (0 to -65 ft) amsl. The colors represent the resistivity, with blue colors representing the lower resistivities, below 10 ohm-m, the yellow and green colors representing the moderate resistivities (between 10 and 50 ohm-m), the orange and red colors representing the higher resistivities (over 50 ohm-m), and purples representing the highest resistivities (above 100 ohm-m).

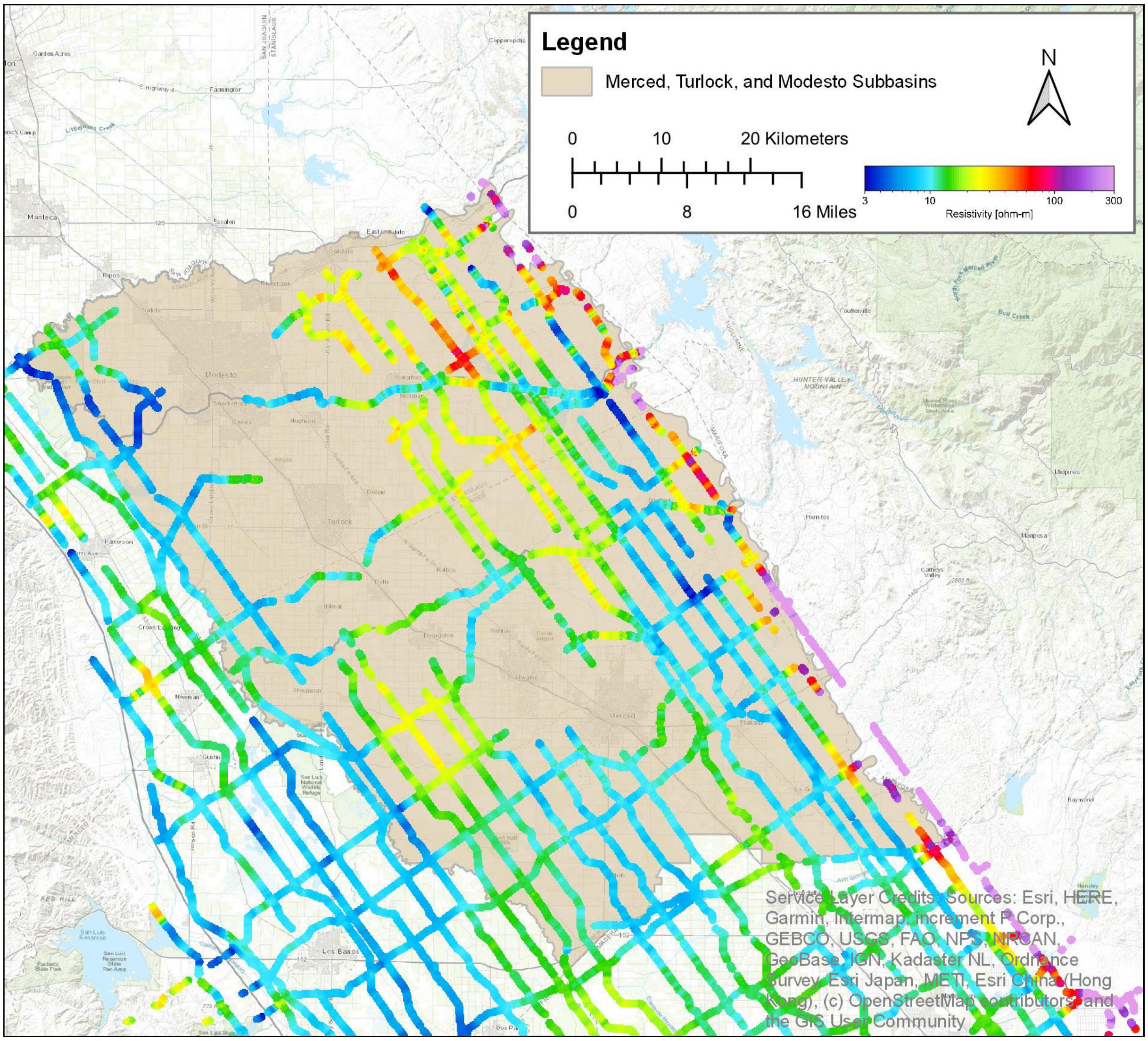

Figure 4-10 Mean resistivity plan-view map in the elevation interval -80 m to -100 m (-260 to -330 ft) amsl. The colors represent the resistivity, with blue colors representing the lower resistivities, below 10 ohm-m, the yellow and green colors representing the moderate resistivities (between 10 and 50 ohm-m), the orange and red colors representing the higher resistivities (over 50 ohm-m), and purples representing the highest resistivities (above 100 ohm-m).

5. LITHOLOGY MODEL

Lithology Transform and Interpretation Disclaimer
This report provides a resistivity-to-lithology transform and applies it to interpret the AEM resistivity data for lithology. The lithology transform and interpretation are based on available existing supporting data and are designed for informational purposes only. These resources are not intended for regulatory purposes as part of the Sustainable Groundwater Management Act. The Department of Water Resources makes no warranties, representations or guarantees, either expressed or implied, as to the accuracy, completeness, correctness, or timeliness of the information that is presented in the lithology transform and lithology interpretations provided in this report, nor accepts or assumes any liability arising from use of this report or underlying data.

5.1 Introduction

The resistivity values estimated using the AEM method provide value for groundwater management because of the relationship between electrical resistivity and subsurface properties of interest. This includes the degree of saturation, groundwater salinity, and lithology. Generally, resistivity will decrease with an increase in fine sediment, salinity, and saturation. The relationship between resistivity values, lithology, and salinity can be seen in Figure 5-1, where the resistivity range corresponding to gravel and sand is higher than that of glacial tills and higher still than that of clays. Similarly, saltwater has a much lower resistivity than does freshwater. Consolidated rocks such as granite will typically have very high resistivities. Shales, on the other hand, can take on a wide range of resistivity values.

The wide range of resistivity values spanned by each bar in Figure 5-1 (most spanning over an order of magnitude) underscores the variable and site-specific nature of the relationship between resistivity and earth materials. Locally variable conditions can cause coarse sediments to have higher resistivity in some areas than in others, and mixtures of sediments (e.g., glacial till) result in resistivity values between those of coarse and fine.

The sharp resistivity model from the data processing and inversion (Section 4.1.2.1) was used for developing the resistivity-to-lithology transform, since the model prefers to keep resistivity values relatively consistent but can also accommodate lateral and horizontal variations. The sharp inversion model has 30 layers, with the first layer thickness of 2 m (7 ft), with the layers gradually increasing with depth to 600 meters (1,970 ft). However, the lower boundary in the resistivity-to-lithology transform was set as the first layer boundary above the DOI (Section 4.1.2.2).

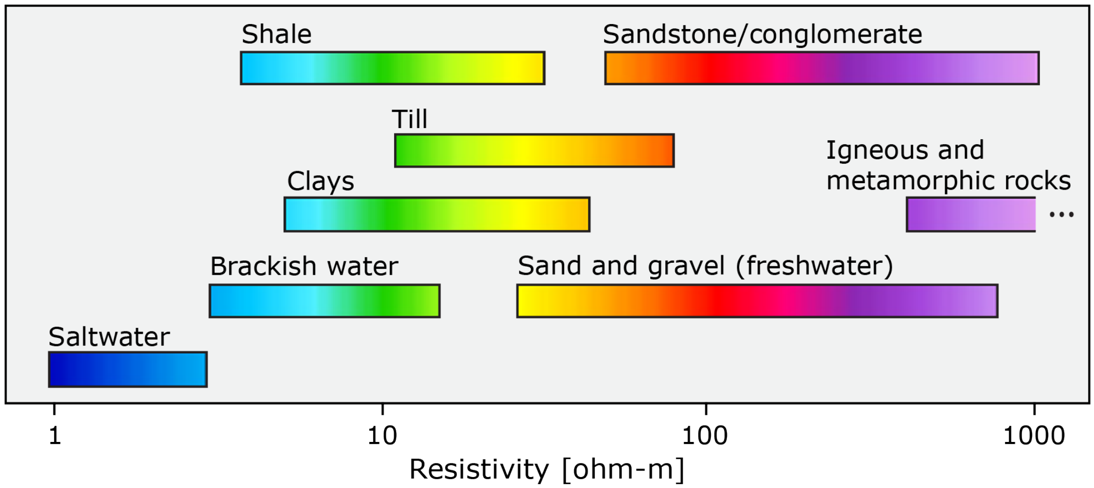

Figure 5-1 Typical relationship between resistivity, lithology, and salinity (after Palacky, 1987).

Establishing a transform to predict lithology from resistivity is a challenging task, because (1) in addition to lithology, the resistivity measurement also depends on other subsurface properties (water saturation and water quality), (2) the relationship between resistivity and lithology varies spatially and 3) the transform does not apply to certain geologic variations such as consolidated rocks. One or more of these conditions are typically found across groundwater basins in California and therefore a successful transform should address these dependencies.

The Accumulated Clay Thickness method is specifically developed for translating resistivity models in large AEM datasets—such as those acquired in this project—into models of the fractional thickness of clay sediment (Foged et al. 2014). The resulting clay fraction models can be used to better understand the spatial distribution of coarse and fine sediment and can be an integral data component to support the development of a hydrostratigraphic or groundwater flow model. In this approach, we focus on coarse sediments, and thus ACT refers to Accumulated Coarse Thickness, which is the complement of Accumulated Clay Thickness.

To predict the lithology using the resistivity models, a 3D grid of translator functions was applied. The ACT method has the advantageous property that the resistivity-lithology relationship is not represented by just one “global” translator function. Rather, the translator functions in the grid can vary spatially, calibrated from nearby well lithology data, allowing the resistivity-to-lithology to implicitly account for changes in resistivity due to changes in salinity and saturation, as well as to regional variability in the resistivity-lithology relationship. This section provides a summary of the methods and results of the resistivity-to-lithology transform. A detailed description of the theory, methods and results from the lithology transform are presented in Appendix 4. The resistivity-to-lithology transform results and uncertainty for each line is shown on the profiles presented in Appendix 8.

The resistivity-to-lithology transform was conducted for the entire Survey Area 5, which in addition to Merced, Turlock, and Modesto Groundwater Subbasins, also includes Kings, Madera and Chowchilla, Westside, Pleasant Valley and Delta-Mendota Groundwater Subbasins. These were conducted together to maximize the data available for the resistivity-to-lithology transform.

5.2 Resistivity-to-Lithology Transform Methodology

The resistivity-to-lithology transform used in the Merced, Turlock, and Modesto Groundwater Subbasins follows a modified workflow based on a methodology specifically developed for large AEM datasets (see Foged et al., 2014), using Aarhus Workbench Hydro Structural Modeling module. The resistivity models produced from inversion (Section 4) are used along with well completion report lithology log data (Section 2) to optimize a set of translator functions, each of which can map the resistivity of a depth interval (ACT layer) to the amount of coarse material, quantified as the coarse fraction (CF) within the same layer.

The workflow used to develop the lithology models is followed for each basin/subbasin separately, allowing for adaptation of the conditions addressed in the previous section. The process is as follows:

1. Prepare the data needed for lithologic modeling and evaluate whether the employed methodology is appropriate for the given basin/subbasin.
2. If the methodology is appropriate, establish the resistivity-to-lithology transform.
3. If the methodology is deemed not to be appropriate, implement a manually defined resistivity-lithology transform.
4. Evaluate the transform results.

First, the hydrogeologic setting of the surveyed area was assessed to obtain a general understanding of the different geological units. If necessary, the surveyed area was split into separate lithology modeling areas. In the Merced, Turlock, and Modesto Groundwater Subbasins, one lithology modeling area was established, as it was not part of the low-resistivity area in the southwestern third of the survey area (see Figure 5-2).

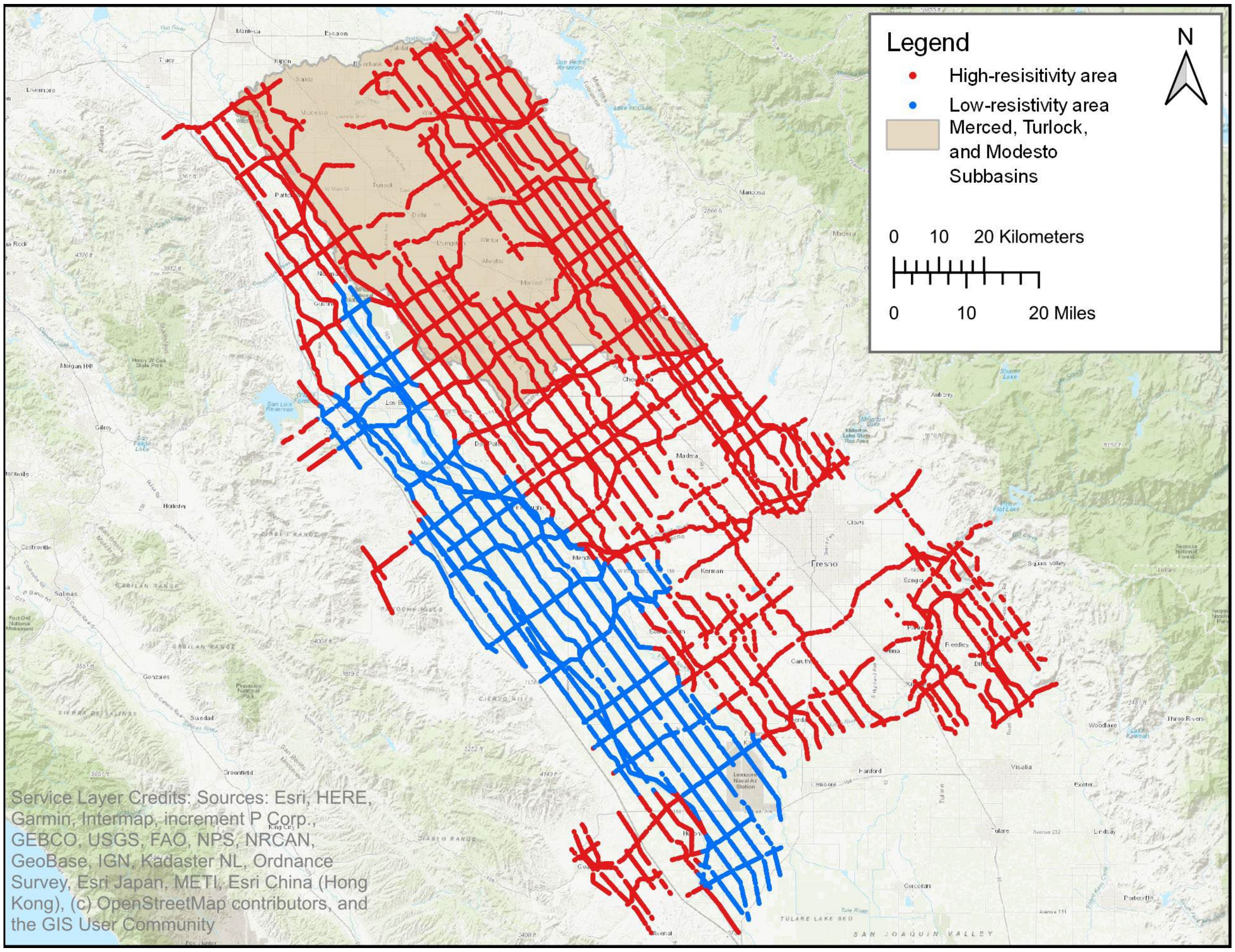

Figure 5-2 Division of the high-resistivity area and the low-resistivity area, where the ACT modeling was conducted. The map shows the entire Survey Area 5 for which the ACT modeling was conducted.

Within each lithology modeling area, further analysis was restricted to regions where the transform modeling is valid. Specific cases that can affect the transform results and the approaches to handle those regions in the analysis are discussed in Section 5.4. Next, a correlation analysis was performed to evaluate the resistivity-lithology relationship within the lithology modeling area. This was done by analyzing the histograms of resistivity for each lithologic unit.

Texture descriptions from lithology logs within 800 m (2,600 ft) of the flown flight lines were used in the analysis. The resistivity data were projected to the actual well log location and both the AEM resistivity models and lithology logs were re-discretized to common transform layers. The texture description from each depth interval from each lithology log was aggregated into either “fine” or “coarse”, where fine corresponds to a CF of 0, and coarse corresponds to a CF of 1. Fine materials were considered to include clay and silt sediments (lower permeability), while coarse materials were considered to include sand and gravel (higher permeability). As an intermediary step, the lithology log descriptions were first simplified to four texture categories: fine, fine with coarse, coarse with fine, and coarse.

Next, initial settings were established with the lateral spacing between nodes in the grid of translator functions set at 10,000 m (32,800 ft) to accommodate the relatively sparse lateral coverage of the AEM data (approximately 3 km spacing. The vertical spacing was set to 5 m for the first three layers, followed by 6 m for four layers, after which the vertical spacing was set to follow the vertical spacing of the resistivity model. In addition, the lower boundary in the resistivity-to-lithology transform was set as the first layer boundary above DOI (Section 4.1.2.2).

After establishing the initial ACT settings, the volume of available lithology data within the 3D grid was analyzed to assess whether sufficient data exist for transform modeling. If so, the ACT numerical optimization was performed, and the results were evaluated and visualized.

If no correlation was found between lithology and resistivity for a basin or if the volume of available lithology data was insufficient, selected well data were manually compared to nearby resistivity values to determine a relationship between resistivity and lithology. In this case, the translator function parameters would be manually determined, and a uniform translator function would be applied throughout the 3D grid. Finally, if a relationship could not be manually established, transforming resistivity to lithology was determined not to be applicable since additional or refined well data are required.

During the resistivity-to-lithology transform, each translator function in the grid is optimized using nearby resistivity models from the survey area and the simplified texture description from nearby lithology logs. Each translator function has the form of the function in Figure 5-3. Nearby resistivity values are input into each translator function to predict the CF. Predicted CF values are compared to the simplified texture values from nearby lithology logs, and the translator function is adjusted through an automated process to minimize the difference between the CF in the lithology logs and the predicted CF from the translator function. The translator function provides a lower resistivity limit m_{lower}, where all layers with a resistivity lower than this limit will contain only fine sediments, and an upper resistivity limit, m_{upper}, where all layers with a resistivity higher than this limit will contain no fine sediments.

Along each of the flight lines in this project, simplified texture descriptions from nearby lithology logs were compared to the sharp resistivity model.

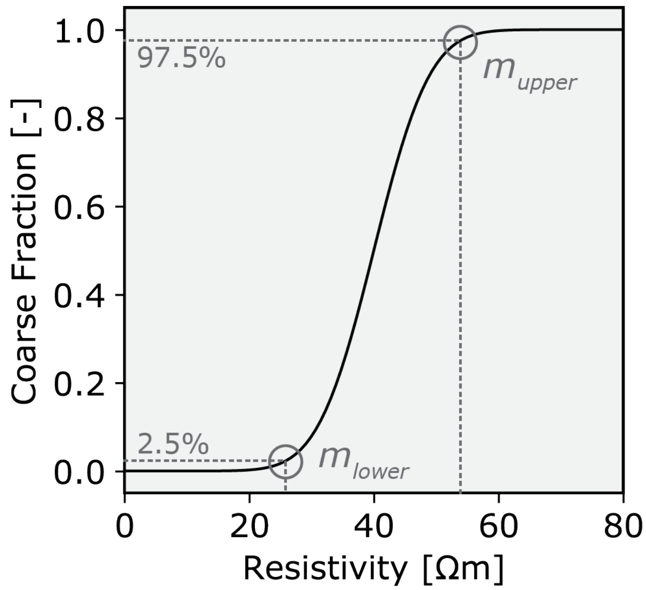

Figure 5-3 An example of a single fraction translator function (after Foged et al., 2014) in the 3D grid. The coarse fraction (CF) ranges from 0 (minimal coarse material) to 1 (coarse dominated). The value m_{lower} represents the lower value where all resistivities below this value represent layers containing only clay, and m_{upper} represents the upper value, where all resistivities higher than this value represents layers containing no clay. In this example, the lower limit is at 25 ohm-m and the upper limit is at 55 ohm-m.

The final step is to calculate the coarse fraction model uncertainty. The uncertainty is based on the uncertainty of the AEM model resistivity related to the transfer function for the specific layer. In other words, the range in resistivity is used for calculating a range in coarse fraction from the specific translator function. This is then converted to a standard deviation factor for the coarse fraction, typically between 1.0 and 1.3, where 1.0 is the most certain with uncertainty increasing as the standard deviation factor increases.

5.3 Transform Results

Figure 5-4 contains a selected profile along a flight line in Merced, Turlock, and Modesto Groundwater subbasin, which shows the lithology model resulting from the resistivity-to-lithology transform in the upper cross-section, and the uncertainty index associated with the lithology model in the lower cross-section. Regions identified as consolidated rock are masked with a hatching pattern. The depth below which no resistivity-lithology pairs were available within the inversion cell is shown as a dashed line through the cross-sections. The lithology models for all flown sections are presented in Appendix 8.

The initial results from the lithology model illustrate the viability in utilizing this approach applied to AEM data in the Merced, Turlock, and Modesto Groundwater Subbasins. Since the survey is at reconnaissance level with a wide flight line spacing, the results of the resistivity-to-lithology transform can only be applied directly along the flight lines; areas where no AEM data were acquired are unknown.

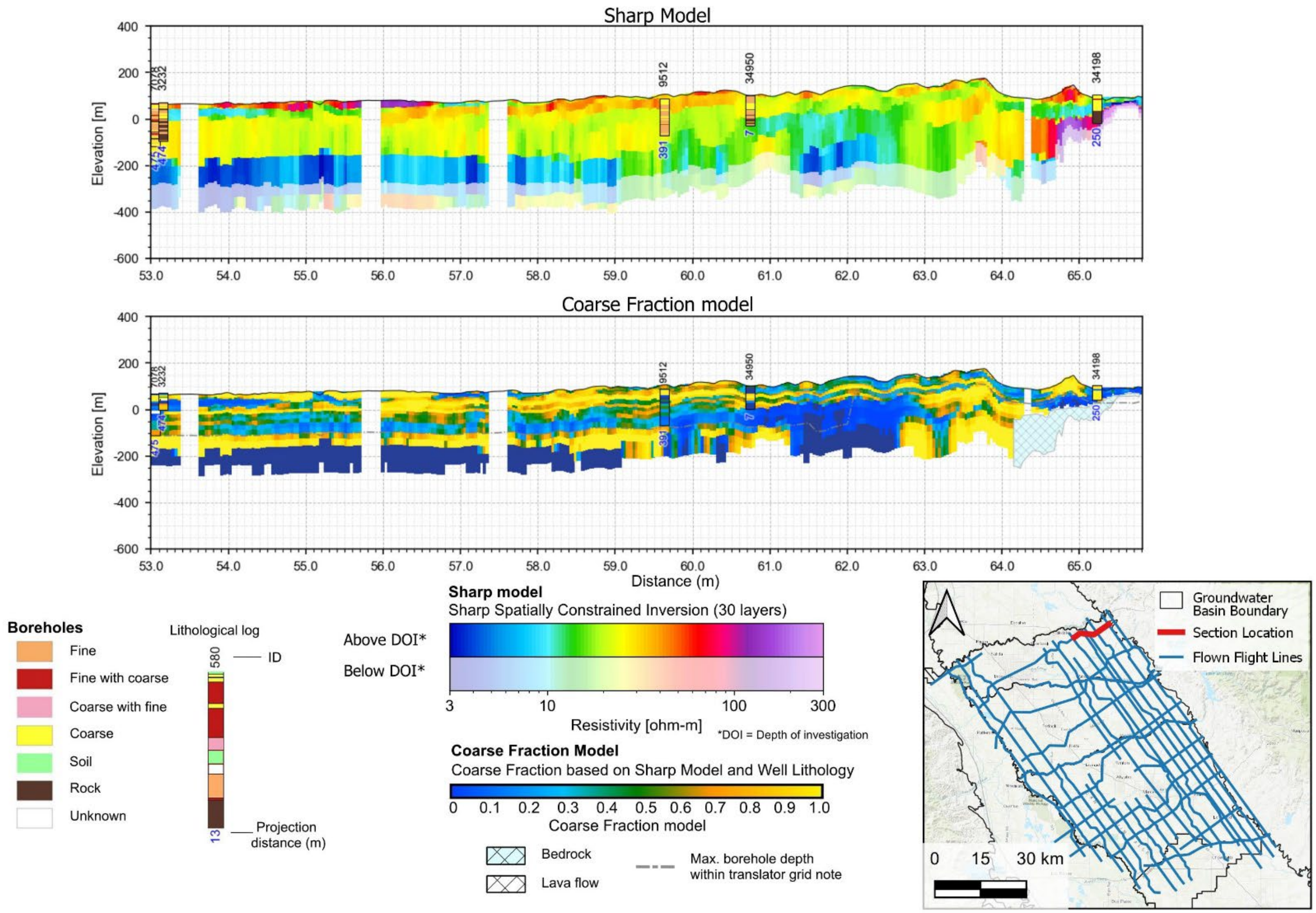

Figure 5-4 Lithology model resulting from the resistivity-to-lithology transform along Profile 290200 In Merced, Turlock, and Modesto Groundwater Subbasins. The top cross-section shows the sharp model resistivity. The bottom cross-section shows the calculated coarse fraction, where the yellow colors show the sediments/materials with high coarse content (scale value 1.0) transitioning to the dark blue colors showing sediments with the highest clay content (scale value 0.0). The areas with bedrock and lava flows are cross-hatched on the Coarse Fraction Model profile. The vertical columns show the accumulated coarse thickness as calculated in the individual lithology logs. The red line on the map shows the location of the profile.

5.4 Specific Cases Affecting Resistivity

Specific cases that can affect resistivity measurements beyond the lithology include, but are not limited to, the degree of sediment saturation, presence of saline water, and the degree of consolidation (rock). These specific cases are discussed below.

5.4.1 Saturated and Unsaturated Sediments

Resistivity is not only influenced by the lithology but also by the water quality and degree of saturation in the subsurface. Unsaturated sediments tend to have a higher resistivity than saturated sediment. This difference in the rock physics relationship between saturated and unsaturated zones can be taken into consideration in the translator function, where a separate translator function is produced for the unsaturated and saturated zone. Separating the unsaturated and saturated zones requires information on the elevation of the water table at the location of each well used in the transform; these data are primarily obtained through water level measurements in unconfined aquifers. In some cases, it is determined that an insufficient density of water level data is available to reliably estimate the water table elevation across the survey area to separate the saturated from the unsaturated sediments in the resistivity-to-lithology transform. However, even without sufficient information on the water table elevation, through use of the 3D grid of translator functions, the resistivity-to-lithology transform is still able to implicitly account for spatial variation in the depth to saturated sediments.

Figure 5-5 shows a schematic of the grid of translator functions above and below the water table. The colored bars representing the resistivity models produced from AEM data have warmer colors (higher resistivity) above the water table shown as a blue line, than below the water table. The nodes of the grid of translator functions, shown as black dots, are separated laterally and vertically by the thickness of each ACT model cell. It is noted that while the translator function nodes are shown on top of the resistivity model cells in this two-dimensional schematic, the nodes of the applied translator grid in 3D did not necessarily intersect a cell in the resistivity model. A translator function (with the shape of the curve in Figure 5-3) is fit to the borehole lithology and resistivity data within each depth interval. Because each translator function is fit separately, a different transform can result above and below the water table.

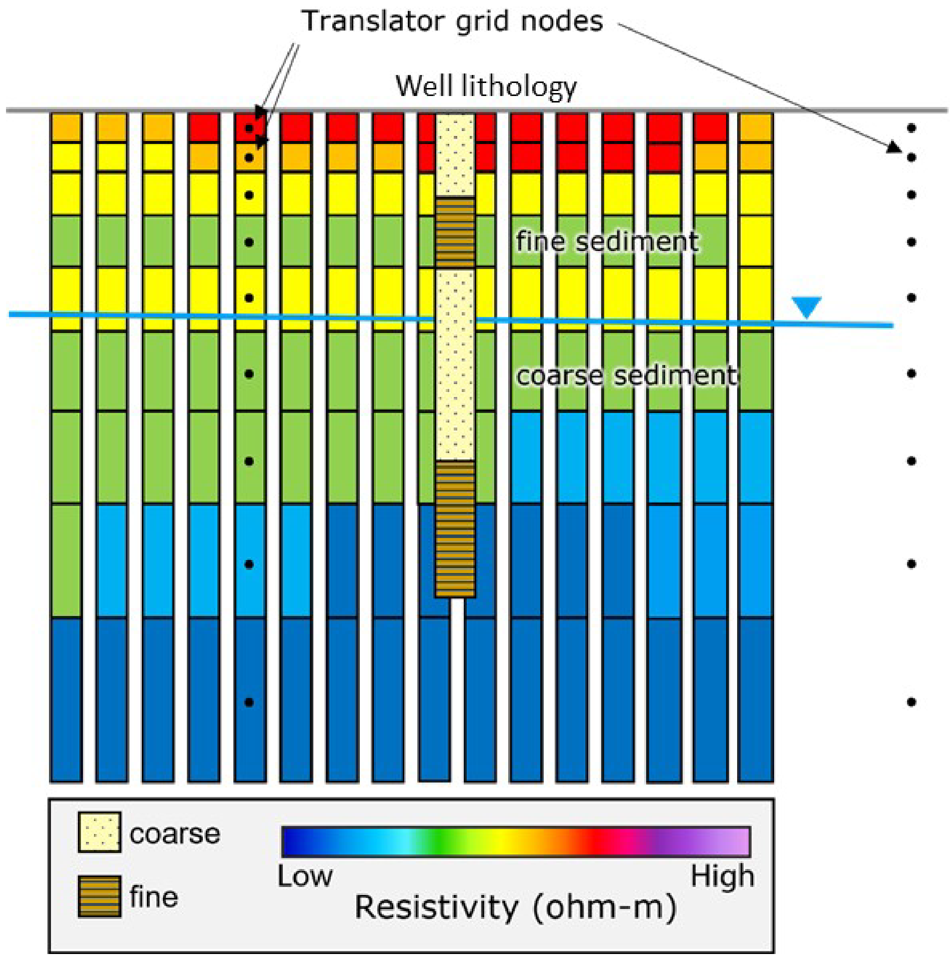

Figure 5-5 Schematic demonstrating the ability of the resistivity-to-lithology transform to implicitly account for the change from unsaturated to saturated sediments. The well shows the simplified lithology from log descriptions.

In the case of Figure 5-5, even if the depth to the water table is unknown, the translator functions above the water table will be fit to the generally higher resistivity values, while those below the water table will be fit to the lower resistivity values. Although the transform can accommodate a small to moderate groundwater gradient in the boundary between unsaturated and saturated sediment, it should be noted that because the grid of translator functions has a large lateral spacing, a steep gradient is expected to cause some smearing in the lithology model resulting from the resistivity-to-lithology transform.

5.4.2 Saline Water

Groundwater salinity can also influence the observed resistivity in the saturated zone. Groundwater with higher TDS values will have lower resistivity. As with the transition from unsaturated to saturated zones, the resistivity-to-lithology transform can implicitly account for variations in salinity, assuming (1) the salinity does not change rapidly over a short lateral distance, (2) the salinity is not very high, and (3) the salinity of the coarser sediment is similar or lower than that of the fine sediment. If the salinity varies rapidly over a short distance, smearing will occur in the translator function in a similar way as when the water table gradient is steep. Once the salinity becomes high (about 3,000 mg/L), differences in the resistivity between coarse and fine materials are damped. Finally, if the salinity of the coarse sediment is higher than that of the fine sediment, the translator function will fail since the function (Figure 5-3) assumes that coarser sediment is more resistive than finer sediment. Coarse sediment may contain more saline water than fine sediment, for example, in areas affected by seawater intrusion, since the water saturating coarse sediments (aquifer) is more readily displaced by intruding seawater than the water saturating fine sediments (aquitard).

In the surveyed area, available TDS measurements screened within the AEM data DOI show an acceptable range in salinity around the flight lines, with TDS not exceeding 3,000 mg/L. Therefore, it was determined that salinity does not have a significant influence on resistivity and subsequently do not affect the inversion process.

5.4.3 Consolidated Rocks

Consolidated rocks (e.g., bedrock) have different hydraulic properties than unconsolidated sediment, often forming a hydraulic barrier within a groundwater basin. The resistivity-to-lithology transform applied in this project was developed for unconsolidated sediments: the translator function considers a spectrum of fine to coarse sediment.

Since many igneous and metamorphic rocks tend to have a high resistivity (Figure 5-1), the resistivity-to-lithology transform will interpret these rocks as coarse sediment (a high CF value). Given their high resistivity, these rocks can often be distinguished from unconsolidated materials in the resistivity models. On the other hand, consolidated sedimentary rocks, including shales and sandstones, take on a wide range of resistivity values that may be similar to those of unconsolidated sediment. The transform will interpret these rocks as either fine or coarse sediment, depending on their resistivity values in comparison to those of nearby unconsolidated sediment. Thus, when analyzing the lithology model resulting from the resistivity-to-lithology transform, it is important to first remove any areas corresponding to consolidated rocks.

In the surveyed area, resistivity values corresponding to consolidated rock were removed from further analysis through inspection of geologic maps, water quality measurements, and the resistivity models produced from inversion.

6. INITIAL HYDROSTRATIGRAPHIC MODEL

6.1 Introduction

The data acquired during an AEM survey can provide valuable information for developing or refining a hydrostratigraphic model of the surveyed area. However, due to the large amounts of data acquired during a typical AEM survey, including this project, manually interpreting the hydrostratigraphic units corresponding to the resistivity or lithology model can be labor intensive.

Here, an automated approach was applied to produce a model consisting of zones of similar properties from a resistivity model and a lithology model. This resulting model could be used to help develop a better understanding of the regional hydrostratigraphy, or as the basis for a numerical groundwater flow model. The approach uses a clustering algorithm, which classifies a set of data points into a predefined number of groups with similar properties. It is a widely used approach for pattern recognition, image processing and analysis of large datasets where grouping is required. Since resistivity is related to the hydrogeologic properties of interest, the clustering approach relies on the assumption that groups defined from resistivity and borehole lithology data also have similar hydrogeologic properties.

There are other approaches, not pursued here, that can provide an automated conversion of AEM data into an interpreted hydrostratigraphic model. These include, for example, the use of multipoint statistics (Gulbrandsen et al, 2021) or the Octree algorithm for 3D voxel modeling (Jorgensen et al, 2013). It is not within the scope of this project to provide a critical review of the different methodologies that can be applied in the interpretation of AEM data to a hydrostratigraphic model. Rather, clustering is presented as an example of an approach that could be used, illustrating the value of AEM data as input to a 3D hydrostratigraphic model. The clustering approach used for this project was chosen for the following reasons:

(1) It provides an automated grouping providing a representation of the hydrostratigraphy
(2) The grouping is data driven, reproducible, and is geographically and depth independent
(3) The process requires only the measured resistivity and lithology log data

This section provides a description of the clustering methodology and the resulting initial hydrostratigraphic model in the Merced, Turlock, and Modesto Groundwater Subbasins. The clustering was conducted for the ACT model for the entire Survey Area 5, including Kings, Madera, Chowchilla, and Westside, Pleasant Valley, Delta-Mendota Groundwater Subbasins, provided in two separate reports.

6.2 Methodology

The clustering modeling methodology, developed by Marker et al. (2015), consists of an algorithm that pairs a lithology model, outlined in Section 4.2.2, with a resistivity model, outlined in Section 4, to produce a defined number of groups, each of which consists of similar resistivity and lithology values. The resistivity value for each cell in the sharp inversion resistivity model is paired with the corresponding lithology model CF value across the entire basin. The result is a set of resistivity-CF pairs that can be visualized as a scatter plot. To aggregate the groups of similar resistivity-lithology value pairs, a clustering algorithm is applied to the pairs, with a predetermined user-defined number of groups, or clusters. The resultant groups then represent points with similar resistivity and lithology and are thus presumed to have similar hydrogeologic properties.

At first glance, combining the CF values with the resistivity values that produced said CF values may seem circular. However, as described in Section 5, the lithology data used in the resistivity-to-lithology transform is simplified as either coarse or fine. This simplification is necessary for the computation-intensive numerical calculations in the ACT transform. However, details in the lithology information are lost in the process, resulting in some details contained within the resistivity model being muted or absent in the lithology model. By adding the resistivity information back into the clustering process, these details can be captured in the resultant initial hydrostratigraphic model.

The process of developing the initial hydrostratigraphic model begins with determining the number of groups, or clusters, to be identified. Determining the number of groups requires an understanding of the depositional environment(s) of the groundwater basin, including the basin’s geologic structure and complexity as well as other parameters which could influence resistivity, such as changes in water quality (both horizonal and vertical) and the depth to saturated sediment. If the basin hydrogeology changes significantly across the survey area, the application of the clustering algorithm can be divided into multiple zones.

Once the number of clusters for each cluster model has been determined, the set of resistivity-CF pairs from the resistivity model and corresponding lithology model is entered into the clustering algorithm, which iteratively works to identify the best partitions between groups. The results of the clustering algorithm in the whole survey lithology modeling area are shown as a scatterplot in Figure 6-1. The CF value for each resistivity-CF pair is shown along the x-axis, while resistivity value is shown on the y-axis. Each point is colored according to the group it was placed in. Cluster 1, represented by 22% of all the clustered datapoints, contains the lowest resistivity values and lowest CF values. This cluster represents the units with the highest amount of clay materials in the initial hydrostratigraphic model. Each following group has a sequentially higher CF and resistivity. A more detailed description of the clustering process is presented in Appendix 5.

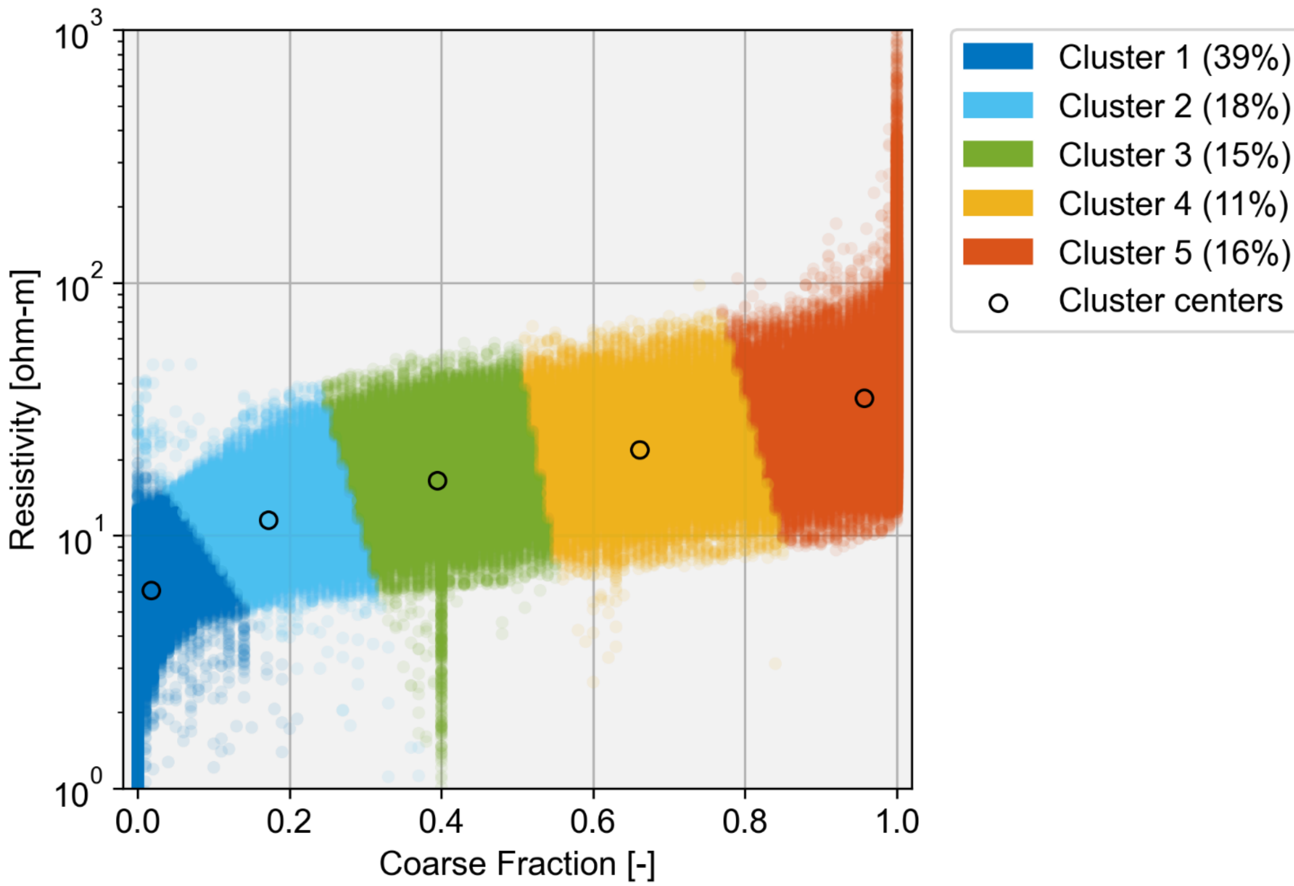

Figure 6-1 The results of the clustering algorithm applied to the data in Survey Area 4. Percentages in the legend indicate the ratio of resistivity-CF pairs included in the respective group. Note that there is overlap of points within the cluster model.

6.3 Clustering Algorithm Implementation

The first step in the cluster modeling process for the Survey Area 5 Groundwater Basins was to determine whether the area should be divided into separate regions due to changes in the hydrostratigraphy, including whether the low-resistivity area should be clustered separately from the high-resistivity area. The dataset was chosen not to be split into the same high-resistivity and low-resistivity area as the lithology modeling, for a better correlation between the two areas. We found the Cluster model to translate the ACT well across the borders of the two separate areas.

Five groups were chosen for the clustering algorithm to identify from the resistivity-CF pairs. This decision was based on the observed hydrogeology of the basin, where the different groups could accommodate the different hydrogeology, including coarse layers above and below the aquifer, mixed units, silty fines, and clayey fines. The choice of five groups was used a starting point producing an initial hydrostratigraphic model, which was subsequently evaluated as to whether a new iteration with more or fewer cluster groups was needed.

6.4 Results

The five different cluster groups representing the initial hydrostratigraphic model layers were plotted as profiles along all the flight lines where AEM data was acquired. The initial hydrostratigraphic model was evaluated for how well the chosen five-group model represents the hydrostratigraphy and whether a different number of clusters was needed. An example profile showing the result of the initial hydrostratigraphic model for the Merced, Turlock, and Modesto Groundwater Subbasins area is shown on Figure 6-2. Evaluation of the profile lines suggests that the clustering resulted in reasonable, continuous layers and the layering correlated well with the basin's geological features. Thus, it was determined that a second iteration with a different number of clusters was not needed. Profiles of all the initial hydrostratigraphic models are shown on the data sheets in Appendix 9.

The uncertainty for the clustering model is presented as an index showing how close the data point is to an adjoining cluster boundary. The basis of the uncertainty index is that the closer a specific point is to another cluster boundary, the greater the chance is that that specific point may have hydrostratigraphic properties closer to the neighbor cluster and the lower the numeric value. Thus, points that have an uncertainty index of over 0.5 are closer to the cluster center than the neighboring cluster and have a high certainty of belonging in that cluster. However, points with an uncertainty index of under 0.2 will be near the neighboring cluster and thus have much higher uncertainty whether that specific point belongs in its own cluster or the neighboring cluster. An example of the results showing the uncertainty index is shown on Figure 6-2, and the uncertainty index for all the clustering results are shown on the profiles on the data sheets in Appendix 9

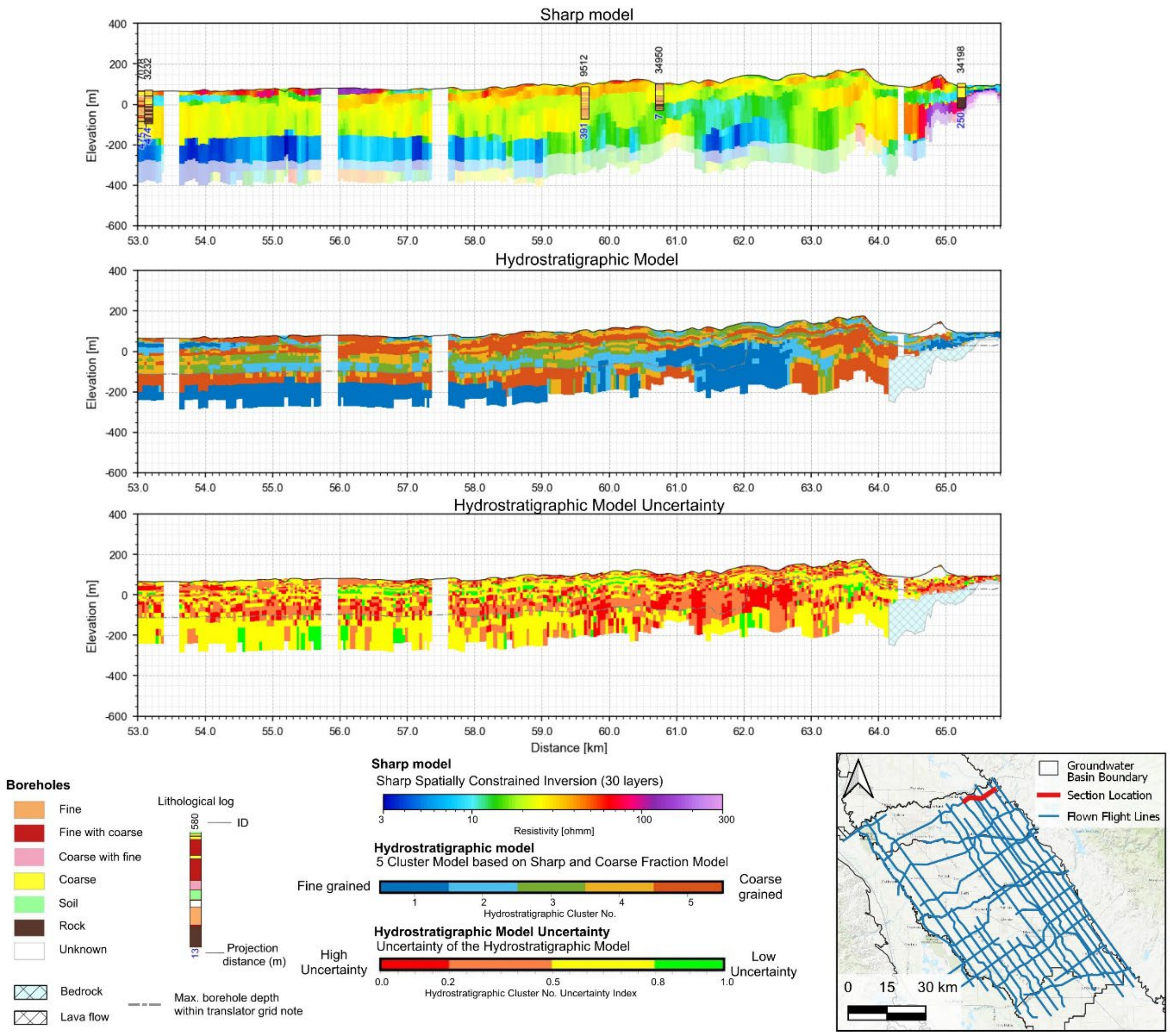

Figure 6-2 Initial hydrostratigraphic model along flight line 290200 in Merced, Turlock, and Modesto Groundwater Subbasins area. Profile A shows the sharp resistivity model used as an input to the cluster model. Profile B shows the results of the initial hydrostratigraphic model along the profile. Profile C shows the uncertainty index associated with the cluster, with 0.0 to 0.2 indicating the highest uncertainty (red) and 0.8 to 1.0 indicated the lowest uncertainty (green). Note that the presence of bedrock is blanked. The index map showing the profile location is shown at the bottom right.

6.5 Perspectives on the Initial Hydrostratigraphic Model

The cluster modeling process provides the opportunity to handle the large amount of resistivity data produced from an AEM survey to construct an initial hydrostratigraphic model. The model is generated solely on a statistical analysis of the gathered data and its relationship with observed coarse versus fine materials and is completely independent from external biases that affect where model boundaries are drawn. As a result, the hydrostratigraphic model resulting from the clustering approach is reproducible.

The main limitation for the use of the clustering model to develop an initial hydrostratigraphic model is the wide spacing of the AEM flight lines. Ideally, the AEM line spacing should be close together, allowing for a 3D AEM model to be developed. With a line spacing in a 2 x 8-mile grid, the spacing is too large to extrapolate the data to the area between the grid lines. Thus, the results of the initial hydrostratigraphic model are only representative along the line where AEM data have been collected. A closer line spacing, on the order of 250 m, will allow for the data to be interpolated between the lines into a 3D model grid, providing the possibility for a direct input into a numerical flow model.

The development of the hydrostratigraphic model is an iterative process. For this project, only one iteration was conducted and thus, the result is considered an initial hydrostratigraphic model. More iterations could be conducted and compared with the known hydrostratigraphy of the basin to provide more realizations. In addition, in the process outlined by Marker et al. (2015), cluster models with varying number of clusters can be evaluated in the flow model calibration process. In this case, the flow model could be used as input to help define the necessary number of clusters in the hydrostratigraphic model when used as input to a numerical flow model. This is an opportunity that could be realized with further infill along the flight lines where AEM data are interpreted.

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APPENDIX C: OUTREACH AND ENGAGEMENT ACTIVITIES

Meeting Title	Date	Key Meeting Topics
Board of Directors Meeting	January 13, 2022	Presentation of the land repurposing roadmap; action to create an ad hoc committee to develop elements of a 2022 Proposition 218 proceeding; discussion regarding additional regional public workshops focusing on the elements of two Phased GSP Implementation Approach and Allocation topics
Technical Advisory Committee Meeting	January 25, 2022	Discussion on Land Repurposing Program landowner survey results and target areas; update on Well Consistency Determination Policy implementation; recommendations to the GSA Board
Stakeholder Advisory Committee	January 31, 2022	Discussion of SGMA Implementation Grant application; discussion of DWR's comments on the GSP; update on drought conditions; reports from GSAs
Coordination Committee Meeting	February 7, 2022	Presentation on Department of Water Resources comments on the GSP; presentation on potential future funding opportunities; presentation on updates for SGM Implementation Planning and Projects Round 1 Grant
Board of Directors Meeting	February 10, 2022	Meeting began with a closed session; adopted a resolution to submit a Sustainable Groundwater Management SGMA Implementation Round 1 Grant application; review of Land Repurposing Survey results; discussion of Proposition 218 Proceeding timeline; discussion of draft well consistency determination policy; discussion on a draft resolution encouraging the sale of surface water within the Merced Subbasin
Board of Directors Meeting	March 10, 2022	Meeting began with a closed session; discussion of Land Repurposing Program and adopted a resolution authorizing the submission of an application to the California Department of Conservation's Multi-Benefit Land Repurposing Grant Program; discussion of a draft well consistency determination policy; discussion of elements of the Proposition 218 proceedings; discussion of outreach to landowners in subsidence focus area; presentation of Water Year 2021 Annual Report
Coordination Committee Meeting	March 21, 2022	Updates on SGM Implementation Planning and Projects Grant, Proposition 68 Round 3 Planning Grant, 2020 SGM Implementation Grant, and SDAC Grant; presentation on Water Year 2021 Annual Report
Stakeholder Advisory Committee	March 21, 2022	Grant updates; presentation on Water Year 2021 Annual Report; refresher on Sustainable Management Criteria; discussion of DWR's comments on the GSP; reports from GSAs
Technical Advisory Committee Meeting	March 22, 2022	Discussion on Well Consistency Determination Policy implementation; discussion on Land Repurposing Program development; discussion of parcel-based water budgets; discussion about enhancing public engagement for allocation discussions
Board of Directors Meeting	April 14, 2022	Meeting began with a closed session; adopted a well consistency determination policy; discussion of Land Repurposing Program development; discussion of Proposition 218 collection and expenditure strategy; authorized submission of a membership application to the Association of California Water Agencies JPIA

Meeting Title	Date	Key Meeting Topics
Coordination Committee Meeting	April 25, 2022	Discussion of potential revisions to GSP
Stakeholder Advisory Committee	April 25, 2022	Discussion of potential revisions to the GSP regarding DWR's comments, groundwater minimum thresholds, subsidence minimum thresholds, and schedule; reports from GSAs
Board of Directors Meeting	May 12, 2022	Meeting began with a closed session; discussion of Land Repurposing Program development; approved Proposition 218 Engineer's Report; presentation on parcel-based water budgets
Technical Advisory Committee Meeting	May 24, 2022	Discussion on Land Repurposing Program development; discussion on Well Consistency Determination Policy implementation; discussion of parcel-based water budgets
Coordination Committee Meeting	June 1, 2022	Discussion of potential revisions to the GSP regarding groundwater levels, subsidence, domestic well mitigation, and adoption of public input opportunities
Stakeholder Advisory Committee	June 1, 2022	Discussion of potential revisions to the GSP regarding groundwater levels, subsidence, domestic well mitigation, and adoption of public input opportunities; Reports from GSAs
Board of Directors Meeting	June 9, 2022	Meeting began with a closed session; discussion of Land Repurposing Program development; informational session on consistency determination template letter
Joint Stakeholder Advisory and Coordination Committee Meeting	June 27, 2022	Review of redline edits to GSP
Board of Directors Special Meeting	July 19, 2022	Public hearing on Proposition 218 proposed per-acre charges to fund Phase 1 of Sustainable Groundwater Management Act (SGMA) implementation
Board of Directors Meeting	August 11, 2022	Established Phase 1 Land Repurposing Program
Board of Directors Meeting	September 8, 2022	Update on Land Repurposing Program
Technical Advisory Committee Meeting	September 27, 2022	Review of available application and documents on the Phase 1 Land Repurposing Program; discussion of proposed appeals process for Phase 1 Funding Mechanism; review of guiding principles for developing demand reduction programs; discussion on requirements of Requests for Proposals for development of an evapotranspiration tracking tool to use with allocations
Board of Directors Meeting	October 13, 2022	Adopted proposed guiding principles for allocation and recharge programs to achieve Sustainability Goal; update on Land Repurposing Program development
Coordination Committee Meeting	October 19, 2022	Recapitulation of Groundwater Sustainability Plan (GSP) July 2022 Update; preview of 5-Year GSP Evaluation; discussion of Proposition 68 Implementation Planning and Projects Grant Round 2

Meeting Title	Date	Key Meeting Topics
Stakeholder Advisory Committee	October 19, 2022	Discussion on drought conditions; recapitulation of GSP July 2022 Update; discussion of 5-Year GSP Evaluation; grant updates; updates on ongoing and upcoming activities
Coordination Committee Meeting	November 8, 2022	Presentation on proposed Proposition 68 Implementation Planning and Projects from Round 2 Application
Board of Directors Meeting	November 10, 2022	Approved Recharge Credit framework; approved resolution for 2021 Sustainable Groundwater Management Grant Program SGMA - Round 2 grant application; presentation of sixth-month review of the GSP Consistency Criteria for Well Construction Applications implementation
Technical Advisory Committee Meeting	November 22, 2022	Update on the implementation of Phase 1 Land Repurposing Program; review of Recharge Framework for Water Year 2023; discussion of potential elements of an allocation approach
Board of Directors Meeting	December 8, 2022	Action to respond to a Government Claims Act presentation of claims regarding per acre charge; approved Land Repurposing Program contracts; set 2023 Board Meeting Calendar
Board of Directors Meeting	January 12, 2023	Meeting began with a closed session; presentation by Lower San Joaquin Levee District on the impact of subsidence on levees and public safety
Technical Advisory Committee Meeting	January 24, 2023	Discussion of potential elements of an allocation approach
Board of Directors Meeting	February 9, 2023	Meeting began with a closed session; presentation on the Water Accounting Platform; update on Land Repurposing Program agreements; update on recharge framework and forms
Coordination Committee Meeting	February 27, 2023	Presentation on Water Year 2022 Annual Report; discussion on demand reduction; grant updates
Stakeholder Advisory Committee	February 27, 2023	Preview of Water Year 2023 Annual Report; discussion on demand reduction; grant updates
Technical Advisory Committee Meeting	February 28, 2023	Discussion of potential elements of an allocation approach
Board of Directors Meeting	March 9, 2023	Meeting began with a closed session; adopted a resolution to apply to the California Department of Conservation's Round 2, Multi-benefit Land Repurposing Grant Program; presentation on the Buchanan Hollow Mutual Water Company Groundwater Recharge and Recovery Suitability Study; approved UC Merced memorandum of understanding
Board of Directors Meeting	March 27, 2023	Adopted a resolution to join Association of California Water Agencies Joint Powers Insurance Authority; update and discussion on flood water recharge opportunities made available by Executive Order N-4-23
Technical Advisory Committee Meeting	March 28, 2023	Discussion of potential elements of an allocation approach; discussion of recommended elements of the Merced Subbasin Groundwater Sustainability Agencies' (GSAs) efforts to instrument existing wells to fill data gaps

Meeting Title	Date	Key Meeting Topics
Board of Directors Meeting	April 13, 2023	Meeting began with a closed session; update on Land Repurposing Program; update to Recharge Framework
Board of Directors Meeting	May 11, 2023	Meeting began with a closed session; update on Land Repurposing Program; approved proposal for Groundwater Allocation Framework analysis
Technical Advisory Committee Meeting	May 23, 2023	Discussion on the second year of the Land Repurposing Program
Joint Stakeholder Advisory and Coordination Committee Meeting	May 24, 2023	Presentation on Flood-Managed Aquifer Recharge (MAR) Pilot Project; updates on SGMA Implementation Round 2 Draft Awards, Filling Data Gaps Project, and Merced Subbasin Integrated Managed Aquifer Recharge Evaluation Tool (MercedMAR); preview of GSP 5-Year Update
Board of Directors Meeting	June 8, 2023	Approved updated applications and documentation for 2023 Land Repurposing Program; discussion on Sandy Mush Mutual Water Company Reservoir Storage Project and CEQA determination
Board of Directors Meeting	July 13, 2023	Meeting began with a closed session; discussion of revisions to Sustainability Zones; update on Land Repurposing Program and Multi-benefit Land Repurposing Program grant award
Board of Directors Meeting	August 10, 2023	Meeting began with a closed session; report on local groundwater level monitoring data and analysis; report on WY 2024 Land Repurposing Program; discussion on revisions to Sustainability Zones; discussion of the Allocation Program Schedule
Technical Advisory Committee Meeting	August 22, 2023	Discussion on revisions to the Sustainability Zones for application in the Allocation Policy; discussion of recommendations for the allocation program schedule
Board of Directors Meeting	September 14, 2023	Meeting began with a closed session; discussion and approval of revisions to the Sustainability Zones; Report on Data Gaps Filling Project
Joint Stakeholder Advisory and Coordination Committee Meeting	September 18, 2023	Discussion on GSP 5-Year Update; update on data gaps
Board of Directors Meeting	October 12, 2023	Meeting began with a closed session; report on Mariposa Creek Temporary Water Right Permit; approved actions for maintenance of the Parcel Fee Model, GSP Consistency Criteria for Well Construction Applications, modifications to Sustainability Zone Parcel boundaries, and updates to Land Repurposing Agreements
Board of Directors Meeting	November 9, 2023	Meeting began with a closed session; update committee assignments for the Coordination and Ad Hoc Committees; approved the release of Request for Proposals for a Merced Subbasin GSA Executive Director; approved letter of support of MID's temporary recharge permit to divert water from Bear and Mariposa Creeks

Meeting Title	Date	Key Meeting Topics
Coordination Committee Meeting	November 29, 2023	Consideration of updates to Sustainable Management Criteria
Board of Directors Meeting	December 14, 2023	Meeting began with a closed session; review of Year 1 and 2 Land Repurposing Program Agreements; approved 2024 Board meeting calendar
Board of Directors Meeting	January 11, 2024	Authorized Multi-benefit Repurposing Program partner contracts
Coordination Committee Meeting	January 24, 2024	Discussion of potential amendment to Merced County's Groundwater Ordinance Export Policy; discussion of inelastic land subsidence; discussion of minimum data standards for groundwater levels
Stakeholder Advisory Committee	January 24, 2024	Discussion of potential amendment to Merced County's Groundwater Ordinance Export Policy; consideration of updates to Sustainable Management Criteria
Board of Directors Meeting	February 8, 2024	Meeting began with a closed session; approved Request for Proposal for Multi-benefit Land Repurposing Program Plan; discussion on updates the Allocation Policy Framework
Board of Directors Meeting	March 14, 2024	Meeting began with a closed session; presentation of Water Year 2023 Annual Report; discussion on updating draft allocation values in Allocation Policy Framework
Coordination Committee Meeting	March 20, 2024	Presentation on Water Year 2023 Annual Report; updates on Basin Conditions and Sustainable Management Criteria for GSP Update
Stakeholder Advisory Committee	March 20, 2024	Presentation on Water Year 2023 Annual Report; discussion of inelastic land subsidence
Technical Advisory Committee Meeting	March 26, 2024	Discussion of draft Allocation Policy Framework; discussion of updated Sustainability Zones; discussion of initial Groundwater Allocation Values; presentation on the Groundwater Accounting Platform and upcoming workshops
Board of Directors Meeting	April 11, 2024	Meeting began with a closed session; presentation on irrigation efficiency; discussion on the Groundwater Accounting Platform; action to approve Request for Proposal for Multi-benefit Land Repurposing Program
Technical Advisory Committee Meeting	April 30, 2024	Discussion of draft Allocation Policy Framework; discussion of initial Groundwater Allocation values; update on Groundwater Accounting Platform
Board of Directors Meeting	May 9, 2024	Meeting began with a closed session; presentation on update to Land Repurposing Program
Technical Advisory Committee Meeting	May 13, 2024	Discussion of draft Allocation Policy Framework
Public Workshop	May 22, 2024	Updates on actions to achieve sustainability; presentation on updates to the GSP regarding comments from the California Department of Water Resources

Meeting Title	Date	Key Meeting Topics
Coordination Committee Meeting	May 22, 2024	Overview of MercedWRM Modeling Scenarios; Update on draft Historical and Baseline Conditions Model Output
Stakeholder Advisory Committee	May 22, 2024	Updates on basin conditions and Sustainable Management Criteria for GSP update; presentation on MercedWRM modeling scenarios and initial draft outputs
Technical Advisory Committee Meeting	June 5, 2024	Discussion of Allocation Policy Framework and Allocation Policy Workshop
Board of Directors Meeting	June 19, 2024	Groundwater accounting platform launch workshop planning; update on Multi-benefit Land Repurposing Program; draft Groundwater Allocation Rule released for public comment
Board of Directors and Technical Advisory Committee Workshop	June 27, 2024	Review of draft Groundwater Allocation Rule
Public Hearing	July 11, 2024	Meeting began with a closed session; public opportunity to speak on draft Groundwater Allocation Rule
Joint Stakeholder Advisory and Coordination Committee Meeting	July 17, 2024	Discussion of Sustainable Management Criteria for new Representative Groundwater Level Monitoring Network Wells; update on modeling result for Baseline Projected Conditions and Projects & Management Actions scenarios
Board of Directors and Technical Advisory Committee Workshop	July 24, 2024	Review of draft Groundwater Allocation Rule
Board of Directors Meeting	August 8, 2024	Meeting began with a closed session; review of GSP updates; discussion on the appointment of Coordination Committee and Ad Hoc alternates; discussion on Multi-benefit Land Repurposing Program; Approval of draft Groundwater Allocation Rule
Public Workshop	August 26 2024	Presentation of projects proposed to augment groundwater supplies and methods proposed to reduce groundwater use; presentation on how the Merced Water Resources Model quantifies the benefits of collective action; discussion of how progress will be tracked and the GSP will be updated to reflect changing conditions
Joint Stakeholder Advisory and Coordination Committee Meeting	October 16, 2024	Review of redlined 2025 GSP