Workplan: Addressing Uncertainty and Validating the Groundwater Protection Formula, Values, and Targets

Prepared for:
Buena Vista Coalition
Cawelo Water District Coalition
East San Joaquin Water Quality Coalition
Grassland Drainage Area Coalition
Kaweah Basin Water Quality Association
Kern River Watershed Coalition Authority
Kings River Watershed Coalition Authority
Sacramento Valley Water Quality Coalition
San Joaquin County and Delta Water Quality Coalition
Tule Basin Water Quality Coalition
Westlands Water Quality Coalition
Westside San Joaquin River Watershed Coalition
Westside Water Quality Coalition

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LIST OF ABBREVIATIONS

A	Applied nitrogen
A-R	The mass balance of applied nitrogen less nitrogen removed
C2VSIM	California Central Valley Groundwater-Surface Water Simulation Model
C2VSimFG	California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid Version
CDFA	California Department of Food and Agriculture
CVDRMP	Central Valley Dairy Representative Monitoring Program
CVHM	Central Valley Hydrologic Model
CVHM2	Central Valley Hydrologic Model Version 2
CV-NPSAT	Central Valley Non-Point Source Assessment Tool
CVRWQCB	Central Valley Regional Water Quality Control Board
CV-SALTS	Central Valley Salinity Alternatives for Long-term Sustainability
CV-SWAT	Central Valley Soil and Water Assessment Tool
DWR	Department of Water Resources
ET	Evapotranspiration
FREP	Fertilizer Research and Education Program
GAMA	Groundwater Ambient Monitoring & Assessment
GAR	Groundwater Assessment Report
GNLM	Groundwater Nitrate Loading Model
GQMP	Groundwater Quality Management Plan
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GWP	Groundwater Protection
HVA	High vulnerability area
INMP	Irrigation and Nitrogen Management Plan
LTIRLP	Long-term Irrigated Lands Regulatory Program
MAR	Managed aquifer recharge
MCL	Maximum contaminant level
MPEP	Management Practices Evaluation Program

MZIP	Management Zone Implementation Plan
N	Nitrogen
Nitrate-N	Nitrogen in the form of nitrate
NMP	Nitrogen Management Plan
NMZIP	Nitrate Management Zone Implementation Plan
NPSAT	Non-Point Source Assessment Tool
NRCS	Natural Resources Conservation Service
R	Nitrogen removed with crop harvest and sequestered in perennial tissue
RZWQM	Root-zone Water Quality Model
SGMA	Sustainable Groundwater Management Act
SVSim	Sacramento Valley Groundwater-Surface Water Simulation Model
SWAT	Soil and Water Assessment Tool
SWRCB	State Water Resources Control Board
UC	University of California
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WDR	Waste Discharge Requirement

1 EXECUTIVE SUMMARY

Waste Discharge Requirement General Orders that apply to members of third-party groups (often referred to as the Long-term Irrigated Lands Regulatory Program, or LTILRP) require third-parties (referred to as Coalitions) on behalf of their members to submit Groundwater Protection (GWP) Formula, Values, and Targets for high-priority townships to the Executive Officer of the Central Valley Regional Water Quality Control Board (CVRWQCB). Coalitions subject to the GWP Formula, Values, and Targets requirements include the following:

- Buena Vista Coalition
- Cawelo Water District Coalition
- East San Joaquin Water Quality Coalition
- Grassland Drainage Area Coalition
- Kaweah Basin Water Quality Association
- Kern River Watershed Coalition Authority
- Kings River Watershed Coalition Authority
- Sacramento Valley Water Quality Coalition
- San Joaquin County and Delta Water Quality Coalition
- Tule Basin Water Quality Coalition
- Westlands Water Quality Coalition
- Westside San Joaquin River Watershed Coalition
- Westside Water Quality Coalition

These thirteen Coalitions have worked collectively to develop a single GWP Formula to generate GWP Values and Targets for all high-priority townships (i.e., GWP Townships). This work was completed over several years in collaboration with the CVRWQCB, USDA Natural Resources Conservation Service (NRCS), researchers at the University of California (UC), UC Cooperative Extension, and other stakeholders. The GWP Formula, Values, and Targets reflect a comprehensive assessment framework intended to achieve compliance with receiving water limitations for groundwater. The framework considers soil, crop, and root-zone processes as well as key processes in the vadose zone, hydrologic conditions (e.g., recharge and dilution), and other regionally significant factors that affect the concentration of nitrate nitrogen (N) (nitrate-N) reaching receiving waters. Integral to this framework are process-based models, informed by a broad base of scientific research and monitoring data, that represent the crop root-zone as well as the groundwater system. Detailed information regarding the development of the GWP Formula, Values, and Targets is available in the reports prepared by the Coalitions (Central Valley Coalitions, 2020, 2021, 2021a, and 2022), which were all conditionally approved by the CVRWQCB.

As described throughout the GWP Reports, the assessment framework uses the best available data and tools (Central Valley Coalitions, 2020, 2021, 2021a, and 2022) to generate a rigorous assessment of current conditions and future targets. These data and tools are the product of decades of investments, research, refinements, and validation from academic institutions and government agencies. Moreover, their adaptation by the Coalitions, including the integration of spatially and temporally detailed grower-reported data, to address the GWP requirements reflects a scientifically rigorous and substantial undertaking. The assessment framework includes:

- A powerful, unprecedented characterization of the irrigated agricultural landscape based on information included in grower reported Irrigation and Nitrogen Management Plans (INMPs) Summary Reports (location, crop, N applied [A], and crop yield which is used to compute N removed [R] using N removal coefficients developed by Geisseler (2016, 2021).

- Use of modeling tools that 1) are physically based and rely on known physical processes related to the N cycle and water and solute movement through a porous system, 2) leverage detailed data on climate, soil and subsoil characteristics, land use, and water use, and 3) have been accepted by the scientific community and utilized in a variety of applications within California and abroad.
- Integration of climate, soil, crop models, and management in the Central Valley Soil and Water Assessment Tool (CV-SWAT) to simulate the fate of the A-R N balance and provide a conservative estimate of nitrate-N leaching. This includes simulation of approximately 450-750 management scenarios per crop across each soil x climate combination in each watershed. The annual average was taken for each 38-year simulation of unique crop x climate x soil x management and stored in a database referred to as the Root-zone Library. The Root-zone Library includes more than ½ billion modeled outputs of nitrate-N discharge to groundwater based on crop, soil, climate, applied N, and yield.
- Linkage of CV-SWAT to the Central Valley Non-Point Source Assessment Tool (CV-NPSAT), which uses calibrated hydrological models to create a spatiotemporal linkage between the land surface and shallow domestic wells to understand current and future impacts of irrigated agriculture (and other dischargers) on groundwater quality with respect to nitrate-N contamination concentrations. Specifically, this included simulation of different crop root-zone management practices and their effect on future water quality across the entire Central Valley for approximately 95,000 virtual domestic wells. This provides a substantially improved representation of the crop root-zone and its connection to the groundwater system as compared to existing groundwater models.

Nonetheless, when addressing such a complex environmental issue over a vast and diverse landscape, uncertainty around modeled inputs and outputs will exist. It is therefore important to remain cognizant of the limitations of available data and existing models, the sensitivity of relatively unknown model parameters on key outputs, and to be aware of what scales (time and space) are appropriate for the use and interpretation of model output for achieving regulatory objectives. Sufficient time and process are necessary to refine the GWP Values and Targets through uncertainty analyses and validation efforts, and as the state of scientific knowledge and available tools are continually enhanced.

Several priorities for reducing uncertainty were identified in the GWP Targets Report, and in the conditional approval by the CVRWQCB. These are related to refinement and validation of CV-SWAT, hydrologic conditions, other nitrate-N loads, post-root-zone denitrification, and the groundwater processes and estimation of well nitrate-N concentrations to determine GWP Targets.

The purpose of this Workplan is to describe the activities the Coalitions will engage in (in collaboration with UC researchers, the CVRWQCB, and other stakeholders) to characterize and reduce uncertainty (where possible) within the assessment framework as well as perform additional validation efforts. This Workplan proposes methodologies to 1) characterize and reduce (over time) uncertainties in various aspects of the assessment framework and computed GWP Targets, 2) integrate and leverage complimentary regulatory programs aimed at addressing water quality (Central Valley Salinity

Alternatives for Long-term Sustainability (CV-SALTS)) and quantity (Sustainable Groundwater Management Act, (SGMA)), and 3) validate GWP Targets in collaboration with researchers at the UC Davis via providing disaggregated GWP Value information (average crop x township loading). If approved, the results of the proposed activities will inform the next review and update of GWP Targets due on June 30, 2028. These potential updates will further inform growers and their Coalitions on GWP Targets to manage towards, as well as provide additional assurance to the CVRWQCB and stakeholders that irrigated agriculture will no longer be causing or contributing to an exceedance of the water quality objectives if the GWP Targets are achieved.

Table 1 and Figure 1 summarize the proposed activities to support validation, characterize uncertainty, and refine the assessment framework. The activities are numbered according to whether they primarily apply to the GWP Formula (Activity F), GWP Values (Activity V), or GWP Targets (Activity T), recognizing that several activities are interconnected. As shown in Figure 1, some of the activities are sequential, whereas others will occur simultaneously. Each activity will ultimately lead to a refined and/or better understood estimation (i.e., degree of uncertainty) of groundwater quality.

TABLE 1. SUMMARY OF ACTIVITIES TO ADDRESS UNCERTAINTY AND VALIDATE THE GWP FORMULA, VALUES, AND TARGETS.[a]

Activities To Characterize and Address Uncertainty and Validate Key Model Component and Outputs	Implementation Approach
Irrigated Agriculture and the GWP Values	
Activity F1. Continually refine the Root-zone Library to reflect newly available data. New or refined N-removal coefficients will be available for 34 crops by December 2024. After publication, the crop model parameters for each crop will be updated in CV-SWAT and new Root-zone Library entries will be generated. The Coalitions will continue to refine and update the Root-zone Library as additional data and information are made available (e.g., new N removal data) from university researchers and/or commodity groups.	This activity is being conducted by the Coalitions, in collaboration with UC Davis and with support from an existing CDFA FREP Grant. Results for 34 crops will be reflected in the 2028 GWP Targets. Additional refinements will be incorporated by the Coalitions as additional data become available.
Activity F2. Assess CV-SWAT results relative to newly available data from field studies and other root-zone models. Data from three monitoring studies will be used to build upon the validation of CV-SWAT water and N budgets and nitrate-N leaching estimates under specific management scenarios. The project team will use the collected field data from these established, intensively monitored research sites to validate CV-SWAT. This work is anticipated to be completed in December 2026.	The monitoring studies are being conducted by UC Davis. CV-SWAT validation using the study results will be conducted by the Coalitions in collaboration with UC Davis with support from an existing CDFA FREP Grant. Results will be reflected in the 2028 GWP Targets.
Activity V1. Reassess GWP Townships. The Coalitions will reevaluate the fraction of HVA within Central Valley townships that exist in areas where GARs and HVA delineations have been updated. As done previously, GWP Townships will be defined as townships that have at least 10% HVA within their boundary.	This activity will be conducted by the Coalitions before each GWP Targets update to ensure that the appropriate GWP Townships are identified and GWP Values and GWP Targets are computed for them.
Activity V2. Calculate GWP Values annually based on INMPs. The Coalitions will calculate GWP Values annually based on INMPs to allow the generation of rolling annual averages, rather than a single year snapshot. This will improve the representation of crop rotations and of growers' adaptive management over time (i.e., progress towards GWP Targets), smooth parcel-scale highs and lows in A-R driven by abnormally low or high yields (and other factors), and reduce overall uncertainty in GWP Values.	This activity will be conducted by the Coalitions annually and reflected in each update to the GWP Targets.
Activity V3. Improve estimation of nitrate-N loads from non-HVA lands based on INMPs. The assessment framework includes estimation of all nitrate-N loads, including from dairy lands, irrigated agriculture from non-HVA lands, and urban areas. Previously, the estimation of nitrate-N loads for irrigated agriculture from non-HVA lands (where GWP Values do not exist) was based on the Root-zone Library in conjunction with the most current DWR land use maps available. This activity includes updating this estimate based on INMPs.	This activity will be conducted by the Coalitions annually and reflected in each update to the GWP Targets.
Hydrologic Conditions	

Activities To Characterize and Address Uncertainty and Validate Key Model Component and Outputs	Implementation Approach
Activity T1. Evaluate uncertainty in currently available local water budget components. Researchers at UC Davis are currently reviewing CVHM2 and carrying out a detailed comparison to C2VSimFG and SVSim (Sacramento Valley only) at the regional and local (e.g., township) scale to identify and characterize similarities and key differences in estimated budgets, including groundwater recharge. The Coalitions will consider these findings and integrate them with water budget information presented in GSPs and CV-SWAT at the GSP and township scales, respectively.	The comparison of modeling results is being conducted by UC Davis. Opportunities for refinement will be assessed collaboratively by UC Davis and Coalitions and incorporated into the assessment framework by the Coalitions. Refinements are anticipated before the 2028 GWP Targets.
Activity T2. Reduce uncertainty in modeled hydrologic conditions by incorporating groundwater model refinements when released by model developers. New data and information generated through SGMA, beyond what is currently available, is anticipated to be incorporated into the groundwater models. When groundwater model updates are released, the Coalitions will collaborate with the groundwater model developers to assess whether updates to the assessment framework are warranted.	Improvements to estimates of local water budget components will be conducted by GSAs. Refinement of surface and groundwater models (C2VSIM, CVHM, and CV-NPSAT) will be led by respective model developers (DWR, USGS, and UC Davis). The Coalitions will lead incorporation of refined conditions and models into the assessment framework, when warranted. This will occur on an on-going basis.
Activity T3. Validate CV-NPSAT flow field and travel times. This activity will be carried out by the CV-NPSAT developers utilizing groundwater age tracker isotopes. This activity is expected to be complete by 2025.	This activity will be conducted by UC Davis. Results will be reflected in the 2028 GWP Targets.
Other N Loads	
Activity T4. Review other nitrate-N loads in GWP Townships identified by CVRWQCB. The GWP Townships will be reviewed by the Coalitions in greater detail to better understand if the representation of hydrologic conditions and other nitrate-N loads in the assessment framework, as compared to past and current conditions (e.g., assuming an A/R of 1.4 dairy crop lands), contributes to identification of appropriate GWP Targets. This activity is expected to be complete by the end of 2027.	This activity is being conducted by the Coalitions. Results will be reflected in the 2028 GWP Targets.
Activity T5. Integrate Nitrate Reduction Program Milestones. As the nitrate-N loading estimates associated with the CV-SALTS Priority 1 Management Zone Implementation Plans / Nitrate Reduction Programs are determined for other nitrate-N dischargers, the Coalitions' will integrate them into the assessment framework.	Results from this activity will be integrated into the assessment framework as available.
Post-Root-zone Denitrification	

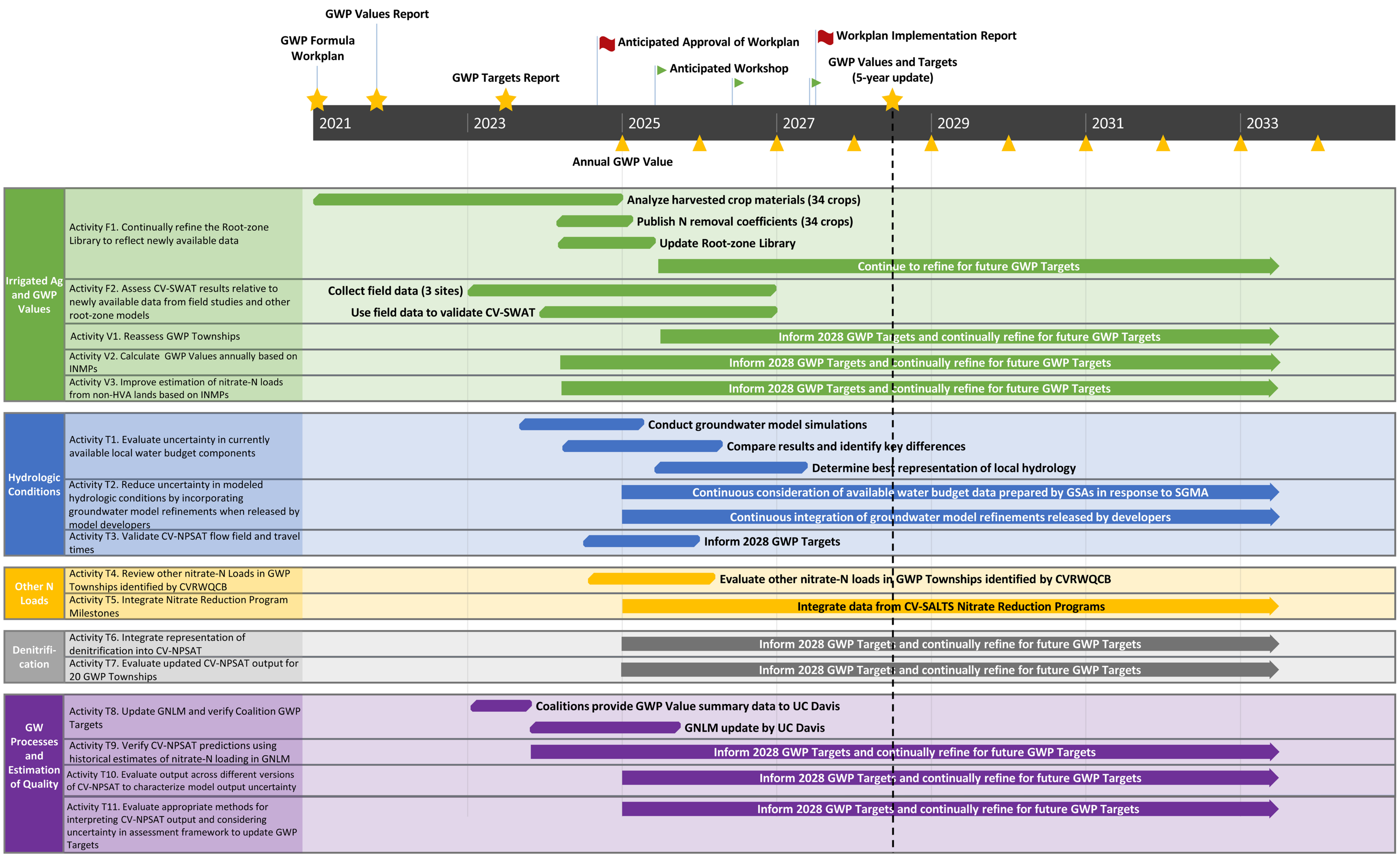
Activities To Characterize and Address Uncertainty and Validate Key Model Component and Outputs	Implementation Approach
Activity T6. Integrate representation of denitrification into CV-NPSAT. This activity includes integrating denitrification into CV-NPSAT by the model developers using available data (e.g., USGS redox maps developed by Rosecrans et al., 2017), building on previous work within the region (Liang et al., 2014, Ransom et al., 2018), and evaluating a mass balance approach (Henri and Harter, 2022). This task is anticipated to be completed by the end of 2025.	This activity will be conducted by UC Davis. Results will be reflected in the 2028 GWP Targets.
Activity T7. Evaluate updated CV-NPSAT output for 20 GWP Townships. After Activity T6, the Coalitions will evaluate whether apparent overestimations of nitrate-N concentrations persist. If not, then an updated version of CV-NPSAT will be used to determine the 2028 GWP Targets. If they do, then the Coalitions will reassess the approach to determining GWP Targets for these townships and propose an approach to the CVRWQCB.	This activity will be conducted by the Coalitions. Results will either be reflected in the 2028 GWP Targets or result in development of an alternative approach to calculation of GWP Targets for the 20 townships.
Groundwater Processes and Estimating Groundwater Water Quality	
Activity T8. Update GNLM and verify Coalition GWP Targets. This activity includes supplying summaries of updated GWP Value information to UC Davis to support refinement of the GNLM. Once GNLM is updated with the GWP Values, UC and/or other stakeholders can use the public version of CV-NPSAT to evaluate loading scenarios.	This activity will be conducted by UC Davis. Results will be incorporated into Activity T9.
Activity T9. Verify CV-NPSAT predictions using historical estimates of nitrate-N loading in GNLM. After Activity T8, UC Davis will simulate estimated historical and current conditions of nitrate-N loading in CV-NPSAT and determine how well it estimates historical and current nitrate-N concentrations in domestic and production wells across the Central Valley. This activity is anticipated to be complete by the end of 2026.	This activity will be conducted by UC Davis. Results will be reflected in the 2028 GWP Targets and continually refined thereafter.
Activity T10. Evaluate output across different versions of CV-NPSAT to characterize model output uncertainty. This activity includes characterizing uncertainty with CV-NPSAT predictions by simulating the multiple versions of the tool based upon the different groundwater models and/or steady state hydrology representations. This activity will be carried out by the Coalitions in collaboration with the model developers, with the Coalitions working with the detailed GWP Values and other N load inputs and the model developers with the updated GNLM (Activity T8). This work is anticipated to be complete by the end of 2026.	This activity will be conducted by UC Davis and the Coalitions. Results will be reflected in the 2028 GWP Targets and continually refined thereafter.

Activities To Characterize and Address Uncertainty and Validate Key Model Component and Outputs	Implementation Approach
Activity T11. Evaluate appropriate methods for interpreting CV-NPSAT output and considering uncertainty in assessment framework to update GWP Targets. This activity will be a collaboration between the Coalitions and UC Davis to continue to explore and understand appropriate methods for interpreting CV-NPSAT output to update GWP Targets. This will include additional investigation into scientific literature and theories to determine whether the currently employed approach is justified or whether preferred alternatives exist. Preliminary work will be completed by the end of 2026, but efforts will likely continue beyond.	This activity will be conducted by UC Davis and the Coalitions. Results will be reflected in the 2028 GWP Targets and continually refined thereafter.

a. Refer to Figure 7 for a schematic of each component and how they are connected.

FIGURE 1. TIMELINE OF ACTIVITIES TO REDUCE UNCERTAINTY AND VALIDATE THE GROUNDWATER PROTECTION FORMULA, VALUES, AND TARGETS.

Numerous activities are anticipated to be completed before the next review and update of the GWP Targets, whereas other activities will be continually refined and improved by the Coalitions over time or by ongoing initiatives by other stakeholders. Activities are numbered according to whether they primarily apply to the GWP Formula (Activity F), GWP Values (Activity V), or GWP Targets (Activity T).



2 BACKGROUND

2.1 CENTRAL VALLEY IRRIGATED AGRICULTURE

The Central Valley of California is a vast and complex agricultural region spanning approximately 20,000 sq. mi. and extending roughly 450 miles from north to south, supporting over 5.5 million acres of irrigated cropland comprising over 400 commodities. Agricultural output of food and fiber from the region is significant to local, state, national, and global food supply and economy. Leading commodities include nut crops (almonds, pistachios, walnuts), grapes (wine, table, raisin), citrus (orange, mandarin, lemon), and processing tomato (CDFA, 2022). The Central Valley is well suited for supporting a wide variety of crops due to its Mediterranean climate (cool wet winters, warm dry summers) with a precipitation gradient that gradually decreases from north to south, and a diversity of soil types that vary as a function of differing geologic parent material, depositional processes, and other soil forming factors. In total, over 20,000 growers farm in the Central Valley. Together, these factors create a vibrant and diverse agricultural landscape.

2.2 GENERAL ORDER REQUIREMENTS

In 2003, the Central Valley Regional Water Quality Control Board (CVRWQCB) adopted Waivers from Waste Discharge Requirements that applied to the discharge of waste to surface waters from irrigated agricultural lands. Starting in 2012, the program was expanded to include discharges to groundwaters and the CVRWQCB adopted Waste Discharge Requirement (WDR) General Orders (often referred to as the Long-term Irrigated Lands Regulatory Program, or LTILRP). To assist growers in complying with the early waiver requirements and subsequently the LTILRP requirements, third party groups formed (referred to as Coalitions). (Figure 2). In 2018, The California State Water Resources Control Board (SWRCB) adopted Order WQ 2018-0002 in response to the petitions of General Order R5-2012-0116 for growers within the Eastern San Joaquin River Watershed. This order was precedential and, as such, was applied to the other WDRs for growers in the Central Valley and members of the Coalitions. Requirements of these WDRs are the basis for the previously completed and proposed work described in this Workplan.

WDR General Orders that apply to members of third-party groups require third-parties (Coalitions) on behalf of their members to submit Groundwater Protection (GWP) Formula, Values and Targets for high-priority townships[1] to the Executive Officer of the CVRWQCB. The Coalitions subject to the GWP provisions include the following and are displayed geographically in Figure 2[2]:

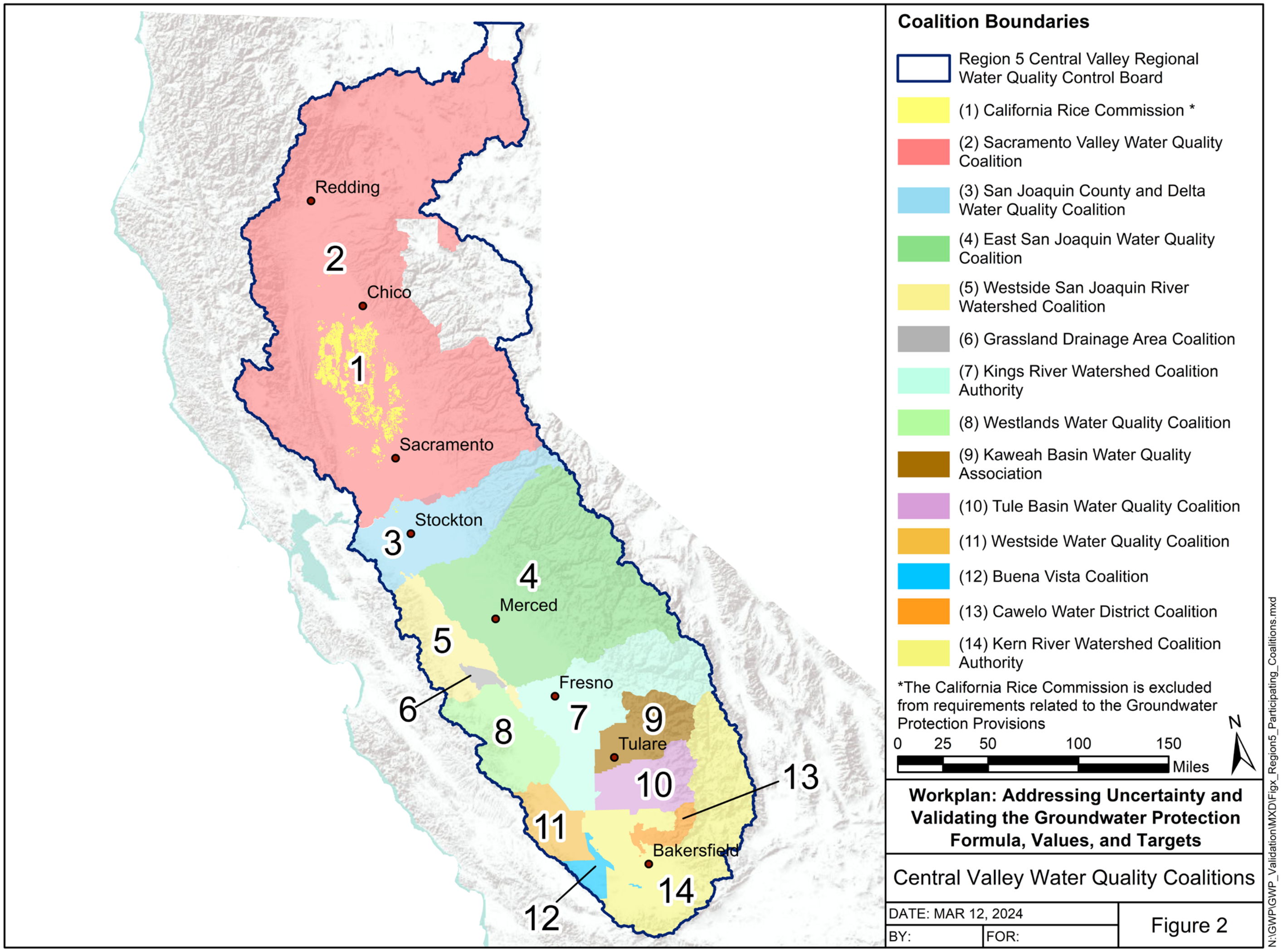
[1] High-priority areas are those areas where the Executive Officer determines that irrigated agriculture may be causing or contributing to exceedances of water quality objectives or a trend of degradation that may threaten applicable beneficial uses (Order WQ 2018-0002, p. 66).

[2] The GWP provisions are not in the California Rice Commission's Third-Party Order and thus are not applicable to rice growers in the Sacramento Valley.

- Buena Vista Coalition
- Cawelo Water District Coalition
- East San Joaquin Water Quality Coalition
- Grassland Drainage Area Coalition
- Kaweah Basin Water Quality Association
- Kern River Watershed Coalition Authority
- Kings River Watershed Coalition Authority
- Sacramento Valley Water Quality Coalition
- San Joaquin County and Delta Water Quality Coalition
- Tule Basin Water Quality Coalition
- Westlands Water Quality Coalition
- Westside San Joaquin River Watershed Coalition
- Westside Water Quality Coalition

The GWP Formula, Values, and Targets reflect a comprehensive assessment framework intended to achieve compliance with receiving water limitations for groundwater. The purpose of the GWP Formula is to integrate appropriate data and methods to generate GWP Values for high-priority townships (i.e., GWP Townships). The GWP Values, expressed as either nitrate as nitrogen (N) (nitrate-N) loading rates or as concentrations of nitrate-N in water (e.g., mg/L), reflect the influence of total applied N, total removed N, recharge conditions, and other relevant and scientifically supported variables that influence the potential average concentration of nitrate-N in water expected to reach groundwater in a high priority township over a given time period. GWP Targets are required for each GWP Township for which a GWP Value has been computed. The purpose of the GWP Targets is to set a desired target intended to achieve compliance with receiving water limitations for groundwater. Receiving water limitations are limitations on growers that state "[w]astes discharged from Member operations shall not cause or contribute to an exceedance of applicable water quality objectives in the underlying groundwater, unreasonably affect applicable beneficial uses, or cause or contribute to a condition of pollution or nuisance." (See, e.g., Waste Discharge Requirements General Order for Growers within the Eastern San Joaquin River Watershed that are Members of the Third-Party Group, Order No. R5-2012-0116-11, p. 23.) The receiving water limitation for nitrate-N is the state's drinking water standard that is set at 10 mg/L-N, and the time to meet the limit is subject to time schedules for each of the thirteen Coalitions. The time schedules are generally for ten years, but the starting and end dates for the schedules vary amongst the Coalitions. The GWP Values and Targets are to be included in each Coalition's Groundwater Quality Management Plans (GQMPs), with the latter serving as performance goals. However, GWP Targets themselves are not enforceable, regulatory standards as included in the WDRs General Orders at this time. The GWP Targets shall be reviewed and revised as necessary every five years.

FIGURE 2. MAP OF THE THIRTEEN WATER QUALITY COALITIONS SUBJECT TO THE GROUNDWATER PROTECTION PROVISIONS.



2.3 DEVELOPMENT OF GROUNDWATER PROTECTION FORMULA, VALUES, AND TARGETS

This section provides a summary of the approach and milestones related to development of the GWP Formula, Values, and Targets, consistent with the LTILRP Orders. This work was completed over several years in collaboration with the CVRWQCB, USDA Natural Resources Conservation Service (NRCS), researchers at the University of California (UC) and Cooperative Extension, commodity organizations and other stakeholders (Figure 4). This included a series of briefings with technical partners, the CVRWQCB staff, commodity organizations, Environmental Justice advocates and other stakeholders to build an understanding of the approach, incorporate feedback, and to address questions and concerns (Figure 4).

The GWP Formula, Values, and Targets reflect a comprehensive assessment framework intended to achieve compliance with nitrate receiving water limitations for groundwater (Figure 3). This framework considers soil, crop, and root-zone processes as well as key processes in the vadose zone, hydrologic conditions (e.g., recharge and dilution), and other regionally significant factors that affect the concentration of nitrate-N reaching receiving waters. An important component of the framework is the ability to evaluate a broad range of agricultural management actions. Management actions that affect nitrate-N fate and transport in any given field varies greatly, and outcomes depend on crop, soil, and climatic conditions, as well as antecedent and ongoing fertilization, irrigation, tillage, and other cultural practices. However, it is the regional N loading, along with the combined effect of many unique management systems in the context of field-specific and broader hydrologic processes, that influences groundwater quality. The assessment framework is intended to reflect 1) water and nitrate-N movement through root-zones of agricultural lands, 2) how this movement is affected by management in each field, and 3) how hydrology and biogeochemical processes mediate receiving water quality (i.e., accounting for surface, vadose zone, and groundwater processes known to influence regional water quality). In this way, both the nitrate-N source and receiving water can be understood in detail and evaluated at the appropriate scales to guide and assess the effectiveness of measures to protect beneficial uses.

The GWP Formula, Values, and Targets build on and optimize data and information developed in response to requirements of the LTILRP and efforts carried out by the Coalitions, including:

- **Groundwater Assessment Reports (GARs).** GARs were developed to 1) characterize the physical conditions of the Central Valley aquifer across space and 2) define areas that are highly vulnerable (referred to as high vulnerability areas, or HVAs) to nitrate-N loads. These HVAs were used as the basis to prioritize the development of GWP Values and Targets. In the 2020 Groundwater Protection Formula Workplan, 399 high vulnerability Townships (i.e., GWP Townships) were identified for inclusion in the GWP Value and Targets submittals in 2021 and 2022 respectively, covering over 3.5 million acres of irrigated acres on HVA.[3] As described in Section 3.1, GWP Townships will be re-evaluated in concert with GWP Targets updates to reflect updates to GARs

[3] Reporting requirements for the GWP Values focus on grower reports from HVAs. However, as described below in Section 3.1, grower INMP Summary Reports from lower vulnerability areas will be utilized as model inputs in subsequent updates to GWP Targets.

and ensure that the appropriate GWP Townships are identified and GWP Values and GWP Targets are computed for them.

- **Nitrogen Management Plans (NMPs) / Irrigation Nitrogen Management Plans (INMPs).** The NMPs and more recent INMPs are completed and certified by growers or approved technical service providers and certain information from the INMPs are summarized and submitted to the growers' respective Coalition(s) on an annual basis (Figure 4). These Summary Reports detail crop type, irrigated acreage, total N inputs available to the crop, and achieved yield on a field, parcel, or management unit basis. All growers are required to prepare and submit INMP reports to their Coalitions.
- **Groundwater Trend Monitoring Program.** The Coalitions have established trend monitoring programs for testing and reporting to the CVRWQCB on an annual basis, regarding wells located in parcels owned by growers subject to the LTILRP. These data are incorporated into the broader Groundwater Ambient Monitoring & Assessment (GAMA) program established by the SWRCB.
- **Drinking Water Supply Well Monitoring.** Members of the Coalitions conduct annual sampling of private drinking water supply wells located on their property in order to identify drink water supply wells that have nitrate-N concentrations exceeding the MCL and notify any well users and the CVRWQCB of exceedances. If nitrate-N concentrations are below 8 mg/L in three consecutive annual samples, Members may conduct sampling every five years.

Integral to this framework are process-based models, informed by a broad base of scientific research and monitoring data, that represent the crop root-zone as well as the groundwater system. Early in the 21st century, Fogg and La Bolle (2006) wrote that the following in regards to evaluating the efficacy of regulations, "*There is no way of knowing… without much more in-depth study of the underlying phenomena, including predictive modeling at largely unprecedented space and timescales and long-term monitoring that is largely absent or in its infancy. The future of groundwater quality regulation will ultimately depend on the underlying scientific foundation."* Indeed, both before their article and since, substantial advancements have been made in modeling capabilities and available tools (e.g., Figure 4) and robust groundwater trend monitoring programs have been established in the Central Valley by the Coalitions (referenced above) and others. While monitoring of groundwater is an invaluable aspect of addressing water quality issues through providing insight into water quality trends and supporting model calibration and validation, limitations of exclusive reliance on this approach include:

- Changes in groundwater quality as a function of shifts in land and water management may require years to decades before being reflected in monitoring well results.
- It is difficult (and in some circumstances likely impossible) to relate well observations back to specific management actions at the land surface.
- Legacy conditions (e.g., existing nitrate-N loads in the vadose zone) from historical management can mask effects and confound whether or not current management practices are having an effect on groundwater quality.

Moreover, the inherent challenges with measuring percolation and nitrate-N leaching in agricultural fields, coupled with the scale of Central Valley agriculture, renders comprehensive root-zone monitoring infeasible. These intrinsic issues with monitoring necessitate the need for utilizing modeling tools to provide estimations of current conditions and evaluate the potential effects of land and water management on future conditions, all in a very large-scale domain.

As described throughout the GWP Reports, the assessment framework uses the best available data and tools to generate a rigorous assessment of current conditions and future targets. The current GWP Values and GWP Targets are their respective first versions, and the Coalitions remain committed to refining them through a collaborative and iterative process with CVRWQCB, UC researchers, commodity organizations and other stakeholders. This dynamic process is necessary due to the scale and complexity of computing these metrics, which cannot be understated. Sufficient time and process are necessary to refine the GWP Values and Targets through uncertainty analyses and validation efforts, and as the state of scientific knowledge and available tools are continually enhanced, additional refinements will continue to occur.

Detailed information is available in the GWP Formula Workplan, GWP Values Report, and GWP Targets Report (Central Valley Coalitions, 2020, 2021, 2021a[4], and 2022, respectively). Each report was submitted per the schedule required by the General Order and each report received conditional approval by the CVRWQCB's Executive Officer (Table 2). The conditions of approval required that the Coalitions address questions and/or provide additional information to the CVRWQCB. For the GWP Formula, conditions of approval were addressed in the GWP Values Report. For the conditions of approval associated with the GWP Values Report and Targets Report, they are being addressed through this Workplan (Table 2).

[4] The GWP Values Report was submitted to the CVRWQCB on July 19, 2021. An addendum to the July 19, 2021, GWP Values Report was submitted on December 14, 2021, to include additional Sacramento Valley Townships (collectively hereafter referred to as the GWP Values Report).

FIGURE 3. SCHEMATIC OF THE GROUNDWATER PROTECTION PROVISIONS AND KEY FACTORS CONSIDERED WITHIN THE ASSESSMENT FRAMEWORK.

Root-zone-based GWP Values: Calculated using the approved Root-zone GWP Formula for irrigated agriculture within GWP Townships.

GWP Township Targets: Account for other scientifically supported variables (post-root-zone processes) that influence the potential average concentration of nitrate in water expected to reach groundwater (e.g., vadose zone attenuation, regional recharge conditions).

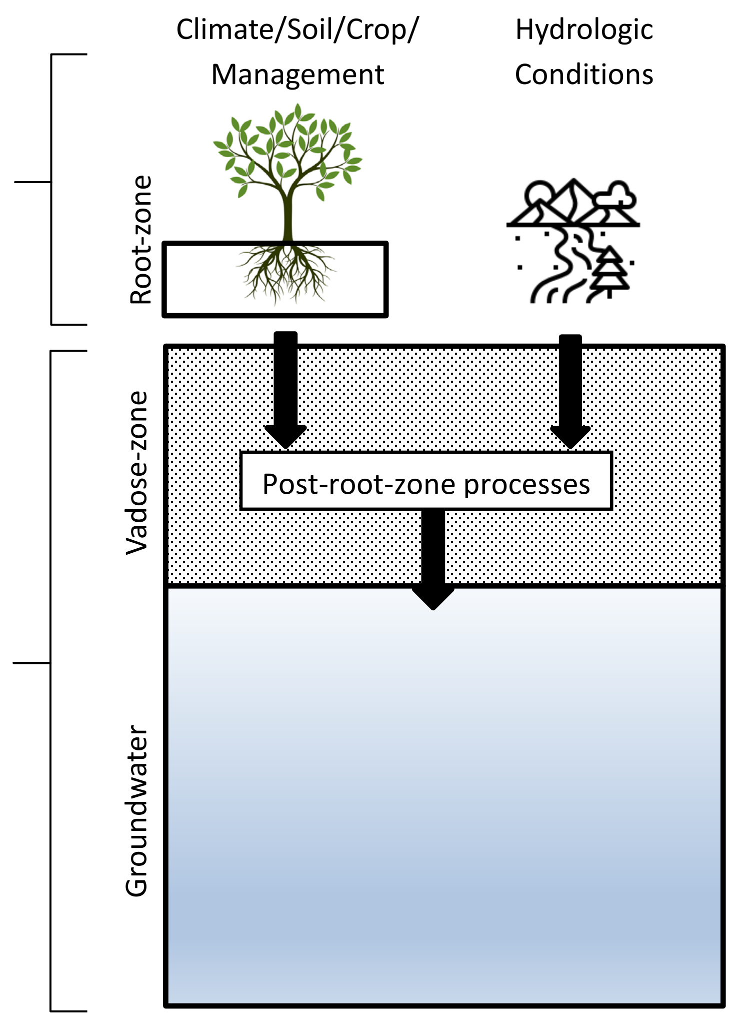


FIGURE 4. TIMELINE OF ROOT-ZONE AND GROUNDWATER MODEL DEVELOPMENT AND APPLICATION FOR THE GROUNDWATER PROTECTION FORMULA, VALUES, AND TARGETS.

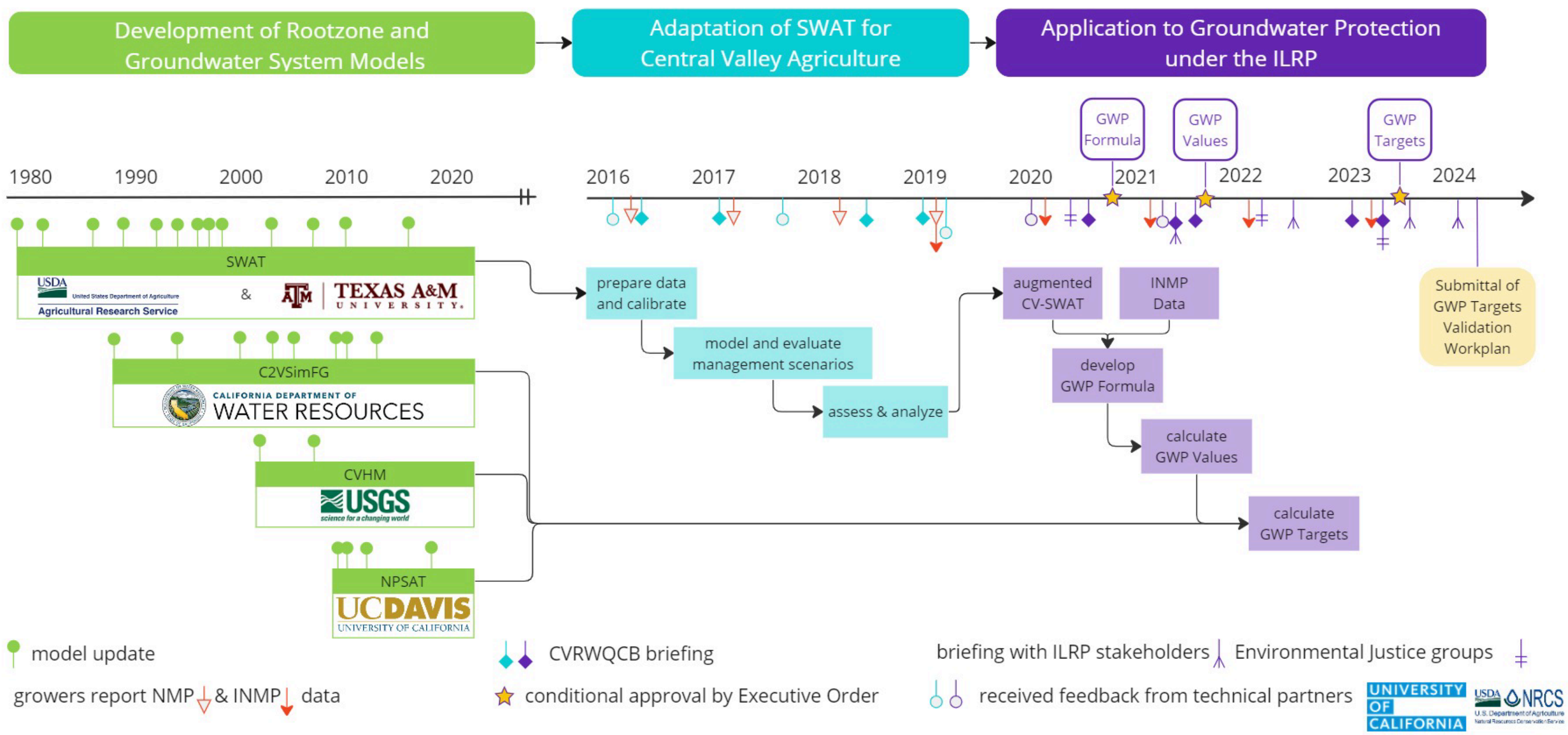


TABLE 2. CONDITIONS OF APPROVAL FROM THE CVRWQCB EXECUTIVE OFFICER FOR THE GROUNDWATER PROTECTION FORMULA, VALUES, AND TARGETS.

Conditions of Approval	Status
GWP Formula	
Documentation of model inputs and results used to develop the Root-zone Library (crop growth parameter definitions and values, management parameters, irrigation method and volume by crop, crop coefficients, assumed irrigation efficiency, etc.).	Complete / included in GWP Values Report
A sensitivity analysis that identifies the model parameters exhibiting the largest influence on N losses (e.g., volatilization, sequestration, runoff) for each of the top five crops by acreage.	
A summary for each of the three model domains describing the range of estimated N losses by crop. At a minimum, the summary should include each of the top five crops by acreage.	
Summaries of overall water budget (precipitation, runoff, ET by crop, irrigation, percolation) and N mass balance (applied, uptake, runoff, deposition, denitrification, volatilization, storage, leached) by township.	
Descriptions of the specific methods and criteria that will be used to account for post-root-zone processes (if any). Any proposal would be subject to public review and EO approval before use.	
Comparisons of other sources of percolation and nitrate leaching estimates (e.g., field studies, HYDRUS) to model estimates.	
Comparisons, aggregated by township, of grower-reported data (N applied, N removed) to model estimates (N applied, N Removed, N Leached).	
GWP Values	
Assessment of model performance with respect to any relevant and available information (e.g., pending UC Davis field studies, updated crop-specific coefficients for conversion of yield to nitrogen removed).	Section 3.1 of this Workplan
GWP Targets	
A workplan that describes a proposed methodology for conducting a detailed uncertainty analysis and plans for validating model outputs and key components.	Section 3.1 – 3.5 of this Workplan
Following approval and implementation of the workplan, a final report shall be submitted that includes results of the uncertainty analysis and provides recommendations to refine the GWP Targets during preparation of the 5-Year GWP Targets Update report. This report must also specifically address the "apparent overestimations of nitrate-N" noted in portions of the Sacramento Valley and identify a method to be used to calculate appropriate GWP Targets for these townships during the next five-year update.	To be developed pending approval and implementation of this Workplan
By 1 July 2024, the Coalitions must submit GQMP updates that incorporate the approved GWP Targets and contain the required components identified in Appendix MRP-1 of the ILRP General Orders.	GQMP updates to be submitted by July 1, 2024

Notes:

The GWP Formula Workplan was submitted July 1, 2020, and conditionally approved January 19, 2021.

The GWP Values Report was submitted July 19, 2021 and conditionally approved October 27, 2021. An addendum was submitted December 15, 2021.

The GWP Targets Report was submitted July 19, 2022, and conditionally approved June 30, 2023.

GWP FORMULA

The purpose of the GWP Formula is to capture the current state of the agricultural landscape with respect to potential nitrate-N discharges below the root-zone. The effects of irrigated agriculture on groundwater quality are mediated through the crop root-zone, which in turn is influenced by soil properties, climate, crop type, and management. As such, a robust GWP Formula that considers these factors is paramount for the accurate characterization of agricultural discharges below the root-zone (i.e., the GWP Values) and for setting GWP Targets and tracking progress towards their achievement.

For these reasons, the Coalitions elected to develop a process-based root-zone model capable of reflecting many distinct and unique crop x soil x climate x landscape position x management scenarios. This effort was supported in part by a $2 million Conservation Innovation Grant awarded to several Coalitions by NRCS. In partnership with the NRCS, UC, and other agriculture industry experts, the Coalitions evaluated several commonly used root-zone models, including the Soil and Water Assessment Tool (SWAT), HYDRUS, and the Root-zone Water Quality Model (RZWQM). The Coalitions ultimately selected SWAT, which is the product of over 40 years of continuous model development by the United States Department of Agriculture – Agricultural Research Service, Texas A&M AgriLife Research Agency, and numerous other public and private collaborators (Figure 4). SWAT was selected due to its detailed and comprehensive representation of the crop root-zone, the presence of a crop growth model, rigorous vetting and refinements, and its ability to feasibly and efficiently simulate large watersheds like those in the Central Valley without sacrificing important spatial and temporal detail (i.e., SWAT simulates sub-field conditions on a daily timestep). To adapt SWAT for the Central Valley (i.e., to build CV-SWAT), the Coalitions integrated detailed climatic and soil data, defined representative crop management scenarios, and calibrated crop models to reflect California production systems. More information on the CV-SWAT model can be found in Appendices 3 and 4 of the GWP Values Report (Central Valley Coalitions, 2021 and 2021a) and in the SWAT Report (MPEP Team, 2019).

In contrast to the selected approach, the NMP/INMP data can be used to develop a simplified metric of N potentially available for leaching below the root-zone. Reported yield can be converted to an estimate of N removed (R) based on N removal coefficients developed by Geisseler (2016, 2021). These data can be used to develop a simple (partial) mass balance (A-R, or applied minus removed N) for each unit within the Central Valley and to create an estimate of N potentially available for leaching below the root-zone. However, due to the complexity of the N cycle, A-R does not actually reflect or equate to nitrate-N leaching below the root-zone because there are multiple potential fates of root-zone N that are affected by biological, physical, and chemical processes. Moreover, the response of root-zone N dynamics to management is an important linkage to be understood by growers and advisors so that N can be managed efficiently. Accordingly, the Coalitions selected the process-based root-zone model described previously in connection with the NMP/INMP data.

The GWP Formula integrates grower reported NMPs/INMPs with the CV-SWAT model to simulate nitrate-N loading estimates at the sub-field scale (Figure 5, Figure 6). To reflect the diversity of N application rates and yields reported in NMPs/INMPs, an automation procedure was developed to simulate approximately 450-750 management scenarios per crop across each soil x climate combination in each watershed. The annual average was taken for each 38-year simulation of unique crop x climate x soil x management combination and stored in a database referred to as the Root-zone Library. The Root-zone Library includes more than ½ billion modeled outputs of nitrate-N discharge below the root-zone based on crop, soil, climate, applied N, and yield. Entries in the Root-zone Library are matched with INMP Summary Reports for each GWP Township.

GWP VALUES

The GWP Values reflect the sub-field level physical processes simulated in CV-SWAT to calculate robust estimates of N loads and percolation at the bottom of the root-zone based on grower-reported INMP/NMP Summary Report data. This calculation is done by matching the appropriate Root-zone Library entry with INMP/NMP Summary Report data (based on yield, applied N, soil, climate, and parcel) and aggregating the results to the township level (Figure 6). The GWP Values (reported as Nitrate-N load) express the mass of nitrate-N at the bottom of the root-zone in total pounds (lbs) and average pounds per acre (lbs/ac) for each high priority township.

The Coalitions submitted GWP Values for the 399 GWP Townships based upon the NMP/INMP data reported in the 2019 crop harvest year. Supporting documentation (Table 2) included 1) the modeled N and water mass balances simulated for each GWP Township and for major crop types, 2) the CV-SWAT model inputs, 3) the CV-SWAT comparisons to scientific literature findings and other process based modeled (i.e., HYDRUS 2D/3D) to support model validation, 4) summary information on the Root-zone Library, and 5) a sensitivity analysis of model parameters on simulated N fates. This information aided public review and validation of the CV-SWAT model and GWP Values.

FIGURE 5. INFOGRAPHIC OF GROUNDWATER PROTECTION FORMULA AND VALUES.

The GWP Formula includes three steps. Step 1 involves aggregation and analysis of daily climatic, detailed soil, parcel, and Irrigation and Nitrogen Management Plan (INMP) Summary Report data. Step 1 also includes development of a Matrix that reflects the reported distribution of applied nitrogen and yield for each crop. Step 2 includes evaluating those data using the Central Valley Soil & Water Assessment Tool (CV-SWAT) to estimate percolation and nitrate-N loading below the root-zone for each management scenario. Model output will be cataloged in a Root-zone Library. Step 3 includes aggregation of the results to the township scale to provide root-zone-based GWP Values. This will be done by 1.) matching the appropriate Root-zone Library entry (from the CV-SWAT model) to each INMP report (based on yield, applied N, soil, climate, and parcel) and 2) developing a "calculator" to aggregate the resulting percolation and nitrate-N loading estimates to the township scale.

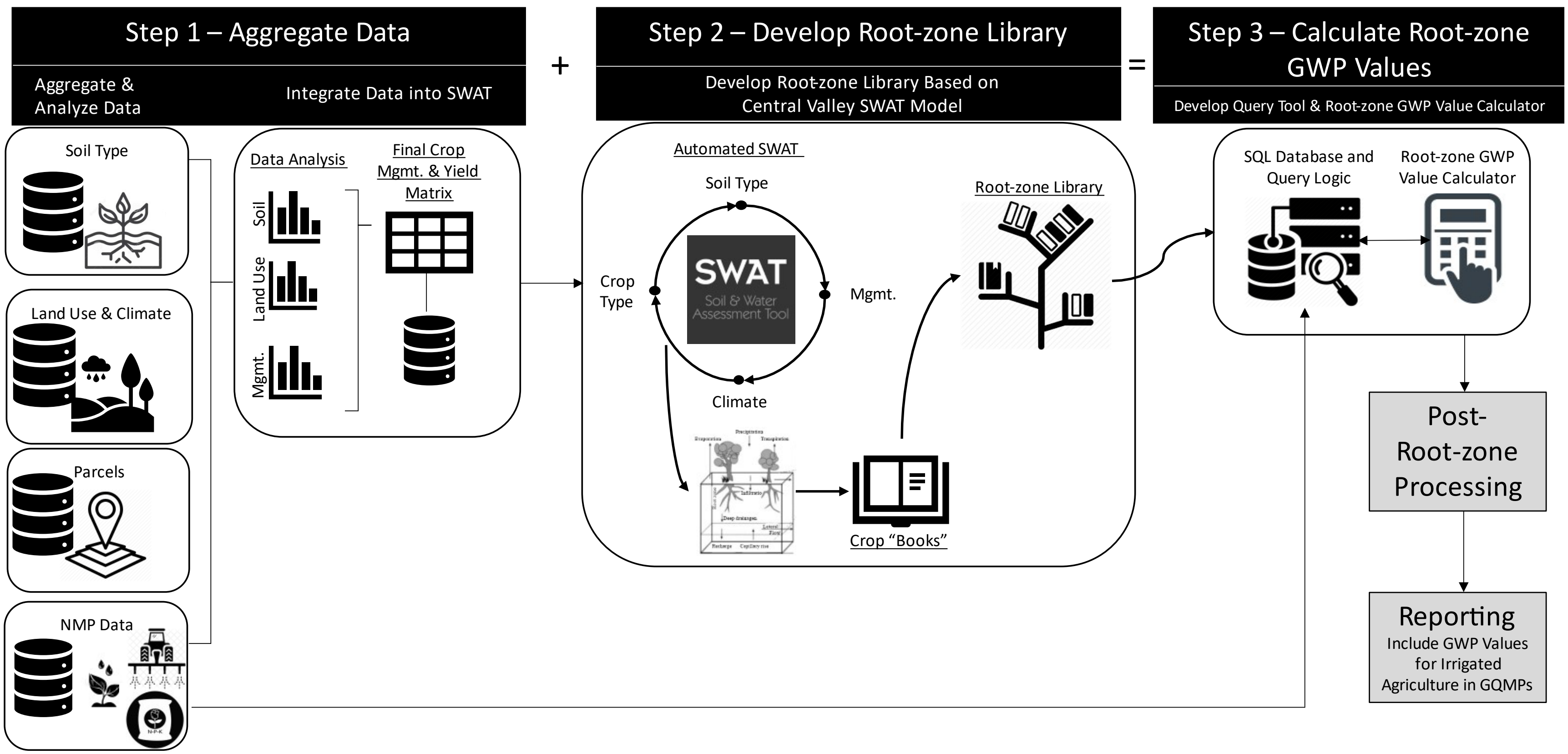
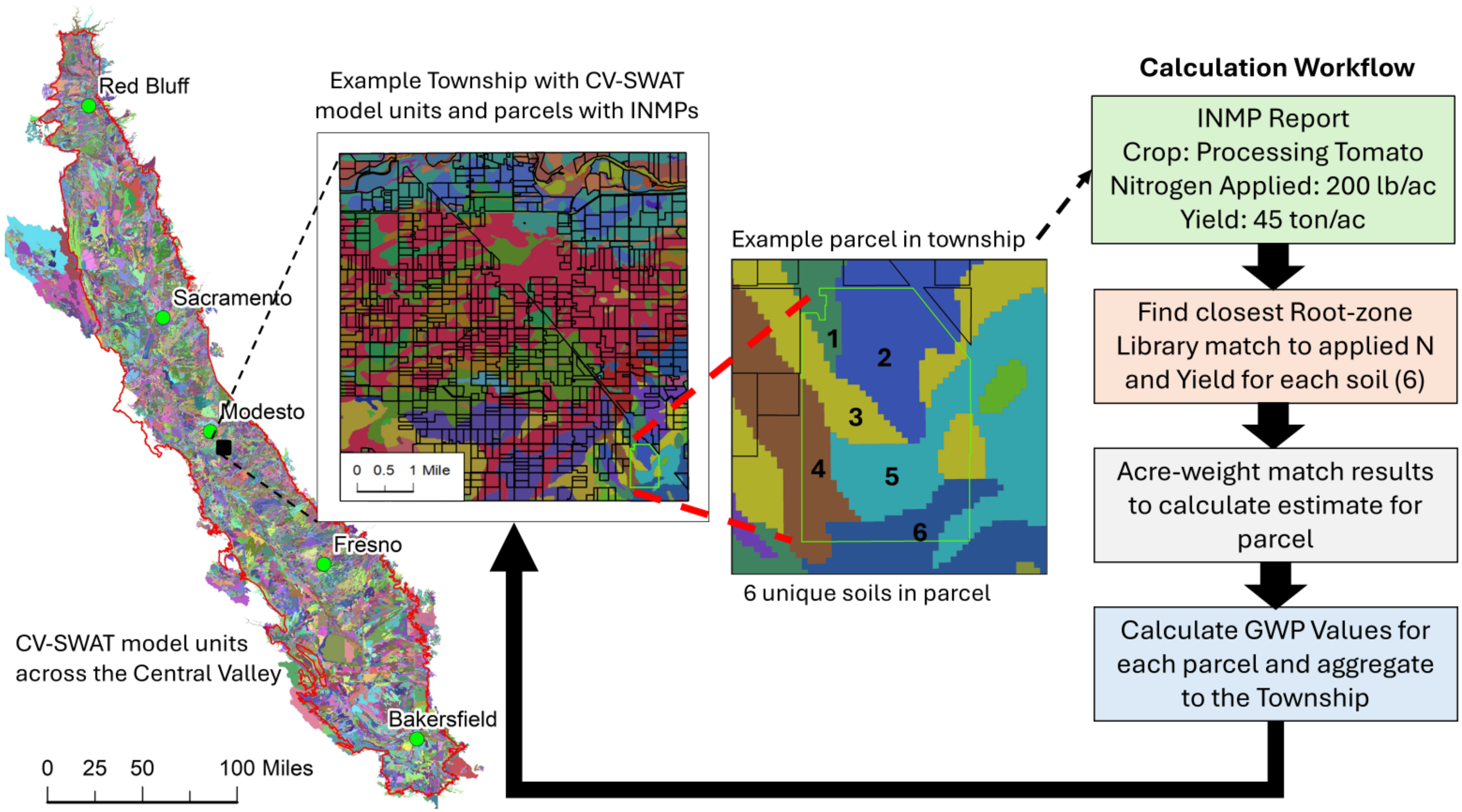


FIGURE 6. OVERVIEW OF THE GWP VALUE CALCULATION BASED ON CV-SWAT RESULTS AND GROWER-REPORTED INMP/NMP SUMMARY REPORT DATA.



GWP TARGETS

The purpose of the GWP Targets is to define loading targets (i.e., average lb N/ac at the bottom of the root-zone) to comply with receiving water limitations after considering other relevant post-root-zone processes. The calculation of GWP Targets requires integrating the GWP Values (i.e., nitrate-N loading estimates from irrigated agriculture) into the broader Central Valley hydrologic system to understand the effect of current agricultural management practices on groundwater quality. The assessment framework for developing GWP Targets entails using CV-SWAT and other surface loading information in conjunction with a groundwater model capable of simulating the fate and transport of nitrate-N (i.e., the Non-Point Source Assessment Tool [CV-NPSAT]). This framework facilitates consideration and incorporation of hydrologic conditions, other nitrate-N and water sources, and post-root-zone processes (Figure 7). Specifically, the assessment framework to determine the GWP Targets includes the following:

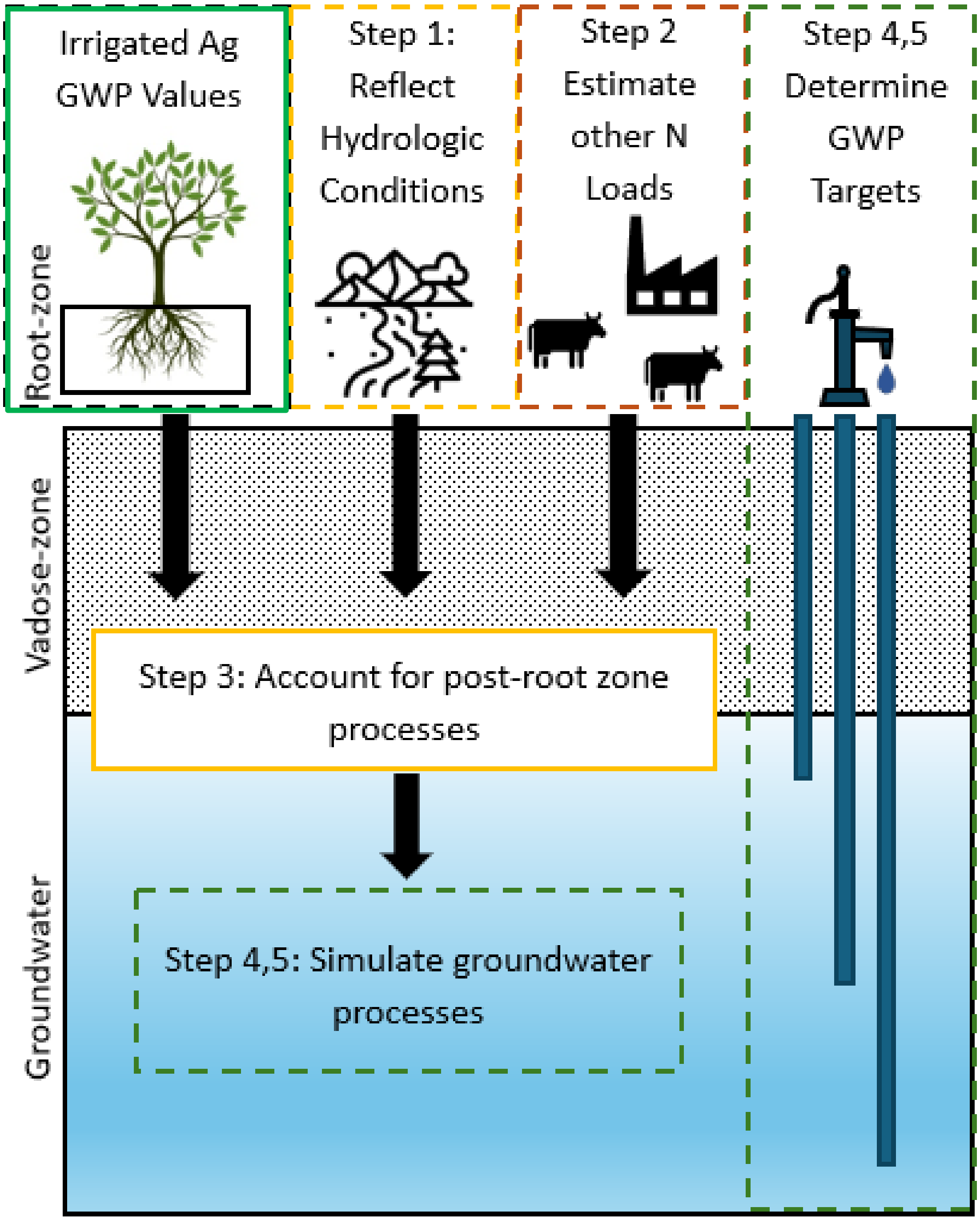
- **Step 1. Reflect Regional Hydrologic Processes and Recharge**. In its current form, CV-SWAT does not consider recharge from natural streams/rivers, canals, or recharge basins/projects, which realistically impacts groundwater quality. As such, comprehensive recharge estimates were incorporated into the assessment framework using regional hydrological models. These models have been developed and refined over time by the California Department of Water Resources (DWR) and the United States Geological Survey (USGS), namely the California Central Valley Groundwater-Surface Water Simulation Model Fine Grid version (C2VSimFG) (DWR, 2020) and the Central Valley Hydrologic Model (CVHM[5]) (Faunt, 2009), respectively (Figure 4). More recently, DWR has also developed the Sacramento Valley Groundwater-Surface Water Simulation Model (SVSim) that only covers the Sacramento Valley. These calibrated models are the best available tools to simulate regional hydrology and include subsurface texture models based on well bore logs and land surface water balances for agriculture and other land uses. However, these models do not currently simulate the fate and transport of solutes such as nitrate, meaning a groundwater model (i.e., CV-NPSAT) was necessary to identify GWP Targets.

  CV-NPSAT was developed by UC Davis with funding from the California State Water Resources Control Board and NRCS (Kourakos et al., 2012, Kourakos and Harter, 2014a, Kourakos and Harter, 2014b, Kourakos and Harter, 2021). CV-NPSAT is based on a scientifically reasonable steady-state hydrology representation (Bastani and Harter, 2020) and simulates non-point source pollution transport through groundwater to wells and is intended to be used by stakeholders, decision-makers, and land managers to understand the potential effects of future management practices on water quality. Different versions of CV-NPSAT exist that are based off C2VSimFG, CVHM, and SVSim. The assessment framework used the C2VSimFG version as it represented the most current and up-to-date hydrology at the time of computing GWP Targets. Moreover, the long-term average recharge volumes from C2VSimFG's calibrated period (1985-2015) were used to compute the nitrate-N concentration entering the aquifer in CV-NPSAT.

[5] CVHM2 has not yet been released to the public, but is currently being reviewed by researchers at UC Davis.

FIGURE 7. OVERVIEW OF ASSESSMENT FRAMEWORK USED TO DETERMINE GWP TARGETS.

The root-zone-based GWP Values were calculated using the approved GWP Formula for irrigated agriculture in GWP Townships (green box). The GWP Targets were determined with other scientifically supported variables that influence the potential average concentration of nitrate-N in water expected to reach groundwater.



- **Step 2. Estimate N Loads from other Dischargers**. The determination of GWP Targets requires the most up to date and accurate nitrate-N loading information to better evaluate the impacts of surface processes on underlying groundwater quality. As such, the Coalitions developed a new nitrate-N loading map for integration in the assessment framework. It includes estimates of nitrate-N loads 1) for irrigated agriculture on HVA lands (i.e., GWP Values), 2) for irrigated agriculture outside of HVAs (where GWP Values do not exist) based on the Root-zone Library in conjunction with the most current DWR land use maps available, 3) for dairy land generated in collaboration with the Central Valley Dairy Representative Monitoring Program (CVDRMP), and 4) for urban areas (e.g., golf courses, residential areas, wastewater treatment plants, etc.) set to discharge at 10 mg nitrate-N/L. These estimates were assumed as one bookend.
- **Step 3. Consider Post-root-zone Attenuation Processes**. The assessment framework includes a conservative approach to accounting for the post-root-zone processes that support nitrate-N attenuation. Currently, CV-NPSAT does not currently consider denitrification in either the sub-root-zone vadose zone or saturated zone. However, there are numerous California-specific studies and literature that call out certain conditions that favor post-root-zone nitrate-N attenuation, and that include some estimates of denitrification rates for specific portions of the Central Valley. Based on available data and studies, the assessment framework currently considers denitrification in the saturated zone under certain specified conditions through a post-processing step. For the vadose zone, the assessment framework currently does not account for nitrate-N attenuation that may occur. Because denitrification and other attenuating factors are not considered in the vadose zone, and these are conservatively represented in the saturated zone, the GWP Targets are themselves conservative.
- **Step 4. Simulate Groundwater Processes and Impacts to Groundwater Quality.** This step includes updating CV-NPSAT with the results from Steps 1 through 3 (above) to connect surface loading to the groundwater processes simulated in CV-NPSAT. CV-NPSAT simulates the water quality of groundwater pumped from virtual domestic wells. Simulations focus on water quality in the virtual domestic wells because they typically represent the drinking water supply most vulnerable to nitrate-N loads and would therefore lead to conservative GWP Targets. The virtual domestic wells in CV-NPSAT are based on the dataset prepared by Pauloo et al. (2019) that reflects approximately 95,000 DWR Well Completion Reports from the California Open Data Portal (data.ca.gov).
- **Step 5. Determine GWP Targets.** The GWP Targets were calculated by determining the GWP Township load reduction required to comply with receiving groundwater limitations based on modeled predictions of future water quality in virtual domestic wells with current nitrate-N loading and hydrology. The GWP Targets reflect the acre-weighted average nitrate-N loading (lbs/ac) at the bottom of the root-zone determined through CV-NPSAT simulations to ensure irrigated agriculture is not causing or contributing to an exceedance of the water quality objective in water pumped from domestic wells.

GWP Targets were computed for 379 of the 399 GWP Townships. A total of 20 GWP Townships were identified where shallow groundwater monitoring data demonstrate low nitrate-N concentrations while CV-NPSAT estimated apparent overpredictions of nitrate-N concentrations. More explanation on potential reasons for this are provided in the GWP Targets Report, and additional efforts are proposed in this Workplan (Section 3.4) to address this discrepancy and develop GWP Targets for these 20 GWP Townships during the next update to GWP Targets, which is due June 30, 2028.

In addition to the GWP Targets Report, the Coalitions also provided a technical memorandum in response to a CVRWQCB request for more detailed modeling information related to hydrology and recharge, as well as the handling of other N loads.

With the initial GWP Targets computed, the Coalitions have begun activities to ensure progress is made toward achieving them, where changes in N leaching rates are currently determined to be necessary. This includes preparing and submitting updates to GQMPs by July 1, 2024, to include the GWP Targets (Table 2) as performance goals, in addition to the Interim Milestones proposed by the Coalitions to focus on near-term load reduction opportunities (Central Valley Coalitions, 2022). Individual strategies to facilitate improved N use efficiency and reduced nitrate-N loading may differ among townships, but Coalitions will likely leverage the detailed information developed through the assessment framework (e.g., grower-reported INMPs, CV-SWAT simulations in the Root-zone Library, the GWP Values) to strategize tailored approaches for specific townships. In addition, complementary programs run by the Coalitions, such as the Management Practices Evaluation Programs (MPEP) (a requirement under the LTILRP), include substantial outreach and education initiatives that leverage existing research and publicly available resources (e.g., UC Cooperative extension, Resource Conservation Districts, California State University system, competitive funding programs from the USDA and CDFA) to educate growers and their advisors on the GWP Formula, Values, and Targets, and provide relevant information and tools to support the achievement of GWP Targets. The Coalitions are committed to working towards these performance goals before the next GWP Targets update and beyond.

2.4 STRENGTHS AND UNCERTAINTIES WITH ASSESSMENT FRAMEWORK

As described throughout the GWP Reports, the assessment framework uses the best available data and tools (Central Valley Coalitions, 2020, 2021, 2021a, and 2022) that are the product of decades of investments, research, refinements, and validation from academic institutions and government agencies (see first column of Figure 4). Moreover, their adaptation by the Coalitions, including the integration of spatially and temporally detailed grower-reported data, to address the GWP requirements reflects a scientifically rigorous and substantial undertaking. Through responsive and frequent interactions, the Coalitions were able to provide sufficient explanation, justification, and data and information to the CVRWQCB to receive conditional approvals of the GWP Formula, GWP Values, and GWP Targets.

Nonetheless, when addressing such a complex environmental issue over a vast and diverse landscape, uncertainty around modeled inputs and outputs will exist. It is therefore important to remain cognizant of the limitations of available data and existing models, the sensitivity of relatively unknown model parameters on key outputs, and temporal and spatial scales that are appropriate for the use and interpretation of model output for achieving regulatory objectives. For example, CVHM (Faunt, 2009) and C2VSimFG (DWR, 2020) documentation highlights several facets of uncertainty that influence locally modeled groundwater pumping and recharge across the model domain, including but not limited to: 1) representation of aquifer sedimentary layering and properties, 2) surface water inflows and diversions, 3) temporal land use change and adaptation of agricultural management practices during droughts, and 4) lack of representation of emerging groundwater recharge projects, especially in the Tulare Basin (Faunt 2009; DWR 2020). In spite of these uncertainties, CVHM documentation describes that the model is "likely…to represent features accurately at a scale of approximately 5 mi^2," a scale finer than the township-based GWP process. Furthermore, it is important to consider how groundwater quality is influenced and assessed by non-point source discharges. As described by Bastani and Harter (2020) with regard to non-point source pollution policy aimed at protecting hundreds to thousands of wells, "*predicting exact local nonpoint source contaminant behavior is less important, while the more critical decision support will be to correctly predict regional distribution, variability, and trends of water quality across the wells of concern, and to explore how these may change over time without and with land management changes"* and that "*upscaled or effective groundwater flow and transport models for practical scenario analysis and predictions at large scales are needed"*. Moreover, these authors go on to show that responses to groundwater quality as a function of changes in management of the crop root-zone can require years to decades to manifest. These facts suggest that characterizing and addressing uncertainty in the representation of the groundwater system should focus more so on an upscaled (broader) spatial and (longer) temporal basis.

In contrast to this is the finer spatial and temporal scale at which the crop root-zone varies as a function of varied conditions and management. Given that this is the portion of the system that can be most readily managed by growers, it is critical to ensure that the GWP assessment framework represents it with as high a degree of certainty as is feasible to understand how management actions will actually affect groundwater quality. Accordingly, the CV-SWAT model is simulating a finer spatial (sub-field) and temporal (daily) level of detail compared to the groundwater models and uncertainty assessments and validation efforts should focus on review of model outputs at the field scale and within and across growing seasons.

The continued characterization of uncertainty with the key aspects of the GWP assessment framework will be useful for informing updates to GWP Targets moving forward. Below lists what are considered to be the current strengths and recognized uncertainties associated with this framework.

Key existing strengths include:

- Modeling tools are physically based and rely on known physical processes related to the N cycle and water and solute movement through a porous system.
- Modeling tools optimize use of detailed data on climate, soil and subsoil characteristics, land use, and water use.

- Modeling tools have been accepted by the scientific community and utilized in a variety of applications within California, the U.S., and abroad.[6]
- The CV-SWAT linkage to CV-NPSAT provides a substantially improved representation of the crop root-zone and its connection to the groundwater system as compared to the existing groundwater models.
- This framework allows for the computationally efficient simulation of various crop root-zone management practices and their effect on future water quality across the entire Central Valley for approximately 95,000 virtual domestic wells – as contained in the CV-NPSAT.
- Existing documentation across all modeling tools highlights their ability to produce outputs consistent with monitoring data and other models. For more information, see the following:
    - The GWP Values Report (Central Valley Coalitions, 2021 and 2021a) for CV-SWAT.
    - The C2VSimFG Version 1.0 Development and Calibration Report (DWR, 2020).
    - The assessment of groundwater availability in the Central Valley with CVHM (Faunt, 2009).[7]
    - The evaluation of CV-NPSAT to a sub-regional calibrated MODFLOW-MT3D groundwater model (Bastani et al., 2019).
- Tools are in a constant state of evaluation and refinement and will continue to be improved over time.

Meanwhile, several uncertainties are described in the GWP Targets Report and in the conditional approval by the CVRWQCB. A summary of the recognized uncertainties is provided below and detailed in Section 3.

- **Irrigated agriculture and the GWP Values.** Uncertainty includes CV-SWAT performance of simulated N and water balances under additional Central Valley crop x soil x climate x management scenarios not yet evaluated.
- **Hydrologic conditions.** Uncertainty includes:
    - Representation of the Central Valley groundwater system simulated by the latest (or pending) versions of C2VSimFG and CVHM (i.e., CHVM2), both within and across both groundwater models, including:
        - Aquifer sediment texture models and associated hydraulic conductivities and storage properties.

[6] https://swat.tamu.edu/publications/ is a comprehensive database for scientific publications leveraging the SWAT model.
[7] The CVHM-based version of CV-NPSAT was not used to determine GWP Targets because the simulation period in CVHM terminates in 2003, whereas C2VSimFG simulates through the end of water year 2015. As described in Section 3.2, CVHM2 will be evaluated moving forward when it is available for use.

        - Regional, subregional, and local representations of water budget terms including water deliveries, groundwater pumping, total applied water, evapotranspiration, total recharge, groundwater flow, and changes in groundwater storage.
        - The response of groundwater models to perturbations and changes in how the system is managed.
    - How land use, regional hydrology, and water management will evolve as a function of SGMA and other drivers (e.g., local, national, and global food markets), and what the implications will be for local irrigation practices, consumptive water use, local recharge projects, and ultimately GWP Targets in the future. It is important to note, however, that while these potential changes to land use and crop and water management introduce uncertainty around future GWP Targets, the assessment framework is capable of reflecting them as they occur.
- **Other nitrate-N loads.** Uncertainty includes the magnitude and variability of other N loads within GWP Townships, as well as how they may change as a function of CV-SALTS implementation.
- **Post-root-zone denitrification.** Uncertainty includes the magnitude and spatial distribution of post-root-zone denitrification in the vadose zone and groundwater nitrate-N concentrations.
- **Groundwater processes and estimating well nitrate-N concentrations to determine GWP Targets.** Potential refinements or adjustments to the methodology employed for interpreting modeled output for the purposes of updating GWP Targets.

3 ASSESSMENT FRAMEWORK VALIDATION, UNCERTAINTY, AND REFINEMENT

This section describes the proposed activities the Coalitions will engage in, in collaboration with UC researchers, the CVRWQCB, commodity organizations and other stakeholders, to characterize and minimize uncertainty (where possible) within the assessment framework components as well as perform additional validation efforts. If approved and implemented in a manner as set forth in this Workplan, the results of the proposed activities in this Workplan will be documented and reported to the CVRWQCB within approximately three years and one-year before the update of the GWP Targets due June 30, 2028. Three years is necessary given the scope of the Workplan and time needed for specific activities (Figure 1). During the three-year implementation period, this Workplan proposes three workshops with the CVRWQCB and other stakeholders to review progress and preliminary results related to specific activities. The final report will include key findings of these activities and propose how they will be used to update GWP Targets. These updates will further inform growers and their Coalitions on GWP Targets to manage towards, as well as provide additional assurance to the CVRWQCB and stakeholders that irrigated agriculture will not be causing or contributing to an exceedance of the water quality objectives if the GWP Targets are achieved.

Several of the identified activities are anticipated to be completed before the next review and update of the GWP Targets, whereas other activities will be continually refined and improved by the Coalitions over time or by ongoing initiatives by other stakeholders. Ongoing initiatives by other stakeholders include groundwater model refinements by model developers (DWR, USGS, UC Davis) and estimates of local water budget components prepared by GSAs. It is important that all data used in the assessment framework are the best available and be applicable at the scale necessary to inform the GWP. Overtime, this will result in continually improved GWP Values and Targets.

Notably, several items need to be considered when discussing the validation, characterization and minimization of uncertainty, and general refinement to the assessment framework. First, the assessment framework integrates many datasets, utilizes a groundwater flow and transport model (CV-NPSAT) that is based upon other hydrological models (C2VSimFG, CVHM/CVHM2), and couples a detailed root-zone loading model to the groundwater flow and transport model. This degree of complexity is necessary to develop a scientifically rigorous answer to the question at hand. This complexity does mean, however, that the degree to which various components of the assessment framework can be validated, and their uncertainty quantified and minimized, will vary somewhat. For instance, conducting a sensitivity analysis of uncertain model parameters (a common approach to understand model uncertainty) is infeasible when the chain of events required to complete a model simulation is considered (e.g., re-run the Central Valley groundwater model followed by re-solving the flow field of CV-NPSAT). This then requires that a thoughtful approach be taken when seeking to achieve the objectives of this Workplan. Some key pillars include:

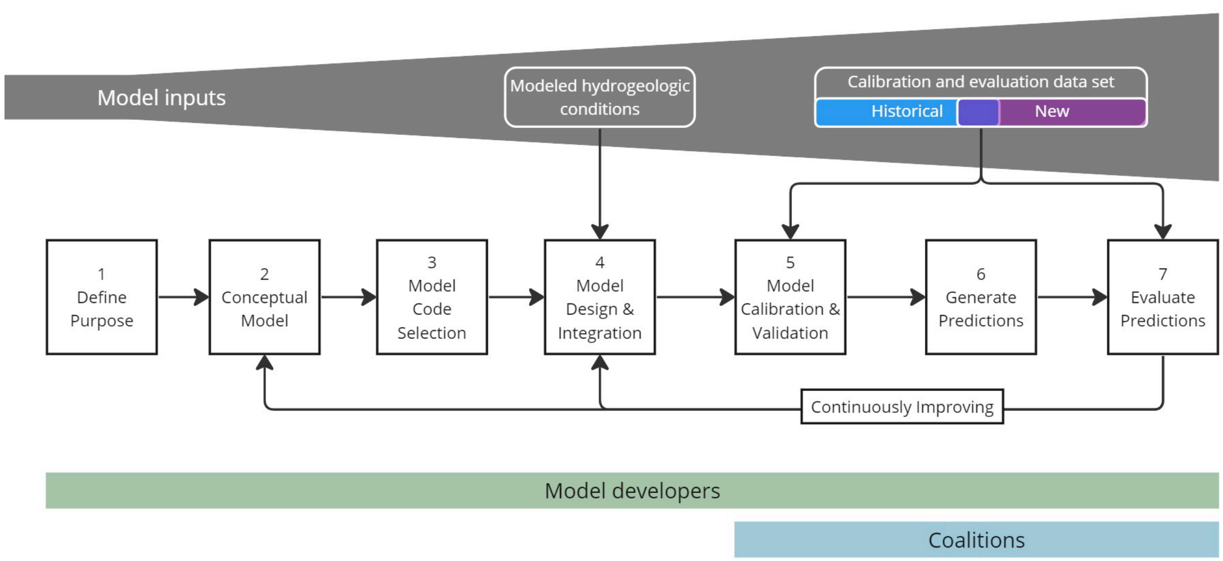
- Understand and remain cognizant of sources of uncertainty identified by the model developers (DWR, USGS, UC Davis),

- When appropriate, seek to improve specific aspects of the assessment framework inputs to contribute to robustness of the approach (i.e., improved inputs equal improved outputs),
- Identify and conduct feasible validation exercises and uncertainty analyses with existing available information to inform existing strengths and areas for refinement,
- Identify appropriate approaches to account for uncertainty in the context of determining GWP Targets, and
- Understand that, over time, additional data, information, and model refinements will be available to further improve the assessment framework.

The following sections outline the proposed activities to support validation, characterize uncertainty, and refine the assessment framework. These activities should be considered in the context of a general modeling protocol as depicted in (Figure 8). The sections are organized by the key themes and the activities are numbered according to whether they primarily apply to the GWP Formula (Activity F), GWP Values (Activity V), or GWP Targets (Activity T), recognizing that several activities are interconnected. As shown in Figure 1, some of the activities are sequential, whereas others will occur simultaneously. Each activity will ultimately lead to a refined and/or clearer estimation (i.e., with a lesser degree of uncertainty) of appropriate GWP Targets for irrigated agriculture.

FIGURE 8. MODELING PROTOCOL SCHEMATIC (ADAPTED FROM ANDERSON ET AL. [2015]).

This schematic illustrates the main steps of the modeling protocol, includes planning (Steps 1-3), model development (Step 4), calibration and validation of historical conditions utilizing available data (Step 5), and generating and evaluating model predictions (Steps 6 and 7). As illustrated, the evaluation of predictions leads to model improvements through re-visiting the conceptual model (Step 2) and onward. Moreover, historical and newly acquired data can support calibration/validation efforts (Step 5) as well the evaluation of predictions (Step 7). The model developers (USDA, DWR, USGS, UC Davis) have engaged and will continue to engage in the entire modeling protocol (Steps 1-7). The Coalitions are focused on model calibration and validation (Step 5) of CV-SWAT as well as generating and evaluating model predictions (Steps 6 and 7) with CV-SWAT and CV-NPSAT as they are refined.



3.1 IRRIGATED AGRICULTURE AND THE GWP VALUES

Activities to characterize and minimize uncertainty as well as validate CV-SWAT include incorporation of newly available and relevant data to 1) refine the Root-zone Library based on published N-removal coefficients, 2) assess CV-SWAT results relative to new monitoring data from UC Davis field studies and other root-zone models, and 3) calculate annual GWP Values. Specifically, this includes the following:

Activity F1. Continually refine the Root-zone Library to reflect newly available data. The Coalitions are assessing N removal and N storage in perennial plant parts in collaboration with UC researchers and with support from a CDFA FREP grant. This involves procuring and analyzing harvested crop materials for the N content to refine the crop N removal coefficients utilized in INMP Summary Reporting and CV-SWAT modeling. New or refined N-removal coefficients for nine crops are anticipated to be published in March 2024, followed by an additional 25 crops in December 2024. After publication, the crop model parameters for each of these 34 crops will be updated in CV-SWAT and new Root-zone Library entries will be generated. These refinements will reduce uncertainty in CV-SWAT estimates of nitrate-N loading below the root-zone.

The Coalitions will continue to refine and update the Root-zone Library as-needed as additional data and information are made available (e.g., new N removal data) from university researchers and/or commodity groups.

Activity F2. Assess CV-SWAT results relative to newly available data from field studies and other root-zone models. As described in Section 2, CV-SWAT has been calibrated and validated as documented in the GWP Values Report (Central Valley Coalitions, 2021 and 2021a). That said, it is understood that CV-SWAT would benefit from additional validation to increase confidence in results from the model simulations. This validation will be accomplished through a comparison of CV-SWAT's predictions to 1) field measurements from commercial farms and 2) predictions from HYDRUS[8], a different, less comprehensive, but very detailed root-zone model.

Data from three known monitoring studies, led by UC Davis with state and federal funding, will be used to build upon the validation of CV-SWAT water and N budgets and nitrate-N leaching estimates under specific management scenarios. The studies involve data collection on commercial farms that are intensely instrumented to provide detailed water and nitrate-N data from the root-zone, vadose zone, and shallow groundwater (at one of the sites). The three monitoring sites reflect key cropping systems in the Central Valley (Figure 9). Each study is summarized below.

- **Annual Cropping System Study (Yolo County).** This study is focused on investigating the relationship between management systems and nitrate-N leaching in cropping systems

[8] HYDRUS is a numerical model that simulates water flow, solute transport, and heat transport in nonuniform soils. Recent studies have shown that CV-SWAT and HYDRUS produce comparable results in a processing tomato cropping system at the annual time scale (GWP Values Report, 2021, Raij-Hoffman, et al. 2022). The inter-model comparison completed as part of this workplan will compare new combinations of crops, soil types, and time scales to add another dimension of uncertainty assessment and validation for the outputs from CV-SWAT.

including processing tomato, cucurbits, and grain crops. It includes a co-located eddy-covariance station to measure meteorological data and evapotranspiration, as well as soil moisture sensors and a vadose zone monitoring system[9] that samples pore water in the root-zone and below. This site is currently fully instrumented and collecting plant, soil, and vadose zone water and N data.

- **Almond Study (Stanislaus County).** This study is focused on assessing the relationships between 1) management systems and nitrate-N leaching, and 2) measured water and N mass balances, measured vadose zone water and N fluxes, and measured groundwater quality (nitrate-N concentration) through development of an integrated groundwater-vadose zone-crop model. Monitoring technology includes soil moisture sensors, neutron probes, suction lysimeters, and groundwater monitoring wells. This site is currently fully instrumented and collecting plant, soil, and vadose zone water and N data.

- **Valencia Orange Study (Fresno County).** This study is focused on investigating the relationship between management systems and nitrate-N leaching in a Valencia orange grove. In 2022, researchers installed both an eddy-covariance station to measure meteorological data and evapotranspiration, and a root-zone/vadose zone monitoring system (similar to the technology employed in the Annual Cropping System Study). This site is currently fully instrumented and collecting plant, soil, and vadose zone water and N data.

The project team, including UC Davis and the Coalitions, will use the collected field data from these established, intensively monitored research sites to validate CV-SWAT. This validation of CV-SWAT is anticipated to be completed by December 2026. Further, if additional research sites are established now or in the future, the Coalitions will update CV-SWAT to include the results of additional studies.

Activity V1. **Reassess GWP Townships.** The Coalitions will reevaluate the fraction of HVA within Central Valley townships that exist in areas where GARs and HVA delineations have been updated. As done previously, GWP Townships will be defined as townships that have at least 10% HVA within their boundary. This reevaluation will be conducted ahead of each GWP Targets update to ensure that the appropriate GWP Townships are identified and GWP Values and GWP Targets are computed for them.

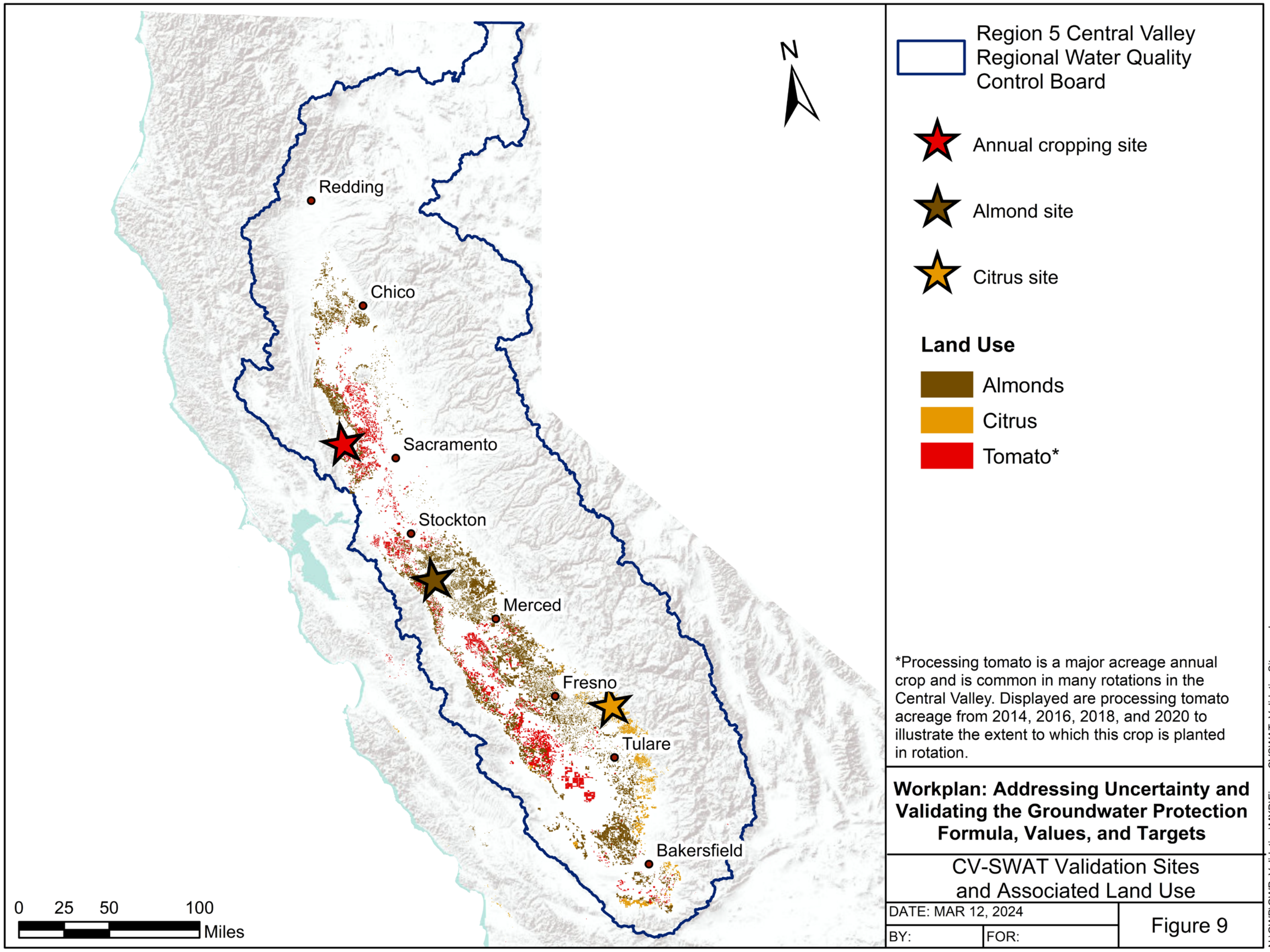
Activity V2. **Calculate GWP Values annually based on INMPs**. The Coalitions will calculate GWP Values annually based INMPs to allow the generation of rolling annual averages, rather than a single year snapshot. Benefits of this approach include improving the representation of crop rotations, improving the representation of growers' adaptive management over time, smoothing of parcel-scale highs and lows in A-R driven by abnormally low or high yields (or other factors), and reducing overall uncertainty in GWP Values. The calculation of annual

[9] https://sensoil.com/technology/

GWP Values can also be used by Coalitions to understand township-by-township progress toward achieving the GWP Targets.

Activity V3. Improve estimation of nitrate-N loads from non-HVA lands based on INMPs. The assessment framework to determine the GWP Targets includes five main steps (Section 2.3). Step 2 is estimation of all nitrate-N loads, including from dairy lands, irrigated agriculture from non-HVA lands, and urban areas. Previously, the estimation of nitrate-N loads for irrigated agriculture from non-HVA lands (where GWP Values do not exist) was based on the Root-zone Library in conjunction with the most current DWR land use maps available and local (e.g., township) averages of applied N and yield from available INMPs**.** This activity includes updating this estimate based on INMPs.

FIGURE 9. LOCATION OF THREE EXISTING MONITORING SITES THAT WILL BE USED TO SUPPORT CV-SWAT VALIDATION.



3.2 HYDROLOGIC CONDITIONS

Addressing uncertainty in modeled hydrology and validating water balance and groundwater flow estimates produced by the groundwater models is important to refining the assessment framework because 1) recharge estimates (from all sources) drive the estimated nitrate-N concentration entering the aquifer in CV-NPSAT, and 2) the groundwater flow fields determine the connections between discharge from the land surface and interception by virtual domestic wells in CV-NPSAT, thus driving estimated nitrate-N concentrations in pumped groundwater. These analyses will be achieved through 1) comparisons of available datasets that describe regional and local hydrologic conditions to understand how consistent or inconsistent estimates of groundwater recharge estimates are, 2) improvements to CV-CV-NPSAT's representation of hydrologic processes including managed aquifer recharge (MAR), and 3) continued calibration and validation activities by model developers (Figure 8). As illustrated in Figure 1, these activities will be performed in the near-term to inform the next update of GWP Targets in 2028, but will also need to continue onward into the future given anticipated model refinements, potential changes to GSPs between 5-year updates, and because of the unknown effects that SGMA and other forces (e.g., markets, drought) will have on future hydrologic conditions. Available data as well as specific proposed activities are described below in greater detail.

The main datasets that can be used to evaluate regional and local water budgets, including estimated recharge, include:

- Available GSPs,[10]
- DWR's C2VSimFG (used to compute the initial GWP Targets),
- SVSim for the Sacramento Valley,
- USGS's CVHM2 (currently in review by UC Davis), and
- The Coalitions' CV-SWAT (with incomplete hydrology and conservative irrigation assumptions).

Notably, the groundwater models developed by DWR and USGS differ in multiple respects, including how their underlying code simulates hydrologic physical processes as well as water management decisions (Dogrul et al., 2011). However, both models represent each agencies' best efforts and have been sufficiently vetted. To the point of assessing uncertainty, Harter and Morel-Seytoux (2013) described that differences among model codes "*cannot be construed as one model being better or worse than the other but represents the uncertainty arising from the difficulty of finding adequate mathematical descriptions (algorithms) of social processes (water management decision making)*". As such, the comparison of water budgets from these two groundwater models that are derived from different underlying codes, quasi-independent aquifer sediment texture models, and distinct calibration efforts, offers a robust opportunity to characterize the uncertainty in regional and local hydrology.

Another consideration is that C2VSimFG and SVSim were used by some GSAs to develop GSPs, so in some instances estimates from these data sources are not completely independent.

[10] While all GSAs within the Central Valley have submitted GSPs, not all have been found to be adequate by DWR. The reasons leading to an incomplete or inadequate designation for specific GSPs vary.

Activity T1. Evaluate uncertainty in currently available local water budget components. Researchers at UC Davis are currently reviewing CVHM2 and developing a detailed comparison to C2VSimFG and SVSim (Sacramento Valley only) at the regional and local (e.g., township) scale to identify and characterize similarities and key differences in estimated budgets, including groundwater recharge rates. The Coalitions will consider these findings and integrate them with water budget information presented in GSPs and CV-SWAT at the GSP and township scales, respectively. While it is likely the CV-SWAT will typically underestimate recharge in most cases, it does provide for a useful, conservative “bookend” for comparison.

Once compiled, the Coalitions will identify which areas have relatively consistent water budgets (with an emphasis on groundwater recharge) that can be considered to have a relatively low degree of uncertainty due to the convergence of the multiple, relatively independent datasets. For areas where water budgets differ and for specific townships highlighted by the CVRWQCB,[11] the Coalitions will consult the findings of the UC Davis groundwater model comparison and augment that analysis (as needed), including the integration of GSP information, to ascertain which factors are driving the differences. After this review, the Coalitions will furnish conclusions about appropriate data and methods for representing groundwater recharge in these areas at this time.

The model comparison carried out by UC Davis should be complete by the end of 2024. The Coalitions’ assessment of the results, subsequent analyses, and findings to address uncertainty are anticipated by the end of 2025.

Activity T2. Reduce uncertainty in modeled hydrologic conditions by incorporating groundwater model refinements when released by model developers. Moving forward, new data and information generated through SGMA, beyond what is currently available, is anticipated to be incorporated into the groundwater models. When groundwater model updates are released, the Coalitions will collaborate with the groundwater model developers to assess whether updates to the assessment framework are warranted. As described at the beginning of Section 3.2, key anticipated updates to CV-NPSAT include the handling of MAR projects. In general, these activities are anticipated to be carried out indefinitely, though specific updates (e.g., including an explicit representation of MAR projects) are expected to be included before the next GWP Targets update.

Activity T3. Validate CV-NPSAT flow field and travel times. This activity will be carried out by the CV-NPSAT developers utilizing groundwater age tracker isotopes. This activity is expected to be complete by 2025.

[11] In the conditional approval of the GWP Targets, the CVRWQCB staff identified townships for which the “scaling factor” used to align CV-SWAT recharge estimates with C2VSimFG was largest and requested that these townships be a specific focus of this Workplan.

3.3 OTHER NITRATE-N LOADS

The approach to representing nitrate-N sources from sources other than Irrigated Agriculture is important in that CV-NPSAT model results are affected by all discharges from the land surface, though the purpose of the GWP Targets as addressed in this Workplan is to identify nitrate-N loading Targets for Irrigated Agriculture. The initial approach to representing other nitrate-N loads is defined in the GWP Targets Report (Central Valley Coalitions, 2022) and involved utilizing other available data (i.e., the Groundwater Nitrate Loading Model (GNLM) developed by researchers at UC Davis) and assuming that dairy cropland was in compliance with the Central Valley's 2013 Dairy General Order requirement that A/R be 1.4 or less.

In their review, the CVRWQCB identified several GWP Townships for which 1) current monitoring data indicates exceedances of the nitrate-N maximum contaminant level (MCL), 2) the GWP Value estimates a township average discharge concentration above the nitrate-N MCL (assuming efficient irrigation in CV-SWAT), and 3) GWP Targets suggest no proposed loading reductions. This review prompted the CVRWQCB to request the Coalitions further evaluate these townships to understand what potential factors may be driving this observed anomaly.

Moving forward, under CV-SALTS, Priority 1 Management Zones have prepared and submitted Management Zone Implementation Plans (MZIPs) to the CVRWQCB. Within these MZIPs, Nitrate Reduction Programs are developed for permitted dischargers on a sector-by-sector basis. These programs include Interim Milestones, which are Nitrate Management Activities and Milestones, which are Nitrate Reduction Goals to be achieved over time to ensure that sources individually and collectively do not cause or contribute to exceedances of the water quality objectives within a time period not to exceed 35-years. One of the key Interim Milestones across all of the sector-based Nitrate Reduction Programs is to update and verify the Nitrate Loading estimates used in development of the MZIPs. This means that within five-years of implementation of the MZIPs, better, more accurate data and information should be available about the level of N loading from other sources within each township. Further, in conjunction with obtaining improved N loading data and information, the Management Zones will work with all sectors to identify Final Milestones for each sector or facility to ensure that sources collectively do not cause or contribute to exceedances of the nitrate-N water quality objective on a township or facility basis. As N loading data is refined and improved, and Final Milestones are identified, the Coalitions will use this information in the Assessment Framework to represent the other N loads.

Activity T4. Review other nitrate-N loads in GWP Townships identified by CVRWQCB. The GWP Townships will be reviewed by the Coalitions in greater detail to better understand if the representation of hydrologic conditions and other nitrate-N loads in the assessment framework, as compared to past and current conditions, contributes to identification of appropriate GWP Targets. This activity is expected to be complete by the end of 2027.

Activity T5. Integrate Nitrate Reduction Program Milestones. As the nitrate-N loading estimates and Final Milestones are determined for other nitrate-N dischargers through implementation of the Priority 1 MZIPs, the Coalitions will integrate them into the assessment framework.

3.4 POST-ROOT-ZONE DENITRIFICATION

Post-root-zone attenuation mechanisms have the potential to transform nitrate-N discharges from the land surface. Denitrification is one of the factors that can contribute to nitrate-N attenuation or transformation in the vadose and saturated zones. However, denitrification in the current assessment framework is highly conservative in the saturated zone and not considered in the vadose zone. This means the current assessment framework does not fully account for denitrification and its mitigating impact on water quality. CV-NPSAT currently conserves all nitrate-N delivered from the root-zone in the vadose and saturated zones, whereas it is known that in areas with favorable conditions (e.g., low redox potential and elevated organic carbon or other electron donors), considerable nitrate-N is converted into gaseous forms through denitrification (e.g., McMahon et al., 2008; Landon et al., 2011, Green et al., 2016). Although quantitative work to determine denitrification rates in the Central Valley has been limited, the process of denitrification is well understood, as are the environmental factors that influence it (Rivett et al., 2008).

The Coalitions hypothesized that the 20 GWP Townships identified with an apparent overestimation of predicted nitrate-N concentrations were the result of an under-estimation of post-root-zone denitrification. The following activities will determine whether this hypothesis is likely correct and will inform the setting of GWP Targets for these GWP Townships.

Activity T6. Integrate representation of denitrification into CV-NPSAT. This activity includes integrating denitrification into CV-NPSAT by the model developers with the help of available data (e.g., USGS redox maps developed by Rosecrans et al., 2017), building on previous work within the region (Liang et al., 2014, Ransom et al., 2018), and evaluating a mass-balance approach (Henri and Harter, 2022). This task is anticipated to be completed by the end of 2025.

Activity T7. Evaluate updated CV-NPSAT output for 20 GWP Townships. Once CV-NPSAT is updated by the model developers to reflect denitrification, the Coalitions will evaluate whether apparent overestimates of nitrate-N concentrations persist. If they do not, the updated version of CV-NPSAT will be used to determine the GWP Targets leading up to the next update in 2028. If the overestimates remain, the Coalitions will reassess the approach to determining GWP Targets for these townships and propose an approach to the CVRWQCB upon the submittal of the final Workplan implementation report.

3.5 GROUNDWATER PROCESSES AND ESTIMATING WELL NITRATE-N CONCENTRATIONS TO DETERMINE GWP TARGETS

The purpose of developing and implementing each component of the assessment framework is the estimation of water quality in virtual domestic wells to determine GWP Targets. Activities identified in Sections 3.1, 3.2, 3.3, and 3.4, will lead to a better understanding of sources of uncertainty, validation of key environmental components influencing groundwater nitrate-N, and a generally improved ability to determine appropriate GWP Targets. It will then be necessary to evaluate new model runs with CV-NPSAT to validate the model's ability to represent historical and current conditions and to characterize uncertainty associated with future predictions of water quality. The following activities describe the approach to these challenges:

Activity T8. Update GNLM and verify Coalition GWP Targets. Currently, the only existing alternative dataset for nitrate-N loading beyond the GWP Values is GNLM. GNLM is based on a mass balance accounting of major nitrate-N sources and sinks (e.g., fertilizer sales, crop N removal, dairy waste, urban sources, etc.) throughout the Central Valley. Although it contains spatially explicit nitrate-N loading estimates, the high-level estimates of nitrate-N for certain land uses and locations are based on various sets of assumptions that in some cases have not been evaluated to determine their level of accuracy. The GNLM assessment is currently being reevaluated and updated by its developers. This activity includes supplying summaries of updated GWP Value information to UC Davis to support refinement of the GNLM. Once GNLM is updated to better reflect actual nitrate-N loading rates, UC and/or other stakeholders can use the public version of CV-NPSAT to evaluate loading scenarios.

Activity T9. Verify CV-NPSAT predictions using historical estimates of nitrate-N loading in GNLM. Once GNLM is updated, the model developers will simulate estimated historical and current conditions of nitrate-N loading in CV-NPSAT. This, coupled with Activity T3, will determine how well CV-NPSAT estimates historical and current nitrate-N concentrations in domestic and production wells across the Central Valley. Additionally, this analysis will provide insight into the performance and accuracy of specific versions of CV-NPSAT (based on different groundwater models and/or steady state hydrology representations). This activity is anticipated to be completed by UC Davis by the end of 2026.

Activity T10. Evaluate output across different versions of CV-NPSAT to characterize model output uncertainty. The most direct and feasible way to characterize uncertainty with CV-NPSAT predictions is to simulate the multiple versions of the tool based on the different groundwater models and/or steady state hydrology representations. An additional factor can be added that entails integration of various estimates of recharge compiled under Activity T1 to compute differing nitrate-N concentrations leaving the root-zone. In this way, simulation results from the different inputs and model versions can be assessed across populations of virtual domestic wells associated with specific GWP Townships to understand the general degree of consistency or inconsistency in model predictions (e.g., in cumulative distribution functions) and contextualized with sources of uncertainty identified with the underlying groundwater models (C2VSimFG, CVHM2) and variability in recharge estimates (Activity T1). As with assessing recharge estimates in Activity T1, areas that tend to yield similar answers can be considered less uncertain, whereas areas with larger discrepancies in computed water quality concentrations and estimated required load reduction to achieve water quality objectives would be considered more uncertain.

This activity will be carried out by the Coalitions in collaboration with the model developers, with the Coalitions working with the detailed GWP Values and other N load inputs and the model developers with the updated GNLM (Activity T8). This work is anticipated to be completed by the end of 2026.

Activity T11. Evaluate appropriate methods for interpreting CV-NPSAT output and considering uncertainty in assessment framework to update GWP Targets. This activity will entail a collaboration between the Coalitions and model developers to continue to explore and understand appropriate methods for interpreting CV-NPSAT output to update GWP Targets.

This will include additional investigation into scientific literature and theories to determine whether the currently employed approach is justified or whether other promising alternatives exist. Preliminary work will be completed by the end of 2026, but efforts will likely continue thereafter.

4 TEAM QUALIFICATIONS

Soil Scientists/Agronomists
Mr. Brian Schmid: Mr. Schmid is the Managing Partner of Formation Environmental with over 16 years of experience providing technical and programmatic leadership on large, complex, multi-disciplinary agricultural and water resource projects. This includes management of science, technology, and regulatory strategy projects totaling more than $30M over the last 5 years. Mr. Schmid has extensive programmatic experience leading diverse teams on large, complex, multi-disciplinary projects, many of which involve water quality, air quality, regulatory strategy, and advanced scientific modeling techniques. Mr. Schmid is an agronomist (plant scientist) and soil scientist by training and specializes in the application of remotely sensed data and modeling techniques to quantify land surface conditions pertaining to crop identification, evapotranspiration mapping, wetland vegetation, agricultural production, soil science, and precision agriculture. This includes providing strategic guidance, consulting expert, and testifying expert services for several confidential projects involving water resource and land management throughout the Western United States and South America.
Mr. Kenneth Miller: Mr. Miller is a Soil Scientist and Agronomist. His training is focused in plant biology and physiology as well as soils and biogeochemistry. As a graduate student at the University of California, Davis, he studied the influences of soil physical, chemical, and biological properties on nutrient cycling in California agroecosystems. At Formation, Mr. Miller applies his agronomic training and expertise to support model development, calibration, and analysis of the CV-SWAT model, evaluation of grower-reported management information, and outreach to refine nutrient management strategies with respect to minimizing nutrient losses. Mr. Miller has served as the Project Manager in the development of GWP Values and GWP Targets.
Dr. Timothy Hartz: Dr. Hartz is a Crop Specialist with more than 35 years working with horticultural industries as an academic, a consultant, and a production manager in private industry. He was an Extension Specialist for the University of California, where he worked closely with the vegetable and strawberry industries on a range of production issues as an Extension Specialist for the University of California. His work has focused on soil fertility, drip irrigation management, and environmental water quality protection. Dr. Hartz was instrumental in refinement of the crop models for the CV-SWAT model.
Dr. John Dickey: Dr. Dickey is a Principal Soil Scientist and Agronomist with over 30 years of experience. His expertise includes the fate of salts, trace elements, and nutrients in surface and subsurface return flows; water and soil quality analyses for irrigation; and analysis, reclamation, and revegetation of saline, sodic, and saline/sodic soils. Dr. Dickey is the Program Manager for the SSJV MPEP, which is focused on the identification and implementation of management practices protective of groundwater quality, particularly related to nitrate leaching. Dr. Dickey brings experience in environmental science consulting in the western United States, as well as in agricultural research, extension, production, and consulting in California, Indiana, Burkina Faso, and China.
Dr. Mark Roberson: Dr. Roberson in a Senior Soil and Water scientist with over 29 years of agricultural and urban irrigation water management, and water quality experience. Dr. Roberson has an extensive understanding of irrigation district operations, agronomy, fertility, soil sampling, nutrient recommendations, urban and agricultural plant water demands, and on-farm water management. He has extensive knowledge and experience with drainage, particularly from the perspective of water quality. He studied as a USDA National Need Fellow and obtained a Ph.D. in soil chemistry. Dr. Roberson's academic training provides him with a thorough knowledge of soil and water chemistry as well as soil-water interactions. Since 1998 he has served as consulting staff for local, state, and federal agencies and provides consulting services for private clients.
Root-zone, Vadose Zone, and Groundwater Modeling

Dr. George Paul: Dr. Paul is a Senior Agricultural Engineer with Formation Environmental, with more than 16 years of experience in field measurements and numerical modeling of soil, vegetation, and hydrologic processes. As an expert in evapotranspiration research, he has incorporated improvements to major remote-sensing-based surface energy balance algorithms. He developed the daily actual evapotranspiration (ETa) datasets for Oklahoma, Kansas, Texas, and California, which are extensively used for water management and ecological applications. He has supported the DWR in statewide water planning efforts, and with developing water conservation objectives and metrics. Dr. Paul is the lead modeler in the SSJV MPEP, for which he is responsible for hydrological model development, calibration, and validation to simulate agricultural nitrate leaching in the Central Valley, California.
Dr. Yohannes Yimam: Dr. Yimam has more than 14 years of experience in soil-, water-, plant-, and atmosphere-related data analysis, research, and development work. He is an expert in the development, application, calibration, and validation of prominent crop-growth, ecological, hydrological, land-surface, meteorological, and air-quality models. He also has advanced experience in analysis of large datasets, digital soil and crop mapping, geostatistics, GIS, and remote sensing data. Dr. Yimam has also been managing and leading multi-agency and multi-disciplinary projects for the last five years. He applies his expertise in root-zone modeling using SWAT for assessing agronomic conditions in the Central Valley, California.
Dr. Scott Devine. Dr. Scott Devine is a Quantitative Soil Scientist with Formation Environmental, with over 16 years of experience in soil science, agronomy, hydrologic modeling, data science, and irrigation management in California. Before Formation, he was a postdoctoral scholar at University of California, Davis, where he directed several statewide hydrologic modelling projects, requiring integration of complex soil, crop, and climate datasets to address California water resource challenges. This work provided knowledge to improve irrigation timing to reduce consumptive water use in agriculture and a compass for the agricultural management of floodwaters for groundwater recharge, while mitigating nitrate leaching risk. Dr. Scott Devine has expertise utilizing SWAT, HYDRUS, and the Rootzone Water Quality Model.
Mr. Peter Townsend. Mr. Townsend has 30 years of experience as a consulting hydrogeologist. Peter specializes in hydrogeologic characterization, groundwater flow and contaminant transport modeling, environmental data management, environmental statistics, and geographic information systems. Peter provides expertise and technical leadership on a range of projects, including groundwater resource development, environmental litigation, remedial investigations, and remedial design.
Mr. Mike Tietze Mr. Mike Tietze is a Professional Geologist, Certified Hydrogeologist and Certified Engineering Geologist in California. He has over 30 years of experience performing and managing water resources, engineering geologic, and environmental planning, permitting and compliance projects. He advises clients regarding project permitting and compliance; site selection and feasibility evaluation; resource characterization, impact assessment and management; and site decommissioning and restoration. His key technical strengths include water resources (especially groundwater resources) assessment, permitting, management and supply development; water quality assessment, management and cleanup; engineering geology, geomorphology and geologic hazard assessment; and the integration of environmental compliance considerations and resource data with project engineering and development workflows. He is experienced in the determination of thresholds of significance for groundwater resources, and in the development of mitigation and monitoring programs.
Mr. Will Gnesda: Mr. Gnesda is a hydrogeologist specializing in groundwater modeling and probabilistic contaminant transport modeling within the unsaturated and saturated zones. He has expertise in geospatial information systems (GIS) and hydrogeologic modeling including MODFLOW modeling (same code as CVHM/CVHM2), Analytic Element Modeling (AnAqSim), analytical transport modeling, and unsaturated zone with HYDRUS. His master's research explored the retention of per- and poly fluoroalkyl substances (PFAS) within the unsaturated zone and implications for long-term impacts to groundwater resource. He continues to explore probabilistic approaches within groundwater and contaminant modeling through geostatistics and parameter estimation.

Dr. Thomas Harter: Thomas Harter is the Robert M. Hagan Endowed Chair for Water Resources Management and Policy at the University of California, Davis. He holds a joint appointment as Professor and Cooperative Extension Specialist in the Department of Land, Air, and Water Resources, is currently chair of the Hydrologic Sciences Graduate Group, and, as Associate Director of the Center for Watershed Sciences, is a team partner for the World Water Center. Dr. Harter received his BS and MS in Hydrology from the Universities of Freiburg and Stuttgart, Germany; and his PhD in Hydrology from the University of Arizona. He spent the first six years of his career with UC Davis at the Kearney Agricultural Research Center in Fresno County, where he became familiar with San Joaquin Valley groundwater management and protection issues and established his research program in agricultural groundwater hydrology - a program he has continued to pioneer over the past 18 years at UC Davis. He is a member of the American Geophysical Union and is serving on the Board of Directors of the Groundwater Resources Association and of the Water Education Foundation. He is associate editor for the Journal of Environmental Quality. Dr. Harter's research and extension emphasizes the nexus between groundwater and agriculture. His research group focuses on nonpoint-source pollution of groundwater, sustainable groundwater management, groundwater and vadose zone modeling, groundwater resources evaluation under uncertainty, groundwater-surface water interaction, and on contaminant transport. His work uses a range of numerical, statistical, and stochastic modeling approaches, often with field research, to evaluate the impacts of agriculture and human activity on groundwater flow and contaminant transport in complex aquifer and soil systems, and to support development of tools needed in agriculture and by decision- and policy makers to effectively address sustainable groundwater management and water quality issues in agricultural regions. Dr. Harter and his team are the developers of NP-SAT.

Dr. Giorgos Kourakos: Dr. Kourakos is a Project Scientist at the Department of Land Air and Water Resources at the University of California, Davis. He has more than 10 years of experience in numerical modeling with a focus in groundwater flow and transport simulation, seawater intrusion, system optimization, code development, parallel computing and visualization. He has developed several numerical tools for simulating agricultural non-point Source pollution. He contributed to the development and validation of NP-SAT.

Mr. Chuan-Shin Chong: Mr. Chong is a Senior Remote-Sensing Developer with over 16 years of experience. He specializes in developing analytical solutions through remote-sensing and geospatial techniques. Mr. Chong is an expert in manipulating large datasets, automated image analysis techniques, and database management. He has utilized various types of remotely sensed data, including multispectral, hyperspectral, LiDAR, and thermal products in both pixel and object-based remote-sensing analysis techniques. Mr. Chong works closely with agronomists, soil scientists, and engineers to develop solutions for complex problems, including automation of CV-SWAT model runs and CV-NPSAT on Formation’s High Performance Compute Cluster.

5 REFERENCES

Bastani M., G. Kourakos, and T. Harter, 2019. Cross-validation, using MODFLOW-MT3D, of a nonpoint source contaminant transport simulator based on unit response functions along flow streamlines in regional aquifers. Chapter 3 in: Bastani, M., 2019. Nonpoint Source Groundwater Transport Models for Assessment and Management of Nitrate Pollution in Agricultural Aquifers, Ph.D. Dissertation, University of California Davis.

Bastani, M., and T. Harter. 2020. Effects of upscaling temporal resolution of groundwater flow and transport boundary conditions on the performance of nitrate-transport models at the regional management scale. Hydrogeology Journal 28:1299–1322.

Burt, C., Hutmacher, R., Angermann, T., Brush, B., Munk, D., duBois, J., McKean, M., Zelinski, L. 2014. Conclusions of the Agricultural Expert Panel. Recommendations to the State Water Resources Control Board pertaining to the Irrigated Lands Regulatory Program. Irrigation Training & Research Center California Polytechnic State University.

California Department of Food and Agriculture. 2022. California Agricultural Statistics Review. March 6.

Central Valley Coalitions. 2020. Workplan: Groundwater Protection Formula. Prepared for Buena Vista Coalition, Cawelo Water District Coalition, East San Joaquin Water Quality Coalition, Grassland Drainage Area Coalition, Kaweah Basin Water Quality Association, Kern River Watershed Coalition Authority, Kings River Watershed Coalition Authority, Sacramento Valley Water Quality Coalition, San Joaquin County and Delta Water Quality Coalition, Tule Basin Water Quality Coalition, Westlands Water Quality Coalition, Westside San Joaquin River Watershed Coalition, Westside Water Quality Coalition. Prepared by Formation Environmental, PlanTierra, LLC, and MLJ Environmental. July 1.

Central Valley Coalitions. 2021. Groundwater Protection Values. Prepared for Buena Vista Coalition, Cawelo Water District Coalition, East San Joaquin Water Quality Coalition, Grassland Drainage Area Coalition, Kaweah Basin Water Quality Association, Kern River Watershed Coalition Authority, Kings River Watershed Coalition Authority, Sacramento Valley Water Quality Coalition, San Joaquin County and Delta Water Quality Coalition, Tule Basin Water Quality Coalition, Westlands Water Quality Coalition, Westside San Joaquin River Watershed Coalition, Westside Water Quality Coalition. Prepared by Formation Environmental, PlanTierra, LLC, and MLJ Environmental. July 19.

Central Valley Coalitions. 2021a. Addendum to Groundwater Protection Values. Prepared for Buena Vista Coalition, Cawelo Water District Coalition, East San Joaquin Water Quality Coalition, Grassland Drainage Area Coalition, Kaweah Basin Water Quality Association, Kern River Watershed Coalition Authority, Kings River Watershed Coalition Authority, Sacramento Valley Water Quality Coalition, San Joaquin County and Delta Water Quality Coalition, Tule Basin Water Quality Coalition, Westlands Water Quality Coalition, Westside San Joaquin River Watershed Coalition, Westside

Water Quality Coalition. Prepared by Formation Environmental, PlanTierra, LLC, and MLJ Environmental. November 9 (submitted December 15).

Central Valley Coalitions. 2022. Groundwater Protection Targets. Prepared for Buena Vista Coalition, Cawelo Water District Coalition, East San Joaquin Water Quality Coalition, Grassland Drainage Area Coalition, Kaweah Basin Water Quality Association, Kern River Watershed Coalition Authority, Kings River Watershed Coalition Authority, Sacramento Valley Water Quality Coalition, San Joaquin County and Delta Water Quality Coalition, Tule Basin Water Quality Coalition, Westlands Water Quality Coalition, Westside San Joaquin River Watershed Coalition, Westside Water Quality Coalition. Prepared by Formation Environmental. December 15.

Department of Water Resources (DWR). 2020. California Central Valley Groundwater-Surface Water Simulation Model – Fine Grid (C2VSimFG) Development and Calibration Version 1.0. Accessed on July 19, 2022. https://data.cnra.ca.gov/dataset/c2vsimfg-version-1-0/resource/4f904e97-a47b-4138-81df-9b74bd952948

Dogrul, E. C., W. Schmid, R. T. Hanson, T. Kadir, and F. Chung, 2011. Integrated Water Flow Model and MODFLOW-Farm Process: A Comparison of Theory, Approaches, and Features of Two Integrated Hydrologic Models, Technical Information Report, California Department of Water Resources, November 2011.

Escriva-Bou, A., Hui, R., Maples, S., Medellín-Azuara, J., Harter, T., and Lund, J.R., 2020. Planning for groundwater sustainability accounting for uncertainty and costs: An application to California's Central Valley. Journal of environmental management, 264, p.110426.

Faunt, C.C., ed. 2009. Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey Professional Paper, 1766, 225 p. Accessed July 6, 2022. https://pubs.usgs.gov/pp/1766/

Fogg, G. E., and E. M. LaBolle. 2006. Motivation of synthesis, with an example on groundwater quality sustainability. Water Resources Research 42.

Geisseler, Daniel. 2016. Nitrogen concentrations in harvested plant parts – A literature overview. Accessed July 12, 2021. http://geisseler.ucdavis.edu/Geisseler_Report_2016_12_02.pdf.

Geisseler, Daniel. 2021. Nitrogen concentrations in harvested plant parts – Update 03/2021. Includes updated values for carrots, corn for silage, cotton, peaches, pistachios, plums, pomegranates, tomatoes, processing, safflower, sunflower, walnuts, perennial parts of trees. March 31. Accessed July 13, 2021. http://geisseler.ucdavis.edu/Geisseler_Report_U1_2021_03_31.pdf.

Green, C.T., B.C. Jurgens, Y. Zhang, J.J. Starn, M.J. Singleton, and B.K. Esser. 2016. Regional Oxygen Reduction and Denitrification Rates in Groundwater from Multi-Model Residence Time Distributions, San Joaquin Valley, USA. *Journal of Hydrology*, 543, Part A (2016): 155–166. https://doi.org/10.1016/j.jhydrol.2016.05.018.

Harter, T. and Morel-Seytoux, H. 2013. Peer Review of the IWFM, MODFLOW and HGS Model Codes: Potential for Water Management Applications in California's Central Valley and Other Irrigated Groundwater Basins. Final Report, California Water and Environmental Modeling Forum, August 2013, Sacramento. http://www.cwemf.org

Henri, C. V., and T. Harter. 2022. Denitrification in heterogeneous aquifers: Relevance of spatial variability and performance of homogenized parameters. Advances in Water Resources 164:104168.

Kourakos, G., Klein, F., Cortis, A., and Harter, T. 2012. A Groundwater Nonpoint Source Pollution Modeling Framework to Evaluate Long-term Dynamics of Pollutant Exceedance Probabilities in Wells and Other Discharge Locations. Water Resources Research 48, W00L13. Accessed July 6, 2022. doi:10.1029/2011WR010813.

Kourakos, G. and Harter, T. 2014a. Vectorized Simulation of Groundwater Flow and Streamline Transport. Environmental Modelling & Software, 52, 207–221. Accessed July 6, 2022. https://doi.org/10.1016/j.envsoft.2013.10.029.

Kourakos, G. and Harter, T. 2014b. Parallel Simulation of Groundwater Non-point Source Pollution Using Algebraic Multigrid Preconditioners. Computational Geosciences. Accessed July 6, 2022. DOI 10.1007/s10596-014-9430-2.

Kourakos, G. and T. Harter, 2021. Simulation of unconfined aquifer flow based on parallel adaptive mesh refinement. Water Resources Ressearch. 57(12), e2020WR029354, https://doi.org/10.1029/2020WR029354

Landon, M.K., C.T. Green, K.B., M.J. Singleton, and B.K. Esser. 2011. Relations of Hydrogeologic Factors, Groundwater Reduction-Oxidation Conditions, and Temporal and Spatial Distributions of Nitrate, Central-Eastside San Joaquin Valley, California, USA. Hydrogeology Journal 19: 1203–1224. https://doi.org/10.1007/s10040-011-0750-1

Liang, X. Q., T. Harter, L. Porta, C. van Kessel, and B. A. Linquist. 2014. Nitrate Leaching in Californian Rice Fields: A Field- and Regional-Scale Assessment. Journal of Environmental Quality 43:881–894.

McMahon, P.B., and F.H. Chapelle. 2008. Redox Processes and Water Quality of Selected Principal Aquifer Systems. Ground Water 46, no. 2: 259–271. https://doi.org/10.1111/j.1745-6584.2007.00385.x

MPEP (Management Practices Evaluation Program) Team. 2019. Assessment of Management Practice Performance in the Central Valley Using the Soil and Water Assessment Tool. Prepared for the Southern San Joaquin Valley MPEP Committee.

Pauloo, R., Dahlke, H., Fogg, G., Guillon, H., Fencl, A., and Escriva-Bou, A. 2019. Domestic Well Vulnerability to Drought Duration and Unsustainable Groundwater Management in California's Central Valley, Dryad, Dataset. Accessed July 7, 2022. https://doi.org/10.25338/B8Q31D.

Ransom, K.M., Bell, A.M., Barber, Q.E., Kourakos, G. and Harter, T., 2018. A Bayesian approach to infer nitrogen loading rates from crop and land-use types surrounding private wells in the Central Valley, California. Hydrology and Earth System Sciences, 22(5), pp.2739-2758.

Rivett, M.O., S.R. Buss, P. Morgan, J.W.N. Smith, and C.D. Bemment. 2008. Nitrate Attenuation in Groundwater: A Review of Biogeochemical Controlling Processes. Water Research 42, no. 16: 4215–4232. https://doi.org/10.1016/j.watres.2008.07.020

Rosecrans, C.Z., B.T. Nolan, and J.M. Gronberg. 2017. Prediction and Visualization of Redox Conditions in the Groundwater of Central Valley, California. Journal of Hydrology 546: 341–356. https://doi.org/10.1016/j.jhydrol.2017.01.014