Phase II Report of
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Review of the Numerical Groundwater Model Developed by Ramboll for the Indian Wells Valley (IWV) Groundwater Basin, California

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Acronyms

%	Percent
3D	Three-dimensional
AEM	Airborne electromagnetic
AFY	Acre-feet per year
BCM	Basin Characterization Model
BCMv8	Basin Characterization Model Version 8
DWR	California Department of Water Resources
ET	Evapotranspiration
GSP	Groundwater Sustainability Plan
HCM	Hydrogeological conceptual model
IWV	Indian Wells Valley
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
MBR	Mountain block recharge
MFR	Mountain front recharge
RCH	Recharge package of MODFLOW
USGS	United States Geological Survey
WEL	Well package of MODFLOW

Executive Summary

I have been retained to review the numerical groundwater model developed by Ramboll for the Indian Wells Valley (IWV) groundwater basin (Ramboll Model). The Ramboll Model is a regional groundwater flow model developed using MODFLOW-NWT, an industry-standard and widely accepted code suitable for estimating the basin's safe yield in accordance with best modeling practices. The model structure is based on the Hydrogeologic Conceptual Model (HCM); incorporates reasonable representations of stratigraphy, aquifer properties, and hydrologic boundaries; and applies standard MODFLOW packages for boundary conditions and water budget components to simulate transient conditions from 1986–2023. This period captures a diverse set of hydrologic conditions in the IWV, including some dry, average, and extremely wet years. Spatial and temporal discretization, along with calibration procedures, follow accepted practices, with results indicating that the model reasonably reproduces historical groundwater levels and overall temporal trends. Ramboll has made effective use of available datasets to inform model conceptualization and parameterization, producing a defensible model for evaluating basin safe yield, estimating groundwater storage, and assessing future water management decisions.

In my professional opinion, the model adequately represents relevant hydrogeologic components needed for estimating safe yield for the IWV groundwater basin. The report outlines my opinions and the basis on which I formed these opinions.

REPORT

Section 1.
Summary of Opinions

I have reached the following opinions about the Ramboll Model on the basis of review presented in this report, together with my professional and academic experience. I hold these opinions to a reasonable degree of scientific certainty, though they are subject to change pending further review of existing and new documents and data.

- Opinion 1: The numerical model developed by Ramboll uses a modeling code, model inputs, and implementation that is industry standard and suitable for the intended use, i.e., to calculate safe yield for the groundwater basin.

- Opinion 2: The numerical model incorporates essential hydrogeologic components that are needed for safe yield calculations.

- Opinion 3: The model calibration is reasonable.

Section 2.
Introduction

I was retained by Murphy & Evertz LLP to review the Ramboll Model that simulates conditions in the IWV groundwater basin. A copy of my CV, listing my qualifications, publications, and matters in which I have given testimony, is included as an appendix to this report. S.S. Papadopulos & Associates, Inc. is compensated for my work on this matter at the rate of $269.00 per hour, plus expenses.

The Ramboll Model simulates the hydrologic and hydrogeologic conditions in the Indian Wells Valley located in California. The model was developed for estimating the safe yield of the groundwater basin and calculating groundwater storage. The model is a physically based numerical model built using the modeling software MODFLOW-NWT that simulates the movement of water within the groundwater system, and the associated inflows and outflows. Inflows to the model include precipitation, applied recharge, stream discharge, among other sources and outflows include evapotranspiration and groundwater pumping. The objective of my review was to ascertain that the Ramboll Model is appropriately designed to serve its intended use.

My expertise includes the development and review of numerical surface water-groundwater interaction, and flow and transport models. I have twenty-four years of professional experience in water-resource consulting and numerical software development. I have worked on the development of various versions of the MODFLOW numerical simulator and am the lead developer of the solute transport code MT3D-USGS.

In preparation of this report, I have relied upon the Ramboll Model files, the modeling report provided by Ramboll, and external references relevant for the review as listed in the References Section.

Section 3.
Model Overview

The Ramboll Model is a three-dimensional (3D) numerical groundwater model that simulates groundwater conditions in the Indian Wells Valley groundwater basin located at the intersection of Inyo, Kern, and San Bernardino Counties in California. The groundwater model follows the Indian Wells Valley groundwater basin boundary (Basin Number 6-054) as delineated by Bulletin 118 (DWR, 2020). The Bulletin 118 boundary and the model boundary are shown in Figure 3-1. The objective of the Ramboll Model is to quantify the safe yield and groundwater storage of the basin and for potentially assessing future water management decisions.

The model was constructed using MODFLOW-NWT (Niswonger et al, 2011), a robust and widely recognized numerical groundwater modeling software developed by the United States Geological Survey (USGS). MODFLOW-NWT is considered an industry standard, extensively utilized within the groundwater modeling community for simulating complex groundwater flow system such as the Indian Wells Valley groundwater basin. Importantly, MODFLOW-NWT represents a significant advancement over earlier versions of MODFLOW, specifically addressing challenges related to the numerical solution of unconfined groundwater flow problems. As documented by Bedekar et al (2012), the Newton formulation implemented in MODFLOW-NWT allows for improved model convergence and stability, particularly in situations where safe yield calculations are important.

The Ramboll Model converged for all time steps and the water balance errors are close to zero. These findings indicate that the model was numerically stable and did not introduce any numerical errors or artifacts.

Section 4.
Model Structure

The selected model domain reasonably encompasses the Indian Wells Valley groundwater basin floor and includes boundaries that account for external watershed contributions. Representing inflows from watersheds outside the model domain as specified flow boundary conditions is a common and acceptable approach for regional models. The use of inflow rates derived from watershed models such as the Basin Characterization Model (BCM) is consistent with established practice and ensures that boundary fluxes are supported by independent hydrologic analysis. BCM (Flint et al, 2021a) is a regional water-balance model developed by the USGS that provides monthly, gridded, water budget components and BCM version 8 (BCMv8) provides the latest datasets (Flint et al, 2021b). However, it is acknowledged here that the adequacy of this representation depends on the accuracy of the BCM estimates and the spatial correspondence between contributing watersheds and model boundaries.

The finite-difference grid is defined using a uniform 1,320 feet by 1,320 feet cell size, which provides sufficient spatial resolution for a regional-scale assessment of basin-wide safe yield while balancing computational efficiency.

The model layering is based on the HCM, and the reported total thickness of the simulated system aligns with the geologic cross sections provided in Ramboll (2025). As shown in Figure 4-1, the simulated thickness is consistent with the geologic cross sections presented in Figures 3-4 of Ramboll (2025). The approach of defining layers to represent the hydrostratigraphic units described in the HCM is standard practice and provides a defensible framework. The review finds this horizontal and vertical spatial discretization approach reasonable.

The temporal setup of the model, steady-state conditions for 1980–1985 followed by transient simulation from 1986–2023, appropriately captures a range of hydrologic conditions across wet and dry periods. The use of quarterly stress periods is an acceptable approach for the intended purpose of this model. The discretization appears adequate for the stated purpose of estimating basin safe yield.

Section 5.
Aquifer Properties

Aquifer properties in the model are represented using discrete zones. These zones generally follow the regions described in the HCM in Ramboll (2025). To independently evaluate whether the spatial distribution of these zones is reasonable, a brief texture-based assessment was performed using lithologic well log data supplemented with airborne electromagnetic (AEM) survey data collected by DWR. This approach is appropriate for validating the conceptual framework of hydraulic property distribution, provided the input datasets and interpretations are of sufficient quality and resolution.

For this evaluation, the Texture2Par tool (DWR, 2025; Scantlebury et al, 2025; Scantlebury et al, 2022), developed to support DWR's Basin Characterization program, was utilized. Texture2Par combines lithologic well and boring log data and AEM survey results to generate a three-dimensional texture model of the subsurface. While this tool can also be used to estimate hydrogeologic parameters (e.g., hydraulic conductivity, specific storage, specific yield) from texture classifications, in this application it was used solely to visualize and qualitatively assess the reasonableness of the spatial distribution of aquifer property zones in the model.

Data availability for this analysis included a set of lithologic well logs distributed in the basin that provided sediment texture classification. Additionally, AEM data collected in two survey phases, in 2017 and in 2024, were available. Figure 5-1 shows the locations of lithologic well and boring logs and the AEM flight lines from both phases, while Figure 5-2 presents the preliminary inferred distribution of sediment textures derived from these datasets. The review finds that the spatial distribution of aquifer property zones in the model generally aligns with patterns inferred from well log texture analysis and the preliminary AEM interpretations. However, it is noted that the AEM data interpretation remains preliminary and is expected to be revised to improve consistency between the two survey phases. Future refinements of the AEM interpretation may warrant revisiting the zonation of aquifer properties to ensure continued agreement with updated geophysical and lithologic information.

Aquifer properties in the model were changed as part of model calibration. A discussion of aquifer properties, their ranges, and a review of whether these aquifer properties are reasonable is provided in the model calibration section.

Several geologic faults are mapped within the groundwater basin. In the Ramboll Model, two major fault systems, the El Paso Fault and the Little Lake Fault, are explicitly represented. These faults are implemented as hydraulic flow barriers, a standard and defensible approach for simulating faults that may restrict groundwater movement.

Section 6.
Boundary Conditions

The Ramboll Model simulates a variety of inflows to the groundwater basin, including mountain front recharge (MFR)/mountain block recharge (MBR), inter-basin flow from Rose Valley, mountain runoff and stream seepage, agricultural return flows, leakage from water mains and the Los Angeles Aqueduct (LAA), percolation from wastewater treatment ponds, and Los Angeles Department of Water and Power (LADWP) periodic releases (Ramboll, 2025). These sources generally capture the key hydrologic inputs to the basin and are consistent with the conceptual model of the system. Outflows from the system include evapotranspiration (ET) and groundwater pumping.

Boundary condition implementation uses standard MODFLOW packages. MFR/MBR and inter-basin flow from Rose Valley are applied via the Well (WEL) package, while other distributed recharge sources are implemented through the Recharge (RCH) package. Outflows are represented through the Evapotranspiration (EVT) package and pumping wells using the WEL package. The Horizontal Flow Barrier (HFB) package is used to simulate fault zones restricting groundwater movement. These selections are appropriate and align with established modeling practice.

Detailed water budgets are provided in this report in Section 7 and two of the major water budget components, groundwater pumping and groundwater inflow from mountain front recharge and other sources, were verified as part of this review and are presented here.

6.1 Groundwater Pumping

The data sources used in the model to estimate and implement groundwater pumping in the model are documented in Ramboll (2025). The pumping rates implemented in the model were reviewed and verified against the reported pumping rates in Ramboll (2025). Figure 6-1 shows the pumping rates implemented in the Ramboll Model. The rates used in the model match the reported values, as shown in Figure 4-5 of Ramboll (2025), for the years 1986 through the end of the simulation in 2023. For the period 1980-1985, which is represented as a steady-state period in the model, the reported rates are higher than the implemented values in the model.

A steady-state simulation is typically intended to establish initial groundwater conditions for the transient analysis. This approach assumes no change in storage during the simulated period, and boundary conditions are often adjusted to generate groundwater heads that are considered reasonable for initializing the model. These heads serve only as a starting point for subsequent transient simulations.

6.2 Groundwater Inflow

Groundwater inflows are represented in the model using MODFLOW's RCH and WEL packages. These inflows represent a variety of different natural and human-induced sources of water to the IWV basin. These inflows emanate from surrounding watersheds as well as within the basin. The details of these inflow calculations are documented in Ramboll (2025).

The total inflows in the model are shown in Figure 6-2. It is noted that there are a few years that show inflow rates close to or greater than 30,000 AFY while most other years have inflow rates less than 10,000 AFY. To independently assess the high inflow rates for the years 1993, 1995, 1998, 2005, 2010, 2017, and 2023, three sets of precipitation and snowpack timeseries were qualitatively compared with the inflow rates used in the model.

The first dataset evaluated was the precipitation data available at China Lake NAF Station number 041733. These data were obtained from IWVGA (2025, Attachment C). The second and third timeseries were obtained from the BCMv8 statewide model for the Northern Sierra sub-watershed. There are several other sub-watersheds that provide inputs to the Ramboll Model, however, for qualitative comparison, only the Northern Sierra sub-watershed was considered. The BCMv8 statewide model-derived values considered include the total monthly precipitation inputs and the computed snowpack for the Northern Sierra sub-watershed.

The precipitation data and the snowpack values are plotted together with the modeled inflow rates in Figure 6-3. It is noted that the high inflow rates in 1993, 1995, 1998, 2005, 2010, and 2023 agree with the high precipitation observed at the China Lake NAF, No. 041733 as well as the precipitation data used in the BCMv8. High inflow rates in 1993, 1995, 1998, 2017, and 2023 can be fully or partially attributed to the snowpack values in the Northern Sierra area, which is particularly high for the year 2017.

Overall, the representation of inflow rates and their variability from year to year in the Ramboll Model seem reasonable.

Section 7.
Model Calibration and Results

7.1 Observations

Model calibration is achieved by history-matching measured or observed data with equivalent simulated values. Model inputs are typically changed to achieve a good match between the simulated and observed values. Aquifer properties and flow barrier properties of faults were changed during calibration of the Ramboll Model. Groundwater heads were used as the observations that guided the calibration process.

Figure 7-1 shows a scatterplot that qualitatively presents the model calibration. Figure 7-1 illustrates that although the overall flow system is well represented, local differences in observed and simulated groundwater elevations are present. To explore these local differences, the observed dataset was divided into several groups of observations based on their spatial locations. These groups of observations qualitatively classify observed data spatially into areas that are affected by similar hydrologic conditions. The location of the groups A-G are shown in Figure 7-2.

The segmented scatterplots presented in Figure 7-3 show the calibration for the different groups and help identify the areas that demonstrate an attenuated response in the model as compared to the observed data. Groups B, E, and F, located in the east and southeast, show the attenuated response in simulated water level changes. Despite these local simulated responses, the model is unbiased on average. The overall head residual is close to -4 feet, i.e., simulated groundwater levels are on average 4 feet greater than observed values and the average absolute head residual is less than 15 feet despite the minimum and maximum residuals being -127 and 92 feet, respectively. A low average head residual indicates that the majority of simulated water levels closely agree well with the observed values. Table 7-1 provides additional calibration statistics.

To further review spatial bias in head residuals a spatial distribution of average head residuals is shown in Figure 7-4. The map showing the spatial distribution of groundwater head residuals indicates that no particular spatial bias exists in the calibration. Figure 7-4 shows the model calibration is spatially unbiased.

The comparison of observed and simulated water levels suggests that the model captures the general declining water level trends observed in majority of the observation wells (Ramboll, 2025: Appendix E). A few observed data show a temporary increase in groundwater levels following large precipitation events such as 2011 and 2017. These increased water levels are generally represented by the model, even though the timing and magnitude of the increased water level does not track exactly between the simulated and the observed groundwater levels.

7.2 Calibration Parameters

In addition to reviewing the good-of-fit of observed data, it is critical to review the calibration parameters to ensure that the values that were calibrated remain within a plausible range. Aquifer properties and flow barrier properties of faults were changed during the calibration of Ramboll Model. Any deviation of aquifer properties outside of an acceptable spatial distribution or a reasonable range of calibrated values may reduce the predictive capability of the model.

Calibrated aquifer properties were reviewed. Figures 7-5 to 7-9 show exceedance plots of all aquifer properties. It is seen that the properties are within a reasonable range for an alluvial valley broadly described as lakebed, stream, and alluvial fan deposits. Horizontal hydraulic conductivity ranges from 0.1 to 30 feet/day with a majority of the values in the order of 1 to 10 feet/day. Vertical hydraulic conductivity ranges from 0.002 to 3.9 feet/day. Bulk anisotropy was calculated as horizontal conductivity divided by vertical conductivity for each model grid cell and the distribution is shown in Figure 7-7. The values range from 2 to 1,000 and are within an acceptable range of values. Freeze and Cherry (1979) state that horizontal to vertical conductivity is possible in the order of 100:1 or even larger. In another study, Spitz and Moreno (1996) compiled anisotropy ratios that ranged from 1 to 500. Anderson and Woessner (1992; p. 70) indicate that vertical anisotropy ratios ranging from 1 to 1000 "are common in model application."

Specific storage values range from 8×10^{-7} 1/foot to 3×10^{-4} 1/foot and specific yield ranges from 0.08 to 0.11. Although 3×10^{-4} 1/foot is the upper limit of specific storage values, majority of the values are less than 2×10^{-6} 1/foot. A higher specific storage value is typically associated with fine-grained sediments, which are known to exist in the groundwater basin (Ramboll, 2025). Aquifer storage properties are within reasonable ranges.

The calibrated fault conductance values are more subjective and the head values across the faults dictate the quality of calibration of faults. Overall, the aquifer properties and the fault conductance values used in the calibrated model appear reasonable.

7.3 Model Robustness

In addition to reviewing the quality of model calibration and the resulting aquifer properties, a simulation was performed to test the robustness of the model. The simulation experimented by switching off groundwater withdrawal in the model. In the absence of groundwater pumping the IWV basin is expected to pool in low lying areas, consistent with historical understanding of the pre-development conditions. To account for the potential pooling, the model was assigned a drain boundary using the drain (DRN) package assigned at the land surface elevation. This simulated drain boundary discharge from the model represents rejected recharge, surface runoff, and evapotranspiration caused by the pooled water.

Although the expectation of the 'no-pumping' simulation is to provide insights into how well the model would represent the 'pre-development' conditions in the basin, it is acknowledged that the simulation uses a simplified approach. The simulation does not represent realistic pre-development conditions by considering land use changes, native vegetation, and the associated recharge, ET, and other boundary changes. The no-pumping simulation only serves to test the robustness of the model by imposing conditions that are outside of the calibrated conditions.

A map with the discharge locations of water under the no-pumping conditions is shown in Figure 7-10. It is noted that the map is consistent with areas in and around China Lake where water pooling occurred historically, as evidenced by Ramboll (2025) (original reference: Rosenthal et al, 2017) and as shown in Figure 7-11. The experimental no-pumping simulation illustrates that the Ramboll Model adequately represented the no-pumping conditions in the IWV basin.

7.4 Results

Annual water budgets are the key results from the modeling study. These water budgets are shown in Figure 7-12. As the conceptual model suggests, the majority of water in the basin enters in the form of MFR or MBR and from Rose Valley, which accounts for 77% of the overall inflow on average. The remaining 23% of inflow comes into the basin from mountain front runoff, focused recharge in the form of system leakage, LAA leakage, LADWP periodic

releases, and agricultural return flow as simulated in the Ramboll Model. Groundwater pumping is the primary sink in the system. Although ET is a small percentage of the water budget, it is anticipated to be an important consideration when calculating safe yield and is also a highly uncertain water budget component given the lack of any direct ET measurements.

Figure 7-13 shows the three key components including (1) the recharge from MFR/MBR and Rose Valley flow combined; (2) other inflow components; and (3) ET. It is apparent that the largest variability in the inflows is caused by the MFR/MBR, while the other sources of inflow and ET are relatively more stable from year to year.

Section 8.
Assumptions, Limitations, and Recommendations

The Ramboll Model provides a structured, data-informed framework for quantifying groundwater basin inputs, outputs, and overall water balance in support of safe yield evaluation. It represents a well-constructed and defensible regional groundwater flow model that makes effective use of the data currently available. However, as with all groundwater models, it approximates a complex and heterogeneous system, and its results are subject to assumptions and inherent uncertainties. Furthermore, opportunities exist to refine and strengthen the model framework as additional data, improved characterization methods, and enhanced analytical tools become available.

8.1 Assumptions and Limitations

The following are some assumptions and inherent limitations in the Ramboll Model:

1. Model non-uniqueness and uncertainty: Multiple parameter combinations can reproduce observed groundwater levels and flows within acceptable tolerances. This non-uniqueness, coupled with uncertainties in conceptual understanding and data inputs, means that the model represents one plausible interpretation of basin conditions rather than a unique solution. However, the representation of the groundwater system in the Ramboll Model is reasonable.

2. Representation of recharge and land-use processes: Inflows to the basin are quantified as net groundwater recharge, without explicitly simulating detailed land-use or surface infiltration processes. While this is a reasonable and common approach for regional-scale models, it assumes that net recharge estimates appropriately capture all relevant processes, including irrigation, return flows, and percolation.

3. Streamflow Interactions: The model does not explicitly simulate streamflow dynamics, relying instead on estimates of stream discharge to aquifers included in net recharge values. This is a pragmatic simplification but introduces uncertainty in areas where stream-aquifer interactions may vary seasonally or spatially.

4. Data gaps in monitoring and recharge quantification: Data limitations remain a key constraint. Sparse groundwater level measurements, particularly in the northeastern portion of the basin, reduce the ability to tightly constrain hydraulic properties and flow patterns in that area. Similarly, mountain front recharge estimates are uncertain due to

limited measurements, requiring assumptions about infiltration and subsurface flow pathways that may not be fully verified.

5. Uncertainty in ET: ET is one of the most difficult water budget components to quantify, particularly in arid regions where it may vary significantly with vegetation, soil, and climate conditions. Limited site-specific ET studies increase reliance on generalized estimates, which may affect the accuracy of groundwater discharge calculations.

8.2 Recommendations

The following recommendations are provided for future consideration:

1. Enhanced representation of aquifer properties: While the current zonation of aquifer properties is reasonable, the availability of lithologic well log and airborne electromagnetic (AEM) data presents an opportunity to develop a more spatially continuous parameterization. Tools such as Texture2Par can be used to integrate well and geophysical data into a three-dimensional texture model from which aquifer properties such as hydraulic conductivity and storage can be inferred. Any such refinement would likely necessitate recalibration of the model to ensure consistency with observed groundwater levels.

2. Addressing data gaps for calibration: Significant data gaps remain in the northeastern portion of the basin with regards to groundwater levels. Expansion of groundwater level monitoring networks, particularly in data-sparse regions, would enhance the ability to constrain hydraulic properties and improve model calibration.

3. Improving recharge estimates: One of the largest sources of water in the area is the mountain front recharge and runoff emanating from the surrounding watersheds. Stream inflow and mountain front recharge studies will help improve the quantification of these important water budget components.

4. Improving evapotranspiration estimates: Evapotranspiration (ET) is among the most uncertain components of the water budget and a challenging term to quantify in regional models. Additional field or remote-sensing studies focused on ET processes could improve understanding of ET in the area. Incorporating refined ET estimates into future model updates would likely improve the accuracy of water budgets and reduce model uncertainty.

Overall, the Ramboll Model provides a sound foundation for evaluating safe yield, and these recommendations are intended to support incremental model improvements as new data and analytical capabilities become available.

Section 9.
Summary and Conclusions

The Ramboll Model has been developed using MODFLOW-NWT, an industry-standard and widely accepted groundwater flow modeling code. This choice of software is appropriate for the purpose of estimating the safe yield and groundwater storage of the basin and is consistent with current best practices in regional groundwater modeling.

The model structure is based on the HCM for the basin and reflects the current understanding of stratigraphy, aquifer properties, and hydrologic boundaries. Boundary conditions are implemented using standard MODFLOW packages in a manner consistent with typical practice for basin-scale models. The representation of aquifer properties appears reasonable, and the values used in the model are within plausible ranges.

The model development process demonstrates adherence to accepted best practices, including the use of appropriate spatial and temporal discretization and representation of key inflow and outflow components. Model calibration results appear reasonable, suggesting that the model can reproduce observed historical groundwater levels within acceptable tolerances and represent general trends.

The Ramboll Model has made extensive use of available data and has incorporated multiple datasets to inform the conceptualization and parameterization of the model. While uncertainties inherent in regional-scale groundwater models remain, the model framework is consistent with professional standards and provides a defensible tool for evaluating the basin's safe yield.

Section 10.
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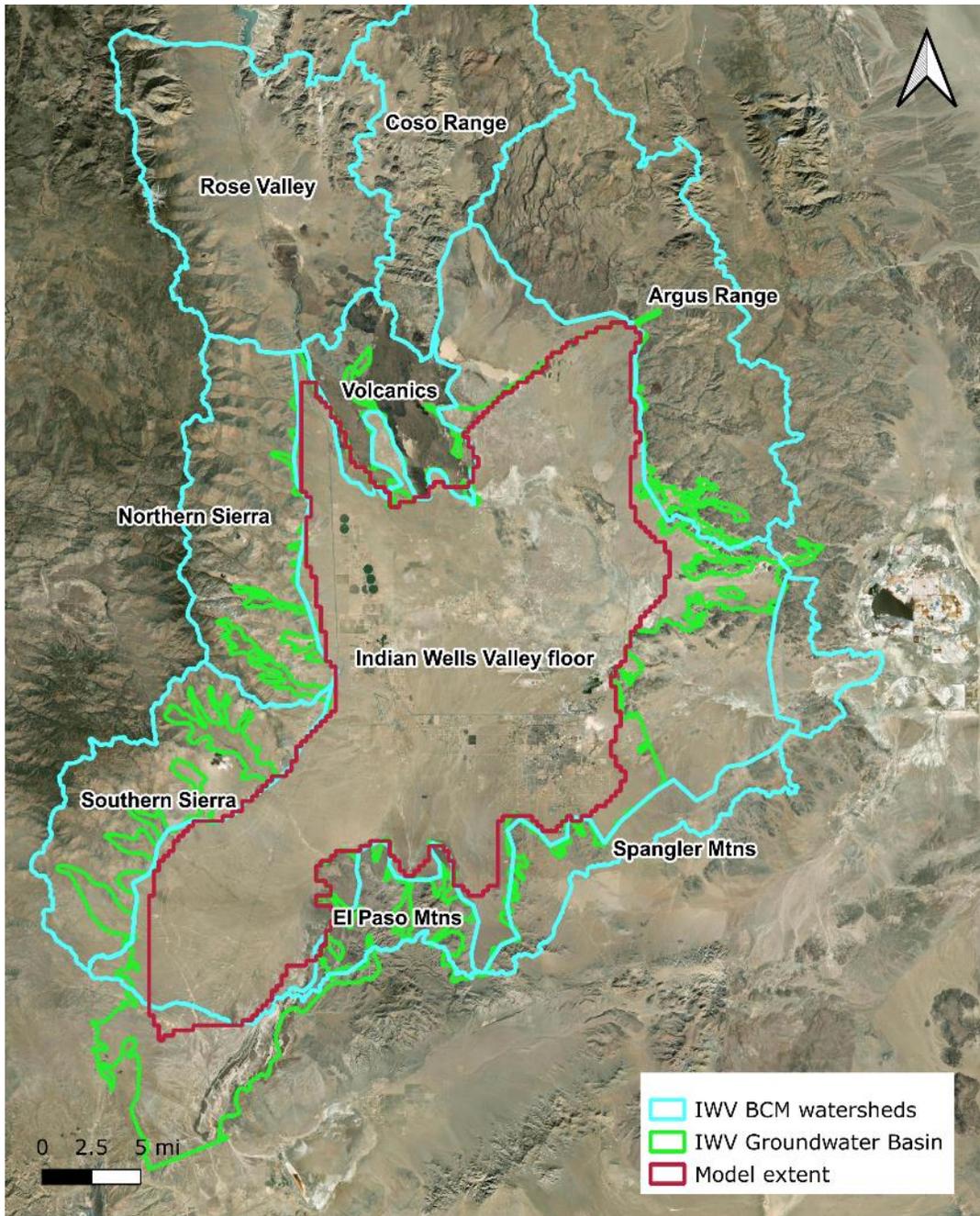
FIGURES

Figure 3-1: Location of Indian Wells Valley groundwater basin and model extents (after Ramboll, 2025).

Figure 4-1: Spatially varying model thickness and conceptual cross sections. Cross sections reproduced from Ramboll (2025).

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Figure 7-8: Exceedance plot showing the variation of specific storage within different model layers. Values used in all model layers are shown here for completeness.

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Figure 7-10: Map showing the discharge locations of water under the no-pumping conditions.

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Figure 7-12: Annual water budgets based on Ramboll Model.

Figure 7-13: Annual Total Inflow and ET based on Ramboll Model.

TABLES

Statistic	All Observations	By Model Layer					
		1	2	3	4	5	6
Mininum Residual (feet)	-126.5	-103.5	-126.5	-99.3	-86.6	-50.1	-16.5
Average Residual (feet)	-3.6	-10.4	-2.7	-3.6	-2.7	-6.5	11.5
Maximum Residual (feet)	91.8	12.8	75.7	91.8	31.2	68.0	32.1
Average Absolute Residual (feet)	14.6	12.7	12.0	17.1	20.2	20.5	19.5
Root Mean Square Error (feet)	20.9	27.0	18.2	21.3	25.0	24.9	22.0

Statistic	All Observations Within Last 10 Years	By Model Layer					
		1	2	3	4	5	6
Mininum Residual (feet)	-118.7	-100.2	-118.7	-59.9	-63.9	-46.3	-16.5
Average Residual (feet)	-3.7	-7.9	-1.8	-3.9	-5.6	-7.5	3.9
Maximum Residual (feet)	69.0	11.0	69.0	44.6	31.2	68.0	27.7
Average Absolute Residual (feet)	15.4	9.9	12.1	18.5	21.3	21.6	17.0
Root Mean Square Error (feet)	21.6	19.5	19.4	22.4	26.6	26.0	18.0

Table 7-1: Calibration statistics for Ramboll Model.

Appendix A

Curriculum Vitae of Vivek Bedekar

Vivek Bedekar, Ph.D., P.E.

Associate, Engineer

Dr. Bedekar is a water resources and environmental consultant with experience working on a variety of modeling and software development projects. His experience includes the development of numerous local and regional models, surface-water/groundwater interaction models, flow-and-transport models, and variable density models. He has developed numerous modeling codes and is the lead author of MT3D-USGS. Dr. Bedekar publishes research papers, provides peer reviews, and instructs at modeling and software training courses.

REPRESENTATIVE EXPERIENCE

S.S. Papadopulos & Associates, Inc. – *Rockville, Maryland*

Third-party Review of GULF and Groundwater Management Area 14 (GMA 14) Models, Lone Star Groundwater Conservation District, Conroe, Texas: Lead Reviewer for a groundwater model that is currently being developed for joint planning purposes for GMA 14, which partially or fully includes five GCDs and two subsidence districts.

Phoenix AMA Groundwater Model, Arizona: Calibrated the Phoenix AMA Groundwater Model for the Arizona Department of Water Resources. The model is used by AZ-DWR to assess groundwater conditions in the Phoenix AMA. The model is used by AZ-DWR to make basin-scale water availability projections into the future to achieve the objectives laid out in Arizona's Groundwater Management Act of 1980.

Confidential Client, Arizona: A third-party model review was performed for two different models in support of two litigation cases. The models were developed for source identification of pumped water. Expert reports and rebuttal comments were submitted; and appeared for depositions in both cases.

Airborne Electromagnetic (AEM) Survey Data Application, Department of Water Resources (DWR), California: In collaboration with Woodard & Curran, the project involves the development of methods, utility tools, documentation, and case studies with application of AEM data. The first phase of the project is currently underway.

Confidential Client, California: Provided expert opinion to a confidential client in support of a litigation matter. A Declaration was provided that demonstrated the connection between groundwater pumping wells and streamflow depletion, which formed the basis for judgement in the matter.

Texas Water Development Board: Teamed with WSP, created an online tool for TWDB for mapping statewide injectate migration in Class II injection wells. Literature review was performed for existing solution methodologies. Evaluated various numerical experiments to demonstrate the sensitivity of assumptions in the screening level analysis performed by the online mapping tool. Analytical solutions were implemented in the tool. The mapping tool was developed to work in coordination with other database processor tools developed by the teaming partner WSP that compiles well information from the Railroad Commission databases. Presented the methodology and tool at workgroup meetings comprised of close to 40 oil and gas, water resources, academic, and government professionals.

Texas Water Development Board – Aquifer Parameters: Managing an ongoing project for TWDB's groundwater modeling team to develop a statewide aquifer/ well test data compilation. More than 150,000 PDF documents were evaluated,

YEARS OF EXPERIENCE

25

EDUCATION

» **PhD**, Civil Engineering, Auburn University, 2019
» **MS**, Environmental Engineering, Indian Institute of Technology, 2001
» **BS**, Civil Engineering, University of Pune, India, 1998

REGISTRATION

» Professional Civil Engineer, Washington District of Columbia No. PE904565

EXAMPLE AREAS OF EXPERTISE

» Flow and Transport Modeling
» Numerical Software Development
» Surface Water-Groundwater Modeling
» MODFLOW, MT3D, and IWFM Development

AWARDS AND HONORS

» DAAD scholarship for master's project, Institute for Hydraulics and Water Resource Management, RWTH-Aachen, Germany: 2000–2001
» Gold Medal awarded for best academic performance in MS, Department of Civil Engineering, Indian Institute of Technology (IIT), Madras, India: 1999–2001

APPOINTMENTS

» 2023 – 2024: Co-convener, California Water and Environmental Modeling Forum (CWEMF), California
» 2023: Chair, GRACast subcommittee, Groundwater Resources Association (GRA), California

and relevant information was digitized and assembled in a database. A concerted stakeholder outreach effort was conducted by SSP&A and TWDB to obtain any aquifer or well pumping information available with organizations, agencies, GCDs, and other stakeholders. The TWDB documents and other data sources obtained from the stakeholder outreach were synthesized into usable, consistent, traceable and reproducible form.

Delayed-Subsidence in Integrated Water Flow Model (IWFM), California Department of Water Resources (DWR): Developed numerical code within DWR's IWFM flow simulator for DWR's Bay Delta Office. The code development accounted for delayed effect of pumping on storage change within clay interbeds that results in land subsidence. A technical memorandum provided to the DWR summarized mathematical formulation, numerical implementation, and examples.

Goleta Groundwater Basin, California: Assisted senior staff in support of a litigation matter. Reviewed models developed using several alternate groundwater and land surface models, including MODFLOW-SURFACT, Parflow-CLM, and DPWM. Supported evaluations of model development, recalibration, assessment of appropriate boundary conditions, and review of hydrogeology to develop a thorough understanding of the hydrogeologic system. Also performed water budget assessment, particle tracking, and solute transport simulations.

Confidential Client, California: Assisted senior staff in support of a litigation matter. Reviewed models developed using several alternate groundwater and land surface models. Supported evaluations of model development, calibration, and application.

Confidential Client, California: Developed MODFLOW 6 models to evaluate the fate and transport of injectate from UIC wells. Benchmarked aspects of model against analytical solutions before implementing 3D models. Incorporated client's detailed 3D geologic model using sediment texture data to derive hydraulic conductivity using power law averaging.

Monterey Peninsula Water Supply Project, California Marine Sanctuary Foundation: Teamed with Weiss Associates for a project that involved the calculation of freshwater captured by slant wells proposed for a desalination plant. The desalination plant would incur penalties for any freshwater captured by the withdrawal wells. An existing flow model was utilized, and boundary conditions and parameters were modified to perform sensitivity analysis and meet project objectives. In place of the original methodology of particle tracking used by the previous version of the model to assess flow paths, MT3D was used to identify the source of water and to quantify the amount of saltwater captured by the pumping wells.

MODFLOW-USG Development: Solute Transport in Lakes: Arcadis, Chile tasked SSP&A to add capability in MODFLOW-USG to simulate solute transport in lakes. The new capability added to the MODFLOW-USG code enables the simulation of solute transport within lakes, assuming instantaneous mixing within each lake, and their interaction with the underlying groundwater system. The project was completed in collaboration with Dr. Sorab Panday.

MODFLOW-USG Development – Transient Domain and Transport Properties: In collaboration with Dr. Sorab Panday, added transient IBOUND capability; added transient transport properties capability; added an option to reorder matrix to solve only active nodes, reducing run-times proportional to number of active cells in the model.

Continued from previous page

- » 2022: Co-chair, GRACast subcommittee, Groundwater Resources Association (GRA), California
- » 2021 – 2023: External faculty in the Civil Engineering Department at the University of Memphis (three-year term)
- » 2017: Member, Scientific Advisory Committee, Seventh International Groundwater Conference (IGWC-2017), Coimbatore, India, February.
- » 2016: Judge for NASA's Special Award at 35th Annual Loudoun County Public Schools Regional Science & Engineering Fair (RSEF), Freedom High School, March.
- » 2013 – 2015: Committee Member, Loudoun County Water Resources Technical Advisory Committee, Virginia.
- » 2012: Panel Member, International Groundwater Conference (IGWC) panel on fracture flow modeling and issues related to local farmers, Aurangabad, India.

PROFESSIONAL HISTORY

- » S.S. Papadopulos & Associates, Inc.: 2008–present
  - – Associate: 2023–present
  - – Senior Engineer: 2020–2023
  - – Senior Project Engineer: 2008–2020
- » University of Memphis, External Graduate Faculty: 2021–2023
- » HydroGeoLogic, Inc., Senior Engineer: 2001–2008
- » Shashi Prabhu and Associates, Civil Engineer: 1999

EMAIL

vivekb@sspa.com

South Fork Eel River Model, State Water Resources Control Board (SWRCB), California: Lead groundwater modeler for developing two integrated groundwater-surface water models for SWRCB in collaboration with Paradigm Environmental. LSPC was integrated with MODFLOW-USG to simulate the effects of pumping on instream flow. The calibrated model provided the basis for instream temperature modeling.

Shasta River Model, State Water Resources Control Board (SWRCB), California: Lead groundwater modeler for developing two integrated groundwater-surface water models for SWRCB in collaboration with Paradigm Environmental. LSPC was integrated with MODFLOW-NWT to simulate the effects of pumping on instream flow. The model provides a scientific basis for making a variety of groundwater management decisions.

Development of MT3D-USGS: In collaboration with U.S. Geological Survey (USGS), developed a new version of solute transport simulator, MT3D-USGS. This software is based on MT3DMS, developed by Dr. Chunmiao Zheng, but with new features in MT3D-USGS including simulation of transport in lakes and streams, a kinetic reaction module to simulate multiple electron-donors and acceptors, a contaminant treatment system package for simulating aboveground treatment and circulation of solutes, and unsaturated-zone transport. Other improvements include the handling transport in dry cells of MODFLOW-NWT and corrections to the storage formulation.

Sacramento Valley Model (SVSim), California Department of Water Resources (DWR): The Sacramento Valley model (SVSim) was calibrated in a stepwise systematic manner, by first targeting water budgets, then calibrating land use parameters, and finally calibrating aquifer parameters. This holistic approach helped obtain a reasonably calibrated model for estimating reliable water budgets, calibrating the model to streamflow and groundwater heads. Sensitivity analysis was also performed. Cluster analysis was performed to assess groundwater head trends and the identified trends called type-hydrographs were utilized as additional calibration targets. Aquifer parameters were developed utilizing sediment texture data with the use of the Texture2Par utility. Valley-wide water budgets were calculated using time-series analysis and reviewing CalSim reports. Issues in the IWFM code were identified and feedback on the IWFM code with respect to convergence and robustness was provided to DWR. Code changes in IWFM were made to accommodate variable wetted perimeter and dynamic connection to GW over wide stream reaches. Model comparisons with Femflow3D were performed. The model was applied to estimate stream depletion caused by pumping. Two technical memorandums were written at the conclusion of this project.

Fine-grid Central Valley Model (C2VSim-FG), California Department of Water Resources: Model calibration of the central valley model, C2VSim-FG, was performed using parameter estimation software, PEST. Groundwater head data was synthesized using cluster analysis to identify short- and long-term temporal trends from groundwater level data available for more than ten-thousand wells and the developed type-hydrographs were used as additional calibration targets. Texture2Par utility was used for developing aquifer parameters based on sediment-based texture data. A technical memorandum was produced at the conclusion of the project.

Texture2Par Utility Development: An open-source utility, Texture2Par, was developed to calculate aquifer parameters based on sediment-based texture data. Power-law averaging is used to compute bulk aquifer parameters based on percent coarse information available from well log texture data and relevant aquifer parameter model input files for MODFLOW or IWFM are written by the utility. Texture2Par incorporates capability to implement depth-decay of hydraulic conductivity. The standalone utility can also be incorporated seamlessly within the parameter estimation software, PEST. Sediment-based aquifer parameters can be varied and interpolated between pilot points.

Red Hill Bulk Storage Facility, Hawaii: Provided technical guidance at the Facility regarding simulation of fuel components in the subsurface, and analyses of calculations made using MODFLOW-USG in particular, the main modeling code used at the Red Hill Facility by the Navy and its contractors.

Evaluation of Repetitive Sump Pump Failure at Private Residence, Maryland: The project involved the evaluation of the repetitive failure of a sump pump at a private residence. Analysis demonstrated that flow of water through alkaline fill material into the drains was causing the pump to fail. Tasks involved water level analysis in the vicinity of the residential property, model development to simulate groundwater flow to compute a drain elevation required to lower groundwater levels at the residential property to avoid the flow of water through the fill material.

Confidential Client, Atlanta: The project involved the release of organic compounds from a cleaning facility and the source identification associated with the contaminant release. The project involved reviewing data, expert reports, and depositions provided by subject matter experts. Tasks involved vadose zone modeling, developing analytical models for saturated zone transport, and linking the vadose and saturated zone models.

Confidential Client, North Dakota: Developed a flow and transport model to simulate the fate and transport of contaminants resulting from a pipeline leak. Sensitivity analyses were performed to evaluate parameter uncertainty and predicted results related to the percolation of contaminant at the site. Vadose zone modeling was also performed for additional analysis.

Confidential Client, Salisbury, Maryland: The project initially involved the evaluation of the reactive transport and fate of hexavalent chromium (Cr [VI]), which arose as the result of historical plating activities at a manufacturing facility, within an alluvial aquifer in Maryland. Tasks involved reactive transport analyses to assess short- and long-term remedial effectiveness and support long-term monitoring (LTM) design. Subsequently, the project also involved the delineation and mobility-assessment of light non-aqueous phase liquid (LNAPL); and evaluating the disposition, transport, and fate of chlorinated volatile organic compounds (CVOCs).

Kings River Conservation District Model Conversion, California: Converted an existing surface-water/groundwater interaction model (originally developed using IGSM) to California Department of Water Resources' IWFM modeling code. The model was extended in time with new data, finer vertical discretization was added, and the model was recalibrated to root- zone water requirements and groundwater head and surface-water flow measurements. The model calculated regional budgets, stream flows, and groundwater hydrographs using irrigation data, crop distribution, and dynamically changing land-use. This model will be used as a scientifically based management tool to evaluate various Integrated Regional Water Management Plan projects.

Nevada Energy: A 2D density-dependent flow and transport model was developed to assess the fate of a highly dense TDS plume. The objective of the model was to determine the timing and expected maximum concentration of TDS at the downstream end of the existing plume. The groundwater system in this case represented a 'theoretically' unstable system with a higher-density TDS plume overlying a relatively lower-density system in lower aquifer formations.

Analysis of Impact of Lakes on Subsurface Freshwater Resources of Low-lying Islands: Collaborative project with University of South Florida, Michigan Technological University, University of Florida, and SSP&A, exploring impacts of lake formation on low-lying islands resulting from inundation due to climate change. Research found that on low-lying islands with dry climates (evapotranspiration exceeds rainfall) freshwater storage can substantially decrease if sea level rise results in lake formation within interior topographic lows, splitting the freshwater lens and reducing available freshwater. Results were published in Geophysical Research Letters (Gulley *et al*, 2016). Follow up work included the evaluation of climate change impacts on small islands like the Abaco Island in The Bahamas.

Bannister Federal Complex Groundwater Model, Kansas City, Missouri: Developed a groundwater model as part of a comprehensive due diligence investigation of the Bannister Federal Complex (BFC) in Kansas City. The groundwater model assisted with the evaluation of redevelopment scenarios and evaluation of remedial alternatives and costs. Predictive results from the model were beneficial in identifying locations at the site that are prone to flooding during and post-demolition. Uncertainty analysis was performed using PEST to assess the range of possible groundwater levels in the anticipated flooding areas during the post-demolition phase. Predictive results were also used to design a well network to capture the plume. Analysis was also performed to assess the efficacy of slurry walls in maintaining inward head gradients.

Daly City, California: Developed a solute transport model for the assessment of fate and transport of methyl tertiary butyl ether (MTBE) and tert-butyl-alcohol (TBA) in the subsurface released at a gas station. The numerical model developed using MT3D-USGS simulated the production of TBA resulting from the degradation of MTBE and the movement of both plumes in groundwater; and provided projections of long-term concentrations of both MTBE and TBA in the subsurface.

New York State Department of Environmental Conservation, Elmont, New York: Co-developed capabilities in MT3DMS to simulate natural attenuation processes using multi-species kinetic reactions. A general form of reaction equation was implemented in MT3DMS to simulate the consumption of multiple electron donors by multiple electron acceptors.

Livermore Valley Groundwater Basin Surface-Water Transport in MT3D, California: Added surface-water transport capability to MT3DMS to simulate contaminant transport in surface-water features, particularly to work with the lake (LAK) and the stream flow routing (SFR) packages of MODFLOW. Capability was also added to these packages to interact with the unsaturated zone transport in the case where the vadose zone is simulated using the unsaturated-zone flow (UZF) package of MODFLOW. A flexible numerical solution was implemented to easily select a spatial and temporal weighting scheme. Solutions were compared to analytical solutions and OTIS as part of the verification process. This development was performed to provide Zone 7 a tool to develop salt-management strategies so that Zone 7 could use the capability of transport of salt between groundwater and surface-water features in the Livermore Valley Groundwater Basin.

U.S. Department of Energy (DOE), Hanford, Washington: As part of a multi-firm team, contributed to the evaluation and development of remedial alternatives and strategies for RI/FS and post-ROD activities. Developed and applied modeling approaches for remedy design and analysis. Evaluated remedy performance using multiple lines of evidence approach. Evaluated the capacity of an infiltration pond with an axisymmetric model developed using MODFLOW-SURFACT and MODFLOW-USG. Developed

MODFLOW, MT3D, and MODPATH as part of the DOE software approval process.

Model Review, Gallup, New Mexico: Reviewed models to evaluate the accuracy of data, modeling results, and interpretations resulting from models that were created in support of pumping well permit applications by the City of Gallup. Impacts were evaluated on the water levels of wells in the vicinity of pumping wells owned by Tri-State Generation and Transmission Association, Inc.

Treated Water Discharge Impact Evaluation, Freeland, Washington: Evaluated the impacts of discharging treated water on groundwater and surface water in the vicinity of an infiltration site. Developed a groundwater model using MODFLOW.

Halliburton Energy Services, Inc., Duncan, Oklahoma: Assisted Halliburton Energy Services, Inc. in their effort to investigate and remediate perchlorate contamination. Seepage from evaporation ponds containing perchlorate impacted groundwater beneath the site. Evaluation of the spread of a perchlorate plume and the development of potential source terms contributing to the plume were analyzed using MODFLOW, MT3D, and analytical models.

Evaluation of Corrosion Inhibitor Spreading, Cushing, Oklahoma: Evaluated the distribution and spreading of a vapor-phase corrosion inhibitor upon application in porous and permeable materials beneath large aboveground storage tanks at a petroleum tank farm. Constructed a flow-and-transport model (using MODFLOW-SURFACT) to simulate the migration of the aqueous solution injected beneath the tanks and the subsequent transport of the vapor-phase inhibitor compound in the sand pack air beneath the tanks.

Water Resource Assessment, White Bear Lake, Minnesota: Developed a transient integrated surface water – groundwater model based on USGS' NMLG model. The transient model evaluated potential reasons for declining lake levels in White Bear Lake and other lakes in the region. The model is being used by MDNR for predictive assessment and development of mitigation strategies. MODFLOW-NWT was utilized for groundwater modeling and Soil Water Balance (SWB) was utilized for simulating land surface processes. At the conclusion of the project, technology transfer was conducted to pass the model to MDNR staff; attended a public meeting in Minnesota that shared modeling results with stakeholders.

Data and Model Review for Litigation, Orange County, California: Provided data and model reviews in support of a litigation case for evaluating the fate and source of VOC plumes.

Model Review and Contamination Calculations, Great Neck, New York: Reviewed a DYNFLOW model and provided calculations of the mass and volume of contamination.

Hardage-Criner Superfund Site, Oklahoma: Performed flow-and-transport modeling in 2011 to analyze the migration of contaminants across Criner Creek, safe shut-down duration of V-trench, and decreasing flow rates in the V-trench, and future scenarios were performed through 2025 to evaluate the fate and transport of the VOC plume. Post-audit simulations were performed in 2021, ten years subsequent to the original model to evaluate the robustness of the model calibrated in 2011.

Agrico MODFLOW Model Evaluation for Litigation, Florida: Evaluated a MODFLOW model in support of a litigation case to estimate the impact of historical activity at a fertilizer plant on the local groundwater system.

Model Review, St Croix, Virgin Islands: Reviewed ARMOS, BioTrans, and MODFLOW-SURFACT models.

Dry Cell Problem of MODFLOW and MT3D: Developed MODFLOW, MT3D and MODPATH codes to handle dry cells in a numerically stable, robust, and efficient manner. Work primarily involved reformulation of governing equations to incorporate Newton-Raphson numerical techniques and addition of solvers to the MODFLOW code and to handle mass flowing through unsaturated cells in the MT3D code. Other features were also added, including recirculation for pump-and-treat systems and simple reaction module.

Development of a Source Screening Module: Developed an Excel module to implement an analytical solution for tracking transport from a contaminant source to a receptor well through the vadose zone and saturated zone. Documentation was completed for the Excel module. The module was then applied to onsite data to compare against STOMP results.

Data Management and Analyses, New York, NY: Managed data and performed analysis for a 60-acre urban area underlain by petroleum hydrocarbons. Mapped apparent product thickness and evaluated product recovery. Evaluated gradients caused by pumping activities.

CTS Package for MT3D: Developed a contaminant treatment system (CTS) module in MT3D. The objective of this project was to enable simulation of a typical pump-and-treat system and to represent mixing and reinjection of treated contaminated groundwater. Tasks involved planning, conceptualization, programming, testing, and preparing the documentation for the module.

MODFLOW Developments: Several features were added to MODFLOW: injection/extraction well management in WEL and MNW2 packages; adaptive time-stepping; nodal mass balance for tracking local mass balance error; and general head boundary time series as part of the FHB package.

MT3D Developments and Related Research: Activities included:

▪ Adding chain decay and MONOD kinetics options; prescribed concentration boundary on the highest active node; separate Kd for mobile and immobile domains.

▪ Density-Dependent Reactive Transport Modeling Code Development: Ph.D. research at Auburn University, with Dr. Prabhakar Clement. Objective is to develop a simulation code to simulate density-dependent flow and reactive transport. These capabilities exist individually in separate codes, SEAWAT and RT3D. This project will combine these capabilities into one code to investigate the impact of density on reactive transport.

▪ Laboratory and Modeling Investigation of Saltwater Intrusion in Strip Islands: Ph.D. research at Auburn University, with Dr. Prabhakar Clement. Lab-scale sand-tank experiments were simulated using SEAWAT to study transient changes in freshwater lenses during dry and wet cycles were studied. The findings have been submitted to the journal Water Resources Research.

HydroGeoLogic, Inc. – *Reston, Virginia*

Upper Santa Clara River Chloride TMDL Collaborative Process, California: Developed a numerical model for the Upper Santa Clara River (USCR) watershed for the Santa Clarita Valley Sanitation District of Los Angeles County and the Los Angeles Regional Water Quality Control Board. The model evaluated the fate and transport of chloride in surface-water and groundwater basins of the USCR in accordance with the chloride total maximum daily load (TMDL) collaborative process. A water supply systems module was developed to deal with the complex water routing and resulting water quality between purveyors, groundwater, surface-water and water reclamation plants.

South Florida Ecosystem Office of the National Park Service (NPS), Florida: Developed a groundwater/surface-water interaction model simulating flow and transport to analyze the effectiveness of a Marsh Driven Operations Plan for three pumps and detention basins along the L-31N canal. Used the calibrated model to analyze the migration of total phosphorus (TP) and estimate TP budgets in detention ponds in the vicinity of the canal. Training was provided to NPS staff and students at Florida International University. The objective of the Marsh Driven Operations Plan was to manage surface-water flows to achieve flood protection and ecosystem protection by implementing operation strategies.

Groundwater Interactions in Western Orange and Seminole Counties, Florida: As Project Engineer of a project funded by the St. Johns River Water Management District, developed an integrated regional groundwater/surface-water model for western Orange and Seminole counties in east-central Florida. Responsible for data assimilation and processing, MODHMS model

development and simulations, and post-processing of results and model calibration. The model developed assisted the water management district in more efficient management of the water resources in its jurisdiction, including balancing of surface-water and groundwater sources for water supply, and establishing a sound scientific and engineering basis for water use permitting.

St. John's River Water Management District, Florida: Assisted with litigation support to the Division of Water Use Regulation in reviewing three-dimensional groundwater flow, saltwater-intrusion models. Provided data analysis relating to a consumptive use permit application for a wellfield. Reviewed MODFLOW and SEAWAT models and prepared presentation material in assisting senior staff to support the District's attorneys in formulating questions and responding to questions from other parties. The judgment was in favor of the District.

Modeling in Support of a Well Permit Application, Florida: Performed numerical modeling in support of a well permit application for the county. The project involved performing sensitivity simulations for the pre-development ECF model, preparing, and simulating future conditions, compiling observations within the county, processing and analyzing results, and preparing the report.

Regional Saltwater Intrusion Modeling for Water Supply Planning, Okaloosa, Santa Rosa, and Coastal Walton Counties, Florida: As the Project Engineer, responsible for supporting the development of two regional, density-dependent saltwater intrusion models covering coastal Walton County in the northwest Florida panhandle. The DSTRAM-based model is designed to address concerns of upconing of deeper saline waters and of saltwater intrusion from the Gulf of Mexico and its impact on water supplies and existing wellfields. Responsibilities included pre-processing of input files, DSTRAM simulations, post-processing using TecPlot and other tools, sensitivity analysis and calibration.

Three-Dimensional Density-Dependent Flow and Transport Modeling of Saltwater Intrusion, Southern Water Use Caution Area, Florida: Supported the predictive simulations to assess the benefits and consequences of establishing a sub-surface trough or a pressure ridge along the Tampa Bay coast. Responsible for preliminary simulations assessing the effects of a sub-surface trough and pressure ridge, predictive simulations and post-processing using ArcView, ViewHMS and Tecplot.

Gilbert & Mosley Site, Wichita, Kansas: Developed a groundwater transport model for the Gilbert & Mosley Site. This project used a MODFLOW-SURFACT-based contaminant transport model to simulate a PCE-TCE-DCE-VC plume. Tasks involved pre-processing of the field observation data, calibration of the model, remediation well simulations, post-processing of results using

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TECPLOT, and plotting and presentation of calibration results.

U.S. Army Corps of Engineers, Buffalo District, Niagara Falls Storage Site, Lewiston, New York: Developed groundwater models for the Niagara Falls Storage Site. This model simulated flow and transport of a variety of radionuclides and metals. One-dimensional flow was simulated using Hydrologic Evaluation of Landfill Performance (HELP) program for modeling unsaturated zone. Three-dimensional flow and transport were simulated using MODFLOW-SURFACT. Tasks involved data compilation, model development using MODFLOW-SURFACT and HELP, analyses of results, and post-processing.

Enhancement of Generic Soil Column Module (GSCM): The objective of the project was to enhance the existing module (GSCM) to include kinetic mass transfer between solid, aqueous, and gaseous phases. Tasks included code development in Fortran and C++ languages, performing test cases in MOFLOW-SURFACT and verification cases for GSCM, performing sensitivity runs, generating plots using MS Excel, and generating a static library (LIB) file compatible with C++ wrapper for GSCM. The proposed use of this module was for the dynamic simulation of fate and transport of chemical constituents in various types of waste management units.

Dyes and Pigment Industry Waste Listing Determination: Provided modeling services in support of human health risk modeling and sensitivity analysis corresponding to exposures from the disposal of dyes and pigment industry wastes. Tasks included data collection and the preparation, management, and execution of EPACMTP simulations.

Fossil Fuel Combustion Waste Listing Determination: Provided modeling services in support of human health and ecological groundwater risk modeling and sensitivity analysis corresponding to exposures from the disposal of fossil fuel combustion wastes. Tasks included data collection, preparation, management, and execution of EPACMTP simulations.

Development of a Probabilistic Screening Module for Industrial Waste Management Evaluation Model (IWEM) Software: Developed a model for the EPA's Office of Solid Waste for the management of non-hazardous industrial wastes. The probabilistic screening module used parameter generation techniques to ensure that only physically feasible scenarios were executed by the IWEM software.

U.S. Environmental Protection Agency Office of Radiation and Indoor Air, Probabilistic Risk Assessment Modeling of Low-Level Activity Waste: This project coupled EPACMTP with a source release model that tracked a radioactive parent and its daughter products. The project involved development of a Monte Carlo wrapper for a source release model, MCDUST (Monte Carlo - Disposal Unit Source Term), that produced results usable by EPACMTP. Tasks involved development of Monte Carlo wrapper capable of exchanging information with MS access database, understanding the structure of model input files, stochastic variables, and distributions from CMTP code, verification using MODFLOW-SURFACT, writing tools for pre- and post-processing using Visual-Fortran, data transfer from databases using Fortran, data assimilation, model simulations, testing and documentation.

Development of MODHMS/MODFLOW-SURFACT: Developed software as a part of the research and development program. Tasks involved formulation, code development, source control, and testing and documentation of MODHMS/MODFLOW-SURFACT. Tasks also included sales and technical software support. Specific modules/features added to the code included two additional numerical matrix equation solvers, a Land Use Parameterization (LUP) package and a Water Supply Systems (WSS) package, a Zone Budget (ZNB) package, enhancement of MODFLOW packages like the Flow and head boundary (FHB) package, a subsidence (SUB) package, and a Channel Package with two new channel structures. Related tools like MODPATH and PEST were enhanced to work seamlessly with MODHMS/MODFLOW-SURFACT.

Courses & Workshops

COURSES TAUGHT:

- 2024 – Training on PEST-facilitated calibration of SVSIM and C2VSimFG models for California Department of Water Resources staff in Sacramento, February 5-9, 2024

- 2022 – Invited talk (webinar) given to faculty and students at the University of Maryland Baltimore Campus' Center for Urban Environmental Research and Education, Spring 2022 Seminar Series, May 6, 2022.

- 2021 – Invited talk given to faculty and students at Indian Institute of Technology, Madras (IIT Madras) India. November 6, 2021.

- 2020 – Invited talk (webinar) given to faculty and students in India. November 16, 2020.

- 2018 – Provided a groundwater demonstration with a water tank at Discovery Elementary School, Ashburn, Virginia, 2018.

- 2013 – Assisted Mr. Chris Neville in teaching a short course "*Effective Solute Transport Simulation.*" GeoMontreal, Montreal, Canada, September 2013.

- 2003 – 2008 – Assisted Dr. Sorab Panday in teaching MODHMS / MODFLOW-SURFACT courses to the following organizations: University of Washington; Federal Energy Regulatory Commission; Malcolm Pirnie;

U.S. Army Corps of Engineers; Jacksonville District, Florida; Everglades National Park; National Parks Service, Florida; Florida International University (at HydroGeoLogic, Inc.).

COURSES ATTENDED:

- 2017 – MODFLOW 6 Training Workshop, Golden, CO, May 2017

- 2014 – IWFM Training Workshop in Sacramento, CA, January 2014

- 2013 – Numerical Methods in Hydraulics and Hydrology, Auburn University

- 2013 – MODFLOW-USG 2-day course, Bethesda, MD

- 2013 – Integrated Water Flow Model, IWFM training workshop

- 2012 – Numerical Modeling of Free Surface Flows, Auburn University

- 2012 – Chemical Principles of Environmental Engineering, Auburn University

- 2011 – Subsurface Transport Over Multiple Phases – STOMP short course

- 2010 – Parameter Estimation – PEST short course

Publications & Presentations

Scantlebury, L., Bedekar, V., Tonkin, M.J., Karanovic, M., and Harter, T., 2025. *Texture2Par: A Texture-Driven Tool for Estimating Subsurface Hydraulic Properties*. Environmental Modelling & Software. doi: 10.1016/j.envsoft.2025.106372

Bedekar, V., Hatch, T., Traum, J.A., Tolley, G., Singh, A., and Faunt, C.C., 2024. *Models: Tools for Estimating and Predicting Subsidence*. Hydrovisions, 2024 Spring Issue, p. 14-17.

Hatch, T., Neely, W., Bedekar, V., and Tolley, G., 2023. *California's Sinking Feeling: An Introduction to Subsidence*. Hydrovisions, 2023 Fall Issue, p. 10-12.

Bedekar, V., C. Neville, M.J. Tonkin, R.D. Bartlett, and P. Plato, 2023. *A Unit-Concentration Method to Quantify Source Contribution*: Groundwater, vol 62, issue 2, p. 303-309. doi: 10.1111/gwat.13333

Bedekar, V., R. Goswami, 2023. *Aquifer Characterization Using Texture2Par. Texas Groundwater Summit*, August 29-31, San Antonio, Texas.

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