Appendix A

Resume of Dr. Sorab Panday

ENVIRONMENTAL

Sorab Panday, PhD

Principal Engineer

Education

Ph.D., Civil & Environmental Engineering, Washington State University, Pullman, Washington, 1989

M.S., Civil Engineering, University of Delaware, Newark, Delaware, 1986

B. Tech., Civil Engineering, Indian Institute of Technology, Bombay, India, 1984

Awards & Affiliations

American Geophysical Union; National Ground Water Association; International Association of Hydrogeologists; Groundwater Resources Association of California

M. King Hubbert Award, National Groundwater Association, 2015

Member of the National Academy of Engineering, 2017

Lifetime Achievement Award, California Groundwater Resources Association, 2022

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Dr. Sorab Panday is a Principal Engineer at GSI Environmental with 33 years of experience in directing, managing, developing, troubleshooting, and reviewing flow and transport models for subsurface contamination / remediation evaluations, groundwater/ surface-water interactions, and water resource management. He has worked on hydrologic and hydrogeologic modeling projects spanning a wide range of schedules and budgets. These projects involve multiple spatial and temporal scales; complex geological settings; diverse stakeholder concerns; extreme climatic conditions; unique water/contaminant management issues; and challenging numerical conditions.

Dr. Panday has provided leadership, mentorship, training and guidance on projects for client and staff; executed and managed modeling projects for various industries and government agencies; managed regulator and stakeholder modeling committees; provided expert-witness services; participated in expert panels; conducted workshops and webinars on water resource and subsurface contaminant transport modeling; and maintained effective communication with regulators and clients. He has developed code for several of the industry's state-of-the-art water resource modeling tools and is the lead author on MODFLOW-USG, an unstructured-grid version of MODFLOW released by the USGS. Dr. Panday is also a part-time Research Professor at University of Nebraska, Lincoln. He publishes regularly in leading industry journals and provides review and editorial support to industry publications and conferences.

Dr. Panday is the 2015 recipient of the M. King Hubbert Award, presented by the National Ground Water Association for major science or engineering contributions to the groundwater industry through research, technical papers, teaching, and practical applications. He was also elected as a Member of the National Academy of Engineering (NAE) in 2017 for the development of computer code for solving complex groundwater problems. He is also the recipient of the 2022 Lifetime Achievement Award from the California Groundwater Resources Association for his contribution towards analyzing complex groundwater problems.

PROJECT EXPERIENCE

Water Resource Modeling

Preliminary Inland Injection Well Siting, Water Replenishment District, Lakewood, CA. Provided guidance and input for modifying and using an existing groundwater flow of the West Coast Basin to optimize placement of wells to inject between 1 and 4 MGD of Advanced Treated Water (ATW) subject to environmental constraints, minimum residence time to municipal well restraints, land availability and cost, and cost of additional infrastructure from existing ATW plant.

Peer Review of Groundwater Flow Model, Ventura County, United Water Conservation District (UWCD), Santa Paula, CA. Reviewer for UWCD's groundwater flow model development. UWCD is developing a numerical groundwater flow model of portions of Ventura County in support of efforts to estimate basin-specific sustainable yields and evaluate overdraft mitigation measures. The model is being used to support potential future groundwater extraction, recharge, and other management scenarios within the Basins. Provided review of the model development effort and continuing with ongoing, long-term guidance and review of the model for conducting uncertainty evaluations and predictive simulations for basin management and planning. Also provided support to UWCD in meetings with stakeholders and technical experts.

Review of Regional Groundwater Flow Model at Aerojet Superfund Site, Carmichael Water District, Carmichael, CA. Review regional groundwater flow model at Aerojet Superfund Site and evaluate current remediation performance as it relates to the Carmichael Water District. Identified areas of limited data and specified model improvements. Present findings to client in technical memorandum.

Groundwater/Surface-Water Interaction Model, Los Angeles County Sanitation Districts, CA. Project manager and principal investigator for developing a flow and transport Groundwater/Surface-Water Interaction Model (GSWIM) of the Upper Santa Clara River watershed to address chloride TMDL issues. Model highlights include use of a curvilinear grid to provide resolution near the river; parameterizing evapotranspiration and land surface properties via temporally varying land use types; and water supply systems that distribute pumped and imported water for outdoor use as per the unit demand of each land use type. The water supply systems further discharge indoor-use water (with or without treatment) to discharge locations in streams or apply it to the land surface as reuse. The model was developed and calibrated to groundwater levels, stream flows, groundwater chloride levels and stream chloride measurements for daily-averaged rainfall stresses over a 31-year period from 1975 through 2005. The model is being applied to examine the effects of various scenarios on chloride levels till 2030 and to examine various alternatives that meet the TMDL limits in an optimal manner. Provided leadership in model conceptualization, development, calibration and application; managed scope, budget and work-plans; prepared reports; provided presentations to staff and stakeholders; and attended stakeholder and technical meetings.

Flow and Transport of Potential Solutes at the Water Table from Jet Fuel Storage Tanks, NAVFAC, Hawaii. Principal Investigator for simulating source water zones of water supply shafts and migration of potential solutes from beneath the Red Hill Facility, Oahu, Hawaii. The modeling was conducted under supervision and guidance of Subject Matter Experts (SMEs) from the US EPA and the Hawaii Department of Health. A multi-model framework was employed to address conceptual and parameter uncertainties and make allowance for divergent concerns of various stakeholders and SMEs. Provided leadership in modeling, report preparation, presentation to SMEs, and addressing difficult modeling issues with SMEs and stakeholders.

Density-dependent Groundwater Flow and Transport Model of the Lower Rio Grande Valley River Basin, Texas Water Development Board, Austin, TX. Developed a numerical model of the Lower Rio Grande Valley (LRGV) to evaluate the impacts of increased fresh and brackish groundwater pumping in the LRGV, as outlined in the 2016 Region M plan. The model was developed with a density-dependent flow and transport version of MODFLOW-USG and included a quad-patch refined grid around the River and irrigation canals to provide finer resolution in capturing the surface-water interactions. The model was calibrated from 1984 through 2013 using annual stress periods. The model was used to evaluate the impact of pumping on groundwater and surface-water flows and levels; salinity within the groundwater basin; and salinity of the extracted water for current and planned additional desalination plants in the area. Drawdown computations from the model for planned future desalination operations also provide estimates of compaction stresses to help evaluate the potential for land subsidence. The model was also applied towards evaluating the impact of data gaps and different conceptualizations (e.g., for faulting) within the basin.

Update of Groundwater Availability Model for the Northern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers, Texas Water Development Board, Austin, TX. Coordinated development of a numerical model of the Northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers for managing the water resource. The numerical model was developed using MODFLOW 6 and included a quad-patch refined grid along rivers to provide finer resolution in capturing surface-water interactions. The grid further included vertical coarsening with depth and displaced connections across faults. The model was calibrated from 1984 through 2013 using annual stress periods. The pumping and water level datasets were highly uncertain; therefore, the model was further used to evaluate the pumping and recharge responses of monitoring wells and determine the associated influences. The model was applied to evaluate pumping potential for desired future conditions.

Update of Groundwater Availability Model for the Southern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers, Texas Water Development Board, Austin, TX. Coordinated development of a numerical model of the Southern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers for managing the water resource. The numerical model was developed using MODFLOW 6 and included an oct-patch refined grid along rivers to provide finer resolution in capturing surface-water interactions laterally and vertically. The model was calibrated to predevelopment conditions and from 1985 through 2017 using annual stress periods. An ensemble of models was also constructed from the final model for potential use in evaluating uncertainties in future management scenarios. The model is being applied to evaluate desired future conditions.

Impact of Coal Bed Methane (CBM) Extraction on Regional Groundwater Systems, Department of Natural Resources and Mines, Brisbane, Queensland, Australia. Provided simulation support under a sub-contract from Watermark Numerical Computing, to evaluate the impact of CBM extraction facilities on the regional groundwater system. The gas is adsorbed onto coal bed seams under pressurized conditions. Large quantities of water are extracted to desorb gas from the seams – the operation of several such facilities can have a cumulative impact on the overlying potable water aquifers. The regional nature of the analysis precludes practical use of a multiphase simulator for analysis. Therefore, the multi-phase flow conditions were simplified and the modified equations were implemented into a customized version of the MODFLOW-USG code. Benchmark and verification simulations were conducted to validate the methodology against a rigorous multi-phase simulator. Upscaling procedures and parameterization are being investigated to evaluate large aquifer systems, 10s of thousands of kilometers in size.

Modeling Dissolution Behavior of DNAPL at the Ironton Coke Plant Site, Subcontract through AMEC for Honeywell International Inc., Golden Valley, MN. Principal Investigator for modeling conducted to support EPA's 5-year efficiency evaluation for remedial operations at the Ironton Coke Plant Site in Ironton, Ohio. DNAPL removal efforts at the site to date, have not resulted in significant decrease of the measurable subsurface DNAPL mass or of dissolved concentrations of the DNAPL components. The study evaluated the dissolution behavior of major components of a DNAPL pool at the site and compared results with simulations initiated with only residual DNAPL (assuming all mobile DNAPL could be removed). Results from the study indicated that the more soluble components would dissolve and be removed from the system with groundwater migration for both cases. However, the more insoluble components would persist as a source of downstream contamination for over 100 years even if all mobile DNAPL were instantly removed. Therefore, groundwater plume control and monitoring, as is being performed at the site, is an effective strategy and removal of the mobile DNAPL with associated treatment does not provide any significant gains over the 100 year analysis period.

Simulation of Seep and Remedial Alternatives at the Former Invista North Terminal Site, Koch Remediation & Environmental Services, Wilmington, SC. Principal Investigator for developing a groundwater flow model to evaluate and address a low-volume seep of water containing low concentrations of para-xylene. A steady-state groundwater flow model was developed and calibrated to current site conditions, and various alternative remedial measures were evaluated for effectiveness in addressing the issue. Simulations indicated that the preferred French-drain design alternative may not be effective due to low conductivity soils down-gradient from the site; however, backfilling or capping would reliably eliminate the seep even under wet weather conditions.

City of Flagstaff 100-year Water Supply Investigation, City of Flagstaff, AZ. Principal Modeler for construction and calibration of a groundwater model for simulating the 100-year water supply for the city as per ADWR's Adequate Supply Program and proposed Hydrologic Guidelines and Proposed Rulemaking Changes. The modeled scenarios consider a mixed use of surface water, groundwater and reuse to meet its projected requirements.

Groundwater Modeling Impact Analysis at Red Gap Ranch (RGR), City of Flagstaff, AZ. Principal Modeler for construction and calibration of a groundwater model simulating various groundwater pumping scenarios from future wells in the C-Aquifer at RGR. The evaluations also considered impacts of pumping on adjacent Native American lands. Unsaturated Zone Recharge Modeling, GSI Water Solutions Inc., Portland, OR. Modeling Consultant for simulating vadose zone injection to investigate design and operational goals for injection wellfields for a large-scale Aquifer Storage and Recovery (ASR) project at Jeju Island, in Korea. Assisted with conceptualization of the system and preliminary model simulations and provided modeling staff with training and QA. The model was used to evaluate and optimize the number of wells, spacing, and well depth for injection of 6 MGD during the wet season, including maintaining perched water columns for well rehabilitation.

Unsaturated Zone Recharge Modeling, GSI Water Solutions Inc., Portland, OR. Modeling Consultant for vadose zone injection simulation used to investigate design and operational goals of injection wellfields during a large-scale Aquifer Storage and Recovery (ASR) project at Jeju Island, South Korea. Assisted with conceptualization of the system and preliminary model simulations, and provided modeling staff with training and QA. The model was used to evaluate and optimize the number of wells, spacing, and well depth for injection of 6 MGD during the wet season, including maintaining perched water columns for well rehabilitation.

Saltwater Intrusion Hydraulic Barrier Evaluation and Resource Management, West Coast Regional Water Supply Authority, West Basin, CA. Directed and conducted updating of an existing groundwater flow and transport model of the West Coast Basin Barrier Project in Los Angeles, California from SUTRA to the SEAWAT code. The model was calibrated and used to assess movement of tertiary treated wastewater injected as saltwater intrusion barriers.

Model for 5-Year Dewatering Plan, Bingham Canyon Mine Kennecott Utah Copper, Utah. Under subcontract from Montgomery and Associates, assisted with model development, review and troubleshooting support for evaluating dewatering and mine planning at the mine pit using the unstructured grid code MODFLOW-USG. The groundwater model will ultimately be used to support geotechnical analyses conducted in support of ongoing mine planning and to assist in optimization of the mine dewatering system and will replace the 3-D regional model in conjunction with 2-D cross-sectional models being used for planning. Vertically and horizontally nested grids provide resolution and conduit flow mechanisms move water within the workings to simulate regional conditions and required details with one model.

Model for Mine Dewatering at the Antamina Mine, Peru. Provided model development, review and troubleshooting support for modeling of mine dewatering to estimate pumping and treatment infrastructure requirements, and the impact of dewatering to nearby surface water bodies. The model covers the entire watershed and includes linear conduit elements to evaluate fracture flow in the region. A nested grid was developed with MODFLOW-USG to provide resolution in the vicinity of the mine workings. Steady-state and transient simulations were conducted to evaluate seepage under various weather conditions to assist in mine development planning. A modeling seminar was also conducted in Peru to present the MODFLOW-USG code and provide technology transfer.

Review of Oil Sands Mine Models, Confidential Client, Alberta, Canada. Reviewed FEFLOW numerical models of at oil sands mines to evaluate tailings storage and processed water storage. Modeling objectives included evaluation of transport of processed affected water using particle tracking to aid mine design and design of interception well network.

Reviews of Tailings Impoundment Models, British Columbia, Canada. Senior Reviewer at AMEC for various finite element and finite difference models constructed to evaluate containment systems to prevent tailings effluents from entering the regional groundwater system. The project locations were across British Columbia and included gold mines and sulfide deposit mines.

Brighton and Worthing Groundwater Flow Model, London, UK. Provided modeling support and review for development of a MODFLOW-USG model to simulate well and adit yields in the Chalk of the South Downs. The model is being applied in conjunction with climate models to provide predictions of future yields under changing precipitation patterns.

Integrated Surface and Subsurface Flow and Transport Modeling, National Parks Service (NPS), Everglades, FL. Project manager and principal investigator for developing a surface/subsurface flow and transport model to evaluate the Marsh Driven Operations Plan (MDOP) for the Rocky Glades, as part of the multi-billion-dollar Comprehensive Everglades Restoration Program (CERP). The MDOP is developed to manage pumping operations from the L-31N canal into adjacent detention areas to minimize drainage of the Everglades to the canal without introducing high levels of phosphorous into the Everglades ecosystem. The model was developed using MODHMS and calibrated to daily water levels at over 40 wells and gauge stations over a 3-year period. Phosphorous transport in the surface and subsurface domains was also evaluated. The model was to be used further to evaluate other MDOP systems which may be more effective in achieving several conflicting objectives including flood prevention, drought maintenance, and ecosystem restoration. Provided technical input and supervision, managed project tasks and budgets, provided presentations and technical training to NPS staff.

Integrated Surface Water-Groundwater Model, St. Johns River Water Management District, Western Orange and Seminole Counties, Palatka, FL. Project manager and principal investigator for development and application of an integrated surface-water/subsurface water model in East-Central Florida. Performed integration of complex surface and subsurface data into a comprehensive model to investigate various conjunctive issues, including recharge areas, water movement in the system of interconnected ponds and lakes, and effects of groundwater pumping on surface-water bodies. Additional modules were developed within the MODFLOW framework of MODHMS to include the complexity of the system. Predictive analyses were conducted for transient conditions starting in 1999 and will continue through 2025, with current pumping and increased pumping estimates used to observe the effect of pumping on various lakes, wetlands, surface water bodies, spring flows and stream flows. Provided leadership to a team of hydrologists, hydrogeologists, engineers, and scientists in conducting this project, including assimilating vast quantities of information and data for model development. Managed project progress and budgets; provided technical direction; prepared reports, presentations; conducted training sessions; and communicated progress and issues regularly with the client.

Integrated Groundwater, Surface Water Modeling of Flow and Transport, U.S. EPA Gulf of Mexico Programs, Stennis Space Center, MS. Principal Investigator for conjunctive surface/ subsurface modeling study of the Mobile River Basin, LA. A MODHMS model was conceptualized and constructed for the approximately 3,000 square mile area of Hydrologic Unit Catalog (HUC) 204 and 205 surrounding and including Mobile Bay. Data for the system was obtained electronically in ArcView coverages of topography (DEMs), Land Use/Land Cover, and STATGO Soils databases which were translated appropriately for the subsurface, overland flow, and channel flow models. Simulations were performed to examine various hazard scenarios including heavy local rainfall, and effects of floods propagating down the Mobile River. Transport simulations included point and non-point of contaminants in upstream regions of the model. This model was further coupled with a coastal model to predict the associated impacts on Mobile Bay.

Integrated Tiger Bay, Bennett Swamp Model, St. Johns River Water Management District, Western Orange and Seminole Counties, Palatka, FL. Project manager for conversion of a MIKE SHE model into the MODHMS framework. The model included complex surface and subsurface interactions to determine recharge and runoff, as well as surface-water bodies such as canals, lakes, and ponds that discharge water from the domain. A comparison study was then performed between MODHMS and MIKE SHE by evaluating simulation results from both codes for the 1985 through 1999 time period. The models give comparable results, though the MODHMS model provided additional flexibility for handling operations of structures.

East-Central Florida Groundwater Modeling, St. Johns River Water Management District, Palatka, FL. Lead modeler for development and application of MODFLOW and DSTRAM regional flow and sub-regional saltwater intrusion models at several locations within the District, to meet various objectives of the District. Tasks have included conceptual model development, model calibration (manual adjustments with automatic refinement of parameters using PEST), sensitivity analyses, uncertainty analyses, predictions with uncertainty of alternate demand scenarios, and safe-yield determination. Provided hands-on training on the set-up and application of these models, as well as QA and trouble-shooting support to District staff in model evaluation of groundwater withdrawal impacts for water-supply development, consumptive use permitting and minimum flows and levels development.

Regional Groundwater Modeling for Water Supply Planning, Northwest Florida Water Management District, Havana, FL. Project manager and principal investigator for development and application of density-dependent saltwater intrusion models. Two models – an Eastern Domain and a Western Domain – were developed covering Escambia, Santa Rosa, Okaloosa and Walton Counties, to address concerns of up-coning of deeper saline waters and of saltwater intrusion from the Gulf of Mexico. The District-wide MODFLOW model was translated onto the local grids and the complexities of chloride intrusion were subsequently introduced. Calibration was performed for steady-state pre-development and transient post-development conditions. Sensitivity analyses have been performed on various parameters, with model application for predictive simulations of various future scenarios.

Evaluation of Streamflow Reductions due to Pumping, Northwest Florida Water Management District, Havana, FL. Principal investigator for a modeling evaluation of groundwater flow and surface-water interactions in the Apalachicola-Chattahoochee-Flint River Basin. The USGS finite-element code, MODFE, was applied for simulating the basin to estimate transient streamflow reduction due to pumping, for various alternative scenarios. Sensitivity analyses were also conducted to determine the range of streamflow reductions subject to parameter uncertainty.

Review, Training, and Support Services, St. Johns River Water Management District, Palatka, FL. Reviewer and instructor. Reviewed the ECF model of McGurk and Presley, and the Volusia County model of Williams. Reviewed the drafts and final reports for these studies. Conducted an in-depth examination of the data files for the respective models, for further QA of the report and modeling effort. Provided 3-day training on conjunctive surface/subsurface modeling using MODHMS to 12 staff members of the District. The theory and application of MODHMS were discussed, proceeding in complexity from the MODFLOW framework to include the unsaturated zone, and the surficial domain (overland flow and channel flow). Density-dependent solute transport was also detailed. Hands-on exercises were conducted to exemplify the theory and familiarize staff with the processing involved with conducting complex simulations that include density processes and surface/subsurface interactions.

Saltwater Intrusion Model of the Geneva Freshwater Lens, St. Johns River Water Management District, Palatka, FL. Primary modeler for numerical modeling of saltwater intrusion. Activities involved development of the model using the finite-element density-dependent flow and solute transport code, DSTRAM, with further application for understanding the freshwater lens response to various ambient and groundwater development conditions for withdrawal permitting.

Consumptive Use Permit Consolidation, Seminole County Water Supply, Seminole County, FL. Principal investigator for developing and applying models towards evaluation of the impacts of various alternatives to current groundwater supplies including impacts of land-use changes, surface-water withdrawals, waste-water reuse for irrigation and artificial recharge via rapid infiltration basins. The East-Central Florida groundwater flow model was examined and used to evaluate the maximum groundwater withdrawals achievable without adverse impacts and that meet the growing needs of the county in conjunction with surface water supplies.

Saltwater Intrusion Study, Southwest Florida Water Management District, Brooksville, FL. Principal investigator for the Southern Water Use Caution Area (SWUCA) density-dependent saltwater intrusion modeling project. The project used the Southern District groundwater MODFLOW model already developed by the District as a starting point for the local, refined density-dependent saltwater intrusion model developed with MODHMS. The conceptual regional model was translated onto the local grid, and the complexities of chloride intrusion were successively introduced to the model, which was then calibrated for steady-state pre-development, and transient post-development conditions. Also developed the local scale model; guided calibration, sensitivity and model applications for predictive simulations; provided training on use of the model and on the theory and application of the software; and provided quality assurance oversight during application of the model by District staff.

Model Investigations for Consumptive use Permit Applications, Southwest Florida Water Management District, Brooksville, FL. Project manager responsible for the development and application of cross-sectional and 3-D DSTRAM finite-element models for predicting groundwater flow and saltwater intrusion in the Eastern Tampa Bay WUCA. Also assisted in reviewing previous MODFLOW regional and subregional groundwater modeling studies as part of the consumptive use permit (CUP) applications.

Water Resources Assessment Program HCWRAP2, Southwest Florida Water Management District, Brooksville, FL. Directed the development of MODFLOW-based regional groundwater flow and saltwater intrusion models that were used in conjunction with management optimization techniques to determine optimal locations of wells to minimize their impacts on lakes and wetlands and on the movement of the saltwater/freshwater interface. Several models were developed and calibrated which were then used with the well optimization simulations to investigate various objectives of the District.

Safe Yield Analysis of County Wellfields, Pinellas County Water System, Pinellas County, FL. Project manager for the development of a safe yield analysis model for the Eldridge-Wilde and East Lake Road wellfields operated by the County. Water management concerns included drying up of lakes and wetlands, and saltwater intrusion from the Gulf of Mexico and Tampa Bay. Developed a finite-element model using DSTRAM to investigate the effects of pumping on saltwater intrusion and the surface water impacts. Performed safe yield analyses to optimize operation with minimal intrusion of saltwater or degradation of wetlands and lakes.

<u>Contaminant Transport Modeling</u>

Incorporating Matrix Diffusion in the New MODFLOW Flow and Transport Model for Unstructured Grids, ESTCP. Co-investigator for integrating analytical solutions to matrix diffusion processes into the latest MODFLOW software including USG-Transport and MODFLOW 6. Responsibilities included code development, testing, documentation, and assisting with implementation of the software at field sites.

Flow and Transport Modeling of Perchlorate to Support Cost Allocations and Remedial Design, Confidential Client, Rialto, CA. Principal investigator for the development, calibration, and application of a groundwater flow and transport model to assess source conditions from munitions and fireworks manufacturing and storage facilities, and to assist with remedial design for perchlorate and trichloroethene (TCE) plumes emanating from the former bunker and storage facilities. The model was used in mediation/litigation to address cost allocation disputes as well as to evaluate pumping rates and well locations for effective containment and treatment of the perchlorate plume.

Remedial Design Modeling, U.S. Army Corps of Engineers, Fort Ord, CA. Principal investigator for modeling remedial design of the contaminated site at the Fort Ord facility. A local model around the benzene plume was developed and calibrated for flow and transport conditions at the site using MODFLOW-SURFACT. The model was used to evaluate various design alternatives for pump-and-treat of the contaminant, with predictive sensitivity analysis providing uncertainty bounds on the results. Well locations were constrained to avoid drilling in adjacent ecologically sensitive areas, and well pumping was optimized to meet regulatory requirements within a period of six years of operation. Modeling served as a design guide for the project throughout the multi-year cleanup effort.

Estimation of the Volumes, Mobility, Recoverability, and Natural Depletion of LNAPL Plumes, Papa John's Cardinal Stadium Property, Louisville, Kentucky. Co-principal investigator for estimating product volumes, mobility, recoverability and natural depletion of LNAPL plumes. A GIS based mobility and volume approach was used to model LNAPL plumes in a heterogeneous aquifer setting, using the American Petroleum Institute's LNAPL Distribution and Recovery Model equation in multiple dimensions. Volumes of LNAPL were compared with the mobile volumes and the readily recoverable volumes. Mobility distributions were also evaluated to determine optimal site operations. Recoverability estimates were computed for skimming which was the most effective method at the site.

Flow and Transport Modeling of Trichloroethene (TCE) to Support Remedial and Containment Design, Confidential Client, Goodyear, AZ. Principal investigator for development, calibration, and application of groundwater flow and transport models to evaluate remedial and containment designs for pump and treat systems. The MODFLOW and MT3DMS models were used to evaluate pumping rates and well locations for effective containment, capture, and treatment of the TCE plume under various changes in aquifer recharge, municipal pumping and other operations adjacent to the site. The models are still being used to evaluate the impacts of any major hydrogeological decision at the site and in the vicinity and will be further used to evaluate source zone remediation. The models were developed and applied in an open forum that included technical representatives from stakeholders and regulators and were an important component of the remedial and containment plan.

Development of a Site-Specific Impact to Groundwater Soil Remediation Standard, Confidential Client, Roseland, NJ. Principal investigator for the development of site specific soil standards for TCE underneath the site. A SESOIL vadose zone model with normalized soil loading inputs was used to provide input to an AT123D groundwater flow model at various locations to evaluate cleanup objectives for various depths of vadose zone contamination. The site-specific objectives guided soil clean-up levels and locations required for groundwater compliance.

Flow and Transport Modeling for Massachusetts Military Reservation, U.S. Air Force Center for Environmental Excellence, Cape Cod, MA. Project manager responsible for leading a team of personnel in the development, calibration, and application of MODFLOW-based regional and plume-specific groundwater flow, particle tracking and contaminant transport models for examination of alternative remedial strategies and optimization of pump and treat systems at the site. Managed the development of appropriate modules to MODFLOW for stable solution to drying/re-wetting situations and for analyzing contaminant transport. Also provided support for preparation of presentation materials, and participated in technical and public meetings at this highly visible DOD site.

Peer Review of Modeling for Riverbed Water Quality, Fluor Hanford. Served on expert panel convened to evaluate Hanford groundwater issues related to chromium contamination within the hyporheic zone, groundwater surface water interactions, and modeling. Reviewed required reading materials, participated in a three-day technical workshop, prepared presentations, and reports of findings.

Technical Expertise on Flow and Transport Modeling, U.S. EPA Office of Radiation Programs, Carlsbad, NM. Project scientist for providing flow and transport modeling analyses support for the Waste Isolation Pilot Plant (WIPP) project. Evaluated BRAGFLOW, TOUGH2, MAGNAS, STAFF3D, and SECCO (various flow and transport codes) to analyze multi-phase flow, fracture flow and transport; provided EPA personnel training and expert support on model applications to the WIPP site; conducted independent verification of modeling investigations conducted by Sandia National Laboratory for the Performance Assessment (PA); provided other technical assistance and expertise in reviewing PA reports and models; and provided relevant EPA personnel training in principles and numerical implementation of multiphase and fracture flow and transport models for the subsurface.

Flow and Transport Modeling for Niagara Falls Storage Site, U.S. Army Corps of Engineers, Buffalo District, Buffalo, NY. Technical supervisor for vadose zone and groundwater modeling of radionuclides at the Niagara Falls Storage Site. One-dimensional unsaturated zone flow and transport models were coupled with a three-dimensional groundwater flow and transport model to analyze the fate of various radionuclides originating from the storage facility under various future scenarios. The modeling was conducted to evaluate potential migration to the river.

Flow and Contaminant Transport Investigations, U.S. Air Force Center for Environmental Excellence, Beale Air Force Base, CA. Technical supervisor for groundwater modeling project involving regional and sub-regional model calibration using Data Fusion Modeling (DFM) for flow and contaminant transport investigations within the subsurface and their interactions with adjacent streams periodically backed up by beaver dams. Provided model conceptualization, development and calibration guidance, numerical troubleshooting, report review, and quality control reviews. The model was subsequently used to evaluate site remedial operations.

Groundwater Flow Models using Data Fusion Modeling (DFM), Westinghouse Savannah River Company, Savannah River Site, SC. Project engineer for development of a groundwater flow model using Data Fusion Modeling (DFM) for the A/M Area of the Savannah River Site (SRS). Provided troubleshooting for variably-saturated flow simulations using the finite-element VAM3DF code in conjunction with DFM to calibrate a flow model, quantify its uncertainties, perform transport calibration of source area and strength, and then quantify uncertainty in transport of contaminants using Monte Carlo simulations. The modeling was part of a program aimed at better understanding the radionuclide contamination at the site and associated risk by using all available soft and hard information.

Z-area Flow and Transport Modeling of Containment System Design for Low-level Nuclear Wastes, Westinghouse Savannah River Company, Savannah River Site, SC. Co-investigator involved in performance assessment and migration potential modeling of low-level nuclear waste in the Z-area at the SRS. Performed 2-D cross-sectional and 3-D analyses of potential contaminant fate and transport from a containment system design located in the unsaturated zone above the groundwater system using a finite-element saturated/unsaturated flow and transport code VAM3D. The simulations were aimed at assessing effectiveness of a cap-and-drain system of waste burial above the water table.

Groundwater Flow and Waste Migration Modeling, Westinghouse Hanford Company, Hanford, WA. Principal investigator responsible for conducting modeling studies of the groundwater flow and waste migration in support of RI/FS activities at the 200 West area of the DOE Hanford site. The model was used to evaluate the potential migration of several contaminants at the site. Also provided training and troubleshooting of model applications.

Flow and Transport Model Development, Westinghouse Hanford Company, Hanford, WA. Project engineer involved in modeling the migration of low-level nuclear waste at the Hanford site. Tasks included developing and calibrating local and site wide models to assess the extent of contamination, evaluating proposed cleanup strategies, conceptualizations, and problem setups, and analyzing other regional and local-scale models developed by Hanford personnel. Provided training sessions to Westinghouse Hanford personnel on use of the finite-element saturated/unsaturated flow and transport code, VAM3DCG. Provided guidance and troubleshooting support to personnel applying these models for examining a variety of transport related issues.

Flow and Transport Model Applications, Bechtel Hanford Company, Hanford, WA. Project manager responsible for modeling the migration of low-level nuclear waste at the Hanford site. A site-wide model was developed to assess the extent of contamination and to evaluate proposed cleanup strategies. The transport of tritium, nitrate, iodine-129, carbon tetrachloride, TCE, chloroform, uranium, and technetium-99 were simulated using VAM3DCG. Model sensitivity was investigated and the transport model was validated using current monitoring well concentrations. A 200-year predictive simulation was performed for all eight contaminants. Two pump-and-treat scenarios were modeled to predict the effect on future contaminant migration.

Multi-phase Modeling of Cleanup and Containment of LNAPLs at a Refinery Site, Confidential Oil Company, CA. Project manager and principal investigator responsible for conducting large-scale 3-D simulations of LNAPL contaminant movement under a refinery site. Tasks involved detailed literature searches and analysis of available data, model development and parameter estimation from various data sources, model simulations for history-matching at different time periods through several years, sensitivity analyses, and development of optimal remediation and containment strategies for free product and dissolved contaminants. The model illustrated that aggressive technologies were not better at removing LNAPL from the silty soils and that containment strategies such as skimming were the more effective.

Saturated/Unsaturated Modeling for Landfill Liner Design, EPA Office of Solid Waste, Washington, D.C. Project engineer. Performed modeling investigations of synthetic and natural landfill liner materials and designs in support of drafting guidelines for landfill liner designs.

Hazardous Waste Identification Rule (HWIR) Modeling Support, U.S. EPA Office of Solid Waste, Washington, D.C. Task manager for RCRA support contract. Responsible for conducting land disposal and oily waste data surveys, developing composite vadose-saturated zone models for performance assessment of landfills and surface impoundments under RCRA subtitles C and D, and conducting modeling analyses and risk assessment support of the Hazardous Waste Identification Rule (HWIR).

Regulatory Modeling Support, U.S. EPA Office of Solid Waste, Washington, D.C. Project engineer. Conducted a quick-response risk evaluation for the Cement Kiln Dust Rule. Conducted several simulations using the EPACMTP code to examine migration through the groundwater pathway for exposure to various metals.

Multiphase Air-Sparging Remedial Modeling, Texaco, Inc. Loma Linda, CA. Project engineer for UST site remediation project. Performed modeling analyses of pilot field study to estimate the outcome of air sparging at a service station. Responsibilities included site data collection and interpretation, multiphase model development and application, and parameter sensitivity analyses. The strategies that were evaluated showed that air sparging could spread contamination to other parts of the aquifer, and sufficient control could not be exerted by the vacuum extraction wells.

Software Development

Co-developer of the MODFLOW 6 Groundwater Flow Model released by the USGS. MODFLOW 6 uses advanced formulations for robust and efficient solution to the groundwater flow equations and includes a robust hydraulic head formulation for density dependent saltwater intrusion evaluations.

Lead Developer of the MODFLOW-USG Groundwater Flow Model, U.S. Geological Survey, Reston, VA. Co-investigator for development of the MODFLOW-USG code which is an enhancement of MODFLOW to use unstructured grids. Version 1 of the code has been released by the USGS in May 2013 with several enhancements planned for version 2 including turbulent fracture flow, contaminant transport, and saltwater intrusion simulation capabilities.

Co-Developer of the MODFLOW-NWT Groundwater Flow Model, U.S. Geological Survey, Reston, VA. Co-investigator for development of the MODFLOW-NWT code which is an enhancement of MODFLOW that overcomes drying and rewetting difficulties of unconfined solutions. The code uses an upstream-weighting formulation with a Newton Raphson linearization and other robust schemes to provide robust solutions to highly nonlinear problems. MODFLOW-NWT is gaining in popularity since its recent release and is being used throughout the world.

Developer of MODFLOW-SURFACT and MODHMS Codes till 2007, HydroGeoLogic Inc, Reston, VA. Principal Developer of the popular commercial MODFLOW-SURFACT and MODHMS suite of codes from inception through 2007. The USGS groundwater simulation code, MODFLOW, was greatly enhanced to increase functionality and improve simulation capabilities and speed for large, complex problems.

Co-Developer of the HydroGeoSphere Integrated Groundwater, Surface Water Model, U.S. Bureau of Reclamation, Sacramento, CA. Co-investigator for development of the HydroGeoSphere code for physically-based, spatially-distributed modeling of scale-dependent investigations on agricultural plots, small watersheds, and large basins. The code is developed as an extension to the FRAC3DVS model developed at the University of Waterloo. Responsibilities included definition, design, interface, testing and documentation of surface-water flow and transport modules, and modules for interaction between the subsurface and surface systems.

Development of Multi-Phase, Non-Isothermal Model, U.S. National Science Foundation, Washington, D.C. Principal investigator on SBIR grant for development of CAMFACT, a compositional, multi-phase, non-isothermal model for NAPL contamination and remediation investigations. Tasks included delineation of required functionality and objectives, development of a robust formulation, code development, verification, benchmarking, documentation, and examination of steam injection and venting processes for remediation of LNAPL contaminants. The code handles up to seven component species that exist in one or all of up to three fluid phases in the domain. Robust nodal column assembly schemes for the Jacobian, block Orthomin solution routines, adaptive time-stepping, under relaxation formulas, and orthogonal curvilinear grid geometry were incorporated to enable solutions of field scale problems on workstations or minicomputers.

Development of a 3-D Multiphase Flow and Transport Simulator, Los Alamos National Laboratory, Los Alamos, NM. Project engineer with team for the development of MAGNAS, a 3-D multiphase flow and transport simulator. Involvement included providing input on the governing equations and code structure, coding of non-linear modules, interfacing the solver, finalizing the document, and preparing manuscripts for publication in refereed technical journals.

Development of a Finite-Element 3-D Fracture Flow and Transport Code, Sandia National Laboratory, City, NM. Co-developer of STAFF3D, a finite-element, 3-D fracture flow and transport code. A 3-component decay chain and density dependent flow and transport can be handled by the code. Dual porosity as well as discrete fracture options were provided. Orthogonal curvilinear elements and transition elements were implemented to provide a natural discretization for layered systems, irregular boundaries, and nested grids in regions of interest. Various lattice connectivity options, adaptive time-stepping and under relaxation formulas, and robust Orthomin solution schemes were used in the code to provide efficient solutions to large-scale field problems. The model was benchmarked and a documentation and a user's guide was prepared. The code primarily was developed for Sandia National Laboratories for their investigation of the Yucca Mountain site, NV. Responsibilities included code design, numerical algorithm development, and implementation, benchmarking, and documentation.

3-D Density-Dependent Flow and Transport Code Development, St. Johns River Water Management District, Palatka, FL. Co-developer of DSTRAM, a 3-D density-dependent flow and transport code intended for saltwater intrusion investigations. Responsibilities included code development, verification, validation, benchmarking, and documentation.

Saturated and Unsaturated Zone Flow and Transport Model Development, Westinghouse Savannah River Company, Savannah River Site, SC. (Prior to AMEC) Co-developer of VAM3DCG, a 3-D saturated/unsaturated zone flow and transport model. Implemented state-of-the-art techniques including curvilinear elements, transition elements (for creating nested grids), various lattice connectivity options, Newton-Raphson linearization, and robust Orthomin solution schemes. Rigorously modeled unsaturated zone physical processes such as recharge, evaporation, and plant root uptake. Assisted in algorithm development, coding, benchmarking, and documentation of the model and disseminating the effort through referred technical publications.

<u>Litigation Support</u>

Modeling of PFOA in Groundwater and the Water Distribution System at the Merrimack Valley Water District (MVWD), Merrimack, NH. Testifying Expert Witness in court case concerning Brown et al., v. Saint-Gobain Performance Plastics Corporation and Gwenael Busnel, US District Court of New Hampshire, Civil Action No. 1:16-CV-00242-JL (consolidated). Numerical models were developed to evaluate and simulate transport mechanisms of PFOA released at the Saint-Gobain Performance Plastic (SGPP) facility in Merrimack, New Hampshire, that may have resulted in the presence of PFOA in soil and groundwater in the vicinity of this facility. Conducted evaluation of the soil and groundwater modeling performed at the site by consultants and Plaintiff's Experts to evaluate historical environmental conditions in the water supply system and private groundwater wells. Provided deposition regarding my findings. The case is ongoing.

Intrusion of Saltwater from Cooling Canal Ponds of the Turkey Point Power Plant, Office of Public Counsel, Tallahassee, FL. Testifying Expert Witness in environmental cost recovery hearing (Docket No. 20170007-EI) to the Florida Public Service Commission (FPSC). Florida Power and Light (FPL) operates the Turkey Pont Cooling Canal System (CCS) which has contaminated the underlying aquifer with hypersaline water from the CCS. FPL has agreed to implement a process to try and retract the saltwater plume. Evaluated literature and models presented by FPL consultants through the years and conducted modeling simulations to evaluate effectiveness of remedial efforts. Provided written testimony and presented findings to the FPSC.

Impact of Groundwater Pumping on Flow to Rivers and Streams in the Apalachicola, Chattahoochee, Flint (ACF) River Basin, State of Georgia, Atlanta, GA. Expert Witness in a court case concerning State of Florida v. State of Georgia, in the Supreme Court of the United States, Case No. 142, Original. Provided support to Georgia for delineating the impact of pumping within the Basin from weather related impacts to flow at the Florida-Georgia Stateline. Evaluated the weather, streamflow, and hydrogeologic data in the basin and modeled the impact of groundwater pumping on unimpaired flows (UIFs) to the rivers and streams. The UIFs for various pumping and non-pumping cases were also provided to the surface-water testifying expert for calculations that evaluated flow into Florida, considering storage in reservoirs and operations of dams within the Basin regulated by the United

States Army Corps of Engineers (USACE). Plaintiff's modeling efforts and investigations were also reviewed and critiqued. Provided three full days of depositions and testified before the Special Master appointed by the Supreme Court. The Supreme Court has ruled in Georgia's favor.

GIS-Based Mobility Modeling for LNAPL at an Oil Terminal Site, BP Products North America, Inc., Green Bay, WI property. Expert witness in court case Tilot Oil, LLC v. BP Products North America, in the United States District Court Eastern District of Wisconsin, Case No. 09-C-0210. Provided two depositions on NAPL mobility modeling that was conducted in a GIS setting to provide NAPL flux estimates across the property boundary of an Oil Terminal site in support of litigation. The American Petroleum Institute's LNAPL Distribution and Recovery Model equation representing multiphase flow of LNAPL was integrated in the vertical direction over the free product thickness and applied spatially in a GIS environment to provide mobility estimates for free product in an areally distributed manner throughout the area of investigation and specifically, across the property boundary. Plaintiff's modeling efforts were also reviewed and critiqued. The analysis and subsequent report resulted in an undisclosed settlement in the client's favor.

Model Reviews, St Johns River Water Management District, Titusville, Florida. Provided review support for models developed by all parties in this case concerning permit application for pumping from the Area IV well field in Titusville, Florida. MODFLOW and SEAWAT models were developed by the permit applicants and parties opposing the permitted withdrawals. The reviews were provided to allow the District to be unbiased in the permit application process, and to enable the District to defend their position in court.

Litigation Support, Santa Maria Valley Water Conservation District, Santa Maria, CA. (Prior to AMEC) Expert witness for use of MODFLOW-SURFACT in case concerning Santa Maria Valley Water Conservation District V. City of Santa Maria, et al., Santa Clara County Superior Court Case No. CV 70214. Provided deposition for this case, for which the judge later requested the parties to come to an understanding out of court.

Training and Support

Workshops and Webinars on Groundwater Flow and Solute Transport Modeling, GSI Environmental and other clients, TX. Provided workshops and webinars on groundwater flow and solute transport modeling to industry and government clients throughout the US. This includes courses with the National Ground Water Association (NGWA), Groundwater Resources Associations of various States (California, Nevada, Arizona), the US Geological Survey, and various commercial developers of Graphical User Interfaces (GUIs) for groundwater models.

MODFLOW-USG Training, Various Clients. Conduct training courses and webinars on fundamentals and application of MODFLOW-USG with various organizations including the California Groundwater Resource Association (GRA), the National Groundwater Association (NGWA), and with developers of commercial interface codes such as Groundwater Vistas, GMS and Visual MODFLOW.

Code Training and Support, HydroGeoLogic Inc, Reston, VA. Provided modeling support and training nationally and internationally, for users of MODHMS, MODFLOW-SURFACT, DSTRAM, STAFF3D, MAGNAS3D and VAM3D.

U.S. EPA Office of Radiation Programs, Carlsbad, NM. Conducted two, week-long training sessions on principles of modeling multiphase flow and transport through porous media, and on the fundamentals of fracture flow and transport.

Washington State University, Pullman, WA. Research and teaching assistant. Assisted in conducting a short course on the application of MOC, MODFLOW, PLASM, and other public domain groundwater flow and transport codes. Conducted classroom, laboratory, and tutorial sessions for first fluid mechanics course (Fundamentals of Fluid Mechanics) for 4 semesters.

University of Delaware, Newark, DE. Research and teaching assistant. Assisted in conducting NATO-ASI (Advanced Study Institute) seminars and short courses on the application of MOC, MODFLOW, PLASM, and other public domain groundwater flow and transport codes. Assisted in conducting short courses on fundamentals of modeling.

INVITED TALKS

Various forums at University of Nebraska, Lincoln, 2019. Provided seminars and guest lectures to Faculty and students in Civil Engineering and Biological Systems Engineering, as well as staff from Nebraska USGS, and from Nebraska Department of Natural Resources at different occasions on various modeling topics.

Groundwater Modelers Forum, “Pushing the Boundaries – New Issues and Applications in Groundwater Modelling,” Birmingham, UK. May, 2014

“What’s New in Groundwater Modeling?” NGWA, Pillars of Groundwater Innovation Conference, Phoenix, Arizona, November 2013

MODFLOW and More, International Groundwater Modeling Center, Colorado School of Mines, Golden, Colorado, Technical Committee Member, 2006 to 2019

NGWA Conference, "Modeling for Groundwater Management and Sustainability," Garden Grove, CA, May, 2012

PUBLICATIONS

“Extension of the MODFLOW Core into a Multi-Model Generalized Hydrologic Simulator”, C. D. Langevin, J. D. Hughes, A. M. Provost, M. J. Russcher, and **S. Panday**, Groundwater, submitted for publication, 2022.

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“Future of Groundwater Modeling”, C. D. Langevin, and **S. Panday**, Invited article for Column Theme: 50th Year Tribute to Modeling: Past, Current, and Future, Groundwater, Vol. 50, No. 3, p. 333-339, doi: 10.1111/j.1745-6584.2012.00937.x, May-June 2012.

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PROFESSIONAL BACKGROUND

Research Professor, University of Nebraska-Lincoln, Lincoln, Nebraska, 2019-Present

Principal Engineer, GSI Environmental Inc., Herndon, Virginia, 2014-Present

Principal Engineer, AMEC Environment & Infrastructure, Herndon, Virginia, 2008-2013

Principal Engineer, Geomatrix Consultants, Inc., Herndon, Virginia, 2007-2008

Vice President R&D, HydroGeoLogic, Inc., Herndon, Virginia, 1989-2007

Appendix B

Reissued Tables for GSI (2021)

GSI ENVIRONMENTAL

Table 6. Pre-Mining Simulation Water Budget

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

Water Budget Component		Pre-Mining		
		West[1]	East[2]	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%
		51	258	309
	Outflow to Modflow Drain Package[3]	52.0%	41.5%	93.5%
		2,488	1,984	4,472
Percent Mass Balance Error		0.0%		

Notes:

1. West refers to the west of the Trail Ridge crest as shown on Figure 33.
2. East refers to the east of the Trail Ridge crest as shown on Figure 33.
3. Modflow drain packages represents National Hydrography Dataset wetlands and streams as shown on Figures 22 and 23.
4. GSI (2021) Table 3.

GSI ENVIRONMENTAL

Table 7. Pre- and Post-Mining Water Budget Comparisons for Soil Amendment Bentonite Percentages

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

Water Budget Component		Pre-Mining			No Bentonite Soil Amendment		
		West[1]	East[2]	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.1%	5.4%	6.5%
		51	258	309	51	258	309
	Outflow to Modflow Drain Package[3]	52.0%	41.5%	93.5%	52.0%	41.6%	93.5%
		2,488	1,984	4,472	2,486	1,987	4,473
Percent Mass Balance Error		0.0%			0.0%		

Water Budget Component		5.3% Bentonite Soil Amendment			10.9 % Bentonite Soil Amendment			12.5% Bentonite Soil Amendment		
		West	East	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.1%	5.4%	6.5%	1.1%	5.4%	6.5%
		51	258	309	51	258	309	51	258	309
	Outflow to Modflow Drain Package[3]	52.0%	41.6%	93.5%	52.1%	41.5%	93.6%	52.0%	41.6%	93.5%
		2,485	1,987	4,472	2,490	1,984	4,474	2,485	1,987	4,472
Percent Mass Balance Error		0.0%			0.0%			0.1%		

Notes:

1. West refers to the west of the Trail Ridge crest as shown on Figure 33.
2. East refers to the east of the Trail Ridge crest as shown on Figure 33.
3. Modflow drain packages represents National Hydrography Dataset wetlands and streams as shown on Figures 22 and 23.
4. GSI (2021) Table 4.

GSI ENVIRONMENTAL

Table 8. Pre- and Post-Mining Water Budget Comparisons for Recharge Rates

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

Water Budget Component		**Pre-Mining Recharge of 4.13 in/yr**			**Pre-Mining Recharge of 3.5 in/yr**			**Pre-Mining Recharge of 4.5 in/yr**		
		West[1]	East[2]	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,262	1,791	4,052	2,908	2,303	5,210
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.1%	5.8%	7.0%	1.0%	5.2%	6.2%
		51	258	309	46	236	283	54	270	323
	Outflow to Modflow Drain Package[3]	52.0%	41.5%	93.5%	51.6%	41.4%	93.0%	52.3%	41.5%	93.8%
		2,488	1,984	4,472	2,092	1,678	3,770	2,723	2,163	4,886
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Water Budget Component		**10.9% Bentonite w/ Recharge of 4.13 in/yr**			**10.9% Bentonite w/ Recharge of 3.5 in/yr**			**10.9% bentonite w/ Recharge of 4.5 in/yr**		
		West	East	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,262	1,791	4,052	2,908	2,303	5,210
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.1%	5.8%	7.0%	1.0%	5.2%	6.2%
		51	258	309	46	236	283	54	270	323
	Outflow to Modflow Drain Package	52.1%	41.5%	93.6%	51.7%	41.4%	93.1%	52.2%	41.5%	93.8%
		2,490	1,984	4,474	2,093	1,678	3,771	2,722	2,164	4,886
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Notes:

1. West refers to the west of the Trail Ridge crest as shown on Figure 33.
2. East refers to the east of the Trail Ridge crest as shown on Figure 33.
3. Modflow drain packages represents National Hydrography Dataset wetlands and streams as shown on Figures 22 and 23.
4. GSI (2021) Table 5.

GSI ENVIRONMENTAL

Table 9. Pre- and Post-Mining Water Budget Comparisons for Consolidated Black Sands Hydraulic Conductivity

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

Water Budget Component		Pre-Mining w/ Calibrated Hydraulic Conductivity			Pre-Mining Calibration Value x 5			Pre-Mining Calibration Value ÷ 5		
		West[1]	East[2]	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.0%	4.9%	5.9%	1.1%	5.7%	6.8%
		51	258	309	49	235	284	53	271	323
	Outflow to Modflow Drain Package[3]	52.0%	41.5%	93.5%	52.0%	42.1%	94.1%	52.8%	40.5%	93.2%
		2,488	1,984	4,472	2,488	2,011	4,499	2,523	1,935	4,458
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Water Budget Component		10.9% Bentonite w/ Calibrated Hydraulic Conductivity			10.9% Bentonite w/ Calibration Value x 5			10.9% bentonite w/ Calibration Value ÷ 5		
		West	East	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.0%	4.9%	5.9%	1.1%	5.7%	6.8%
		51	258	309	49	235	284	53	271	324
	Outflow to Modflow Drain Package	52.1%	41.5%	93.6%	52.1%	42.0%	94.0%	52.6%	40.6%	93.2%
		2,490	1,984	4,474	2,490	2,007	4,497	2,514	1,944	4,458
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Notes:

1. West refers to the west of the Trail Ridge crest as shown on Figure 33.
2. East refers to the east of the Trail Ridge crest as shown on Figure 33.
3. Modflow drain packages represents National Hydrography Dataset wetlands and streams as shown on Figures 22 and 23.
4. GSI (2021) Table 6.

GSI ENVIRONMENTAL

Table 10. Pre- and Post-Mining Water Budget Comparisons for Unconsolidated & Semi-Consolidated Sands Hydraulic Conductivity

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

Water Budget Component		**Pre-Mining w/ Calibrated Hydraulic Conductivity**			**Pre-Mining Calibration Value x 5**			**Pre-Mining Calibration Value ÷ 5**		
		West[1]	East[2]	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.8%	7.9%	9.7%	0.7%	4.1%	4.8%
		51	258	309	86	378	464	34	196	230
	Outflow to Modflow Drain Package[3]	52.0%	41.5%	93.5%	48.4%	41.9%	90.3%	53.5%	41.7%	95.2%
		2,488	1,984	4,472	2,313	2,006	4,319	2,556	1,995	4,551
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Water Budget Component		**10.9% Bentonite w/ Calibrated Hydraulic Conductivity**			**10.9% Bentonite w/ Calibration Value x 5**			**10.9% bentonite w/ Calibration Value ÷ 5**		
		West	East	Total	West	East	Total	West	East	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
Outflows (as % of Total Recharge and gallons per minute)	Lateral Outflows	1.1%	5.4%	6.5%	1.8%	7.9%	9.7%	0.7%	4.1%	4.8%
		51	258	309	86	378	464	34	196	230
	Outflow to Modflow Drain Package	52.1%	41.5%	93.6%	48.4%	41.9%	90.3%	53.4%	41.8%	95.2%
		2,490	1,984	4,474	2,314	2,004	4,317	2,554	1,998	4,551
Percent Mass Balance Error		0.0%			0.0%			0.0%		

Notes:

1. West refers to the west of the Trail Ridge crest as shown on Figure 33.
2. East refers to the east of the Trail Ridge crest as shown on Figure 33.
3. Modflow drain packages represents National Hydrography Dataset wetlands and streams as shown on Figures 22 and 23.
4. GSI (2021) Table 7.