

MEMORANDUM

- TO: Twin Pines Minerals, LLC
- FROM: Dr. Sorab Panday, PhD, PE, GSI Environmental
- CC: TTL, Inc. Jones Fortuna LP
- **RE:** Response to Public Comments Regarding the Proposed Twin Pines Mining Project, Charlton County, Georgia

EXECUTIVE SUMMARY

Scope of Investigation

I have been retained on behalf of Twin Pines Minerals, LLC, to evaluate potential hydrologic impacts resulting from the proposed Twin Pines Mine project along Trail Ridge in Charlton County, Georgia. The scope of my investigation has involved assessment of non-mining, mining period, and post-mining hydrology for the area near the mine site including Trail Ridge, nearby streams including the River Styx and St Marys River, and southeastern boundary of the Okefenokee National Wildlife Refuge (ONWR). In addition and for the purposes of this report, my evaluation addresses public comments including: 1) The National Park Service (Bahm and Paudel, 2023) regarding their technical review of numerical modeling performed in support of the Twin Pines Mine permit application; 2) Dr. C. Rhett Jackson (Jackson, 2022a; Jackson 2022b; and, Jackson, 2023) regarding general conceptual understanding of the hydrology on Trail Ridge and surrounding areas and evaporative technologies proposed for water management; and, 3) comments from the Southern Environmental Law Center (SELC) also related to groundwater modeling of Trail Ridge hydrology and potential water quality impacts resulting from proposed mining activities (Hutson, 2023).

Summary of Findings and Conclusions

Twin Pines' proposed Saunders Demonstration Mine, including associated mine pit dewatering and groundwater withdrawals from the Upper Floridian Aquifer (UFA), will have no perceptible impact on water levels in the ONWR or flows in the St. Marys River or the River Styx. Detailed groundwater modeling has been conducted to analyze the effects of the proposed mine on freshwater inputs to the ONWR. That modeling shows that Twin Pines' mining activities will have no effect on groundwater baseflow contributions to the ONRW or the River Styx, the ONRW tributary located closest to the mine site. Any reductions in groundwater contributions to unnamed wetlands that contribute flow to the River Styx will also be negligible. Even assuming that 100% of any groundwater contributions "lost" to these unnamed wetlands ultimately would have flowed into the River Styx and then into the ONWR, a highly conservative assumption, reducing inputs to the ONRW by this negligible amount would have no perceptible effect on water levels in the ONWR or the OWNR's annual water budget.

The ONWR is a huge water body containing an estimated 285 billion gallons of water. Even if just the southeast section of the ONWR was considered (25% of the entire volume), assuming that this section was disconnected from the rest of the ONWR (which is not the case), the volume of water contained in it is 72 billion gallons. Precipitation alone on just the southeast corner of the ONWR contributes approximately 152 billion gallons annually (assuming average rainfall of 51.25 inches per year). Precipitation directly over the full ONWR exceeds 600 billion gallons, with precipitation over the entire watershed that feeds the ONWR far greater still. In contrast, any



reduction in inflows due to mine pit dewatering is estimated to range, at most, from 0.07 cfs to 0.09 cfs, or between 17 and 21 million gallons per year. (Even these estimates are highly conservative, as I explain in my Findings in Section 2.) Compared to the size of the ONWR and the inputs to the ONWR presented above, reductions from mining activities on this scale are a drop in the bucket. They would be negligible compared to the water budgets of the ONWR, and will have a negligible impact on ONWR water levels or flows out of the ONWR to the St. Marys River.

Furthermore, the moving mine pit area is negligible compared to the size of Trail Ridge. Trail Ridge is not going to be flattened such that the groundwater divide that it creates will be breached, and the ONWR will not be drained.

Responses to Public Comments

I have reviewed the comments submitted by Dr. Rhett Jackson, the National Park Service's South Florida Natural Resource Center (NPS), and Mark Hutson. The claims and concerns raised in those comments are unfounded.

Responses to Dr. Jackson

First, contrary to Dr. Jackson's claims, Trail Ridge does not form an "earthen dam" that impounds the ONWR, and active mining on a small portion of Trail Ridge does not threaten to alter the hydrology of Trail Ridge. Rather, the elevation and hydrology of Trail Ridge form a natural groundwater divide. Much like the Continental Divide dictates the direction of surface water runoff, the Trail Ridge groundwater divide results in groundwater on the west side of the divide flowing to the west and groundwater on the east side of the divide flowing to the east. Field measurements, hydrogeologic considerations, and modeling analysis show that this regional groundwater divide will continue to exist during mining and under post-mining conditions, and the general flow of groundwater west from Trail Ridge that feeds the ONWR will not be affected by the proposed mine.

Second, Dr. Jackson's suggestion that the proposed mine will substantially reduce inflows to the ONWR, adversely affect water levels in the swamp, increase the frequency and severity of drought in the southeastern portion of the ONWR, significantly increase fire risk due to reduced water levels in the ONWR, or measurably impact flows in the St. Marys River are without basis. As I explain above, any effect on the ONWR inflows resulting from mine pit dewatering and related drawdowns of the surficial aquifer will be negligible. The effect of pumping groundwater from the UFA will also be negligible. Withdrawals from the UFA will be limited, because water from the surficial aquifer withdrawn to dewater the mine pit will provide the process water needed for mining operations, with the UFA wells used primarily to supply water to charge the process water ponds when operations initially commence, or for top-up of lost water if the process water ponds cannot supply the required amount. Further, due to the low permeability and large thickness of the Hawthorn formation underlying the proposed mine and ONWR, vertical connectivity is extremely low and attenuated. Withdrawals from the UFA will thus have a negligible effect on the ONWR and other surface water and surficial aquifer resources.

Finally, Dr. Jackson is incorrect that mining activities will reduce flows in the Upper St. Marys River. As I explain above, reductions in inflows to the ONWR will be negligible, leakage through the Hawthorn formation will be negligible, and there will be a negligible effect on water levels in the ONWR. Dr. Jackson's assertion that flows in the St. Marys River (which is downstream of and fed by the ONWR) will be affected is without basis.



Responses to the National Park Service

The comments submitted by the NPS and its critique of the modeling conducted to date range from general comments regarding modeling decisions (e.g., use of the Theis solution, use of a steady-state model, omission of a validation/verification approach) to specific elements of the model itself (e.g., use of a constant head boundary, positioning of the no-flow boundary). As I explain below, NPS's comments and concerns are unfounded.

- NPS claims that the Theis solution cannot be used to calculate UFA drawdown is unsupported. To the contrary, analytical solutions, such as the Theis Equation, are a standard approach for estimating potential water level declines in confined aquifers due to well pumping and for the analyses of aquifer test data to derive hydraulic conductivity and aquifer storage parameter values and have been used for estimating drawdowns long before numerical modeling was practicable or reliable.
- NPS's suggestion of supporting model calibration through a validation/verification approach is not supported by current industry standard best practices for groundwater modeling.
- 3. NPS is incorrect in asserting that hydraulic conductivity and groundwater elevation data are insufficient to characterize the groundwater system.
- 4. NPS's assertion that steady-state models cannot be used to quantify potential effects on Trail Ridge and the surrounding area's hydrology is wrong.
- 5. NPS claims that there is no direct flow path in the model between the proposed mine site and the ONWR is not correct and surface water flow modeling is not required.
- 6. NPS's comments that the drain elevations in the model do not match the description in the report (GSI, 2021) are correct; however, the drain elevations are consistent with the conceptual model and do not change the conclusions of the analyses.
- 7. NPS incorrectly states that recharge rates need to be spatially and temporally variable to properly understand potential changes in regional hydrology due to mining, especially during periods of drought. Recharge variability would affect the flows to the ONWR, however, it has marginal impact when differences in flows are considered between non-mining, mining, and post-mining conditions.
- 8. NPS states that use of a constant head boundary condition in the model is inappropriate. This is incorrect. It is also irrelevant, because any impacts of mining in the proposed mining area on the ONWR do not reach the constant head condition along the western or eastern boundaries due to its distance from the proposed mine area.
- 9. NPS states that the MODFLOW drain package was not appropriate for simulating surface water dynamics. There is no intent to simulate surface water dynamics as this is a groundwater analysis issue. Water that leaves the drains can be assumed to mostly flow to the ONWR. If the same amount of water drains to these wetlands for non-mining, mining, and post-mining conditions, then that same amount of water will flow to the ONWR regardless of the surface water dynamics that move this water to the ONWR.
- 10. NPS claims that the no-flow boundary condition along the north and south lateral boundaries is not appropriate. This boundary condition is appropriate as flow lines are generally parallel to the north and south boundaries which are the no-flow boundaries.



Furthermore, these boundaries do not impact how mining would change hydrogeologic conditions.

- 11. NPS states that the model is not set up to mimic the system's natural variability. This is not relevant, as the modeling effort was designed to evaluate the impact of mining on the local hydrogeology, and adding more complexity to a model than is needed is not appropriate. NPS further states that drain boundary conditions were not considered in the sensitivity run when considering impacts on ONWR for dry conditions. Contrary to NPS's statements, the drain elevations should not be incorporated into a drought sensitivity analysis since the wetland bottom or riverbed elevation does not change whether it rains or it is dry.
- 12. NPS's claim that effects on ONWR from mine dewatering were not properly quantified is not substantiated.
- 13. NPS correctly observes that re-dredging of the soil amendment layer was not taken into consideration in the analysis available to NPS at the time its comments were submitted. Additional analysis indicates that the inclusion of re-dredging in the model results in negligible changes in the modeling outcome.
- 14. NPS correctly states that there are mathematical errors in some data tables from GSI (2022); however, these do not affect the conclusions of the report and are reissued, here, as Appendix B.
- 15. NPS incorrectly claims that modeling and analysis segmentation does not account for combined effects of the boundary condition changes if the changes were made simultaneously. Different boundary condition combinations result in different water flows, however, results between non-mining and post-mining conditions indicate minimal change.
- 16. NPS assumes that any future expanded mine project will not be evaluated after permitting for the current demonstration mine, but this is incorrect. Any new mining project will require independent environmental review and permitting by GA EPD. The current demonstration project under review will provide valuable data that can be used in that process.

Responses to Southern Environmental Law Center (SELC)

SELC claims that fixed head and no flow boundaries do not reflect existing conditions or conditions which could develop during and after mining around much of the domain, and that the use of drain boundary conditions to represent surface water flow in streams is inappropriate. These comments are incorrect and are addressed above in response to NPS.

SELC also claims that fate and transport modelling to evaluate the time required for the peak concentrations of mining-related groundwater contaminants to reach monitoring points is missing. However, this comment is a strawman, as any water quality impacts of the mining process are negligible (Jacobs 2020). Jacobs indicated that (emphasis added):

"...leach testing demonstrates that the metals that are detectable in [black humate sands] are not readily leachable and would not generate any concentrations exceeding GA EPD drinking water MCLs. Based on these comparisons relative to background water quality data and GA EPD MCLs, the disposal of the post-process sand (i.e., sand tailings) and the humate isolates back into the open pit during mining will not have any significant impact on groundwater quality of the regional shallow aquifer."



Numerical modeling of fate and transport simulations is not required since the water quality does not change.

Organization of Report

Background information related to this study is presented in Section 1 of this expert report, while Section 2 presents my affirmative conclusions. Sections 3 and 4 provide the basis for my conclusions in response to the reports of Dr. C. Rhett Jackson (concerned citizen), and Ms. Kiren Bahm and Dr. Rajendra Paudel (National Park Service), respectively. Section 5 provides additional conclusions in response to Mr. Mark Hutson (Southern Environmental Law Center). Section 6 contains bibliographic citations of documents referenced in this report or upon which I have otherwise relied.

I am continuing to review available information and reserve the right to supplement this report, or the conclusions contained in this report should further information become available which would have a bearing on my conclusions Furthermore, I reserve the right to use graphics or other exhibits to further address the matters discussed herein and to supplement this report based on new or additional data.

Personal Qualifications and Experience

Dr. Sorab Panday is a Principal Engineer at GSI Environmental with 34 years of research and environmental consulting experience. Dr. Panday specializes in developing numerical models for water resource evaluations and groundwater contamination. He has managed projects, published research, and conducted short courses and webinars on numerical model development and application for flow and transport in subsurface systems. He has developed computer code for several of the industry's state-of-the-art water resource modeling tools and is a contributing author on the latest releases of the popular groundwater modeling software MODFLOW, by the US Geological Survey. 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. Dr. Panday's resume is provided in Appendix A.



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EXHIBITS

- Exhibit 1-1. Location of Proposed Twin Pines Minerals Mine.
- Exhibit 1-2. Regional location of Proposed Twin Pines Mineral Mine.
- Exhibit 2-1. Comparison of a Generalized Conceptual Model of a Groundwater Divide and the Simulated Groundwater Divide at Trail Ridge.
- Exhibit 2-2. Regional Water Table Contour Comparisons for Non-Mining and Western Moving Mine Pit Scenario. Pit Location for Seepage Scenario 1 is indicated in orange.
- Exhibit 2-3. Location of Proposed Twin Pines Minerals Mine and General Groundwater Flow Directions.
- Exhibit 2-4. Wetland Areas for River Styx Flow Analyses.
- Exhibit 3-1. Schematics from Dr. Jackson's August 2022 comments (Jackson, 2022a) and January 2023 comments (Jackson, 2023).
- Exhibit 3-2. Regional Water Table Contour Comparisons for Non-Mining and Western Moving Mine Pit Scenario. Pit Location for Seepage Scenario 1 is indicated in orange.
- Exhibit 4-1. Locations of Hydraulic Conductivity Values Derived from Field Data.
- Exhibit 4-2. GSI (2021) Figure 41, indicating that that post-mining impacts do not reach constant head boundaries for 10.9% bentonite amendment.
- Exhibit 4-3. Area used for Water Balance Calculations.
- Exhibit 4-4. Difference in water levels between post-mining conditions without Bentonite mixed in the reclaimed sands (and with a layer of sand with 10.9% bentonite) and post-mining conditions with bentonite mixed in reclaimed sands (and with a layer of sand with 10.9% bentonite).

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- Table 2-2.Theoretical Water Level Declines in SE Quadrant of the ONWR Resulting from Proposed
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APPENDICES

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1.0 TECHNICAL BACKGROUND

1.1 Site Location and Description

Twin Pines Minerals, LLC (TPM) has submitted a permit application to the Georgia Environmental Protection Division (GA EPD) for a surface mining permit to develop a heavy mineral sand mine along Trail Ridge in Charlton County, Georgia. The proposed mine is located 3.2 miles west of St. George, Georgia, on Georgia State Highway Route 94 (Exhibit 1-1 and Exhibit 1-2).



Exhibit 1-1. Location of Proposed Twin Pines Minerals Mine.





Exhibit 1-2. Regional location of Proposed Twin Pines Mineral Mine.

Trail Ridge (ridge) forms an approximately 100-mile long topographic high that separates the Okefenokee Basin from the coastal plain of Georgia (Force and Rich, 1989). Beneath the ridge lies a shallow water-table aquifer, commonly referred to as the Surficial Aquifer, which is characterized by a distinct groundwater divide where groundwater flows either to the west toward the ONWR and the River Styx or to the east toward the St Marys River. Beneath the Surficial Aquifer is the Upper Hawthorn group, which is over 300 feet thick in the project area and predominantly contains clays that form the upper confining unit of the regional Floridan Aquifer (e.g., Williams and Kuniansky, 2016).

The mining process will involve excavation of heavy mineral sands to a maximum depth of 50 feet below ground surface in the Surficial Aquifer within the proposed project area, with about 98% of the post-processed sand (sand tailings) returned to the mine pit. The depth of mining will not exceed the water surface elevation of the Okefenokee Swamp. The dragline will move through the mining area excavating approximately 100-feet wide by 50-feet-deep cuts, in an east to west



or west to east direction. Mining rates are anticipated to vary from approximately 100 to 200 feet of pit length excavation per day with an active pit length of approximately 500 feet. As the pit advances into unmined areas, the inactive portion of the pit will be filled with sand tailings as mining continues to advance. The topography of the reclaimed mined area will be restored as closely as possible to non-mining elevations. Furthermore, the post-project wetland area will be roughly equivalent to the pre-project wetland area, and upland areas will be re-constructed for longleaf pine.

1.2 Existing Studies

Numerous studies have been performed to characterize baseline (non-mining) conditions and to evaluate potential hydrologic and water quality impacts both during mining and following mine reclamation. These include the following:

- 1. **Hydraulic Properties of Surficial Aquifer:** Field activities were conducted to characterize the local hydraulic properties of the surficial aquifer within the proposed study area documented by Holt et al., (2019a). Aquifer pumping tests and slug tests were conducted on wells within the study area to determine the areal and vertical distribution of hydraulic conductivity of the surficial aquifer materials.
- 2. **Geology of Surficial Aquifer:** The geology of the surficial aquifer within the proposed study area was characterized and documented by Holt et al., (2019b). The boring logs of wells within the proposed study area were evaluated to characterize the subsurface geology.
- 3. **Groundwater and Surface Water Quality:** Water quality analyses of groundwater and surface water within the proposed study area was documented by Holt et al., (2019c). Water samples were analyzed for pH, dissolved oxygen, specific conductance, Oxidation Reduction Potential and major constituents with groundwater protection standards. The analyses serve to provide background conditions for a non-mining state of water quality at the site.
- 4. **Climate**: Local and regional climate data were evaluated and documented by Holt et al., (2019d). Precipitation and evapotranspiration were evaluated to estimate groundwater recharge to the surficial aquifer within the study area.
- 5. **Hydrogeologic Model:** A hydrogeologic conceptual model was developed and documented by Holt et al., (2019e). Water level data from piezometers and observation wells, water level differences between shallow and deep piezometer pairs, and potentiometric surface maps were developed to understand subsurface hydrogeologic conditions.
- 6. Hydrogeologic Properties of Soil: Laboratory testing was conducted to evaluate hydrogeologic properties of the soil types as documented by Holt et al., (2019f). Measurements for the various subsurface units helped to quantify the hydraulic conductivity, and to understand contrast between the hydrogeological units and variability within each unit.
- 7. **Geologic Model:** A geologic conceptual model was developed and documented by Holt et al., (2019g). The major subsurface lithologies of the surficial aquifer includes (with increasing depth) an unconsolidated and semi-consolidated sand unit; a consolidated black sand unit; a silty-clayey sand unit; and a sandy clay unit overlying the Hawthorn Group.
- 8. **Numerical Groundwater Model:** A numerical groundwater model was developed and calibrated by GSI (2021). The groundwater flow model was the culmination of all the data

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collection and model conceptualization efforts, meant to evaluate the non- and postmining hydrogeologic conditions in the study area.

9. **Numerical Groundwater Model Addendum:** A numerical groundwater model addendum was issued by GSI (2022) providing estimation of seepage rates from the Surficial Aquifer to the moving mine pit during mining operations, additional water balance evaluations for non- and post-mining conditions, and sensitivity to boundary conditions.

2.0 FINDINGS

2.1 A naturally occurring groundwater divide is present beneath the crest of Trail Ridge.

Both interpretation of observed groundwater elevations as well as modeling results indicate the presence of a groundwater divide along Trail Ridge (GSI, 2021). Exhibit 2-1 provides a United States Geological Survey (USGS) generalized conceptual model of groundwater flow in the presence of a topographic ridge underlain by a hydrogeologic confining unit, similar to the conditions found along Trail Ridge. Exhibit 2-1 also provides an east-west cross-section of the simulated water table from the GSI groundwater model (GSI, 2021), which mirrors the USGS conceptual model, and demonstrates that groundwater flows towards decreasing water levels in both directions from the crest of Trail Ridge.





Exhibit 2-1. Comparison of a Generalized Conceptual Model of a Groundwater Divide and the Simulated Groundwater Divide at Trail Ridge.

It is the inherent hydrogeologic behavior of the system, rather than the Ridge itself behaving as an earthen dam, that causes groundwater to flow away from Trail Ridge and, on the western side, toward the Okefenokee Swamp. In contrast, an earthen dam would have water backed up on the upstream end with flow direction being only from upstream to downstream instead of having divergent flow as in a groundwater divide.

The water table on Trail Ridge is near the ground surface, while the mine pit will have a maximum depth of 50 feet below ground surface. Given this, water from the shallow surficial aquifer will necessarily seep into the mine pit as it progresses across the site. This seepage water will be removed from the mine pit and pumped to the Water Management Ponds, where it will either be used as process water or evaporated (Wood, 2023). GSI has conservatively estimated the average seepage rate at the site to be 783 gpm (Wood, 2023).

Concerns have been raised that removal of water from the surficial aquifer through mine pit dewatering could adversely affect water levels beneath Trail Ridge. These concerns are unwarranted, however. Exhibit 2-2 compares water level contours for non-mining conditions with water level contours with the addition of a modeled seepage pit, assuming that seepage water



management continues in perpetuity in the western portion of the proposed mine footprint (GSI, 2022). This is a conservative assumption because the moving mine pit will, in reality, cross back and forth across the ridge as part of the mining process. As indicated in Exhibit 2-2, the drawdown from draining the pit is constrained to the general area immediately within the proposed mine vicinity with no perceptible difference in the water table contours under a non-mining and active mining condition off of Trail Ridge (Exhibit 2-2). Moreover, the groundwater divide remains in place, with flow diverging to either side from the crest of Trail Ridge (flowing to the west on the west side of the ridge and to the east on the east side of the ridge).



Exhibit 2-2. Regional Water Table Contour Comparisons for Non-Mining and Western Moving Mine Pit Scenario. Pit Location for this Seepage Scenario is indicated in orange.



2.2 No measurable reduction in baseflow will occur within the St. Marys River or the River Styx as a result of Twin Pines mining activity.

Groundwater flow from the proposed mine site is divergent from the crest of Trail Ridge – flow directions are oriented to the east in locations east of the ridge and toward the west in areas west of the ridge (Exhibit 2-1).

Because the Twin Pines mine will be located south of the Okefenokee Swamp, and given the mine's overall distance to the swamp, westward groundwater flow from the site does not enter the Okefenokee directly. Rather, any contributions to the Okefenokee would occur from the River Styx, a tributary located between approximately 1.3 and 2.3 miles from the western boundary of the proposed mine (Exhibit 2-3).



Exhibit 2-3. Location of Proposed Twin Pines Minerals Mine and General Groundwater Flow Directions.



To evaluate potential depletion in stream flows, three separate models were used to compare the combined groundwater contributions to wetlands and surface water flows that may contribute to the River Styx for non-mining, and active mining conditions as presented in GSI (2022) and discussed further below. The models include the non-mining calibrated model, and two mine dewatering models – one with the moving mine located at the west end of the proposed mining area and the other with the moving mine located near the center beneath the ridge.

Groundwater volumetric discharge simulated within the non-mining calibrated model was extracted for the contributory wetlands and the River Styx. National Hydrologic Dataset wetlands and drain boundary conditions used to represent these wetlands within the numerical model are shown in Exhibit 2-4 (GSI, 2021). Wetlands that are assumed to eventually contribute surface water flows to the River Styx as well as drains representing the River Styx, directly, are also highlighted in Exhibit 2-4.



Exhibit 2-4. Wetland Areas for River Styx Flow Analyses.



The same process was then performed for the two models that represent the moving mine pit within the western and central portions of the project area, respectively (GSI, 2022). Exhibit 2-4 shows the locations of the two moving mine-pits (and their dimensions, to provide a sense of scale of the active mining operations in comparison to the surrounding features). The differences in groundwater contributions to surface water between the mine pit dewatering models and the non-mining model are provided in Table 2-1. The process was conducted for average base case conditions and for dry climactic conditions.

Table 2-1 shows that groundwater baseflow contributions directly to the River Styx will not be affected by mine pit dewatering within the proposed mine area. Unnamed wetlands have an average cumulative reduction of 0.09 cubic feet per second (cfs) if mining were to occur in perpetuity at the moving mine pit locations shown in Exhibit 2-4.



Table 2-1. Non- and Post-Mining Stream and Wetland Baseflow Comparisons for Non-Mining and Mining Conditions.

		Simulated Groundwater Baseflows							
		Non-Mining (gpm)	Western Pit Location (gpm)	Central Pit Location (gpm)	Average Decrease (gpm (cfs))				
Average Climatic	Unnamed Wetlands	1,106	1,081	1,052	39 (0.09)				
Conditions	River Styx	95	95	95	0 (0.00)				
	Total	1,201	1,176	1,147	39 (0.09)				
Dry Climatic	Unnamed Wetlands	832	811	786	34 (0.07)				
Conditions	River Styx	64	64	64	0 (0.00)				
	Total	896	875	850	34 (0.07)				

Notes:

gpm = gallons per minute cfs = cubic feet per second



However, because approximately 60% of the proposed mining area occurs west of the Trail Ridge crest, the moving mine will be on the other side of the groundwater divide for approximately 40% of the total mining period. Therefore, it is likely that baseflow reductions will be substantially lower (i.e., approximately 40% lower) than the already minimal values shown in Table 2-1.

These changes are negligible when considered against the water budget of the ONWR generally, or the southeastern portion of the ONWR specifically. Even assuming 100% of the water from the unnamed wetlands would flow into the ONWR, (which is highly conservative because water will be lost to evaporation and evapotranspiration), reducing inflows to the Okefenokee Swamp by 0.09 cubic feet per second (39 gallons per minute) would not change its water level.

The ONWR is an extremely large waterbody with annual inflows that dwarf any potential reductions that could result from mining activities. Precipitation over the surface of the ONWR contributes approximately 610 billion gallons each year, with approximately 152 billion gallons falling over the southeastern quadrant alone. Focusing on the southeastern quadrant alone, this is approximately 7,300 to 8,600 times more water than the conservatively estimated inflow reductions from mining activities described above. The annual contribution from precipitation over the entire ONWR is approximately 30,000 to 35,000 times greater than the conservatively estimated effects from mine pit dewatering. And this does not even consider inflows from other sources, such as groundwater base flow, surficial wetlands, and surface water tributaries.

It is possible to construct a scenario to demonstrate the negligible effect that any reductions would have on water levels in the ONWR. For example, if we assume that (1) the southeastern quadrant of the ONWR is isolated and hydrologically segregated from the rest of the ONWR; (2) inflows to the southeastern quadrant of ONWR are reduced by 0.09 cfs as described above; and (3) the OWNR receives no inflow from any other source — meaning there is zero precipitation, zero contribution from groundwater, and zero contribution from other surface water sources— reducing inflows by 0.09 cfs would reduce surface elevations in the southeast portion of the Okefenokee Swamp by, at most, 0.002 feet (0.028 inches or 0.71 millimeters; Table 2-2) in total over the mining period of 4 years. To reiterate, even these negligible impacts will not occur, because the estimated inflow reductions are conservative, the southeastern quadrant of the ONWR is not segregated and the very significant inputs to the Okefenokee Swamp from other sources (e.g., precipitation, groundwater contributions, and surface water flows) would far exceed and offset any losses, but are not considered. Nevertheless, this exercise demonstrates that mining activities will not alter water levels in the ONWR.



Table 2-2. Theoretical Water Level Declines in SE Quadrant of the ONWR Resulting from Proposed Pit Dewatering Activities Assuming Zero Inflows from Other Sources.

Average Water Depth (Feet)	Area ¹ Okefenokee (Acres) (Billion Gallons)		Okefenokee Southeast Section Area (Acres) ²	Annal Precipitation Input over ONWR (Billion Gallons)	Annual Precipitation Input Southeast Section Area of ONWR ³ (Billion Gallons)
2.0	438,000	285	109,500	610	152

Theoretical Okefenokee Water Depth Reduction Calculation Assuming Reduction in Baseflow Contributions to Unnamed Wetlands and the River Styx									
Average Climatic Conditions	Reduction in Okefenokee Inputs (cubic feet per second)	Reduction in Okefenokee Inputs (gallons per minute)		Water Depth Reduction Over ¼ Okefenokee Swamp (Inches) ⁴					
Average	0.09	39.5	4	0.028					
Dry	0.07	33.7	4	0.024					

Notes:

1. United States Fish & Wildlife Service (2006)

2. Assumes ¹/₄ portion of the of the Okefenokee Swamp is directly affected by the mining operations and the rest of the swamp is disconnected from this southeast section during drought periods.

3. Assumes annual precipitation of 51.25 inches per year (TTL, 2019) over the southeast section area.

4. Water Depth Reduction Over Okefenokee Swamp = (Reduction in ONWR Inputs * 4 years) /ONWR Southeast Section Area



3.0 RESPONSE TO DR. C. RHETT JACKSON COMMENTS

3.1 Dr. Jackson's finding that Trail Ridge behaves as an "earthen dam" impounding groundwater is incorrect, as a naturally occurring groundwater divide is present beneath the crest of Trail Ridge and water flows in both directions from the crest.

Dr. Jackson claims that Trail Ridge acts as an earthen dam that impounds the swamp, and he suggests mining will breach this dam. However, as described above in Section 2.1, this assertion is incorrect.

In an attempt to support his opinion that a dewatered mine pit may drain the swamp, Dr. Jackson includes schematics (reproduced as Exhibit 3-1 below) indicating how this may occur.



Exhibit 3-1. Schematics from Dr. Jackson's August 2022 comments (Jackson, 2022a) and January 2023 comments (Jackson, 2023).

Importantly, these schematics are out of proportion, and misrepresent the magnitude of the mining operation's moving mine pit. The moving mine pit size is just 500 feet in length and 100 feet wide. As indicated on Exhibit 3-2 below, it is just a tiny sliver on Trail Ridge.





Exhibit 3-2. Regional Water Table Contour Comparisons for Non-Mining and Western Moving Mine Pit Scenario. Pit Location for Seepage Scenario 1 is indicated in orange.

Clearly, Dr. Jackson's schematics are misleading. The mine pit is actually very small in relation to Trail Ridge; and the potential impact of dewatering this pit is accordingly very small. Exhibit 3-2 compares water level contours for non-mining conditions with water level contours for a modeled mine pit (GSI, 2022). As indicated in Exhibit 3-2, the drawdown from mine pit dewatering is limited to the general area immediately within the vicinity of the active mine pit with no perceptible difference in the water table contours under a non-mining and active mining condition off of Trail Ridge (Exhibit 3-2). Moreover, the groundwater divide remains in place, with diverging flow from the peak of Trail Ridge (flow to the west on west side of the ridge and to the east on the east side of the ridge).



3.2 Contrary to Dr. Jackson's claim, mine pit dewatering and pumping from the UFA will not reduce water levels in the ONWR.

Dr. Jackson claims that dewatering the mine pit will remove groundwater from the surficial aquifer, water that otherwise would have supported streamflows and water levels in the upper St. Marys basin. Specifically, Dr. Jackson asserts that mine pit dewatering will "reduc[e] flows to the swamp by at least 0.87 cfs," thus "removing that water from the water budget of the swamp." Dr. Jackson claims that this "loss will be most noticeable during drought conditions, as it is this surficial groundwater seepage that helps sustain the swamp during droughts" (Jackson, 2023). Based on this, Dr. Jackson claims, among other things, that mining on Trail Ridge "will damage the tourism potential of the Okefenokee Swamp, to the detriment of the state and the region" (Jackson, 2023) and "will increase the number of days on which recreational boating is not possible in parts of the swamp" (Jackson, 2023). Dr. Jackson further asserts that "the proposed mine can be expected to make the swamp drier in dry periods and also to make dry periods last longer" and that as a result, "[d]rought frequency and severity, along with fire risk, would increase (Jackson, 2022a).

Each of these conclusions is incorrect. As discussed above in Section 2.2, any reduction in inflows to the ONWR will be negligible. Even using the most conservative assumptions, Dr. Jackson has overstated the potential reductions in ONWR inflows by more than an order of magnitude. Furthermore, as I explain above, even an estimated reduction in ONWR inflows of 0.09 cfs, which is highly conservative, would be negligible in comparison to the overall water budget of the ONWR generally or the southeastern portion of the OWNR specifically.

3.3 Contrary to Dr. Jackson's claim, there will be no measurable reduction in baseflow within the St. Marys River as a result of mining activity.

Dr. Jackson asserts that reducing inflows to the ONWR by 0.87 cfs will result in a corresponding decrease of 0.87 cfs in St. Marys River flows (Jackson, 2023). According to Dr. Jackson, this will increase the periods in which the St. Marys River has no flow at the Moniac gage from 3% to 9.5%, thus "tripl[ing] the frequency of severe drought in the Upper St Marys River" (Jackson, 2023).

This is incorrect for numerous reasons. First, Dr. Jackson is incorrect in claiming that ONWR inflows will be reduced by at least 0.87 cfs. As explained above, estimated flow reductions to the ONWR are on the order of 0.09 cfs under the most conservative assumptions. This is at least an order of magnitude lower than Dr. Jackson assumes. Second, it is not correct to assume, as Dr, Jackson does, that any reduction in inflows from the River Styx and its associated unnamed wetlands would result in an equivalent reduction in flows in the Upper St. Marys River. Finally, and most significantly, water levels in the ONWR will not be affected, as I explain above. That being so, there will be no effect on outflows to the St. Marys River and no reduction in flows in the Upper St. Marys River.



4.0 RESPONSE TO NATIONAL PARK SERVICE (NPS) SOUTH FLORIDA NATURAL RESOURCE CENTER COMMENTS

4.1 NPS's claim regarding the appropriateness of the Theis solution to calculate Upper Floridan Aquifer drawdown is unsupported. Furthermore, any drawdown in the surficial aquifer as a result of pumping in the Upper Floridan aquifer will be negligible because of a thick confining layer separating them. Finally, as per the current Mine Land Use Plan, which NPS does not consider, the Upper Floridan wells will likely almost never be used.

NPS claims that the use of the Theis solution to predict drawdown of the Upper Floridan due to pumping is too simplistic to accurately predict effects on ONWR. This claim is baseless. Analytical solutions, such as the Theis Equation, are a standard approach for estimating potential water level declines in confined aquifers due to well pumping and for the analyses of aquifer test data to derive hydraulic conductivity and aquifer storage parameter values (Anderson et al., 2015). These solutions were used to successfully manage aquifer resources in complex geologic settings long before the development of today's complex hydrogeologic numerical modeling codes. Using the Theis equation is appropriate to understand the potential for water level drawdowns in the confined Upper Floridan Aquifer.

Furthermore, the Upper Floridan Aquifer is not connected to the Okefenokee Swamp or the Surficial Aquifer, so drawdown impacts in the Floridan Aquifer will not be transmitted to the overlying water bodies. The Upper Floridan Aquifer and the Surficial Aquifer are separated by a low hydraulic conductivity unit comprised predominantly of clays and silts (the "Hawthorn Formation") that is more than 300 feet thick in the area of the Okefenokee Swamp (Williams and Dixon, 2015). Any linkage between surface waters and the Upper Floridan Aquifer is negligible and exceedingly attenuated. Therefore, any drawdown in the surficial aquifer as a result of aquifer pumping in the Upper Floridian aquifer will be negligible.

Additionally, as stated in the Water Use and Management Plan (Wood, 2023), the Upper Floridan wells will likely almost never be used. Their main purpose is to fill the process water ponds prior to mining operations before seepage water is available. Once the mining process begins, the Upper Floridan wells will be used solely as a backup, as they will never be used when seepage water is available in the water management ponds; therefore, any drawdown in the surficial aquifer or impact to the ONWR will be instead of, rather than additive to, the impact of seepage from the surficial aquifer.

4.2 NPS's suggestion of supporting model calibration through a validation/verification approach is not supported by current industry standard best practices for groundwater modeling.

NPS claims that model validation/verification must be conducted to ensure model reliability. However, the groundwater model calibration approach NPS suggests is not consistent with current industry standards. Verification generally refers to a demonstration that a model reproduces field data values independently of the data used as part of model calibration (Anderson et al., 2015). This general approach is commonly used in statistical learning techniques where models are trained on a subset of data and then the ability of these models to make predictions is evaluated against the remaining data held in reserve (James et al., 2017). However, in groundwater modeling, because the number of parameters requiring calibration is



often so large, and available data are comparatively small, it is now recommended that all available data are used in calibration (Doherty and Hunt, 2010). Consequently, the validation/verification approach to groundwater model calibration is no longer the preferred methodology (Anderson et al., 2015), and all the available data was used for calibration to make the model as accurate as possible.

4.3 NPS is incorrect in asserting that available hydraulic conductivity and groundwater elevation data are insufficient to characterize the groundwater system.

NPS claims that the aquifer test data used to obtain hydraulic conductivity values were not sufficient, making the datasets describing the properties of the groundwater system questionable. This claim is incorrect. Extensive characterization of hydraulic conductivity has been performed within the proposed mining area, northward along Trail Ridge, and west toward the ONWR. Slug and aquifer test data and soil samples collected from well borings were analyzed resulting in 36 and 38 horizontal and vertical hydraulic conductivity estimates, respectively, which were used to inform the calibrated groundwater model (GSI, 2021). Data were of greater density near the proposed mine area, since this is where management of seepage water into the moving mine pit will be performed and any potential aquifer drawdown in the Surficial Aquifer will be at its maximum. However, the Surficial Aquifer has been characterized as far as 3.5 miles north of the Twin Pines mine site and 2 miles northwest towards the ONWR.

Exhibit 4.1 shows locations where aquifer tests were performed to obtain hydraulic conductivity estimates for the groundwater model. At some of these locations, data were collected at multiple vertical intervals to characterize the profile of the Surficial Aquifer. Therefore, some locations shown in Exhibit 4-1 have multiple hydraulic conductivity estimates for a single boring or well location to account for variability in the vertical direction. Detailed reporting of aquifer parameter characterization is provided in Holt et al., (2019a, 2019b, 2019f, and 2019g) and the use of data in the model is described in GSI, (2021).

NPS also claims that indicator kriging of hydraulic conductivity values was used to calibrate the groundwater model. That is incorrect. Indicator kriging of hydraulic conductivity values was not used to calibrate the groundwater model (GSI, 2021). Instead, estimates derived from aquifer tests and soil samples were assigned as initial estimates within each respective Surficial Aquifer hydrostratigraphic unit and hydraulic conductivity values were then adjusted using the automatic calibration software PEST on a set of interpolation points termed "pilot points" (Doherty and Hunt, 2010) such that groundwater levels throughout the model domain and water level differences across the consolidated black sands were accurately simulated. The hydraulic conductivity field was constrained to stay within reasonable limits of measured conditions. The results for the PEST automated parameter estimation simulations were evaluated for quantitative and qualitative calibration metrics and to note that hydraulic conductivity values for the various hydrogeologic units were reasonable and that the conceptual model was represented appropriately by the numerical model. Calibration proceeded in this manner until satisfactory results were obtained for the calibration metrics, hydrogeologic property values, and conceptual flow conditions. This is the industry standard approach towards model calibration (Anderson et al., 2015).

The numerous hydraulic conductivity values, taken together with water level measurements from 87 well and piezometer locations used to calibrate the model (GSI, 2021), means the Surficial Aquifer is sufficiently characterized to model potential impacts resulting from mining activities along Trail Ridge.





Exhibit 4-1. Locations of Hydraulic Conductivity Values Derived from Field Data.

4.4 NPS's assertion that steady-state models cannot be used to quantify potential effects on Trail Ridge and surrounding area hydrology is incorrect.

NPS claims that the use of a steady-state model is flawed. This claim is not justified, as the use of a steady-state model provides a conservative approach towards evaluating the impact of the mine on the surrounding hydrogeology. The objective of the modeling effort was to evaluate the difference between mined versus non-mined conditions and a steady-state model calculates the **maximum** impact that would occur and is therefore conservative with regards to comparing non-mining, active mining and post-mining conditions. In other words, a steady state analysis depicts the worst-case scenario. A transient analysis on the other hand would not depict the maximum impact and obscure the analysis. Water level fluctuations would occur due to climate variability but that would occur for non-mining, mining, and post-mining conditions. Therefore, sensitivity analyses have been conducted to evaluate the impact of mining for low recharge as well as high



recharge conditions and though groundwater levels are very different during the drought compared to normal or wet conditions, the change that would occur due to the mine (difference between mining and non-mining conditions) is indicated to be similar for drought and non-drought conditions (see section 4.8, below).

4.5 NPS's claim that there is no direct flow path in the model between the proposed mine site and the ONWR is incorrect.

NPS claims a direct flow path connection between the proposed mine site and the ONWR is omitted in the groundwater model. This is incorrect, as the model allows for a direct groundwater flow path between the proposed mine site and the ONWR due to the high hydraulic conductivity of the sands. No barrier has been placed in the model that prevents groundwater from discharging to the ONWR.

Running the model under non-mining, mining, and post-mining conditions provides an approach to evaluate the difference in the discharge to surface-water bodies as a result of mining. If the same amount of water discharges to the drain boundaries under non-mining, active mining and post-mining conditions (which is the case as noted in Table 2.1, then that same amount of water is going to reach the ONWR and a surface water model is not needed to determine that.

4.6 NPS correctly observes that drain elevations in the model do not match the description in the report (GSI, 2021); however, the drain elevations are consistent with the conceptual model, as described below.

NPS observes that drain cell elevations in model do not match the description in GSI's 2021 report. The drain elevations in the models were set to the streambed elevation or the elevation of the wetland for all of the drain cells in the model (a difference of 0.5 feet). However, it does not change the conclusions on impacts of non-mining and post-mining conditions as explained below.

The United States Geologic Survey's National Hydrography Dataset (NHD) was used to establish the locations of the drain boundary conditions in the model, which represent both NHD mapped wetlands and stream courses. To expand on previous descriptions provided in GSI (2022), the following procedure was utilized to ensure that drain elevations were consistent with the conceptual model. Where wetlands coincide with a model cell, drain elevations are set equal to ground surface. In cells where streams are present, but no wetlands have been mapped, drain elevations were set to 0.5 feet below ground surface. In instances where both a stream network and wetlands are present in a single cell, if the mapped wetlands cover a small percentage of the cell, the drain elevations are set to 0.5 feet below ground surface, otherwise they are set to ground surface.

This minimal difference in elevations of drains is not material to the numerical flow solution. Also, the minor differences that may be present as a result if a different drain elevation (by 0.5 feet) will be present in non- and post-mining conditions, thus cancelling out any differences.



4.7 NPS incorrectly states that recharge rates need to be spatially and temporally variable to properly understand potential changes in regional hydrology due to mining, especially during periods of drought. While recharge variability may affect the flows to the ONWR, it has marginal impact when differences in flows are considered between non-mining, mining, and post-mining conditions.

NPS claims that recharge rates need to be spatially and temporally variable, as it is otherwise difficult to evaluate the impacts of mining on the ONWR, particularly during the dry periods. However, NPS's conclusion is incorrect. A regional recharge estimate of about 4.13 inches/year was used to calibrate the groundwater model and is consistent with values calculated by the USGS (2003) for the area. Further details of the USGS evaluation are provided in GSI (2021).

NPS states that without spatio-temporal variability in the simulated recharge, it is difficult to evaluate possible impacts on the ONWR resulting from mining during dry periods. This is incorrect. Adding complexity to a model that does not satisfy the objectives is not an appropriate approach to modeling. Spatio-temporal variability in recharge would occur during non-mining, mining, and post-mining conditions and would have an impact on the flow regime, but it is the difference between these two conditions that reveals the impact of mining. The addition of spatio-temporal variability for recharge would have no impact on the analysis of the **difference** between non-mining, mining, and post-mining conditions, and would needlessly complicate the analyses.

The impact of drought conditions has been evaluated via a sensitivity analysis for non-mining and post-mining conditions in GSI, (2021), where model recharge rates were decreased and prescribed groundwater elevations assigned to constant head boundary conditions were reduced. The impact of non-mining versus post mining was shown to be minimal, and similar to the impacts when conditions were wetter. Note that using a steady state model with these types of adjustments represents an extreme case since the steady state model assumes conditions persist in perpetuity.

A sensitivity analysis to drier conditions, comparing non-mining hydrogeology to that during mining activities, is discussed in Section 2.2.

4.8 NPS states that use of a constant head boundary condition in the model is inappropriate; however, this is incorrect, and further, irrelevant, as any impacts of mining in the proposed mining area on the ONWR do not reach the constant head condition along the western boundary due to its sufficient distance from the proposed mine area.

NPS claims that the use of a constant head boundary condition in the model is inappropriate as one cannot conclude that there will not be any effects on water stage in the areas of the model at (or near) the fixed-head boundaries of a steady state model. However, this conclusion is irrelevant, as modeling (GSI, 2021; GSI, 2022) shows that any effects from mining occur in the immediate vicinity of the mining areas, and do not extend to the constant head boundaries. This can be seen in figures (GSI, 2021, Figures 39-49) that indicate the difference between non-mining and post-mining conditions. Figure 41 from GSI (2021) is reproduced below to show, as an example, that post-mining impacts do not reach constant head boundaries for 10.9% bentonite amendment, which was the proposed composition of reworked sand. Thus, the lateral boundary does not impact model results regarding non-mining versus post-mining conditions and this



comment is not relevant to evaluating post mining conditions hydrogeology as compared to nonmining conditions hydrogeology.



Exhibit 4-2. GSI (2021) Figure 41, indicating that that post-mining impacts do not reach constant head boundaries for 10.9% bentonite amendment.

As part of their Technical Review document, NPS includes a figure to support their allegation that the constant head boundaries are inappropriate. However, the figure shown by NPS (Figure 14 of their comments) is not from the GSI (2021, 2022) models, which were used for evaluating nonmining, mining, and post-mining conditions for this permit application. Rather, this figure is from an earlier modeling approach, which was superseded by the current GSI models (GSI, 2021; GSI, 2022) to address comments by GA EPD. As stated, the impact of mining from GSI models is limited to the immediate vicinity of the mining area, as shown, for example, on Exhibit 4-2, which indicates only localized effects in the proposed mining area and far from the prescribed head boundaries.

To further assess boundary impacts, a sensitivity analysis was conducted for groundwater elevations assigned to constant head boundaries. Results are presented in GSI (2022). For this analysis, the western constant head boundary cells were lowered by 10 feet in both the calibrated non-mining model and the 10.9% bentonite soil amendment post-mining conditions model. There was no difference in the simulated water balance for the Okefenokee Swamp when comparing the non-mining and post-mining conditions for the lowered constant head values (reproduced



here as Exhibit 4-3 and Table 4-1) indicating that mining does not affect flows at or past this location regardless of how the boundary was set.

Water Budget Com	ponent	Non-Mining	Post-Mining 10.9% Bentonite Soil Amendment
Inflows	Recharge	322.1	322.1
(gallons per minute)	Lateral Inflows	37.5	37.5
	Lateral Outflows	142.9	142.9
Outflows (gallons per minute)	Outflow to Okefenokee Wetlands	216.7	216.7
Percent Mass Balance Error		0.0%	0.0%

Table 4-1. Non- and Post-Mining Water Budget Comparisons for Lower Western Boundary Constant Heads.





Exhibit 4-3. Area used for Water Balance Calculations of Tables 4-1 and 4-2.

For the purposes of this report, an additional evaluation has been performed using the models described immediately above (with lower water levels at the boundary) where, in addition to the lower constant head values, recharge was simultaneously decreased from 4.13 inches/year to 3.5 inches per year to simultaneously simulate both lower recharge and lower water level conditions that would occur in a drought. Table 4-2 provides non- and post-mining water balance volumetric flow rates for the ONWR area. Again, there is no difference between the non- and post-mining water balance for the ONWR under this drier condition scenario.



Water Budget Com	ponent	Non-Mining	Post-Mining 10.9% Bentonite Soil Amendment
Inflows	Recharge	272.9	272.9
(gallons per minute)	Lateral Inflows	21.5	21.5
	Lateral Outflows	123.6	123.6
Outflows (gallons per minute)	Outflow to Okefenokee Wetlands	170.7	170.7
Percent Mass Balance Error		0.0%	0.0%

Table 4-2. Non- and Post-Mining Water Budget Comparisons for Lower Western Boundary Constant Heads with Reduced Recharge.

4.9 NPS states that the MODFLOW drain package was not appropriate for simulating surface water dynamics. There is no intent to simulate surface water dynamics as this is a groundwater analysis issue. Water that leaves the drains can be assumed to mostly flow to the ONWR. If the same amount of water drains to these wetlands for non-mining, mining, and post-mining conditions, then that same amount of water will flow to the ONWR.

NPS claims that a coupled surface water-groundwater model should be used instead of a groundwater model with a drain package because the MODFLOW drain package does not allow us to directly quantify surface water flows into the refuge, or to predict mining impacts on the flow volumes and stages in the ONWR. However, this conclusion is incorrect. The numerical model uses the MODFLOW drain boundary to represent wetlands and streams, which allows water to flow out of the groundwater system when water levels are at or above a prescribed "drain" elevation. In the case of this model, water removed from the model via the drain package represents the groundwater discharged to wetlands and streams. Some of the water removed from the drain package also becomes surface water flow that eventually contributes to the ONWR. Consequently, the model can be used to compare cumulative groundwater discharge to wetlands and streams for non-mining, mining, and post-mining conditions. The same amount of water flows to the drains for these conditions, and therefore, the same amount of water will flow to the ONWR for these conditions and complicating an analysis to include a surface water model is not justified.

4.10 NPS claims that the positioning of the no-flow boundary condition is not appropriate. This boundary is appropriate as flow lines are generally parallel to the north and south boundaries which are the no-flow boundaries. Furthermore, these boundaries do not impact how mining would change hydrogeologic conditions.

NPS claims that the use of a no-flow boundary condition causes water in the model to be redirected to places it would not normally flow. However, this conclusion is not relevant, as groundwater elevation contours demonstrate that the highest groundwater levels in the area occur beneath Trail Ridge resulting in predominant flow directions that are oriented in the east-west direction (GSI, 2021). There may be some local variations in flow directions, which may slightly affect water levels near the northern and southern boundaries; however, flow is predominantly



parallel to the edge of the active domain in the north and south and hence it is appropriate to set them as no-flow boundaries (i.e., there is no flow across those boundaries). Local variations near the boundary would occur for non-mining, mining, and post-mining conditions and those impacts cancel out when differences are taken to evaluate the impact of mining or post-mining conditions. Thus, not only is this boundary appropriate, but it also does not impact the comparison between mining and post-mining conditions.

4.11 NPS states that the model is not set up to mimic the system's natural variability. This is not relevant, as the modeling effort was designed to evaluate the impact of mining on the local hydrogeology, and adding more complexity to a model than is needed is not appropriate. NPS further states here that drain boundary conditions were not considered in the sensitivity run when considering impacts on ONWR for dry conditions. Contrary to NPS statements, the drain elevations should not be incorporated into a drought sensitivity analysis.

NPS claims that given the high temporal variability in groundwater levels and precipitation in the study, the steady state model is not an appropriate tool to simulate the dynamic behavior of groundwater in this system. This conclusion is incorrect, however, as steady-state models are commonly used to represent average hydrologic conditions. In this case, model calibration was performed using average measured groundwater elevations collected between January and October 2019 (GSI, 2021) as calibration targets. As NPS indicates, there is generally low variability in water levels over time indicating that transient conditions and associated fluctuations are mild. Furthermore, steady-state models are conservative, as they provide the maximum impact of pumping or recharge stresses which may be buffered by transient models. Since the modeling objectives were to evaluate the impact of mining, the steady-state model provides the maximum potential impact, and results are therefore appropriately characterized as conservative estimates.

Droughts do occur, and water levels do fluctuate as a result. Therefore, as discussed previously, sensitivity analyses to recharge and lateral boundary conditions have been performed (see Section 4.8, as well as GSI, 2021, GSI, 2022) to evaluate whether different climatic conditions would affect the ONWR water balance. Even though climate does impact the ONWR water balance, the non- and post-mining water budget for ONWR remains unchanged for all scenarios.

Contrary to NPS statements, the drain elevations should not be incorporated into a drought sensitivity analysis. The drain elevation is the elevation at which water is removed from the model and becomes surface water in either streams or wetlands and therefore, it is conceptually the elevation of the bottom of the wetland or stream bed, which does not change because of drought conditions. Under a drought scenario, the model simulates a reduced groundwater elevation that can fall below the elevation of some of the drains – in which case, water leaving the domain is reduced relative to a wetter scenario or stops altogether (for non-mining, mining, and post-mining conditions). This approach is consistent with a conceptual model that includes the reduction of wetland areas and/or stream flows under drought conditions.



4.12 NPS suggests that effects on ONWR from mine dewatering were not properly quantified.

NPS claims that changes in water flow in the streams and channels feeding the ONWR were not quantified. Potential impacts to surface water flows are discussed in my findings and in response to comments made by Dr. Rhett Jackson as noted in Sections 2.2 and 3.2.

4.13 NPS claims that re-dredging of the soil amendment layer was not taken into consideration. However, additional analysis indicates that the inclusion of re-dredging in the model results in negligible changes in the modeling outcome.

Reclamation of the mine will include on average, a 3-foot soil amendment layer consisting of reclaimed sand with 10.9% bentonite in the approximately 50-foot mine pit. If it is assumed that a successive mine cut includes 75% clean native sands, and 25% of a reclaimed cut, then the bentonite in the resulting mixture would be 0.164%.

Layer Material	Layer Thickness (feet)	% Bentonite		
Bentonite	3	10.9		
Reworked Sand	47	0		

% Bentonite of Reworked Sands with 25% Cut in Bentonite = $\frac{(10.9\% * 25\% * 3 feet) + (0\% * 47 feet)}{50 feet}$

To determine hydraulic conductivity, and as previously implemented in GSI (2021), a regression equation for hydraulic conductivity as a function of the percent of bentonite in the mixture, was used (Holt et al., 2020):

$$Log(K_{sb}) = (-0.3567 \, pB - 3.108)$$

Where Ksb is the hydraulic conductivity of the sand-bentonite mixture in units of cm/sec, and pB is the percent of bentonite added to the sand. Using this equation, the hydraulic conductivity of reworked sand that includes 25% of the cut from a reclaimed sands layer is 1.93 ft/day.

The post-mining model with 10.9% bentonite was again run with the hydraulic conductivity of reworked sands of 1.93 ft/day (the original run with no bentonite in the reclaimed sand had a hydraulic conductivity of 2.21 feet/day). Exhibit 4-4 shows the water table difference for this sensitivity case compared with the case where there is no bentonite in the reworked sand. This shows that incorporating the lower hydraulic conductivity of bentonite in the reworked sand due to redredging of the soil amendment layer raises the water levels from 0.1 feet to a maximum of 1.14 feet in a limited area of the mine site, with a drop in water levels ranging from 0.1 feet to a maximum of 0.5 feet at the eastern and western peripheries.

These increases will not result in any decrease in overall flow to the ONWR, as the same volume of water will exit the site and the direction of flow will not change. Instead, the primary consequence of higher water level elevations from soil amendment and bentonite in the reworked sands will be the formation of additional and/or larger surficial wetlands on the mining site



following reclamation. This is consistent with the stated objective of the amendment plan, which was restoration of surficial wetlands. Finally, if EPD is concerned about increased water elevations resulting from the reclamation plan requested by the State Geologist, those increases could be avoided by revising the soil amendment layer by reducing the bentonite concentration in certain areas.



Exhibit 4-4. Difference in water levels between post-mining conditions without Bentonite mixed in the reclaimed sands (and with a layer of sand with 10.9% bentonite) and post-mining conditions with bentonite mixed in reclaimed sands (and with a layer of sand with 10.9% bentonite).

4.14 NPS correctly states that there are mathematical errors in some data tables from GSI (2022); however, these do not affect the conclusions of the report and are reissued, here, as Appendix B.

An error did occur when transcribing the volumetric flows for lateral and drain volumetric outflows. However, all conclusions discussed in GSI (2021 and 2022) have been based upon outflows expressed as total percentages of recharge and those values were correct and does not change the conclusions. The tables with corrected lateral outflow volumes are reissued below as Appendix B.

4.15 NPS incorrectly claims that modeling and analysis segmentation (i.e., modeling condition changes individually as opposed to modeling them in combination) does not account for combined effects of the boundary condition changes if the changes were made simultaneously. Different boundary condition combinations result in different water flows, however, results between non-mining and post-mining conditions indicate minimal change.

NPS claims that the combination of factors (soil disturbance, dewatering, and aquifer pumping), must be modeled simultaneously using a non-steady state model, as the interaction of these



processes could result in unforeseen impacts to ONWR, especially during dry periods. Combining factors simply gives an additive result of the combined factors for both non-mining and postmining conditions, which gets washed out in the difference. Also, as discussed above, steadystate modeling with appropriate sensitivity analyses to various boundary and hydrogeologic conditions is sufficient to quantify potential impacts to the ONWR resulting from proposed mining activities. The objective of the modeling efforts was to evaluate the potential hydrogeologic impact of mining activities as compared to non-mining conditions. The use of a steady-state model for this comparison shows the maximum possible impact of mining, without the dampening of effects that would occur if a transient model were used. Running the model for the different conditions of wetness or drought in a combined manner, as is done in response to comment 4.8 (see also Table 4.2 above) showed no substantive change between non-mining and post-mining conditions. This example shows that adding complexity may change the flows in each scenario, but will not affect the difference in flows between non-mining and post-mining conditions.

4.16 NPS wrongly assumes that any future expanded mine project will not be evaluated after permitting for the current demonstration mine.

NPS claims that approval of the demonstration mine may set a precedent for future mining without evaluating impacts of expanded mining footprints. That is incorrect. The permit currently under consideration by GA EPD is the only permit being considered. If additional mining is proposed in the future, any future permit application will require additional analysis based on the best available information at that time. In addition, data collected as part of the demonstration mine operation and post-mining conditions would provide valuable information to ensure the continued implementation of appropriate environmental protections for the hydrogeology around Trail Ridge and the ONWR.

- 5.0 RESPONSE TO MARK A. HUTSON GROUNDWATER MODELING COMMENTS MADE ON BEHALF OF THE SOUTHERN ENVIRONMENTAL LAW CENTER (SELC)
- 5.1 SELC and Mr. Hutson erroneously claim that the constant head boundaries on the east and west side of the domain and the no flow boundaries to the north and south do not reflect existing conditions which could develop during and after mining around much of the domain.

SELC and Mr. Huston claim that fixed head and no flow boundaries do not reflect existing conditions or conditions which could develop during and after mining around much of the domain. However, this comment is incorrect. Similar comments were made by Bahm and Paudel (2023) and the responses provided in sections 4.8 and 4.10 fully address the concerns raised by SELC and Mr. Hutson.

5.2 SELC and Mr. Hutson appear to suggest that the MODFLOW drain package is an inappropriate approach to represent wetlands and streams within the mine project area. This is incorrect.

SELC and Mr. Huston claim that the use of drain boundary conditions to represent wetlands and streams is inappropriate. However, this comment is incorrect. Similar comments were made by

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Bahm and Paudel (2023) and the responses provided in Section 4.9 fully address the concerns raised by SELC and Mr. Hutson.

5.3 SELC and Mr. Hutson express concern at the lack of fate and transport modelling.

SELC and Mr. Huston claim that fate and transport modelling to evaluate the time required for the peak concentrations of mining-related groundwater contaminants to reach monitoring points is missing. However, this comment is incorrect. Water quality and geochemical evaluations for reworked sands have been previous performed by Jacobs (2020) and demonstrate that the potential leachability of possible constituents of concern for previously undisturbed soils and emplaced reworked sands is comparable.

As stated by Jacobs (2020), "...leach testing demonstrates that the metals that are detectable in [black humate sands] are not readily leachable and would not generate any concentrations exceeding GA EPD drinking water MCLs. Based on these comparisons relative to background water quality data and GA EPD MCLs, the disposal of the post-process sand (i.e., sand tailings) and the humate isolates back into the open pit during mining will not have any significant impact on groundwater quality of the regional shallow aquifer."

Therefore, water quality impacts to nearby surface water or groundwater resources would be the same for mining and non-mining conditions and no additional numerical modeling, including the additional of fate and transport simulations to the groundwater flow model, is required.



6.0 CITED REFERENCES

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- Jackson, C. Rhett, 2022b. Re-Analysis of hydrologic effects of TPM's proposed Trail Ridge mine on the Okefenokee Swamp Based on new Water Management Plan and Groundwater Memo released November 2022. 22 November 2022.
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- Wood, 2023. Water Use Management Plan Saunders Demonstration Mine.



Appendix A

Resume of Dr. Sorab Panday





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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Sorab Panday, PhD

Principal Engineer

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 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.

Contaminant Transport Modeling

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 historymatching 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.

Litigation Support

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 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.
- "Innovative numerical procedure for simulating borehole heat exchangers operation and interpreting thermal response test through MODFLOW-USG code", S. Barbieri, M. Antelmi, **S. Panday**, M. Baratto, A. Angelotti, L. Alberti, Journal of Hydrology 614, 2022. https://doi.org/10.1016/j.jhydrol.2022.128556.
- "Simulating Groundwater Interaction with a Surface Water Network Using Connected Linear Networks", C. Muffels, **S. Panday**, C. Andrews, M. Tonkin, and A. Spiliotopoulos, Groundwater, 60 (6), 2022. https://doi.org/10.1111/gwat.13202.
- "Performance Analysis of the XMD Matrix Solver Package for MODFLOW-USG", Ibaraki, M., Y. Zhang, R.G. Niswonger, and **S. Panday**, Groundwater, 59 (6), 2021.
- "Simulation of thermal perturbation in groundwater caused by Borehole Heat Exchangers using an adapted CLN package of MODFLOW-USG", Antelmi M, L Alberti, S Barbieri, **S. Panday**, 2021. Journal of Hydrology, https://doi.org/10.1016/j.jhydrol.2021.126106.
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- "Hydraulic-Head Formulation for Density-Dependent Flow and Transport", C.D. Langevin, **S. Panday**, A.M. Provost, Groundwater, 58(3), 2020, doi: 10:1111/gwat.12967.
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- "Numerical Groundwater Modelling in Karst", N. Kresic, and **S. Panday**, 2017. Advances in Karst Research: Theory, Fieldwork and Applications (Parise, Gabrovsek, Kaufmann and Ravbar Eds), Geological Society of London, Special Publications, 466, https://doi.org/10.1144/SP466.12



- "Incorporating the effect of gas in modelling the impact of CBM extraction on regional groundwater systems", D. Herckenrath, J. Doherty, and **S. Panday**, Journal of Hydrology 523, 587–60, 2015.
- "A method for estimating spatially variable seepage and hydraulic conductivity in channels with very mild slopes", M. Shanafield, R.G. Niswonger, D. E. Prudic, G. Pohll, R. Susfalk and S. Panday, Hydrological Processes, DOI: 10.1002/hyp.9545, 2014.
- "MODFLOW-USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation", **Panday, Sorab**, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., U.S. Geological Survey Techniques and Methods, book 6, chap. A45, 66 p, May 2013.
- "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.
- "Improving sub-grid scale accuracy of boundary features in regional finite-difference models", **S. Panday** and C. D. Langevin, Advances in Water Resources, Volume 41, pages 65-75, June 2012.
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- "Impact of Sea Level Rise on Groundwater Salinity in a Coastal Community of South Florida", Guha, H., and **S. Panday**, Journal of the American Water Resources Association 1-19. DOI: 0.1111/j.1752-1688.2011.00630.x, 2012.
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- "An Un-Structured Grid Version of MODFLOW", **Panday, S.**, R.G. Niswonger, C.D. Langevin, M. Ibaraki. MODFLOW and MORE 2011 Conference, Golden, CO. 2011.
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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)



Table 6. Pre-Mining Simulation Water Budget Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

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



Table 7. Pre- and Post-Mining Water Budget Comparisons for Soil Amendment Bentonite Percentages Twin Pines Minerals, LLC

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	
	Lateral Outflows	1.1%	5.4%	6.5%	1.1%	5.4%	6.5%	
		51	258	309	51	258	309	
Outflows (as % of Total Recharge and gallons per minute)	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%			

St. George, Charlton County, Georgia

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
	tflows al Recharge and ber minute) Lateral Outflows Outflow to Modflow Drain Package ³	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
(as % of Total Recharge and gallons per minute)		52.0%	41.6%	93.5%	52.1%	41.5%	93.6%	52.0%	41.6%	93.5%
34 PSt minuto)		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.



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

Twin Pines Minerals, LLC

St. George, Charlton County, Georgia

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

Water Budget C	omponent	10.99 Recha	% Bentonite rge of 4.13	e w/ in/yr	10.9 Rech	% Bentonit arge of 3.5	te w/ in/yr	10.9 Rech	ntonite w/ of 4.5 in/yr	
		West	East	Total	West	East	Total	West	Bentonit arge of 4.5 East 2,303 5.2% 270 41.5% 2,164 0.0%	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,262	1,791	4,052	2,908	2,303	5,210
	Latoral 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	9% bentonite arge of 4.5 East 2,303 5.2% 270 41.5% 2,164 0.0%	323
(as % of Total Recharge and gallons per minute)	Outflow to Modflow	52.1%	41.5%	93.6%	51.7%	41.4%	93.1%	52.2%		93.8%
ganono por minato)	Drain Package	2,490	1,984	4,474	2,093	1,678	3,771	2,722		4,886
Percent Mass Ba	ance 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.



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			Calib	Pre-Mining pration Valu	le x 5	Pre-Mining Calibration Value ÷ 5		
		West	East ²	lotal	West	East	lotal	West	East	lotal
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
	Lataral Outflows	1.1%	5.4%	6.5%	1.0%	4.9%	5.9%	1.1%	Pre-Mining ration Value 2,113 5.7% 271 40.5% 1,935 0.0%	6.8%
0.1	Lateral Outflows	51	258	309	49	235	284	53	271	323
Outflows (as % of Total Recharge and gallons per minute)	Outflow to Modflow	52.0%	41.5%	93.5%	52.0%	42.1%	94.1%	52.8%	40.5%	93.2%
3	Drain Package ³	2,488	1,984	4,472	2,488	2,011	4,499	2,523	1,935	4,458
Percent Mass Ba	lance Error		0.0%		0.0%			0.0%		

Water Budget Co	omponent	10.9% Bentonite w/ Calibrated Hydraulic Conductivity10.9% Bentonite w/ Calibration Value x 5		10.9% bentonite w/ Calibration Value ÷ 5							
		West	East	Total	West	East	Total	West	0.9% bentonite ilibration Value 2,113 5.7% 271 40.6% 1,944	Total	
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782	
	Latoral Outflows	1.1%	5.4%	6.5%	1.0%	4.9%	5.9%	1.1%	% bentonite ration Value East 2,113 5.7% 271 40.6% 1,944 0.0%	6.8%	
		51	258	309	49	235	284	53	271	324	
(as % of Total Recharge and callons per minute) Outflow t	Outflow to Modflow	52.1%	41.5%	93.6%	52.1%	42.0%	94.0%	52.6%	40.6%	93.2%	
ganerie per minate)	Drain Package	2,490	1,984	4,474	2,490	2,007	4,497	2,514	1,944	4,458	
Percent Mass Ba	ance Error		0.0%			0.0%			0.0%		

Notes:

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.

^{1.} West refers to the west of the Trail Ridge crest as shown on Figure 33.



Table 10. Pre- and Post-Mining Water Budget Comparisons for Unconsolidated & Semi-Consolidated Sands Hydraulic Conductivity Twin Pines Minerals, LLC

Water Budget Co	omponent	Pre-Mining w/ Calibrated Hydraulic Conductivity			Calil	Pre-Mining bration Value	e x 5	Pre-Mining Calibration Value ÷ 5		
		West ¹	East ²	Total	West	East	Total	West	Pre-Mining Calibration Value West East 2,669 2,113 0.7% 4.1% 34 196 33.5% 41.7% 2,556 1,995	Total
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782
	Latoral Outflows	1.1%	5.4%	6.5%	1.8%	7.9%	9.7%	0.7%	4.1%	4.8%
0.1		51	258	309	86	378	464	34	196	230
(as % of Total Recharge and gallons per minute)	Outflow to Modflow	52.0%	41.5%	93.5%	48.4%	41.9%	90.3%	53.5%	Pre-Mining Calibration Value ÷ st East 59 2,113 % 4.1% 90 2,113 % 4.1% 196 196 % 41.7% 56 1,995 0.0% 0.0%	95.2%
gallono por minato)	Drain Package ³	2,488	1,984	4,472	2,313	2,006	4,319	2,556		4,551
Percent Mass Ba	ance Error		0.0%			0.0%			0.0%	

St. George, Charlton County, Georgia

Water Budget C	Water Budget Component 10.9% Bentonite w/ Calibrated Hydraulic Conductivity West East				10.s Calil	9% Bentonite bration Value	e w/ e x 5	10.9% bentonite w/ Calibration Value ÷ 5			
Inflows (gallons per minute)	Recharge	2,669	2,113	4,782	2,669	2,113	4,782	2,669	2,113	4,782	
	Lateral Outflows	1.1% 51	5.4% 258	6.5% 309	1.8% 86	7.9% 378	9.7% 464	0.7% 34	4.1% 196	4.8% 230	
Outflows (as % of Total Recharge and gallons per minute)	Outflow to Modflow	52.1%	41.5%	93.6%	48.4%	41.9%	90.3%	53.4%	10.9% bentonite w/ Calibration Value ÷ West East 2,669 2,113 0.7% 4.1% 34 196 53.4% 41.8% 2,554 1,998 0.0% 0.0%	95.2%	
ganono por minato)	Drain Package	2,490	1,984	4,474	2,314	2,004	4,317	Total West East 1 4,782 2,669 2,113 4 9.7% 0.7% 4.1% 4 464 34 196 4 90.3% 53.4% 41.8% 5 4,317 2,554 1,998 4	4,551		
Percent Mass Ba	ance 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.